    

Is Your Dam Safe?

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Dr. GILBERTO VALENTE CANALI

- ⇒ Civil Engineer, post graduated in Hydraulic Engineering (Delft Institute for Water Education), and Lawyer. Over 55 years of professional practice in the areas of Engineering and Planning of Water Resources, Hydraulic Works, Dam Safety, Environmental Management, and Sanitation. Over 22 years of experience in the Brazilian Water Legislation and other related legal instruments, such as the National Dam Safety, Sanitation and Environment Policies;
- ⇒ Former President of the Brazilian Water Resources Association (1997-1999);
- ⇒ Former Technical Director and Vice-President of the Brazilian Committee on Dams (1999-2008);
- ⇒ Currently, World Bank Consultant in dam safety in several projects.

How safe is your dam?

What an intriguing and provocative question is this one posed by the authors ***Andriolo, F.R.*** and ***Moreira, J.E.*** as the title of their new book!

Indeed, as dams have been built for centuries, providing unquestionable benefits, one may tend to think that they are intrinsically safe and will last for long time even if due care is disregarded, as demonstrated by a large number of dams in poor conditions that dam safety professionals face every day. The cruel reality, on the contrary, is the frequent news about accidents with dams, as explained in **Chapter 7**, causing life loss and damage to the infrastructure and the environment, showing that, as all human endeavor dealing with nature, dam building does need respect, knowledge and careful procedures to deal with uncertainties and risks.

The question is provocative as it becomes clear from such frequent accidents that serious responsibility is required from dam owners and professionals from the very beginning of the inception of a new project to the end of their usable life. Fortunately, this is becoming more and more accepted as a principle for the profession, if not because legislation is becoming more and more stringent, so that the question that dam owners and engineers should ask themselves at every stage of process really is: **how safe am I planning, designing and building *my* dam?** In this connection, this book is of extreme value for the guidelines the authors so well summarize in accordance with updated sources of best practices.

In a broader sense, however, perhaps there is still a long way to before achieving it, as dams are conceived to provide, in on way or another, economic and social benefits at large – under the concept of water security - and not just for the owner, the question that should be raised by society is: **how safe are *our* dams?** This should be a matter of great concern particularly in relation to public dams, the ones that frequently suffer from lack of adequate funds and management to keep them safe. The issue here certainly and necessarily would involve the users and direct beneficiaries of the projects to contribute to such a goal, as a counterpart of the benefits they get from investments that ultimately are provided for and paid by the society in general through taxes. In many instances, governments are blamed for not providing due maintenance to public dams, thence exposing communities to risk if a dam fails. However, dam professionals should help creating the notion that dam users and direct beneficiaries must contribute to keep a dam safe as it is the means by which they get benefits and minimize undesirable consequences, so that maintenance should not be a government's responsibility solely.

The authors offer here excellent material for reflection along this line, very closely with a recent global survey sponsored and published by the World Bank which showed how dam safety issues are being dealt with in different countries and legal systems.

But the authors also provide many examples and a lot of information, resulting from their long and rich international experience, in several chapters about technical aspects of dam engineering. Besides, they included contributions of equally experienced professionals, namely ***Abrahão, R***. and ***Souza Freitas, M.***, which make this book an excellent reference for all those working in this field of activity.

Of particular interest, **Chapters 4**, **6** and **8** bring extensive and essential information for professionals working on design and implementation of dam projects, while **Chapters 9** and **10** will be found very useful for those working on the operation, monitoring and maintenance of a dam.

To close the book, the authors offer a set of rather interesting suggestions and recommendations in **Chapter 12**, as lessons learned which for sure will be greatly appreciated by anyone who cares about the complex aspects of dam safety.

Reading this book prior of preparing these words was an immense pleasure for which I wish to thank the authors, especially to my long-time profession colleague and good friend ***Francisco Andriolo***, being invited by him for this task was a great honor indeed.

Prof. Dr. JOAQUIN DIEZ-CASCON SAGRADO

Ingeniero de Caminos Canales y Puertos por la Universidad de Cantabria (1977); Dr. Ing. de Caminos Canales y Puertos por la Universidad de Cantabria (1982); Catedrático del Área de Ingeniería Hidráulica (Docencia en Presas) de la Universidad de Cantabria (1992); Director del Departamento de Ciencias y Técnicas del agua y Medio Ambiente de la Universidad de Cantabria (1987-1996); Presidente de la Sociedad Española de Presas y Embalses (SEPREM) (1997-2007) y (2013-2016); Director de 9 (nueve) Tesis Doctorales; Director de 5 (cinco) Tesinas de Máster; Autor o coautor de 13 (trece) Libros/Monografías; Autor o coautor de más de 70 (setenta) Artículos y Comunicaciones a Congresos nacionales e internacionales; Director de más de 20 (veinte) Proyectos de Investigación y Desarrollo en la Universidad de Cantabria.

Es un honor para mí hacer un Prefacio al libro **"IS YOUR DAM SAFE ?"** de ***Francisco Rodrigues Andriolo y Jose Eduardo Moreira*** pues, además una vieja y consolidada amistad, tengo un enorme respeto por sus trayectorias profesionales. Además, comparto las ideas, conceptos, planteamientos y sensibilidades que en él se recogen.

El objetivo fundamental de la Seguridad de Presas es proteger a las personas, los bienes y el medio ambiente de los efectos perjudiciales de una operación inadecuada o del eventual fallo o colapso de las obras. Dicho objetivo debe estar presente durante todo el ciclo de vida de las obras: planificación, proyecto, construcción, puesta en carga, explotación, vigilancia, mantenimiento y un eventual abandono.

En el libro **"IS YOUR DAM SAFE ?"** se recoge de forma clara y completa el paradigma científico y técnico de la Ingeniería de Presas, organizando la formulación de los problemas de estudio, métodos, técnicas y formas de práctica, así como los criterios de verdad y procesos de verificación. Dicho de otra forma, el libro refleja la imagen del mundo y creencias básicas de la comunidad presística acerca de su realidad y define lo que se debe estudiar, las preguntas que es necesario responder, cómo deben preguntarse y qué reglas es preciso seguir para interpretar las respuestas obtenidas.

La disponibilidad de agua ha sido desde épocas remotas uno de los condicionantes más fuertes para el establecimiento y posterior progreso de las sociedades. Es necesario alcanzar un equilibrio entre las necesidades y las disponibilidades de agua, el cual depende de los condicionantes relativos al entorno natural y a las actividades humanas. La búsqueda de este equilibrio ha requerido en cada circunstancia particular la adopción de soluciones de distinto tipo, entre las que siempre han destacado los azudes de derivación y las presas de embalse.

La Ingeniería de Presas tiene, y ha tenido siempre, un imperativo categórico muy claro: hay que hacer realidad una idea con la máxima seguridad posible de su eficacia y la máxima economía de medios. A lo largo de la historia, para conseguir tan utópico objetivo, se ha utilizado toda la ciencia y la tecnología disponible en cada momento, pero su falta o escasez en algún punto nunca fue excusa.

Los condicionantes de la Ingeniería de Presas vienen fijados por una parte por la naturaleza: el río y su cuenca, los materiales, el clima etc., y por otra por la sociedad: los científicos, tecnológicos, políticos, económicos, etc...

En los capítulos del libro ***"IS YOUR DAM SAFE ?"*** se tratan de forma amplia los condicionantes que se consideran determinantes en el diseño, construcción y explotación segura de las presas de embalse: hidrológicos e hidrogeológicos, geología, material de construcción, tecnología de construcción, conocimiento de la interacción de la presa y embalse con su entorno, vigilancia, mantenimiento y conocimiento del comportamiento de las presas y embalse.

Por último, una cuestión de orden cardinal en la Ingeniería de Presas es la formación de sus técnicos, y tengo el convencimiento que el libro **"IS YOUR DAM SAFE ?"** contribuirá de forma importante a ello.

En Santander 12/2021

ROMANO ALLIONE - Dr. Eng. Polytechnic of Milan – Italy

- ⇒ Professional Engineer, Project Management Consultant,
- ⇒ Member Fidic President's List of Approved Adjudicators
- ⇒ Charter Member of the Dispute Resolution Board Foundation (***DRBF***),
- ⇒ Former President of the DRB Foundation. Recipient of ***DRBF*** Al Mathews Award
- ⇒ Contributions during the construction of major infrastructure projects in Africa, Asia, and Latin America, including ***Tarbela*** Dam Project in Pakistan; ***El Cajon*** double curvature concrete arch dam in Honduras; ***Katse*** double curvature concrete arch dam in Lesotho.

Is your Dam Safe? The book title does not really describe or even pay justice to the Authors' vast and extensive coverage of all subjects related to dam conception, design, construction, and operation and the problems encountered in the process.

Description of the various phases are detailed and commented and abundant examples of accidents, failures, and problems have been presented, inviting/requiring the Designers, Employers, Contractors and Operators to reconsider, evaluate and review all dam components and take action, as necessary, to prevent/avoid such accidents to affect their dam projects.

The Authors' work does not only refer to dams completed and in operation, the book is developed in a way to cover all the phases, clearly indicating that the safety consideration and review shall be paramount in all dam project phases, from inception, geotechnical investigations, design, construction and long term operation.

This book must be studied in all chapters and taken as a reference handbook for all professionals working in dam inception, design, construction and operation and be kept handy for consultation, knowing that all matters are covered in depth. In fact, *mutatis mutandis*, the Authors' approach shall be applied to most type of projects, not only dams.

Specific review of the many accidents described in this book teach enormous lessons and give ample background of technical knowledge. The various dam failures and accidents are covered by photos and short descriptions which will allow the readers to have a view of a vast number of problems, enhancing the knowledge of possible problems during dam life with related causes.

Going through the various chapters of the book, the professional will largely improve their overall basic understanding of events giving also indications on specific tools to prevent accidents, to review the actual "safety" conditions and take, in good time, the remedial actions if and as necessary.

The Authors correctly emphasize the importance of planned and continuous maintenance of the dam and project during operation. We know that, generally, there is not much glory in proper maintenance, no inauguration or ribbon cutting, but, as the Authors have pointed out, this is essential to continuous, proper operation and to avoid major disasters. The institutions, and even the general public, should understand and recognize the importance of proper preventive maintenance.

Knowledge Management introduced by the Authors is a brilliant definition and important objective toward improvements, the book goes a long way towards deepening and dissipating such knowledge, providing a vast array of technical data and information which shall be fully understood and utilized by all professionals.

I could not close these notes without congratulating and commending the Authors for putting all said knowledge at the disposal of the public by loading their work on the Web and thus allowing all interested persons to have access to such vast expertise for free.

It has been an honor to be requested to preface such interesting and comprehensive book which all professionals in dam construction and operation will appreciate and utilize. Moreover, the public will have free access to it and will certainly be interested to get some understanding of the complexity and beauty of "our" dam projects.

Dr. GILBERTO JOSÉ VAZ

Brazilian, has bachelor's degrees in Law and Civil Engineering and a post graduated in Economics.

He specialized in Construction Contract Management in London, UK, is Project Manager instructor at the graduate studies course at Fundação D. Cabral-BH (licenced), and guest professor at FGV GVLaw-RJ, PUC-BH, and IBMEC-BH in Brazil.

He is mediator certified by Fundação Libra B. Aires, Argentina, and by the International Institute for Conflict Prevention and Resolution (CPR), New York, USA. Chair certified by the Dispute Resolution Board Foundation- DRBF - NC, USA. He is former General Director for DRBF - R2 and Vice-President of Arbitration Chamber CAMARB - BH. He has been the head of GILBERTO JOSÉ ENGENHEIROS e GILBERTO JOSÉ VAZ ADVOGADOS since 1995.

Initially, I would like to register my pleasure to receive the invitation of engineer Francisco Rodrigues Andriolo to be one of the presenters of his 11th book, this one shared with engineer José Eduardo Moreira. ***IS YOUR DAM SAFE*** is, in fact, an extensive custodian of the State of the Art of Engineering Technology Knowledge for design, planning, construction, operation, maintenance and decommissioning of dams. Its depth in addressing the various stages of the implantation and life of a dam is much greater than its title suggests. This is a true Dam Engineering Handbook.

Despite having already participated in varying degrees and/or specific stages of more than 30 dam projects in Brazil and abroad, I have learned a lot by reading the presented work and I think Francisco Andriolo built his masterpiece with this book, this time counting on the excellent partnership of Moreira.

In spite of having been ***Chico Andriolo****'s* classmate in the large structure engineering course at ***EESC-USP***, our professional lives have intersected only in recent years, when we shared some Projects which was a great satisfaction for me and served to increase my professional and personal admiration for him.

As a professional in construction disputes and litigation, I particularly appreciated Chapters 2, 4, and 6. Specially the last two ones, in which the authors discuss very properly the importance and scope of what it is called Design Criteria in Design and Technical Documentation and in Construction of dams in order to mitigate risks and damages. The Design Criteria along with the geological-geotechnical themes have been present in almost all the controversies and arbitrations in which I have participated in my long career.

Engineering Projects, by their very nature, are subject to great amount of risks which cannot be ignored and have to be faced and (payed) by someone throughout the life of the Project. The planning, identification, and allocation of these potential risks, in a technical way, among the various actors involved in an Engineering Project, are fundamental to properly implement the safety of the Project throughout its useful life.

As ***Andriolo*** & ***Moreira*** teach, it is essential first to understand and then to use properly the Engineering Technology knowledge for the correct assessment and mitigation of potential risks and damages to dam Projects.

It can be said that the synthesis of the present book, in the authors' own words, is: "***THE PROPER MANAGEMENT OF THE ENGINEERING TECHNOLOGY KNOWLEDGE***".

Along with the evolution of existing design and construction technology, Projects have become increasingly complex and challenging in terms of deadlines, risks, and prices. Similarly, in recent years, contractual documents and management practices have also evolved.

Currently, Project Owners seem to have renewed themselves in the use of the old practices of trying to allocate to their contractors the totality of the risks of the Job in an unreasonably and unbalanced way. Many Employers close their eyes to the fact that the Job and its site belongs to them.

Turnkey/EPC forms of contract traditionally allocate a large portion of risks to contractors but, on the other hand, have provisions to deal with this risk situation in a fair way. Nowadays, it is not so easy to find balanced contracts. Today, modified Turnkey/EPC terms of contract represent a large portion of current engineering dam Project contracts, and an even larger share of these contracts ends up in litigation or arbitration, causing losses to the Project, the parties, the environment, and the society.

Likewise, in recent years, there has been an extreme growth and strengthening of the Financial Market around the world, which has been increasingly subduing the real economy of the corporate business world.

Companies need to pursue scale economy, and especially the need for funding sources for their development have made large enterprises increasingly dependent on the Financial Market. Thus, Employers and Contractors have to accept the conditions, practices and metrics of the Financial Market in the evaluation of their own corporate management.

In this business context, with prevalence of a more financial vision, Engineering Technology, which has always commanded the practice of Entrepreneurship, has been losing strength given the need to present short-term results for the valuation of the company's shares. Specialists, engineers, and technicians have lost power in managing the business (and thus also the risks) of their Companies.

Financial indicators such as Return on Earnings - ROE, Return on Equity - ROI, and Internal Rate of Return - IR, have been incorporated into the management practices of Engineering Companies and have begun to guide their rules of Governance.

This may be the main factor that has generated an increase in the insecurity of Projects, particularly dam Projects, and an increase in occurrence of damage and breakdowns, as the authors demonstrate in this book.

Executives of Dam Owners and Contractors are led to take increasing risks at each stage of the Projects under their supervision in order to meet tight schedules and optimize their cash flow.

Existing risk assessments are often made lightly and solely by isolated discipline professionals and not in a systemic way and with multidisciplinary teams. This fact, from a statistical point of view, distorts the result of the analysis and reduces the mitigation of failures and associated damages in Projects.

In other words, currently, dam safety is a subject that seems to depend more on business evaluations made with Financial management tools and less on technical evaluations made with Engineering Technology management tools.

It should be noted, in recent years, some positive initiatives in favor of the adoption of Environmental, Social and Governance (ESG) practices that protect stakeholders and not simply benefit stockholders, including from some investment funds. Another recent positive ESG movement came from the New York Business Roundtable Association. However, these are initiatives with still incipient reach.

In Chapter 2, the Authors did not fail to address regulatory and legal aspects of the subject. A difficult issue be cause of the existence of diverse national jurisdictions in the world. In general, it could be said that, in most countries, the responsibility for the safety of dams is usually attributed to their Owner. It is up to the State Agencies to regulate and supervise them (not always effectively).

Considering that, most of the time, the Owners of Dam Projects are responsible for their safety to achieve the revaluation of Engineering Technology practice lectured by Andriolo & Moreira, a suggestion could be the hiring by Shareholders of an independent Review Board. This Review Board, linked but not subordinated to the Company's Shareholders Board, should be formed by multidisciplinary technical experts from the market, with autonomy, independence and neutrality. This solution could be implemented spontaneously by the Shareholders Board or alternatively by force of law.

This Board, formed by independent experts with notoriety and impeccable reputation, would act as the driver and guardian of the application of the best Engineering Technology for the implementation and safety of dams. And in the same way for the incorporation of the Technology knowledge into the company's Governance and Compliance rules.

This Review Board of independent experts would be the vehicle to transport and deliver to its destination the precious load of the State of the Art of Technology knowledge that ***Andriolo*** & ***Moreira*** lectured on 1400 pages of this fantastic Compendium of Dam Projects. Cheers!

Prof. Dr. MÜMTAZ TURFAN

⇒ Lecturer at Middle East Technical University, since 1986;

⇒ General Director os State hydraulic WOrks, Turkey, 2000-2002;

⇒ Vice President of ICOLD, 1999-2002.

With intensive populated metropolis and logarithmic increase of demand in agriculture and industry, construction of dams, especially large ones, has been unavoidable for civilized life in recent centuries.

Not only the construction period, but all reconnaissance, planning, design, operation and maintenance periods of dams require experienced and eligible engineers. They are called "civilization builders".

Francisco Rodrigues Andriolo is one of the brightest names in this group with his extensive and multidimensional experience on dams.

One can find essential theoretical knowledge in many science books related to dams; however, each dam is unique in itself concerning geology, climate, and water source conditions, materials, earthquakes, etc.

Therefore, referring to the experiences gained during both in construction and operation and even in failure of other dams is of crucial importance for professional engineers, especially newly graduates. ***F.R. Andriolo*** comprises in this book the valuable experience results with scientific facts, and calls strong attention of the dam people to all critical issues.

I highly consider that it will serve students as a great reference book and refresh the knowledge of dam engineers, as well as lead them in critical situations they could face.

I wish to congratulate ***F. R. Andriolo*** for writing this book and cordially thank him for sharing his valuable experiences with us

RICARDO ABRAHÃO

Brazilian citizen (born July 9th, 1948), has a degree in Geology with major in engineering geology and rock mechanics from the University of São Paulo (IG USP)-1971.

- ⇒ Owner of Ricardo Abrahão Geociencias S/S and consultant for Engineering Geology and Rock Mechanics with aim in the design, construction, operation, arbitration, and safety of dams.
- ⇒ He has written more than 30 papers published in Brazil and abroad. In 2019, he produced the chapters 'Foundation' and 'Dams' for the new ABGE (Brazilian Association of Engineering Geology and Environment) book. For the new ISRM book on 'Soft Rocks', he prepared Chapter 17 – Soft Rocks in Dam Foundation and Dam Sites.
- ⇒ Former Vice Chair of the ICOLD Committee on Dams and Water Transfers, from 2004 and 2013, editing the Bulletin 161.
- ⇒ Consultant for projects in countries as Ecuador, Algeria, Chile, Costa Rica, Venezuela, Colombia, and Peru, and ephemeral contribution in Nigeria, Libya, Panama, Argentina, Portugal, Mexico, and Dominican Republic.
- ⇒ Lecturer at ITA – Instituto Tecnológico da Aeronáutica, (1977-1984), where he implemented the course of Engineering Geology.
- ⇒ He has delivered courses on Geology and Dams for ABGE, CBDB (Brazilian Committee on Dams) and few in house training. He is a lecturer at the graduate studies courses on Dam Safety at the IDD Group and Federal University of Bahia.
- ⇒ He was design manager and technical coordinator of hydropower plant projects and at the São Francisco River Water Transfer system.
- ⇒ He has worked at CESP (São Paulo Energy Company) and Promon Engineering (1972-1991), And has collaborated in more than 130 projects of infrastructure and hydro resources, such as Água Vermelha, Itaipu, Xingó, Belo Monte, and São Francisco River Water Transfer project.
- ⇒ He is a member of the Board of Consultants of Belo Monte and Passo do Meio hydropower plants.

MANOEL DE SOUZA FREITAS JUNIOR

Brazilian citizen (born May 17th, 1946), has a degree in Civil Engineer, São Carlos Engineering School, University of São Paulo, State of São Paulo (EESC-USP), December 1969, Brazil.

⇒ Post graduation courses on Soil Mechanics and Foundation Engineering, Earth and Rockfill Dams and Engineering Geology at the Polytechnic Engineering School, University of São Paulo, from 1970 to 1973.

Membership in the following organizations:

⇒ ICOLD International Commission on Large Dams;

⇒ USSD United States Society on Dams;

⇒ Brazilian Society of Soil Mechanic and Geotechnic Engineering.

KEY QUALIFICATIONS

⇒ Civil Engineer, currently working as Independent Consultant on geotechnical and engineering geology on Supervising and Management design and Construction on earth and rockfill dams associated with water supply and hydroelectric power generation purposes;

⇒ Experienced on Technical Evaluation of Dam Safety Conditions of large hydro Projects (≥120 m height) in Brazil and abroad (South and Central America and Asia);

⇒ Independent Consultant for the Word Bank and BID – InterAmerican Bank International in Water Multi-Purpose Resources Projects on feasibility studies, bidding phase, construction and design, Safety Inspection during Operations on EPC (Engineering, Procurement, Construction) hydro Project Contracts in Brazil;

⇒ Participation in International Symposiums and Congresses on Large Dams and Soil Mechanics and Geotechnical Engineering, having presented several technical papers in these events;

⇒ In May 2009, during the Twenty Third International Congress (ICOLD) in Brasilia, Brazil, launched the book "Concrete Face Rockfill Dams" (Portuguese- English), together with two colleagues;

⇒ Independent Engineer for technical design and construction Planning for the Brazilian Federal Financial Organization Bank (CAIXA ECONOMICA FEDERAL) for the mammoth Hydro Plant of Belo Monte at Xingú River, state of Pará, Brazil (11,233 MW).

SPONSORS

The main objective in the Edition of this Book in having Sponsors is to enable this text to be free of charge for the Technical Community involved in the Public Good of the Dams. In this sense, the Authors are honored, immensely satisfied, and deeply grateful to **Norte Energia**, **Elera-Brookfield**, **Brennand Group** and **Brennand Institute** for their spontaneous contributions, which provided us with the necessary confidence in the undertaking of this Book.

BOOK EVENT

The book's project was completed with the Book Release Event, held at the Instituto de Engenharia - Institute of Engineering of São Paulo on September 22nd, 2022, by special concession of its President, Eng. **Paulo Ferreira**, and the support of its Counselor, Eng. **Edson José Machado.**

Foreword and Prefaces

The selection and choice of professionals who make up the Presentation and Prefaces of this Book, covered special care and appreciation to People and Professionals with extensive knowledge in the subjects dealt with in its various Chapters, from the social, legal, behavioral themes on Dams, to the evident technical requirements, safety, and purpose of Dams. Thus, the words by eminent connoisseurs - **Canali, Cascón, Allione, Gilberto** and **Turfan** - besides those of affection, are positions of concepts that enhance this Book, for which the Authors are honored and extremely grateful.

Voluntary and Essential Contributions

The modest knowledge and limited vision of the Authors, besides restraining themselves in the words and knowledge of the Prefaces, had the suggestions and voluntary contributions of professionals **Ricardo Abrahão** and **Manoel Freitas**, in addition to the understanding of the

Sponsors with the arduous and persevering contribution of **Antonio Carlos Campos Fernandes, Milena Murta, Antonio Pelissari, Uriel Garber, Mozart de Siqueira Campos Araujo, João Alberto da Silva,** and **Milena Fonseca Souza.**

Editor and Team

The editorial and graphic framework of this Book was developed by **Editora Scienza**, coordinated by the Professional and great friend **Gustavo Kaimoti**, and by the team of language reviewers and graphic works, to whom the Authors are deeply grateful.

Family

There is no doubt that, in the development of this Enterprise-Book, our Family members suffered the sums of absences caused by our commitment to the activities of this writing. To them, our apologies and thanks!

Note from Condolences

This book was almost fully conceived and realized during the period of a Pandemic, which caused the passing away of several "Dam Workers" - **"Barrageiros"** friends in Brazil and around the World. To these Dam Professionals and their families, our sorrow and memories.

Is your Dam Safe?

The authors objective in this text is to present to Engineers and Public Administrators a set of information and discussions about a Dam Project, and complement the need to follow the various stages, processes, and methodologies that precede the existence of a ***Durable Public Good***, as well as the care during its usefulness, in order to respond to the question above.

Dam Engineers are both morally and legally responsible for the communities. The first implies that they must act with integrity, giving due consideration not only to the particular purpose of their project, but also to its ultimate effects on their fellow human beings.

The authors leave aside the various and useful examples of printed formats, usual in the inspection phases, as well as the abundant set of instrumentation data, but induce the aspect of Responsibility resulting from the indication of its purpose for ***Dam Safety***.

In other words, Instrumentation and Monitoring are part of a ***Dam Safety System*** that stem from previous and necessary knowledge for the design and implementation phases of a dam, and the consequences to its surroundings.

The authors recognize that the greatest merit is the work, and exercise their profession committed to serving society, considering the welfare and progress of all. By transforming nature for the benefit of mankind, engineers must increase their awareness of the world as the abode of humanity, their interest in the universe as a guarantee of overcoming their spirit, and knowledge about reality to construct a fairer and happier world.

Concerns about dam safety started in the 1970's in the USA, and safety measures were implemented in the 1980's, but have been adjusted to the present time, and some countries created Laws and Codes between 1990 and 2010; however, they are still not technically and financially aware to trigger ***Dam Safety Programs***. Some accidents and disasters have occurred since the 1920's, leading some Government Agencies to create defenses to protect Society.

The Authors note that are some different scenarios concerning the ***Dam Safety***.

⇒ Although some Countries and Entities have adopted Laws and Codes, they do not provide Budgets for Maintenance and Inspection Programs, neither Emergency Action Plans, to establish the Safety of their Dams;

⇒ Some countries still do not have regulations to ensure Dam Safety;

⇒ There are countries that have laws and regulations and budget to ensure the safety of dams, but some Entities/Concessionaires have difficulties in ensuring them because of lack of ***Knowledge Management*** and/or trained labor Force.

This text does not aim to suggest routines of reading instruments or which types should be used, but to awaken Designers, Owners, Government Agencies to the need of having the following objectives:

⇒ The works of the **PUBLIC GOOD** must be Planned and Organized;

⇒ Have Quality and Controlled Materials, available for the construction of the Work;

⇒ Professionals must be trained to know the difference ***Simple***, but ***Not Poorly Executed***;

⇒ Owners must understand and make understand about Knowledge Management, Risk and Development, as well as manage Costs compatible and compensating with the work;

⇒ Contractual Documents must be clear as to the Responsibilities inherent in the **PUBLIC GOOD** and Society;

⇒ Design Criteria must preserve the ***Dam Safety***.

In this text, the authors seek to draw attention that a Dam can be imagined as being the "***Human Body***", which when well born, well cared for, well nourished, and having its health monitored over time, can be healthy, only suffering with unforeseen natural events.

While dams embrace complex social, environmental, and political choices, they also make important contributions to economic prosperity, improved resilience, and poverty reduction. Ensuring sound construction, safe operation, and sustained services from such infrastructure requires a sound regulatory framework that is durable and equitable and can safeguard downstream communities while enabling economic development. Sustainable infrastructure is, therefore, key to enabling a water-secure world for all. For thousands of years, societies have strived to manage the temporal and spatial variability of water to satisfy human needs and serve productive purposes.

While dam failures very seldom occur and result from unpredictable events, they often have dramatic consequences. Catastrophic dam failures are characterized by the sudden uncontrolled release of water. Such failures can result in extremely adverse consequences, including large-scale loss of human life and significant economic and environmental impacts. Lesser degrees of failure can progressively lead to or increase the risk of a catastrophic failure. As such, it is essential to establish a dam safety system that can ensure the safety of downstream communities.

In other words, when a dam is well designed, built based on safe design criteria, with known materials, under controlled discipline, with proper methodologies, and operationally maintained, its monitoring will ensure a ***Safe Dam*** that will suffer only from the surprises of Nature, when not properly admitted.

This can be translated in the following schematic Figures:

A properly designed, built and controlled Project.

A poorly designed, constructed and controlled Project.

Dam safety is defined in various ways, often depending on the country context. The safety of a dam is manifested as free of any conditions or developments that could lead to its deterioration or destruction.

At this point, it is important to add some statements mentioned by the Prof. Dr. ***Joaquin Diéz Cascón Sagrado*** (see Preface in this text);

"...Comments and Previous Issues

A Dam is an artificial structure that intercepts a stream of water and creates, upstream of it, a reservoir (water storage) dedicated to various uses:

⇒ ***Roman idea*** *(mainly as reservoir)*

⇒ ***Arabic idea*** *(bypass-deviation dam)*

⇒ ***Modern idea*** *(multipurpose)*

It should be noted that a Dam is both what nature gives and what man builds. For the project of a dam, it is advisable to take into account a number of issues:

⇒ *The foundation ground plays an important role in the ability to retain water and in the mechanical stability of the system- foundation and the dam body;*

⇒ *The flows determine the necessary capacity of a dam, which should be equipped to return water to the river in optimal downstream conditions;*

⇒ *In concrete dams, 42% of breaks are caused by foundation failure and 12% by overtopping;*

⇒ *In dams made of loose materials, 12% of breaks are caused by foundation failure and 50% by overtopping.*

The feasibility of a reservoir dam, its typology and characteristics cannot be determined without perfect knowledge about the foundation, the river, the basin, and the climate.

⇒ ***DIVINE LAW****. If the* ***Divine Law*** *is not fulfilled:*

⇒ *There will be a need to adjust the project;*

⇒ *The cost will be increased;*

⇒ *The work will be delayed;*

⇒ *Economic and social losses will occur and irreparable damage may occur during construction and, if problems are not solved, they can remain during operation.*

Environmental Water, Development, and Dams

The development of societies is based on the availability of water and preservation of the environment. The balance between water supply and demand requires greatly different solutions, and reservoir and deviation dams are the most widely used.

The development and evolution of Dam Engineering is based on the following pillars:

⇒ *Economy;*

⇒ *Technology;*

⇒ *Safety during:*

- ✓ *Construction,*
- ✓ *Exploitation.*

Dam Safety

The following two sentences are the beacon that guides the thought to be developed:

- ✓ ***"What really matters in dealing with things is judgment"*** *Albert. Einstein*
- ✓ ***"Knowing to anticipate and foresee to protect"*** *Alfonso Nápoles Gándara*

The creation of a reservoir is one of the most unique public works, and it has an impact on society greater than any other.

*The construction of a dam is an act of alteration of nature, and if faithful to the principle of action and reaction (**Newton's Third Law**), it will inexorably tend to eliminate it. This phenomenon is not only observed for Dams, but it rarely becomes so apparent.*

The objective condition of the entire process of designing, building, and operating a dam and reservoir needs to consider the effects, as large as possible, to the point of providing proper defenses.

The importance and complexity of the impact, especially on the population affected by the risk of the presence of a dam, have made it necessary to intervene with the Public Administrations at different stages of a dam's life.

*The **safety of a dam** is not a target physical attribute, as its volume. Safety is an artificial and complex concept, influenced by psychological expectations and social-cultural conditioning, and is subject to evolution over time.*

It must be recognized that the methodologies usually used to determine the degree of safety of a dam lack the essential requirement of scientific objectivity: the reproducibility of evaluations carried out from the same data by different equally qualified expert groups.

Basic Aspects on Civil Infrastructure Safety

The Safety of civil infrastructure is mainly expressed in the following basic elements:

⇒ *As broad as possible knowledge of the elements whose safety you want to control;*

⇒ *Existence of the necessary technique to enable achievement of the needed safety;*

⇒ *There are clear, precise and possible compliance regulations establishing the safety requirements to be observed.*

Existence of an organization dependent on the Public Authorities and independent of the owners and managers of the structures, whose purpose is to effectively control compliance with the regulations and safety, is required. This organization must obviously have the precise means and sufficient authority to carry out its work.

Looking at the evolution of these basic elements in the field of Dam Engineering, it can be seen that:

a) *At first in history, the basis of knowledge was the experience gained in the execution and results of the works and, above all, in the failures obtained. This period has lasted almost 50 centuries, from 3.100 B.C., the first written reference to a dam, to the mid-19th century;*

b) *The first qualitative leap in knowledge occurred in the mid-19th century, when Rational Mechanics began to be applied to certain aspects of Dam Engineering;*

c) *The second great leap was the result of the breakage of several dams, especially two:* ***El Habra Dam*** *(1881) and* ***Bouzey Dam*** *(1895). These ruptures exposed the physical reality of interstitial pressure;*

d) *The third major leap occurred in the 1920's as a result of the generalization of trials in small models and the onset of auscultation and behavioral analysis. The results made it possible to structurally optimize shapes and develop new solutions;*

e) *The fourth big leap was the result of the breakage of the* ***Malpasset Dam*** *(1959). Its rupture occurred as a result of the combination of a number of phenomena unknown until then and related to the geo-mechanical and hydraulic characteristics of the rocky massif supporting the dam. Rock Mechanics use as a whole new era began, with spectacular advances in a few years.*

f) *The fifth, and final great impulse, occurred with the systematization of auscultation and behavioral analysis of a dam and its foundations. The development of this technology allowed the establishment of means of observation to know the response of a dam and its foundation in face of the forces that act on it, and interpret the results of the measurements carried out.*

When a dam is designed, a theoretical model is established based on a series of hypotheses that make the calculation affordable to the available media at all times, having to assume that, to a greater or lesser extent, the results will be different from the actual behavior.

To know the actual behavior of a dam and its foundation, it is necessary to measure a series of significant and representative variables and interpret them according to the actions that take place. Measurement involves properly installing auscultation instruments in the dam, and interpretation involves establishing a model of behavior, thereby being able to compare the imagined with the actually observed behavior and investigate the premises and hypotheses used in the theoretical model.

At this time, it is necessary to refer to something that some researchers forget, although this is known since the Middle Ages: the principle of economics, principle of parsimony or principle of simplicity, also known by the ***Ockham's razor****. This is a methodological and philosophical* *principle according to which "**on an equal basis, the simplest and most sufficient explanation is the most likely, but not necessarily the true one**". This implies that when two theories on an equal basis have the same consequences, the simplest theory is more likely to be correct than the complex one. Perhaps the most appropriate, and simple, proposal of the principle is the one suggested by **Ockham** himself "**pluralitas non est ponenda sine necessitate"**, that is, that "**entities should not be multiplied beyond necessity**".*

*People have expressions that could be complementary and here under consideration "**the sum of many half-truths can be a great lie**".*

Auscultation can detect weaknesses and possible foreboding signs of deterioration. One could say that the main purpose of auscultation applied to a prototype is actually the detection of anomalies and the explanation of their cause.

With regard to the design, construction forms and modes, and exploitation of all types of dams, it can be said that it is what can be called a mature technique for a few decades and, of course, subjected to a continuous process of criticism and improvement…"

Dam safety assurance can be achieved through a range of interventions (regulatory, technical, institutional, and so on), and the regulatory framework should include pluralistic approaches across the entire life cycle of a dam. This includes planning, design, and construction, as well as surveillance, operation and maintenance, rehabilitation and refurbishments, and, eventually, decommissioning.

Special Note from the Authors: Some photos are displayed repeatedly in different Chapters to highlight the themes mentioned under different aspects.

FRANCISCO RODRIGUES ANDRIOLO

Brazilian citizen (August 24th, 1945), has a degree in civil engineering-structures (1969) from the School of Engineering of São Carlos - University of São Paulo-Brazil (EESC-USP).

⇒ Between 01/1970 and 06/1975 he worked in the Quality Control System during the construction of the ***Ilha Solteira Hydroelectric*** Dam and Power Plant (3.600.000 m^3 of concrete)

⇒ Between 07/1975 and 09/1980 he was responsible for the Quality Control System of Materials and Concretes (Laboratory, Aggregates, Concrete Production, Instrumentation and Construction Control) of ***Itaipu Binacional Project*** (14.000.000 m^3 of concrete) and for the installation of approxiamtely 1.500 instruments for the Itaipu Dam monitoring;

⇒ Between 10/1980 and 1984 he worked for ***Themag Engenharia- Hydroelectric Design Company*** in Brazil;

⇒ Since 1984, he has been a consultant and director of ***Andriolo Engenharia Ltda*** (www.andriolo-eng.com), having participated in more than 220 works in 36 countries;

⇒ He has published 10 books and more than 170 papers;

⇒ He has been a member of the ***Brazilian National Academy of Engineering*** since 2015 (www.anebrasil.org).

JOSÉ EDUARDO MOREIRA

Is a Brazilian citizen (November 25th, 1947), has a degree in Civil Engineering with a major in geotechnics (1970) from the Federal University of Rio de Janeiro (UFRJ).

⇒ Master's degree in Geotechnical Engineering from Coppe/UFRJ (1974);

⇒ Post graduated in Water Resources – Coppe/UFRJ (1976);

⇒ Power Project management – **World Bank – IPEA – Eletrobrás** (1982);

⇒ Professor at the University of Brasília (UNB): 1982–1987;

⇒ General Rapporteur in Large Dams Congresses;

⇒ He has been a member of the ***Brazilian National Academy of Engineering*** since 2014 (**www.anebrasil.org**);

⇒ 1976 – 1990: **ELETRONORTE** (**www.eletronorte.gov.br**), where he was Technical Manager and Project Manager of a myriad of Hydropower Plant projects, including the **Tucuruí HPP (4.000 MW)**, in addition to developing **Dam Inspection and Safety Plans.**

⇒ 1990 – Present: founder, director, and president of **PCE – Projetos e Consultorias de Engenharia S/A. *(*www.pcebr.com.br*).*** In this engineering company, he has led more than 50 Hydroelectric Power Plant and Dam projects, **including the development of Belo Monte (11,233 MW), Santo Antônio (3,568 MW),** and **Teles Pires (1,820 MW)** in Brazil, in addition **strategic projects in Latin America** (Ecuador, Dominican Republic, Peru, and Panama).

Brennand Energia and Brennand Investments

The Ricardo Brennand Group started its commercial activities more than 80 years ago producing sugar and alcohol. In the 1950s, the Group began to diversify and expand its operations and, in the 1990s, its assets units included ceramics, glass and cement with factories in the states of Goiás, Paraíba and Alagoas.

In the early 2000´s, the Group entered the electricity generation and development area with the foundation of **BRENNAND ENERGIA ("BE")**, a time in which it promoted the construction of Small Hydroelectric Power Plants (PCH´s) on the Jauru River, in the state of Mato Grosso (PCH´s Antonio Brennand, Indiavaí and Ombreiras).

Then, in 2004, **BRENNAND INVESTIMENTOS ("BI")** acquired two Hydroelectric Power Plants (UHE´s) on the Juba River, also in Mato Grosso (UHE´s Juba I and Juba II).With this new focus, the Group improved management, developed its own and effective expertise in the construction of environmentally sustainable hydroelectric plants.

A few years later, in 2008, BE introduced in its business the development of wind

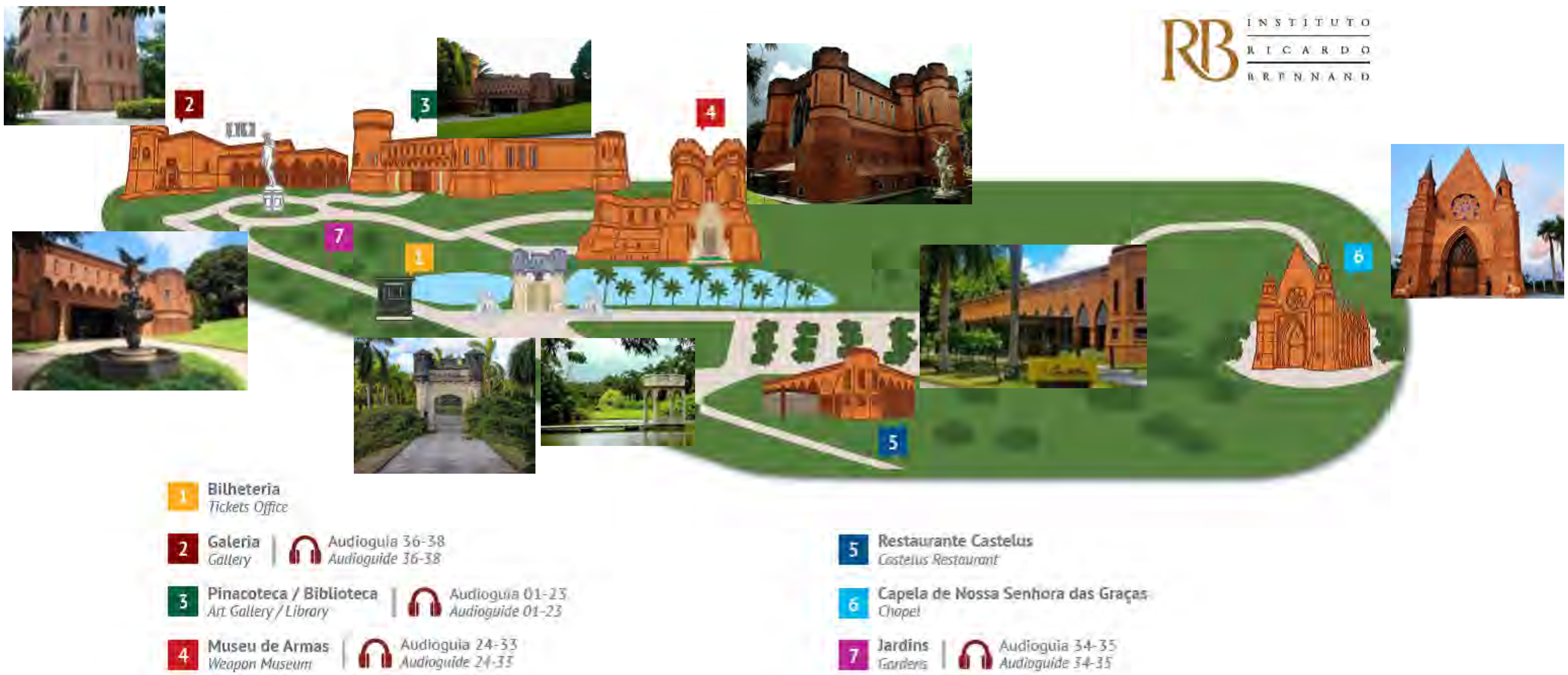
energy source projects, with operation of the first parks in 2013, with expansion of installed capacity in 2015, for the sale of energy in the regulated market, all located in the state of Bahia. At the end of 2020, BI began the implementation of wind farms for the commercialization of energy in the free market, and continues to expand the business in the same region, with the development of new projects of wind and photovoltaic power. At the same time, in 2020, BE also continued the implementation of new wind farms focused on the free market, and today has already developed more than 1.5 GW in design, with winds exceeding 10 m/s.

In order to improve the quality of customer service, Brennand installed its commercial area in the city of São Paulo, where it serves customers in all sectors of the Brazilian industry and energy traders, and companies have become important players at the national level in the supply of energy to free customers.

Currently, Brennand Energia's installed capacity is 453 MW and Brennand Investimentos is 248MW. The total of the plants operating in several regions of the national territory, is the generating park consisting of 15 (fifteen) Small Hydroelectric Power Plants (PCH´s), 02 (two) Hydroelectric Power Plants (UHE´s) and 11 (eleven) Wind Farms, in addition to 4(four) Wind Farms under implementation, which will enter into commercial operation in 2022, reaching the installed capacity of 853 MW. In addition, companies have been developing new projects in the field of power generation of water, wind and solar sources, which could add more than 2.0 GW of power generation in the coming years.

Ricardo Brennand Institute: Culture that Generates Citizenship

To generate conscious and responsible citizens, willing to make the world a better place to live. It is with this objective that the Ricardo Brennand Group invests in culture. They are educational programs for children and young people through the Ricardo Brennand Institute.



The Institute, located in an area of 30,000 m², where national and international cultural events are held, is a non-profit cultural complex, formed by Museum, Pinacoteca, Library, Chapel and Restaurant. It was born in 2002 with the objective of bringing an alternative form of art contemplation and learning to large portions of the population, possessing valuable collection, originating from the private collection of the Pernambuco industrialist Ricardo Coimbra de Almeida Brennand. It is focused on the preservation of art and culture, with emphasis on the "Dutch Brazil" period, bringing together the largest private collection of Frans Post in Brazil. Today, it already stands out throughout the country as an important cultural center of the Brazilian Northeast, internationally recognized, and receiving about 217,000 visitors/year.

"When God Wants, man dreams, work is born"

Ricardo Brennand

Global presence

Elera Renováveis is part of **Brookfield Asset Management**, a manager that has been in the market for over 100 years and has more than US$550 billion in assets under management, with 100,000 operational employees in 30 countries.

As a global company, **Brookfield Asset Management** has an outstanding performance in high quality and long-term assets, such as commercial real estate, infrastructure, private equity and renewable energy generation, being one of the main companies in this segment in the world.

Hydroelectric

Wind

Brookfield Renewable Partners

Brookfield Renewable is present in North America, South America, Europe and Asia, and has approximately 19,300 MW of installed capacity and more than 5,000 assets.

Elera Renováveis

Present in South America since 2001, the ***Elera Renováveis*** operation also presents significant results, with 78 assets and an installed capacity of approximately 2GW.

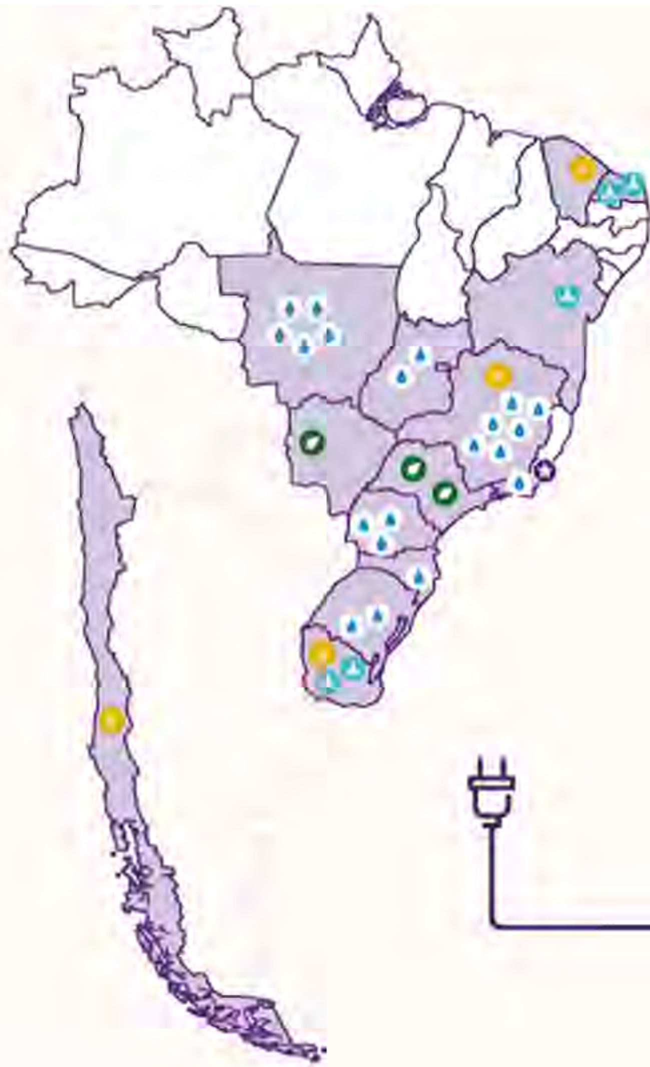
These numbers, added to a transparent performance in the market, accredit ***Elera*** as a stable and efficient business partner. After all, in addition to energy, our mission is also to generate results for customers, believing in their business and maximizing their gains. But these are not the only goals of ***Elera Renováveis***.

We are always looking to minimize the social and environmental impacts of our operations and make a positive contribution to society. Because, even with years of experience, this is just the beginning of our story.

Solar

Biomass

Country	Installed Capacity (MW)
Brazil	2100
Canada	1651
Chile	160
China	435
Colombia	3032
Great Britain	11
Honduras	19
India	558
Ireland	384
Malaysia	19
Mexico	398
Portugal	144
South Africa	65
Spain	474
United States	7265
Uruguay	26



DIVERSIFIED PORTFOLIO

10 WIND ASSETS UNDER CONSTRUCTION

42 HYDROELECTRIC ASSETS

20 SOLAR ASSETS UNDER CONSTRUCTION

04 BIOMASS COGENERATION PLANTS

09 SOLAR PARKS

04 HYDROELECTRIS ASSETS UNDER CONSTRUCTION

2.1 GW BRAZIL CURRENT GENERATION CAPACITY

3.4 GW GENERATION CAPACITY IN UP 3 YEARS

Our assets produce energy to meet all residential consumption in the city of Rio de Janeiro

Subtitle: Headquarters · Hidro · Solar · Wind · Biomass

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Our daily efforts to produce renewable energy for millions of people and operations take on an equal dimension, accounting for about 7% of one of the cleanest electricity matrices on the planet and driving the country's sustainable development.

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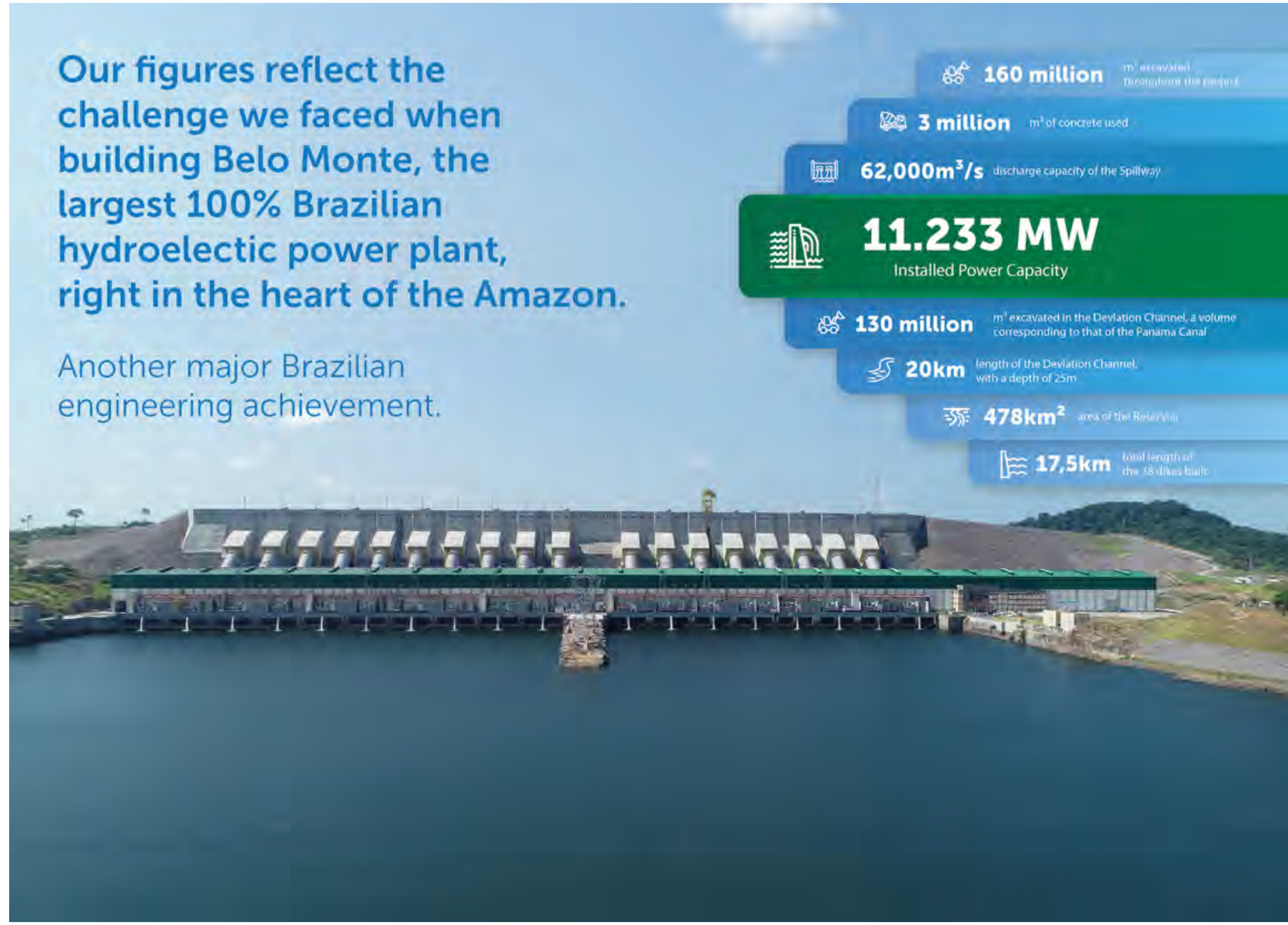


1

THE NATURE AND THE REGION

1.1 The River and Hydrology

1.1.1 General Aspects and the Landscape Evolution

Every landform on the Earth's surface reflects a particular accommodation between properties of the underlying geologic materials, the type of processes affecting those materials and the amount of time the processes have been operating. Because landforms are the building blocks of regional landscapes, the character of the local surroundings is ultimately controlled by factors of geology, process, time and regional development, climatology and population growth.

Rivers are much more than sluiceways that simply transport water and sediment. They also change a nondescript geologic setting into distinct topographic forms. This is caused primarily because the movement of sediment-laden water is capable of pronounced erosion, and it also happens when the transporting of energy decreases. Landforms are created by the deep erosion of the geological units leaving behind the most resistant ones that then form the cradle for the fitting of the valleys. Sedimentation also creates landscapes when the energy flow is no longer sufficient to erode and deposits the material taken in the erosion.

Some fluvial features are entirely erosional, and its form is clearly unrelated to the transportation and deposition of sediment. Other features may be entirely depositional. In these cases, topography is constructed of sediment that buries some underlying surface that existed prior to the introduction of the covering sediment. Realistically, many fluvial features result from some combination of both erosion and deposition, and those forms represent end members of a continuum of fluvial forms.

The water in the rivers comes from many different sources. Rivers can begin in lakes or as springs that bubble up from underground. Other rivers start as rain or melting snow and ice high up in the mountains. Most rivers flow quickly in the steeply sloping sections near their source. Fast moving water washes away gravel, sand and mud leaving a rocky bottom.

Rivers flowing over gently sloping ground begin to curve back and forth across the landscape. These are called meandering rivers. Rivers start as very small streams and gradually get bigger as more and more water is added. Heavy rains and spring meltwater add so much water to some rivers that they overflow their banks and flood the surrounding landscape.

Rivers literally "make their beds" (the riverbed is the bottom) by eroding and depositing rocks, sand, silt, and organic materials. The energy source for all this work is the flow: water moving downhill. Where the flow is very fast, such as in the upland portions of a river, the riverbed will be very rocky because of the fast-moving water that carries the fine sand and silt downstream but is not strong enough to move the underlying rock up the mountain. The riverbed is made of much finer materials such as sand and silt when the flow slows down in pools, man-made reservoirs, or lowland portions of the river.

When the river gets out of its banks, it floods land on either side. This land is called the floodplain. Like the riverbed, the floodplain will reflect the amount and composition of sediments carried by the river. Sediments that are deposited on the floodplain are generally relatively fine, because of the water moving across the floodplain travels slower than the one on the main channel.

Rivers are often managed or controlled to make them more useful or less disruptive to human activity. Water plays a fundamental role in sustaining life, we need it for core human needs such as drinking, food preparation and hygiene, as exemplified on the Figure ahead[01-01].

By roughly 6000 to 8000 years ago, agriculture was well under way in several regions including Ancient Egypt, around the Nile River; the Indus Valley civilization; Mesopotamia, between the Tigris and Euphrates rivers; and Ancient China, along the Yellow and Yangtze rivers. This is because the regular river flooding of the river made the soil fertile around the banks and the rivers could also supply fresh water to irrigate crops. It's no coincidence that as agriculture allowed denser and denser populations along with more specialized societies, some of the world's first civilizations developed in these areas as well:

⇒ Dams or weirs may be built to control the flow, store water or extract energy;

⇒ Levees may be built to prevent river water from flowing on floodplains or floodways;

⇒ Canals connect rivers to one another for water transfer or navigation;

⇒ River courses may be modified to improve navigation or straightened to increase the flow rate.

River management is a continuous activity as rivers tend to ‘undo’ the modifications made by people. Dredged channels silt up, sluice mechanisms deteriorate with age, levees and dams may suffer seepage or catastrophic failure. The benefits sought through managing rivers may often be offset by the social and economic costs of mitigating the bad effects of such management. As an example, in parts of the developed world, rivers have been confined within channels to free up flat flood-plain land for development. Unfortunately, floods can inundate such developing areas at high financial cost and often with loss of lives.

A Timeline for Human Effect on Rivers: Intensifying in the Early Holocene through agriculture, the use of fire, irrigation, cities, and river engineering (Courtesy of Martin R. Gibling)[01-01]

The engineering of dams is a vital part of the story of civilization. Water reservoirs were undoubtedly among the earliest structures devised by mankind. The role of dams is documented in many records of ancient lands. They have been linked closely to the rise and decline of civilizations, especially to those cultures highly dependent upon irrigation.

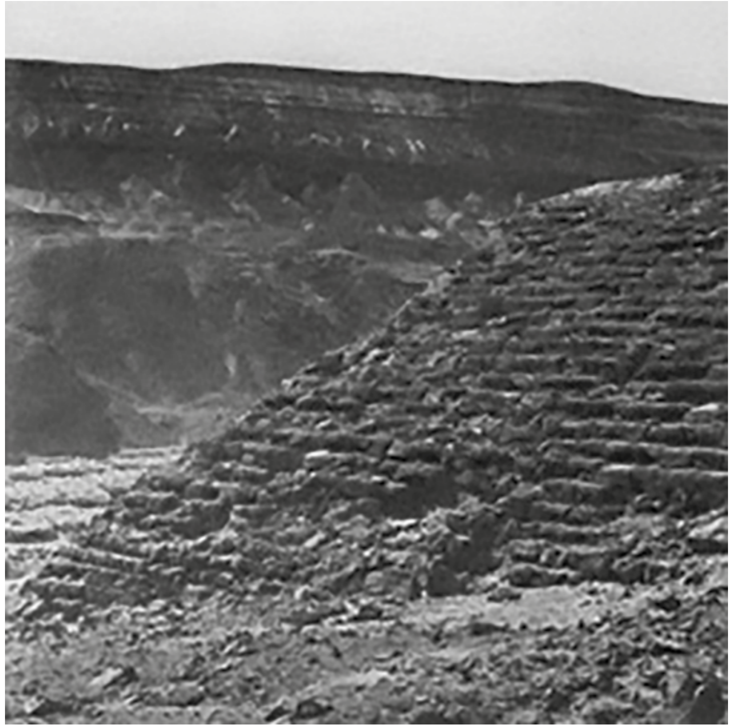
The Cornalvo Dam, a Roman gravity dam built in the 1st or 2nd century AD, still supplies water to the people of former Emerita Augusta - now Merida, Spain (Photo by Andriolo – 2002)

The Proserpina Dam is a Roman gravity dam in Badajoz (province), Extremadura, Spain, dating back to the 1st or 2nd century AD. It was built as part of the infrastructure which supplied the city of Emerita Augusta with water (Photo by Andriolo – 2002)

The first known dam to be built is the ***Jawa Dam***, which is actually the largest in a series of dams that are all part of one reservoir system. Located in modern-day Jordan, the ***Jawa Dam*** was originally built around 3,000 BC in what was then Mesopotamia.

Surprisingly, the ***Jawa Dam***[01-02] was actually an architectural feat of the times. While most ancient dams were simple gravity dams constructed of gravel and masonry, the ***Jawa Dam*** was reinforced with rock fill behind the upstream wall in order to protect the wall from water pressure breach. This safety feature was incredibly innovative for this time period.

Around 2950-2750 B.C, the ancient Egyptians built a dam that was called the ***Sadd el-Kafara***, which in Arabic means "Dam of the Pagans".



Upstream face of northern wall, photo of 1982. Remains of the poorly designed Sadd el-Kafara[01-03]

Unfortunately, as it was nearing completion, it failed. ***Due to poor design and lack of a spillway, the dam was washed away during a heavy rainfall and was never repaired or completed***. Discouraged by the failure of this massive project, ancient Egyptians were dissuaded from building other dams until many years later.

The Romans, highly regarded for their advances in hydraulic engineering, were prolific in dam construction during the height of the empire. The study of Roman dam-building has received special attention from ***Prof. J. Diez Cascon*** in comparison to their other civil engineering activities, even though their contributions in this field have been ranked alongside their expertise in constructing the well-known Roman aqueducts, bridges and roads.

Roman dam construction began in earnest at the early imperial period. For the most part, it was concentrated at the semi-arid fringe of the empire, namely the provinces of North Africa, the Near East, and Hispania. The relative abundance of Spanish dams below is due partly to the more intensive field work there.

With the hundreds of thousands of existing large dams throughout the world, and the ever-increasing demand for water and power, dams will continue to make a significant impact on modern day life, and as is evidenced by history, dam engineering will continue to evolve as additional innovations, discoveries and technological advances are made.

Fluvial systems are dominated by rivers and streams. Stream erosion may be the most important geomorphic agent. Fluvial processes sculpt the landscape, eroding landforms, transporting sediment and depositing it to create new landforms. Human civilization and ecosystems are equally dependent on fluvial systems. Rivers provide water for hydroelectric power and shipping, as well as supporting stream-side wetlands that are critical for clean water and to provide rich habitat.

A very known example is the **Nile River**, that has been a symbol and living element of great importance for the development of the ancient Egyptian civilization as well as the current and modern nation. In ancient times, most of its cities were settled bordering the river valley while its rich and majestic delta was located north of Aswan.

In the ancient Egyptian language, the river was called Iteru, which meant “Great River”. The word Nile comes from the Arabic ‘ni-l which in the Greek language was translated as Neilos meaning “River Valley”.

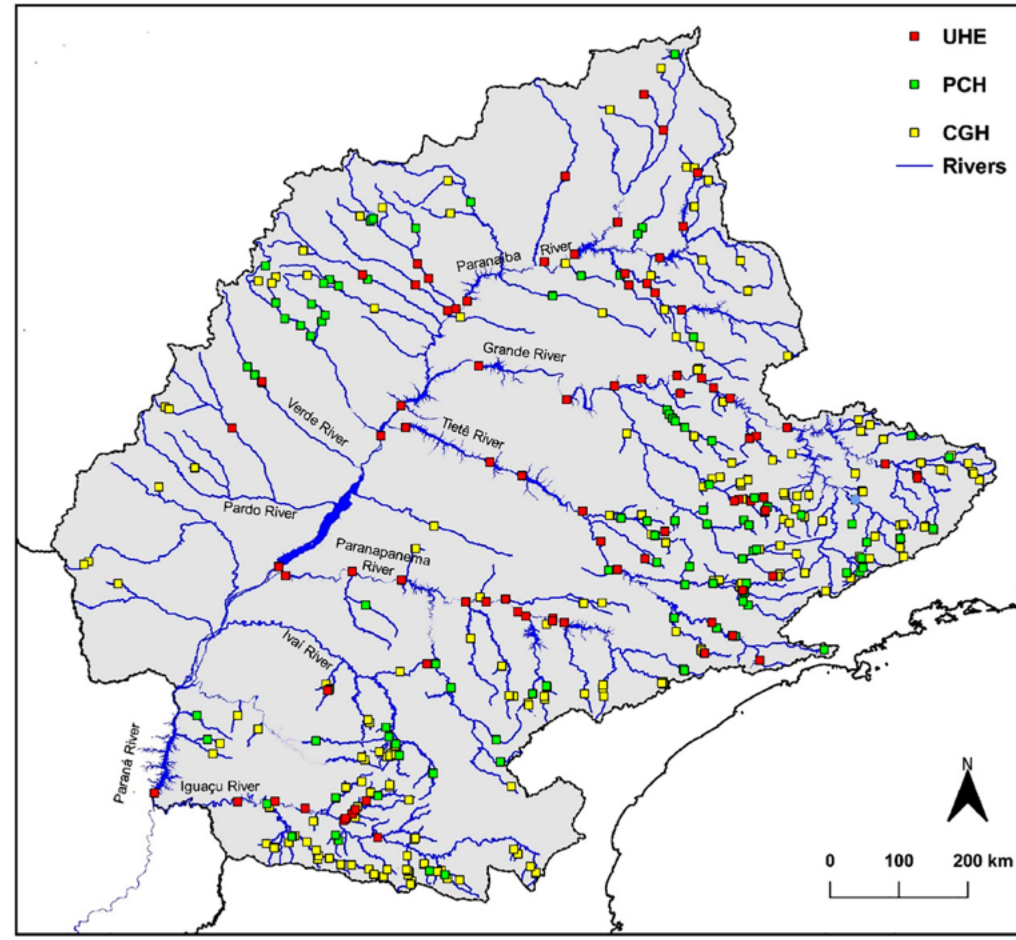
Nile River and Aswan High Dam location – From Internet

Aswan High Dam – from Google Earth

Aswan High Dam, in Arabic **Al-Sadd al-Ali**, a rockfill dam across the Nile River, at Aswan, Egypt, was completed in 1970. The Aswan High Dam yields enormous benefits to the economy of Egypt. For the first time in history, the annual Nile flood could be controlled by man. The dam impounds the floodwaters, releasing them when needed to maximize their utility on irrigated land, to water hundreds of thousands of new acres, to improve navigation both above and below Aswan, and to generate enormous amounts of electric power.

Another very important example is the Paraná River that is the tenth largest in the world in flow, draining much of Central South America, including parts of five states in Brazil. Its basin covers more than 10% of the Brazilian territory. Two large rivers, Grande and Paranaíba, drain part of the waters of the states of Goiás, Minas Gerais and São Paulo, forming the Paraná River from its confluence.

Parana River Basin - Encyclopaedia Britannica - *Wikipedia*



Distribution map of hydropower dams in the main rivers from Upper Paraná River Basin, by type of enterprise: UHE = large, PCH = medium, and CGH = small-sized hydropower plants

The Tietê, Paranapanema and Iguazú rivers are its tributaries, all flowing into the left side. The Paraná River, in its upper section, limits the states of São Paulo and Mato Grosso do Sul. Until its incursion into the Argentinian territory, four hydroelectric plants, Jupia, Ilha Solteira, Porto Primavera and Itaipú block its course. On its way, just after the confluence with the Paranapanema River, Paraná waters the state of the same name.

The **Paraná River**, in South America, rises on the plateau of southeastern Brazil and generally flows south to the point where, after a journey of around 5.000 km, it joins the Uruguay River to form the vast Atlantic Ocean estuary on the Río de la Plata.

The name Rio Paraná comes from the Tupi-Guarany native language where para = "**sea**" and na = "**like**", which means "that resembles the sea" or "like the sea".

The Paraná River drainage basin, with an area of approximately 2,800,000 square km, includes most of southeastern Brazil, Paraguay, southeastern Bolivia, and northern Argentina. It is the main river that forms the La Plata Basin.

From its birth at the junction of the Grande and Paranaíba rivers to its confluence with the Paraguay River, the river is known as the Alto (High) Paraná. This upper basin includes three important rivers, the Tietê, the Paranapanema and the Iguazú. All three have their sources near the Atlantic coast in the southeast of Brazil.

Itaipú Hydro Project – Paraná River - on the border between Brazil and Paraguay

The Paraná River flows south and forms a natural boundary between Paraguay and Brazil to the confluence with the Iguazú River. Shortly after this confluence, however, it is dammed by the impressive dam of the Itaipú hydroelectric. After merging with the Iguazú, Paraná becomes the natural border between Paraguay and Argentina.

March 14, 1987

May 12, 2000

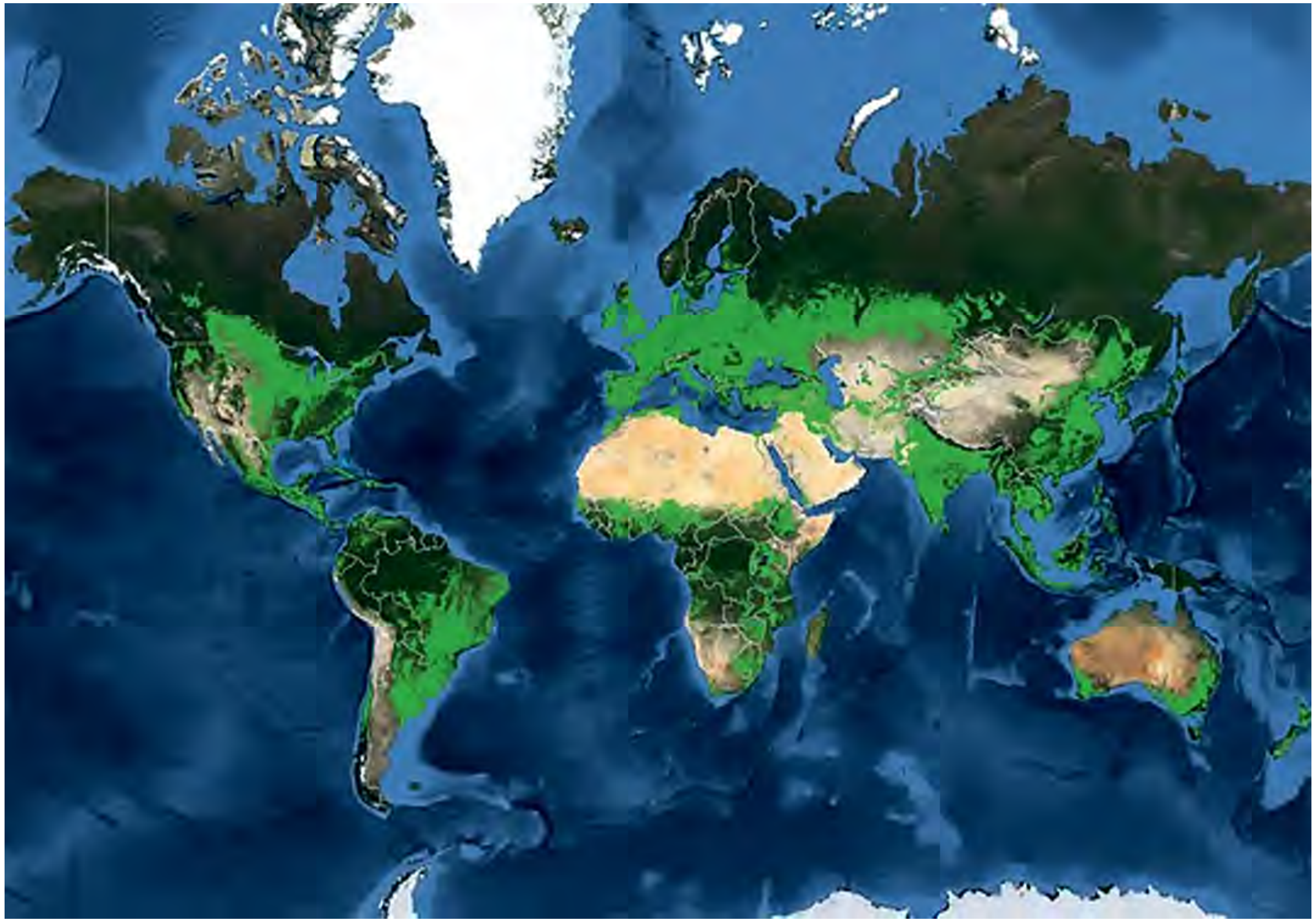
Porto Primavera Dam on Paraná River - it can be noted that the reservoir expanded to the level where previous farming zones were

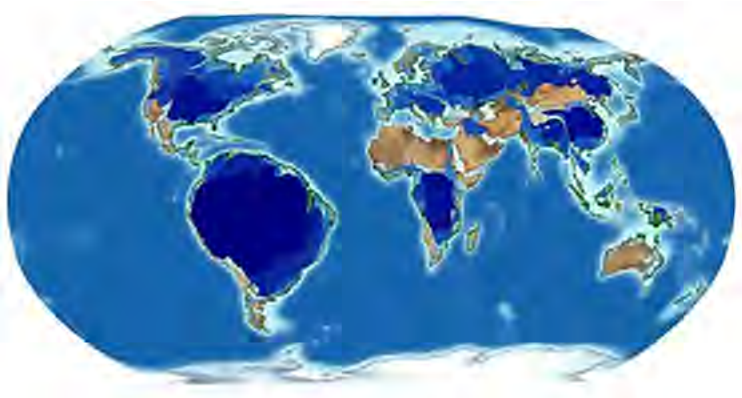
Belo Monte Hydro Project - Before and after Belo Monte Construction[01-05] - NASA Earth Observatory images by Joshua Stevens, using Landsat data from the U.S. Geological Survey

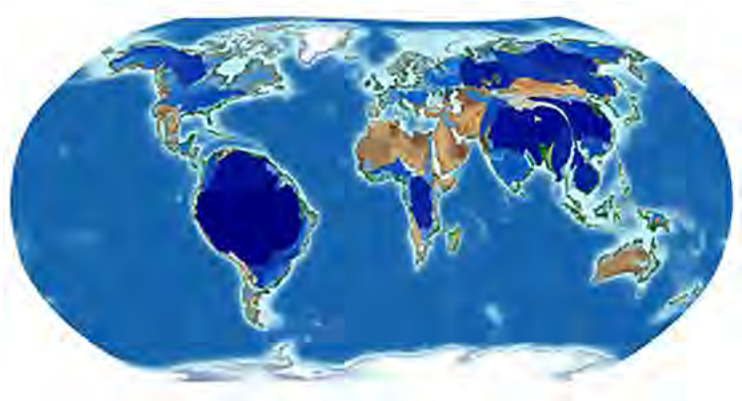
1.1.2 Hydrology and Transport of Solids

Hydrology has evolved as a science in response to the need to understand the complex water systems of Earth and help solve water problems. Hydrology is the dominant factor that determines development of the biological and physical characteristics of a wetland. Tidal flooding is the most obvious hydrologic factor that affects zonation of plant species, plant growth, soil chemical and physical properties and biological processes in tidal marshes. The hydrology is largely determined by elevation, slope, and tidal regime, which interact to determine the area of the intertidal zone and the depth and duration of flooding that occurs. Subsurface hydrology may also affect these same physical and biological processes. Rainfall, river flow, and wind effects also influence the hydrology of tidal marshes. A clear understanding of the site's hydrology is critical for successful tidal marsh creation.

Hydrology is the science that encompasses the occurrence, distribution, movement, and properties of water, also from its transportation of solids on earth and its relationship with the environment within each phase of the hydrological cycle. The water cycle, or hydrologic cycle, is a continuous process by which water is purified by evaporation and transported from the earth's surface (including the oceans) to the atmosphere and back to the land and oceans.







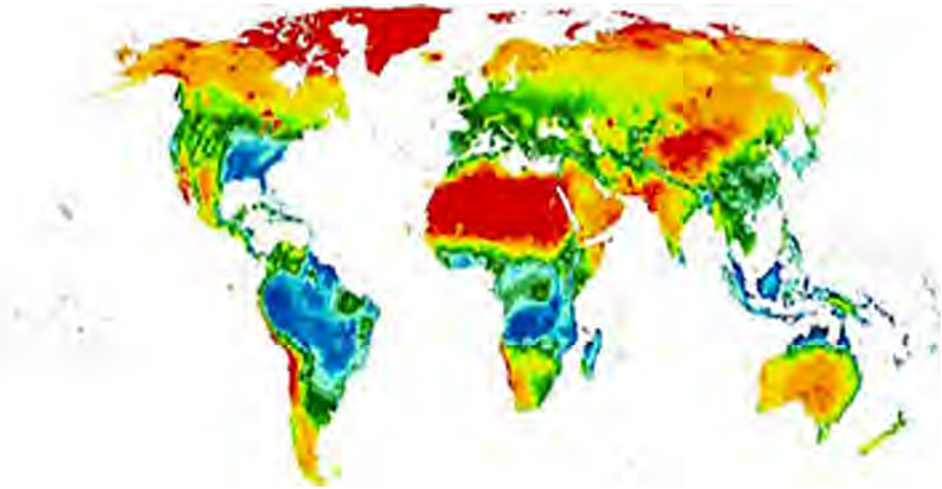
Average flow from the world's largest watersheds over the course of the year[01-06]

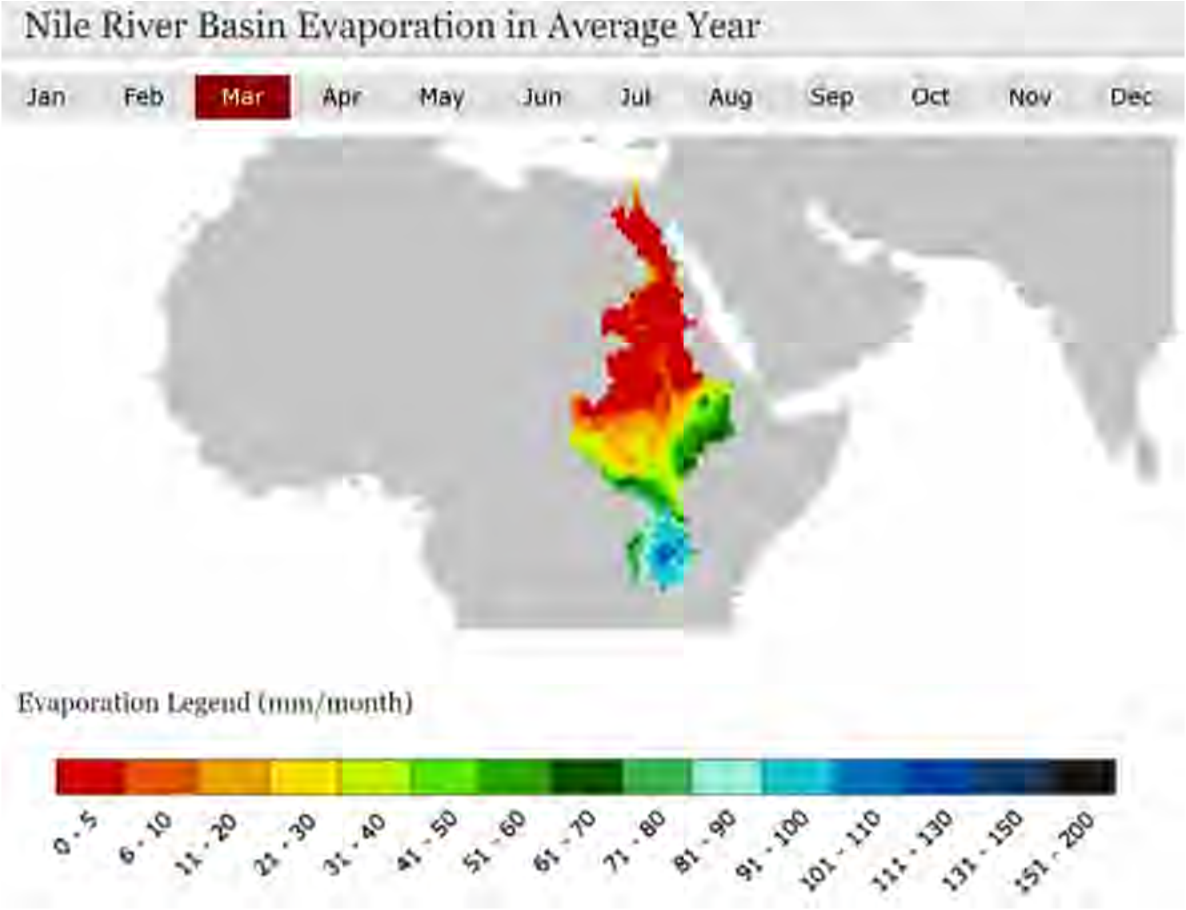
The natural development of tidal marsh occurs when sediments accumulate to an elevation that can be colonized by pioneer marsh plant species by seed, rhizomes or whole marsh sods that may wash up on the site.

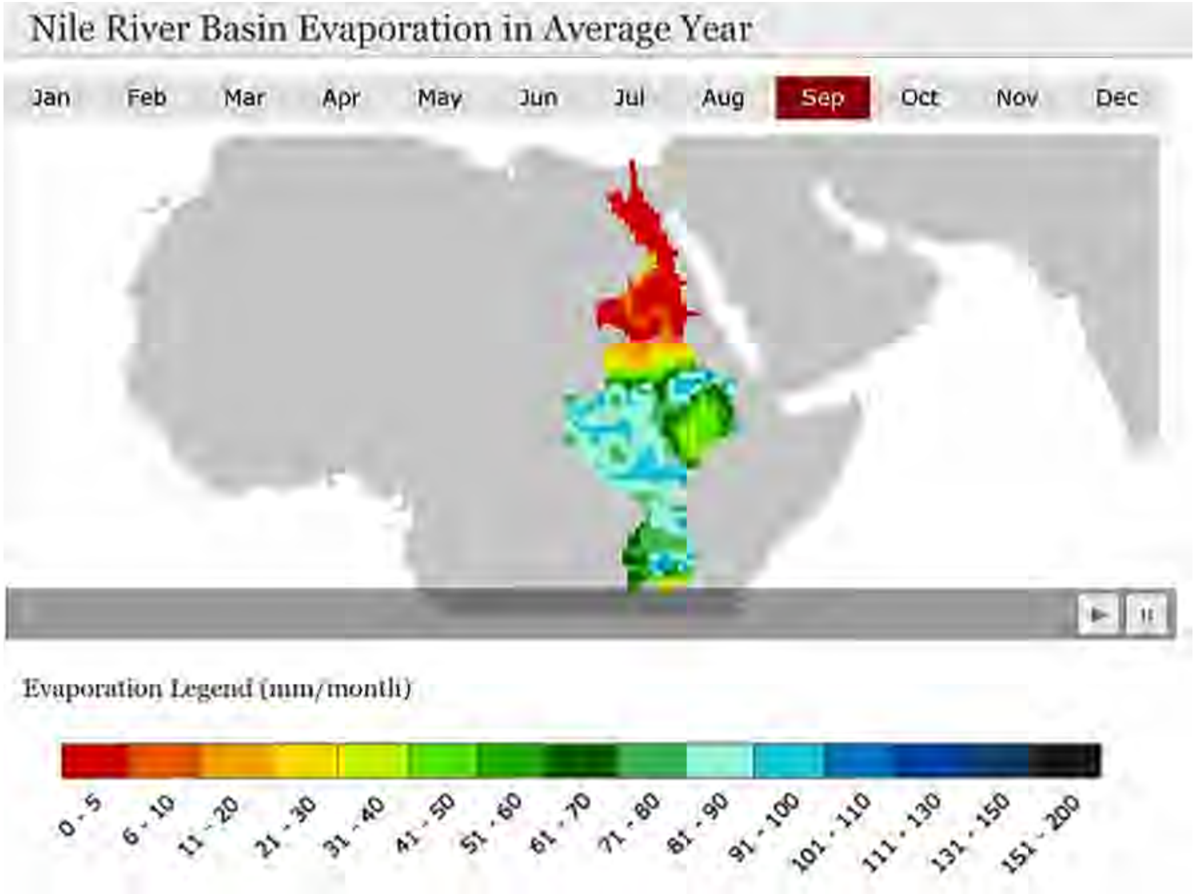
There are many pathways the water might take in its continuous cycle of falling as rainfall or snowfall and returning to the atmosphere. It might be captured for millions of years in polar ice caps. It may flow to rivers and finally to the sea. It might soak into the soil to be evaporated directly from the soil surface as it dries or to be transpired by growing plants. It might percolate through the soil to ground water reservoirs (aquifers) to be stored or it might flow to wells or springs, or back to streams by seepage. The cycle of water might be short, or it might take millions of years.

People tap the water cycle for their own uses. Water is diverted temporarily from one part of the cycle by pumping it from the ground or drawing it from a river or lake. It is used for a variety of activities such as households, businesses and industries; for irrigation of farms and parklands; and for production of electric power. After the use, water is then returned to another part of the cycle: perhaps discharged downstream or allowed to soak into the ground. Used water is normally lower in quality, even after treatment, which often poses a problem for downstream users.

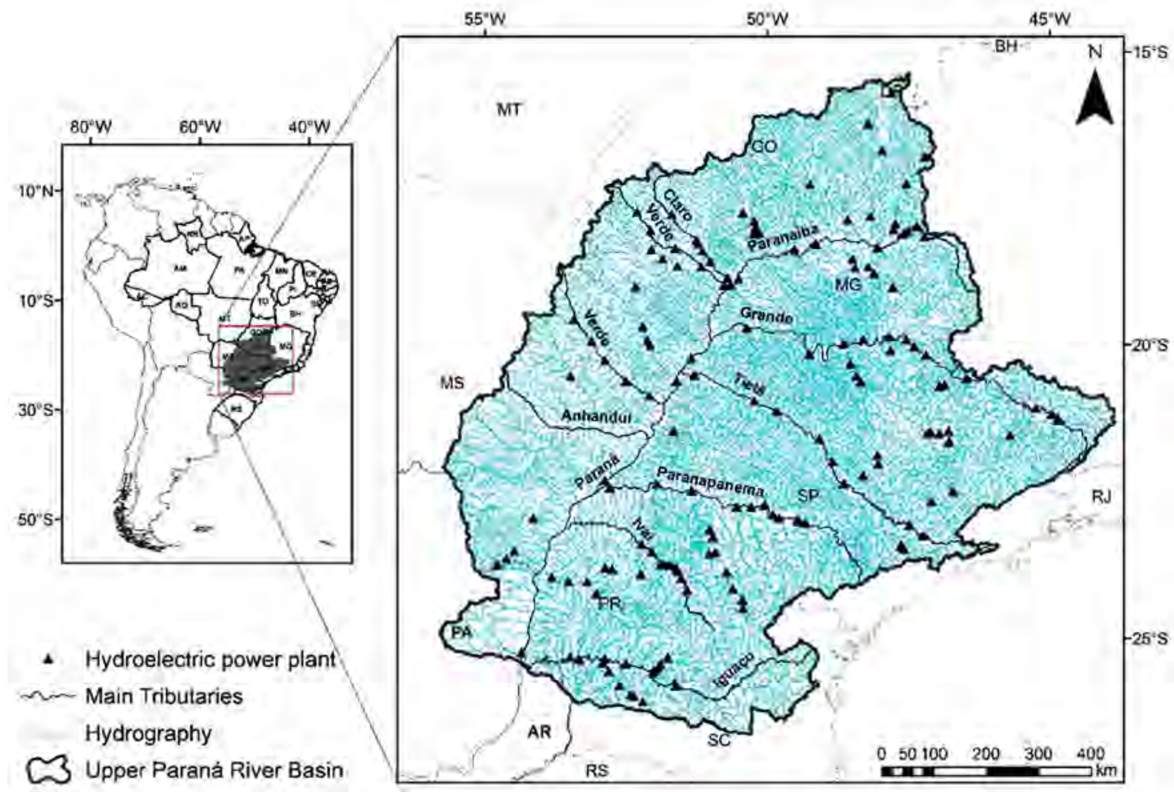
Evapotranspiration is one of the major components of the water balance over the Nile Basin and its sub-basins. Evapotranspiration (Evaporation + Transpiration) is a natural process through which water moves from land and water surfaces back to the atmosphere. The two processes occur simultaneously and are difficult to separate. They form an integral part of the hydrological cycle. It is difficult to measure evapotranspiration but recent advances in satellite observations have enabled its estimation over large areas such as the Nile basin. It is one of the largest components of the water balance of the Nile Basin. It accounts for more than 70% of the water balance in the wettest areas of the Nile Basin like the Blue Nile and the Equatorial Lakes sub-basins and even a higher percentage in drier areas.




Nile River Basin Evaporation in Average Year
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Evaporation Legend (mm/month)
0 - 5
6 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 130
131 - 150
151 - 200



Nile Region affected by large Evaporative Phenomena during two seasons[01-07]



Upper Paraná River Basin[01-08]

The Upper Paraná River Basin (UPRB)[01-08], plays a significant role in the Brazilian economy and development, greatly contributing to economic sectors such as agriculture, livestock, energy, and urban and industrial water supply. In particular, this watershed houses 87 hydropower plants (see Figure above), that provides more than 41,000 megawatts (MW) of electricity. The importance of modelling the hydrology of this basin as a whole is evident, but most of the studies discussing the hydrology of the basin, are local ones that focus on sub-basins and do not represent the whole basin. During the 20th century, rapid population growth and pronounced urbanization have led to a significant land use change in the UPRB.

- ✓ ***So, these two examples shows that different input data are required to build a hydrological project, including meteorological, hydrologic, and physical variables.***

1.1.3 Hydrology and Statistics

Hydrological phenomena such as precipitation, floods, and droughts are inherently random by nature. Due to the complexity of the hydrologic system, these physical processes are not fully understood, and reliable deterministic mathematical models are still to be developed. Therefore, in order to provide useful analyses for designing hydraulic facilities and infrastructures, statistical approaches have been commonly adopted.

The analysis of all data (flows and solids transportation) is extremely important because it can be used to understand why and how processes happen. Although, many statistical methods ignore the understanding of behavior and focus upon probabilities, fitting data to particular distribution patterns whose form can be defined.

It is not surprising that hydrological analyses and models have become progressively complex. The attempt to derive models that can be generalized for use in many geographical regions yet at the same time give accurate results, demands complexity, but could be regarded as self-defeating. In addition, many hydrological data must be analyzed in a manner that cannot be regarded as “modelling” in any mathematical sense. These analyses are essentially the treatment of data to provide further information or to render basic data into more useful forms.

It is important, however, to carefully evaluate the needs that are required for a particular project. For many projects the cost of data collection (both in money and time) and the duration of records will impose severe limitations on the analysis of data and the development of models. Understanding and describing the variability of hydro-climatological processes and measurements is essential for assessing the performance of water resources infrastructure and its management. Analyzed data provide valuable insights into the dynamics of hydrological processes that represent the hydrological cycle.

- ✓ ***This knowledge is critical for planning successful and efficient water resources projects, as well as environmental systems management alternatives.***

The engineer must ensure that the structures are correctly designed to withstand high intensity floods based on probabilities established for each type of project, in other words, a risk category. Dams must be able to resist severe floods that have high return periods, for example, a thousand years or a ten thousand years (a flood corresponding to a thousand-year or ten thousand year return period, that would occur on average every 1.000 or 10.000 years). Basically, function of the height of the dam, the volume of the reservoir and the consequences of eventually rupture.

In contrast, a small bridge used to cross a river should be able to withstand only a one-hundred-year return period flood. The determination of flood discharges equivalent to very low probabilities is determined by extrapolation using statistical adjustment functions based on historic flood data.

1.2 Geology

1.2.1 General Aspects

It has been well said that the task of the engineer is " ***to overcome by art the difficulties of Nature***". Much of his effort is used in the contest with space, time, and weather or in the ingenious harnessing of sources of power. But in the great construction enterprises already mentioned, he also contends with the earth's material and the forces that operate on them and thus must solve problems within the field of geology.

Many engineers and many great construction enterprises have contributed to geologic knowledge. All engineering structures constitute a load on the earth's crust. If this crust were everywhere of the same character and strength, the design of such structures could be much simplified, but the heterogeneity of the materials of the earth's crust and the complexity of their arrangement are notorious, and these geologic conditions enter most engineering problems.

Certain structures, such as bridge piers, dams, tunnels, and heavy buildings, require both for design and construction unusual precise knowledge of the strength, attitude, and water-bearing character of the local rocks.

Moreover, unusual earth movements and the resulting tremors or earthquakes often endanger the works of men and, in certain localities, should be largely avoided in the design of engineering structures.

The engineer has learned all the geology that it is necessary to know within the test limits and in ordinary construction where the limits are narrow. However, on large undertakings simple procedure and rule of thumb methods derived from such simple tests are inadequate and elaborate investigations by means of pits, rotary drilling, loading tests, optical profiling of the bores and so on, are resorted in order to obtain the necessary information for intelligent design.

A growing number of undertaking geologists are being called upon to offer the benefit of their specialist knowledge and their ability to reduce the number of tests required, placing them in a truly significant place. They are also needed to correctly interpret the results obtained.

1.2.2 Dam Site

The requirements of a reservoir site are many and exacting; the main one of these is, in a modified form from **Lippincott's**[01-09] statement:

1) an ample size tight basin;
2) a narrow outlet requiring a relatively small and economical dam, with ***foundations able to sustain the dam***;
3) opportunity for building a ***safe and ample spillway to dispose of surplus water***;
4) available (***and durable-added by the authors***) materials of which to construct the dam;
5) assurance that the basin will not fill with mud and sand carried in the water in too short time;
6) ample and available water supply;
7) use for the stored water or other adequate reason to justify the cost.

The geologist, therefore, must give this question not only a qualitative but also a quantitative determination in order to realize its greatest usefulness. He must consider whether leakage will progressively enlarge the openings and thereby increase and also whether it will destroy the stability of the ground.

The size and cost of the dam required are largely determined by a survey of the site. Although, the character of the dam and its details are, in many localities, governed by the geology, especially the capacity of the foundations and abutments to transmit water or to sustain weight. These problems require the closest cooperation of geologists and engineers, as the number of engineering devices to overcome natural difficulties continually increases.

Locally available materials of good quality decrease costs, so, the geologist should act as a scout to locate and evaluate the rock, gravel, sand, and clay that is available nearby. These investigations fall within the ordinary field of engineering.

The detritus carried by a stream will lodge in all reservoirs formed by damming a stream valley. On muddy streams the quantity of this material, usually called " silt," may be very large and the reservoir may be filled or "silted" in so short a time as to make its construction inadvisable. Measurement of the " silt" content of a stream falls into the field of engineering, but preliminary surveys estimate that geologists may give useful advice, because the amount of detritus carried by a stream is a function of the distribution and area of the rocks in the drainage basin.

Stream channels and fluvial landforms are influenced by the complex interplay among regional geology, climate, topographic gradient, river history, drainage basin hydrology and sediment load. Over time rivers can cut through bedrock. Rivers flowing over soft sedimentary rocks can cut deep gorges and canyons.

The study of dam sites is of interest to geologists because of the necessity for precise and detailed work and because funds are often available for test pits and borings to obtain information not obtainable by surface examination. A dam consists of an impervious or nearly impervious membrane, supported against the thrust of impounded water. The geologist is not concerned with the methods which the membrane and its supporting structure shall be built except the one in relation to the geologic difficulties and he should avoid expressions that give him the appearance of dictating engineering details to the designer.

The geology of dam sites shall be considered under the following headings:

⇒ Stability, durability and ***safety of the upstream and downstream zones around the dam***;

- ⇒ Foundations (bearing capacity and leakage conditions), for the dam and cofferdam;
- ⇒ Abutments (leakage) and stability;
- ⇒ Spillways, tunnels (bypass, discharge, etc.) and deviation structures;
- ⇒ Materials for construction (availability and quality).

This division is quite arbitrary, however, because the factors are so related that in the examination of any site all must be considered.

The most common type of dam site lies in a narrow part of a valley where the rock of the abutments of the dam is more or less visible but the bottom of the cross section is covered with the alluvium of the stream. ***A misinterpretation of conditions during preliminary examination involved additional trouble, expense in building a dam recently completed, in the safety of the dam and on what will be found at downstream***.

In addition to the bearing capacity of the rock of the foundations, the number and kind of openings, faults and discontinuities in the rock must be considered. If there is free communication from the reservoir through these openings, it will result in the uplift of pressure on the base of the dam proportional to the depth of water in the reservoir. This pressure must be allowed in the design of the dam. Leakage must also be analyzed, if the rock is expansive, contains soluble parts as karstified foundation rock or if fine material such as sand is eroded from the rock by the flowing water, the leaks may increase with a resulting loss in water and weakening of the foundation. The likelihood that limestone may be cavernous should be borne in mind.

The abutments of dams may be hard or soft rock. In the harder rock joints, cracks, and bedding planes may form passages through which leakage may take place, but if these cracks are clean, they may be grouted under pressure and made watertight. Abutments of basalt must be regarded with suspicion on account of the many openings that may occur in such rock. These openings may allow leakage, but they are not likely to enlarge, and the stability of the abutment is not menaced by them. However, limestone, the still more soluble gypsum and rock salt give rise to large cavities that will, as leakage goes on, increase in size. Obviously if the abutments are broad, these defects are relatively unimportant, whereas if the abutments are narrow ridges, not much wider than a dam, joint cracks and other crevices have more weight as unfavorable factors.

The rock of the abutments that has been exposed to the weather is more or less unsound and should be removed to a depth sufficiently great so that the impervious portion of the dam may rest on "sound rock". Similarly, if the base of the dam or the cut-off structures are to be placed in bedrock, the depth to "sound rock" must be estimated.

1.2.3 Additional Attention

⇒ **Sinkholes - Erosion** - Internal erosion or piping of embankment or foundation materials can cause sinkholes to develop on the dam crest or slopes. A void or seepage passageway develops that eventually collapses and forms the sinkhole. Damaged outlet pipes or separated pipe joints can cause voids. Uncontrolled seepage can also cause passageways to form. Close observation of seepage discharge can determine if seepage is carrying soil particles. Internal erosion is dangerous and can lead to total failure of a dam.

⇒ **Remedial Action:** If a sinkhole is caused by internal erosion, measures must be taken to stop the cause. Pipe failure or leakage can be mitigated by discontinuing use of the pipe. Otherwise, lowering the reservoir will reduce the reservoir head causing the seepage. Filling the depression is a temporary measure to gain freeboard during a storm. Fill for an active sinkhole should be an inverse filter; first rock, then gravel and sand, and finally, soil fill.

The rock should be large enough not to be carried away by seepage. The rock will filter the gravel while the gravel filters the sand, and so on. Sinkholes due to rodent activity should have all loose material excavated and compacted fill placed in the hole. To maintain freeboard during a storm, sandbags can be used.

⇒ **Cracks**

- **River and Reservoir Banks** – Some cracks can be induced due to the variation of the river level;
- **Longitudinal Cracks** – Differential movement of portions of the embankment can cause cracks to develop parallel to the dam axis. This signifies a major defect and could result in slope failure. Longitudinal cracks caused by differential movement indicate uneven settlement, foundation failure, or the initiation of an embankment slide. This situation can develop into a dangerous condition;
- **Transverse Cracks** – Differential settlement of the embankment can cause cracks to develop perpendicular to the dam axis. Generally, transverse cracks form in an area where the dam was constructed on a steep abutment slope. Subsequent to crack formation, uncontrolled seepage can develop. Reduced freeboard from settlement can increase the risk of overtopping. This is a dangerous situation, and the embankment should be repaired as soon as possible;
- **Drying Cracks** – During dry weather surface drying can cause cracks, which are generally shallow with no signs of movement. In most cases, the crack pattern is random so that transverse or longitudinal cracks are not formed. This situation does not represent a dangerous condition.

⇒ **Remedial Actions:** Transverse cracks above the reservoir level can be sealed with clay placed at the upstream end to regain lost freeboard. Transverse cracks inundated by the reservoir and discharging water on the downstream slope should first have rock placed on the extreme downstream end of the crack. The rock must be sized so that it does not wash out but slows the flow rate. Next, gravel should be placed over the rock. Individual gravel particles should be large enough not to be washed through the rock. Then, a type of sand that will not wash through the gravel and finally, soil should be placed on the upstream end of the crack, sealing it. Longitudinal cracks may indicate mass movements and should be treated as a slide, except that the cracks should be sealed in to prevent flow of water. Do not use excessive material that could increase the driving force, causing the slide to further develop.

⇒ **Mass Movements of Portions of the Dam**

- **Rotational Slides** – These are slides in which large masses of material move rotationally. The upper section moves down creating a scarp, or nearly vertical surface, and a similar mass of material is pushed out, forming a bulge at its lower section. This slide is generally caused by embankment or foundation loss of strength and changes in the saturated zone in the dam. Upstream slope instability can be caused by rapid reservoir drawdown. This instability can cause additional sliding. Generally, freeboard is lost, and, in some cases, reservoir storage is released. This is a dangerous situation and could result in total dam failure;
- **Shallow Slides** – These are caused by an overly steep slope and surface saturation of the embankment to a shallow depth. This condition generally occurs during periods of continued heavy rainfall. As a dam surface becomes saturated, the soil strength can decrease resulting in slides on steep slopes. This condition generally does not cause dam failure, because it can be repaired before a dangerous situation develops.

⇒ **Remedial Actions:** Rotational slides indicate that the dam is unstable. Even if the upper part of the slide does not intersect the upstream slope, with time, additional sliding can cause loss of freeboard. Reservoir drawdown is recommended as an immediate step. If freeboard is lost, sandbags can be added to the crest to regain it. Sandbags, however, will increase the driving force so the risk of continued sliding versus the risk of overtopping must be taken into consideration. If at all possible, material should be placed at the toe of the slide to provide a buttress against additional sliding.

⇒ **Slumping or Sloughing** – Soil or rock that fills slope erosion, especially at the lower end of a slope, can cause slumping. This condition occurs on an upstream slope, due to wave erosion, and also in a downstream area where spillway discharge comes into contact with an earth/rockfill slope.

⇒ **Embankment Seepage**

- **Concentrated Seepage** – Large rates of seepage from a very small area indicate that a direct link to the reservoir has been established. This can result in internal erosion of foundation or embankment of materials leading to dam failure. This is a dangerous situation and should be mitigated as soon as possible. Immediately lowering the reservoir can help prevent dam failure;
- **Discolored Seepage** – Muddy or discolored seepage indicates that the internal erosion of embankment or foundation is taking place. This is a very dangerous situation that can rapidly lead to dam failure, therefore, emergency measures should be instituted as soon as possible;
- **Seepage Over a Large Area** – A large wet area indicates that a significant part of the dam has reduced soil strength because of its saturated condition. Such an area should be closely monitored for bulging, flowrate changes, clarity of discharge and area of saturation.

⇒ **Foundation Seepage**

- **Concentrated Seepage** – A punctual infiltration discharge in the floodplain below the dam indicates that seepage is occurring through the foundation of the dam and that the cutoff wall is ineffective or has been bypassed. Movement of soil particles with the seepage means that internal erosion -as piping- is taking place. Foundation and dam failure can occur if erosion is allowed to continue;
- **Seepage Over a Large Area** – Foundation seepage can manifest over a large area of the floodplain below a dam. This indicates that foundation seepage is moving under the dam through a large area and the speed is fairly slow. Generally, internal erosion does not accompany this type of seepage but monitoring should be instituted;
- **Abutment Seepage** – Generally, abutment seepage does not affect the dam. Erosion of embankment materials can occur if discharge comes into contact with the dam;

- **Karstic zones** – Leakage from dam reservoirs has been reported in different karst regions of the world. Water leakage occurs through the karst features directly or indirectly. The estimation of leakage locations, paths, and quantity are subject to error due to uncertainties in the non-homogenous nature of a karst formation, method of study, and limited investigation due to time and cost factors. All information obtained about karst development based on the measurements and tests in the boreholes may be uncertain. Karst development is a heterogeneous process making the detection of critical leakage zones difficult. A karst topography formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum, is characterized by underground drainage systems with sinkholes and caves. It has also been documented for more weathering-resistant rocks, such as quartzite and sandstone, given the right conditions.

⇒ **Seepage Collection System**

- **Discolored Discharge** – This condition indicates the absence of a filter or filter failure in the drain system, thus allowing seepage to carry soil particles into the drain or downstream slope. This is a dangerous situation that could lead to dam failure;
- **Increased Flow Rate** – Increased flow without discoloration indicates an increase in the operating level of the reservoir or changes in the seepage characteristics of the dam;
- **Discolored discharge** with **increased seepage rates** indicates a severe condition in which the drain system has failed and provided a direct connection to the reservoir. Internal erosion of the dam can result in dam failure.

⇒ **Remedial Actions:** Discolored seepage exiting from a small area of the embankment or foundation indicates internal erosion. Lowering the reservoir will decrease the seepage pressure. The best action is to construct a weighted filter over the exit point and a sandbag dike to create a backwater condition to slow down the seepage exit speed. Seepage exiting over a large area is not as dangerous; however, it can eventually cause instability and should be regularly monitored. Seepage exiting from an internal drain system is collected in a controlled fashion. If discharge is discolored, it indicates that the system has failed in some manner and internal erosion is taking place. Aside from lowering the reservoir, no emergency measures can be taken. An increased flow rate indicates that the reservoir levels have increased, a major problem has developed with the cutoff trench, or the cutoff trench has been bypassed. Lowering the reservoir will decrease the seepage pressure.

⇒ **Seepage Associated with Appurtenant Works**

- **Outlet Pipes** – Seepage observed in the vicinity of an outlet pipe indicates that a flow path has developed along the outside of the pipe. The source of seepage is either the pipe itself or the reservoir. Pipe defects include a separated joint, a crack or break, corrosion, or a leaking valve. Such problems must be closely monitored for flowrate and discoloration.
- **Under Spillway Slabs** – Spillway slab under seepage indicates that there is no effective cutoff or drainage system. Spillway failure can result if unabated seepage continues;

⇒ **Remedial Actions:** Lowering the reservoir will lessen the head or eliminate spillway under seepage. Sand bagging may also help to slow or stop under seepage. For seepage associated with pipes, removing the pipe from service and dewatering it is the best action. In cases where seepage is flowing along the outside of the pipe from the reservoir, no emergency actions can be taken aside from lowering the reservoir.

⇒ **Threatened Overtopping**

- **Low Area on Crest** – Reduced freeboard is the result of a low area on the dam crest. Low areas are caused by localized settlement, erosion, cattle paths, sinkholes, uprooted trees, transverse cracking, off road vehicle traffic, rodent activity, and inadequate final grading of the crest during initial construction. Overtopping can cause dam failure; therefore, this condition must be repaired as soon as possible;
- **Inoperable Spillway** – Reduced spillway capacity is caused by a damaged, blocked, or failed spillway. Improperly designed drop inlet spillways can be damaged by lake ice. Floating debris can block the spillway entrance and open channel spillways can undergo reduced capacity because of excessive vegetative growth and channel-side failure. This condition is very dangerous as it can cause dam failure;

⇒ **Remedial Actions:** Low crest areas that have reduced freeboard can be sandbagged to regain lost freeboard. Inoperable spillways are extremely hard to repair or replace when the reservoir is rising. Sometimes, a backhoe can clean out debris from a spillway inlet or an open channel. Extreme care must be taken in doing this during high reservoir levels. In other cases, another spillway channel can be excavated to increase the discharge rate; however, extreme care is needed to identify a suitable channel route.

1.3 Climatic Aspects

1.3.1 General

River floods are a common natural disaster in many countries and, along with storms, have resulted in fatalities, affected millions of people, and caused massive direct economic losses over the past three decades. Climate change is likely to increase the occurrence and frequency of flooding. Heavy rainstorms are projected to become more common and more intense due to warmer temperatures.

In some regions, certain risks, such as early spring floods due to reduced snow accumulation during winter, could decrease in the short term, but new risks associated with climate change may outweigh positive effects in the medium term.

Impacts on water resources produced by climate change can be exacerbated when occurring in regions already presenting low water resources levels and frequent droughts, and subject to imbalances between water demands and available resources. However, the detection of those effects is not simple, because the natural variability of the water cycle and the effects of water abstractions on flow discharges complicate the establishment of clear trends. Therefore, there is a need to improve the assessment of climate change impacts by using hydrological simulation models.

Climate change will increase water stress in some regions of the world, decreasing runoff (mainly in some parts of Europe, Central and Southern America, and Southern Africa). In other water-stressed areas, particularly in South and East Asia, climate change will increase runoff, though these increases may not be very beneficial because they tend to occur during the wet season, therefore the excess water may not be available during the dry season when it is most needed.

1.3.2 Humidity, Temperature and Freezing-Thawing Aspects

As it was mentioned before, temperature also affects river processes. During winter temperatures can drop below freezing, particularly at night and in upland areas. This leads to freeze-thaw weathering. Chemical weathering tends to increase during the summer as temperatures rise. These processes of weathering can affect the shape of a river landscape as mass movement such as rockfalls become more likely, as it loosens material on the valley side. Some of this material can enter the river channel and be transported when discharge increases.

Changes in climate, including rainfall, temperature, evaporation, and extreme weather events, influence the water cycle, which is the primary driver of the hydrology of waterways. The condition and stability of waterways depends not only on their hydrology, but also on a complex and dynamic network of interactions between bacteria, algae, plants and animals with sediments, rocks, surface water flow, groundwater, and chemicals. Climate change will affect these components and the processes and interactions that occur between them, in a range of different ways.

The ambient temperature and moisture conditions can affect the properties and behavior of soil and concrete constructions. Some early cracks can appear due to evaporative conditions, and later cracks can appear also, due to settlement in soil construction and due to creep in concrete construction.

Moisture causes problems for soil and concrete construction. Many common moisture problems can be traced to poor decisions in design, construction, or maintenance.

The effect of high ambient temperatures and high temperature concrete component materials have on the setting time of concrete mixtures is a topic of concern due to the reduced time in which the concrete must be placed, consolidated, and finished. This can increase the potential for plastic shrinkage cracking, thermal cracking, and cold joints; potential strength reduction due to high water demand and high curing temperatures; difficulty in controlling air content; and increased urgency for applying appropriate curing method at an early age.

Precautions may include the use of materials with a good performance history in high temperature conditions, cool concrete materials or concrete mixture, provide concrete consistency and placement equipment and crew for rapid placement, reduce time of transport, schedule placement to limit exposure to atmospheric conditions (night time placement or more favorable weather), plan to limit rapid moisture loss (sun screens, wind screens, misting, or fogging), and consider the use of an evaporation retarder.

While hot weather conditions are commonly encountered in summer, combinations of high temperatures, winds, and low humidity could result in conditions leading to problems with concrete placement and finishing at any time. For the purposes of this text, hot weather is any combination of:

⇒ high ambient temperature;

⇒ low relative humidity;

⇒ high wind speed.

It is usually accepted a 35°C limit at the maximum concrete temperature at the time of delivery. However, when the air temperature rises above 30°C, it is usually recommended that precautions be taken, particularly if there is also hot dry wind. This is firstly to ensure an acceptable concrete temperature at the point of delivery, and secondly to avoid problems with plastic shrinkage cracking and premature stiffening of the concrete.

On the opposite side, concrete gains very little strength at low temperatures. Accordingly, freshly placed concrete must be protected against freezing until the degree of saturation of the concrete has been sufficiently reduced by cement hydration.

Concrete placed during cold weather will only develop sufficient strength and durability to satisfy intended service requirements if it is properly produced, placed, and protected.

Some technical documents define cold weather concreting as a period of more than three (3) consecutive days, when the following conditions exist:

⇒ The average daily air temperature is less than 5°C;

⇒ The air temperature is not greater than 10°C for more than one-half of any 24-hour period.

Even though not defined as cold weather, protection during Spring and Fall is required during the first 24 hours to avoid freezing.

Freeze-thaw damage is a potentially serious deterioration process that occurs in concrete structures in cold climates. Premature damage to concrete slabs during freeze-thaw cycles represents a major challenge to pavement durability and resilience.

When water freezes, it expands about 9 (nine) percent. As the water in moist concrete freezes, it produces pressure in the pores of the concrete. If the pressure developed exceeds the tensile strength of the concrete, the cavity will dilate and rupture. The accumulative effect of successive freeze-thaw cycles and disruption of paste and aggregate can eventually cause expansion and cracking, scaling, and crumbling of the concrete.

When concrete freezes, the pore water in concrete starts to freeze around -1°C. As some water freezes, the ion concentration in the unfrozen water increases, further lowering the freezing point. At around -3 to -4°C, enough of the pore water will freeze, so that hydration will completely stop and depending on the extent of hydration and therefore the strength of the concrete, the forces generated by ice expansion (ice occupies ~9% more volume than water) can be detrimental to the long-term integrity of the concrete.

1.3.3 Landslides

Landslides and avalanches are concentrated in the main mountain ranges. However, the banks of the rivers that drain the large basins are also unstable. The relief, together with the lithological component, is accounted for the geographic distribution of the slope failures, whereas the origin of snow avalanches is due to both the accumulation of snow in the supra crestal and the steep relief. The main triggering mechanisms of landslides are rainfall, melted snow, earthquakes, volcanic eruptions, and undermining by both waves and river erosion. Landslides can also occur spontaneously for no apparent reason.

Climate-related landslides are the most frequent. The relationship between climate and slope instability, however, is complex due to the great variety of failure mechanisms. High-intensity, short-lasting rainfall episodes generally cause shallow landslides, debris flow and rockfalls. Prolonged low or moderate-intensity rainfall lasting for several days or weeks reactivate landslides and mudslides.

The behavior of landslides mass is very dependent on its geological-geomorphological context, but their reactivation is frequently associated with abnormally rainy seasonal periods. It must be kept in mind, in any case, that anthropic modifications (logging, leaks, overloading) are a frequent cause of new, apparently spontaneous slope failures. Uncertainty related to the increased frequency of torrential rainfall and abnormally rainy episodes prevent from any conclusive statement. Increased torrentiality will cause a greater number of shallow landslides and debris flows, the effects of which could be exacerbated by changes in land use and reduced plant cover. An increase in slope erosion can be consequently expected, which will be reflected in the degradation of surface water quality, due to increased turbidity and a higher clogging rate in reservoirs.

The decrease in snowfall does not necessarily imply less avalanches, because of the increase in melting snow avalanches, although their geographic area can be expected to decrease. The best adaptive tool involves regional and urban planning that avoids the development in the most susceptible areas. Winter tourism, however, could be negatively affected by the decrease in snowfall.

1.4 Earthquakes

1.4.1 General

Earth's major earthquakes occur mainly in belts, coinciding with the edge of tectonic plates. This has long been apparent, from early catalogs of felt earthquakes, and is even more readily discernible in modern seismicity maps, which show instrumentally determined epicenters.

An earthquake is defined as a sudden and rapid shaking of the earth caused by the breaking and shifting of rock beneath the Earth's surface and it creates seismic waves, which can result in damages and failures on man-made structures built on the crust of earth.

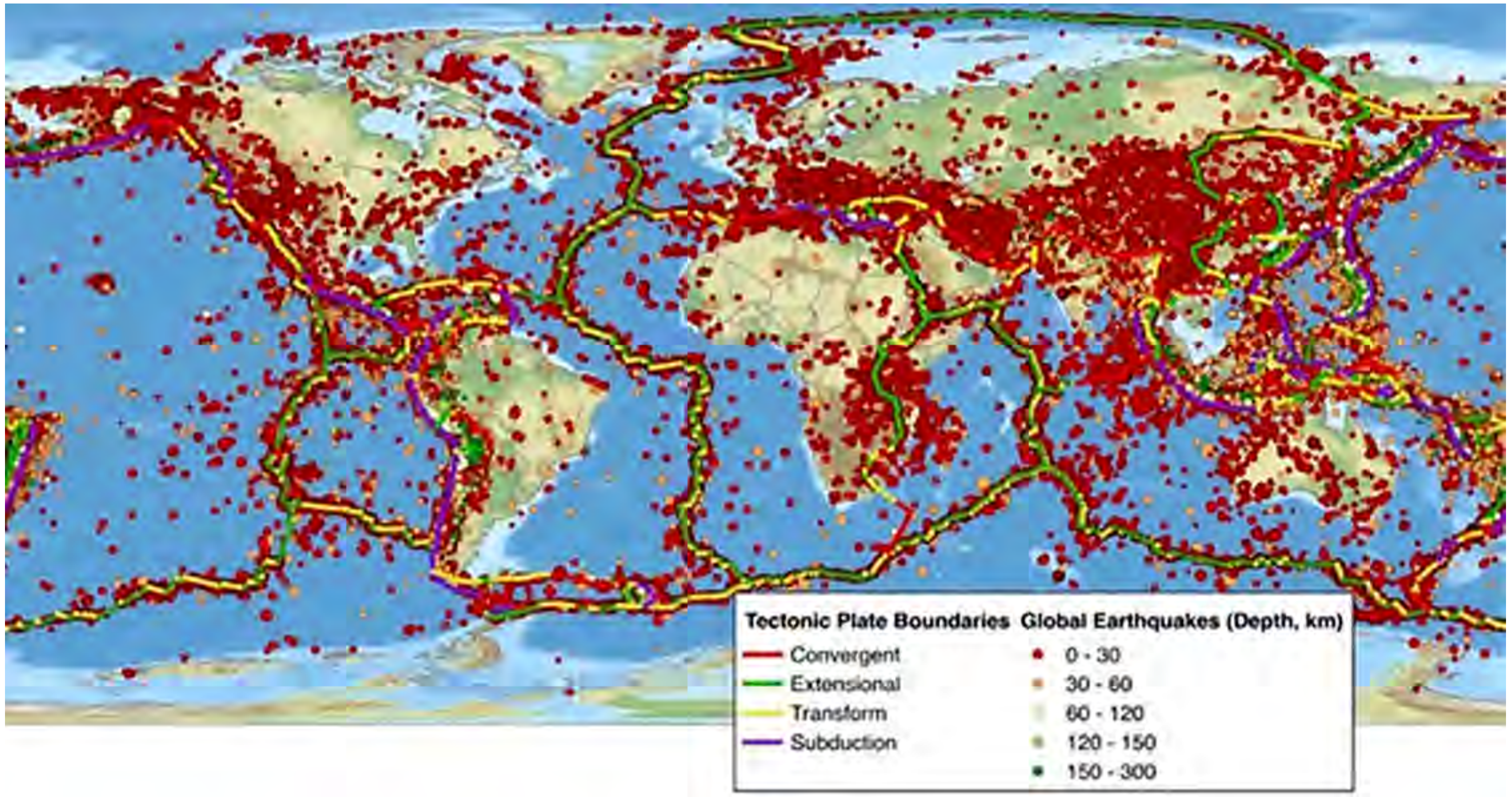
Earthquakes are caused by the sudden release of energy within some limited region of the rocks of the Earth. The energy can be released by elastic strain, gravity, chemical reactions, or even the motion of massive bodies. Of all these, the release of elastic strain is the most important cause because this form of energy is the only kind that can be stored in sufficient quantity on Earth to produce major disturbances. Earthquakes associated with this type of energy release are called tectonic earthquakes.

Global earthquake activity. Most earthquakes are generated at boundaries where plates converge, diverge, or move laterally past one another. The greatest amount of seismicity occurs 3 in regions where lithospheric plates converge. These convergent boundaries may manifest as regions of subduction, where the oceanic crust is forced down beneath either the continental plate or the younger oceanic crust.

Convergent boundaries may also produce regions of continental collision resulting in tectonic compression. Both types of environments are characterized by regions of high earthquake activity and host faults capable of generating very large earthquakes.

Divergent plate boundaries represent areas where shallow crust is being pulled apart. These may manifest as rift zones, where the shallow continental crust is undergoing extension, resulting in moderate to high seismicity. Transformed and transcurrent plate boundaries manifest where the relative movement of the plates is lateral. Because of their proximity to many large urban centers, these systems can pose a significant threat to society.

The most important earthquake belt is the Circum-Pacific Belt, which affects many populated coastal regions around the Pacific Ocean — for example, those of New Zealand, New Guinea, Japan, the Aleutian Islands, Alaska, and the western coasts of North and South America. A second belt, known as the Alpide Belt, passes through the Mediterranean region eastward through Asia and joins the Circum-Pacific Belt in the East Indies. There are also striking connected belts of seismic activity, mainly along oceanic ridges — including those in the Arctic Ocean, the Atlantic Ocean, and the western Indian Ocean — and along the rift valleys of East Africa. This global seismicity distribution is best understood in terms of its plate tectonic setting.



The global distribution of earthquakes in the period from 1900 to 2014, and global plate boundaries[01-10]

An earthquake is the ground shaking caused by a sudden slip in a fault. Stresses in the earth's outer layer push the sides of the fault together. Stress builds up and the rocks slip suddenly, releasing energy in waves that travel through the earth's crust and cause the shaking that we feel during an earthquake. Faults are caused by the tectonic plates grinding and scraping against each other as they continuously and slowly move.

There is no scientifically plausible way of predicting the occurrence of a particular earthquake. It is important to note that prediction, as people expect it, requires predicting the magnitude, timing, and location of the future earthquake, which is not currently possible.

Changes in animal behavior cannot be used to predict earthquakes. Even though there have been documented cases of unusual animal behavior prior to earthquakes, a reproducible connection between a specific behavior and the occurrence of an earthquake has not been made. Because of their finely tuned senses, animals can often feel the earthquake at its earliest stages before the humans around it can. This feeds the myth that the animal knew the earthquake was coming. But animals also change their behavior for many reasons and given that an earthquake can shake millions of people, it is likely that a few of their pets will, by chance, be acting strangely before an earthquake. There is no scientific explanation for the symptoms some people claim to have preceding an earthquake and more often than not there is no earthquake following the symptoms.

A separate type of earthquake is associated with volcanic activity and is called a volcanic earthquake. Yet it is likely that even in such cases the disturbance is the result of a sudden slip of rock masses adjacent to the volcano and the consequent release of elastic strain energy.

There is a correspondence between the geographic distribution of volcanoes and major earthquakes, particularly in the Circum-Pacific Belt and along oceanic ridges. Even in cases where an earthquake's focus occurs directly below structures marked by volcanic vents, there is probably no immediate causal connection between the two activities; most likely both are the result of the same tectonic processes.

Earthquakes are sometimes caused by human activities, including the injection of fluids into deep wells, the detonation of large underground nuclear explosions, the excavation of mines, and the filling of large reservoirs. In the case of deep mining, the removal of rock produces changes in the strain around the tunnels. Slip on adjacent, preexisting faults or outward shattering of rock into the new cavities may occur. In fluid injection, the slip is thought to be induced by premature release of elastic strain, as in the case of tectonic earthquakes, after fault surfaces are lubricated by the liquid. Large underground nuclear explosions have been known to produce slip on already strained faults in the vicinity of the test devices.

Of the various earthquake-causing activities, some significant cases have been documented in which local seismicity has increased following the impounding of water behind high dams. Reservoir-induction effects are most marked for reservoirs exceeding 100 meters in depth and 1 cubic km in volume. The most generally accepted explanation for earthquake occurrence in such cases assumes that rocks near the reservoir are already strained from regional tectonic forces to a point where nearby faults are almost ready to slip.

1.4.2 Effects

The effects from earthquakes include ground shaking, surface faulting, ground failure, and less commonly, tsunamis. Earthquakes have varied effects, including changes in geologic features, damage to man-made structures, and impact on human and animal life. Most of these effects occur on solid ground, but, since most earthquake foci are actually located under the ocean bottom, severe effects are often observed along the margins of oceans.

Earthquakes often cause geomorphological changes, including ground movements —either vertical or horizontal — along geologic fault traces; rising, dropping, and tilting of the ground surface; changes in the flow of groundwater; liquefaction of sandy ground; landslides; and mudflows. The investigation of topographic changes is aided by geodetic measurements, which are carried out systematically in several countries seriously affected by earthquakes.

Ground shaking is the vibration of the ground during an earthquake, caused by body waves and surface waves.

Surface faulting is the differential movement of the two sides of a fracture on Earth's surface and can be strike-slip, normal, and reverse (or thrust). Surface faulting, in the case of a strike-slip fault, generally affects a long narrow zone whose total area is small compared with the total area affected by ground shaking.

Liquefaction: is not a type of ground failure. It is a physical process, that takes place during some earthquakes, that may lead to ground failure. As a consequence of liquefaction, primarily sands and silts, temporarily lose strength and behave as viscous fluids rather than as solids. Liquefaction takes place when seismic shear waves pass through a layer of saturated granular soil, distorting its granular structure and causing some void spaces to collapse. The soil disruptions generated by these collapses cause the transfer of the soil-shaking load from the grain-to-grain contacts in the soil layer to the pore water. This load transfer increases pressure in the pore water, either causing drainage to occur or, if drainage is restricted, a sudden buildup of pore water pressure. When the pore water pressure rises to about the pressure caused by the weight of the soil column, the granular soil layer behaves like a fluid rather than a solid for a short period. In this condition, deformations can occur easily.

Liquefaction is restricted to certain geologic and hydrologic environments, mainly areas where sands and silts were deposited. Generally, the younger and looser the sediment and the higher the water table, the more susceptible the soil is to liquefaction.

Liquefaction causes three types of ground failure: lateral spreads, flow failures, and loss of bearing (shear) strength. In addition, liquefaction enhances ground settlement and sometimes generates sand boils (fountains of water and sediment emanating from the pressurized liquefied zone). Sand boils can cause local flooding and the deposition or accumulation of silt.

The liquefaction is a phenomenon in which the strength and stiffness of a saturated soil is reduced due to earthquake shaking. It generally means the state change from solid to liquid. And because of these earthquakes, so many elements of the dam such as dam body, spillways, powerhouses, penstocks, switchyards, hydro-mechanical, and electro-mechanical equipment, temporary structures can be damaged, and other disasters such as rock falls, landslides and landslide dams can be observed. The dams must be designed to withstand strong earthquakes, which can seriously result multiple hazards.

There is no one major problem in seismic safety of embankment dams. Whereas, near source effect appears to be the most serious problem for embankment dams. The active faults, which are very close to the dam foundation, have the potential to cause damaging displacement of the structure.

⇒ **Lateral Spreads** - Lateral spreads involve the lateral movement of large blocks of soil as a result of liquefaction in a subsurface layer. Movement takes place in response to the ground shaking generated by an earthquake. Lateral spreads usually break up internally, forming numerous fissures and scarps. Damage caused by lateral spreads is seldom catastrophic, but it is usually disruptive. Lateral spreads are destructive particularly to pipelines.

⇒ **Flow Failures:** Flow failures, consisting of liquefied soil or blocks of intact material riding on a layer of liquefied soil, are the most catastrophic type of ground failure caused by liquefaction.

⇒ **Loss of Bearing Strength** - When the soil supporting a building or some other structure as a dam liquefies and loses strength, large deformations can occur within the soil, allowing the structure to settle and tip.

⇒ **Landslides:** Past experience has shown that several types of landslides take place in conjunction with earthquakes. The most abundant types of earthquake-induced landslides are rock falls and slides of rock fragments that form on steep slopes. Shallow debris slides forming on steep slopes and soil and rock slumps and block slides forming on moderate to steep slopes also occur, but are less abundant. The reactivation of dormant slumps or block slides by earthquakes is rare.

Large earthquake-induced rock avalanches, soil avalanches, and underwater landslides can be very destructive. Rock avalanches originate on over-steepened slopes in weak-weathered rocks.

⇒ **Tsunamis:** Tsunamis are water waves that are caused by sudden vertical movement of a large area of the sea floor during an undersea earthquake. Tsunamis are often called tidal waves, but this term is a misnomer.

1.4.3 Dam Safety and Earthquakes

Historically, only a few dams have been significantly damaged by earthquakes. On a worldwide basis, only about a dozen dams are known to have failed completely as the result of an earthquake. These dams were primarily tailings or hydraulic fill dams, or relatively old, small and earth fill embankments of **perhaps inadequate design or construction**. About half a dozen other embankment or concrete gravity dams of significant size have been severely damaged. Several of the embankment dams experienced near complete failure and were replaced.

Hence, if one considers the total number of existing large dams, the current performance record appears outstanding, based on the limited number of failures. This excellent record, however, may be largely related to the fact that only few dams have been shaken by earthquakes of duration and intensity sufficient to jeopardize their structural integrity.

Earthquake effects on dams mainly depend on the dam types. The safety concerns for embankment dams subjected to earthquakes involve either the loss of stability due to a loss of strength of the embankment and foundation materials or excessive deformations such as slumping, settlement, cracking, and planer or rotational slope failures. The safety requirements for concrete dams subjected to dynamic loadings should involve evaluation of the overall stability of the structure, such as verifying its ability to resist induced lateral forces and moments and preventing excessive cracking of the concrete.

Earthquakes can result in damages or failures for dam structures, while dams with large reservoirs can induce to earthquakes. Case studies about the seismic performance of dams under large earthquakes are available in the literature.

The ***earthquake safety of dams*** is an important phenomenon in dam engineering and requires more comprehensive seismic studies for understanding the seismic behavior of dams subjected to severe earthquakes. It is a well-known phenomenon that earthquakes can cause damages and failures for dams and their appurtenant structures. There is another fact that dams with large reservoirs can also trigger earthquakes.

In order to prevent the uncontrolled rapid release of water from the reservoir of a storage dam during a strong earthquake, the dam must be able to withstand the strong ground shaking from even an extreme earthquake, which is referred to as the Safety Evaluation Earthquake (SEE) or the Maximum Credible Earthquake (MCE). Large storage dams are generally considered safe if they can survive an event with a return period of 10.000 years, i.e., having a one percent chance of being exceeded in 100 years. It is very difficult to predict what can happen during such a rare event as very few earthquakes of this size have actually affected dams.

Conversely, a few dams suffered significant damage from tremors that were substantially less demanding than what was, or should have been, considered in their design.

Historic Performance of Dams During Earthquake > 350 Dams[01-11 & 01-12]	
Conceptual Damage - Rating	**Percentage of Dams affected**
None	57
Minor	17
Moderate	10
Serious	8
Major	< 1
Collapse	7

Earthquakes have always been a significant aspect of the design and safety of dams[01-11 & 01-12].

Dams and large reservoirs built on the area with ***high seismicity, pose a high-risk potential for downstream life and property***. It is clear that active faults, which are located close to dam sites, can induce to damaging deformation of the embankment as based on instability of the dam and strength loss of foundation materials. The damages to dams and their appurtenant facilities may result from:

⇒ direct fault movement across the dam foundation or;

⇒ from ground motion induced at the dam site by an earthquake located at some distance from the dam.

The second one is commonly seen, however, the first one results more serious problems for dams and their appurtenant structures, because dams located on active faults pose significant risk for ***total stability of project and public safety***.

The total risk for dam structures mainly depends on the seismic hazard rating of the dam site and the risk rating of the completed structure. Clearly, the main requirement in earthquake-resistant design for dams is to protect public safety, downstream life and property.

Therefore, some important factors listed below should be considered during the design stage:

⇒ Large dams must be ***designed with a capability of resisting severe earthquake motion or fault movement at the dam site without uncontrolled release of water stored in reservoir***,

⇒ For large dams located on non-active seismic area, Reservoir Triggering Seismicity (RTS) can be more critical. Therefore, RTS should be defined sensitively based on local geological units and tectonic structures through a detailed seismic hazard analysis;

⇒ Damages to dams and their appurtenant facilities may result from:

- direct fault movement across the dam foundation or;
- ground motion induced at the dam site by an earthquake located at some distance from the dam. The second one is commonly seen, however, the first one results more serious problems for dams and their appurtenant structures.

⇒ Active faults pose the potential to cause damaging displacement of the structure when they are located very close to the dam site. There are some examples of dams, which were damaged during the earthquakes that occurred in the past. Near source effect should be considered with more attention for large dams during the design stage.

⇒ For the dams which are under the effect of a near source, the embankment type with clay core seems to be the more appropriate type because of the self-repairing properties of clay material when this type is technically and economically feasible for the selected dam site.

The dams, which are located on shear zones, have high risk potential when they are subjected to strong ground motion. In general, strong ground shaking can result in the instability of the embankment and loss of strength at the foundations and the structures. Most of dam engineers think that embankment dams are suitable types when well compacted according to the specification, however, it is not an acceptable thought that embankment dams can be induced to damages and failures, even if well compacted, while they are under the effect of a near source.

1.4.4 Selected Case Histories

The following case histories of dam performance during earthquakes were in the first USCOLD publications[01-11 & 01-12; 01-17]:

Year	Dam	Height (m) aprox.	Dam Type	Site	Earthquake Event and Energy Released Richter- Magnitude (Mw)	Damages/(deaths)
1906	Lower Crystal Springs	73	Earthfill	California-USA	San Francisco (8,3 estimated)	Moderate
	Chabot	41				None
1925	Sheffield	8			Santa Barbara (6,8)	Collapsed
1928	Barahona	61	Tailing	Chile	Talca (8,2)	Collapsed (54)
1943	Cogoti(#)	85	CFRD		Illapel (7,9)	Minor
1946	Honekike	29	Arch Buttress	Japan	Nankai (7,2)	Minor
1948	Hosorogi	9	Earthfill	Japan	Fukui (7,3)	Collapse
1952	Isabella	56	Earthfill	California-USA	Kern County (7,7)	None
1957	Blacbrook	21	Massonry	Great Britain	Great Britain (5,6)	Moderate
1959	Hebgen	27	Earthfill	Montana-USA	Hebgen Lake (7,2)	Serious
1967	Koyna	103	Concrete Gravity	India	Koyna (6,5)	Serious (Cracks)
1971	Lower Van Norman	43	Hydraulic Fill	California-USA	San Fernando (6,5)	Major
	Pacoima	113	Concrete Arch			None

Year	Dam	Height (m) aprox.	Dam Type	Site	Earthquake Event and Energy Released Richter- Magnitude (Mw)	Damages/(deaths)
1976	Ambiesta	59	Concrete Arch	Italy	Friuli (6,5)	None
1977	Poiana Uzului	80	Concrete Gravity Buttress	Romania	Romanian (7,2)	None
1978	Mochikochi	30	Tailing	Japan	Izu-Ohshima Kinkai (7,0)	Collapse (1)
	Long Valley(*)	38	Earthfill	California-USA	Earthquake sequences (6,3)	None
1979	El Infernillo(**)	148	CFRD	México	Guerrero (7,5)	Minor
1980	Vermilion	46	Earthfill	California-USA	Eastern Sierra Nevada sequences(6,3)	None
1985	Rapel,	110	Concrete Arch	Chile	Central Chile (7,7)	Moderate
	Cerro Negro	32	Tailing			Collapse
	Los Leones	108	CFRD			None
	El Infiernillo(**)	148	CFRD	Mexico	Michioacan (7,5 to 8,1)	Minor; none
	La Villita	60				Minor
1986	Long Valley(*)	38	Earthfill	California-USA	Earthquake sequences (5,0)	None
1987	Matahina	79	CFRD	New Zealand	Edgecumbe (6,2)	Moderate
1989	Austrian	56	Earthfill	California-USA	Loma Prieta (7,1)	Serious
	San Justo Dam	45				None

Year	Dam	Height (m) aprox.	Dam Type	Site	Earthquake Event and Energy Released Richter- Magnitude (Mw)	Damages/(deaths)
1990	Ambuklao	130	CFRD	Philippines	Philippines (7,7)	Moderate
	Pantabangan	107	Earthfill			Minor
	Masiway	25				Serious
	Binga	102				Moderate
	Sefid-Rud	106	Concrete Gravity Buttress	Iran	Manjil (7,7)	Moderate
1992	Bear Valley	24	Massonry	California-USA	Landers (6,6)	None
1994	Los Angeles	40	Earthfill		Northridge (6,7)	Minor-Cracks
1995	Dondo	72	Concrete Gravity	Japan	Kobe (6,9)	None
1997	Cogoti(#)	85	CFRD	Chile	Punitaqui (6,8)	Moderate
1999	Techi	180	Concrete Arch	Taiwan	Chi-chi (7,6)	None
	Shih -Kang	21	Concrete Gravity			Collapsed
2008	Zipingpu	156	CFRD	China	Sichuan (7,9)	The quake caused some damage to the dam, with some being cracked and fissured. The reservoir had to be gradually drained to permit consolidation works. This information shows some controversy.
	Shapai	132	RCC Arch Dam			No damages
2010	Cogoti(#)	85	CFRD	Chile	South Central Chile (8,3 to 8,8)	An accumulated settlement of 1,2m
2015						

1.4.5 Earthquakes and the Performance of Each Type of Dam

By looking at the statistical data and focusing on the performance by type of dam under the action of earthquakes, the following can be observed:

Historic Performance of Dams During Earthquakes > 350 Dams[01-11 to 01-15]

Dam Type	Type related to the total of the Dams analyzed	Conceptual Damage – Rating as Percentage		
		None+Minor+Moderate	Serious+Major	Collapse
Earthfill	61%	86	8	6
Rockfill Clay Core	10%	97	3	
Concrete Gravity	7%	83	12	5
Concrete Arch	5%	90	10	
Concrete Buttress	2%	80	20	
CFRD	2%	100		
Hydraulic Fill	4%	88	12	
Tailings	9%	61	29	10

PERFORMANCE OF EMBANKMENT DAMS

The worst damage to embankment dams has often been associated with liquefaction of embankment materials or of the foundations. Whereas clay dams on clay foundations generally perform well when subjected to earthquakes.

The evaluation of the seismic safety of embankment dams often depends on determining, directly or indirectly, the magnitude of expected deformations. The first step in the design or evaluation of any dam to develop an understanding how the dam can collapse. Several earthquake-induced conditions that can cause an embankment dam to fail are described below.

If the embankment crest falls below the elevation of the reservoir surface, erosion from overtopping can cause the dam to fail. Direct methods of assessing deformation model the design of the earthquake, the dam, and the foundation to calculate the expected deformation.

The worst damage to embankment dams has often been associated with liquefaction of embankment materials or of the foundations.

During strong tremors, permanent deformations (usually small) may occur simply because the dynamic stresses temporarily exceed the available strength. In saturated soils, there is frequently some loss of shearing resistance due to an increase in pore water pressure when shaken. This increases the dynamic deformations over what they would be with no strength loss. Overtopping leading to failure of the dam can also result from the following:

⇒ Movement on a fault through the reservoir or through the embankment foundation, causing the reservoir elevation to rise above the crest of the dam (or the dam crest to fall below the reservoir surface);

⇒ An earthquake-induced landslide that displaces a significant volume of water;

⇒ A large seiche wave generated by an earthquake;

⇒ No complete failures have occurred in embankments constructed with clay soils or rockfill material;

⇒ There were very few cases of dam failures during the earthquake; most failed either a few hours or up to 24 hours after the earthquake.

Cracks are most likely to occur at interfaces with concrete structures or at abrupt changes in the embankment's cross section. There is also evidence that shaking could precipitate piping even without the formation of a crack if the dam is already on the verge of piping.

The amount of deformation a dam can withstand without risk of failure by erosion through cracks depends on the materials in the dam and foundation, the details of internal zoning (filters, drains, and cutoff), the reservoir elevation at the time of the earthquake, and the nature and location of appurtenant structures. Should there be conduits through the embankment, deformation of the dam can rupture them or cause joints to separate, leading to erosive failure by either creating an unfiltered exit for seepage or exposing the embankment or foundation to the full height of the reservoir, where not intended. Erosion along intact conduits also caused dam failures.

Order	Dam	Type	Location-Country
1.4.5-A	Lower Van Norman	Hydraulic Fill	California- USA
Finished	**Height (m)**	**Earthquake Name & Energy**	**References**
1916	43	San Fernando (6,5)	01-11 & 01-12

The 1971 San Fernando earthquake (Mw = 6.5) occurred in the early morning hours of February 9th. The earthquake was generated by thrust faulting on the Sierra Madre fault. This earthquake caused a large damage. The duration of strong ground shaking was approximately 15 seconds.

Lower Van Norman after the damages
(From the references above)

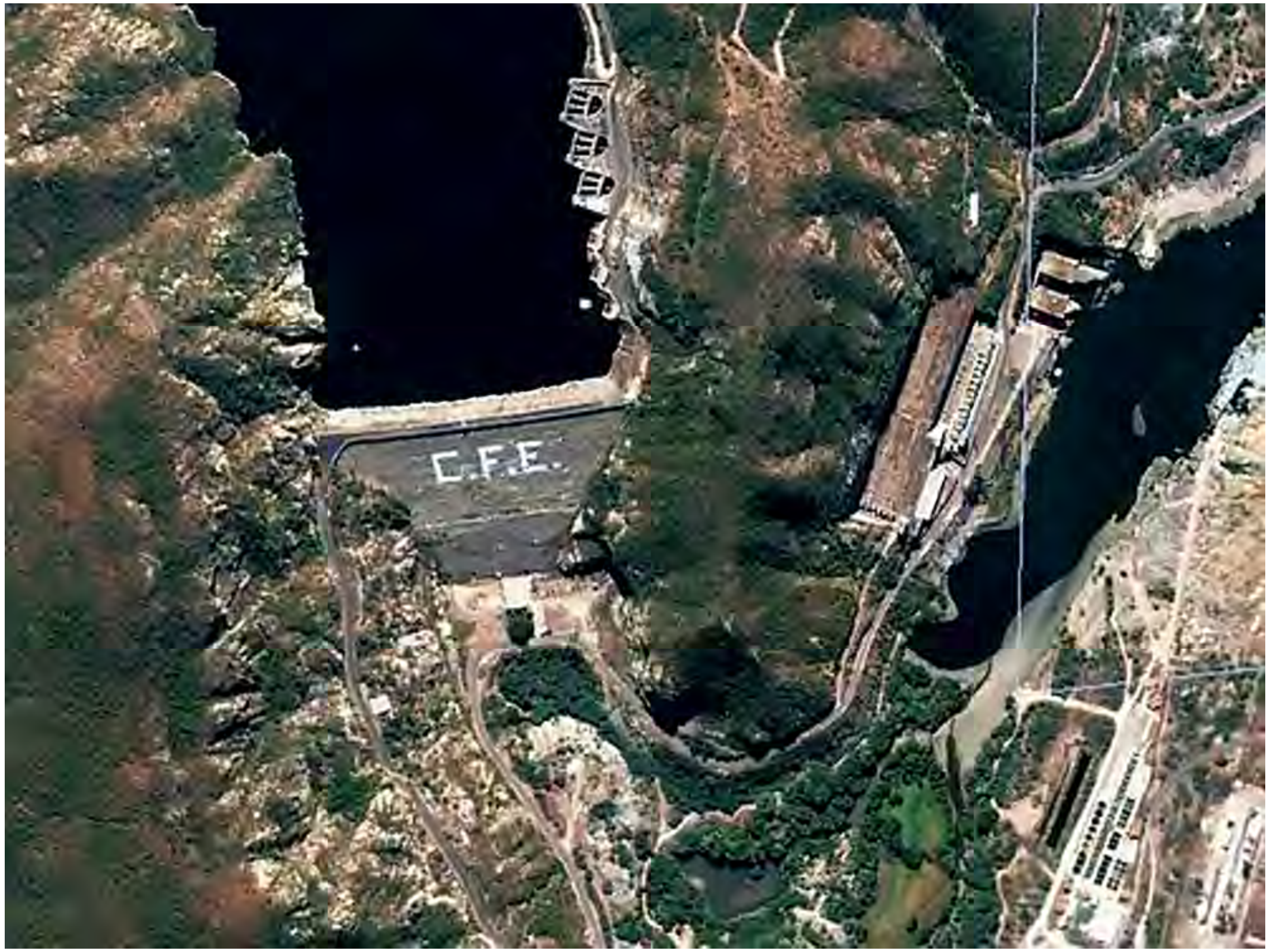
Order	Dam	Type	Location-Country
1.4.5-B	Cogoti	CFRD	Chile
Finished	**Height (m)**	**Energy Earthquake**	**References**
1938	85	South Central Chile (8,3 to 8,8)	01-16

Since the completion of Cogoti, central Chile has been subjected to four major earthquakes. Although Cogoti was constructed of high-lift dumped rockfill with compaction or sluicing, no earthquake damage to the face slab has occurred.

Cogoti CFRD in Chile before (top) and after the 14 October 1997 Punitaqui earthquake (middle); cracks on dam crest (bottom) (Photographs courtesy G. Noguera, Chile)

Order	Dam	Type	Location-Country
1.4.5-C	Infiernillo	CFRD	Guerrero- Mexico
Finished	**Height (m)**	**Earthquake Name & Energy**	**References**
1963	148	Michoacan (7,5 to 8,1)	01-11 & 01-12

The Infiernillo **(Adolfo López Mateos)** Dam was subjected to a second earthquake in 1985 (first one in 1979), to about 60 seconds of strong ground motion during the earthquake, with probable crest accelerations of the order of 0.50g. Overall, the dam performed extremely well and the earthquake effects appeared to be insignificant. Two longitudinal cracks formed on either side of the dam crest along its entire length. The cracks intersected the base layer of the pavement at the top of the dam, immediately above the interface between the impervious core and the upstream and downstream shells. Additional minor longitudinal cracks formed on the crest along the abutments.



Infiernillo Dam also known as Adolfo López Mateos Dam, is an embankment dam near Guerrero, Mexico

It can be summarized by:

⇒ Hydraulic fill dams have been found to be vulnerable to failures under unfavorable conditions, in particular shaking produced by strong earthquakes. Virtually any well-built compacted embankment dam can withstand moderate earthquake shaking, with no detrimental effects;

⇒ Dams constructed of clay soil on clay or rock foundations have withstood extremely strong tremors, with no apparent damage. This conclusion is based on the results of the performance of embankment dams that:

- Two rockfill dams withstood moderately strong shaking with no significant damage. If the rockfill dam is kept dry by means of an impervious facing, they should be able to withstand extremely strong tremors with only small deformations;
- The satisfactorily performance of modern compacted embankment dams was further demonstrated;

⇒ A few recent case histories have provided opportunities to verify analysis procedures for estimating earthquake-induced deformations. In each of these cases, instrumental measurements were taken of accelerations and displacements during and after strong ground shaking, allowing comparison with the predictions of the numerical model of the same quanti;

⇒ To summarize, experience has shown that well-compacted, impervious rolled-fill dams are resistant to earthquake forces, provided they are built on rock or overburden foundations resistant to liquefaction. The same is true of well-drained, compacted rockfill dams or dumped rockfill dams with impervious cores, although some surface deformation can be expected on steep slopes. Rockfill dams with membrane facing (e.g., concrete) have performed well under strong shaking, however, permanent displacement or racking of the facing can be expected, which may require remediation following the seismic event. Low-density embankments constructed of low plasticity granular soils, especially hydraulic or semi-hydraulic fills, are highly susceptible to earthquake damage due to the potential for liquefaction.

The conclusions of the survey are worth summarizing:

⇒ The majority of damaged and failed embankments consisted of sandy soils;

⇒ No complete failures occurred in embankments constructed of clay soils;

⇒ There were very few cases of dam failures during the earthquake; most failed either a few hours or up to 24 hours after the earthquake.

Order	Dam	Type	Location-Country
1.4.5-D	Zipingpu	CFRD	China
Finished	**Height (m)**	**Earthquake Name & Energy**	**References**
2006	156	Sichuan (7,9)	[01-17 & 01-18]

The 7.9 magnitude earthquake on May 12, 2008 caused some damage to the dam, with its wall being cracked. The reservoir had to be gradually drained to allow consolidation and repair works.

Damages observed on Zipingpu CFR Dam[01-17 & 01-18]

Many situations that can evolve into a dam safety emergency or dam failure if not properly designed do not always require extensive analytical evaluation. The simple application of defensive measures will sometimes give the evaluator the assurance that the structure will perform satisfactorily, assuming even the worse scenario. Conversely, poorly designed defensive measures may invalidate the beneficial effects of the defensive measures. Such defensive measures include the following:

⇒ Remove foundation materials that may present problems;

⇒ Use wide core zones of plastic materials resistant to erosion;

⇒ Use large well-graded filter zones upstream of the core to help block any cracks that might open and downstream to prevent movement of eroded particles from the core;

⇒ Construct chimney drains downstream of the embankment core to lessen saturation;
⇒ Use crest details and downstream slope protection that will prevent or greatly inhibit erosion in the event of moderate overtopping;
⇒ Flare the embankment core at abutment contacts;
⇒ Locate the core to attain the lowest practicable phreatic line within the embankment;
⇒ Stabilize slopes around the reservoir rim to prevent mass slides into the reservoir;
⇒ Provide special details for treating the embankment-foundation interface if the potential for fault movement in the foundation exists;
⇒ Provide high quality, free draining rockfill shells;
⇒ Provide ample freeboard to allow for settlement, slumping, or fault movements;
⇒ Shape foundation contacts to avoid abrupt changes in profile, overhangs, or large "stairsteps";
⇒ Adequately compact embankment fill materials to prevent or minimize the generation of excess pore pressures;
⇒ Provide filters or other measures to prevent erosion along the outside of conduits or other structures within the embankment;

Existing dams that were built on foundations of low density cohesionless materials formed in continuous layers may also be subject to excessive deformations during the seismic event due to liquefaction.

The combination of maximum earthquake, increasing demands for environmental protection and increasing values of the risks associated with tailings deposits impose severe requirements for seismic design of dams. Tailing material liquefaction might cause the upstream dam embankment to fail. As the consequences of liquefaction may result in large deformation or failure of the upstream portion of the dam embankment and there are many uncertainties in assessing the liquefaction susceptibility of the tailing material.

From the above statistics, it can be seen that the type of tailings dam shows a greater percentage of failure than other types of dams.

PERFORMANCE OF CONCRETE DAMS

Gravity Dams: Overall, the performance of concrete dams has been satisfactory and such dams, until the mid-twentieth century, were more resistant to earthquakes than embankment dams. Since then, both types of dams, when well designed, have had the same level of safety against earthquake.

Furthermore, concrete dams are probably less susceptible to aging, materials deterioration, seepage, and poor maintenance than older embankment dams. However, the true test of a major thin arch concrete dam in a highly seismic area and subjected to its DBE has yet to come. The Shih-Kang dam experience confirmed that concrete dams cannot be designed to accommodate fault rupture.

The most important safety concern of concrete dams subjected to earthquakes is excessive cracking, which can lead to potential instability from sliding or overturning. Sliding can be on an existing plane of weakness in the dam or foundation or along planes of weakness formed by excessive cracks in the concrete above or at the foundation-dam interface.

For concrete dams, slip instability is possible due to an earthquake-induced vibratory motion in a plane of weakness above or below the foundation-dam interface. Of the two possible types of instability discussed above, historical experience shows that foundation (abutment) induced failure is the main source of concern for concrete dams. In contrast to the dam itself, the support means consists of natural materials of varied composition, irregular joints, and planes of weakness.

The application of defensive design measures when designing new dams is the most reliable approach to alleviate safety concerns. Defensive design measures for concrete dams include the following:

⇒ Sufficient foundation and abutment exploration, material testing, and strengthening to assure foundation and abutment integrity. The importance of foundation and abutment integrity cannot be overemphasized. Adequate drainage is usually the first line of defense against foundation instability, in part because it is the most economical.

- ⇒ Use of the best geometric design and structural detailing appropriate to the structure. The structural configuration should have minimum geometric irregularities and gradual variations in structural stiffness. Examples of good geometric designs are curved transitions, minimal mass at the crest, gradual changes in arch and cantilever stiffness at the top half of arch dams, and a downstream face slab for buttress dams. Continuous load paths, load path redundancy, and ductile behavior are important safeguards to ensure that structures loaded past their elastic limit will continue to perform adequately and will function after extensive cracking. Any necessary structural irregularities should be properly detailed to account for the localized effects of stress concentrations.
- ⇒ Effective quality control during construction to ensure adequate foundation preparation.
- ⇒ Strength of concrete, proper cleaning as well as preparation of lifting joints, and placement of reinforcement when used. For existing dams where the seismic loading has substantially increased and engineering analysis demonstrates poor performance of the structure, remediation schemes will depend on site-specific conditions. However, general types of seismic remediation of existing concrete structures where the dam or foundation has been determined to be inadequate are post-tensioned anchors, additional mass concrete, buttressing, and drainage.

Order	Dam	Type	Location-Country
1.4.5-E	Shi Kang	Concrete Gravity	Taiwan
Finished	**Height (m)**	**Earthquake Name & Energy**	**References**
1977	21	Chi-Chi (7,6)	[01-19 & 01-20]

The Shi-Kang Dam built in 1977 and failed in 1999, due to the action of the Chi-Chi Earthquake

The failure of Shih-Kang Dam did not result in catastrophic release of the reservoir water. Due to upstream changes in topography and the failed gates and piers obstructing the passage of water, uncontrolled release was limited, and the reservoir drained overnight without flooding downstream. The owner plans to repair the dam.

Arch Dams: Some of the observed ability of arch dams is to resist large earthquakes, even though calculations show large tensile stress, it may be due to the ability of arch dams to transfer load. For an arch dam, sliding instability is more likely to occur by failure of the abutment support because the arching (shell) effect provides additional resistance to sliding within the dam. In general, gravity instability and arch dams caused by excessive cracking in the concrete are most likely to occur in the upper half of the dam. When cracking occurs as a result of large tensile cantilever stresses, the decrease in flexibility of the section will cause loads to transfer to adjacent arches and cantilevers, thereby reducing the areas that are over-stressed. Vertical cracking may be pre-empted by additional damping due to non-linearity of material properties or the computed but non-existent formation of horizontal tensile stresses across contraction joints. The implementation of good defensive design mechanisms in the construction of arch dams may have contributed to their sound performance.

No damage to the dam's concrete was observed. There were no signs of vertical joint movements. Minor curb cracking was observed

Buttress Dams: The principal damage to the central monoliths were cracks at lift joints extending from the dam face through the buttress face and web. Buttress dams are also particularly vulnerable to cross-valley shear motions that can result in tipping of the buttresses and loss of support for the reinforced concrete slab.

Overall, the performance of concrete dams has been satisfactory, and it can be inferred that such dams are more resistant to earthquakes than embankment dams.

This is perhaps due to the fact that the concrete dams may have been built to design standards higher than those used for some of the previous embankment dams. Furthermore, concrete dams are probably less susceptible to aging, materials deterioration, seepage, and poor maintenance than older embankment dams. However, the true test of a major thin arch concrete dam in a highly seismic area and subjected to its DBE is yet to come. The Shih-Kang dam experience confirmed that concrete dams cannot be designed to accommodate fault rupture.

PERFORMANCE OF TAILINGS DAMS

The failure of tailings dams is often caused by multiple factors and, in essence, is due to the influence of the external environment. For example, through increased tailings dam loading, earthquakes, rainfall, floods, liquefaction of the tailings, and subsidence of the dam foundation. This type of dam, when raised by upstream, is more susceptible to failure, and has been prohibited in Brazil since 2019.

The Mochikoshi tailings dams owned by the Mochikoshi gold mining company failed due to liquefaction during the 1978 Izu-Ohshim-Kinkai Japan earthquake. The earthquake comprised of a main shock with magnitude M=7 and a large after shock with M5.8. The earthquake was shallow, having a focal depth of about 10 km.

In 1965, two tailings' dams collapsed in the El Cobre Copper Mine in Chile and released 2.3 million m^3 of tailings water in the downstream valley. This tailings dam failure was mainly caused by earthquake liquefaction and flow failure. The majority of breakage events are related to dams that were built using the upstream method.

The following four main factors contributed to the instability of this Chilean tailings dam:

⇒ the construction method of tailings dam;

⇒ a low degree of compaction;

⇒ fine particle size of tailings sand;

⇒ high saturation of tailings sand.

Another reason was that the designer did not design the dam according to the established criterion. In earthquake-prone areas, downstream or centerline methods should be used to build dams to reduce accidents.

Order	Dam	Type	Location-Country
1.4.5-F	Kayakari	Tailings	Japan
Finished	**Height (m)**	**Earthquake Name & Energy**	**References**
1951	15	Great East (9,0)	[01-21]

A great earthquake occurred in eastern Japan in 2011, with magnitude M=9,0. The Kayakari dam at the Ohya mine liquefied because of the tailing's material, releasing a large amount of clay and causing damage to the downstream environment. Studies have shown that liquefaction leads to a significant reduction in the safety factors of tailings dams. In addition, the construction method of the dam body, the particle size of the tailings, and the magnitude of the earthquake affect the stability of the tailings dam during an earthquake.

Kayakari dam at the Ohya mine - Japan[01-21]

The reasons for the damage of the Kayakari dam during this earthquake were as follows:

⇒ the accumulation material of the tailings pond was inferior in strength and unable to resist the attachment force generated by the earthquake;

⇒ finer tailings particles had lower plasticity and were easier to liquefy;

⇒ the contact surface between the mountain body and the dam body was not well protected, and the groundwater seeped into the reservoir area, causing the tailings to remain saturated;

⇒ the earthquake caused the tailings to liquefy and the tailings dam to break;

⇒ the protection of the smaller tailings pond was ignored.

The following damage scenarios can be summarized:

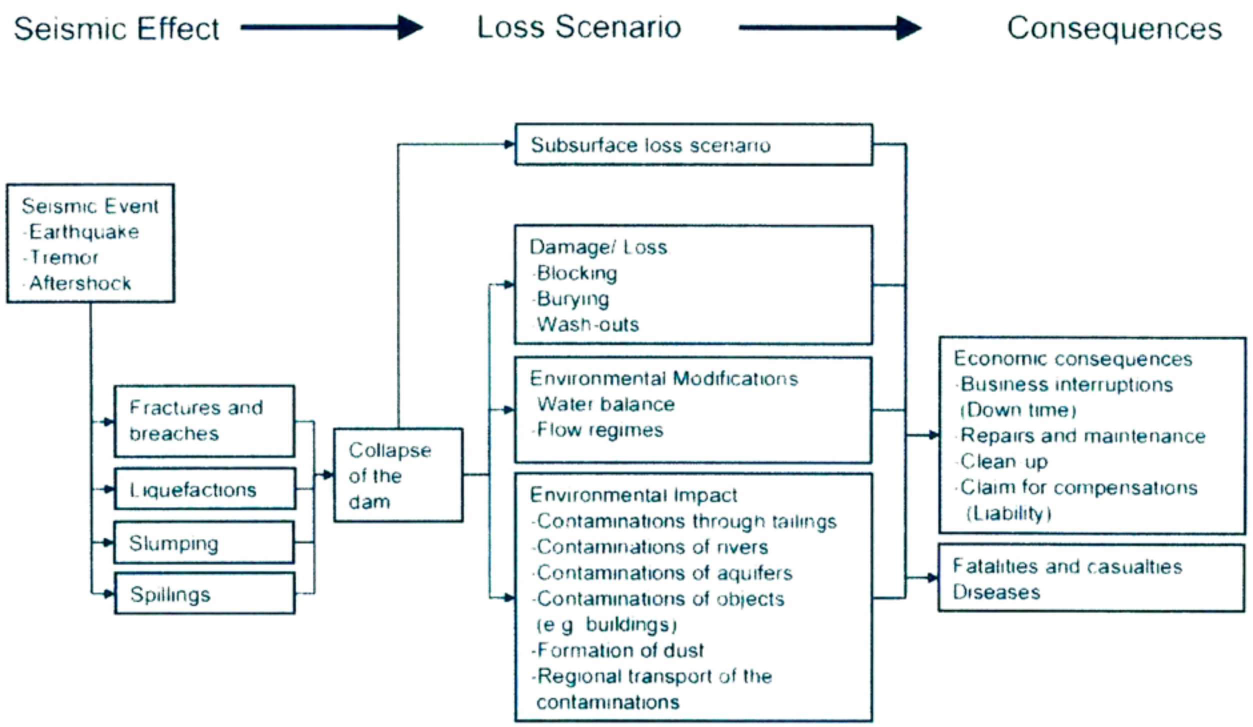
⇒ **Surface**
  - Fractures and breaches
  - Liquefaction
  - Slumping
  - Spilling

⇒ **Subsurface**
  - Flooding of the mine
  - Destruction of the facilities for the subsurface operations

⇒ **Surface loss scenarios depending on the structure of the dam and the tailings**

⇒ **Linking of loss scenarios between surface and subsurface**

⇒ **Environmental damages**



Implications of Earthquakes on the Stability of Tailing Dams[01-22]

1.4.6 Dam behavior due to Triggered or Induced Earthquake

Large reservoirs can trigger earthquakes. This phenomenon is defined as **R**eservoir-**I**nduced **S**eismicity (***RIS***) or **R**eservoir-**T**riggered **S**eismicity (***RTS***), which is primarily depended on excessive water pressure created in the micro-cracks and fissures in the foundation units under and near the reservoir.

Water within the rock masses under huge hydrostatic pressure acts to lubricate faults, which are already under tectonic strain, yet are prevented from slipping by friction of rock planes. It is clearly known that it mainly depends on nature of structural geology and lithology of surrounding rocks.

Water pore pressure reduces the normal stress within a rock while not changing the shear stress. Under any circumstances, an increase in water pore pressure means that a failure is more likely. The critical value of shearing stress may be made arbitrarily low by increasing the pore pressure.

It is not easy to predict whether a new reservoir will experience reservoir induced seismicity, because the two most important factors – the state of stress and the rock strength at earthquake depths – cannot be measured directly. This is the same reason why prediction of normal (non-induced) earthquakes is normally unsuccessful.

Reservoir induced seismicity is a transitory phenomenon that will occur either immediately after the filling of the reservoir, or after a delay of a few years. Whether there is a delay depends on the permeability of the rock beneath the reservoir.

Once the stress and pore pressure fields have stabilized at new values, reservoir induced seismicity will cease. Earthquake hazard will then revert to similar levels that would have existed if the reservoir had not been filled.

Even for those reservoirs that show a correlation between earthquake activity and water level, reservoir induced seismicity does not continue indefinitely as it is limited by the available tectonic energy.

Large new reservoirs can trigger earthquakes. This is due to either:

⇒ change in stress because of the weight of water, or more commonly by

⇒ increased groundwater pore pressure decreasing the effective strength of the rock under the reservoir.

Pore pressure can increase in two ways:

⇒ Due to the decrease in pore volume caused by compaction under the weight of the reservoir. This occurs while the reservoir is being filled;

⇒ Due to diffusion of reservoir water through permeable rock under the reservoir. The flow rate depends on the permeability of the rock, so this effect is not instantaneous. The increase in pore pressure takes more time depending on the distance from the reservoir. It may take years for the pore pressure to increase at depths of kilometers beneath a reservoir.

For triggered earthquakes to occur, both mechanisms require that the area is already under considerable tectonic stress. Reservoir triggered earthquakes are often referred to as reservoir induced seismicity (***RIS***), but the use of the term "induced" is now becoming unfashionable. To many people it implies that the reservoir caused the earthquake. The energy released in a reservoir-triggered earthquake is normal tectonic strain energy that has been prematurely released because of the reservoir.

Reservoir-induced seismicity (RIS) or Reservoir-triggered seismicity (RTS)						
Dam	**Type**	**Country**	**Depth (m)**	**Volume x (1.000.000)m^3**	**Magnitude Energy (Mw)**	**Action required/ developed**
Almendra	Arch	Spain	185	2.469	3,2	
Aswan	Embankment	Egypt	90	160.000	5,2	
Benmore	Embankment	New Zealand	96	2.040	5,0	
Blowering/ Taibingo	Embankment	Australia	142	2.559	3,5	
Camarillas	Concrete Gravity	Spain	43	37	4,1	
Canelles	Arch	Spain	132	678	4,7	
Capivara	Embankment	Brazil	60	10.500	4,4	
Cenajo	Concrete Gravity	Spain	97	472	4,2	
Danjianangkou	Concrete Gravity	China	97	16.000	4,7	
Eucumbene	Embankment	Australia	106	4.761	5,0	
Hoover	Arch Gravity	USA	191	36.703	5,0	
Jocassee	Embankment	USA	107	1.431	3,8	
Kariba	Arch	Zambia	122	160.368	6,3	
Kastraki	Embankment	Greece	91	100	4,6	
Khoa Laem	CFRD	Tahiland	80	7.000	4,5	
Khoina	Concrete Gravity	India	100	2.780	6,3	Damaged and strengthened
Kremasta	Embankment	Greece	120	4.750	6,3	
Kurobe	Arch	Japan	180	199	4,9	

Reservoir-induced seismicity (RIS) or Reservoir-triggered seismicity (RTS)						
Dam	**Type**	**Country**	**Depth (m)**	**Volume x (1.000.000)m³**	**Magnitude Energy (Mw)**	**Action required/ developed**
Manicouagan III	Hollow Gravity	Canada	96	10.423	4,1	
Marathon	Arch Gravity	Greece	60	41	5,8	
Mossyrock	Arch Gravity	USA	124	1.957	4,3	
Nurek	Embankment	Tajikistan	285	11.000	4,5	
Oroville	Embankment	USA	204	4.400	5,7	
Paraibuna/ Paraitinga	Embankment	Brazil	102	4.740	3,2	
Porto Colombia/ Volta Grande	Embankment	Brazil	50	3.760	5,1	
Pukaki	Embankment	New Zealand	108	10.500	4,6	
Shenko	Embankment	China	75	790	4,8	
Swift	Embankment	USA	116	932	5,0	
Srinagarind	Embankment	Thailand	133	17.745	5,9	
Vouglans	Arch	France	112	605	4,4	
Xinfengiiang	Concrete Gravity	China	105	13.896	6,0	Damaged and strengthened
Zhelin	Embankment	China	62	7.170	3,2	

Dam Safety Aspects of Reservoir-Triggered Seismicity[01-23]

The depths of reservoir induced earthquakes, especially those occurring immediately after filling the reservoir, are normally very shallow. However, it is very difficult to accurately predict when and where a reservoir induced earthquake will occur. ICOLD recommends that Reservoir Triggered Seismicity (RTS) should be considered for reservoirs having a depth more than 100m. USCOLD has reported that Reservoir Induced Seismicity (RIS) should be considered for reservoirs deeper than 80-100m.

It is clear that the number of seismic events increases near reservoir areas of large dams after the impounding sequence. It is not a negligible value that this mechanism should be considered by engineers in the design phase.

The reservoir capacity is an important factor in triggering earthquakes as well as reservoir depth. Reservoir Induced Seismicity (**RIS**) phenomenon is mainly in line with the reservoir filling periods.

There are a number of cases where earthquakes were triggered by a reservoir. The main prerequisites for reservoir-triggered seismicity (RTS) are:

⇒ the presence of an active fault in the reservoir region, or

⇒ the existence of faults with high tectonic stresses close to failure. The filling of the reservoir in a tectonically active region may merely cause the triggering of an earthquake which in any case would occur at a later date. The occurrence of RTS has been mainly observed in reservoirs with a depth exceeding 100m.

If a large dam has been designed in accordance with the current state-of-practice, which requires that the dam can safely withstand ground motions caused by an extreme earthquake, it can also withstand the effects of the largest reservoir-triggered earthquake. However, RTS may still be a problem for the buildings and structures in the vicinity of the dam, as they would generally have a much lower earthquake resistance than the dam. In the great majority of RTS, the magnitudes are small and with no structural concern.

The technology is available for the construction of dams and appurtenant structures that can safely resist the effects of strong ground shaking. Storage dams that have been properly designed to resist static loads prove to also have significant inherent resistance to earthquake action. Many small storage dams have suffered damage during strong earthquakes. However, no large dams have failed due to earthquake's shaking.

Earthquakes create multiple hazards on dams that need to be accounted for. There are still uncertainties about the behavior of dams under very strong ground shaking and every effort should be made to collect, analyze, and interpret field observations of dam's performance during earthquakes.

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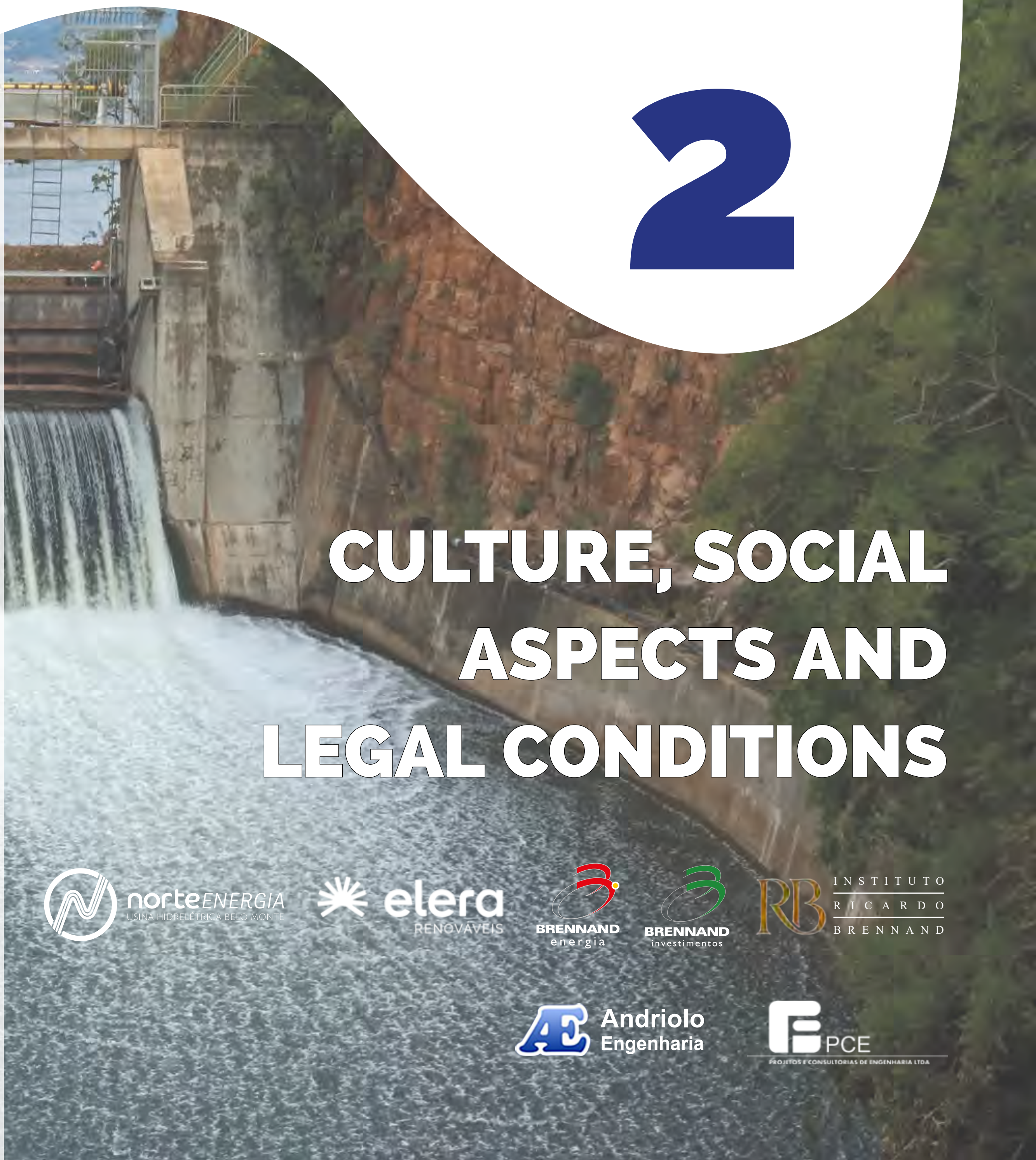

2

CULTURE, SOCIAL ASPECTS AND LEGAL CONDITIONS

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BRENNAND investimentos
INSTITUTO RICARDO BRENNAND
Andriolo Engenharia
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- ✓ ***What are the responsibilities of the Engineer and the Public Administrator?***
- ✓ ***What are the benefits and interests to the Society?***
- ✓ ***What about the Legal Obligations?***

2.1 Culture and Responsibility

2.1.1 Technology and Culture

Technology is sometimes thought of as a domain with a logic of its own – an inevitable trend towards the development of the most efficient artifacts, given the potential represented by a novel scientific or technical insight. The most important is the clear recognition that technology is a social product,

Technology influences everyday life and has a strong influence on culture. Find out how the people within different cultures choose to incorporate technologies. Today and since the dawn of "*Homo sapiens*", technology is embedded in people lives. In the 21st century, technology is integral because not only is there the technology of lights and computers used in everyday life, but also our bodies are physically altered through vaccines and the medicine people take daily. Technology is imperative, so, it is incorporated in all aspects of culture including travel, food, government, art and social benefits and prosperity.

Technology shapes different cultures and differentiates one from another. It allows us to intermix them. Through technology of computers and teleconferencing, a specialized learner can access knowledge through a conference halfway across the world without leaving that persons' home. Technology does allow for every opportunity to be afforded but creates more opportunity than in the past. This technological advancement allows the opportunities previously separated by socioeconomic status to be taken away.

2.1.2 Engineers Procedures and Behavior

A highly used Brazilian Dictionary, it conceptualizes Engineering as:

✓ ***application of scientific or empirical methods to the use of nature's resources for the benefit of the human being.***

Besides this, many engineering professional societies have prepared codes of ethics. Some date to the early decades of the twentieth century. These have been incorporated to a greater or lesser degree into the regulatory laws of several jurisdictions. The general principles of the codes of ethics are largely similar across the various engineering societies and chartering authorities of the world,

Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties.

The engineer should reject any paper that is intended to harm the general interest, thus avoiding ***a situation that might be hazardous or threatening to the environment, life, health, or other rights of human beings***. It is an inescapable duty of the engineer to uphold the prestige of the profession, to ensure its proper discharge, and to maintain a professional demeanor rooted in ability, honesty, fortitude, temperance, magnanimity, modesty, honesty, and justice with the consciousness of individual well-being subordinate to the social good.

The engineers and their employers must ensure the continuous improvement of their knowledge, particularly of their profession, disseminate their knowledge, share their experience, provide opportunities for education and training of workers, provide recognition, moral and material support to the schools where they studied, thus returning the benefits and opportunities they and their employers have received.

It is the responsibility of the engineers to carry out their work efficiently and to support the law. They must ensure compliance with the standards of worker protection as provided by the law and engineering ethics.

Concerned to a Dam Project, people involved in the design, construction and operation of large dams are normally particularly sensitive to earthquakes. This is because of four factors:

⇒ Dams are often built in active earthquake areas;

⇒ Reservoirs can trigger earthquakes;

⇒ Some water supply structures are susceptible to earthquake motion.

⇒ Embankments and outlet towers respond to earthquake vibrations. Shaking an unstable slope that has been weakened after saturation by rises in groundwater levels may produce a landslide into the reservoir.

The consequence of a dam or water supply failure is high. The effects of a dam failure on people and structures downstream are dramatic and obvious. A more likely example of earthquake damage would be loss of control of the water supply.

2.2 Social Interest for the Dams

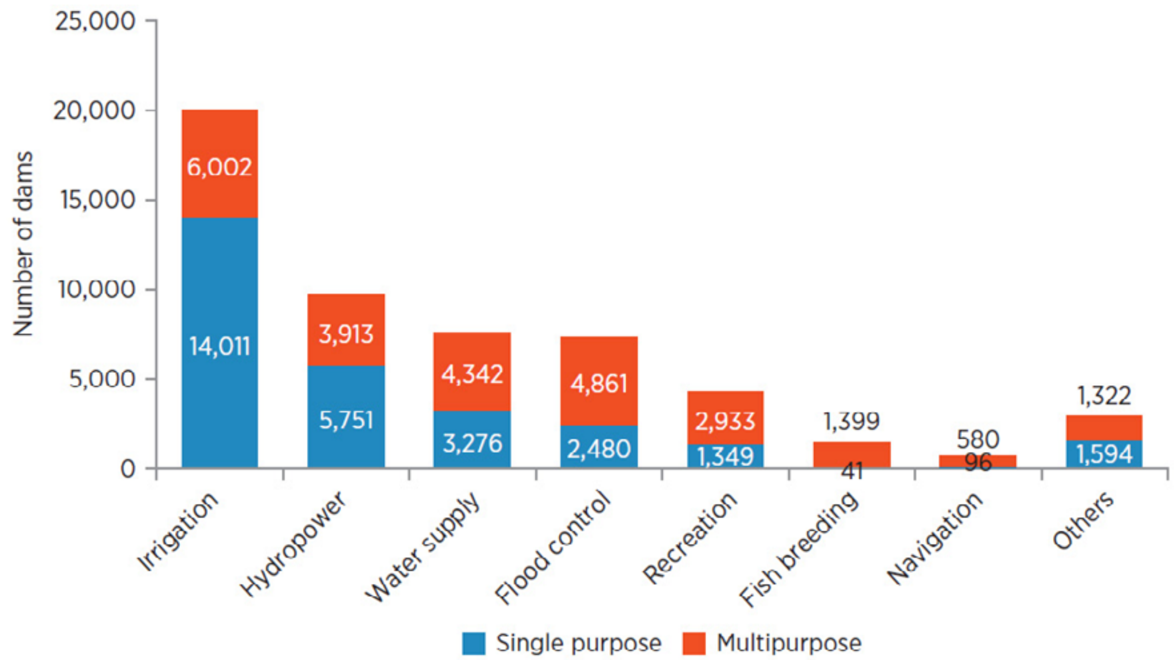
Demand for fresh water, drinking water and water for irrigation will also greatly increase. Without water, there can be no life on our planet. Fresh water resources are limited and poorly distributed. There are regions where the water supply is the absolute pre-condition for any improvement in standards of living—which are currently too low—and even for the survival of existing communities, as well as the satisfaction of the ever-increasing demand that results from the rapid growth in their population. Such regions cannot do without the contribution that dam-reservoirs make to the management of water resources. This will induce to have greatly increase for water resources and build new dams. Water storage infrastructures are seen to be indispensable tools for sustainable development.

Some part of global demographic growth is happening in arid regions that need water to produce food, or in regions where rainfall is very irregular, therefore requiring storage methods such as dams' reservoirs. Hydroelectric dams facilitate adjustable electricity production, by storing huge quantities of water in their reservoirs.

Dams hold back river water. By means of turbines, they generate electricity from a renewable source. This natural storage of energy is the most competitive form of power storage, making use of PSPSs (Pumped Storage Power Stations), which are crucial for electricity networks and play a key role in integrating other modern renewable energies (solar and wind) that are by nature intermittent.

In addition to producing energy, dams can also, simultaneously, serve other functions: irrigating cultivated land, supplying communities with drinking water, reducing flood flows, replenishing low-water levels, aiding waterway navigation, using reservoirs for tourism and sports, fish-farming, protecting estuaries against tidal backup, and so on.

From an updated (2020)[02-01] reference, it can be noted that the number of dams in the World and their uses are as shown ahead.



From an energy and climate viewpoint, dams are clearly very positive, and perhaps even represent the most advantageous of all renewable energies, if geography and hydrology allow for it.

Primary purpose	East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	North America	South Asia	Sub-Saharan Africa	Total
Irrigation	7,104	2,192	769	1,032	1,118	4,921	1,133	18,269
Hydropower	1,496	2,447	1,048	51	1,893	170	131	7,236
Water supply	720	1,532	265	138	1,657	65	344	4,721
Flood control	1,023	448	74	135	2,770	4	7	4,461
Other	50	351	336	119	2,951	-	50	3,857
No data	19,198	140	141	32	46	221	196	19,974
Total	29,591	7,110	2,633	1,507	10,435	5,381	1,861	58,518

But dams also have conflicts of use, risk of breach, and sometimes the displacement of local populations, arousing opposition. And indeed, every dam, hydroelectric or otherwise, blocks watercourses and constitutes an obstacle to the circulation of certain species (fish swimming upstream, notably migratory species such as salmon and eels) and sediments (sand, mud, etc.) which consequently build up and can concentrate pollutants in the reservoir. The absence of new sediments downstream of the dam can cause erosion problems that modify the aquatic environment, undercut riverbanks, or wash away beaches.

Risk-informed approaches are increasingly being used to inform dam safety assurance. This reflects growing recognition that there are a few dam safety incidents caused by nonstructural elements that are not well captured by the traditional standards-based approach. The changing nature of portfolios at the country level coupled with the evolution of societal values and stakeholder expectations advocate for the application of more risk-informed approaches

Dam safety is central to public protection and economic security. For thousands of years, societies have developed hydraulic infrastructure to manage temporal and spatial hydrological variability and ensure that water is available to satisfy human needs and to serve productive purposes. This infrastructure has been used to make water available at the right time, in the right place, and in the right quantities to deliver a range of services. During this time, the development and operation of dams have made important contributions to economic prosperity and poverty reduction.

Dams are therefore a double-sided coin, with a positive side (energy, drinking water, irrigation, flood regulation, river navigation, fight against drought, etc.) and a negative side (ecology, sediments)

Nowadays, the process of building a dam is very different from what it was in the last Century, when the engineer was in sole command. The economist and the financier took their place on the project team, the enormous increase in human knowledge, particularly in the field of environmental science, means that a whole team of specialists is needed to access and utilize that knowledge for any water resource development project. This multidisciplinary approach is better able to encompass the full complexity of this type of project.

Such concerted action requires continuous, comprehensive and objective information on the project to be provided to governmental authorities, the media, local action committees and the people directly or indirectly affected, and their representatives. In this transfer of information from planners to public, dam engineers must contribute, through their professional expertise, to a clear understanding and dispassionate discussion based on facts, and not on emotive ideas about the positive and negative aspects of a project and its possible alternatives.

Due to, the above-mentioned, the ***Safe of the Dam***, cannot create a doubt, or a question.

2.3 Environmental Aspects

It is very clear that environment and sustainable development challenges will be needed for a continuous effort of learning and education. The answer surely lies in successful implementations in the field, close to local populations, in a way that is innovative, sustainable and reproducible, creating a virtuous circle of progress.

The dams are among the greatest single structures built by humanity. They serve as powerful symbols of modernization, national prestige, and of human dominance over nature. The dam-building paralleled with improvements in engineering skills, construction technology and progress in hydrologic analysis. Ecological impact and social consequences of dam projects are discussed in a highly controversial manner.

Economic interests in dam-building for hydropower and water supply are generally linked to far-reaching and often negative environmental and social consequences. Among the most common socioeconomic problems are insufficient material compensation to people adversely affected or dislocated by dam-building and the subsequent lack of economic perspectives available to many rural communities. Despite ongoing controversy over dam projects, the discussion of the last years is also characterized by efforts to find common ground between advocates and opponents, and to possibly find a way out of the dilemma of different development perspectives.

Other basic purposes of dams include the seasonal or annual storage of water for human consumption, agrarian and industrial production and for the reduction of flood peaks. Besides their global economic importance, the dams have become the focus of intense debate because of their frequently severe environmental impact and socio-economic consequences.

2.4 Legal Aspects

2.4.1 General

The dams present immense social and environmental challenges for local communities, which can include resettlement of affected individuals and communities, psychological stress, loss or decline of livelihood and assets, changes to lifestyles and traditions, impacts on fishing, agriculture and food security, impacts on access to and quality of water and a wide range of environmental adverse effects.

The controversial nature of dam projects forced the Public Administration to introduce social safeguard policies to protect local people from the consequences of dam construction and resettlement.

All these studies show important flaws in particular projects and the lack of overall environmental and social standards. At the same time, governments, financiers and dam-building firms often assume that one can mitigate both environmental and social impacts in large hydropower dams.

Responsibility for dam safety refers to the care and consideration that needs to be given to ensure that a dam is kept in safe condition. This includes the accountability of the person or group of persons that are responsible for the safety of the dam throughout its life and, most important, for maintaining it in proper condition during the operation phase to meet the needs that fit its purpose, whether it is water supply, irrigation, energy production, flood protection, or a combination of these.

There is a range of institutional forms with different degrees of independence that exist along a continuum. While oversight institutions should be of a quality assurance nature to maintain independence, regulatory mechanisms need to be aligned to the size and complexity of the portfolio, appropriate for the level of financial capacity and human capital within the country, as well as positioned within the prevailing legal regime, which will then dictate the optimal institutional arrangements. This continuum reflects the individual country characteristics, including the prevailing legal framework along with the evolution of the portfolio and considerations of its size, sectoral distribution, hazard profile, and downstream demographics.

Across the countries, there are diverse portfolios of existing dams and pipelines of proposed developments. The nature of ownership and the purpose associated with most of the dams also differ from country to country.

Given this diversity, it is important to consider the most critical elements required for ensuring the safety of dams and downstream communities, along with the required human and financial capacity to realize this safety.

Governments and Dam Project developers sometimes commit to meeting "international standards" ***to assure people that the dam will be well-built and operated to the highest standard***, but their use of this term can be vague. Thus, it is important to:

⇒ understand what the developer means when it commits to meeting "international standards";

⇒ determine whether these standards are sufficient to protect the rights of affected communities and the environment; and

⇒ whether these standards are voluntary or mandatory, and if enforceable, by whom.

The enabling legal framework for dam safety assurance establishes the minimum standards, along with the duties, roles, and responsibilities, for ensuring the safe development and operation of dams. The legal system of a country (common law or civil law) and its constitutional basis for law making and administration (unitary and central or federal and decentralized) provide the definitive precursors within which the enabling legislative environment for dam safety is formulated.

The level of government at which law making and administration occur in relation to dam safety also affects who are and who could be made responsible for dam safety assurance. Responsibility could range from the central government in national systems to state or provincial governments in federal systems. Furthermore, the degree of decentralization will determine many of the challenges that a country may have to overcome to ensure uniform dam safety standards across the entire territory. The legal framework will also enable collaboration mechanisms to be established among the competent authorities at different levels of a country's administration to ensure integrated application of dam safety assurance and disaster risk management laws.

The legal framework also establishes the applicable regime across different dam owners, sectors, and types of dams. To meet the needs of a country's dam portfolio, the government may choose to provide the same level of dam safety assurance uniformly to all dams or apply different dam safety standards and practices to different types of dams, different sectors, or to dams of a particular size and hazard via dam classification systems, risk assessments, portfolio risk management tools, or sector-specific tools.

The existence of a clear definition of dam failure liability and how liability is determined is another important consideration within the legal framework for dam safety. This defines the standard of care that dam owners, managers, and operators must meet to reduce the probability of dam failure and avoid misoperation of dams. While the standard of care in civil law countries can be found in detail under the law, common law countries may choose to refer to national dam safety committee guidelines.

The legal framework will determine the grounds for dam failure tort-based liability and whether any criminal liability may result. Tort-based liability can be strict liability, whereby the dam owner is liable for all damages caused by the failure of the dam regardless of whether any negligence is involved, or negligence-based, whereby the dam owner is liable only if found to be negligent in not meeting the acceptable standard of care associated with dam management. Criminal liability following a dam failure can also apply if there are grounds for it under the applicable criminal laws of the country (for example, criminal negligence). For this to apply, acts of gross negligence or recklessness usually must be proven beyond reasonable doubt. The legal framework can also inform the role of dam safety insurance for the dam owner, operator, or downstream community.

Failure of a dam does not necessarily mean the same as its ***collapse***. It may mean failure to meet its design objectives. Any damage to a dam short of collapse (such as development of cracks, localized slumps or erosion) or any failure to retain water as designed (such as excessive leakage through, under or around the dam) or inability to pass incoming floodwaters via the spillway, may be termed a failure of the dam. If a dam fails, its owner may be held legally liable for all associated damage.

2.4.2 Local Laws/Standards

A law can be understood as a normative social practice that can purports to guide human behavior, giving rise to reasons for an action.

The legal system of any country is shaped by its legal traditions and incorporates specific variations based on the country's particular geopolitical history. Notwithstanding this variation, most contemporary legal systems are generally based on one of four basic systems: civil law, common law, customary law, or religious law. Some jurisdictions have legal systems that combine aspects of these four systems.

The most relevant "***standards***" throughout any stage of dam building are national laws and policies. National laws set the requirements with which dam builders and financiers are expected to comply. For example, if a national law on water quality exists, then a dam proponent will be expected to meet the requirements of that law, and if the law is violated, the developer is penalized. Some national laws are stronger than others. National laws set a benchmark for performance domestically, and they guide the behavior of companies operating abroad.

Companies are generally expected to follow whatever has been promulgated into national law. Yet, even if laws exist on paper, they are not always implemented; corruption, political interests, or lack of institutional capacity can cause disruptions. Corruption may undercut the efficacy of national laws to assure requirements are being met.

Political interests can cause a government to grant an exception to or suspend a national law, as often happens in investment treaties, or governments simply may not have the budget or technical capacity to monitor implementation. As a result, enforcement of national law is often complicated by other factors.

2.4.3 International Laws/Standards

The term "standards" could also refer to those legal instruments developed by international bodies. Outside national law, various types of policies exist, such as international covenants and declarations. Usually, declarations are binding for states that have signed onto them, but their language is aspirational rather than mandatory. Ideally, declarations should be enacted through national legislation or constitutions. Companies developing dam projects could then fulfill those obligations by complying with national laws where investments are made.

2.4.4 Financial Institutions Policies

Financial institutions have their own standards apart from national and international law, which allow them to independently assess and manage the risks associated with financial transactions. These standards are often requirements that financial institutions expect the borrower to meet to obtain funding for a project. Many are project-level compliance measures expected to be fulfilled before financing is granted, while some are broader expectations of borrower performance, tying financing to borrower implementation of best or good practice principles. One benefit of financial policies is that they outline key outcomes, such as respect for rights and environmental protection, that must be achieved throughout the life of a project. These policies help financial institutions calculate the environmental, social, governance, and other risks involved in financing a project, and often lead the financial institution to support the borrower in creating plans to mitigate impacts. Some financial institutions, especially multilateral development banks, created their own accountability mechanisms to provide access to recourse in response to grievances from affected communities. The ***World Bank,*** for example, created the ***Inspection Panel*** in 1993[02-02] as an independent fact-finding body that investigates grievances filed over World Bank operations.

2.5 Insurance Aspects

There are other ways to share responsibility for dam safety. The financial burden, for example, can be carried by insurance. Coverage can extend to one dam or to many dams. With thousands of reservoirs in operation, comprehensive insurance responds to a common need for spreading risk over a wide area. Not all dams have high disaster potential. In remote unpopulated places, the hazard to life and property may be minimal. And in any dam failure there is an area limit to the damage which can occur. These circumstances therefore ensure that the insurance money paid by the many can pay for the losses of the few. In its widest application, the essential spreading of risk is accomplished by reinsurance, which in international terms means that the insurance industry of one country may make reciprocal exchanges of parts of portfolios with the insurers in another country.

Dam safety insurance does not exist in most of the countries or jurisdictions. Where it does exist, it is usually voluntary, with a few countries adopting mandatory insurance.

Residents in the potential zone of inundation might logically contend that all the costs should be borne by the owner of the reservoir. If the dam did not exist, there would not be any threat of an uncontrolled discharge of water. And, since the owner maintains the hazard, he must be accountable for any damages, no matter what might have been the cause of failure. In many cases, the owner's rebuttal can rest just as logically on the service which his dam and reservoir render the people, including those residing downstream.

These views can be reconciled by having the losses underwritten by the whole community of interest through regional or national disaster funds. Any insurance program should place emphasis on the supervision of dams by experienced specialists.

2.6 The Dam Safety Culture

The theme of ***Dam Safety*** established a Culture for mitigation of damage and risks, effectively from the 1980s, as can be seen from the information below, mainly by administrative actions in the USA[02-03], resulting from some impacting accidents.

Dam Safety View[02-02 & 02-03]		
Year	**Event**	**Occurrence**
1915	The State legislature passed a law requiring all plans for dams and reservoirs to be submitted to the State Engineer for approval, but the act provided no penalty for failure to comply.	
1916	In August, the State Reclamation Board issued a report recommending that the State Engineer regulate all storage reservoirs	
1917	***DAM SAFETY Act Public outcry followed failure of the Lower Otayand Sweetwater Dams in January 1916 in San Diego County. The State Engineer was granted authority over all dams > 10 feet high or which impound > 9 acre-ft (3 million gallons),***	
1917-1929	○ Municipal water agencies were exempt from State overview until August 1929; ○ The State Engineer was given authority to review plans for dams prepared by irrigation districts, private companies, and individuals; ○ The State Railroad Commission was given authority to review dams and reservoirs owned by public agencies subject to the 1917 Public Utilities Act.; ○ In 1920 the Federal Power Commission began supervising dams for power projects involving the public domain.	
1929	Following the failure of the St. Francis Dam State of California enacted a dam safety program.	

Dam Safety View[02-02 & 02-03]		
Year	**Event**	**Occurrence**
1931/ 1936	6-Year Program of Dam Safety Inspection 1931-36: ○ In July 1936 the second series of inspections were concluded by the State; ○ 950 dams were inspected; with 588 of these dams being under the State's jurisdiction; ○ One third of these dams were found in need of repairs; ○ New dam construction was under State observance from August 1929 forward.	
1938	The March 1938 flood spurred the Federal Flood Control Acts of 1936, 1941 and 1944, which placed the U.S. Corps of Engineers into a prominent role to help provide flood control nationwide, on a 65/35 shared cost basis with local agencies.	
1959	After the Vega de Tera Dam (Spain) failed in 1959, civil and criminal lawsuits were filed in the Spanish courts against 10 engineers. Eventually, four of them were found guilty.	
1972	As a result of the major disasters at Malpasset (France), Vaiont (Italy), and Baldwin Hills (United States), Failure of Buffalo Creek Dam, West Virginia governments in several countries enacted new or revised laws for supervision of safety of dams and reservoirs.	Bufallo Creek - 125 deaths
1972	PL 92-367 the National Dam Inspection Act	
1975	In the United Kingdom, the Reservoirs Act of 1975 was written as an updating of 45-year-old rules that were put into effect after the British dam failures at Dolgarrog and Skelmorlie, in 1925. The new law provides authority for regulators to intervene when an in inspecting engineer's report has not been given adequate response.	
1976	Teton Dam Failure	US$1 Billion in losses and 14 deaths

Dam Safety View[02-02 & 02-03]		
Year	**Event**	**Occurrence**
1977	Kelly Barnes Dam Failure	39 deaths
1978	Corps of Engineers begins the National Inspection Program	
1979	○ Federal Guidelines for Dam Safety prepared;	
	○ Executive Order 12148 from President Carter created FEMA; FEMA Director to coordinate Federal Dam Safety efforts;	
	○ Memorandum from President Carter requiring the head of each Federal dam safety agency to implement the Federal Guidelines;	
1982	○ The National Program of Inspection of Non-Federal Dams completed and National Inventory updated by USACE; Final Report to Congress	
1985	○ The Interagency Committee on Dam Safety (ICODS) publishes Charter and Operating Rules	
1986	○ Water Resources Development Act of 1986 includes National Dam Safety Program administered by the Secretary of the Army: Never implemented due to lack of appropriations.	
2006	National Dam Safety Program reauthorized as P.L. 109-460	
2014	National Dam Safety Program reauthorized in the Water Resources Reform and Development Act of 2014. Conference Report to HR 3080 passed on May 20	National Dam Safety Review Board (7 members)

Dam Safety View[02-02 & 02-03]		
Year	**Event**	**Occurrence**

- State dam safety program assistance ($13 million);
- Maintain and update the NID ($500,000);
- Research ($2 million) 1996 National Dam Safety Program Act included in the 1996 Water Resources development Act (PL 104- 303): Administered by the Director of FEMA National Dam Safety Review Board (11 members);
- State dam safety program assistance ($4 million);
- Maintain and update the NID ($500,000);
- Research ($1 million) Training ($500,000) 2002 National Dam Safety and Security Act of 2002 (PL 107-310): Reauthorizes the NDSP;
- National Dam Safety Review Board (11 members);
- State dam safety program assistance ($6 million);
- Maintain and update the NID ($500,000) ? Research ($1.5 million);
- Training ($500,000);
- Adds security to critical dam safety issues Association of State Dam Safety Officials 239 S. Limestone St. Lexington, KY 40508 - www.damsafety.org.

This awareness for ***Dam Safety*** has been gradually absorbed and systematically expanded by other countries around the World.

The list of accidents and dam collapse, as can be seen in **Chapter 7**, shows (until 2020) accidents resulting from various origins in **Knowledge Management**. However, the authors have observed that reasonable attention has been given, just, to inspection and monitoring, and virtually no attention to the aspects that precede and coexist during the implementation of a dam, as summarized in the figures above.

Therefore, the authors seek to indicate aspects, characteristics, defenses, and aspects that can induces to have a **Knowledge Management**, so that since the birth of the Dam Project, conditions can be established to effectively have a ***Safe Dam.***

This text will not go into the merits of discussing the interpretation of Laws, Dogmas, Rules, Instrument and/or monitoring data, because the Authors see this makes part of the required knowledge of the participants of each Project. Much less, type sheets to be pre-filled, as it depends on the Culture, Organization and Facilities of computers and Media available and coveted.

As previously mentioned in **Chapters 0 and 1**, the aspects of Knowledge, Needs for Use, Potential Risks and Failures, Responsibility, Negligence, Compliance, Liability, should be evaluated for the implementation of a dam project.

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3 MATERIALS AVAILABILITY AND CHARACTERISTICS/ REQUIREMENTS

3.1 General

This **Chapter as well as Chapter 4** will address the topics on the main materials used in dam constructions. It is clear and logical that ***Dam Engineering*** seeks to use basically the materials that nature has disposed of around the site of the work to be built, and this depends heavily on ***Engineering Geology***.

The geologist collaborates with the geotechnical engineer to determine if a piece of land proposed for construction has the necessary stability conditions and materials knowledge. It is appropriate to have the knowledge of the following related areas; Geology, Geotechnics, Rock Mechanics; Petrography; Mineralogy; Geochemistry; Hydrogeology and Seismology.

The engineer's job is to design and build structures that interact continuously with the ground. The intention is to give engineers some tips for understanding the basics needed to conduct engineering activity appropriate to the various environments related to the Dam Safety. The objective is to provide, based on what it is mentioned in this Chapter and in the **Chapter 4**, some important points to pay attention.

Engineering Geology is the science devoted to the investigation, study and solution of the engineering and environmental problems which may arise as the result of the interaction between geology and the works and activities of man as well as to the prediction of and the development of measures for prevention or remediation of geological hazards.

As would be expected, the susceptibility to weathering (or the "weatherability") of minerals in some rocks varies in accordance with the temperatures at which they were formed; the susceptibility of a rock substance to weathering and the cause and consequences; the main factors which contribute to the development of weathered profiles; checking for the presence of sulfide; or other minerals and assessment of the risk of possible problems associated with their reactions with other materials that can be in contact.

Deterioration is due to expansions associated with chemical reactions-Alkali-aggregate **r**eactivity (**AAR**) and Pyrite. The expansive processes associated with some chemical reactions, among the elements that constitute the concrete, cause deformations and cracks in the concrete that can affect the functionality and even safety of the structures. These processes are generally aggravated by the presence of water, which, in turn, are facilitated by the opening of the cracks.

The authors in this text will not describe test methods, because this depends on the standards adopted in each Country or from each Technical Society, but they will mention the property, index or characteristics that the Owner and Designer must consider in the Contractual Documents –Contract, Technical Specifications and other requirements. Some definitions and common sense are mention to a proper understanding. Typical embankments may include rock, sand, silt and clay sized particles. Physical tests for embankments should recognize that:

⇒ some embankments behavior and test results will be influenced by processes applied to the construction;

⇒ some embankments behavior and test results will be influenced by processes which occur after deposition, such as segregation; and compaction;

The characteristics (including density, strength and compressibility) of the various components following segregation will not be the same as those for the initial "all in" embankments. It is therefore necessary to consider if segregation will occur, and (if it does), the properties of the segregated components.

Sample preparation prior to testing must also take account of the origin and nature of the sample. Some embankments properties may be strongly influenced by segregation and compaction.

Storage time can be an important consideration, as some materials will change characteristics when stored for extended periods, since the rocks may contain some minerals as nontronite and montmorillonite clays.

Tests which should be carried out and that are generally:

⇒ soil particle density (specific gravity);

⇒ particle size distribution;

⇒ maximum/minimum dry density;

⇒ Shear strength.

Tests influenced by slurry history typically include:

⇒ plasticity (Atterberg Limits);

⇒ settled density;

⇒ density after drying;

⇒ segregation characteristics;

⇒ rheological parameters.

An estimate of the density of the deposited embankments at the end is a common design requirement.

The increase in effective stress (resulting in consolidation and increased density) in an embankment deposit is likely to be the result of a combination of two mechanisms:

⇒ development of negative pore pressure due to evaporation from the surface; and

⇒ increase in overburden stress due to self-weight consolidation.

The permeability (hydraulic conductivity) of embankments depends on the particle sizes, degree of segregation, the amount and type of clay minerals present in the embankments, and the density achieved in the material at a given time.

Laboratory consolidation tests carried out on embankments samples can provide permeability data for low density embankments that cannot be tested by conventional permeameters.

Field tests in boreholes or pits are useful as they also include the influences of layering and shrinkage cracking.

Triaxial tests are the preferred method of strength testing, although shear box methods are still sometimes used. Triaxial tests with pore pressure measurements should be considered in order to obtain the pore pressure parameters in addition to traditional effective and consolidated undrained shear strength parameters.

Strength tests may be carried out on "undisturbed" samples recovered as part of a site investigation program. This may require specialized sampling, handling, and transportation techniques and even then it may be very difficult to achieve a good sample.

Alternatively, specimens may be prepared in the laboratory from either sedimentation and consolidation from a dry/moist preparation followed by saturation and consolidation.

It is important to characterize both the drained and the undrained shear strength properties of embankments, together with residual shear strength parameters if large deformations are expected, particularly under earthquake loadings.

The condition (or state) of existing embankments deposits may need to be evaluated by in-situ testing. The reasons for investigation may include:

⇒ sampling for chemical or geochemical reasons;

⇒ assessment of in-situ strength and/or degree of consolidation;

⇒ assessment of dry density;

⇒ permeability evaluation;

⇒ evaluation of phreatic surface and/or degree of saturation; and

⇒ potential for liquefaction, under seismic action.

The scope of any investigation work must be closely tied to the aims of the investigation. Suitable methods are heavily influenced by trafficability and access, or on the stability of any test hole/excavation.

Typical investigation methods include:

⇒ boring in cased holes, with **S**tandard **P**enetration **T**est (***SPT***) and undisturbed tube sampling;

⇒ **c**one **p**enetration **t**ests (***CPT***), preferably in conjunction with pore pressure probes (***CPTu***);

⇒ pressure-meter tests

⇒ shear vane tests;

⇒ dynamic cone testing;

⇒ in-situ density evaluation by the sand replacement test;

⇒ hand auguring and test pitting; and

⇒ geophysical methods.

In-situ test penetration methods are useful for evaluation of the liquefaction potential of a deposit, and of the post-liquefaction shear strength. Field trials (such as trial embankments) can be used to confirm properties of embankments and proposed construction techniques. Beaching trials can be conducted in association with thickener pilot plant trials.

The knowledge of the mineralogy and chemistry of the contained solids is therefore essential to the proper environmental design of a storage area.

There may also be ongoing chemical reactions within the storage, some of which are deleterious. Examples include:

⇒ oxidation of sulfide ores to create acidic water;

- ⇒ base exchange with cyanide compounds into non-soluble forms;
- ⇒ binding of metals onto clay particles; and
- ⇒ release of gases, sometimes toxic (e.g. if there are some gypsum stockpiles).

Apart from environmental considerations, knowledge of mineralogy and chemistry also helps predict the behavior during disposal, the consolidation phase and for eventual rehabilitation.

The expansive processes associated with some chemical reactions, among the elements that constitute the concrete, cause deformations and cracks in the concrete that can affect the condition of functionality and even safety of the structures. These processes are generally aggravated by the presence of water, which, in turn, are facilitated by the opening of the cracks. In such cases, an expert evaluation and the use of inspections and tests are necessary.

3.2 Organizing and Planning to know the Material

It is important for the development of a Dam Project, or rather of an Enterprise, that the knowledge of the availability and characteristics, properties and indexes of materials that could be used, be obtained in an organized and planned manner. This just, in advance of the start of construction, so that the Designer, and the Owner, can know in a safe way what they may be using.

In view of these needs, the authors present 3 examples of dam in different countries, which adopted a chronology and planning in an organized way to characterize the materials for construction, with due notice to the beginning of constructions

Case	Identification	Country	Materials and Concrete Studies	Dam Construction	References
3.2-A	Itaipu Binational	Brazil/Paraguay	1974-1976- Mass Concrete	09/1977-1983	[03-01]

Technical Information- Concerning the preliminary studies for Design

The studies for geological and rock mechanics knowledge were started in 1974, supported by the CESP Laboratory at Ilha Solteira - São Paulo State – Brazil and continued from 1975 in the Laboratories of Itaipu-Foz do Iguaçu Binational-State of Paraná- Brazil, with additional support from the Furnas Laboratory at Itumbiara - State of Minas Gerais - Brazil. This allowed to support the Designers and the Technical Areas with the properties and characteristics of materials and concrete before the start of the work, with the desired safety.

The initial studies on soundness concerning the inhibition of Alkali Aggregate Reactions, and the basalt weathering (due to the eventual occurrence of expansive clays) were developed until July 1977, considering the adoption of pozzolanic material (Fly Ash). Some special studies such as Creep, Strain Capacity, and Thermal Properties continued until 1978.

From 1976 to 1977, cement plants were inspected (about 8 factories supplied cement during construction, cement shipments were controlled by the Itaipu Quality Control System, through a chemistry and 2 technicians). The Additives and water-stops, rebars and metallic sleeves were pre-qualified in the years 1976-1977 and controlled throughout the construction of Itaipu's work.

Inspection of the dam site

Inspection of the Fly Ash from a Thermal Plant

Itaipu Dam – The materials and concrete studies had begun by 1974 (at Ilha Solteira – CESP Laboratory – Brazil) and during 1975 and 1976 at Itaipu site and Furnas Laboratory-Brazil. The concrete works in the dam had begun in September 30th 1977 (Andriolo's Archive)

Research on Natural Sand, from the Parana River

Crushing basalt rock for initial studies

Itaipu Dam – The materials and concrete studies had begun by 1974 (at Ilha Solteira – CESP Laboratory – Brazil) and during 1975 and 1976 at Itaipu site and Furnas Laboratory-Brazil. The concrete works in the dam had begun in September 30th 1977 (Andriolo's Archive)

Concrete specimens with different sizes due to the Maximum sizes of the aggregates

All the basic studies performed in advance to permit to start the concrete dam in a safety condition

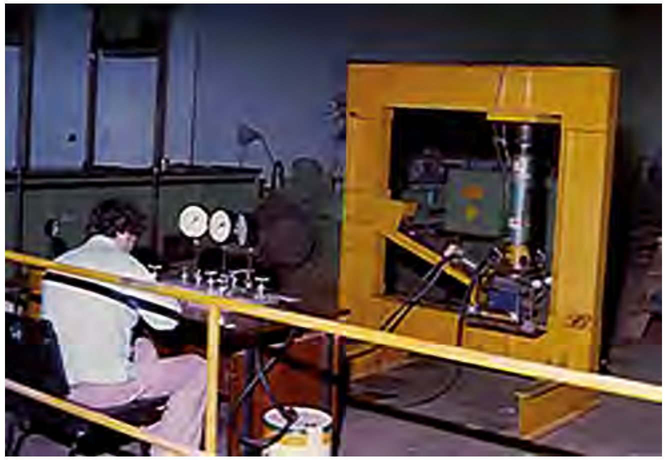
Itaipu Dam – The materials and concrete studies had begun by 1974 (at Ilha Solteira – CESP Laboratory – Brazil) and during 1975 and 1976 at Itaipu site and Furnas Laboratory-Brazil. The concrete works in the dam had begun in September 30th 1977 (Andriolo's Archive)

Permeability tests

Mass concrete creep tests

Strain capacity test

Laboratory Tests (Andriolo's Archive)



Concrete shear test

Concrete Triaxial test

Concrete Adiabatic temperature rise test

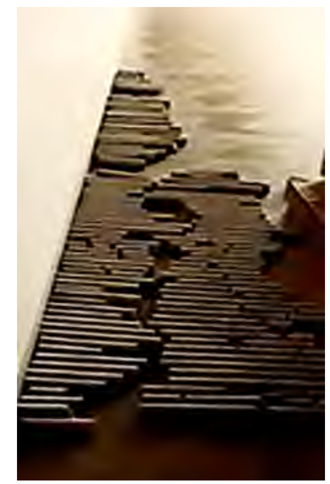
Laboratory Tests (Andriolo's Archive)

Case	Identification	Country	Materials and Concrete Studies	Dam Construction	References
3.2 -B	Capanda	Angola	1987-1989-RCC	10/1989-1992	[03-02]

Technical Information- Concerning the studies for Design and Construction

The Capanda Dam was constructed in Angola, using the RCC methodology, being the first one higher than 100 m, in Africa. The RCC used was proportioned with low cement content (around 70 kg/m³ and a high content of metasandstone crushed powder filler, giving a high paste content). Samples of the rock material (Meta Sandstone) were shipped to the Itaipu Laboratory (Brazil) to perform studies on rock, aggregates, and concretes, CVC and RCC, in between 1987 and 1989. All the RCC properties were checked, mechanical, elastics and thermal.





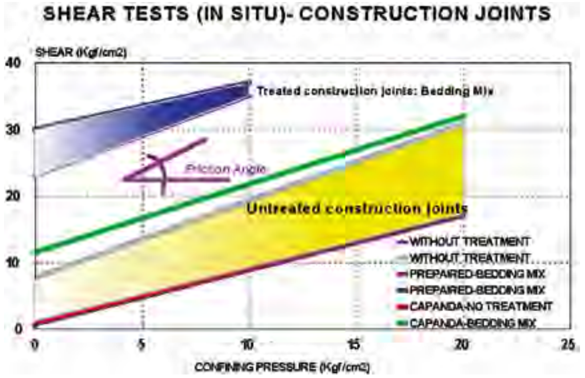

Capanda Dam-Angola, Materials were shipped from Angola to Itaipu laboratory Brazil-Studies performed in between 1987-1989 – RCC Dam start up at October, 1989 (Andriolo´s Archive)

As in Capanda RCC dam it was adopted an upstream face with precast panels lined with a PVC membrane, this geotextile was deeply checked together the supplier at Itaipu Laboratory **(this will be presented in 3.4 ahead).**

A large Full Scale Test Fill was developed, at Capanda site, to check the RCC methodology procedures, considering the construction joint surface treatment and the shear properties at site, besides other characteristics.





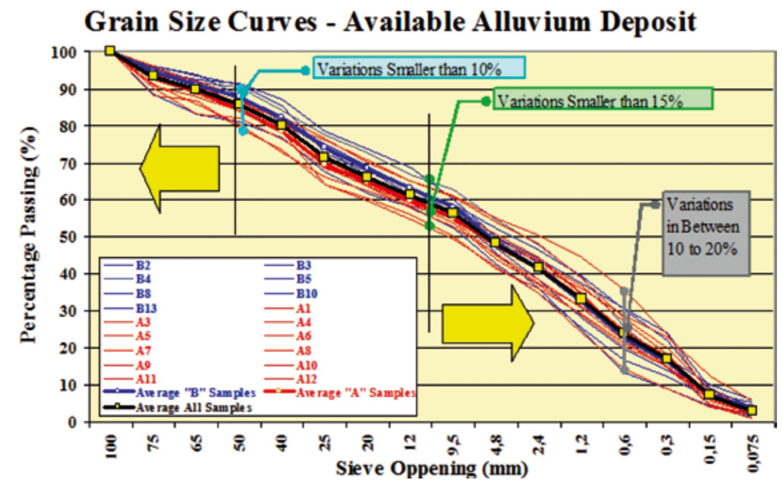


Capanda Dam-Angola - Full Scale Test Fill, under preparation, construction, cutting the slots for the shear test (Andriolo's Archive)

Case	Identification	Country	Materials and Concrete Studies	Dam Construction	References
3.2-C	Beydag	Turkey	2005-2006 -RCC	07/2007-2008	[03-03]

Technical Information Concerning the studies for Design and Construction

The Beydag RCC Dam was constructed in between the Odemis and Nazilli cities in the western zone of Turkey, using the RCC methodology. The RCC studies were performed by the Contractor, supervisioned by the **DSI** (Government Agency) and the Designer (Temellsü), during the period 2005-2006, at job site laboratory. It was used a lean RCC concrete (60 kg/m³ cement+ 30 kg/m³ Fly Ash+ Natural Filler from the alluvium). The aggregate from the River Menderes was so uniform that gives the opportunity to use just one aggregate. More size (below 50 mm) with more than 50% of sand, and around 5-8% of material less 0,075 mm. This had proportioned a high paste RCC. More than 150 RCC trial mixes were performed to reach an optimum one.



Beydag Dam-Turkey, Materials were Studied at Beydag site in between 2005-2006 – RCC Dam start up at July, 2006 (Andriolo´s Archive)

Beydag Dam-Turkey, RCC Studies by 2005- RCC Dam start up at July/2006 (Andriolo´s Archive)

There is no doubt that situations arising from the region or country may prevent the correct and early realization of studies on the availability of materials. However, it is interesting to know as soon as possible about the availability of materials and their characteristics, as exemplified below.

3.3 Soil

3.3.1 Types

3.3.1.1 General

Soils and water are one of Earth's essential natural resources, yet they are often taken for granted. Most people do not realize that soils are a living, breathing world supporting nearly all terrestrial life. Soils and the role they play within an ecosystem vary greatly from one location to another because of many factors, including differences in climate, the animal and plant life living on them, the soil's parent material, its position on the landscape, and its age.

Although soil is the oldest and most common material used by man for his works, it is only within recent decades that the science of soil mechanics been has developed to its present state of capability. Despite the progress that soil science has made, increasing engineering requirements over the next few years will require more soil research. Unlike metals, concrete, wood, and other common engineering materials, soils do not respond to the usual stress, strain, and strength relationships of the more elastic materials. Lacking uniformity because of the varied origins and heterogeneous compositions, soils must be sampled and tested, and the data analyzed by special means and techniques.

The term soil has various meanings, depending upon the general field in which it is being considered, as for Pedologists, Geologists, Engineers and Soil Mechanics, for instance.

This Chapter deals with soil materials and their engineering characteristics that are significant to embankment dam design. Embankment dams are constructed of all types of geologic materials, except for organic soils and peats. Most embankments are designed to utilize the economically available on-site materials for the bulk of construction. Special zones, such as filters, drains and riprap, may come from off-site sources. Soil materials used in embankment dams commonly are obtained by mass production from local borrow pits, and from required excavations where suitable.

Many embankments are constructed of broadly graded soils which do not fit entirely into either category, and exhibit characteristics of both. Moraine deposits are an important example of these mixed soils. The intent of this Chapter is to provide a general overview of soil materials used in embankment dams.

3.3.1.2 Soil Description

It is necessary to adopt a formal system of soil description and classification in order to describe the various materials found in ground investigation. Such a system must be comprehensive (covering all but the rarest of deposits), meaningful in an engineering context *(so that engineers will be able to understand and interpret)* and yet relatively concise. It is important to distinguish between description and classification:

- ⇒ **Description of soil** is a statement describing the physical nature and state of the soil. It can be a description of a sample, or a soil *in situ*. It is arrived at using visual examination, simple tests, observation of site conditions, geological history, etc.
- ⇒ **Soil classification** is the separation of soil into classes or groups, each having similar characteristics and potentially similar behavior. A classification for engineering purposes should be based mainly on mechanical properties, e.g. permeability, stiffness, strength. The class to which a soil belongs can be used in its description

3.3.1.3 Basic Characteristics of Soils

Soils consist of grains (mineral grains, rock fragments, etc.) with water and air in the voids between grains. The water and air contents are readily changed by changes in conditions and location: soils can be perfectly dry (have no water content) or be fully saturated (have no air content) or be partly saturated (with both air and water present). Although the size and shape of the solid (granular) content rarely changes at a given point, they can vary considerably from point to point.

Foremost, consider soil as an engineering material - it is not a coherent solid material like steel and concrete, but it is a particulate material. It is important to understand the significance of particle size, shape and composition, and of a soil's internal structure or fabric. To an engineer, it is a material that can be:

⇒ **built on**: foundations to buildings, bridges;

⇒ **built in**: tunnels, culverts, basements;

⇒ **built with**: roads, runways, embankments, dams;

⇒ **supported**: retaining walls, quays.

Engineers' descriptions give engineering terms that will convey some sense of a soil's current state and probable susceptibility to future changes (e.g. in loading, drainage, structure, surface level). Engineers are primarily interested in thesoil's mechanical properties: strength, stiffness, permeability. These depend primarily on the nature of the soil grains, the current stress, the water content and unit weight.

3.3.1.4 Size Range and Shape of Grains

The range of particle sizes encountered in soil is very large: from boulders with a controlling dimension of over 200 mm down to clay particles less than 0,002 mm (2 μm). Some clays contain particles less than 1 μμ in size which behave as colloids, i.e. do not settle in water due solely to gravity.

The soils can be classified into named Basic Soil Type groups according to size, and the groups further divided into coarse, medium and fine subgroups:

Very coarse soils	BOULDERS		> 200 mm (*)	>300 mm (#)
	COBBLES		6.3-200 mm (*)	75-300 mm (#)
Coarse soils	G- GRAVEL	coarse	20-63 mm (*)	19-75 mm (#)
		medium	6.3-20 mm (*)	
		fine	2-6.3 mm (*)	4,75-19 mm (#)
	S- SAND	coarse	0.63-2.0 mm (*)	2-4.75 mm (#)
		medium	0.2-0.63 mm (*)	0.425-2 mm (#)
		fine	0.063-0.2 mm (*)	0.075-0.425 mm (#)
Fine soils	M- SILT	coarse	0.02-0.063 mm (*)	
		medium	0.0063-0.02 mm (*)	
		fine	0.002-0.0063 mm (*)	
	C- CLAY		< 0.002 mm (*)	

Notes - (*) British Standard; (#) ASTM

Sand and larger-sized grains are rotund. Coarse soil grains (silt-sized, sand-sized and larger) have different shape characteristics and surface roughness depending on the amount of wear during transportation (by water, wind or ice), or after crushing in manufactured aggregates. They have a relatively low specific surface (surface area):

⇒ **Rounded:** Water- or air-worn; transported sediments;

⇒ **Irregular**: Irregular shape with round edges; glacial sediments (sometimes subdivided into 'sub-rounded' and 'subangular);

- ⇒ **Angular**: Flat faces and sharp edges; residual soils, grits;
- ⇒ **Flaky**: Thickness small compared to length/breadth; clays;
- ⇒ **Elongated**: Length larger than breadth/thickness; scree, broken flagstone;
- ⇒ **Flaky & Elongated**: Length>Breadth>Thickness; broken schists and slates.

3.3.1.5 Origins, Formation and Mineralogy

Soils are the results of geological events (except for those produced by man). The nature and structure of a given soil depends on the geological processes that formed it:

- ⇒ **breakdown** of parent rock: weathering, decomposition, erosion;
- ⇒ **transportation** to site of final deposition: gravity, flowing water, ice, wind;
- ⇒ **environment** of final deposition: flood plain, river terrace, glacial moraine, lacustrine or marine;
- ⇒ **subsequent conditions** of loading and drainage - little or no surcharge, heavy surcharge due to ice or overlying deposits, change from saline to freshwater, leaching, contamination;
- ⇒ **manufactured** from crushing large size of rock, or gravels.

All soils originate, directly or indirectly, from solid rocks in the Earth's crust, as mentioned in **3.4.1 in this Chapter**, but it is also important to emphasize some relevant aspects.

Clay minerals are produced mainly from the chemical weathering and decomposition of feldspars, such as orthoclase and plagioclase, and some micas. They are small and very flaky. The key to some properties of clay soils, e.g. plasticity, compressibility, swelling/shrinkage potential, lies in the structure of clay minerals. There are three main groups of clay minerals:

⇒ **kaolinites:** (include kaolinite, dickite and nacrite) formed by the decomposition of orthoclase feldspar (e.g. in granite); kaolin is the principal constituent in China clay and ball clay;

⇒ **illites:** (include illite and glauconite) are the commonest clay minerals; formed by the decomposition of some micas and feldspars; predominant in marine clays and shales;

⇒ **montmorillonites:** (also called smectites or fullers' earth minerals) (include calcium and sodium montmorillonites, bentonite and vermiculite) formed by the alteration of basic igneous rocks containing silicates rich in Ca and Mg; weak linkage by cations (e.g. Na^+, Ca^{++}) results in high swelling/shrinking potential

3.3.2 Materiasl Availability, Samples Technical Characteristic and Attentions

During the investigation and design phases of constructing a large fill dam, the site is explored and evaluated. A very important aspect of this evaluation is the determination of the availability of various types of rock and earth materials for construction and their physical engineering properties. It is important to test these materials with standard test methods so that comparisons can be made with other embankments that have been constructed with similar materials and whose performance has been experienced. These tests determine the unit weight of the material, shear strength, permeability, consolidation characteristics, grain size, specific gravity, and much other engineering physical properties. Many of these same tests will be performed on the fill materials selected for the design during the construction phase. The standard tests performed during construction will include both quality control tests and record tests.

The physical properties determined during the investigation and design phases are used to design the structure. It is important during these phases that the constructability of the fill dam be considered in selecting earth materials, the construction methods and equipment that will be available as well as how the material is used in the design of the dam, and the quality control aspect because the construction quality control procedures are essential to assure materials requirements of design are actually carried out during construction.

Earth excavation and handling more than 24.000.000 m^3 during the construction of Tucurui Project – PA, Brazil (Courtesy from Ulysses Nunes Archive)

There are different methods for determining soils properties, which can be divided into two general categories: direct and indirect methods. The direct methods include laboratory and in situ tests.

	Laboratory Tests		In situ Tests
A	**Characterization**	**B**	**Characterization**
A.1	Classification	B.1	In Place Density
A.2	Gradation analysis	B.2	Permeability
A.2	Atterberg Limits	B.3	Visual identification
A.3	Water Content		
A.4	Specific Gravity		
A.5	Compaction - Density & Relative Density		
A.6	Petrographic Analysis		
C	**Engineering Design**	**D**	**Engineering Design**
C.1	Density	D.1	Density
C.2	Permeability	D.2	Moisture Content
C.3	Direct Shear Strength	D.2	Permeability
C.4	Compressive Strength - Unconsolidated; Undrained	D.3	Relative Compaction
		D.4	Settling - Dynamic Penetration
C.5	Triaxial Compression	D.5	Dispersion- Crumb and Turbidity test
C.6	Petrographic Analysis	D.6	Degree of Muddiness - Drop test
		D.7	Sodium Content - Ultraviolet test

Dispersive soils cannot be identified by visual soil classification or the standard laboratory index tests. Clays should be tested for dispersive characteristics as a routine procedure during feasibility studies for earth dams.

Another aspect that call attention is the characterization of saprolitic soils, that demands other criteria than those usually considered in classical soil mechanics classifications. Identifying them as "hard soils" or "weak rocks" is not sufficient to define their mechanical behavior. A more comprehensive classification should include a description of the weathering profile as well as significant information on chemical, mineralogical and physical aspects of their constituents. Also, preliminary indications of the duality "strength-consistency", by simple parameters (such as unconfined strength), can constitute fair steps for a more complete description of these materials.

Saprolitic soils are derived from saprolites, an advanced state of weathered rock. As these soils undergo further weathering the clay content increases, and by exposure to lixiviation plus oxidation of iron and aluminum ions such soils are transformed to lateritic soils. An advanced state of lateritic soils is laterite. Lateritic soils are erosion resistant, whereas saprolitic soils are not. In short, saprolitic soils are formed in the transition from weathered rock to completely weathered rock, and their clay fraction is small, usually less than 10%.

Lateritic soils have a larger clay fraction, up to 60%, but this clay fraction is aggregated with oxides, forming links with the larger grain sizes.

Laterites and lateritic soils form a group comprising a wide variety of red, brown, and saprolitic soils that are the result of deep weathering of the parent rock that has not yet undergone laterization. The soil name 'laterite' was coined, from the Latin word 'later' meaning brick. Such soils are characterized by forming hard, impenetrable and often irreversible pans when dried. They are found at shallow depths, in low-grade slopes, and are so tough that they are used in Brazil as concrete aggregate, construction stone for pavements and rip-rap for the protection of dam slopes from the wave action of reservoirs.

The rounded forms of the oxides enveloping the grain structure should be noted. These 'stones' are widely used in the northern regions of Brazil, in which rock outcrops are rare, as construction material, and even as concrete aggregate. Laterites may vary from a loose material to a massive rock. Because of this confusion, most workers now prefer to use definitions based on hardening, such as 'ferric' for iron-rich cemented crusts, 'alcrete' or bauxite for aluminum rich cemented crusts, 'calcrete' for calcium carbonate rich crusts, and 'silcrete' for silica-rich cemented crusts.

Lateritic and saprolitic soils show the presence of macro and micropores the size and distribution of which can be investigated by means of the mercury intrusion technique.

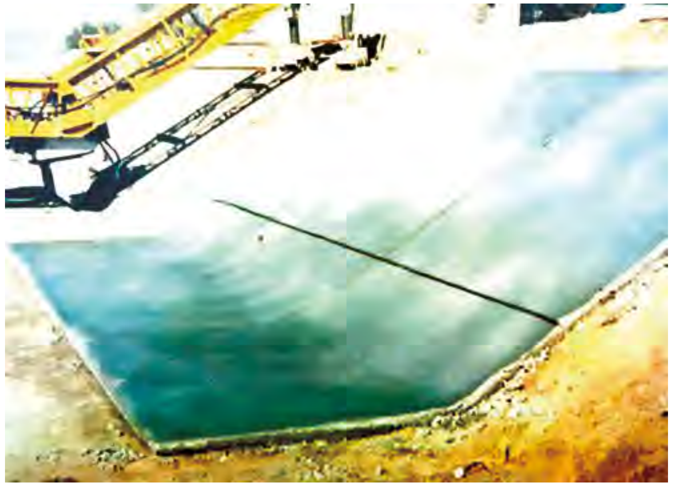
Sinkholes similar to those seen in karstic limestone are known to occur also in some laterite profiles developed on non-carbonate rocks.

From an engineering standpoint, clays are not commonly found in a pure form but may involve mixed layer structures. In addition, different types of clay soils may be intermixed during transportation and deposition. These factors make an identification and ultimate behavior prediction by petrographic analysis difficult.

The montmorillonite soils, with their expanding lattice structure and resulting capacity for wide ranges in water contents, can be particularly troublesome.

Settlement from shrinkage, heave from swelling, and loss of stability caused by shrinkage or swelling can create major structural problems; this is often greatly magnified in the case of hydraulic structures.






A channel that was constructed on an expansive clay, that had expanded and damage the concrete covering (cracks and deformations). (Andriolo's archive)

3.4 Rock

3.4.1 Types

Rock differs from most other engineering materials in that it contains discontinuities such as joints, bedding planes, folds, sheared zones and faults which render its structure discontinuous. A clear distinction must be made between the intact rock or rock material and the rock mass.

⇒ The intact rock may be considered as a continuum or polycrystalline solid between discontinuities consisting of an aggregate of minerals or grains. The properties of the intact rock are governed by the physical properties of the materials of which it is composed and the manner in which they are bonded to each other;

⇒ The rock mass is the "in situ" medium comprised of intact rock blocks separated by discontinuities such as joints, bedding planes, folds, sheared zones and faults. Rock masses are discontinuous and often have heterogeneous and anisotropic properties.

Because rock masses are discontinuous and variable in space, it is important to choose the fight domain that is representative of the rock mass affected by the structure analyzed.

⇒ When the problem domain is much smaller than the blocks of rock formed by the discontinuities, such as the excavation of rock by drilling, the behavior of the intact rock material will be of concern.

⇒ When the block size is of the same order as the structure being analyzed or when one of the discontinuity sets is significantly weaker than the others, the stability of the structure should be analyzed by considering failure mechanisms involving sliding or rotation of blocks and wedges defined by intersecting structural features.

⇒ When the structure being analyzed is much larger than the blocks of rock formed by the discontinuities, the rock mass may be simply treated as an equivalent continuum.

Most dams and reservoirs are located at or near the bases of river valleys. The topography and geological situation at every site will have developed by the interaction of many geological and related processes during vast periods of time.

The resulting geological structure at dam and reservoir sites can be complex, and no two sites will be the same. Some of the processes which formed the site may still be active or may be reactivated by the project and capable of influencing the feasibility of its construction or operation. It is vital, therefore, that sites are investigated using all appropriate knowledge and methods of classical geology.

The engineering team responsible for construction of a dam at each site must be able to make reliable predictions about suitable construction methods and how the dam and its foundation will interact and perform, under every envisaged operating condition. The predictions will usually involve both judgments and quantitative analyses, based on data provided by the site investigation team.

This data is provided as a geotechnical model, which consists[03-04; 03-05]:

⇒ a sufficiently detailed three-dimensional picture or model of the site geological situation, using geotechnical descriptive terms, and an assessment of the history of the site and the effects of any processes which are still active and;

⇒ adopted values of parameters for critical parts of the model, as required for the analyses.

Geological classification of igneous rocks				
	Type			
Grain size	Acid > 65% silica	Intermediate 55-65% silica	Basic 45-55% silica	Ultrabasic < 45% silica
Plutonic	Granite Granodiorite	Diorite	Gabbro	Picrite, Peridotite Serpentinite Dunite
Hypabyssal	Quartz Orthoclase porphyries	Plagioclase porphyries	Dolerite	Basic dolerites
Extrusive	Rhyolite Dacite	Pichstone Andesite	Basalt	Basic olivine basalts
Major mineral constituents	Quartz, orthoclase, sodium-plagioclase, muscovite, biotite, hornblende	Quartz, orthoclase plagioclase, biotite, hornblende, augite	Calcium, plagioclase, augite, olivine hornblende	Calcium-plagioclase, olivine, augite

Classification of metamorphic rocks			
Classification	**Rock**	**Description**	**Major mineral constituents**
Massive	Hornfels	Micro-fine grained	Quartz
	Quartzite	Fined grained	Quartz
	Marble	Fine-coarse grained	Calcite or dolomite
Foliated	Slate	Micro-fine grained laminated	Kaolinite, mica
	Phyllite	Soft, laminated	Mica, kaolinite
	Schist	Altered hypabyssal rocks coarse grained	Feldspar, quartz, mica
	Gneiss	Altered granite	Hornblende

Classification of sedimentary rocks				
Method of formation	**Classification**	**Rock**	**Description**	**Major mineral constituents**
Mechanical	Rudaceous	Breccia Conglomerate	Large grains in clay matrix	Various
	Arenaceous	Sandstone	Medium, round grains in calcite, matrix	Quartz, calcite (sometimes feldspar, mica)
		Quartzite	Medium, round grains in silica matrix	Quartz
		Gritstone	Medium, angular grains in silica matrix	Quartz, calcite, various
		Breccia	Coarse, angular grains in matrix	Quartz, calcite, various
	Argillaceous	Claystone	Micro-fine-grained plastic texture	Kaolinite, quartz, mica
		Shale	Harder-laminated	Kaolinite, quartz, mica
		Mudstone	compacted clay	Kaolinite, quartz, mica
Organic	Calcareous	Limestone	Fossiliferous, coarse or fine grained	Calcite
	Carbonaceous (siliceous, ferruginous, phosphatic)	Coal		
Chemical	Ferruginous	Ironstone	Impregnated limestone or claystone (or precipitated)	Calcite, iron oxide
	Calcareous (siliceous, saline)	Dolomite limestone	Precipitated or replaced limestone, fine-grained	Dolomite, calcite

3.4.2 Materials Availability, Samples Technical Characteristics and Attentions

The determination of the engineering properties of rocks is an important part of all rock engineering problems. There are different methods for determining rock mass properties, which can be divided into two general categories: direct and indirect methods. The direct methods include laboratory and in situ tests. Many rock mechanics and rock engineering textbooks provide information on conducting laboratory and in situ tests to determine rock properties.

LABORATORY TESTS	
X	**Characterization**
X.1	Porosity, density, water content
X.2	Absorption
X.3	Hardness-Schmidt rebound, Shore scleroscope
X.4	Resistance to abrasion
X.5	Point load strength index
X.6	Uniaxial compressive strength and deformability
X.7	Swelling and slake-durability
X.8	Sound velocity
X.9	Petrographic and Mineralogical description
Z	**Engineering design**
Z.1	Triaxial strength and deformability test
Z.2	Direct shear test
Z.3	Tensile strength test
Z.4	Permeability
Z.5	Time dependent and plastic properties

IN SITU TESTS	
Y	**Characterization**
Y.1	Discontinuity orientation, spacing, persistence, roughness, wall strength, aperture, filling, seepage, number of sets, and block size
Y.2	Drill core recovery/RQD
Y.3	Geophysical borehole logging
Y.4	In situ sound velocity
W	**Engineering design**
W.1	Plate and borehole deformability tests
W.2	In situ uniaxial and triaxial strength and deformability test
W.3	Shear strength – direct shear, torsional shear
W.4	Field permeability measurement
W.5	In situ stress determination

It is very important to understand the aspects that the rocks can be weathered or react with other materials in the dam foundation and/or its own body, or with some contaminant or water from the reservoir and climate.

For the use of natural materials such as concrete aggregates and in embankments, there are precautions that must be considered to have their knowledge in a timely manner for technical analyses and their proper use in the works.

One of the fundamental characteristics in the knowledge of rocks for the production of blocks or aggregates for the construction of dams, concerns sanity its alteration over time, under the actions of the Nature, and or arising from the reaction with other materials used.

Susceptibility of igneous rock-forming minerals to weathering[03-04; 03-05]:

Temperature of formation	Susceptibility to weathering	Mineral	Common igneous rock types
Highest	Highest	Olivine	
↓	↓		Basalt, dolerite, gabbro
		Calcic felspar	
		Augite	Andesite, diorite
		Hornblende	
		Sodic felspar	
		Biotite	
			Rhyolite, granite
		Muscovite	
Lowest	Lowest	Quartz	

Susceptibility of other common minerals to weathering

Group	Mineral	Effects of weathering
Carbonates	Calcite	Readily soluble in acidic waters
	Dolomite	Soluble in acidic waters
Evaporites	Gypsum	Highly soluble
	Anhydrite	Highly soluble
	Halite (common salt)	Highly soluble
Sulphides	Pyrite and various other pyritic minerals	Weather readily to form sulphates, sulphuric acid and limonite
Clay minerals	Chlorite	Weathers readily to other clay minerals and limonite
	Vermiculite	Weathers to kaolinite or montmorillonite*
	Illite	Weathers to kaolinite or montmorillonite*
	Montmorillonite	Weathers to kaolinite
	Kaolinite	Stable**
Oxides	Haematite	Weathers to limonite
	Ilmenite	Stable
	Limonite	Stable

*These minerals expand and contract with wetting and drying and this can cause large disruptive forces and disintegration of some rocks.

**Softens on wetting.

Some failures were noted for some aggregates meeting the specification and testing procedure. None of those failures were sufficiently extensive to cause major problems. Repeatability and uniformity of test results presented problems and testing procedures were altered to conform more closely with the standard test method.

3.4.3 Durability - Soundness

Durability refers to the ability of concrete to resist deterioration from the environment or service in which it is placed. The durability of aggregates can be conveniently divided into physical and chemical causes. The physical durability problems include aggregates that are susceptible to freezing and thawing or wetting and drying, as well as physical wear. Chemical durability problems are concerned with various forms of cement-aggregate reactions. Most chemical durability problems result as, for example, structural Portland cement concrete aggregates are exposed to:

⇒ Abrasive forces while the aggregate is in a moist/wet state during stockpiling, transporting, batching, mixing, and placing of the concrete;

⇒ Tensile, shear, and compressive stresses during loading of the reinforced concrete structure;

⇒ Chemical environments of a saturated solution of calcium hydroxide, sodium and potassium hydroxide, and sulfates in the concrete;

⇒ Wetting and drying cycles of the concrete;

⇒ Temperature changes, including freezing and thawing of absorbed moisture of the concrete.

Soundness is used as a general term to describe the durability characteristics of a rock piece or an aggregate as a whole. On the other hand, some literature limits the terms sound and unsound to chemical properties. This test method is used to estimate their soundness when subjected to weathering action in concrete. Thus, soundness includes resistance to wetting and drying, heating and cooling, freezing and thawing, or any combination thereof.

The usual procedures for the evaluation of rock and aggregate soundness:

Petrographic examination of concrete aggregate is visual examination and analysis in terms of both lithology and properties of the individual particles. By petrographic examination, the relative abundance of specific types of rocks and minerals is established; the physical and chemical attributes of each, such as particle shape, surface texture, pore characteristics, hardness, and potential chemical reactivity, are described; coatings are identified and described; and the presence of contaminating substances is determined, each in relation to proposed or prospective conditions of service in concrete constructions.

Petrographic examination is primarily a supplement to the acceptance tests. Probable performance of concrete aggregate is estimated in two general ways by petrographic examination:

⇒ First, the examination reveals the composition and physical and chemical characteristics of the constituents.

⇒ From this information, the probable response of the aggregate to such phenomena as attack by cement alkalis, freezing-thawing, wetting-drying, heating-cooling, or high temperatures usually can be estimated.

In reporting the results of the petrographic examination, the report should supply information on the following subjects as necessary for evaluation of the aggregate for service under the anticipated conditions of exposure in the concrete:

⇒ Mineralogic and lithologic composition

⇒ Particle shape

⇒ Surface texture

⇒ Internal fracturing

- ⇒ Coatings
- ⇒ Porosity, permeability, and absorption
- ⇒ Volume change, softening, and disintegration with wetting-drying
- ⇒ Thermal properties
- ⇒ Strength and elasticity
- ⇒ Density
- ⇒ Hardness
- ⇒ Chemical activity
- ⇒ Solubility
- ⇒ Oxidation
- ⇒ Hydration
- ⇒ Carbonation
- ⇒ Alkali-silica reactivity
- ⇒ Alkali-carbonate reactivity
- ⇒ Sulfate attack on cementitious matrix
- ⇒ Staining
- ⇒ Cation-exchange reactions
- ⇒ Reactions of organic substances
- ⇒ Effects of contaminants

Freeze–thaw Aspects: Many attempts have been made to use an unconfined freeze-thaw test to identify those aggregates which are susceptible to frost action. Deterioration of aggregate in the sodium sulfate soundness test is caused by the accumulation and growth of sodium sulfate crystals in the pores of the aggregate that produces disruptive internal forces, similar to the action produced by expansion of water. Other actions may be involved, including not only the pressure exerted by crystal growth but also the effects of heating and cooling, wetting and drying, and pressures developed by migration of the solution through the pores.

Freeze-thaw aspects on concrete showing some degradation of the elements (Andriolo´s Archive)

The sulfate soundness test is conducted by repeated immersions of the aggregate sample in saturated solutions of sodium or magnesium sulfate alternating with oven drying to precipitate the salt in permeable pore spaces. Expansive forces are exerted by rehydration of the salt when the sample is re-immersed. This expansion is said to simulate the expansion of water upon freezing. Magnesium sulfate is generally more destructive than sodium sulfate.

Thermal Aspects: Because the thermal properties of composite materials such as concrete are dependent on the thermal properties of their constituents, the aggregates have a great influence on the thermal properties of concrete. The degree to which thermal properties of concrete aggregates are of concern to the user depends upon the nature of the concrete structure and the exposure to which it is subjected.

Knowledge of thermal properties are important in the design of massive structures, such as dams, where thermal and volume stability of the composite are important; in concretes exposed to extreme temperatures or temperature cycles, where the relative properties of the individual constituents may be important.

Thermal cracks observed in different concrete structures (Andriolo´s Archive)

The most obvious of these is massive structures, where the dissipation of heat generated by cement hydration, is important to control thermal cracking. Other instances include insulating concrete and the durability of concrete exposed to cyclical temperature changes. The design engineer should carefully evaluate the circumstances of a particular concrete application to estimate the importance that thermal properties of aggregates will have on concrete performance.

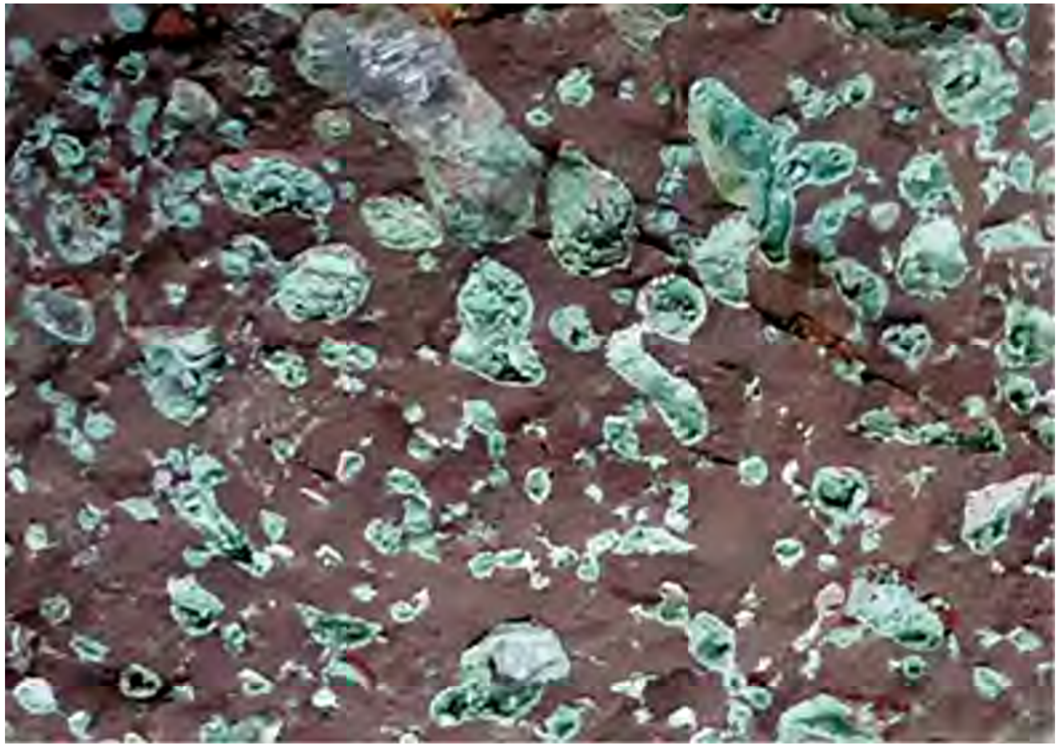
Clay Mineral Aspects: Many basic igneous rocks contain smectite clays as a result of deuteric alteration during their formation or subsequent chemical decomposition. This has resulted in numerous failures when such materials are used in road construction due to inadequate durability. Various methods for assessing material durability have been developed as wetting-drying cycles, oven-ambient- cycles and those using ethylene glycol to expand smectite clays appear to be the most effective

Ethylene glycol has been used extensively by the concrete to identify rock durability issues associated with smectite clay minerals. The presence of these clay minerals is synonymous with rock degradation under normal environmental wetting and drying cycles.

Ethylene glycol is one of the materials that reacts with swelling clays of the montmorillonite group to form an organo-clay complex having a larger basal spacing than that of the clay mineral itself. Hence, a sample of stone containing swelling clay of the montmorillonite group will be expected to undergo expansive breakdown upon soaking in ethylene glycol, if the amount, distribution, state of expansion, and ability to take up glycol is such as to cause such breakdown to occur. If such breakdown does occur, it may be expected that similar breakdown may occur if similar rock samples are exposed, for longer times, to wetting and drying or freezing and thawing in water-soaked condition in service. From[03-06] can be remembered:

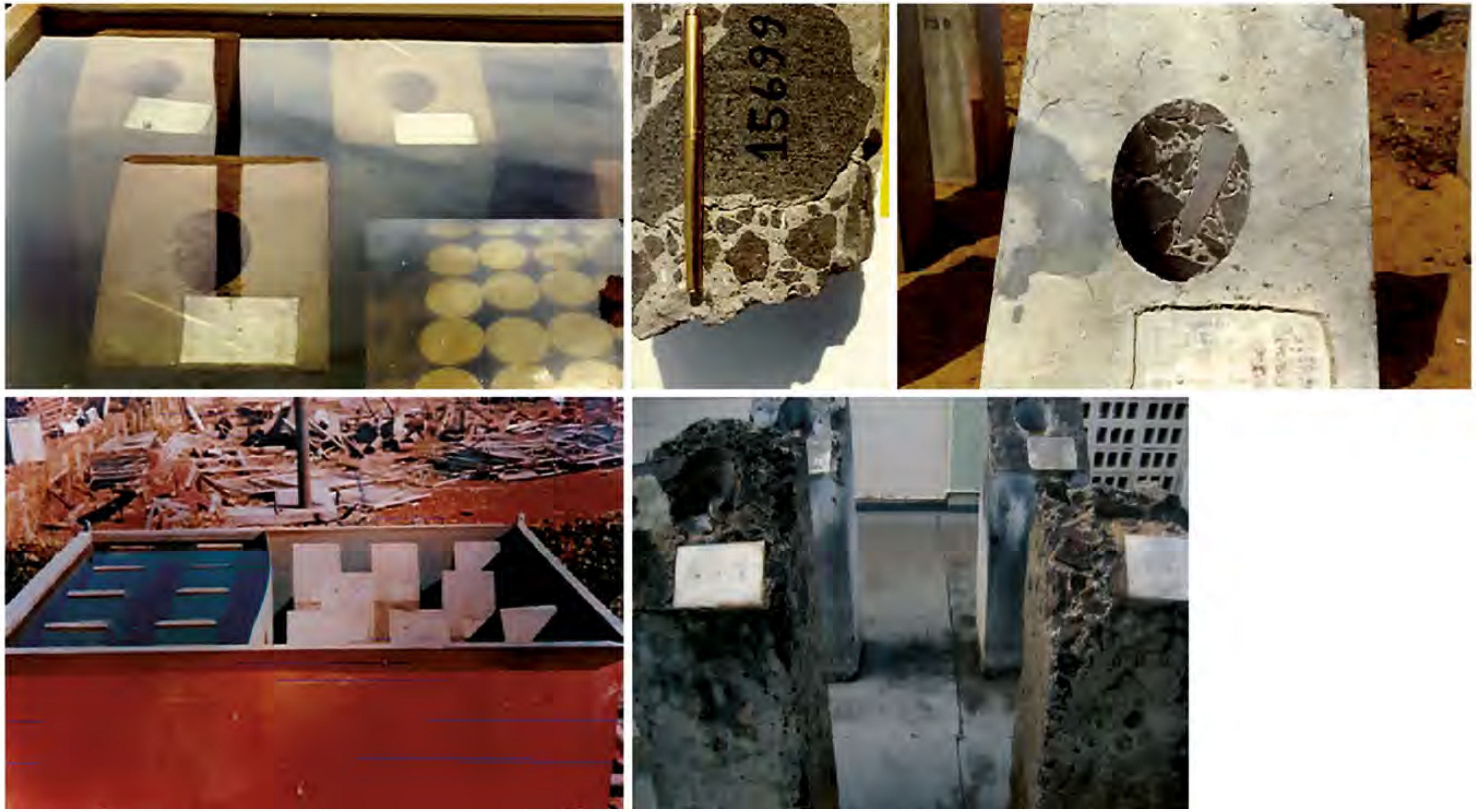
> *"In 1954, Murillo Ruiz and IPT technician Irineu Gonçalves conducted laboratory tests for the technological characterization of basalts in the State of São Paulo, when they were surprised by a probing testimony from Jupiá, which after drying in a greenhouse, cooling and submersion in water, completely disaggregated, precipitating like a handful of dust at the bottom of a container with water. The first reaction was to imagine that it was the "prank" of some colleague, because the laboratory used did not remain closed during the night. The assay was repeated, now with the laboratory locked, with the same phenomenon, now in a larger number of samples. It became imperative, then, the beginning of studies to discover the cause of this behavior, even because in some boot-outs of the excavations of Jupiá, by simple exposure to the sun and rains, many of those same rocks already presented total disaggregation. To identify the mineral or minerals responsible for the breakdown of these semi-unchanged basalts, the chemical engineer Persia de Sousa Santos (IPT Report No. 3,182 of February 6, 1961) and geology*

professor Moacyr Vianna Coutinho were requested. The most frequent staining observed was bottle-green and the mineral was identified as nontronite, from the montmorillonite group, estimating that a better knowledge of this and other associated minerals constituted a good path for further research.



I then decided to grind these green plates to pass sieve number 250 and submit them to tests to determine their expansion capacity." The results obtained were published in the articles Studies of the expansive characteristics of a green clay that occurs in basaltic rocks of the Bariri dam, Tietê River (SP), in 1962..."

Pieces of rocks showing fragmentation due to the expansive clay minerals[03-03]



Large concrete blocks exposed to ambient condition to determine the cement and aggregates performance – since 1972 – CESP Laboratory at Ilha Solteira Project (Andriolo´s Archive)

Basalt quarry with montmorillonite clay and *in situ* test (from Andriolo´s archive)

Alkali Silica Aspects: For many years, the selection of aggregates for use in concrete was based primarily on physical characteristics such as grading, particle shape, hardness, density, and "cleanness." Likewise, such characteristics were the major, if not the only, consideration of the engineer in achieving long-term specified concrete strengths and volume stability. Virtually, no attention was given to the chemical or mineralogical composition of the aggregate, despite the known fact that concrete is a highly alkaline system in which pore solutions usually exceed ***pH*** values of 13. Symptoms of ASR (***Alkali Silica Reaction***) are typified by the expansion of concrete, usually accompanied by cracking. Expansions without discernible or abnormal cracking may be indicated by closing of joints, relative movement or displacement of concrete members or abnormal movement or misalignment of machinery embedded in, or anchored on, the concrete.

Potentially deleteriously reactive rock types probably exist in most countries throughout the world. Many natural siliceous rock types are known to have reacted deleteriously with the highly alkaline solutions in concrete. Probably the most commonly used of such aggregates are those that contain non-crystalline or poorly or imperfectly crystalline silica[03-07].

These include opaline and chalcedonic silica that are found in such rocks as chert, flint, siliceous shale, as secondary fillings in voids in, for example, basalt, and as interstitial and interlayer material in rock types such as sandstone.

Deleteriously reactive silica is also present in metamorphic rocks, where it is classified as strained quartz and microcrystalline quartz. In these cases, crystal structures are variously distorted, thus rendering them susceptible to deleterious ASR. This imperfectly crystallized quartz has been recognized as the reactive component of such metamorphic rocks as gneiss, schist, metagraywacke, and quartzite. These rock types are comparatively slowly reactive and are known to have exhibited deleterious reactivity with high-alkali cements only after five or more years of service.

The other general reactive component of siliceous aggregates is the glassy to cryptocrystalline matrix of volcanic rocks of approximately rhyolitic to andesitic composition. This material constitutes a major proportion of these rock types, and is commonly altered by weathering that facilitates penetration of alkaline solutions into the aggregate particle. Weathered volcanic rock is particularly troublesome in that it has produced ASR-associated distress when used with cements with less than 0.6% equivalent Na_2O.

Obsidian and pumice, which are very dense and very porous volcanic glasses, respectively, also are known to have reacted deleteriously in concrete. Slightly metamorphosed volcanic rocks, such as meta-rhyolite, also have been found to produce expansive ASR.

As demand for concrete increased, in large part to meet the requirements of transportation-related construction, new sources for aggregates were necessarily developed.

Concrete blocks that were cast (1972 – at CESP Laboratory-Ilha Solteira-SP-Brazil) to check the behavior due to the use of different cement-pozzolanic material and aggregates. The block-specimens were observed in between 1972-2012 (Andriolo´s Archive)

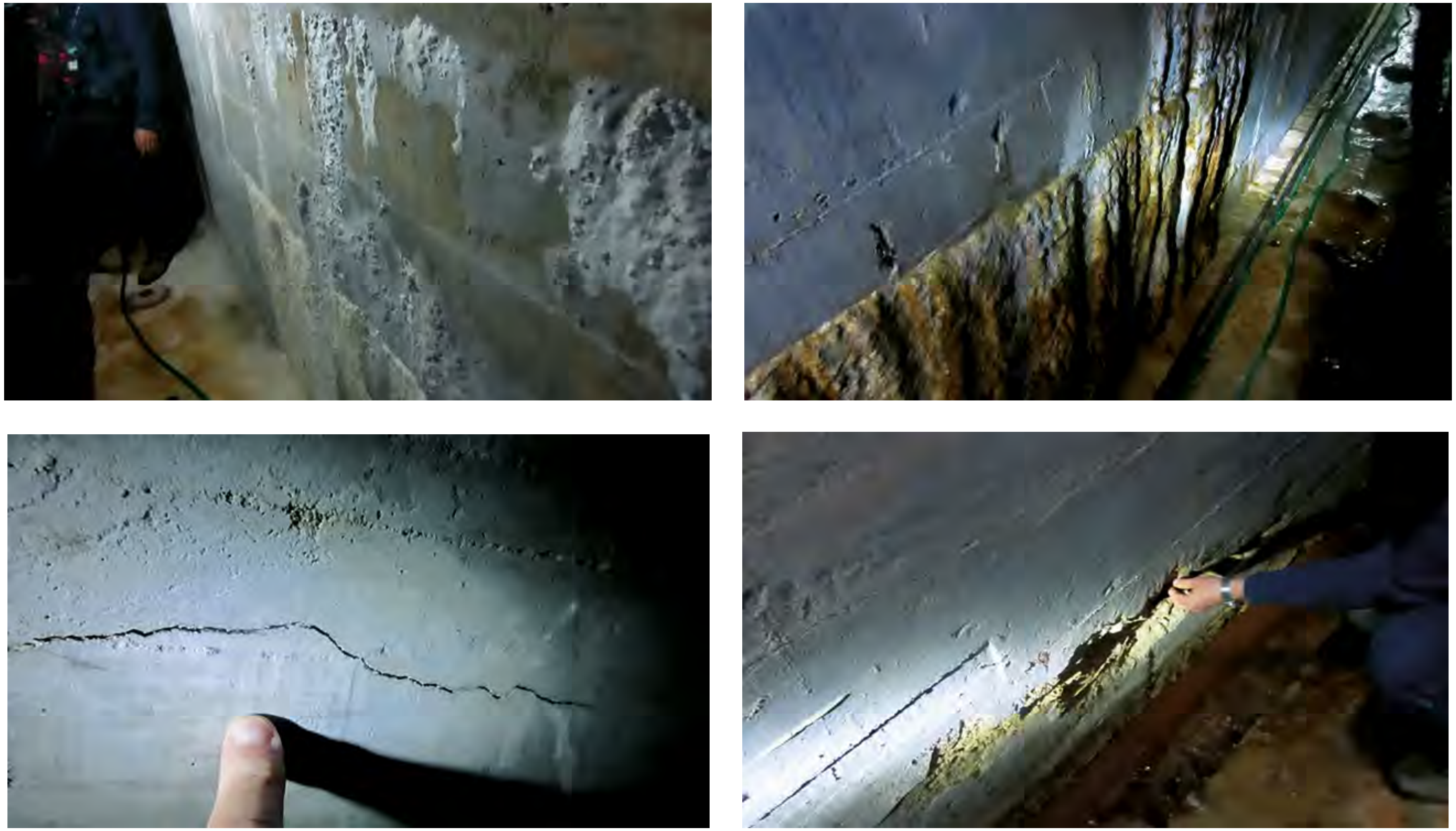
Concrete blocks that were cast (1972 – at CESP Laboratory – Ilha Solteira – SP, Brazil) to check the behavior due to the use of different cement-pozzolanic material and aggregates. Inspection during December, 2021 (Andriolo´s Archive)

Rock piece around the dam, showing quartz

Aspect of the downstream face of the concrete dam

Aspect of the downstream face of the concrete dam

Aspect of the inner part of the dam gallery

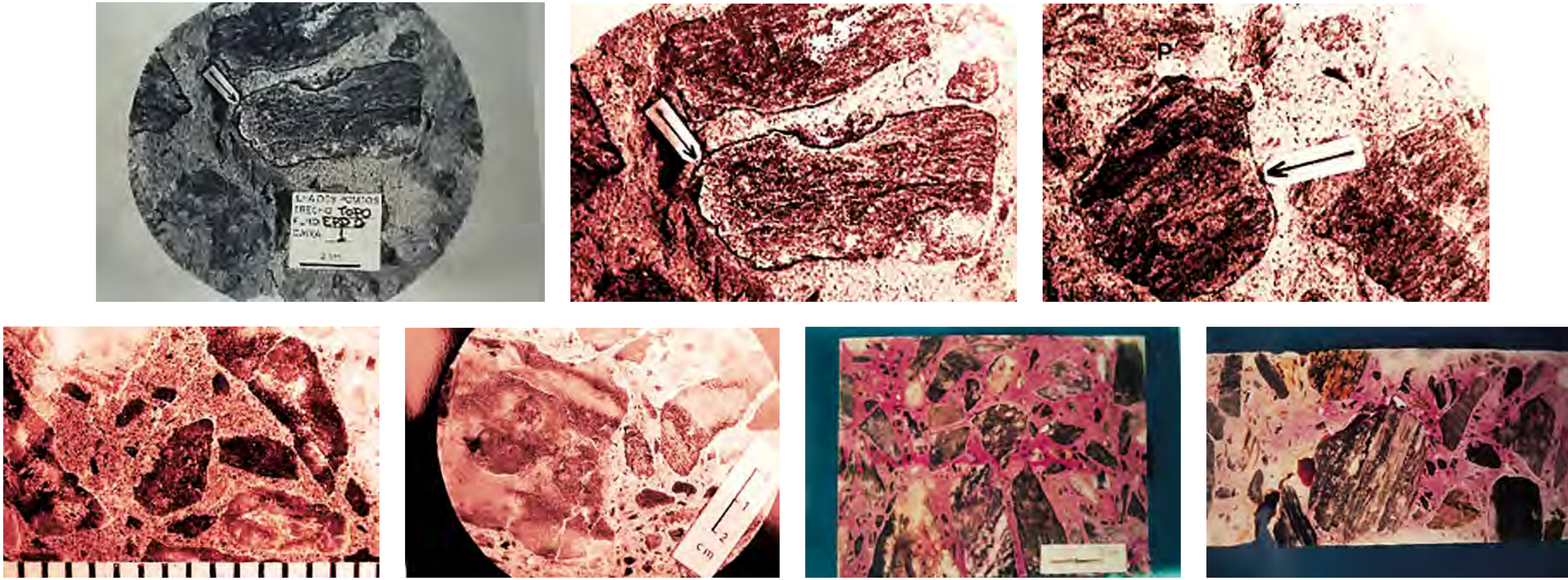


Aspects of the inner part of the dam gallery. Evidence of Alkali Reaction Aggregated, observed inside the gallery of the Ribeirão do Campo Dam-SABESP-SP, Brazil-Built in 1962 (Andriolo´s Archive)

Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.3-A	Ilha dos Pombos	Brazil	1924	1992	[03-10; 03-11]

Technical Information- RAA

Ilha dos Pombos Dam that had been finished by 1924, (Brazil) and had shown RAA expansions (Andriolo´s Archive)



Aspects of the RAA observed on the specimens from drilled cores from the Ilha dos Pombos Dam (Andriolo´s archive)

Alcali Carbonate Aspects: Reactions observed with certain dolomitic rocks are associated with **a**lkali-**c**arbonate **r**eaction (**ACR**). Reactive rocks usually contain larger crystals of dolomite scattered in and surrounded by a fine-grained matrix of calcite and clay. Calcite is one of the mineral forms of calcium carbonate; dolomite is the common name for calcium-magnesium carbonate. ACR is relatively rare because aggregates susceptible to this reaction are usually unsuitable for use in concrete for other reasons — strength potential, etc. Argillaceous dolomitic limestone contains calcite and dolomite with appreciable amounts of clay and can contain small amounts of reactive silica. Alkali reactivity of carbonate rocks is not usually dependent on clay mineral composition. Aggregates have potential for expansive ACR if the following lithological characteristics exist:

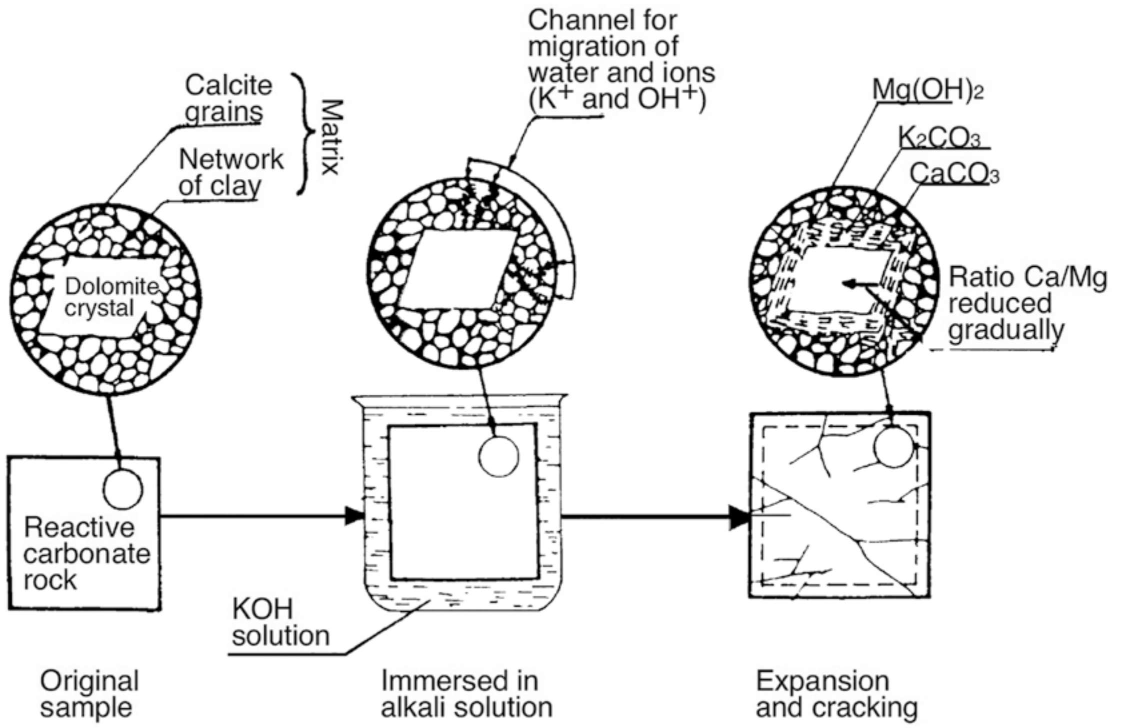
- ⇒ clay content, or insoluble residue content, in the range of 5% to 25%;
- ⇒ dolomite content (percentage in carbonate fraction) in the range of 40% to 60%
- ⇒ interlocking dolomite grains (late expansion);
- ⇒ small size (25 to 30 µm), discrete dolomite crystals (rhombs) suspended in a clay matrix

Expansion may be due to a combination of migration of alkali ions and water molecules into the restricted space of the fine-grained matrix surrounding the dolomite rhomb, migration of these materials into the rhomb, and the growth and rearrangement of the dedolomitization products, especially brucite, which exerts pressures as it crystallizes.

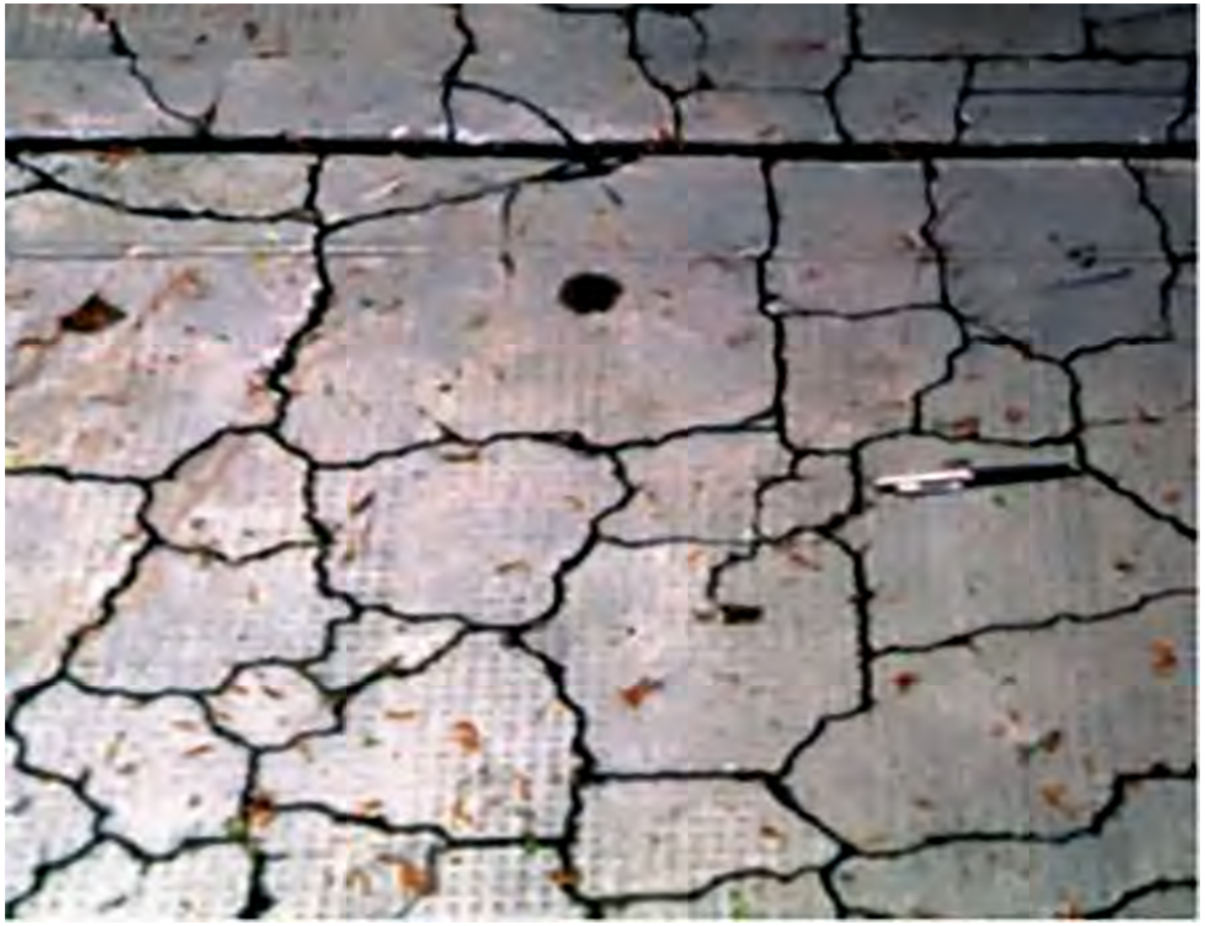
Cracking was due to expansive forces arising from a chemical reaction and expansion of the clay minerals in the aggregate matrix. Other Factors The nominal maximum size of the reactive aggregate influences the amount and extent of reaction.

Alkali-carbonate reaction is also affected by pore solution alkalinity. ACR can occur in a solution with a relatively low pH. As the pH of the pore solution increases, potential for the alkali-carbonate reaction increases.

ACR, like ASR, is a chemical process that can induce physical damage, expansion and cracking of concrete. Information obtained from a site inspection should be evaluated along with testing to determine the destructive mechanism. ACR-affected concrete does not exhibit telltale features to distinctly identify alkali-carbonate reaction as the cause of cracking. The crack pattern will be influenced by restraint conditions and moisture availability.



Schematic diagram of the mechanism of alkali-carbonate reaction. A dolomite crystal combines with alkalis in solution to form brucite, and potassium and calcium carbonates[03-08]



Map cracking pattern caused by ACR[03-08]

Sulfates Aspects: Sulfates in solution in contact with concrete can cause chemical changes to the cement, which can cause significant microstructural effects leading to the weakening of the cement binder (chemical sulfate attack). Sulfate solutions can also cause damage to porous cementitious materials through crystallization and recrystallization (salt attack).

Sulfates and sulfites are ubiquitous in the natural environment and are present from many sources, including gypsum (calcium sulfate) often present as an additive in 'blended' cements which include fly ash and other sources of sulfate. The corrosion often present in the crown (top) of concrete sewers is directly attributable to this process.

Damages caused by sulfide minerals in aggregate are quite rare. In every case, the visible signs were rusty surfaces and pop outs. The first thought was that it is a question about rusty steel bars in the elements. Sulfide-bearing lithologies include:

⇒ Felsic and mafic metavolcanics and intrusive;

⇒ Low-grade sediments (shales, esp. carbonaceous);

⇒ Metasediments-esp. black schists;

⇒ Gneisses of sedimentary origin (paragneiss);

⇒ Lithologies subjected or related to hydrothermal activity

Pyrrhotite is more unstable than pyrite, but is much less common, thus sedimentary pyrite, is also a major concern. Iron sulfide oxidation in presence of high-pH water show that precipitation of ferric iron oxide and iron-hydroxide on sulfide surfaces commonly lead to blocking for further oxidation. This mechanism may be important in presence of high oxygen levels but might not be very relevant for the situation within concrete.

Iron sulfides and their weathering products are the major minerals causing acid rock drainage. Pyrite is by far the most common sulfide and is a common accessory in felsic igneous rocks and sedimentary rocks, especially carboniferous (organic-rich) sediments. Pyrrhotite is the other common sulfide (less common than pyrite), occurring in mafic to ultramafic igneous rocks, in metasedimentary rocks (schists and paragneiss).

In massive sulfide deposits, pyrrhotite is mainly found in the unconformable feeder zone beneath the massive sulfide, whereas pyrite occurs in the massive deposit, in disseminations beside the deposit and in extensive zones and layers distal to the deposit.

Chlorides: Chlorides, particularly calcium chloride, have been used to shorten the setting time of concrete. However, calcium chloride and (to a lesser extent) sodium chloride have been shown to leach calcium hydroxide and cause chemical changes in Portland cement, leading to loss of strength, as well as attacking the steel reinforcement present in most concrete. Chloride is a major factor affecting the corrosion of steel reinforcements in concrete. It can mainly be divided into internal chloride, which is added during the manufacturing process, and external chloride, which penetrates through the concrete during its service period.

Delayed Ettringite Formation-D.E.F.: Delayed ettringite formation (DEF) is a phenomenon in which ettringite is generated and accumulates in concrete after hardening, eventually leading to expansion and destruction of the concrete. The concrete, if cured at high temperature in the initial stage, the formation of ettringite is suppressed and mono-sulphate are formed. When the temperature is lowered during the later stage, the mono-sulfate is converted back to ettringite and absorbs water. This leads to swelling of concrete and possible cracking. The distinct feature of DEF is map cracking**.**

In dam works the D.E.F. is not very common, unless it can occur in structural elements that require high strengths (Power House, Spillways, Precast elements that were cured by thermal curing process), which have used high levels of cement and therefore have high gradient of thermal evolution

Leaching: When water flows through cracks present in concrete, water may dissolve various minerals present in the hardened cement paste or in the aggregates, if the solution is unsaturated with respect to them. Dissolved ions, such as calcium (Ca^{2+}), are leached out and transported in solution some distance. If the physico-chemical conditions prevailing in the seeping water evolve with distance along the water path and water becomes supersaturated with respect to certain minerals, they can further precipitate, making calthemite deposits (predominately calcium carbonate) inside the cracks, or at the concrete outer surface. This process can cause the self-healing of fractures in particular conditions.

Leaching observed in the downstream face of a Dam and in the inner part of the dam gallery-(Andriolo´s archive)

Decalcification: Within set concrete there remains some free "calcium hydroxide" ($Ca(OH)_2$), which can further dissociate to form Ca^{2+} and hydroxide (OH^-) ions". Any water which finds a seepage path through micro cracks and air voids present in concrete, will readily carry the ($Ca(OH)_2$) and Ca^{2+} to the underside of the structure where leachate solution contacts the atmosphere. Carbon dioxide (CO_2) from the atmosphere readily diffuses into the leachate and causes a chemical reaction, which precipitates (deposits) calcium carbonate ($CaCO_3$) on the outside of the concrete structure.

Leaching observed in the downstream face of a Dam and in the inner part of the dam gallery (Andriolo´s archive)

Pop-out due to corrosion of the reinforcement (Andriolo´s Archive)

Geological formations of endogenous and metamorphic host rocks with inclusions of pyrrhotite bands may be found in Nature. In some cases, these rocks have been used to produce aggregates that were then incorporated in the dosage of concrete. Elements cast with this material have shown severe cracking caused by an expansive phenomenon known as **i**nternal **s**ulfate **a**ttack (***ISA***). In such phenomenon, the particles of pyrrhotite included in the aggregates oxidize, producing iron hydroxides and sulfates[03-09]. The latter reacts with calcium and the aluminates from the cement paste to form expansive secondary ettringite.

Several examples of structures affected by the presence of this harmful material are found in the literature. Some of these studies remark the important economic, social and risk related repercussions of using the contaminated rocks in concrete. Ahead shows the case of the downstream face and the galleries of the Graus Dam (Spain), which shows severe cracking and movements due to the ***ISA***.

3.4.4 Damages examples

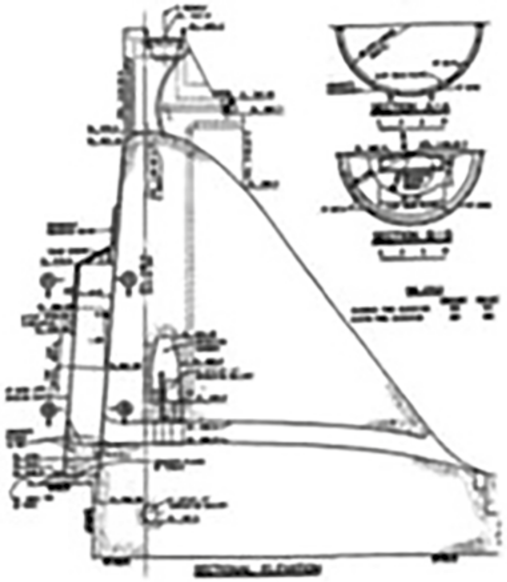
In this item can be seen some occurrences of damage in dams due to materials, as follows.

Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.4-A	Sutton	USA	1961	1980	[03-12 to 03-14]

Technical Information – Water Quality

Construction, operation, and maintenance of the structure adversely affected the aquatic environment downstream of the dam. The problems were primarily caused by depressed water temperatures and increased turbidity resulting from the outflow of water from the lowest stratum of the reservoir. Moreover, winter drawdown and seasonal pool elevations interfered with lake fishery and with water recreation in general. The obvious solution to the problem of downstream water temperature and turbidity was to relocate the intake to permit the outflow of warmer, less turbid water from the highest stratum of the reservoir. Making this change required the construction of a high-level intake connected to one of the sluices of the dam.

An inlet-with-bulkhead was installed below the top of the structure to permit the passage of water during low lake levels. Finally, the top of the structure was capped with concrete. The concrete cap would improve flow, provide support for the trashrack, and provide an aesthetically finished appearance.



Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.4-B	Sasanagare	Japan	1924	1984	[03-15]

Technical Information-Aging

Deterioration occurred at all parts of the dam, particularly the buttresses and slabs. A preliminary repair was made but this only revealed temporary improvement to the extent that in 1965, concrete began to fall off from the surface of the dam. In 1983-1984, after a careful aging survey, the buttresses were overlaid at both sides by 700 mm to 1100 mm thick concrete layers and the upstream slab by 300 mm to 700 mm thick concrete. The whole dam was overlaid by new concrete.

Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.4-C	Wissota	USA	1918	1990	[03-16]

Technical Information – Freeze-Thaw

The sloping surface of the north and south hollow dams were affected by freeze-thaw actions. Deterioration of concrete was most severe at the buttress-slab, cold-joint junctions, where joint filler materials apparently failed, and near the edge of previous repairs. Rapid deterioration developed due to seepage through cracks and joints on the upstream slab, which saturated the downstream face. The dam was declared to be of high hazard and rehabilitation was carried out. The remedial measures included installing steel cofferdam sheeting along the downstream buttress faces down to bedrock; removal of soils between sheeting and slab face; cleaning of rock contact surfaces and concrete, and mass concrete pours for entire height.

Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.4-D	Lago Nero	Italy	1928	1928	[03-17 to 03-19]

Technical Information-Freeze-Thaw

Due to the deterioration (cycles of freezing and thawing) and leakage of the face of the dam, it was repaired using PVC geomembrane.




Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.4-E	Wimbleball	UK	1977	2003	[03-20]

Technical Information- Pyrite damage

The concrete surface of the dam has suffered from spalling. Even towards the end of the construction of the dam, small pop-outs were observed on the inside concrete faces of the dam parapet walls. These were 10 mm in diameter with soft dark aggregate (pyrites-rich shale) exposed and a rust-colored stain below. Then the reinforced concrete valve tower and access bridge only need to be protected. The work involved breaking out all patches of soft or reactive aggregate near the surface and patching with a cementitious mortar, then coating the whole surface to reduce the quantity of oxygenated water penetrating the surface.

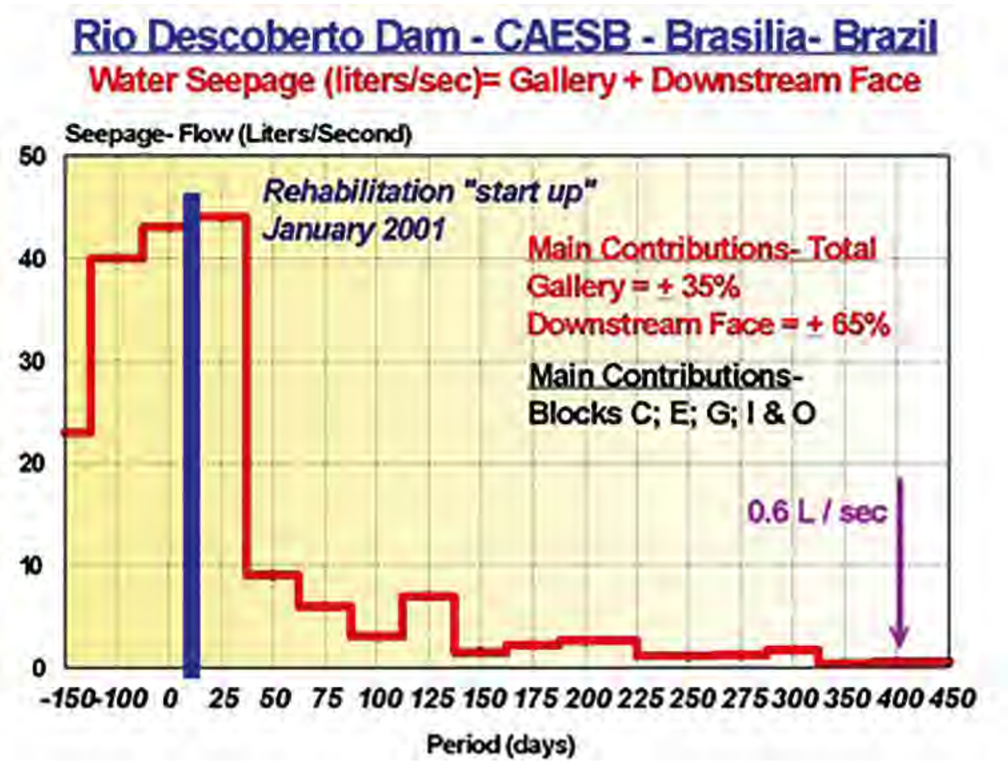
Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.4-F	Rio Descoberto	Brazil	1974	1999-200	[03-21]

Technical Information – Pyrite damage

Some leaching water started to be observed at the downstream face since few years after the end of the construction, and filling the reservoir. Some remedial works were adopted in different periods, adopting grouting and drainage systems, with no remarkable success. After several analyses, the problem origin diagnosis was the presence of pyrite on the concrete aggregate combined with the acidic water action.

A diaphragm wall was adopted as the rehabilitation methodology. This “In the wet” technique, permitted the water supply for Brasília (1.5 million people) to be not interrupted or affected during the rehabilitation works. The reservoir’s water quality was continuously controlled during the process, and kept at the same level.

The process concept is based on the insert of a waterproof secant pile diaphragm wall inside the body of the dam, 70 cm far from the upstream face. The diaphragm is performed from the dam crest without any interference with the reservoir water, need of water level drop or intake obstruction. The secant bores are performed in sequence by drilling equipment with the use of a special guiding template.


Rio Descoberto Dam - CAESB - Brasilia- Brazil
Water Seepage (liters/sec)= Gallery + Downstream Face
Seepage- Flow (Liters/Second)
Rehabilitation "start up"
January 2001
Main Contributions- Total
Gallery = + 35%
Downstream Face = + 65%
Main Contributions-
Blocks C; E; G; I & O
0.6 L / sec
50
40
30
20
10
0
-150-100 0 25 50 75 100 125 150 175 200 225 250 275 300 350 400 450
Period (days)

Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.4.4-G	Pracana	Portugal	1951	1985	[03-17; 03-22]

Technical Information – Alkali Silica Reaction Damage

Comprehensive rehabilitation works followed the confirmed presence of ASR. This included treatment of foundations, injection of a new grouting curtain, construction of a new foundation beam and of two sets of concrete struts between the buttresses on the downstream face.

Pracana Dam shows extensive cracking, owing to an expansive process, during the initial 25 years of operation. Important repair works were developed, including the treatment of the cracks by grouting using cement and epoxy resin. The joints between the diamond heads of the buttresses were treated as well and the upstream face was sealed with a PVC geomembrane All the cracks were mapped and strengthened by grouting.

A new separate spillway and a new water intake were constructed. A drained PVC geomembrane was installed on the upstream face not only to inhibit the flow of water feeding the reaction but also to reduce the uplift pressure in the horizontal cracks in the dam body. The PVC membrane was connected to the new foundation plinth to achieve continuity between it and the new grout curtain.



Case	Identification	Country	Finished	Materials and Studies – Rehabilitation	References
3.4.4-H	Drum Afterbay	USA	1924	1966	[03-23]

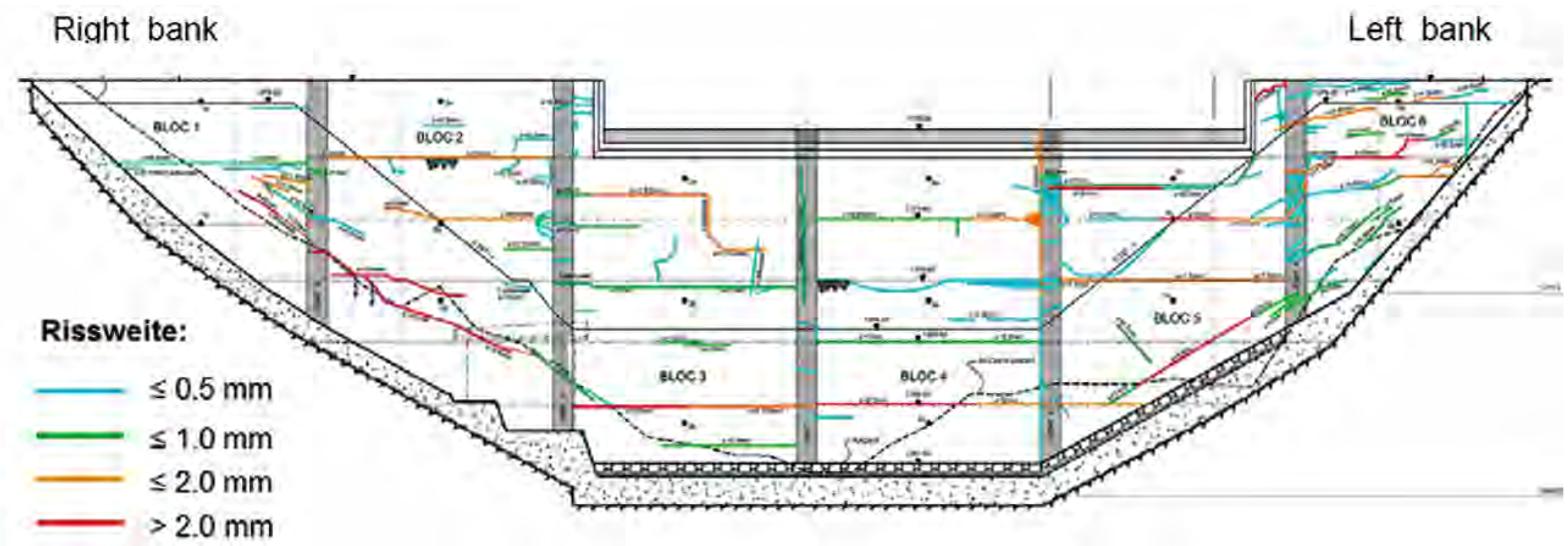
Technical Information- Reconstructed due to Pyrite and ASR

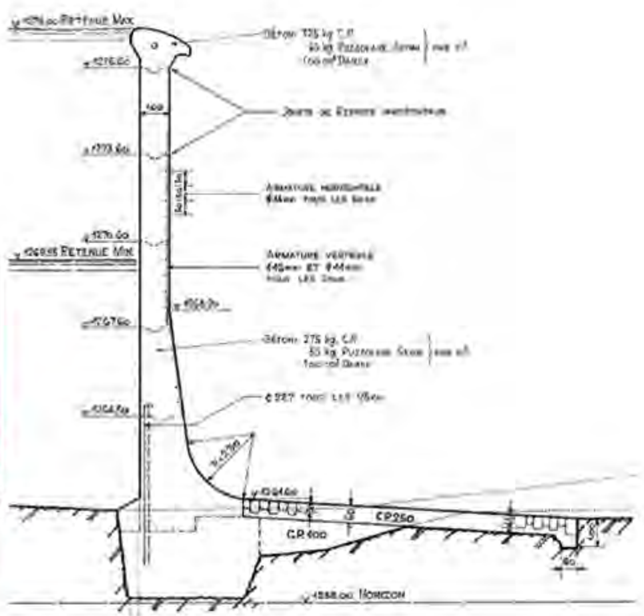
It exhibited alkali aggregate reaction through interaction of pyrite in the schist aggregate with the cement paste. The dam was replaced in 1966.

Case	Identification	Country	Finished	Materials and Studies – Rehabilitation	References
3.4.4-I	Sera	Swiss	1952	2006	[03-09]

Technical Information-Expansion due to Pyrite action

Concerning the concrete expansion in the old Sera Dam, it can see the fissure pattern as structural cracks. The pyrrhotite is potentially unstable in concrete. Upon the exposure to oxygen from air and humidity, a pyrrhotite can oxidize and result in ferrous ions and sulfuric acid. The ferrous ions oxidize further to rust products such as ferrous-hydroxide. Whereas the sulfuric acid will upon reaction with the cement paste result in sulfate containing phases such as gypsum or ettringite, and in the presence of carbonates potentially in thaumasite. The rust products, as well as the formation of ettringite and thaumasite can lead to expansion, cracking and finally disintegration of the concrete.

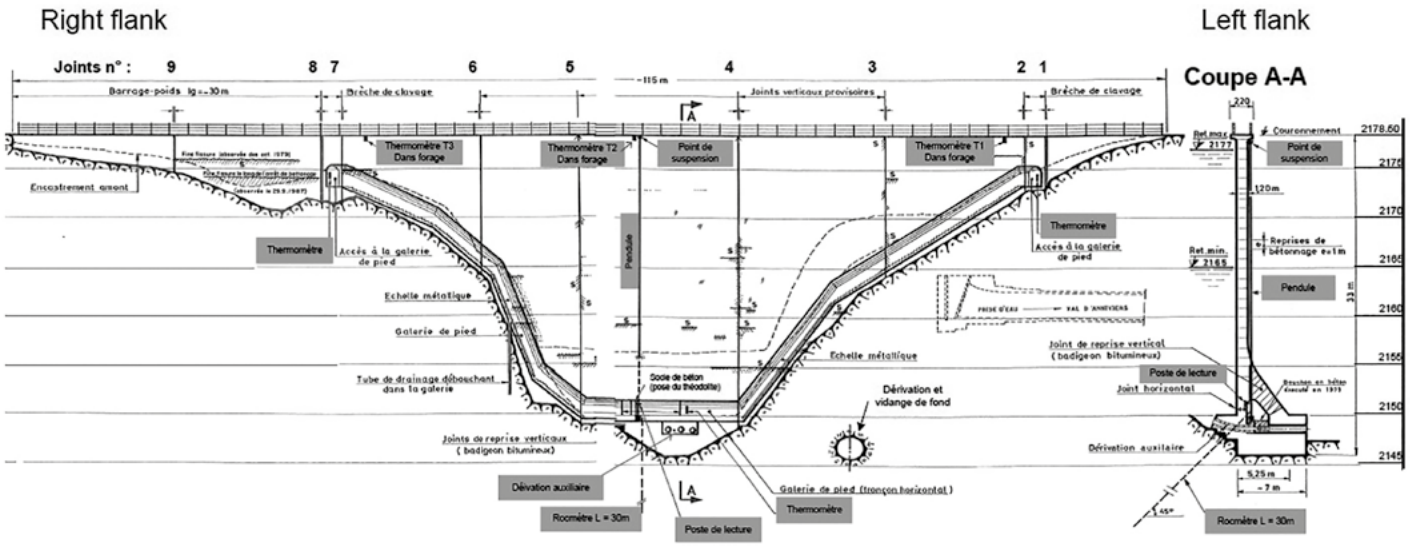




Demolition of the first dam and downstream view of the new Sera dam

Case	Identification	Country	Finished	Materials and Studies – Rehabilitation	References
3.4.4-J	Tourtemagne	Swiss	1958	Pre-stressed tendons – 1962	[03-09]

Technical Information-Expansion due to Pyrite Damage



Downstream view of the dam-Vertical cross-section.

3.5 Cementitious Materials

3.5.1 Actual Aspects and Tendencies

Use of certain wastes as alternative fuels in the cement kiln eliminates wastes that would otherwise be incinerated or placed in landfills. Waste materials that have been used by the cement industry as alternative fuels include petroleum coke, used tires, rubber, paper waste, waste oils, sewage sludge, plastics, and spent solvent. Apart from recovering the thermal energy of the waste, combustion of these waste materials leads to significant reductions in CO_2 emissions.

Since the first standardization of cements, around 1930/1940, at the time of the construction of the Hoover-USA Dam, the Standards have been adjusted to have technical options and environmental mitigation objectives.

At the global level, there is practically a tendency to use two sets of Standards[03-03]:

⇒ one, more widely used, and longest - American Society for Testing and Materials (ASTM), and

⇒ another, more recent, arising from the European Community-Euro Code, since 2000.

BRITISH STANDARD

BS EN 197-1:2000
Incorporating amendments nos. 1 and 2

Cement —

Part 1: Composition, specifications and conformity criteria for common cements

ASTM **Designation: C 150 – 00**

Standard Specification for Portland Cement[1]

ASTM **Designation: C 595 – 00a**[ε1]

Standard Specification for Blended Hydraulic Cements[1]

ASTM **Designation: C 1157 – 00a**

Standard Performance Specification for Hydraulic Cement[1]

Supplementary cementing material including waste products from other industries, such as fly ash and ground granulated blast furnace slag, can be ground with clinker to produce blended cement. Increasing the use of these materials and thus reducing the cement content represents a technically proven approach to reducing greenhouse gas and air pollutant emissions. Limestone filler is being increasingly used in Europe in the clinkering and grinding phases of Portland cement production. These materials also have the added advantages of reducing energy consumption, using materials otherwise destined for landfills, increasing plant capacity without installing new kilns, and improved concrete performance. However, this tendency of replacing **OPC** - **O**rdinary **P**ortland **C**ement - by blended cements requires a deep analysis related to **where the project is located** and how far the project is the cement supplier.

3.5.2 Cement Types

As in many countries with standards that were developed based on the standard provided above, it is important to consider:

⇒ The differences in concepts of some types between both designations. For instance, Type III ASTM means high early strength, whereas Type III CEM means blast furnace slag cement;

⇒ The same differences occur between Type IV ASTM and IV CEM and Type V ASTM and V CEM;

⇒ Other considerations are present when the main contents are being analyzed; and

⇒ Many of the required characteristics (physical, chemical, soundness, and durability) differ due to the above considerations.

✓ ***Thus, it is necessary to understand the differences between the requested indexes in each standard to adopt the values.***

Standard	Cement Type	Concept/Definition
	I	For use when special properties specified for any other type are not required.
ASTM	IA	Air-entraining cement for the same uses as Type I, where air entrainment is desired.
	II	For general use, namely, when moderate sulfate resistance or moderate heat of hydration is desired.
C	IIA	Air entraining cement for the same uses as Type II, where air entrainment is desired.
	III	For use when high early strength is desired.
	IIIA	Air entraining cement for the same uses as Type III, where air entrainment is desired.
150	IV	For use when a low heat of hydration is desired.
	V	For use when high sulfate resistance is desired.
	I S	Portland blast furnace slag cement (Slag - 25% to 70%)
ASTM	I S A	Air-entraining Portland blast furnace slag cement
	I S M	Slag-modified Portland cement (Slag - < 25%)
	I S M A	Air-entraining slag-modified Portland cement
	I P	Pozzolan-modified Portland cement (pozzolan – 15% to 40%)
	I P A	Air-entraining Portland pozzolan cement
	I P M	Pozzolan-modified Portland cement (Pozzolan – <15%)
C	I P M A	Air-entraining pozzolan-modified Portland cement
	I S MS	Moderate sulfate-resistant Portland blast furnace slag cement
	I P MS	Moderate sulfate-resistant pozzolan-modified Portland cement
	S	Slag cement (for use in combination with Portland cement with lime)
	SA	Air-entraining slag-modified cement
	P	Pozzolan-modified Portland cement
595	PA	Air-entraining pozzolan-modified Portland cement
	MH; LH	Moderate heat of hydration; low heat of hydration

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass [a]) Main constituents: Clinker K	Blast-furnace slag S	Silica fume D [b]	Pozzolana natural P	Pozzolana natural calcined Q	Fly ash siliceous V	Fly ash calcareous W	Burnt shale T	Limestone L	Limestone LL	Minor additional constituents
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0 to 5
CEM II	Portland-slag cement	CEM II/A-S	80 to 94	6 to 20	–	–	–	–	–	–	–	–	0 to 5
		CEM II/B-S	65 to 79	21 to 35	–	–	–	–	–	–	–	–	0 to 5
	Portland-silica fume cement	CEM II/A-D	90 to 94	–	6 to 10	–	–	–	–	–	–	–	0 to 5
	Portland-pozzolana cement	CEM II/A-P	80 to 94	–	–	6 to 20	–	–	–	–	–	–	0 to 5
		CEM II/B-P	65 to 79	–	–	21 to 35	–	–	–	–	–	–	0 to 5
		CEM II/A-Q	80 to 94	–	–	–	6 to 20	–	–	–	–	–	0 to 5
		CEM II/B-Q	65 to 79	–	–	–	21 to 35	–	–	–	–	–	0 to 5
	Portland-fly ash cement	CEM II/A-V	80 to 94	–	–	–	–	6 to 20	–	–	–	–	0 to 5
		CEM II/B-V	65 to 79	–	–	–	–	21 to 35	–	–	–	–	0 to 5
		CEM II/A-W	80 to 94	–	–	–	–	–	6 to 20	–	–	–	0 to 5
		CEM II/B-W	65 to 79	–	–	–	–	–	21 to 35	–	–	–	0 to 5
	Portland-burnt shale cement	CEM II/A-T	80 to 94	–	–	–	–	–	–	6 to 20	–	–	0 to 5
		CEM II/B-T	65 to 79	–	–	–	–	–	–	21 to 35	–	–	0 to 5
	Portland-limestone cement	CEM II/A-L	80 to 94	–	–	–	–	–	–	–	6 to 20	–	0 to 5
		CEM II/B-L	65 to 79	–	–	–	–	–	–	–	21 to 35	–	0 to 5
		CEM II/A-LL	80 to 94	–	–	–	–	–	–	–	–	6 to 20	0 to 5
		CEM II/B-LL	65 to 79	–	–	–	–	–	–	–	–	21 to 35	0 to 5
	Portland-composite cement [c]	CEM II/A-M	80 to 94	<-------- 6 to 20 -------->									0 to 5
		CEM II/B-M	65 to 79	<-------- 21 to 35 -------->									0 to 5
CEM III	Blastfurnace cement	CEM III/A	35 to 64	36 to 65	–	–	–	–	–	–	–	–	0 to 5
		CEM III/B	20 to 34	66 to 80	–	–	–	–	–	–	–	–	0 to 5
		CEM III/C	5 to 19	81 to 95	–	–	–	–	–	–	–	–	0 to 5
CEM IV	Pozzolanic cement [c]	CEM IV/A	65 to 89	–	<-------- 11 to 35 -------->					–	–	–	0 to 5
		CEM IV/B	45 to 64	–	<-------- 36 to 55 -------->					–	–	–	0 to 5
CEM V	Composite cement [c]	CEM V/A	40 to 64	18 to 30	–	<---- 18 to 30 ---->			–	–	–	–	0 to 5
		CEM V/B	20 to 38	31 to 50	–	<---- 31 to 50 ---->			–	–	–	–	0 to 5

[a] The values in the table refer to the sum of the main and minor additional constituents.
[b] The proportion of silica fume is limited to 10 %.
[c] In Portland-composite cements CEM II/A-M and CEM II/B-M, in Pozzolanic cements CEM IV/A and CEM IV/B and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement (for example see clause 8).

Portland cement blends are often available as inter-ground mixtures from cement manufacturers, but similar formulations are often also mixed from the ground components at the concrete mixing plant.

Portland blast furnace cement contains up to 70% ground granulated blast furnace slag, with the remainder consisting of Portland clinker and a small amount of gypsum. All compositions produce high ultimate strength, but as the slag content is increased, early strength is reduced, sulfate resistance increases, and heat evolution diminishes.

Portland fly ash cement contains up to 35% fly ash. The fly ash is pozzolanic, and thus, the ultimate strength is maintained. Early strength can also be maintained because fly ash addition allows for a lower concrete water content. Fly ash can be an economic alternative to OPC when good-quality, low-cost fly ash is available.

Portland pozzolan cement includes fly ash cement (because fly ash is a pozzolan) but also includes cements made from other natural or artificial pozzolans. These cements are often the most common form in countries where volcanic ashes are available (e.g., Italy, Chile, Mexico, Philippines, Turkey).

Portland silica fume cement. The addition of silica fume can yield exceptionally high strength, and cements containing 5-20% silica fume are produced in some instances. However, silica fume is typically added to Portland cement at the concrete mixer.

Pozzolan-lime cements. Mixtures of ground pozzolan and lime are the cements that were used by the Romans.

Pozzolan-lime cements can be found in Roman structures that are still standing (e.g., the Pantheon in Rome).

Pozzolan-lime cements develop strength slowly, but their ultimate strength can be very high. The hydration products that produce strength are essentially the same as the hydration products produced by Portland cement.

Slag-lime cements. Ground granulated blast furnace slag is not hydraulic on its own but is “activated” by addition of alkalis, with lime being the most economic option.

Slag-lime cements are similar to pozzolan lime cements in their properties. Only granulated slag (i.e., water-quenched glassy slag) is effective as a cement component.

Geopolymer cements are produced from mixtures of water-soluble alkali metal silicates and aluminosilicate mineral powders, such as fly ash and metakaolin.

The authors consider it is important to know the characteristics of cements for the concrete works of dams, as cam be summarized:

Chemistry: Clinker is produced by combining lime and silica and combining lime with alumina and iron. If some lime remains uncombined (which almost always occurs), this uncombined lime must be subtracted from the total lime content before the calculation to obtain a more accurate estimate of the proportions of the four main clinker minerals present. For this reason, clinker analysis typically considers uncombined free lime.

The correction for uncombined free lime can be ignored when calculating the potential mineral proportions in a clinker. The calculation will then yield the clinker mineral proportions, if all the lime has combined.

The calculation is simple in principle:

⇒ First, according to the assumed mineral compositions, the ferrite phase is the only mineral containing iron. Thus, the iron content of the clinker fixes the ferrite content.

⇒ Second, the aluminate content is fixed by the total alumina content of the clinker minus the alumina in the ferrite phase. The aluminate content can be calculated because the amount of ferrite phase has been calculated.

⇒ Third, all the silica is assumed to be present as belite, and the next calculation determines the amount of lime needed to form belite from the total silica content of the clinker. There will be a surplus of lime.

⇒ Fourth, the lime surplus is allocated to the belite, converting a portion of the lime to alite.

To adjust the calculation for use with Portland cement, it is necessary to consider what other materials may be present in the cement. If the cement is a mixture of clinker and gypsum only, the calcium bound with the gypsum can be approximately allowed for by deducting (0.7°SO_3) from the total CaO. This adjustment does not allow for any clinker sulfate present as potassium or sodium sulfate, and thus, a small error will be introduced.

A similar adjustment can be carried out for limestone. The limestone content can be estimated by determining the CO_2 content of the cement and by calculating the corresponding CaO. If either slag or fly ash is present, the formula could be adjusted to account for the slag or fly ash, but the slag or ash composition would need to be known accurately; this adjustment is not normally made in practice.

The values obtained above may be treated as "potential" values, which do not account for the presence of any free lime; alternatively, Compared to OPC, the low-heat cement has a higher proportion of C_2S, whereas the rapidly hardening cement has a higher C_3S content and fineness. Some standards classify OPC into three different strength grades, which are primarily achieved by differences in C_3S contents and fineness.

However, the long-term strength of concrete does not depend significantly on the grade of cement. Only the strengthening rate of concrete is faster for the higher-grade cements.

the values can be modified to account for free lime. In the latter case, the percentage of free lime is deducted from the percentage of CaO (C) before the percentage of CaO (C) is used in the calculation of the percentage of C_3S.

Hydration:

⇒ **Tricalcium silicate (C_3S)**: Hydrates and hardens rapidly and is largely responsible for the initial set and early strength. Portland cements with higher percentages of C_3S will exhibit higher early strength.

⇒ **Dicalcium silicate (C_2S)**: Hydrates and hardens slowly and is largely responsible for strength increases beyond one week.

- ⇒ **Tricalcium aluminate (C_3A)**: Hydrates and hardens the quickest. Liberates a large amount of heat almost immediately and contributes to the early strength to some extent. Gypsum is added to Portland cement to retard C_3A hydration. Without gypsum, C_3A hydration would cause Portland cement to set almost immediately after adding water.
- ⇒ **Tetracalcium aluminoferrite (C_4AF)**: Hydrates rapidly but contributes little to strength. Its use allows lower kiln temperatures in Portland cement manufacturing. Most Portland cement color effects are due to C_4AF.

Portland cements are commonly characterized by their physical properties for quality control purposes. Their physical properties can be used to classify and compare with each selected standard specification for Portland cement. The tests are typically performed on "neat" cement pastes; that is, the tests include only Portland cement and water. Neat cement pastes are typically difficult to handle and test, and thus, they introduce more variability to the results. Cements may also perform differently when used in a "mortar" (cement, water, and sand). Over time, mortar tests have been found to provide a better indication of cement quality, however, the sand must be carefully specified.

Specific Gravity: Specific gravity is typically used in mixture proportioning calculations. The specific gravity of Portland cement is approximately 3.15, whereas the specific gravity of Portland blast furnace slag and pozzolan-modified Portland cements may have specific gravities near 2.90.

Fineness: The fineness, or particle size, of Portland cement affects the hydration rate and thus the rate of strength gain. A smaller particle size results in a greater surface area-to volume ratio and thus a larger area available for water-cement interactions per unit volume. The effects of greater fineness on strength are generally observed during the first seven days. Because hydration starts at the surface of the cement particle, the rate of hydration depends on the fineness of the cement particle, and high fineness is necessary for high early strength.

However, the cost of binding to a higher fineness is considerable, and finer cement deteriorates more rapidly upon exposure to the atmosphere. Furthermore, the paste of finer cement has a more standard consistency than cement with lower fineness.

Setting and Hardening of Cement: When Portland cement is mixed with water, a paste is formed that passes, i.e., that becomes firm and then hardens. Therefore, setting is known as solidification and hardening with increasing strength. Setting and hardening occur due to hydration, which occurs between the cement and water.

The period of setting is divided into two parts: the initial setting and final setting. The setting is accomplished by temperature changes in the cement paste. The initial setting corresponds to a rapid increase in temperature, and the final setting corresponds to the peak temperature.

The abnormal premature stiffening of cement within in a few minutes of mixing with water is called false setting. False setting is typically due to the dehydration of gypsum when inter-ground with clinker when the clinker is too hot. After the cement paste has undergone final setting, the cement further increases rigidity and strength. This last process is hardening. Setting typically occurs within a few hours (or even minutes), whereas hardening may proceed for months (or years).

Setting Time: The setting time of cement paste is affected by a number of items, including the cement fineness, water-to-cement ratio, chemical content (particularly gypsum content), and admixtures. Setting tests are used to characterize how a particular cement paste set.

For construction purposes, the initial set must not be too early and the final set must not be too late. Additionally, setting times provide some indication of whether cement is undergoing normal hydration. The two setting times are defined below:

⇒ ***Initial setting***. Occurs when the paste begins to stiffen considerably.

⇒ ***Final setting***. Occurs when the cement has hardened to the point at which the cement can sustain a certain load.

These times are arbitrary points used to characterize cement; they do not have any fundamental chemical significance.

Strength: The mechanical strength of hardened cement is the property of the material required for structural use. Strength tests are not performed on a cement paste because of molding difficulties. Cement and mortar of prescribed proportions with specified material under controlled conditions are used to determine the strength of cement.

Several types of strength tests, including direct tension tests, direct compression tests, and direct flexure tests, can be used because cement paste is considerably stronger in compression than in tension. These strengths can be affected by a number of items, including the water-to-cement ratio, cement-to-fine aggregate ratio, type and grading of fine aggregate, manner of mixing and molding the specimens, curing conditions, size and shape of the specimens, moisture content at the time of the test, loading conditions, and age. Because cement gains strength over time, the time at which a strength test is to be conducted must be specified.

Heat of Hydration: The heat of hydration is the heat generated when water and Portland cement react. Heat of hydration is influenced most by the proportion of C_3S and C_3A in the cement, but also by the water to cement ratio, fineness, and curing temperature. As each of these factors is increased, heat of hydration increases. In large mass concrete structures such as gravity dams, hydration heat is produced significantly faster than it can be dissipated (especially in the center of large concrete masses), which can create high temperatures in the center of these large concrete masses that, in turn, may cause undesirable stresses as the concrete cools to ambient temperature. Conversely, the heat of hydration can help maintain favorable curing temperatures during winter.

Soundness: It is essential that the cement after setting shall not undergo any appreciable change in volume because changes in volume after setting of cement cause cracks, undue expansion, and thus disintegration of concrete. Unsoundness in cement may be due to any of the following reasons:

⇒ An excess of lime present in the cement;

⇒ Inadequate burning of the cement;

⇒ Insufficient fineness of grinding or non-uniform mixing of raw materials;

⇒ An excessive proportion of magnesium content in the cement;

⇒ An excessive calcium sulfate content in the cement.

Accelerated tests are required to detect unsoundness in cement before using the cement in a project because unsoundness in cement cannot be observed for a considerable period of time. When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion. This destructive expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). Portland cement specifications typically limit magnesia content and expansion.

3.6 Additives-Admixtures

3.6.1 Understanding

Additive, agent and admixture are general terms for a material that may be used as either an addition to cement or an admixture in concrete.

Mineral Additives are fine solids used to improve concrete workability and durability. They provide additional cementing and concrete properties or effects. They are also referred to as '***Supplementary Cementing Materials***'. Additives are used when special performance is required, such as increased strength, reduced water demand, impermeability, low heat of hydration, improved durability, correction of deficiencies in aggregate gradation (as fillers), etc.

The replacement of cement provides cost and energy savings; the energy required to process additives is also much lower than that for cement. Environmental damage and pollution are minimized with the use of these by-products; approximately 6 to 7% of the total CO_2 emissions occur from the production of cement. Additive usage depends on supply and demand as well as market potential and attitudes.

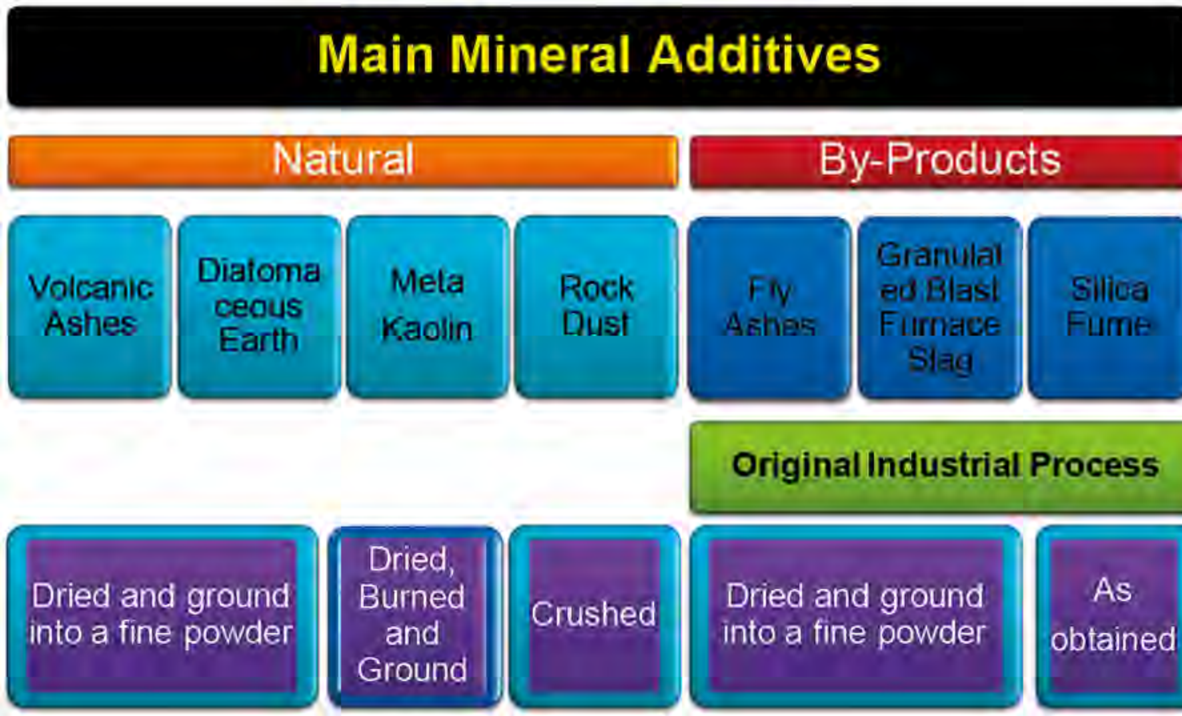
3.6.2 Mineral Additives

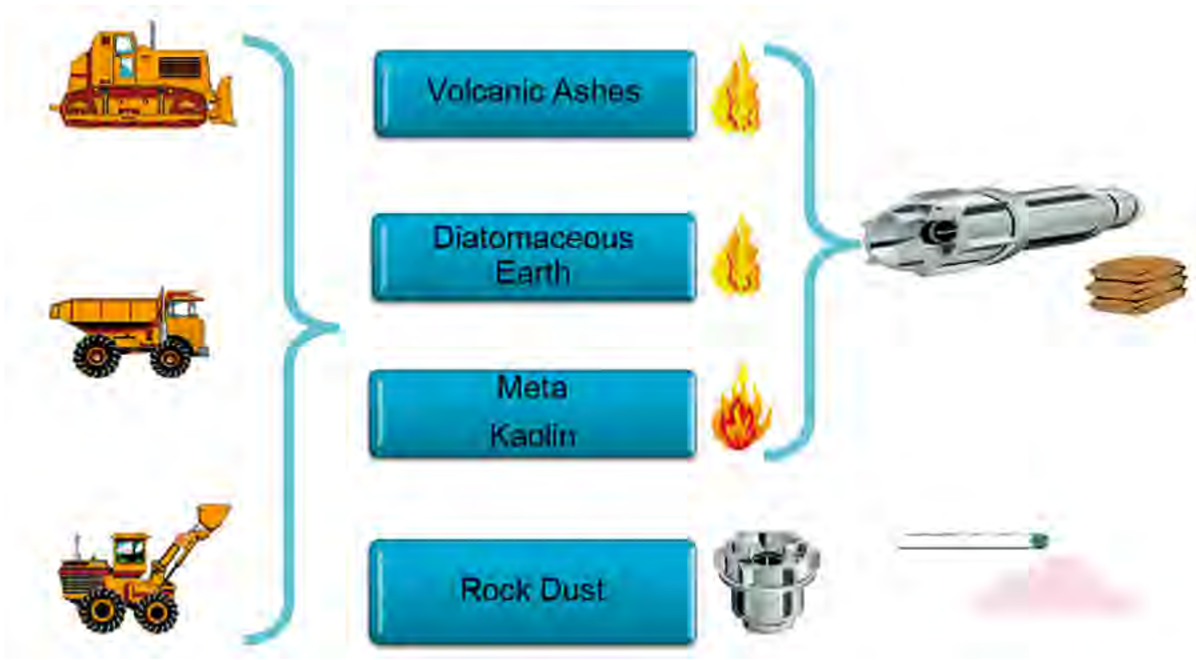
Mineral admixtures are used to improve concrete workability and durability and to harden concrete. This can be accomplished by the introduction of finely ground minerals, which are generally divided into the following three groups:

⇒ ***Materials of Low Reactivity-***Materials that improve the workability of concrete that is deficient in fine aggregates. Generally, cementitious or pozzolanic materials are preferred because of the additional increase in strength and durability provided.

⇒ ***Cementitious Materials-***Materials that exhibit hydraulic reactions of their own, such as hydraulic limestone or blast-furnace slags, which are the most common admixtures in this category.

⇒ ***Pozzolanic Materials-***Materials that react with calcium hydroxide (CH) to form C-S-H. The reaction improves workability and lowers the heat of hydration, producing a more impermeable cement. This reaction is comparable to that of C2S hydration. Type I cement can be turned into Type IV cement with the addition of a pozzolan admixture. Therefore, Type IV cement is rarely manufactured. A low early strength, similar to that observed in Type IV cement, is obtained.





Processes to obtain the Mineral Admixtures – From [03-03]

⇒ **Natural materials** are processed for the sole purpose of producing a pozzolan. Processing usually involves crushing, grinding and size separation; it may also involve thermal activation (some kaolinitic clay).

⇒ **By-product materials** are not the primary products of the industry producing them. Industrial by-products may or may not require additional processing.

Mineral admixtures are finely divided siliceous materials that are added to concrete in relatively large amounts, generally in the range of 20 to 70% by mass of the total cementitious material.

Natural Pozzolans: During explosive volcanic eruptions, the quick cooling of magma, which is primarily composed of aluminum silicates, results in the formation of glass or vitreous phases with disordered structure. All natural pozzolans, except diatomaceous earth, are derived from volcanic rocks and minerals.

Diatomaceous earth is characterized by materials of organic origin. Diatomite is a hydrated amorphous silica composed of skeletal shells from the cell walls of many varieties of microscopic aquatic algae.

Kaolinite is a clay mineral, part of the group of industrial minerals, with the chemical composition Al2Si2O5(OH)4. Metakaolin (MK) is produced from the calcination of kaolinite clay at 740–840 °C.

The crystalline clay loses its structure at this temperature due to the loss of bound water. Burning should be conducted strictly in this range, as recrystallization of the clay occurs above 1000 ˚C.

As a mineral admixture in concrete, metakaolin has a performance comparable to that of silica fume. However, because it is not a by-product, it is expensive to process. Kaolinite is one of the most common minerals. It is mined, as kaolin, in Vietnam, Brazil, Bulgaria, France, the United Kingdom, Iran, Germany, India, Australia, Korea, China, the Czech Republic and the US.

Rock dust, rock powder or rock filler is produced by crushing rocks to a very fine grain size. Rock dust can be produced intentionally or as a by-product from an aggregate processing plant in which the main product is the aggregate, particularly if crushed sand is being produced. In this case, if the rock has a mineralogical composition, it can demonstrate pozzolanic activities. This characteristic is observed in materials from volcanic magma, which are primarily composed of aluminosilicates, resulting in the formation of glass or vitreous phases as previously mentioned.

By-Product Materials

Ashes from coal combustion and rice hull and rice straw crop residues, silica fume from certain metallurgical operations and granulated slag from both ferrous and nonferrous metal industries are major industrial by-products that are suitable for use as mineral admixtures in portland cement concrete.

Fly ash can be divided into two categories that differ in terms of calcium content:

⇒ Ash containing less than 10% CaO is generally produced by the combustion of anthracite and bituminous coals.

⇒ Ash typically containing 15 to 35% analytical CaO is generally produced by the combustion of lignite and subbituminous coals.

⇒ Low-calcium fly ash

- Because of the high percentage of silica and alumina present, this ash consists principally of aluminosilicate glass.
- Partial devitrification of glass in low-lime fly ash accounts for the presence of crystalline aluminosilicates.

  - o Because these crystalline minerals are nonreactive at ordinary temperatures, their presence in large proportions, at the cost of non-crystalline components or glass, tends to reduce the reactivity of the fly ash.

⇒ High-calcium fly ash

  - o This ash is more reactive because most of its calcium is in the form of reactive crystalline compounds.
  - o Greater than 5% carbon in a fly ash that is intended for use as a mineral admixture in concrete is considered undesirable because the cellular particles of carbon tend to increase both the water requirement for a given consistency and the admixture requirement for air entrainment.

Ground-granulated blast-furnace slag (GGBS or **GGBFS)** is produced by quenching molten iron slag (a by-product of iron- and steelmaking) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%) and MgO (1-18%). In general, increasing the CaO content of the slag results in increased slag basicity and an increase in compressive strength. The MgO and $Al_2O_3$3 content follow an identical upward trend to 10 to 12% and 14%, respectively, beyond which no further improvement can be obtained. Several compositional ratios, or hydraulic indices, have been used to correlate slag composition with hydraulic activity; the latter is primarily expressed as the binder compressive strength.

Silica fume is a fine amorphous (non-crystalline) silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon; it is also known as condensed silica fume or microsilica. Silica fume is a by-product of the ferrosilicon industry. It is used as a mineral admixture for concrete, with usage accelerating in the 1980s. The numerous available variants of this highly pozzolanic material as, for example:

⇒ Condensed silica fume, microsilica, silica flour, fume silica (a white fluffy material produced in a flame of hydrogen and oxygen during the vapor phase hydrolysis of chlorosilanes, used as filler in the paint industry);

⇒ Silica gel and precipitated silica.

The particle-size distribution, morphology and surface characteristics of the pozzolan selected for use as a mineral admixture exert a considerable influence on the water requirement, the workability of the fresh concrete and the rate of strength development in the hardened concrete. The chemical composition varies considerably depending on the composition of the pozzolan (natural or by-product), which also affects how the material interacts with the cement.

In a blast furnace, the slag floats on top of the iron and is decanted for separation. Slow cooling of the slag melts results in an unreactive crystalline material consisting of an assemblage of Ca-Al-Mg silicates. The calcination temperature of the metakaolin also affects the behavior of the pozzolan.

The sustainable benefits of pozzolan utilization in cement and concrete include the following:

⇒ First, an economic gain is realized by replacing a substantial portion of portland cement with cheaper natural pozzolans or industrial by-products;

⇒ Second, there is a reduced blended cement environmental cost associated with the greenhouse gases emitted during portland cement production;

⇒ Third, there is an improvement in the durability of the end product;

⇒ Additionally, the increased blending of pozzolans with portland cement interferes minimally with the conventional production process and offers the opportunity to incorporate large amounts of industrial and societal waste into durable construction materials.

All mineral admixtures tend to improve the cohesiveness and workability of fresh concrete, but many do not possess water reducing capabilities;

⇒ For a given consistency of concrete, a large surface area normally increases the water requirement. In this case, a plasticizer must be used;

- ⇒ The workability and flow of concrete are increased due to the spherical shape of the particles, which produces a ball-bearing type effect on the concrete mixture;
- ⇒ In fresh concrete mixtures that show a tendency to bleed or segregate, the incorporation of finely divided particles generally improves workability by reducing the size and volume of voids;
- ⇒ Finer mineral admixtures require a smaller amount of mineral admixture to enhance the cohesiveness and workability of a freshly mixed concrete when a pozzolanic material is used;
- ⇒ Bleeding and segregation are usually reduced for well-proportioned fly ash concrete;
- ⇒ The pumpability is improved;
- ⇒ The cohesiveness of the fresh RCC mix is improved;
- ⇒ The setting time is increased when a pozzolan is used;
- ⇒ More air-entraining admixture is required to entrain air in pozzolan concrete;
- ⇒ The porosity is reduced;
- ⇒ The strength gain in pozzolanic material concrete occurs more slowly than in normal concrete;
- ⇒ The ultimate strength is usually improved when fly ash is used;
- ⇒ The creep and shrinkage in pozzolan concrete are typically higher than in normal concrete because of the increased amount of paste in the concrete;
- ⇒ Expansion during alkali aggregate reactions is reduced by the use of pozzolans;
- ⇒ For properly cured pozzolan concrete, the rate of chloride diffusion is reduced compared to ordinary PC concrete;

⇒ The effects of fly ash on sulfate resistance are inconclusive;

⇒ The potential for thermal cracking is much less than in ordinary PC concrete. The reduction in temperature increase is almost directly proportional to the amount of portland cement replaced by the admixture;

⇒ As a rule of thumb, the total heat of hydration produced by pozzolanic reactions involving mineral admixtures is half as much as the average heat produced by the hydration of portland cement;

⇒ The permeability of concrete plays a fundamental role in determining the rate of deterioration resulting from destructive chemical actions, such as alkali aggregate expansion or attacks by acidic or sulfate solutions;

⇒ Pozzolanic reactions involving mineral admixtures cause pore refinement, which reduces the permeability of concrete. Studies have shown considerable improvement in the chemical durability of concrete containing pozzolans;

⇒ Pozzolanic materials improve concrete's resistance to acidic water, sulfate water and seawater. This is a result of the pozzolanic reaction, which is accompanied by a reduction in permeability and in the calcium hydroxide content of the hydrated product;

⇒ The corrosion rate is reduced by the use of pozzolans because the resulting low permeability leads to a lower availability of moisture and oxygen at the cathodic sites, and the high resistivity inhibits the flow of electrons. The carbonation depth is generally lowered;

⇒ The freeze-thaw resistance is slightly reduced compared to normal concrete, but damage is usually limited because of the extremely low permeability;

⇒ Increased chemical resistance to the ingress and harmful actions of aggressive solutions is one of the primary advantages of pozzolan-blended cements;

⇒ The improved durability of pozzolan-blended binders lengthens the service life of structures and reduces the costly and inconvenient need to replace damaged structures;

⇒ One of the principal reasons for increased durability is the lowered calcium hydroxide content available to take part in deleterious expansive reactions induced, for example, by sulfate attacks;

⇒ The reduced binder permeability inhibits the ingress of harmful ions, such as chlorine or carbonate.

3.6.3 Chemicals Admixtures

In the concrete industry, a *chemical admixture* is any chemical added to concrete to enhance its properties in the fresh or hardened state. Paints and coatings are not considered chemical admixtures. A chemical admixture is an ingredient of concrete or mortar other than water, aggregates, hydraulic cement, pozzolanic materials, or fiber reinforcement that is added to the batch immediately before or during mixing.

Chemical admixtures include general purpose chemicals that reduce the water demand for a given workability ('water reducers'), entrain air in the concrete to provide resistance to freezing and thawing ('air entrainers'), and control the setting time and strength gain rate of the concrete ('accelerators' and 'retarders'). Other chemicals are used for special purposes, e.g., viscosity-modifying agents, shrinkage-reducing chemicals, corrosion-inhibiting admixtures, and alkali-silica reaction-mitigating admixtures.

With the increasing number of types and brands of cement available in the market today, as well as the variety of water-reducing chemicals, the compatibility between these two concrete ingredients is an important issue.

Most users apply a trial-and-error approach for selecting chemical admixtures, often resulting in an unfortunate negative experience and/or low cost-effectiveness; this has resulted in a general bias against using admixtures.

Admixtures can work on the cement/concrete in several ways and can be grouped according to their action as follows:

⇒ Plasticizers (water-reducing agents)

⇒ Super-plasticizers (high-range water reducers)

⇒ Air entrainers
⇒ Accelerators
⇒ Retarders
⇒ Others

Many admixtures provide combinations of properties, for example, acting as plasticizers/retarders or as plasticizers/air entrainers.

Common problems caused by incompatibility between cement and water reducers include a rapid loss of workability, excessive quickening or retardation of setting, and a low rate of strength gain. Often, an incompatibility exists between a particular chemical and a particular batch of the same otherwise compatible cement, indicating that the nature of the problem is complex, thus requiring further research.

Moreover, high-performance concretes, which are currently in wide use, usually incorporate a mineral admixture or filler such as silica fume, fly ash, or limestone powder.

This further complicates the physico-chemical behavior of the cement-based system because these mineral admixtures play an important role in the evolution of the hydration reactions and the availability.

The damage caused by repeated freezing and thawing strongly affects the durability of concrete pavements and the use of concrete in other exterior applications.

Upon investigation, the more durable pavements were found to be slightly less dense, and the cement used had been obtained from mills using beef tallow as a grinding aid during manufacture.

The beef tallow acted as an air-entraining agent, thereby improving the durability of the pavement. After rigorous investigation, air-entrained concrete was specified for climates that experience repeated freezing and thawing.

The quantity added is usually based on the cement content and, for most admixtures, is in the range 0.2 to 2.0% by weight. In terms of active chemical, this equates to less than 0.15% for a typical concrete mix. Even at this low content, the admixtures have a powerful effect and modify the water requirements, setting time, or other properties. The reasons to use admixtures are as follows:

⇒ To increase slump and workability;
⇒ To retard or accelerate initial setting;
⇒ To reduce or prevent shrinkage;
⇒ To modify the rate or capacity for bleeding;
⇒ To reduce segregation;
⇒ To improve pumpability and finishability;
⇒ To retard or reduce heat evolution during early hardening;
⇒ To accelerate the rate of strength development at early stages;
⇒ To increase strength (compressive, tensile, or flexural);
⇒ To increase durability or resistance to severe exposure conditions, including the application of de-icing salts and other chemicals (air-entraining);
⇒ To decrease permeability;
⇒ To control expansion caused by the reaction of alkalis with potentially reactive aggregate constituents;
⇒ To strengthen the bond between the concrete and the steel reinforcement (bonding);
⇒ To strengthen the bond between existing and new concrete;

⇒ To improve impact and abrasion resistance (hardness);

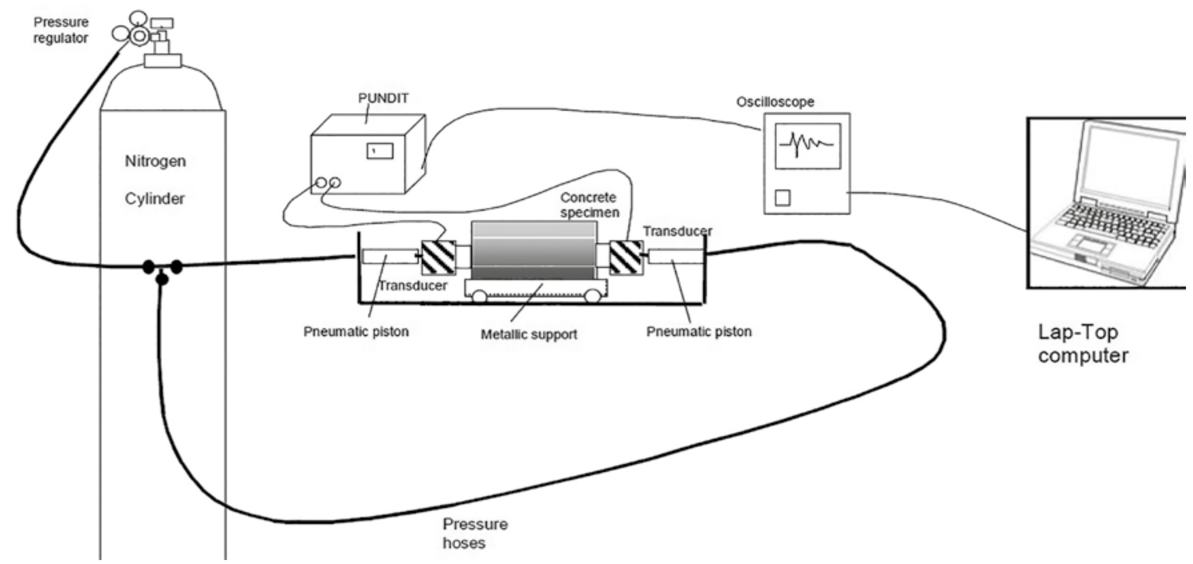
⇒ To inhibit the corrosion of metals embedded in the concrete;

⇒ To produce other effect that are not useful for dam construction (prevent anti-washout effects, create foaming, produce colored concrete, etc.)

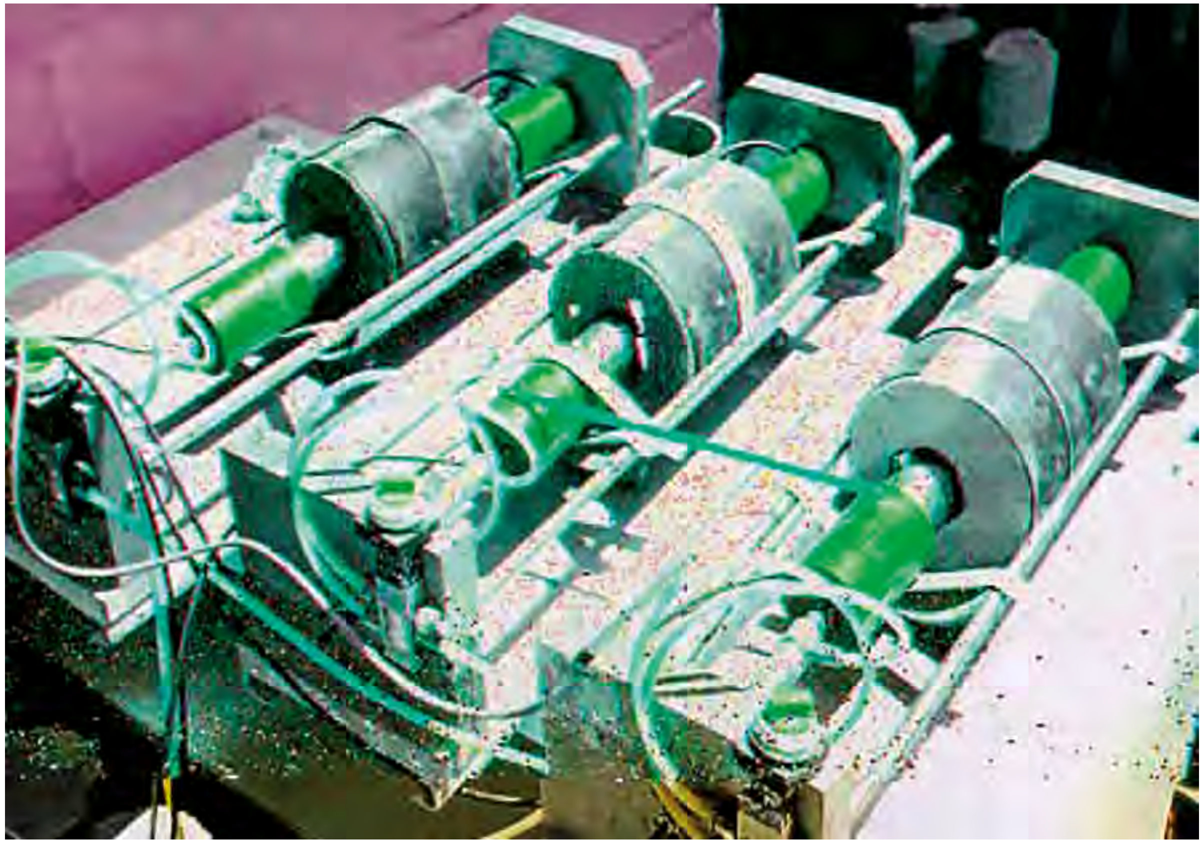
It is important to note that some trends adopted in the RCC (Roller Compacted Concrete) construction methodology have induced the super dosages of Setting Time Retarder agent. This requires care and attention to the compatibility of this use with the adopted cementitious material as well as with the climate of the region (at various times of the year) as well as for the objectives and propositions required.

Some usual standards can help in the understanding and control this aspect, and a new one method of test can give a better control.

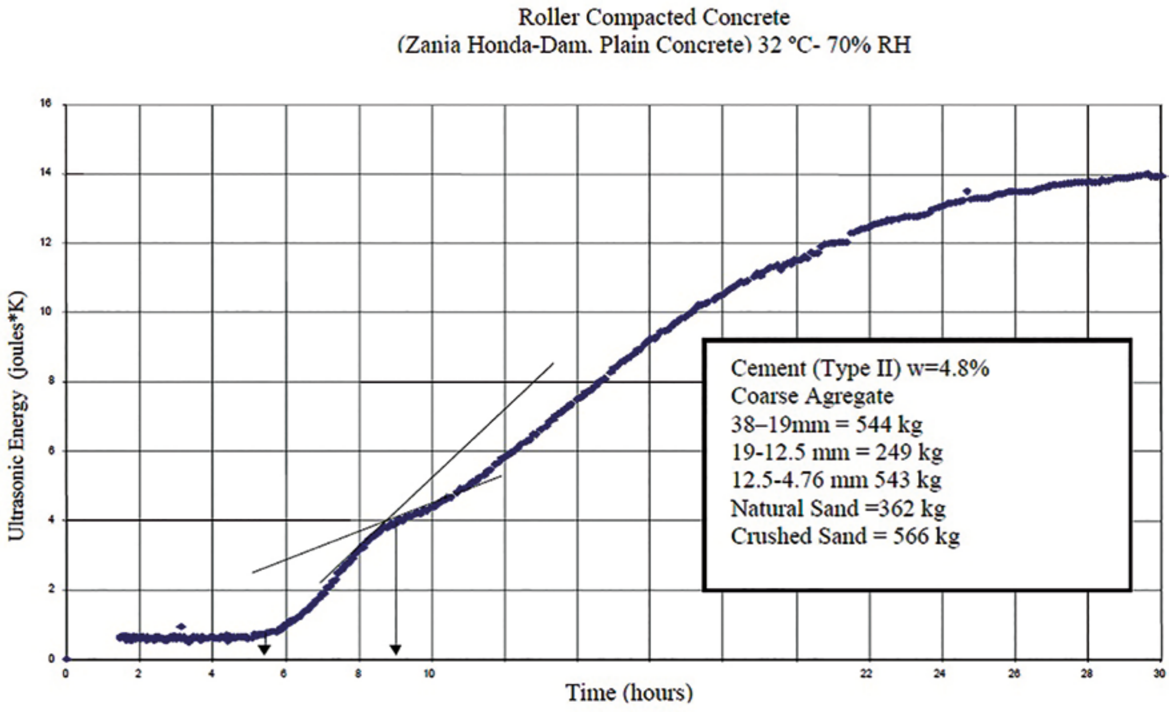
The importance of identifying the setting times on the RCC which has just been compacted and stills fresh, is based on assuring an adequate adherence between layers. The horizontal joints between layers, where the bond is required becomes, from the impermeability point of view, one of the most vulnerable parts of the dam. The correct identification of the setting times, for different atmospheric conditions, allows establishing the limits in time, for which a superficial treatment on the joint should or should not be done, or the use of mortars of bond, to guarantee the level of adherence of design between layers. The evolution of the values of ultrasonic energy showed the effect of the use of different doses of a plasticizing-retarding admixture on the times of setting of RCC[03-24]. According to this, the appropriate dose should be selected according to the construction needs.



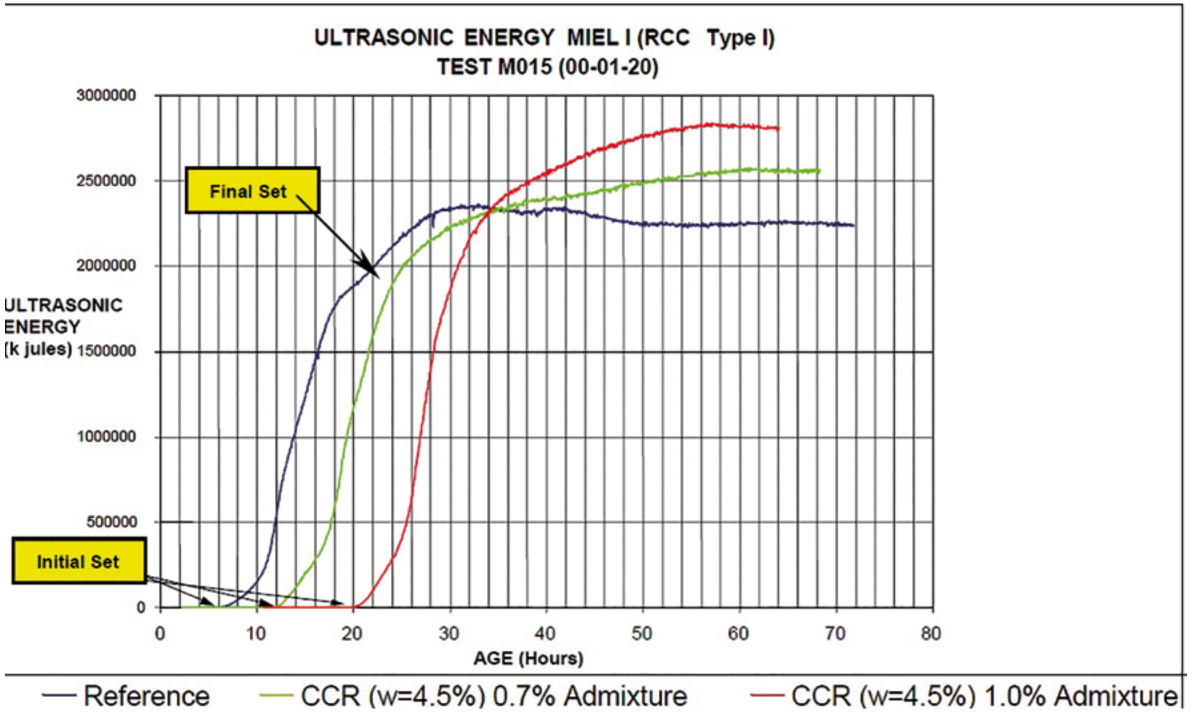
Ultrasonic energy device measuring over an RCC specimen[03-24]



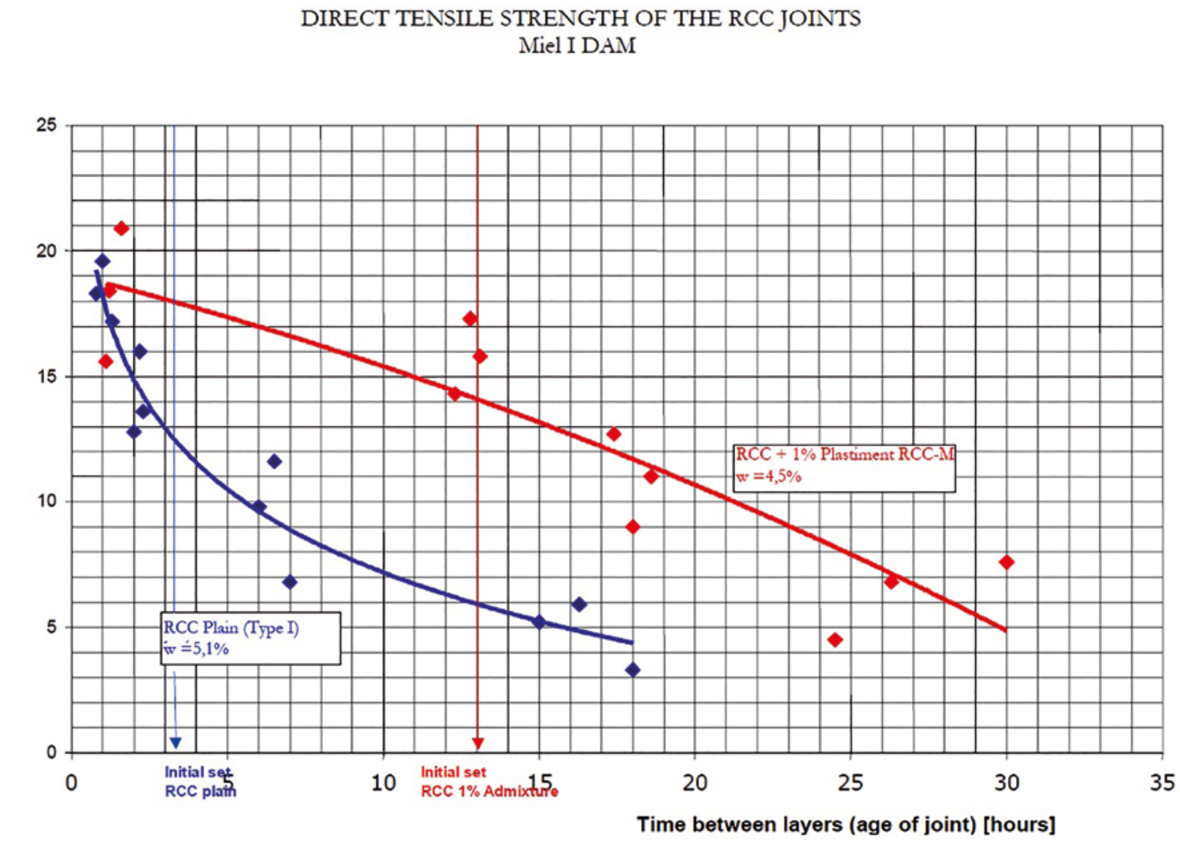
Miel I RCC Dam-Colombia – Ultrassonic energy measurement units[03-24]



Ultrasonic energy values evolution and RCC´s setting times – Zanja Honda dam (Colombia)[03-24]



Ultrasonic energy values evolution and initial times of setting for different admixture doses under controlled temperature and relative humidity[03-24]



Direct tensile strength (kg/cm²) on the RCC joints for the pattern design and for the design with a 1% plasticizing-retarding admixture[03-24]

3.7 Asphalt

3.7.1 General Aspects

Asphalt for watertightness purposes is often the material of choice for a growing number of environmental and hydraulic purposes. The properties of asphaltic concrete can, within fairly wide limits, be tailored to satisfy specific dam design requirements. Asphalt face and/or core embankment dams have proved to be a safe alternative to other traditional designs. The dams have been constructed under various climatic and foundation conditions.

When projecting and constructing the impervious membrane of asphalt concrete, the basic conditions that need to be fulfilled are:

⇒ To be stable enough, not to flow through the slopes, due to high temperatures during construction and latter during exploitation;

⇒ To be elastic enough and resistant to cracks, due to low temperatures;

⇒ Even though the deformations may occur, not to change its basic function-impervious;

⇒ To be resistant on the mechanical damages of the dam, as well as on the freezing conditions;

⇒ To reach the desired properties, it should be designed and constructed properly.

The requirements to foundation preparation and plinth design are, in general, similar to those for a **C**oncrete **F**aced **R**ockfill **D**am (***CFRD***), the main purpose of the plinth is to serve as a grouting cap to ensure high quality grouting to the base and as a horizontal surface for placing the first layer of the asphalt core and transitions zones. Mastic consists of bitumen, aggregates and filler, and an appropriate adhesion agent that secure necessary bonding to the concrete plinth, previously sandblasted or green cut.

Asphaltic concrete has been used as the impervious element of many dams. Among the causes of deterioration of asphaltic concrete faces are oxidation and brittleness under the influence of atmospheric oxygen combined with sunlight and hot temperatures. Such a brittle material is less able to resist the fluctuating stresses.

With a suitable drain behind it, the impervious membrane of asphalt concrete prevents seepage from entering the embankment and so eliminates the reduction in the stability, which is associated with the development of seepage pore pressures. This way, the embankment strength is higher and the margin of safety against shear failure is increased for the upstream and the downstream slopes. If the asphalt concrete is exposed to the light and ultraviolet radiation, it is becoming older, which mean it starts losing its properties as time goes by.

To fulfill its function as water barrier, a properly bituminous concrete facing must satisfy the following requirements:

⇒ Low permeability throughout its lifetime;
⇒ Tightness of connections between the facing and plinth and cut-off and other structures such as spillway, intake;
⇒ Sufficient flexibility, to tolerate without cracking the displacement resulting from the deformation of the supporting embankment;
⇒ High elongation capability under tensile strains;
⇒ Good bond between bitumen and aggregates;
⇒ Good bond of the facing to the supporting surface of the embankment;
⇒ Control of and erosion upon leakage through the facing;
⇒ Good underdrainage of the facing system to control water pressure upon leakage;
⇒ Stability on the supporting surface during construction, when the bituminous concrete mix is still hot and deformable, and over the range of service temperatures;
⇒ Resistance to aging under the environmental conditions;
⇒ Resistance to stripping;

⇒ Ease to access to be inspected and to be possible to repair.

3.7.2 Qualification

Quality control testing during construction must be conduct to ensure that the materials as-mixed and as-placed product conforms to the requirements.

A careful and detailed program of control and inspection during the construction process is necessary to ensure a good quality finished product, considering:

⇒ The quality of the component materials;

⇒ The processing of the materials into it hot bituminous concrete mix;

⇒ The hauling, placing and compaction of that mix on the dam.

Asphalt: The asphalt used in highway paving construction are commonly used for dam and reservoir linings.

Aggregates: Aggregates used in the mixes that make up the component layers of the bituminous concrete are normally crushed stone, as the same ones for conventional concretes. The important characteristics of the aggregate are its durability, affinity to bitumen low porosity, particle shape and gradation. Durability and low porosity seem to go together. The impervious layer requires a well graded material, while the drainage requires a more uniform material with fewer fines.

Filler: Filler is used to the workability and compactibility of the mix. Workability is important because harsh mixes tend to tear when poured. In addition to improving workability, clean of filler also decrease the volume of voids and make the mix denser and more impervious. On the other hand, excessive quantities of filler will significantly increase the bitumen demand, because of the increased surface area. The AC (**a**sphalt **c**oncrete) mix must be controlled concerning with the following;

Prequalification, quality assurance and control

Material	Characteristics/Properties
Asphalt	Density
	Penetration
	Viscosity
	Failure Point
	Ductility
Aggregate	Density
	Grain size distribution of aggregates
	Shape index
	Absorption
	Abrasion –Los Angeles
	Adhesion to the bitumen
Filler	Content
Mix	Asphalt Content
	Density of asphaltic concrete
	Air void Content
Concrete Mix Poured	Density-Nuclear Densimeter

3.7.3 Uses and Performance

3.7.3.1 Use

Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.7.3.1-A	Yashio	Japan	1992	Asphalt concrete face	[03-25]

Technical Information-Recovering the face – 2011

An example, the Yashio Dam[03-25] completed in 1992 is a 90.5 m high asphalt faced rockfill dam. It is one of the highest dams among its type. The facing of this dam was designed as a double-deck structure having an impermeable layer in each upper and lower portion. An intermediate drainage layer is placed to detect clearly the water leakage. There are a total of seven layers, and the thickness of the facing is 37 cm. The surface of the facing is covered with thin layer of asphalt mastic to protect it from damage. The maximum length of the facing of the Yashio Dam is approximately 200 meters. A special portal winch with an extra-long reach was developed specifically for this paving job to allow the entire 200-meter length of slope to be paved in one stage. To improve antiseismic performance of the facing, 8.5% asphalt and 0.8% fiber were added in asphalt concrete.

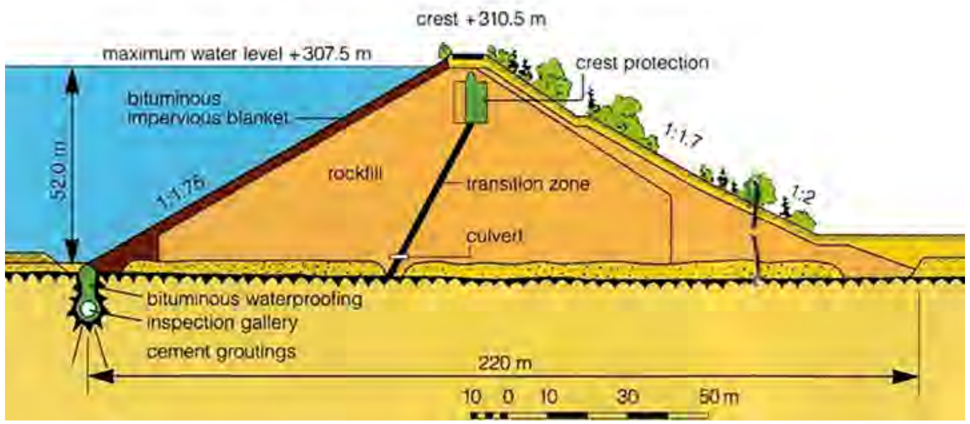


3.7.3.2 Performance

Case	Identification	Country	Finished	Materials and Studies -Rehabilitation	References
3.7.3.2-A	Bigge	Germany	1965	Asphalt concrete face	[03-26 & 03-27]

Technical Information-Recovering the face

The Bigge Dam in Attendorn (North Rhine-Westphalia) was built between 1957 and 1965, and it was renewed the outer asphalt seal of the main dam.



Case	Identification	Country	Finished	Materials and Studies - Rehabilitation	References
3.7.3.2-B	Kinzig	Germany	1981	Asphalt concrete face	[03-28]

Technical Information-Recovering the face due to cracks

The Kinzig Dam in Main Kinzig area - east Frankfurt - was built in between 1976-1981. A regular inspection had revealed cracks in the asphalt lining and damage to the mastic protection layer. A new 100 mm bituminous layer was poured after surface preparation.

3.8 Waterstops and Geomembranes

3.8.1 General Aspects

Concrete is one of the most popular materials used for construction in the world. Its application often requires materials, parts, and elements that contribute to the functionality of concrete structures. These auxiliary elements, besides the aggregates, cement, water, and additives that compose the concrete and its reinforcement, are used as elastic supports, joint seals, and protective membranes.

Plastics, or **polymers**, are among the most recent synthetic building materials. Plastics are hard wearing, highly adaptable, can be molded and cast in a variety of forms, and can mimic and perform the tasks of every other building material. Plastics continue to be seen as a potential replacement for other natural building materials. The first semisynthetic plastics were developed in the mid-19th century to replace natural materials. In the 20th century, plastics, both synthetic polymers and hard, resistant lacquers, were not suited for construction.

However, in the 1930s, new polymers, such as *acrylic, polythene, PVC, polystyrene and nylon*, were introduced, and their potential as building materials was explored. There are two basic kinds of plastics, thermoplastics, which can be re-softened to their original condition by the application of heat, and thermosets, which cannot be re-softened.

The physical properties of the final plastic product can be altered at various stages of the polymerization and production process. The most versatile method of modifying the properties is by compounding. With this method, additives, such as colorants, flame-retardants, heat or light stabilizers, or lubricants, may be added to the resin to achieve a desired result.

Fillers or reinforcement may also be added to the resin, as may other polymers, which form a polymer blend or alloy.

Thermoplastics: Examples of thermoplastic resins include polyethylene, polypropylene, and polystyrene:

⇒ Polyethylene is the highest volume plastic production;

⇒ Polyvinyl chloride (PVC) makes up the second-largest share of the thermoplastics segment;

⇒ Polypropylene, another thermoplastic, is mainly used in the creation of fiber and filaments;

⇒ Polystyrene is used to make miscellaneous products;

⇒ Other thermoplastics segments include polyamid resins, styrene-butadiene, and some polyesters.

Thermosets: Thermosets harden by chemical reaction and cannot be melted and shaped after they are created.

3.8.2 Waterstops

A waterstop is a form of preformed joint material that is either metallic or nonmetallic and can be hydrophilic in design to stop the flow or migration of water through open joints. Waterstops may be used in many types of concrete structures but are primarily utilized in the monolith joints of hydraulic concrete structures such as tanks, navigation locks, dams, floodwalls, and control structures to stop the passage of water and waterborne matter through the joint.

3.8.2.1 Types

Waterstops may be either metallic or nonmetallic:

⇒ **Metallic waterstops** are rigid and are made from steel, copper, bronze, or lead. Metallic waterstops are used in large dams and heavy construction projects where strength rather than flexibility is needed.

⇒ **Nonmetallic and Hydrofilic waterstops** are usually composed of natural rubber; synthetic rubbers such as butyl rubber, neoprene, styrene butadiene rubber, and nitrile butadiene rubber; and polyvinyl chloride. Nonmetallic waterstops provide flexibility rather than strength and must possess good extensibility, good recovery, chemical resistance, and fatigue resistance. Some nonmetallic waterstops are thermoplastic in that they can be easily spliced together on the job site or configured for special joints.

Metallic: Waterstops are shaped for particular applications. Most metallic waterstops are flat, but they may also be preshaped and folded in "Z" or "M" cross-sectional shapes to accommodate unique configurations for special applications. Lead and bronze waterstops are more ductile than other metallic types and can be shaped more readily. Stainless steel and copper waterstops are resistant to corrosion. Copper waterstops should ensure a suitable material. Where steel is desired, stainless steel should be specified for protection against corrosion. Stainless steel is low in carbon and is stabilized with columbium or titanium to facilitate welding and to retain its corrosion resistance after welding. Metallic waterstops are fabricated to specifications when required for individual projects and structures. The thickness of a metallic waterstop represents a compromise between flexibility and susceptibility to damage rather than hydrostatic pressure considerations.

PVC and Cooper Waterstop - Foz do Areia CFRD – 1977 (Andriolo's Archive)

Cooper Waterstop Preparation at Xingó CFRD – 1990 (Andriolo's Archive)

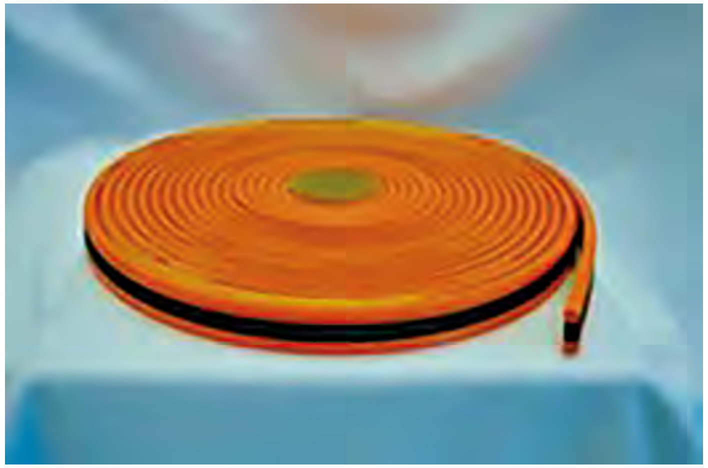
Nonmetallic: Nonmetallic waterstops, which include butyl rubber, neoprene, polyvinyl chloride, butadiene rubber, and natural rubber, are specially shaped to permit a mechanical interlock between the concrete and the waterstop. The rubber waterstops possess high extensibility and resistance to water and most chemicals and may also be formulated for fast recovery and fatigue resistance

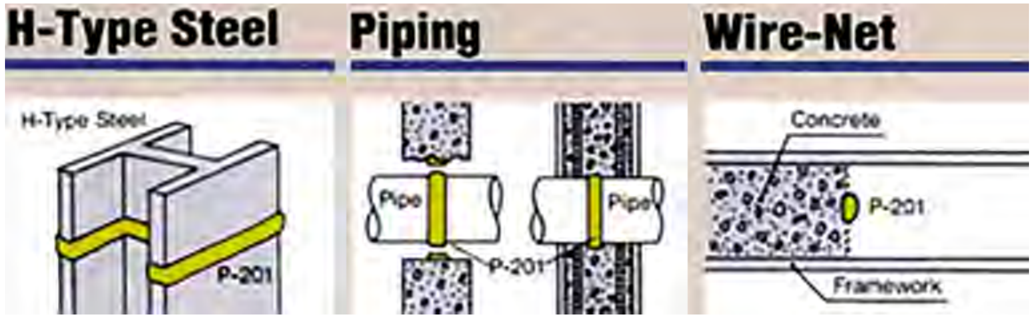
Compared with rubber waterstops, polyvinyl chloride waterstops are not as elastic, they are also slower in recovery, and more susceptible to oils and some chemicals, but polyvinyl chloride is still the most prevalent of the nonmetallic types. Because they are thermoplastic, PVC waterstops provide the great advantage of being easily spliced on site and configured for joint intersections and directional changes

Lines of a PVC Waterstop near a rock foundation and an interface with a PVC membrane at Beidag RCC Dam - 2006 (Andriolo's Archive)

Three Lines of a PVC Waterstop - Itaipu Main Dam - 1979 (Andriolo's Archive)

Hydrophilic: A hydrophilic swelling waterstop is a flexible, coiled strip of butyl rubber with a swellable waterproofing compound that swells upon contact with water to form a long-lasting compression seal in concrete joints. This swelling ability prevents the passage of water through concrete construction joints. Simply existing concrete firmly presses the hydrophilic swelling waterstop to the primed surface, and the second batch of concrete is then poured. This product absorbs water and expands, and it conforms to gap variations along the joint. This action ensures sealing even under hydrostatic pressures.



Hydrophilic swelling waterstop illustration (From Internet)

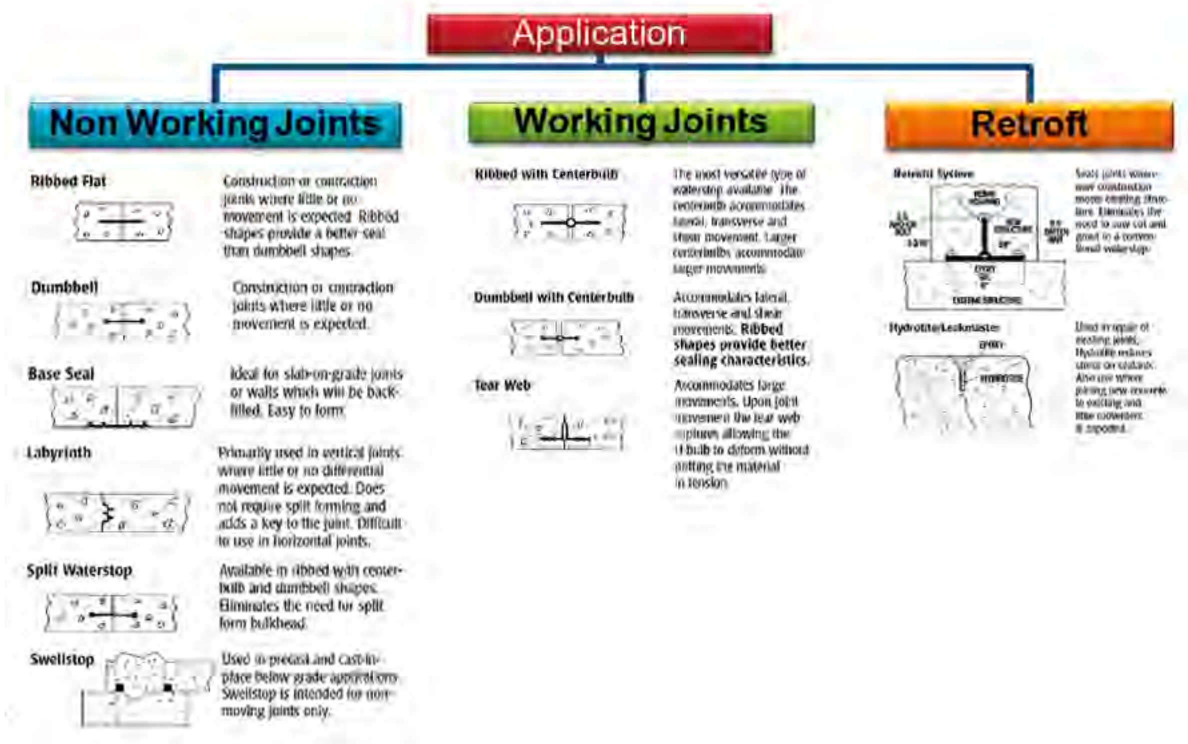
3.8.2.2 Uses

To overcome these problems, waterstop manufacturers developed various ribbed profiles. Multiple ribs at each end of the waterstop grip to concrete tenaciously for better anchoring and sealing. Both ribbed and dumbbell waterstops are available with flat or bulbed centers. Flat waterstops should be used only in construction or contraction joints where little or no movement is expected.

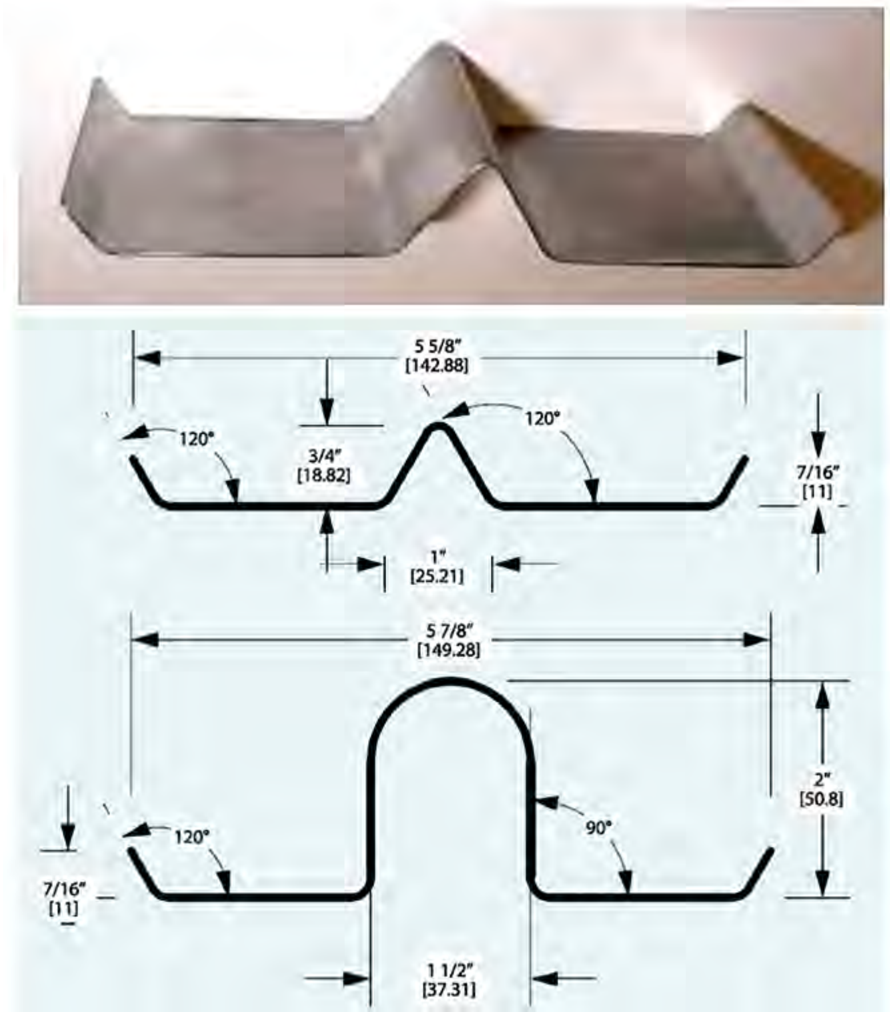
- ✓ ***For use only in joints when little or no movement is expected.***
- ✓ ***For transverse and shear movements that do not induce high stress on the waterstop material.***

The most versatile waterstops are those with an O- or U-shaped center bulb[03-03]. The center bulb flexes to accommodate both transverse and shear movements without placing too much stress on the waterstop material. Ribbed waterstops with center bulbs can be used in expansion, contraction, or construction joints. The center bulbs come in various sizes to accommodate different degrees of joint movement. Larger center bulbs withstand greater joint movements.

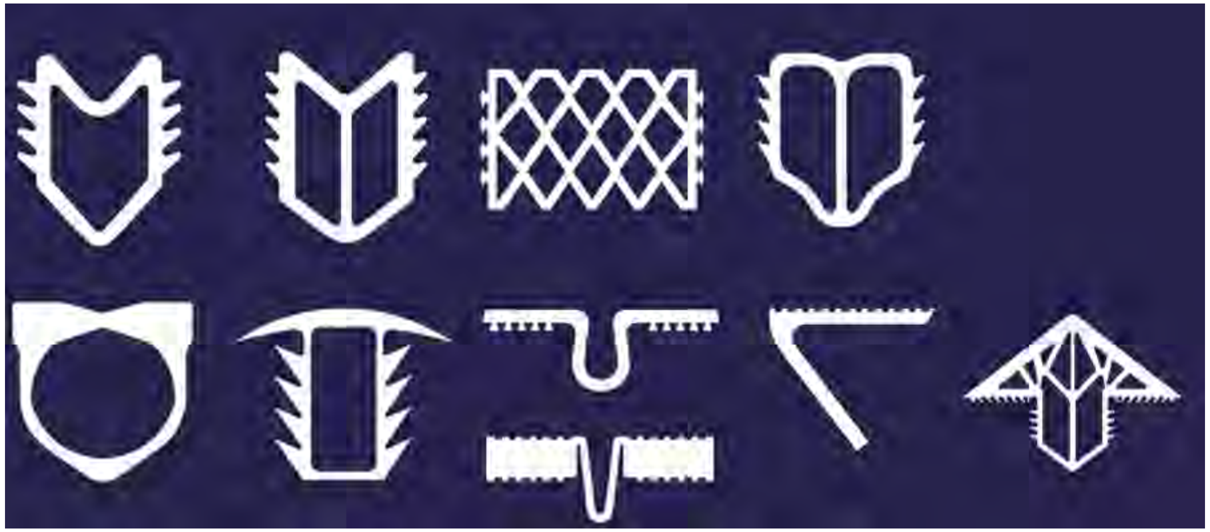
Some ribbed waterstops have a U-shaped center bulb with a tear web or fracture membrane that breaks upon the initial joint extension. With the membrane broken, the joint reportedly can expand up to the extended length of the center bulb without stressing the embedded ribbed sections.



Pictures from GREENSTREAK Catalog

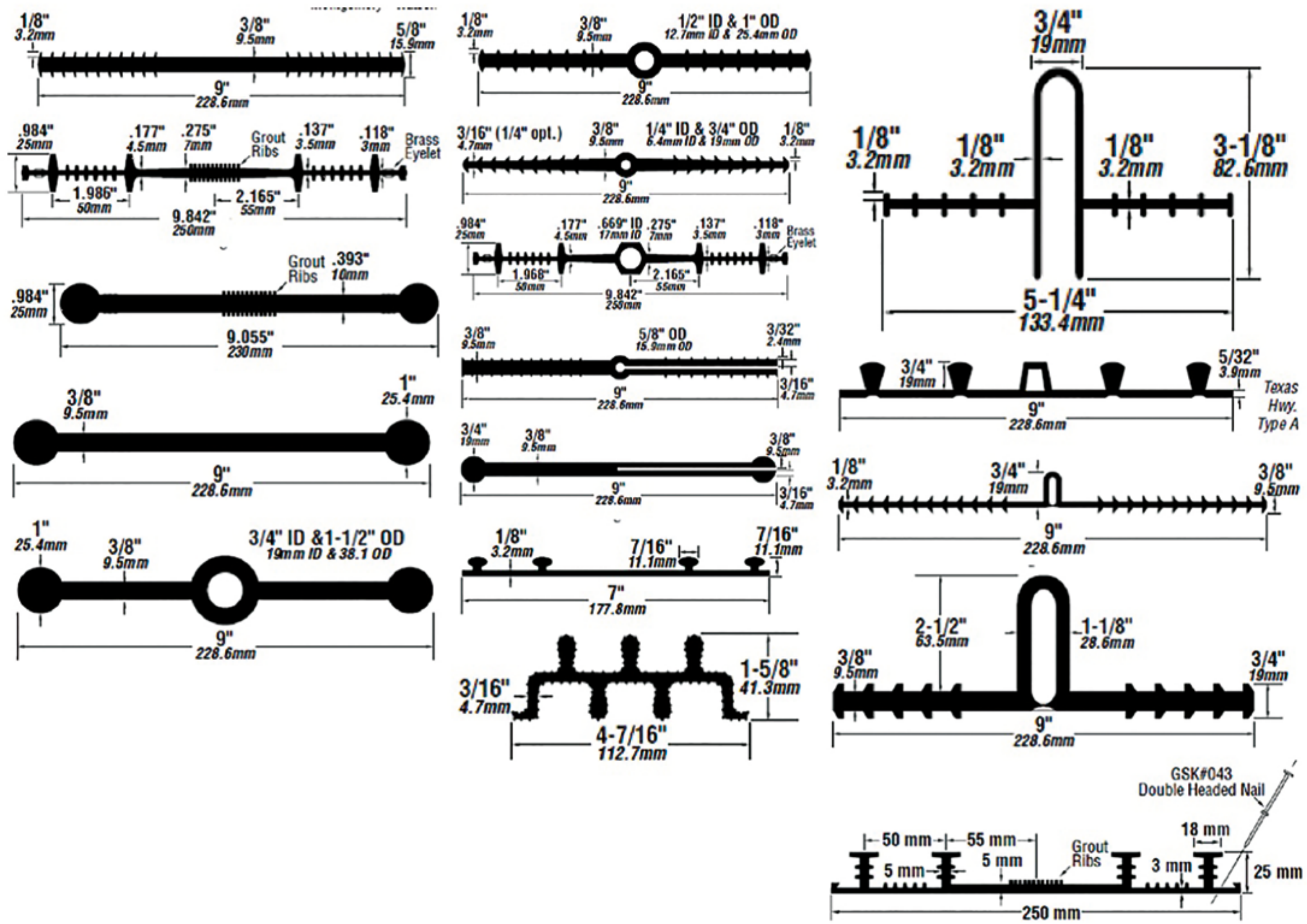


Stainless Steel Waterstop from JP Specialties Catalog



Pictures from Jeene Juntas e Impermeabilizações Ltda Catalog

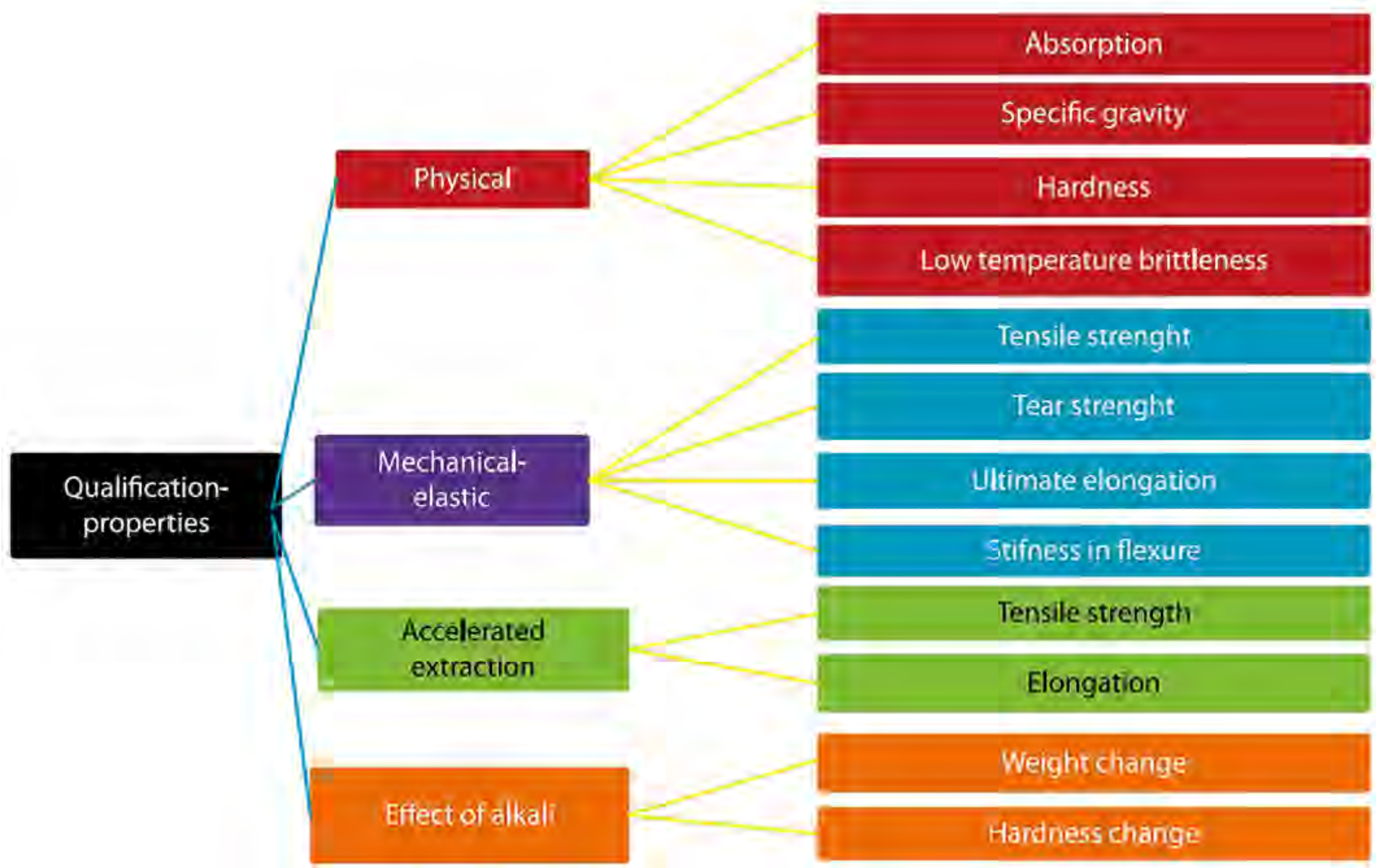
Pictures from GREENSTREAK Catalog



Pictures from GREENSTREAK Catalog

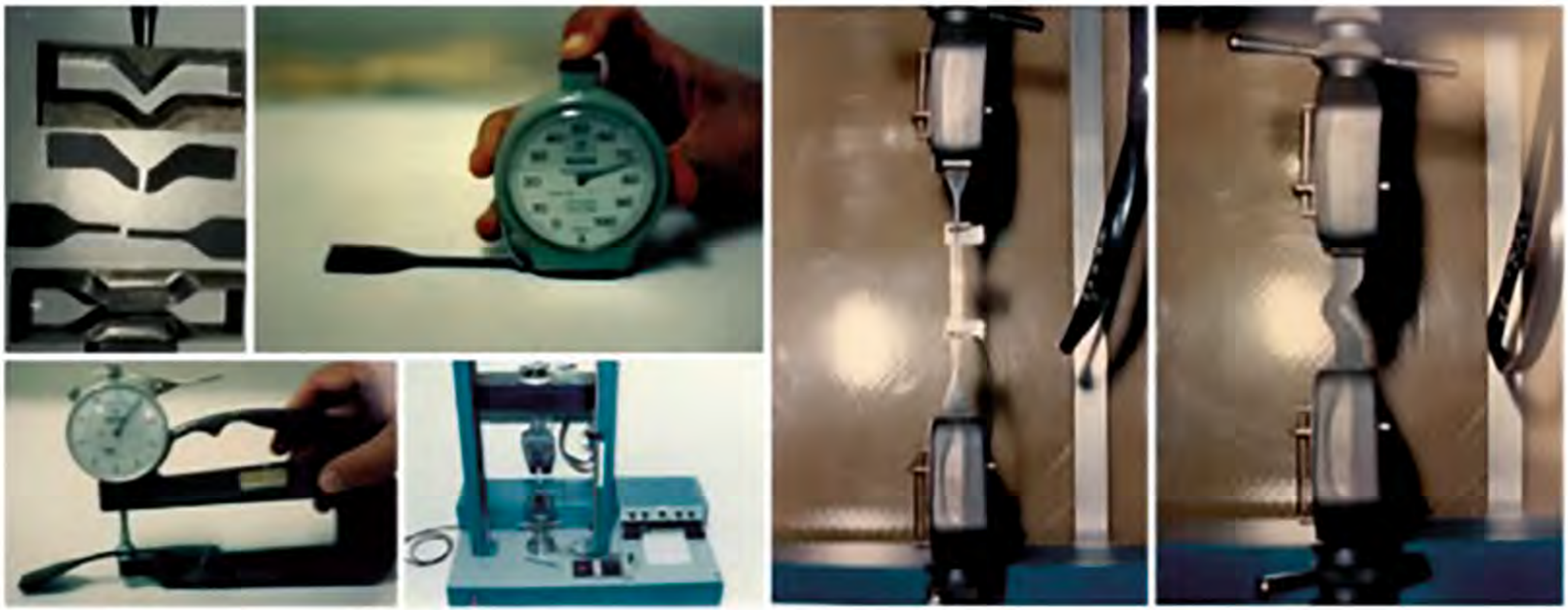
3.8.2.3 Qualification

The waterstop properties must agree with the adopted specification. The Corps of Engineers requirements are normally applied[03-03].



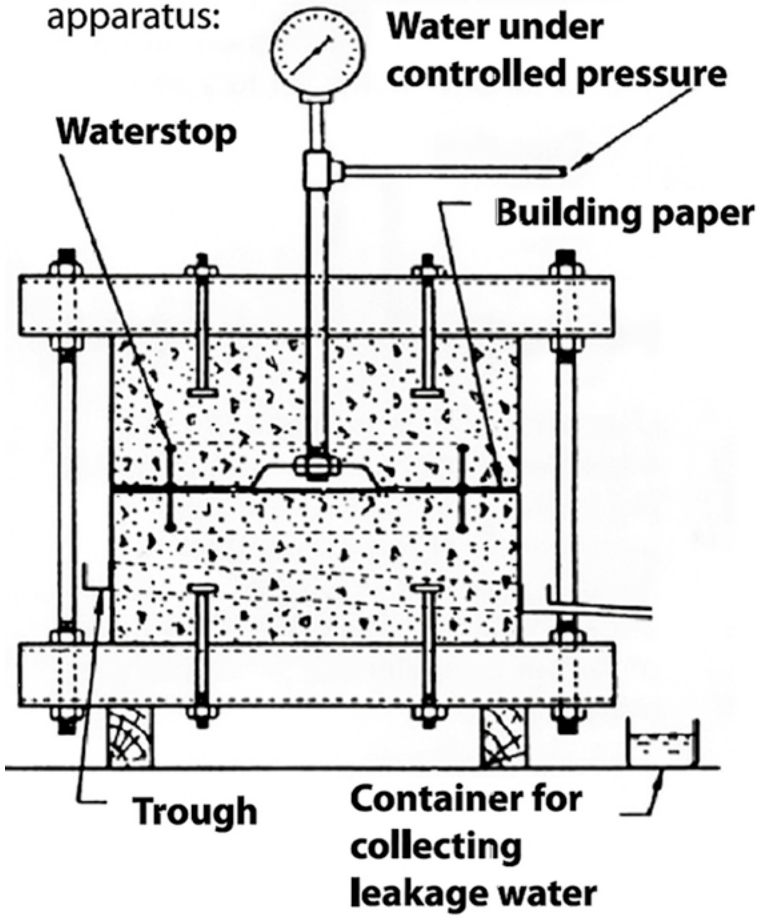
Qualification properties normally required for PVC waterstops[03-03]

An additional assessment should be made to check the performance of the waterstop, especially when indicated for greater than usual hydrostatic loads. This assessment can be conducted in a simulated service test using the waterstop cast in a concrete specimen, thus simulating a contraction joint, and applying a hydrostatic load to assess the watertightness.



PVC Waterstop tests performed at Itaipu Laboratory in 1978 (Andriolo's Archive)

Testing for this failure can be conducted using the following apparatus:



Simulated Service Test for a Waterstop

3.8.2.4 Precautions and Damages

For any joint sealant to be effective, proper design, installation, and concreting practices must be followed. This is especially important when using flexible waterstops because they are embedded in the concrete. If the waterstop fails due to improper installation, it is usually impossible to replace. During installation, avoid contaminating the waterstop surface with dirt, oil, or release agents, which can interfere with the direct contact of the concrete.

Mistakes that need to be avoided during the use of PVC waterstops[03-03]

Mistakes that need to be avoided during the use of PVC waterstops[03-03]

3.8.3 Geomembranes

3.8.3.1 General Aspects

Geosynthetic products are ***"Geosynthetics are synthetic products that are especially designed for the use in engineering, for environmental, geotechnical, and hydraulic purposes, and for underground structures and roads."*** This definition allows for a better understanding of the nature and purpose of this set of products. ***Geomembranes are made from relatively thin, continuous polymeric sheets (polymeric geomembranes) or from the impregnation of geotextiles with natural bituminous materials (bituminous geomembranes)***. These sheets are prefabricated in a factory and transported to job sites, where placement and field seaming are performed to complete the job.

Since the year 1950, geomembranes have been successfully used as the main impervious components on embankment dams up to 110 m high, to repair old masonry and concrete dams up to 174 m high, and to provide a watertight facing on new RCC dams up to 192 m high. They have been installed on dry land and underwater.

Engineers have successfully designed containment systems with a wide assortment of geomembranes and associated geosynthetic products in an effort to protect water resources. Continued research and development by numerous manufacturers have resulted in a wide range of available geomembranes. Refined geomembranes and installation quality control procedures ensure these developments. Recent studies provide further support for these requirements because the total seepage measured through monitored geomembrane installations is extremely low.

Geomembranes are essentially impermeable polymeric lining materials used as fluid barriers in geotechnical engineering applications. Geomembranes can have a smooth or textured surface. A textured surface provides enhanced friction characteristics that can be important in certain applications.

The families of geosynthetics that are commonly used in civil construction are grouped in accordance with their characteristics and their field of application. A geocomposite is at least one geosynthetic: geotextile and geonet, geotextile and geomembrane, or any other combination of these materials with other materials (e.g., deformed plastic sheets, steel cables, or steel anchors). This field is the most creative in geosynthetics, and the potential areas of application are numerous.

3.8.3.2 Types – Materials

A geotextile can be fabric laminated to a geomembrane to form a geocomposite, which increases the tensile properties and dimensional stability and provides additional anti-puncturing resistance and some drainage capability. Geomembranes are made from synthetic ***polymers*** and from ***bitumen***.

The polymers are at least 50% of geomembranes by mass. The remaining mass is fillers, plasticizers, and various additives. There are two main categories, ***thermoplastic*** (PVC-P, PP-F, HDPE and LLDPE, EPDM) and ***thermo-set*** (EPDM) waterstops, as previously noted. A bituminous hot and fluid mass embeds a geotextile by impregnation, usually nonwoven polyester. The geotextile provides both support for manufacturing and reinforcement. The geomembrane can also have gridded glass reinforcement.

Most geomembranes are made from thermoplastic polymers (those that can be thermally welded in the field), and polyvinyl chloride (PVC) is the most widely used. It should be recognized, however, that all polymers are actually formulations containing the designated resin (from which the name is derived), additives (mainly antioxidants), colorants (often carbon black), and some fillers.

Geomembrane Type	Basic Material	Abbreviation- Nomenclature
Polymeric	Polyvinyl chloride	PVC
	Linear, low-density polyethylene	LLDPE
	High-density polyethylene	HDPE
	Butyl rubber, polysobutylene, Ethylene-propylene-diene monomer	BR, PIB, EPDM
	Chlorosulfonated polyethylene	CSPE
	Flexible polypropylene	FPP
	Chlorinated polyethylene	CPE
	Geotextiles impregnated with polymers	In situ membrane
Bituminous	Oxidized bitumen	Prefabricated
	Polymeric bitumen	Polymeric bitumen
	Oxidized bitumen	In situ membrane

Geomembrane types and identification[03-03]

Regarding the important issue of geomembrane aging and its in-service durability, a critical issue is whether a geomembrane is exposed or if it is covered with soil, rock, or concrete. The former is much more critical because of ultraviolet exposure and the usually high accompanying temperatures.

Geomembranes and geosynthetic materials display a wide range of physical, mechanical, and chemical resistance properties. Geomembranes can be compounded for greater resistance to ultraviolet light exposure, ozone, and microorganisms in the soil. Different combinations of these properties exist in various geomembrane materials to address a wide spectrum of geotechnical applications and designs.

3.8.3.3 Uses

Several methods are used to join or seam large panels of geomembranes in both factory controlled and field environments. Each material has highly developed quality control techniques and unique characteristics that govern its manufacture and installation. Advanced products, as well as new manufacturing and installation techniques, continue to evolve as the geosynthetic industry steadily improves the existing technology and strives to address the future needs of the containment industry.

PVC geomembranes used for waterproofing the Balambano Dam-Indonesia - (Carpi Presentation)[03-17]

Impervious geomembrane systems, which are widely used in the rehabilitation of dams (concrete face rock-fill, conventional concrete, and roller-compacted concrete), are also adopted to substitute for concrete facings in new rock-fill dams.

The Bovilla dam **(**650,000 m^3 homogeneous gravel fill)[03-29] is 91 m high from the lowest foundation levee to the crest and 135 m long at the crest. It is located on the Terzuke River, 15 km northwest of Tirana. The embankment structure was originally designed for irrigation water supply, but later its functions were expanded to include drinking water supply for the city of Tirana and eventually hydro-production to exploit the available head in the river.

PVC geocomposite sheets under installation on anti-puncture geotextile (the white material) in stage 2 at Pecineagu CFRD in Romania - 2012[03-29]

Nam Ou VI 88 m high rockfill dam in Lao PDR[03-29]

Another solution (known as the Winchester System) uses a composite geomembrane/geotextile that is prefabricated onto a concrete precast panel. This panel is then used as the upstream forming system of the RCC dam, with the geomembrane facing the concrete as it is being placed. This method allows the preformed concrete to act directly against the impounded reservoir and thus to protect the geomembrane against ultraviolet exposure, puncture damage, and vandalism.

PVC Membrane used in a concrete precast panel for the Beydag RCC Dam in Turkey- (Andriolo's Archive)

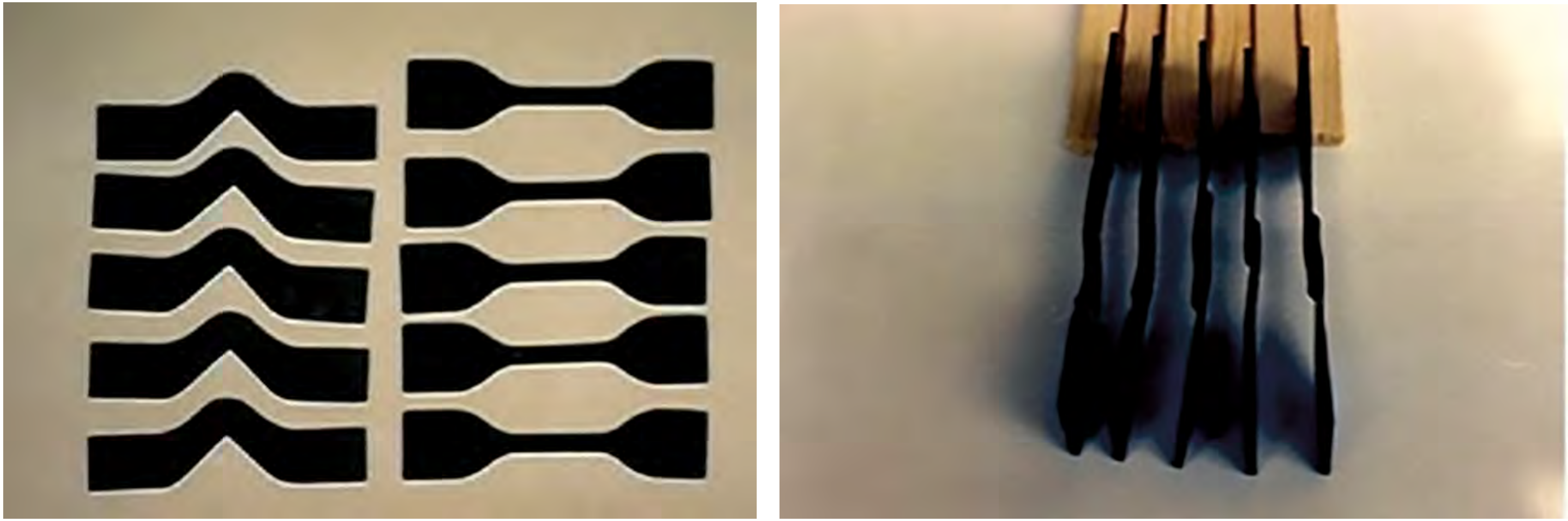
PVC Membrane used in a concrete precast panel for the Beydag RCC Dam in Turkey- (Andriolo's Archive)

PVC Membrane used in a concrete precast panel for the Beydag RCC Dam in Turkey- (Andriolo's Archive)

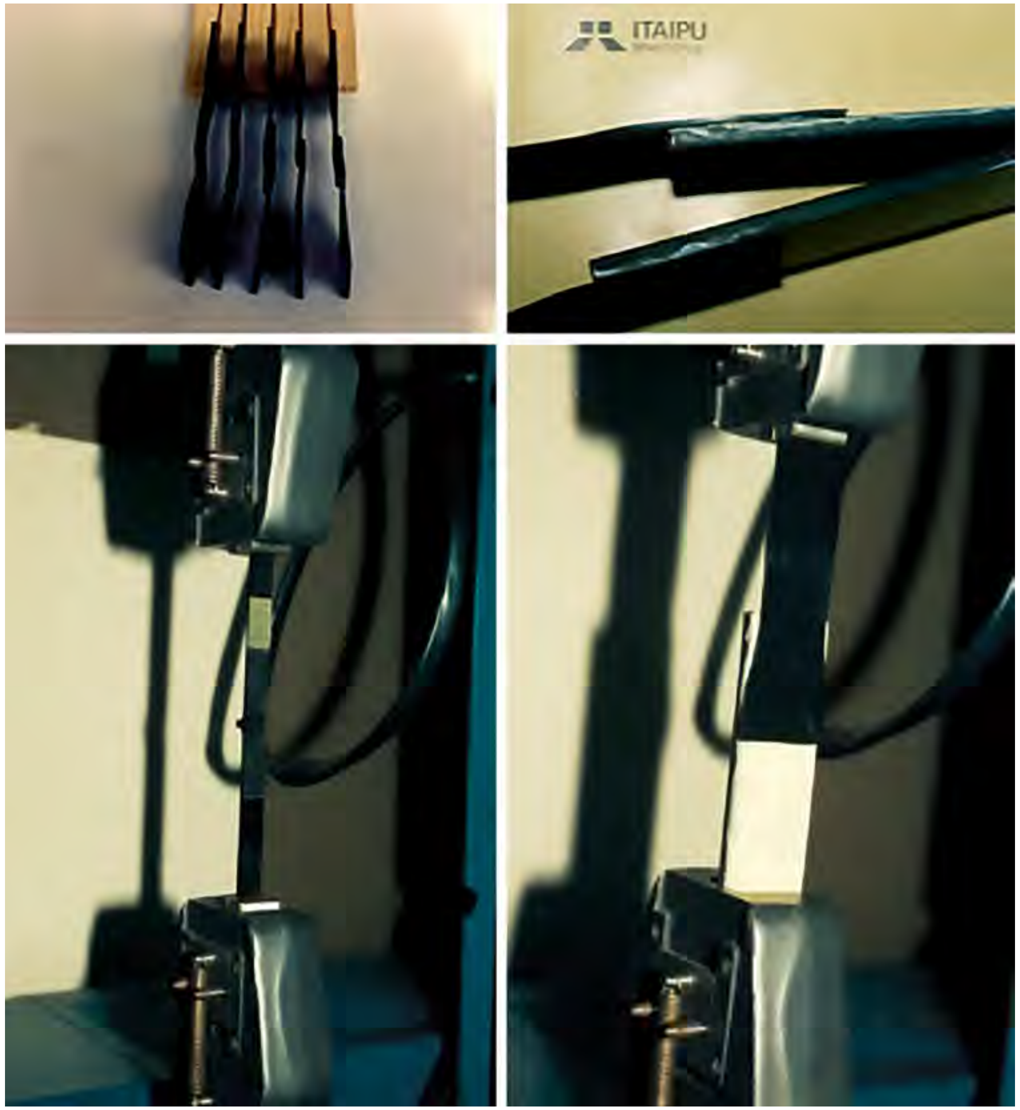
3.8.3.4 Qualification

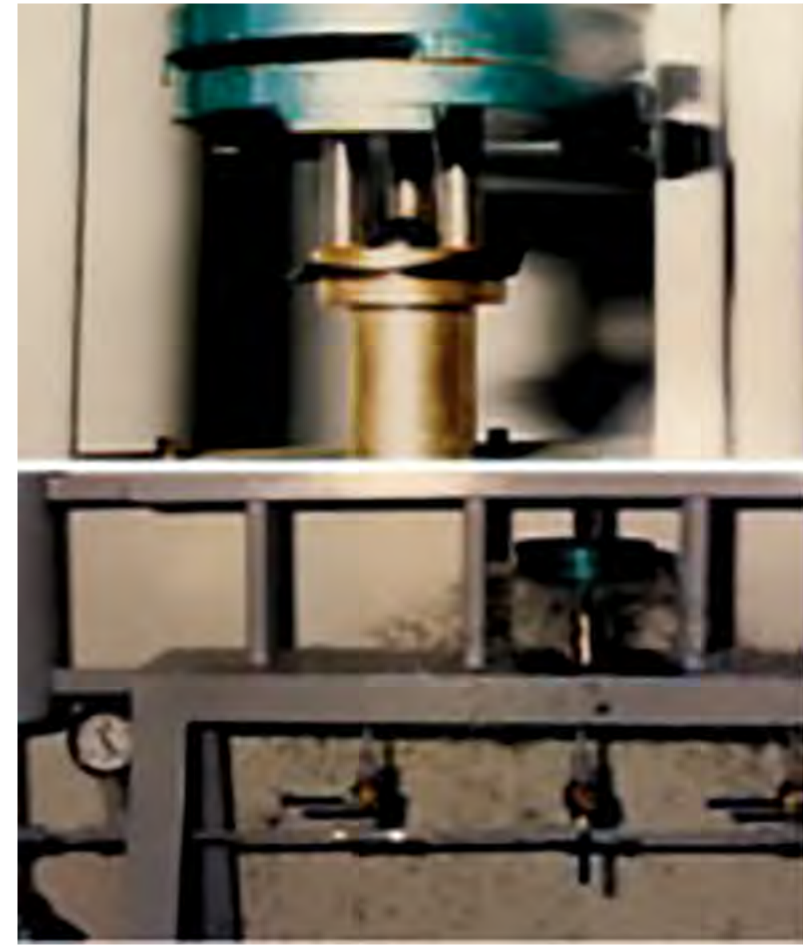
The main applicable and relevant properties are listed below:

- ⇒ Density
- ⇒ Shore hardness
- ⇒ Compression
- ⇒ Water absorption
- ⇒ Temperature range
- ⇒ Linear shrinkage after a specified duration and temperature
- ⇒ Ultimate elongation
- ⇒ Tensile strength
- ⇒ Tear resistance
- ⇒ Resistance to support the hydrostatic pressure
- ⇒ Resistance against various substances (ozone, oil, solvents, acid, alkalis, etc.)
- ⇒ Resistance in various conditions (UV rays, freeze, heat).

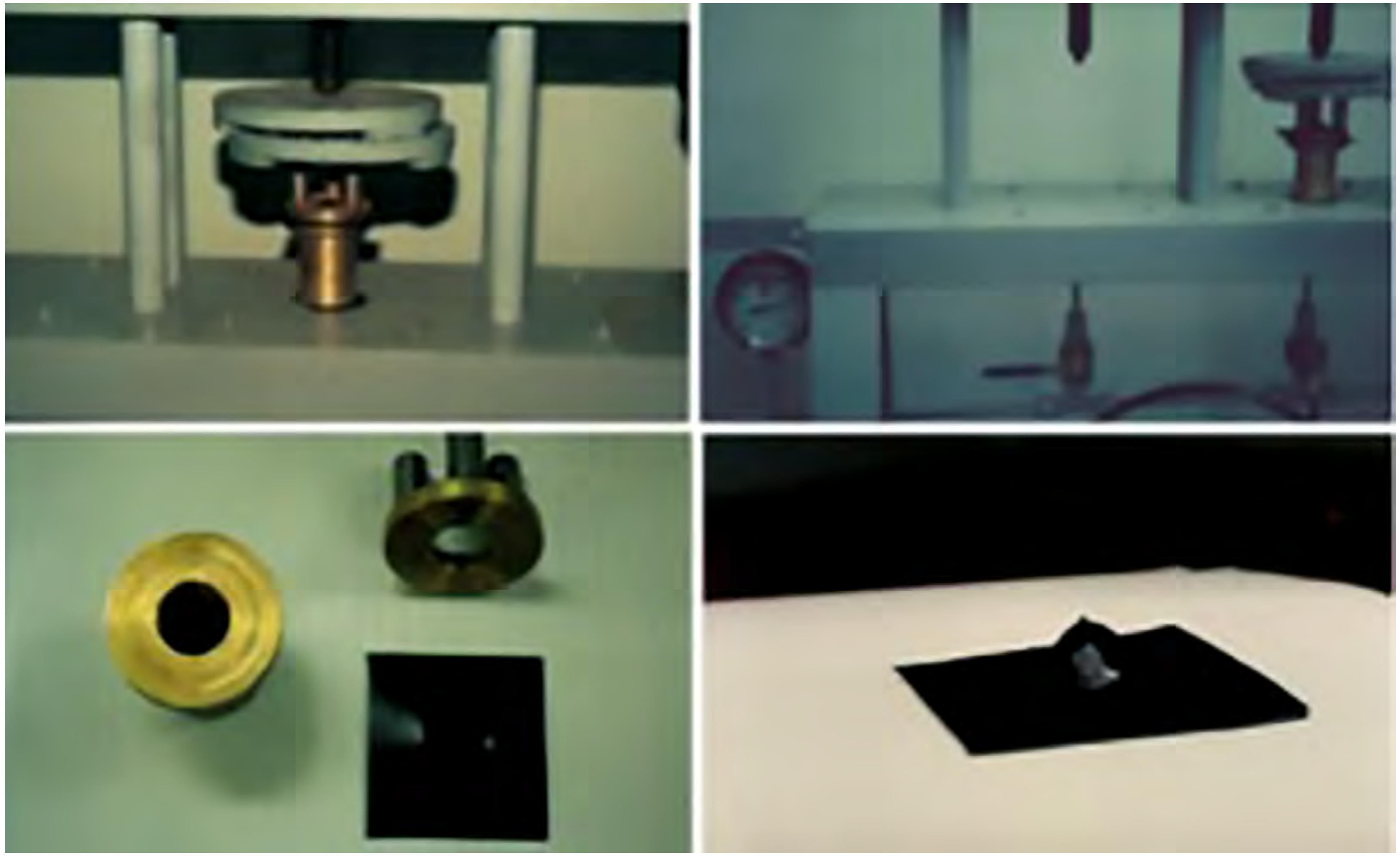


Tensile and tear specimens for tests at Itaipu Laboratory in 1989 on a PVC membrane used in concrete precast panel for the Capanda RCC Dam in Angola (Andriolo's Archive)[03-02]





Tensile on welded specimens for tests at Itaipu Laboratory in 1989 on a PVC membrane used in concrete precast panel for the Capanda RCC Dam in Angola- (Andriolo's Archive)[03-02]



Water pressure test performed at Itaipu Laboratory in 1989 on a PVC membrane used in concrete precast panel for the Capanda RCC Dam in Angola- (Andriolo's Archive) [03-02]

The durability of geomembranes is strictly dependent on the type of material, whether it is exposed or covered, the environment in which it will operate, and the quality of its installation. While the former aspects are widely recognized as important, the quality of the installation is rarely regarded as a key element. In fact, a poor installation that allows excessive stress on a geomembrane at the time of installation will affect the general behavior of the material, greatly reducing its potential longevity.

There is no doubt that all material applied or handled by the human being is conditioned to care and control, to avoid defective execution or errors

Poor preparation of the subgrade or, in the case of a covered geomembrane, the wrong selection of the type of cover and/or its placement can heavily damage a geomembrane

Excessive undesigned stress induced on a geomembrane at the time of installation can reduce its technical life to a fraction of what it should be. The durability of a geomembrane is also correlated with some mechanical property tests mentioned previously. However, good geomembranes, when properly installed, can easily be used for up to 40 to 50 years.

3.9 Metallics

3.9.1 General Aspects

Combining steel bar reinforcement and concrete produces an almost ideal composite material. **R**einforced **c**oncrete (***RC***) is extremely powerful, durable, and cost-effective. It fits into nearly every form, is extremely versatile, and is therefore widely used as a construction material in buildings and bridges. However, to achieve these features, ***RC*** structures must have a minimum thickness to protect the metal reinforcement. A minimum concrete cover of 20-70 mm per layer is necessary to protect the steel bar reinforcements from corrosion during the lifetime of the building.

However, because several layers are required for most applications in major structures, the minimum thickness requirement of ***RC*** is not an actual limitation. However, when thick concrete sections are not required to resist the loads, more lightweight, elegant, and efficient ***RC*** structures become desirable. Textile reinforcement structures produced from carbon elements represent an excellent alternative and complement existing steel reinforcement materials. Reinforcing steel bars are used to reinforce concrete structures, manufacture anchor bolts, etc. Reinforcing bars (re-bars) can be either smooth or deformed.

Types and identification of re-bars[03-01 & 03-03]

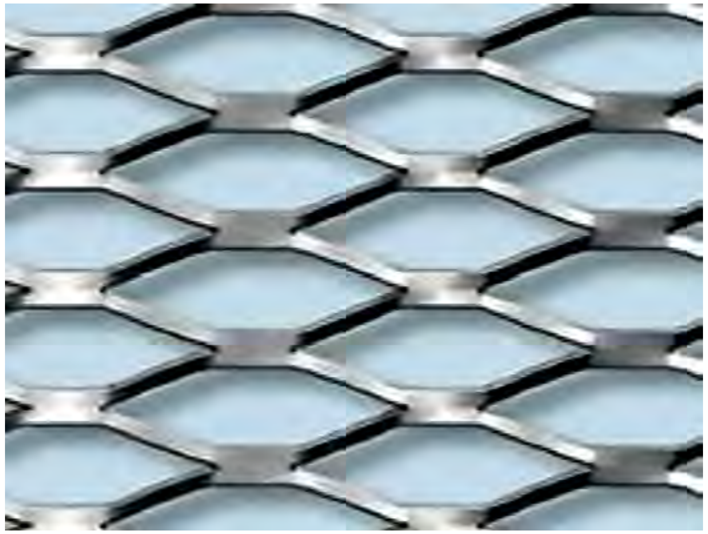
Steel is embedded in concrete so that the two materials act together to resist forces. The reinforcing steel-rods, bars, or mesh-absorbs the tensile, shear, and, occasionally, compressive stresses in a concrete structure.

Welded Steel Fabric is used to produce a new, efficient, high-quality reinforcement that reduces the working hours associated with installation and reducing the use of banding by nearly 50% - 70%. Denser spacing of the steel welded longitudinal and transverse reinforcement bars to form a common network structure helps to prevent the emergence of cracks in the concrete.

Welded **w**ire **r**einforcement (***WWR***) is a prefabricated reinforcement that consists of parallel series of high strength, cold-drawn or cold-rolled wire that are welded together in square or rectangular grids.

Welded wire reinforcement mesh[03-03]

Expanded metal mesh, originally known as Deploye Mesh (from Deploye Expanded Metal Co.), is a form of metal stock that is produced by shearing a metal plate in a press so that the metal stretches and leaves diamond-shaped voids that are surrounded by the interlinked bars of the metal. The most common manufacture method is to simultaneously slit and stretch the material with one motion. Expanded metal meshes are produced from solid sheets or plates of carbon, galvanized and stainless steel, aluminum, and various alloys of copper, nickel, silver, titanium, and other metals.



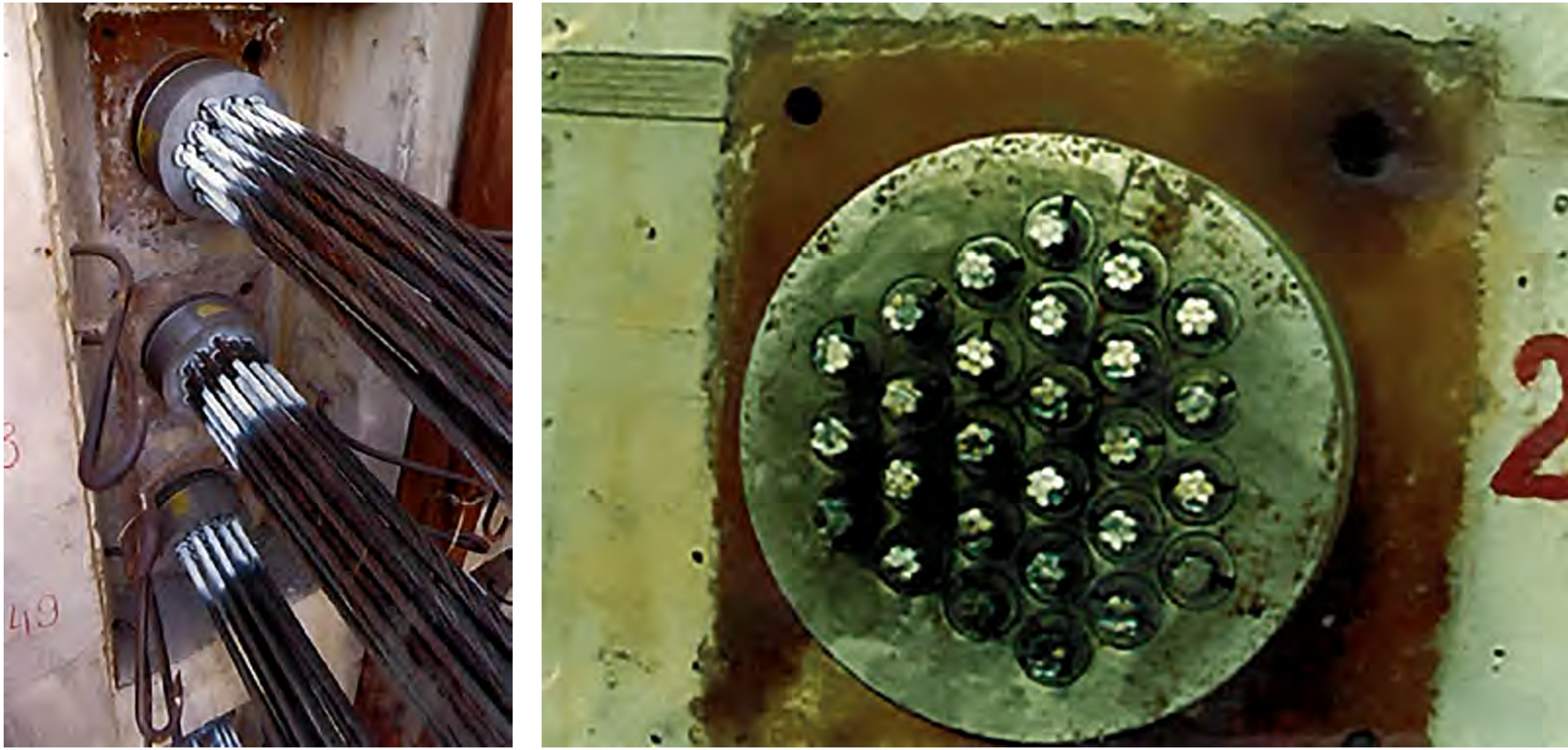

Expanded metal meshes used as form (Andriolo's archive).

Pre-stressing the concrete is used to overcome the concrete's natural weakness in tension. This method can be used to produce beams, floors, or bridges with a longer span than the practical limit for ordinary reinforced concrete, and normally used for trunnion structures of the radial gates in dam spillways.

Pre-stressed tendons (generally of high-tensile steel cable or rods) are used to provide a clamping load that produces a compressive stress that balances the tensile stress that the concrete compression member would otherwise experience because of the bending load. Pre-tensioned concrete is cast around steel tendons - cables or bars or wires - while they are under tension. The concrete bonds to the tendons as it cures, and when the tension is released, the tension is transferred to the concrete as compression by static friction. The tension that is subsequently imposed on the concrete is transferred directly to the tendons.

Pre-tensioning requires strong, stable anchoring points between which the tendons are stretched. Thus, most pre-tensioned concrete elements are prefabricated and transported to the construction site, which may limit their size.

Ducts and tendons for post-tensioning a pier - Itaipu Spillway Piers - 1979 (Andriolo's Archive)[03-01]

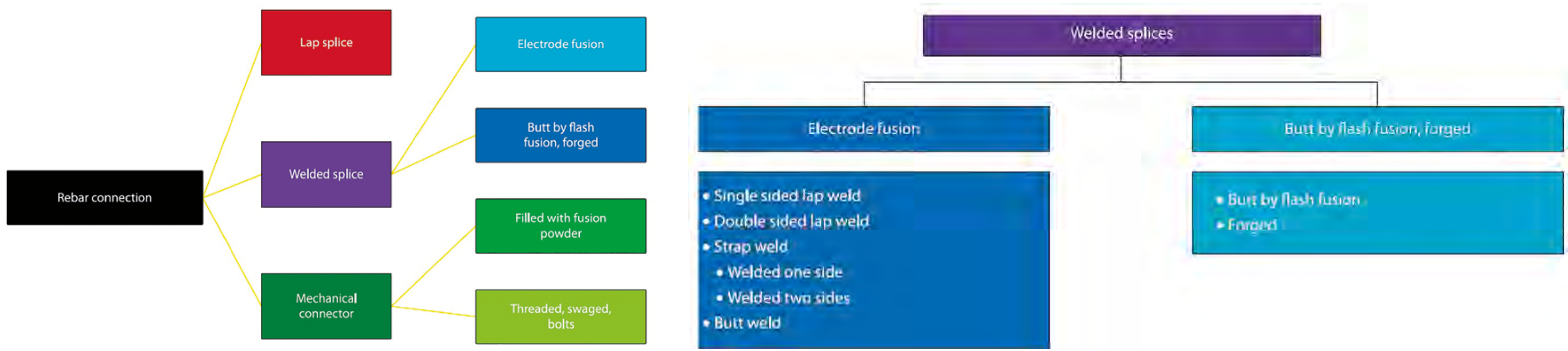


Ducts and tendons for post-tensioning a pier – Itaipu Spillway Piers, 1979 (Andriolo's Archive)[03-01]

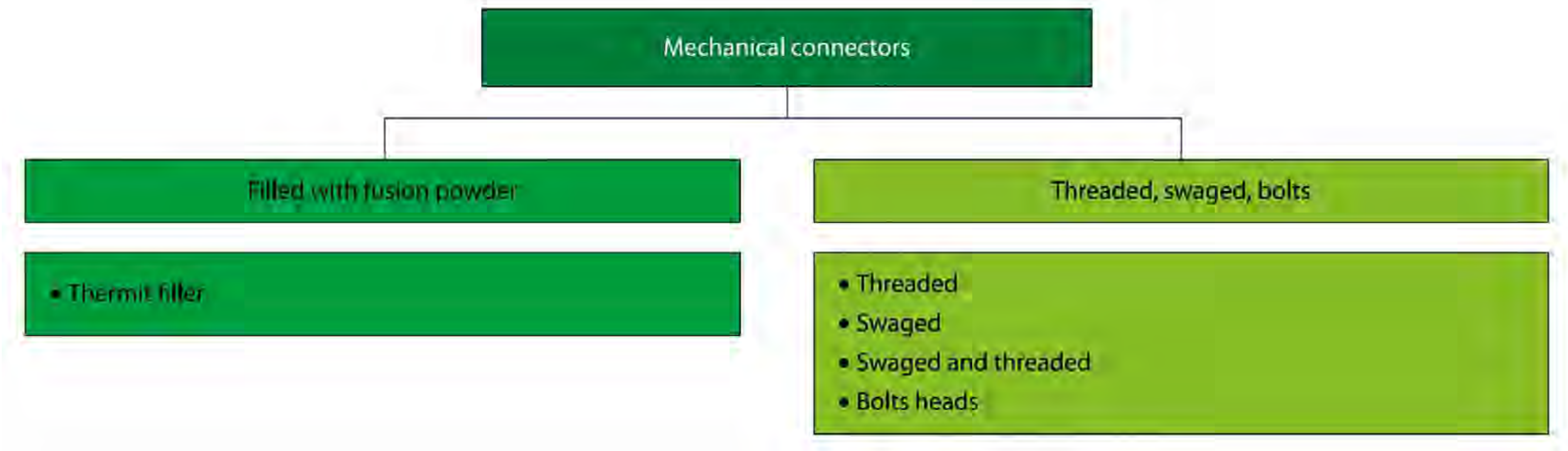
Welding is a method to repair or create metal structures by joining metal or plastic pieces using various fusion processes. Generally, heat is used to weld the materials.

The welding equipment can use open flames, electric arc, or laser light. Arc welding using the carbon arc and the metal arc was developed, and resistance welding became a practical joining process as it is known today. This process welded studs, screws, etc. to the base metal using a special gun that automatically controlled the arc. The fluxing elements on the end of the stud improved the properties of the weld. Stud welding became popular in the manufacturing, shipbuilding, and construction industries.

There are many other variations of these processes that are not specifically processes themselves. Undoubtedly, additional welding processes and methods will be developed and adapted to metalworking requirements as necessary. The rebar connections can generally be classified as follows:

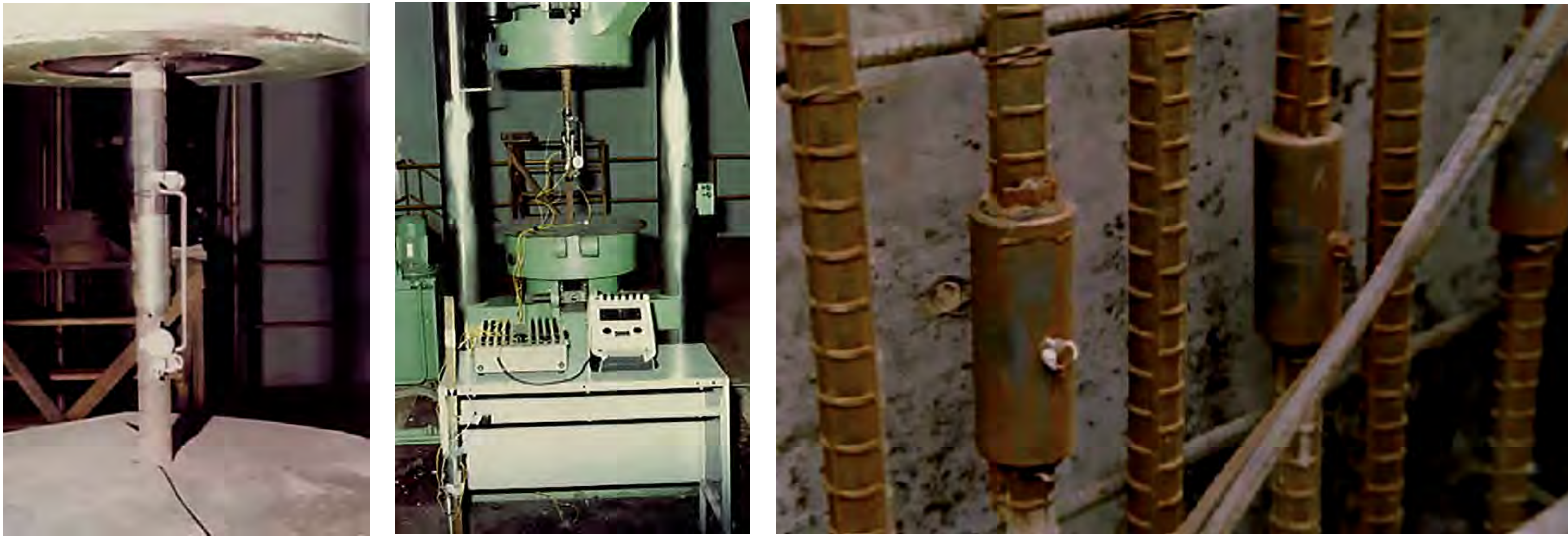


Welded splices and connectors types[03-03]



Welded splices and connectors types[03-03]

To maintain the ductility of the structure, the coupling system must also be ductile. Although a uniform elongation greater than 5% is desirable, very few coupling systems can achieve this result. Care should be taken when locating the couplers to ensure that the structure ductility is not reduced below the design requirements.



Samples of mechanical threaded couplers used for the tensile test at the Itaipu Laboratory. Mechanical couplers filled with fusion powder used during the construction of the Itaipu Project (Andriolo's Archive)

3.9.2 Qualification-Control

Reinforcing bars are classified based on the yield strength of the steel from which they are made. The classifications are designated by the word "*Grade*", followed by a two-digit number that indicates the minimum ***yield strength*** of the steel. The yield is the value at which permanent deformation occurs. After the yield value, subsequent deformation is confined to a small constriction or the neck, and as the area on which the load is acting is reduced, a smaller load is required to produce a greater deformation.

The tensile strength measures the force required to pull something such as a rope, a wire, or a structural beam until it breaks. The tensile strength of a material is the maximum amount of tensile stress that the material can withstand before a failure, such as breaking. There are three typical definitions of tensile strength:

Yield strength: The stress that a material can withstand without permanent deformation. This value is not a sharply defined point. The yield strength is the stress that causes a permanent deformation of 0.2% of the original dimension.

Ultimate strength: The maximum stress a material can withstand.

Breaking strength: The stress coordinate on the stress-strain curve where rupture occurs.

Ductility is the ability of a structure to experience large deformations and deflections when overloaded. If a structure cannot withstand large deformations and deflections when overloaded, then it is subject to brittle failure. The ductility control can be performed during the bending tests for bending members with excessive tensile steel.

Bending stress: When a piece of metal is bent, one surface of the material stretches in tension, whereas the opposite surface compresses. The line or region of zero stress between the two surfaces is called the neutral axis.

Bond-In reinforced concrete beams, the embedded reinforcing bar and the surrounding concrete are assumed to have identical strains. Therefore, the ***bond force*** must develop on the interface between the concrete and the steel to prevent significant slipping at the interface. However, the following points must be considered:

⇒ Weak chemical adhesion

⇒ Mechanical friction between the steel and concrete

⇒ Slip-induced interlocking of the natural roughness of the bar with the concrete

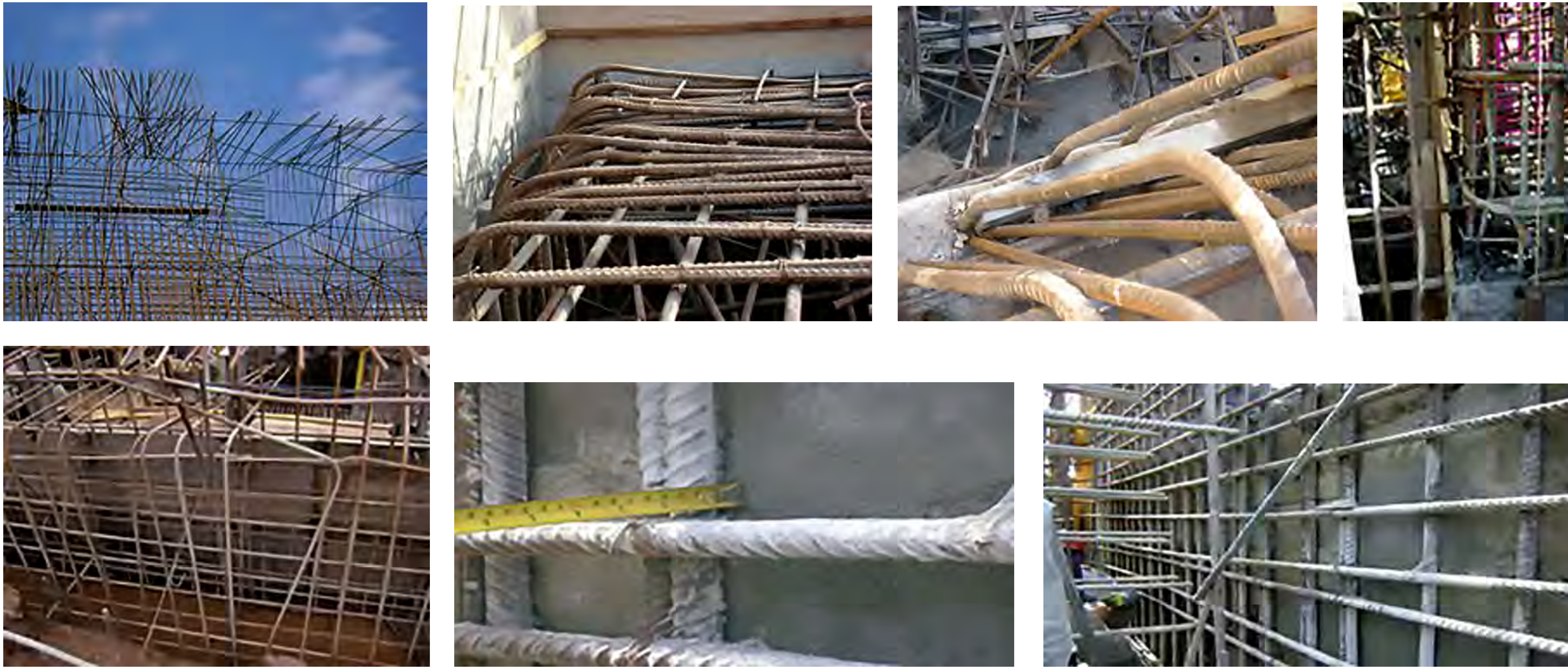
⇒ End anchorage, hooks.

Considerations of the bond and the detail design for anchorage, development length, and structural integrity requirements are important for proper structural performance of a building.

Deformed bars provide the bond force via the shoulders of the projecting ribs on the surrounding concrete. This type of steel bar works with the concrete to withstand the design stress. Rib effects allow the deformed bars to withstand exterior forces.

3.9.3 Rebar Uses

Care should be taken during the transport, fabrication, handling, installation, and concrete placement process. The users must take appropriate steps to inspect the bars after placement and repair any defects that are found.



Poor installation of the rebars. This need be avoided. (courtesy by Pedro Augusto Cassimiro de Araujo)

Inadequate covering of the rebars (Andriolo´s Archive)

Inadequate covering of the rebars, in a Spillway wall, that was noted after a first water flow (Andriolo´s Archive)

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4

DAM DESIGN

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4.1 Design Criteria Development

4.1.1 General

✓ ***The Author's opinion is that: The Engineers and/or Professionals that work on Dam Project Design, cannot use a Design Criteria and expect the answers and solutions as a light switching on!***

Design criteria are the explicit goals that a project must achieve in order to be successful. In recommendation and feasibility reports, especially, the design and decision criteria determine the document's final recommendation for action. Managers use these criteria as their basic tool in evaluating a project's potential for success and how well it fits into the goals of the organization. Experts need explicit design and decision criteria in order to evaluate recommended designs of devices and test procedures. Design criteria need to be as short as possible but as specific as possible, avoiding vague language.

It is not just a Calculation Routine, but one must know the aspects of concerns, the defenses imaginable and the adequacy of these defenses to the known conditions of the region. Many of the experiences in ancient lands, and some accidents (**Chapter 7**) are still relevant today and are useful to teach and call for attention.

In many countries, general interest in the safety of **dams** and reservoirs has grown appreciably in recent years. Protection of the public from the consequences of dam failures has taken on increasing importance as populations have concentrated in limited and vulnerable areas. Each disaster is viewed with public dismay and receives a measure of official scrutiny. A more sustained effort to collect, analyze, and remember the lessons from failures of dams has been made by the professionals charged with their care.

Critical project elements are those elements of a project whose failure could result in dam failure and an uncontrolled release of the reservoir. Critical project elements and associated design events/loading conditions are applicable to such features as: emergency spillways (design floods); impounding barriers (static and seismic loadings); outlet conduits (conduit integrity and seepage control); and impounding barriers.

The following discussion of some of the most significant hazards that lead to public risk illustrates the interrelationship of events that can lead to dam failure and must be understood and mitigate during the Design phase of the Project.

Developing some site-specific risk analysis may involve considering a range of hazards. Such analyses are helpful in stimulating better awareness, planning and design. In some cases, when dam structure analyses are quantitatively based and precise, conclusions about engineering and design can be made.

Judgment and engineering experience should play an important role in reaching useful conclusions in any site-specific analysis of structural risk. The complexity of the hazard is such that "*structural design and causes of dam failure are significant areas of research in engineering*". Indeed, better design criteria have been developed and safer dams are being built, but there is no basis for complacency. Dams continue to age; people continue to move into inundation zones and enough hazards exist that the net risk to the public will remain high for many years.

There are many complex reasons – both structural and non-structural – for dam failure. Many sources of failure can be traced to decisions made during the ***design (criteria, unknow materials properties, poor defenses)***, ***construction process (planning, methodology), poor quality control system***, and to inadequate maintenance or operational mismanagement.

⇒ ***This can be reduced to a unique concept: Poor Knowledge management!***

Failures also resulted from the aforementioned natural hazards – large scale flooding and earthquake movement. However, from the perspective of the owner, the structure of a dam is the starting point for thorough understanding of the potentials for failure.

Three categories of structural failure can be considered:

⇒ Overtopping by flood

⇒ Foundation defects

⇒ Piping

Overtopping may develop from many sources, but it often evolves from inadequate spillway design. Alternatively, even an adequate spillway may become clogged with debris. In either situation, water pours over other parts of the dam, such as abutments or the dam toe, causing erosion and failure to follow. Concrete dams are more susceptible to foundation failure than overtopping, whereas earth-fill dams suffer from seepage and piping. However, when overtopping and foundation failures are lumped together, they represent a great percent of the failures. The most important natural hazards threatening dams include:

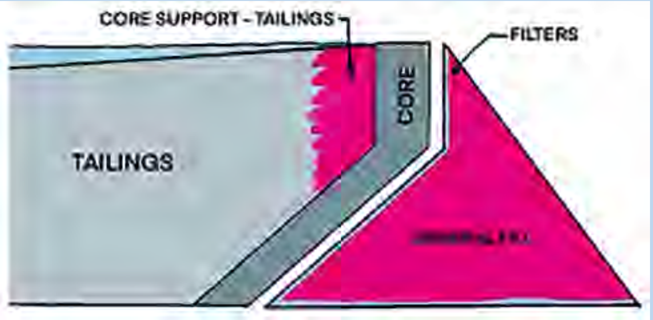
Potential Hazards	Aspects
Flooding from high precipitation	From the natural events that can impact dams, floods are the most significant. Flash floods can happen anywhere, even on small drainages. Floods are the most frequent and costly natural events that lead to disaster in some countries like USA, Brazil, South Asian countries, and Gulf Zone countries. Therefore, flood potentials must be included in risk analyses for dam failure. Dams are sometimes constructed to withstand a probable maximum flood (PMF) assumed to occur on the upstream watershed; this assumed event becomes the basis for the design of safety factors built into the dam (e.g., enhanced structural elements or spillway capacity). However, dams are often built in areas where PMF estimates are based on rather short precipitation and runoff records. As a result, spillway capacity may be underestimated. Often the full Design flood is established statistically considering a recurrence time of 10,000 years. When the flood data contains a limited number of years, a confidence interval of about 95% should be considered for the full project of 10,000 years. In addition, whatever the method used, if there are downstream populations, there should be an additional freeboard for any floods above the Design.

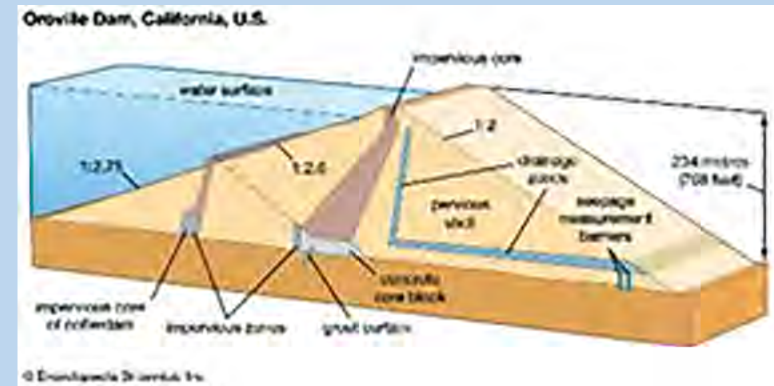
Potential Hazards	Aspects
Flooding from dam failure	When a dam fails as a result of a flood, more people and properties are generally placed in jeopardy than during natural floods. When a natural flood occurs near a dam, the probability of failure and loss of life almost always increases. The sudden surge of water generated by a dam failure usually exceeds the maximum naturally expected flood. Hence, it is important to make residents of those structures cognizant of the full risk to which they are exposed so that they can respond accordingly. When one dam fails, the sudden surge of water can be powerful enough to destroy another dam down the way (***as illustrated in Chapter 7 – item 7.1.1***). The potential for such a snowball effect is huge, but the problem may seem remote to a dam owner who has not studied the potential impacts of upstream dams on his own structure. Upstream dams may seem too far away to be a real threat, but inundation zones and surge crests can extend many miles downstream – especially if the reservoir behind the collapsed dam held a large quantity of water.
Earthquakes	Earthquakes are also significant threats to dam safety. Both earthen and concrete dams can be damaged by ground motions caused by seismic activity. Cracks or seepage can develop, leading to immediate or delayed failure. Dams such as those in California, located near relatively young and active faults are of particular concern. Yet, dams (especially older concrete and earthen structures) located where relatively low scale seismic events may occur are also at risk. However, recent detailed seismic analyses have indicated a much broader area of seismicity sufficient to damage dams; the seismic risk is essentially nationwide. Dam owners should be aware of the history of seismic activity in their locality and should develop their dam safety emergency procedures accordingly.
Landslides	Rockslides and landslides may impact dams directly by blocking a spillway or by eroding and weakening abutments. Indirectly, a large landslide into a reservoir behind a dam can cause an overflow wave which will exceed the capacity of the spillway and lead to failure. A land (or mud) slide can form a natural dam across a stream which can then be overtopped and fail. In turn, failure of such a natural dam could then cause the overtopping of a downstream dam or by itself cause a damage equivalent to the failure of a human-made dam. In addition, large increases in sediment caused by such events can materially reduce storage capacity in reservoirs and thus increase a downstream dam's vulnerability to flooding.
Sedimentation	The sedimentation can also damage low-level gates and water outlets; damaged gates and outlets can lead to failure.

Potential Hazards	Aspects
Human activity	This must also be considered when analyzing the risks posed by dams. By convention, classification of potential dam failure risk is based on the severity of potential impact, not on the structural safety of the dam. Thus, dams that may be of very sound construction are labeled “high hazard” if failure could result in catastrophic loss of life – in other words if people have settled in the potential inundation zone. The “high hazard” designation does not necessarily imply structural weakness or an unsafe dam. Lower classifications include “significant hazard” dams for which failure is estimated to result in large property loss, and “low hazard” dams for which failure is estimated to result in minimal property loss. The following is a common understanding for classifying dam hazards. Two extremes of human purpose – the will to destroy through ***war***, ***terrorism*** or ***vandalism*** and the urge to develop and to construct – can both result in public risks. Dams have proven to be attractive wartime targets, and they may be tempting to terrorists. On the other hand, a terrorist’s advantage of keeping the public at risk may well be illusory; the deliberate destruction of a dam is not at all easy to accomplish (***See Chapter 7 – item 7.2 – Edersee and Möhne Dams***). Yet, there is the possibility that such an act could occur, and it should not be discounted by the dam owner. All sorts of other human behavior should be included in risk analyses; vandalism, for example, cannot be excluded and is, in fact, a problem faced by many dam owners. Vegetated surfaces of a dam embankment, mechanical equipment, manhole covers, and rock riprap are particularly susceptible to damage by people. Every precaution should be taken to limit the access to a dam by unauthorized people and vehicles. Dirt bikes (motorcycles) and four-wheel drive vehicles, in particular, can severely degrade the vegetation on embankments. Other controls should be secured with locks and heavy chains where possible. Manhole covers are often removed and sometimes thrown into reservoirs or spillways by vandals. Rock used as riprap around dams is sometimes thrown into the reservoirs, spillways, stilling basins, pipe spillway risers, and elsewhere. Riprap is often displaced by fishermen to form benches. The best way to prevent this abuse is to use rocks that are very large and heavy to move around easily or to slush grout the riprap. If not, the rock must be regularly replenished and other damages repaired: Regular visual inspection can easily detect such human impacts. Owners should be aware of their responsibility for the safety of people using their facility even though their entry may not be authorized. “No Trespassing” signs should be posted, and fences and warning signs should be erected around dangerous areas. As discussed in **CHAPTER 2**, liability insurance can be purchased to protect the owner in the event of accidents.
Operational routine	Adjust the maintenance of the gate operating system and have an alternative operating system, also that the freeboard above the NA max.max. should be established, taking into account, in addition to the standard criteria, the uncertainties of the studies of flood function of the available data.

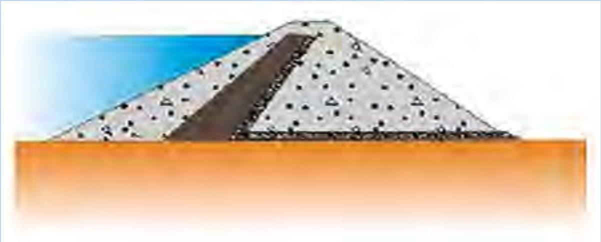
4.1.2 Dam Types

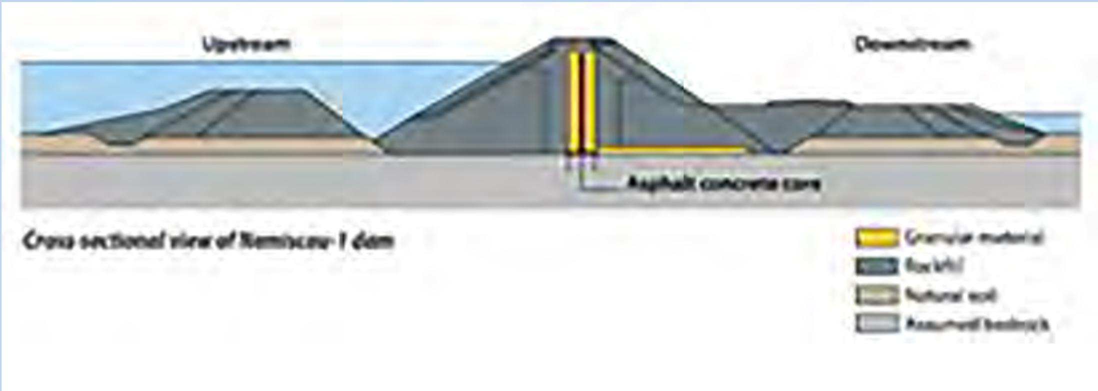
This text will address the following types of dams, commonly used around the World. Some variations may exist but do not constitute the majority, to have representativeness.

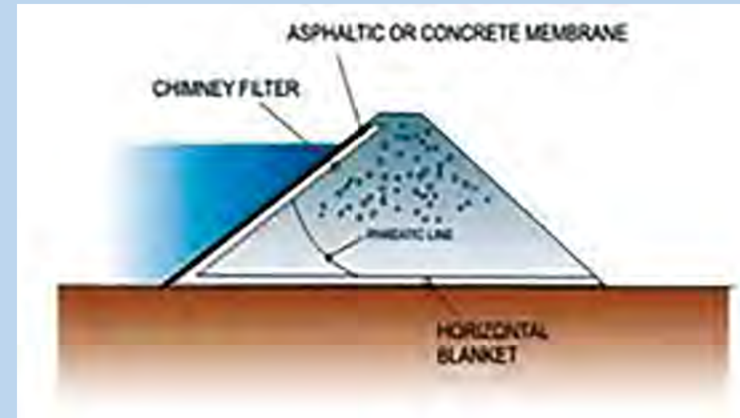
Dam Face	Dam Body	Dam Type	Concept	Ilustration
By Product	**Tailings**	**Embankment**	A **tailings dam** is typically an earth-fill or a by-product embankment dam used to store by-products of mining operations after separating the ore from the gangue. Tailings can be liquid, solid or a fine particles slurry, and are usually highly toxic and potentially radioactive. Solid tailings are often used as part of the structure itself. Tailings dams must be constructed with a filter-drain system and also with foundation treatment similar to those of the other dams. Tailings dams with upstream construction pose great risk and nowadays cannot be adopted in some countries.	 

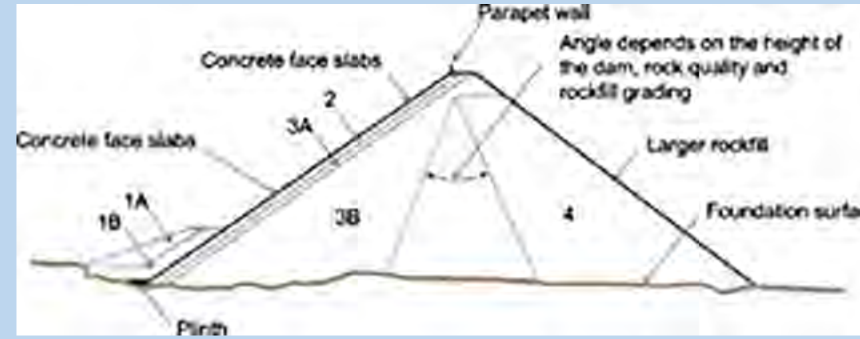
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Soli	Earth	Embankment	An Earth fill Embankment is typically dam created by the placement and compaction of various compositions of soil, sand, clay.	  Oroville Dam – USA

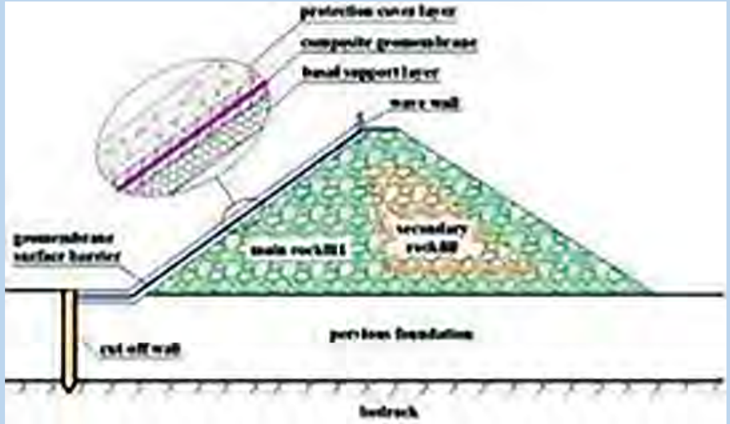
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Soil + Water	**Hydraulic**	**Embankment**	A **hydraulic fill** dam is an embankment or other fill in which materials are deposited in place by a flowing stream of water, with the deposition being selective. Gravity, coupled with velocity control (***Stoke's Law***), is used to develop the selected deposition of material.	  **Fort Peck Dam – USA**

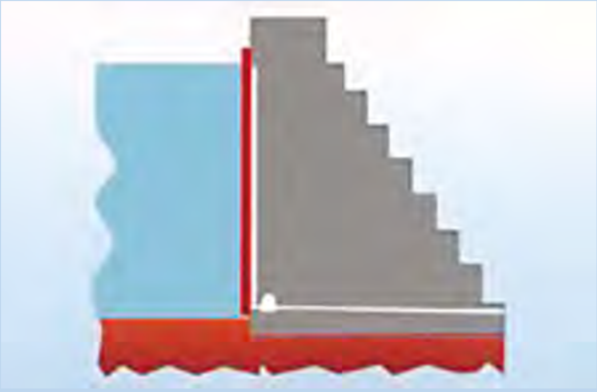
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Core	Rock-Clay	Embankment	A rockfill embankment with clay core may be defined as an embankment dam to form the impermeable barrier with a clay core.	  

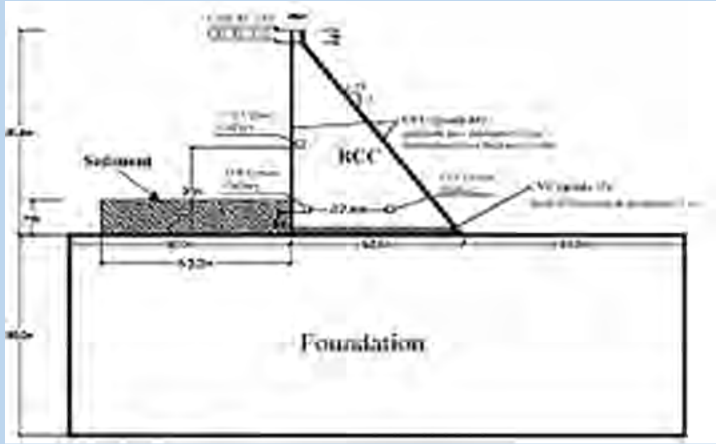
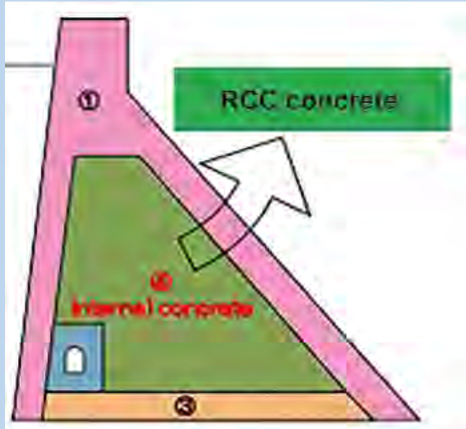
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Rock	Rock-Asphalt Core	Embankment	A rockfill embankment with asphalt core may be understood as an embankment dam to form the impermeable barrier with an asphalt wall as core.	 

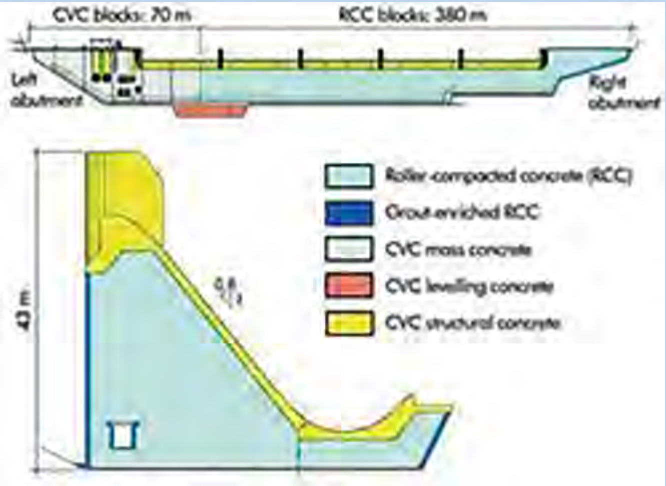
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Asphalt	Rock	Embankment	A rockfill embankment with asphalt face may be defined as a rock body embankment dam to form the impermeable barrier with an asphalt face.	 

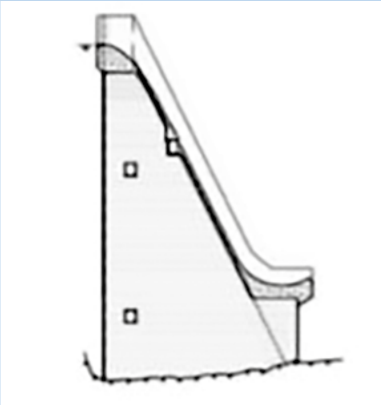
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Concrete	**Rock**	**Embankment**	A rockfill embankment with concrete face (CFRDam) may be defined as an embankment dam to form the impermeable barrier with a concrete slab casted as face.	 

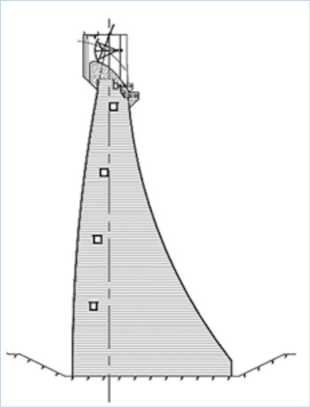
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Geomem-brane	**Rock**	**Embankment**	A rockfill embankment with geomembrane face may be defined as an embankment dam to form the impermeable barrier with a geomembrane placed as a face. ***Note: A membrane can be set as a core, but it is used less.***	  **Morawa Dam – Czech Republic**

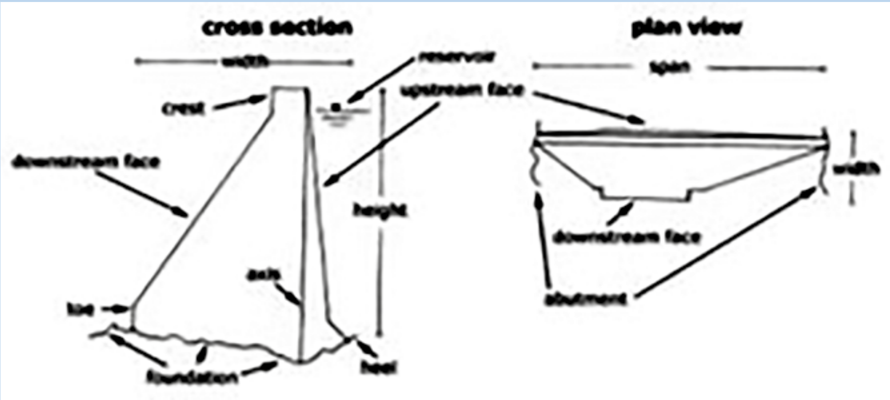
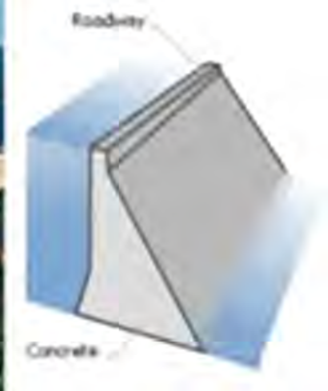
Dam Face	Dam Body	Dam Type	Concept	Ilustration
Geomem-brane	RCC-Gravity	RCC-Concrete	A **gravity dam** is constructed from **Roller Compacted Concrete (RCC)** using the weight of the material alone, with a geomembrane placed as a face.	  Balambano – Indonesia

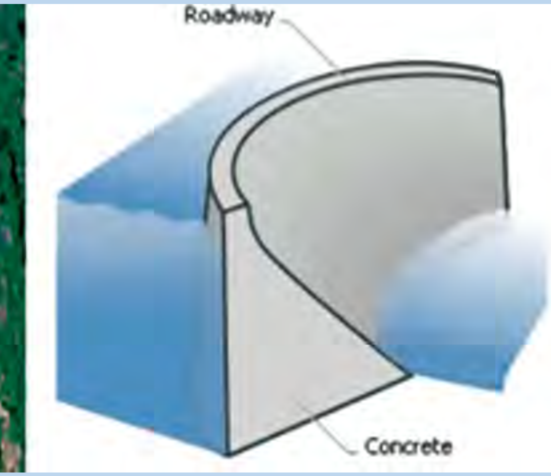
Dam Face	Dam Body	Dam Type	Concept	Ilustration
CVC	RCC-Gravity	RCC-Concrete	A gravity dam is constructed from Roller Compacted Concrete (RCC) by using the weight of the material alone, with a face casted with conventional vibrated concrete (CVC)	 

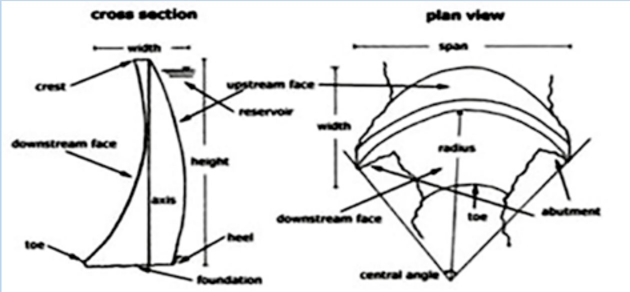
Dam Face	Dam Body	Dam Type	Concept	Ilustration
GE-RCC	RCC-Gravity	RCC-Concrete	A **gravity dam** is constructed from **Roller Compacted Concrete (RCC)** using the weight of the material alone, with a face casted with Grout-enriched RCC (GE-RCC).	  **Pedrogão – Portugal**

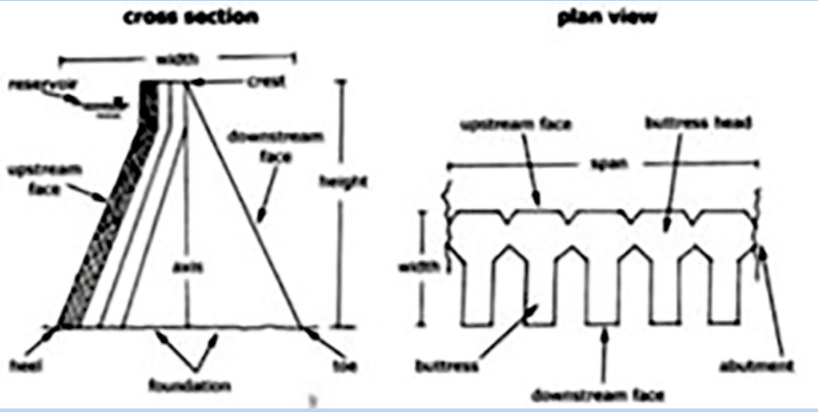
Dam Face	Dam Body	Dam Type	Concept	Ilustration
GE-RCC	RCC – Arch Gravity	RCC-Concrete	An Arched (or a cylindrical arch) **gravity dam** is constructed from **Roller Compacted Concrete (RCC)** using the weight of the material alone, with a face casted with Grout-Enriched RCC – (GE-RCC).	  **Portugues – Porto Rico**

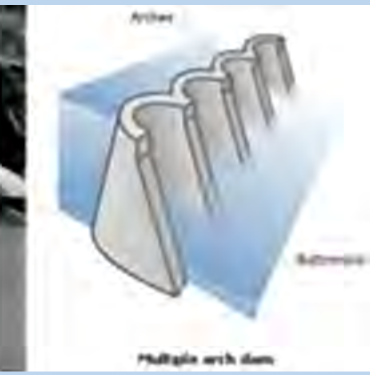
Dam Face	Dam Body	Dam Type	Concept	Ilustration
GE-RCC	**RCC – Double Arch**	**RCC-Concrete**	An Arched (or a double arch) **gravity dam** is constructed from **Roller Compacted Concrete (RCC)** using the weight of the material alone, with a face casted with Grout-enriched RCC (GE-RCC).	  **Linhekou – China**

Dam Face	Dam Body	Dam Type	Concept	Ilustration
CVC	**CVC -Mass**	**CVC Gravity**	A **gravity dam** is constructed with Conventional Vibrated Mass concrete using the weight of the material alone.	  **Shasta – CA – USA**

Dam Face	Dam Body	Dam Type	Concept	Ilustration
CVC	**CVC**	**CVC Arch Gravity**	An Arched (or a cylindrical arch) **gravity dam** is constructed with Conventional Vibrated (CVC) Mass concrete using the weight of the material alone.	  **Monticello – CA – USA**

Dam Face	Dam Body	Dam Type	Concept	Ilustration
CVC	**CVC**	**CVC Double Arch**	An Arched (or a double arch) **gravity dam** is constructed with Conventional Vibrated (CVC) concrete using the weight of the material alone.	  **Theodore Roosevelt – AZ – USA**

Dam Face	Dam Body	Dam Type	Concept	Ilustration
CVC	CVC	CVC Buttress	A **buttress dam** or **hollow dam** is a **dam** with a solid, watertight upstream side that is supported at intervals on the downstream side by a series of **buttresses** or supports constructed with Conventional Vibrated Concrete (CVC) – FLAT.	  Lake Tahoe Dama – CA – USA

Dam Face	Dam Body	Dam Type	Concept	Ilustration
CVC	CVC	CVC Multiple Arch	Is a set **of multiple arches** with a solid, watertight upstream side that is supported at intervals on the downstream by stiffeners casted with reinforced concrete (RCVC).	   Bartlet – AZ – USA

4.1.3 Common Types of Dams

It is clear that each site allows the optimization of a type of dam to meet the interests of society in the most economical, technical and safe way. In general, the following types of dams are adopted in different locations.

Dam Type	Aspects and normal uses
Hydraulic Fill	Suitable in soft material valleys and are constructed by pumping duly consolidated soft material to moderate heights up to 30m. Nowadays this type of dam is not used anymore.
Earth-Fill	Near the site there must be soils of low permeability after compaction, but not necessarily a very clayey soil. Or in the upstream and downstream backrests, the resistance to shear is the deciding factor, and the amount of clay/low permeability is no longer important. An advantage of earthen embankments is that troubles due to the deterioration of the structure by low pH peat waters do not arise. The amount of fines in the available material and the knowledge of the characteristics evaluated allow to optimize the solution and obtain a safe dam.
Rock-Fill	Rockfill dams can be built where the following conditions exist: o Uncertain or variable foundation which is unreliable for sustaining the pressure necessary for any form of concrete dam; o Suitable rock in the vicinity that is hard and weather-resistant; o An adequate amount of clay in the region that can be inserted into the dam either as a vertical core or as a sloping core; o Accessibility of the site and the width of the valley is suitable for the manipulation of heavy earth-moving machinery, caterpillar scrapers, sheep foot rollers and large hard rock at or near the surface.
Gravity	The depth of soft material above the rock should not exceed 7-10m, thereby avoiding excavation. Materials for concrete, i.e., aggregate, stone and sand should be easily accessible within 10-20 km. Gravity dams are suitable when the crest length is five times or more than the dam height.

Dam Type	Aspects and normal uses
Buttress	The buttress dam is suitable where the rock is capable of bearing pressures of 2 – 3 MPa. Buttress dams require between a half and two thirds of the concrete required for a gravity section, hence making it more economical for dams over 14m. Additional skilled labor is required to create the formwork. Threat of deterioration of concrete from impounded water is more likely than from a thick gravity section. There is also an elimination of a good deal of uplift pressure, the pressure resulting from the water in the reservoir and possibly water from the hillside rocks accessing through or under any grout curtain and exerting upwards underneath the mass concrete dam.
Arch	An arch dam utilizes the strength of an arch to resist the loads placed on it by 'arch action'. The foundations and abutments must be competent not only to support the dead weight of the dam on the foundation, but also to withstand the forces that are directed to the abutments due to the action of the arch in response to the forces acting on the dam. Therefore, the strength of the rock mass at the abutments and immediately below the dam valley must be unquestionable and its modulus of elasticity must be high enough to ensure that the deformation under the arch thrust is not so great as to induce excessive stresses in the arch.
Thick Arch	The thick arch dam can be built where the crest chord-height ratio is between 3 and 5. The main geological criterion is that the rock must be absolutely reliable to bear 3.5 MPa or more without any appreciable settlement. A substantial material savings compared to gravity dams. Thick arch dams are difficult to design on paper but are well determined from trials on models.
Thin Arch	Thin arch dams require valleys to have a crest chord-height ratio of under 3, with a radius of less than 150m. The pressure exerted on the valley sides is between 5.5 – 8 MPa. When there is a vertical and a horizontal radius of curvature, it is known as a cupola or dome type. It is used where cement is expensive and labor is cheap.

Dam Type	Aspects and normal uses
Multiple Arch	The multiple arch concrete dam is a variety of buttress dam. The main geological criterion is that the rock must be absolutely reliable to bear 2-3 MPa or more without any appreciable settlement (<8mm). There are some savings in concrete compared with buttress dams. In regards of uplift, corrosion and economy, the two types are very similar.
Composite	Not only can some different types of dams be built in the same valley, but the same dam can be of different types due to the varying geological and topographical features of the dam site. Many buttress dams also join mass concrete gravity dams at their haunches on the sides of the valley and again in the center a mass concrete gravity dam to form a suitable overflow or spillway.

4.1.4 Historical Development

When looking at the Iberian Peninsula[04-01], it is possible to notice the existence of Dams (Proserpina, Cornalbo) built by the Roman Empire. Some major repairs were made in the Proserpina Dam by 1942 including rehabilitation of the masonry. Water is still supplied via a Roman aqueduct between the dam and Merida-Spain. The water supply for Merida was enhanced at a later date by construction of the Cornalbo Dam on the Rio Albarregas.

From **[04-01]** it can be understood that:

"...The Romans built many stone dams throughout their empire. These were usually composed of mortared cut-stone masonry of great durability and impermeability. The Romans also recognized the need for soil conservation. The complex of masonry dams which the Romans erected in the wadis was designed for two purposes – water supply for the cities and protection of the land from erosion...

...Early in the 17th century, the Ternavasso Dam was built in the southeast of Turin in Italy. Another Italian structure of the same period is the Ponte Alto Dam, a thin arch on the River Fersina just east of Trento.

In 1747, the Almendralejo Dam was built about 51 kilometers south of Badajoz, Spain. It is also known as the dam of Albuera de Feria, south of Badajoz, Spain. It is also known as the dam of Albuera de Feria. This rubble-masonry buttress dam has survived without any significant deterioration. Buttresses provide support at the downstream face.

The design concepts of the early Spanish dam engineers were conveyed to the colonies in America. However, in some of these lands, water projects had been developed before the conquest. Hundreds of masonry dams were erected by the Spanish in Mexico.

The first true multiple-arch water barrier recorded is the Meer Allum Dam, built in about 1800 near Hyderabad in India.

During the XIXth century, the art of masonry dam construction made important advances. European gravity dams developed architectural form and finish quite in contrast to their crude predecessors. French dam design began to incorporate rational approaches to analysis of forces. In 1853, M. de Sazilly, a French engineer, advocated that pressures within a dam be held to specific limits and that the structure be dimensioned to preclude sliding. However, he did not recognize the concept of keeping the resultant of forces within the middle third of each horizontal plane. This was emphasized about 25 years later by W. J. M. Rankine of England, who also sought a relationship between pressures on different planes in the structure.

At about the same time, engineers in the eastern part of the United States of America were starting to build some notable dams. Among them were the Old Croton Dam, completed in 1842, on the Croton River for water supply to New York City; Mill River Dam in 1862 for New Haven, Connecticut; Lake Cochituate Dam in 1863 for Boston, Massachusetts; and the Druid Lake Dam in 1871 for Baltimore, Maryland.

While these relatively crude works were being constructed by the western American pioneers, European engineers were engaged in more sophisticated projects. In France, the Zola Dam regarded as the first arch dam built by the French, was completed in 1854.

In the United States, early gravity dams generally had conservative proportions. Cheesman Dam, completed in Colorado in 1904, was 72 meters in height and curved in plan on a radius of 122 meters even though it was a full gravity section. This established an American precedent for the arch-gravity barrier. Engineers recognized that the joints in these structures should be filled so as to resist loads. Otherwise, the arch function could not develop until deflection under gravity action had closed the joints…

…Design concepts for gravity dams were beginning to change. The middle third criterion for dimensioning these structures was being questioned. It had been generally accepted as assurance against overturning of moderately loaded dams. But several failures demonstrated that uplift and sliding could be of greater concern. Designers began to consider these factors in engineering new projects.

As early as 1882, a drain network to reduce uplift had been incorporated into the design of the Vyrnwy Dam for the water system of Liverpool, England. Engineers in the United States gave first recognition to uplift in design of the Wachusetts Dam in Massachusetts (1900-1906). A cutoff was built under the dam downstream from its heel, but no drains were provided. Olive Bridge Dam in New York State (1908-14) was constructed with drains in the structure itself but with none in the foundation. Among the first dams with both masonry and rock drainage were Medina in Texas (1911-12), Arrowrock in Idaho, and Elephant Butte in New Mexico (1914-15). The foundations at these sites were drilled to control seepage. Since then, drilling has been common practice for large gravity dams…

...However, this new record was soon surpassed. Within the next few years, three important arched barriers were completed in the West. The 85 meter high Theodore Roosevelt Dam (1911), a thick, arch-gravity structure in Arizona, and the 65 meter high Pathfinder Dam (1909) in Wyoming...

...Americans were also making progress in embankment construction. Some of their first major earth fills were in California. Rock fill dam technology was given new impetus in the United States. The Owyhee Dam (1932), a concrete, thick, arch-gravity structure in Oregon, was designed as an arch...

...The increase in the number of dams since 1900 has been impressive. Around the globe, very high dams kept up with this rapid pace. Up to 1939, only 11 dams more than 100 meters high were completed – 5 in western Europe and 6 in the United States. By 1960, there were 88 such structures in operation throughout the world, and 65 more were built in just the next 5 years. New records have been set in quick succession...

...Outstanding height precedents for concrete structures have been achieved since midcentury by the Mauvoisin Dam (1957) in Switzerland, 237 meters; the Vaiont Dam (1961) in Italy, 265 meters; and the Grande Dixence Dam 285 meters and Contra Dam 220 meters (1965) in Switzerland...

...The records for volume and height of dam are also being surpassed. Since the distant beginnings of human history, the engineering of dams has evolved from primitive trial-and-error ventures to increasingly sophisticated analytical approaches. Early dam building was an uncertain art resting on cumulative experience. As the centuries unfolded, the art was gradually merged with science. Mathematics and the mechanics of materials have become increasingly effective in development of safer designs. Theoretical analysis combined with the practical judgment of the experienced engineer will provide the best insurance as the search for water moves to new horizons."

Over time the dams were built considering the characteristics of the site with increasing heights, as exemplified below:

Dam Type	Name of Dam	Country	Height (m)	Year Completed
Hydraulic Fill	Fort Peck	USA	76	1940
Concrete Gravity	Grand Dixence	Switzerland	285	1962
Concrete Multiple Arch	Daniel Johnson	Canada	214	1968
Rock Fill	Chicoasén	México	265	1981
Earth fill	Nurek	Tajikistan	300	1985
Earth Rock Fill	Kinshaw	India	253	1985
Tailing	Syncrude – Mildre MLSB	Canada	88	1995
Concrete Arch Gravity	Ertan	China	240	1999
Concrete Faced Rockfill	Changheba	China	240	1999
Concrete Arch	Xiaowan	China	292	2010
Roller Compacted Concrete	Gibe	Ethiopia	243	2015

4.1.5 Risks Mitigation

The risk of the failure of a dam is one of the inevitable burdens of civilization. A primary duty of the engineer is to minimize this hazard. In no other field of engineering is the responsibility to the public heavier or more exacting.

- ✓ ***Dam safety programs are of vital importance to all of society and call for a multidisciplinary use of talent. Engineers must work closely with other professionals, including geologists and seismologists. Coordination can help to reduce the uncertainties but, due to difficult constraints, not all dam failures can be averted.***

As builders are forced to use poorer sites, the job of protection becomes more difficult. Since millions of people live practically in the shadows of major dams, it is imperative that increasing attention be paid to finding the best ways to ensure protection.

This requires united effort by all agencies dedicated to safe water and power services. Offsetting some of the increased risk, including the greater consequences of failure as populations swarm in the lands below reservoirs, is the growing body of knowledge of dams.

- ✓ ***More is known about how to design them, how to build them, and how to keep them safe***.

A significant part of this knowledge was acquired from failures. Even the best designers of any of man's works have seen their structures in trouble. They have become even better designers by learning from these lessons. Some critics have said that certain kinds of dams are safer than others. They recommend that any of the weaker types should be built. But there is no consensus as to which is stronger and which is weaker.

- ✓ ***The argument is largely a waste of time. Dams cannot be rated in terms of generalities. Certainly, when site specifics are considered, one type of dam may be judged preferable to another. But the selection among alternatives must follow exhaustive examination of local conditions – past, present, and future – and their possible effects on the structure***.

The investment in safety should be accepted as an integral part of project cost, and not an extra item that can be eliminated if the budget is tight. This concept of safety applies throughout all phases of project development, from planning through design and construction, to operational surveillance.

Economy should not take precedence over doing the job right. While an engineer is trained to consider cost as a deciding factor in choosing among alternatives, each option considered must produce a safe structure. Engineers must not be concerned that a good design will price them out of business. Defensive design measures have their prices, but they must not be compromised.

Striking a balance between saving money and safety is not easy. Increasingly, the dam sites now being considered are not of first quality, and dam designers are forced to build on foundations that would not have been selected just a few years ago. This comparative quality of sites must be recognized in budgeting for projects. Even with anticipated higher costs, we it must be willing to pay the price for the necessary additional safeguards. The temptation to cut corners must be resisted. If good engineering cannot be guaranteed, the project should not be built.

Yesterday's practices may not necessarily be good enough for tomorrow's needs. Future dam sites will continue to present new challenges to engineers. As technology improves, we must continue to learn and to apply this new knowledge.

Existing dams and reservoirs should be reanalyzed periodically to ensure that they can still meet the test of safety by current standards. As knowledge of hydrology, seismicity, and the geological environment accumulates, and technology advances, facilities once regarded as safe may need modifications. Safety of dams requires consideration of more than the technical factors.

Looking at the organization, for example, one thing which must be assured is that all voices are heard. Ideas may come from within the organization – from nearly any level – or from outside. The latter includes, of course and particularly, consultants. One of the greatest hazards in the engineering of major structures is the exclusion of the ideas of those who may have valuable contributions to make. The management of any organization must exert special effort to assure that this does not happen.

In case histories of projects gone wrong, the dominance of single decision makers – sometimes authorities whose reputations for expertise were well earned – is not uncommon. Even experts can make mistakes, and probably the worst is to assume that an expert's judgment need not be questioned by those qualified to question it.

Another consideration, especially in large organizations composed by many compartments, is to assure that information flows among the units. The many ideas essential to good engineering must be shared freely across the internal boundaries. The integration of separate efforts should be continuous throughout the evolution of designs, rather than simply gluing together individual final products. This means that designing must start with a general perspective and then focus on the individual parts – not vice versa.

There must be recognition of the inseparable relationship of design and construction. These functions are best considered as a single process. Design is not completed until construction is accomplished. Designers and construction engineers must work in concert during design and while the dam is being built so that the disclosed site conditions can be weighed against design objectives. Any necessary modifications in design during this period should be a collaborative effort of designers, geologists, climatic and nature knowledge, and construction engineers. The vital relationship between the engineer and the geologist needs continuing emphasis. They must work as closely together as the dam and the nature.

The organization must assure that its engineers, geologists, and other professionals continue to learn and apply the latest technology. This can be accomplished in various ways, including attendance at professional conferences, counseling and lecturing in-house by consultants, advanced university courses, personnel exchanges with other organizations, and periodical recruitment of new personnel with advanced education or advanced experience.

A generally competent organization must still be willing to accept – in fact it should seek – independent review of its engineering practices. The levels of technological advancement and the expertise of individual staff members can vary from unit to unit even within the best of engineering organizations. The inflow of knowledge from the outside will serve to strengthen areas of relative weakness.

Dams require defensive engineering, which means listing every imaginable force that might be imposed, examination of every possible set of circumstances, and incorporation of protective elements to cope with each and every condition. Lines of defense should be erected in succession, so that if one fails the next will take over. Each project calls for its own tailoring of defenses to meet the hazards inherent and peculiar to the site.

To assemble the array of possible occurrences, the proposed construction site must be thoroughly known and understood. Exploration and testing must pursue all clues relating to surface and underground conditions. Those responsible for the project budget must understand that the knowledge gained is absolutely essential and worth the price. Also, the same can be said for expenditures related to instrumentation which will continue to provide information on site conditions once the project is built. The different ways in which dams can fail are known.

The **Chapter 7** shows a large list of accidents and the published causes. Single-arch dams have been known to collapse quickly when their foundations failed (Malpasset in France), although arches are inherently very strong structures. Dams dependent on buttresses, such as slabs and multiple arches, may disintegrate as the buttresses fail in succession like a row of dominoes. Embankments tend to fail more slowly, but they are obviously more susceptible to erosion than masonry structures.

There are reliable ways to design against such tendencies. Potential causes and modes of failure must be thoroughly listed and examined. One of the greatest risks of error in the design process is to overlook any one of these possibilities. In searching for adverse combinations of occurrences, the designer must consider the structure, the site, and the vicinity. The dam and its foundation must be designed to function together as an integral unit. These considerations are fundamental, but they need repeated emphasis.

- ✓ ***Concepts and hypotheses will often be more important than calculations, which may be worth little if founded on the wrong assumptions***.

Most failures can be attributed to simple, sometimes apparently insignificant, causes. Sophisticated designs have sometimes failed due to oversights that were obvious in retrospect. Designers should be encouraged to use the most advanced analytical techniques, but at the same time, they must be cautioned not to forget elementary forces.

Accidents and failures provide lessons which must be thoroughly learned and shared. A wise engineer will examine all such information that can be found, including his own mistakes as well as those of others. The designer must assume that any of these problems can occur on any project and must make every effort to prevent them.

- ✓ ***One of the basic guiding principles that must be followed is that extreme conditions should be averted by changing the setting. Seepage barriers or interceptors will do this.***

Designs must be as foolproof as possible. This also includes auxiliary facilities. For example, even well-trained operations personnel may not perform as expected. In an emergency, they may not be where they are needed.

Mechanical and electrical equipment may fail to operate. These are real possibilities or probabilities. The safest designs therefore will be those that can function despite any of these happenings. This is accomplished by minimizing dependence on operators and equipment for making emergency releases. An ungated spillway gives such assurance. Where gates or valves are used for spillways and outlets, redundant power and control systems will enhance reliability.

In imagining what can go wrong with a dam, its typical characteristics and those of its foundation must be recognized. We it is know, for example, that an arch depends on unyielding abutments and that a gravity structure may have to resist foundation water pressures of high magnitude. It is also must accept that the zones of an embankment will not be homogeneous, despite the best of construction controls. While the designer of an embankment may assume uniform characteristics to facilitate analysis, he must remember that the materials in the as-built embankment will be variable. Borrow areas and quarries may yield soils and rock that only roughly resemble what the designer assumed, even if the specifications are exact.

There will be further differences in the embankment from lift to lift. Moisture, density and gradation may be considerable. It is quite understood that consolidation causes permeability to range appreciably from crest to base. Even though the design objective is theoretically to have uniform zones – and the construction engineers must strive for such quality – this is an ideal that is never achieved. Knowing this, the prudent engineer will incorporate successive line of defense to guard against defects.

Filters and drains must be incorporated into the design to control seepage that theoretical calculations may not forecast. No matter how much foundation exploration and testing has been done, the designer should be concerned about the foundation's capabilities, and should require enough foundation treatment to compensate for the unknowns.

Despite the best work of the best people, some seepage is inevitable at the dam site. As long as precautions are taken for its control, the dam should be safe.

The key question, of course, is:

- ✓ ***Where might the water go, and what damage can it do?***
- ✓ ***The potential for damage will depend upon the water pressure differences along the seepage path.***

Consider the example of a severely open-jointed foundation rock intercepted by a single grout curtain. If water can flow from the reservoir to the curtain with minimum head loss, the pressure differential through a window in the grout barrier may be high – depending on how effective the curtain is in reducing general pressures on its downstream side. Anything standing in the way of a stream through the window is best not to be movable. This would suggest that a grout curtain by itself may not be totally beneficial, even if it is a zone of appreciable thickness. It may be most ineffective at its top, where grouting pressures were low. And this is where it needs to be most effective.

Unless the foundation itself is erodible, the escaping water can probably do its greatest damage where it impinges on the underside of an embankment. While grout curtains are useful to reduce foundation water losses, they should not be considered to protect embankment materials from contact with the foundation. The fill should be isolated from potentially detrimental flows in the foundation by one or more safeguards. These may include consolidation grouting, slush grouting, concrete dental work, a concrete layer, or filters.

Seepage control by drainage often provides more reliable results than cutoffs, including grout curtains. But these measures are not mutually exclusive; each may have an important function and depending on the characteristics of the foundation, both should be used simultaneously. Drains should be capable of conveying water under low hydraulic gradients. In designing them, we must remember that discharge capacity can be restricted by breakdown of aggregates, by excessive fines, and by compression under embankment loads. Some engineers still rely on unscreened sands and gravels for drains and filter zones. The use of such materials transported directly from natural deposits can lead to serious problems. They cannot be condemned without reservation however, because their characteristics vary widely from site to site. Some have enough drainage capacity while some do not.

Compared with masonry structures, embankments are generally less homogeneous, even within each zone. Differences in internal conditions might make them vulnerable. A permeable layer inadvertently placed within a zone intended to be impervious might constitute a conduit through the dam.

An impermeable layer placed within a zone intended to be pervious may preclude proper drainage. Placement of a fine zone against a coarse zone without a filter may permit the movement of particles from one zone to the other. These hazards are obvious, and yet they have sometimes been disregarded, even by engineers who should have known better.

Embankments and their foundations must be designed so that internal boundaries will always be maintained. The dangers may include movement or solution of the foundation rock itself, or migration of embankment material into the rock joints and fractures.

The tendency to think of averages in the engineering of dams must be resisted. Failures occur where the dam or its foundation is weakest, not where it is in average condition. The design must focus on the potential weaknesses. Exploration and testing will necessarily depend on sampling techniques, with results varying sometimes over a wide range.

Natural materials (and at this point is important to remember the 10 books from ***De Architectura – Marcus Vitruvius – 40 AD*** [04-02] – as will be mentioned in **Chapter 6**) available for construction may exhibit average characteristics that meet requirements; yet they may be judged totally unacceptable when their variations are considered.

The variability of natural conditions does not encourage unreserved faith in standard guidelines or "cookbook" approaches to dam engineering. No matter how many exploratory holes are drilled or how many samples are tested, the reservoir site may still contain surprises – and these may appear at any time during the life of the structure.

For example, in the interest of economy, engineers may elect to leave channel alluvium in place under an embankment. Prudent engineering will require at least that the streambed materials be thoroughly sampled and that gradations be determined. While this testing may indicate that the alluvium is compatible with overlying zones of the dam, a designer with good judgment will recognize that irregularities may still exist. Without debating the advisability of building a dam on such a base, as the very least, the interface between foundation and superimposed materials should be protected.

Writers of manuals cannot foresee exactly what should be done in such cases. Professional judgment must be applied by the engineer on the spot.

In the field of dam safety, however, those who possess such judgment are not numerous enough to match the needs. Therefore guidelines can be of value, especially if they are used with some flexibility. They do provide a way for experts to share their knowledge with those who are less experienced. Flexibility is the key. Rigid criteria are useful only as long as conditions match the underlying assumptions. They fail when deviations are not perceived or when the latitude and the judgment are not available to make the necessary adjustments. The trouble with a "cookbook" is that some of its users may come to think that it contains all the recipes. Design by the book is especially hazardous in an organization insulated from professional interchange.

4.2 Problems that the Dams can Suffer

The life of a dam [04-01] can be threatened by natural phenomena such as ***floods, rockslides, earthquakes, and deterioration of the heterogeneous foundations and construction materials. Over time, the structure may take on anisotropic characteristics. Internal pressures and paths of seepage may develop.***

Usually, the changes are slow and not readily discerned by visual examination. Continuous monitoring of a dam's performance will usually ensure detection of any flaws which may lead to failure. This must be done by personnel who know the signs of distress. Knowledge of the forces which cause deterioration can be acquired by studying the postmortems of failed structures.

Some of these were conceived by acknowledged masters of the profession. Even they could not always foresee the potential weaknesses nor the neglect that their works might suffer. As more knowledge is accumulated, similarities are found in the malperformances of dams from site to site. These teach valuable lessons.

Analysis of the performances of the various types of dams will show their relative suitability for conditions that may be encountered at a given location. Each type can generally be related to a certain failure mode. A gravity dam may collapse only in the section which is overstressed. A buttress dam may fall in domino fashion through the successive collapse of its buttresses.

The rupture of an arch may be sudden and complete. Failure of an embankment may be relatively slow, with erosion progressing laterally and downward and then accelerating as the flood tears through the breach.

The records of dams indicate that earth fills have been involved in the largest number of failures, followed in order by gravity dams, rock fills, and multiple and single arches. That more problems would occur among the more prevalent dam types is not surprising. Considering the number of failures compared to the total number of dams built for each type, the multiple-arch type shows a comparatively poor record.

4.2.1 Foundation Problems

Foundation failures may lead to the complete breaching of the dam. In other cases, inherent strength or deformability of the structure may save it from total collapse. Foundation deficiencies may be related to the natural condition of the foundation or to its treatment during construction. Differential settlement, sliding, high piezometric pressures, and uncontrolled seepage are common evidences of foundation distress. Cracks in a dam, even relatively minor ones, may also be indicative of a foundation problem.

Concrete dams can withstand overtopping for at least a limited time without damage. The key to safety may be the ability of the foundation to bear the impact of the overflow, rather than the resistance of the dam itself, which is likely to be more than adequate.

The safety of arch dams is highly dependent upon the strength of their abutments. Failure may stem from weakness in the rock resulting from saturation, deterioration, excessive flood loading, or from abutment shearing under hydrostatic pressures. Failures of arch dams also may be triggered by the erosion of foundation materials by overtopping. However, arch dams are inherently capable of passing floods.

Potential erosion of the foundation itself must be considered. Clay or silt in weathered joints or faults cannot easily be removed by washing and therefore may preclude effective grouting. Seepage may gradually transport these materials into downstream voids. Consequent enlargement of the joint or fault conduits may threaten the integrity of the dam.

Foundation seepage can cause internal erosion or solution. The removal of foundation material may leave collapsible voids and consequently precarious dam support. Such potential weaknesses sometimes can be identified by examining geologic conditions in the immediate vicinity of the reservoir. Actual deterioration may be evidenced by increased seepage, by sediment in seepage water, or an increase in soluble materials disclosed by chemical analyses.

The records of site exploration may yield clues of the presence of materials vulnerable to attack, such as dispersive clays, water reactive shales, gypsum, and limestone. Uncontrolled seepage through an erodible foundation may open voids which must be bridged by the dam.

A concrete structure can have such capabilities if the stresses are within tolerable limits and the opening is not too large. The same phenomenon in the foundation of an embankment can cause collapse of the overlying fill and the eventual breaching of the dam.

Ground subsidence caused by pumping from the underground can cause foundation settlement and distortion of the dam. Such distress can also be due to the collapse of foundation soils caused by loading and wetting. Fine sands and silts with low densities and low natural moisture contents are especially susceptible to this phenomenon. The consequent cracking of the dam can create a dangerous condition, especially in earth fills of low cohesive strength.

General settlement of a rock foundation under the weight of dam and reservoir is usually not a cause of concern. However, differential settlement at irregular rock surfaces has not been an uncommon problem.

The resultant cracking of embankment is one of the most threatening conditions to be encountered. Preparation of rock foundations, therefore, should include shaping of projections and overhangs by removal and/or filling with concrete or shotcrete.

Foundation failures may occur due to saturation of foundation material and consequent washout or sliding. Foundation erosion may progress slowly, but major slides may occur suddenly.

Foundations with generally low shear strength or with seams of weak material such as clay or bentonite may be vulnerable to sliding. Seams of pervious material may also contribute to sliding if seepage through them is not controlled to preclude detrimental uplift.

Shear zones have often caused problems at dam sites and therefore warrant close examination. Two common types that have been troublesome are bedding-plane zones in sedimentary rocks and foliation, and fault zones with metamorphism. Shales and schists, respectively, are prime suspects in such cases. Meticulous work must be done to identify and evaluate the potentially hazardous inter beds or foliations, which may be deceptively thin.

Because of their inherent weakness, drill core recovery might be difficult. Where they pose significant threat to the dam or reservoir, exploratory excavations by trenching, tunneling, or shafts may be justified.

Once the dimensions, orientation, and materials in the shear zones are known, preventive or remedial engineering may call for drainage, rock reinforcement, and/or buttressing to reduce sliding potential. Water pressures on suspect shear surfaces can be reduced by vertical or horizontal drainage holes, drainage adits, or toe drains.

4.2.2 Movement

Movement [04-03] is perhaps the most important indicator of structural distress. Though all dams deform in response to applied loads, excessive movement may indicate developing problems. The deformation characteristics of embankment materials are usually not precisely predictable, and the effects of weather and poor construction effort may also be uncertain.

In an older embankment dam, the condition of materials may vary considerably. There may be small or extensive areas of low strength. Location of these weaknesses must be a key objective for the evaluation of such dams. Instability of an embankment may be caused by deleterious materials used in its construction.

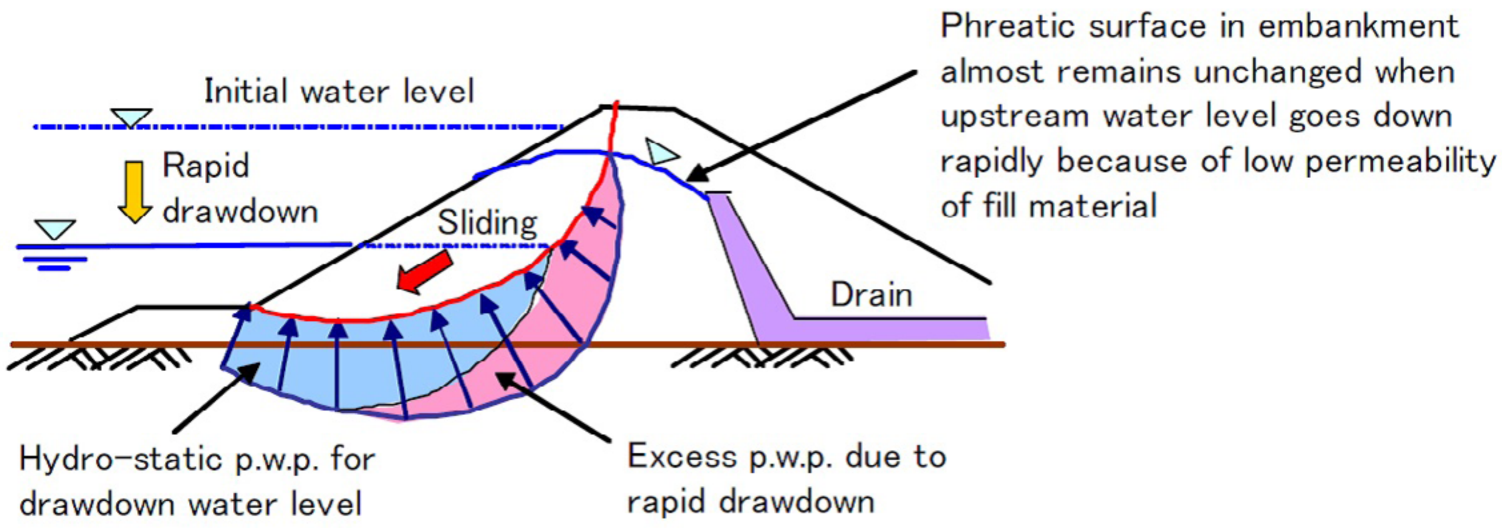
Soluble minerals such as gypsum may be carried away, leaving solution channels or may cause general settlement due to loss of volume. Erosion of dispersive clays may result from seepage of water with low salt content. Decomposition of wood or other organic material in an embankment can leave voids and cause settlement cracks. Adverse conditions which have been well known at embankment dams, and which deserve attention are listed:

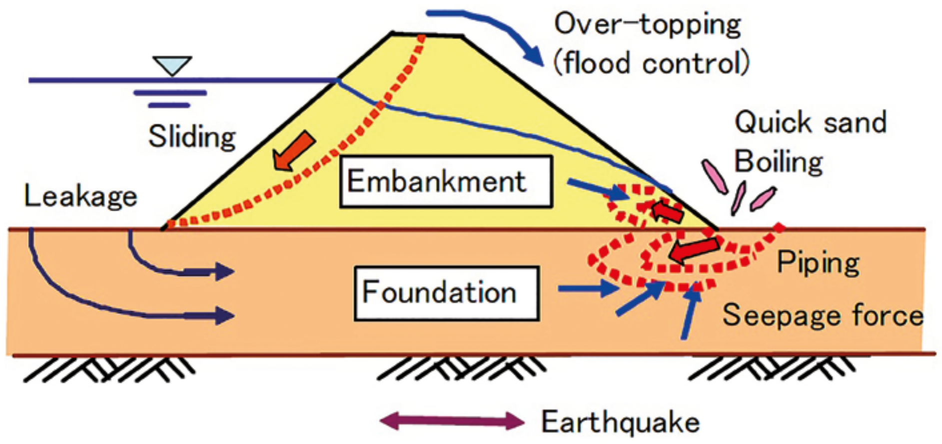
⇒ Poorly sealed foundations;

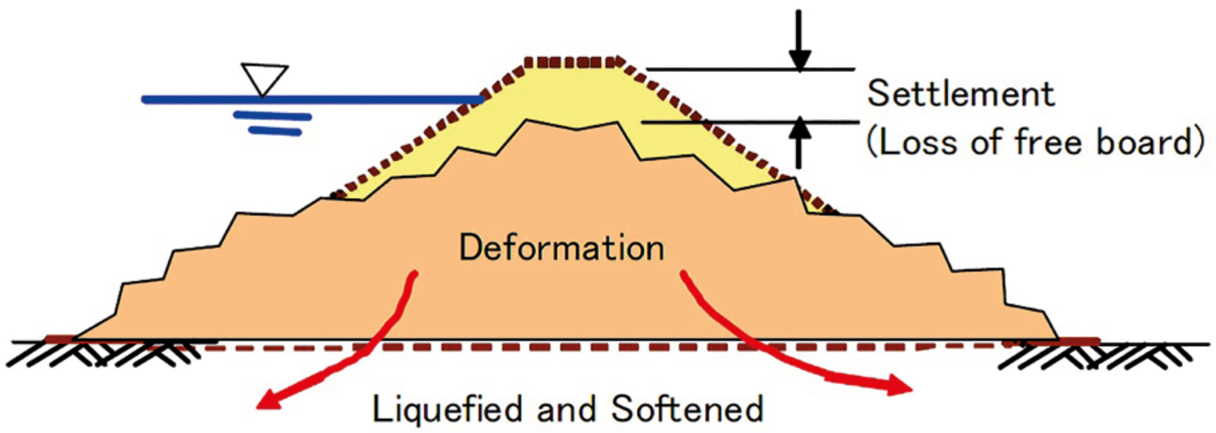
⇒ Cracking in the core zone;

- ⇒ Cracking at zonal interfaces;
- ⇒ Soluble foundation rock;
- ⇒ Deteriorating impervious structural membranes;
- ⇒ Inadequate foundation cutoffs;
- ⇒ Desiccation of clay fill in unprotected zones;
- ⇒ Steep slopes vulnerable to sliding;
- ⇒ Blocky foundation rock susceptible to differential settlement;
- ⇒ Ineffective contact at adjoining structures and at abutments;
- ⇒ Pervious embankment strata;
- ⇒ Vulnerability to "quick" conditions of the foundation during an earthquake.

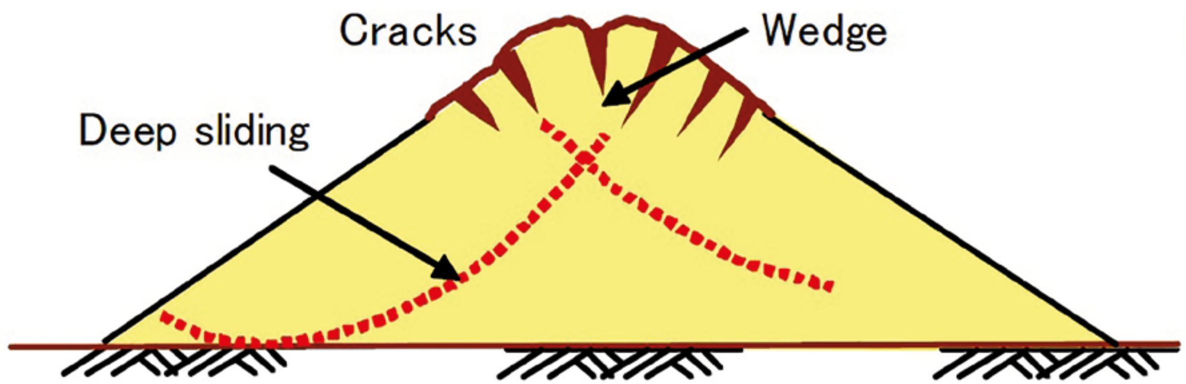
Embankment dams can be damaged to a dangerous degree by distortions at critical points. When embankment materials are poorly compacted or their moisture content is too low, excessive, or uneven settlement can result, especially if quickly saturated upon rapid initial filling of the reservoir. Differential settlement can be most severe at steep abutments and at buried structures where effective compaction is difficult to obtain.



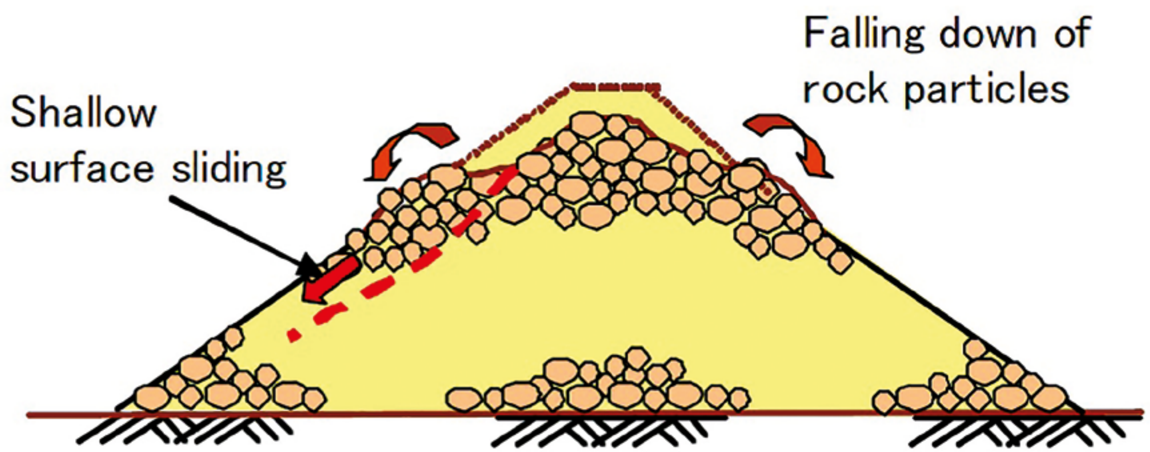




Pictures From [04-03]



(a) Homogeneous Earthfill Dam
A wedge type soil block is formed in the crest, and it grows up gradually as the excitation increases, causing deep circular sliding



(b) Homogeneous Rockfill Dam
The extent of falling down of rock particles along slope moves down from crest to toe, leading to a flat circular crest and lowering of the fill. Shallow surface sliding also appears during this process.

Pictures From [04-03]

At such locations the fill may crack or slump and arch, opening paths of seepage which can be dangerous. For this reason, many failures have occurred along outlet pipes. The fill materials used in contact with rock foundations or concrete abutments must have plastic properties that allow them to accommodate any movements that may occur.

An embankment may be most vulnerable at its interface with rock abutments. Especially during first impoundment of the reservoir, saturation of granular materials in the upstream shell may result in substantial settlement.

The crest tends to develop extension strains near the abutments and increased compression in its central sections. At this critical stage, the embankment may be susceptible to transverse cracking. Deformations of an embankment or its foundation might have especially adverse consequences at structures in or adjoining the dam, such as:

⇒ Thin concrete cutoff walls projecting from abutments into the fill might be cracked or sheared;

⇒ Conduits constructed through or under the embankment might be subjected to tension that tends to pull joints apart;

⇒ Vertical towers within the embankment might be bent or tilted.

Dumped and sluiced rockfills were built for many years and generally have provided a good service. However, such dams usually undergo appreciable settlement. This may cause cracking of thin, sloping cores. A rockfill compacted by heavy rolling equipment and constructed to slopes that are flatter than the angle of repose should have a greater inherent resistance to failure than a rockfill that has been dumped and sluiced on natural slopes. Major difficulties have also been experienced with concrete face slabs placed on dumped rockfills. Characteristically, adjustment of the rockfill results in horizontal compression at the middle of the slab and tension at the abutments. Settlement can be significantly reduced if the entire rockfill is mechanically compacted rather than dumped and sluiced. Also, it is preferable that the placement of the concrete slab on the rockfill is delayed long enough to permit the maximum compaction or settlement.

In some ways, a compacted earth core is superior to a concrete slab as the impervious element of a rockfill dam. If constructed of materials of sufficient plasticity, the core should be flexible enough to adjust without significant damage. During settlement, it should tend to mold itself to the abutments more readily than a relatively rigid concrete slab. A well-graded impervious earth core also has the important advantage of healing minor cracks which may develop during adjustment of the fill. Improvements in zoning, compaction, cutoff and slab details have produced superior embankments with much less deformation and have led to construction of such dams at greater heights.

Concrete gravity, arch, and buttress dams deform elastically in response to changing reservoir loads and seasonal temperature changes. However, inelastic movements might indicate potential instability.

4.2.3 Seepage and Leakage

Water movement through a dam or through its foundation is one of the most important indicators of the condition of the structure and may be a serious source of trouble. No one can be sure what effect the construction of a dam might have on its foundation. The impoundment usually can be expected to increase – substantially in the case of deep reservoirs – the percolation and the pore pressures in the underlying formations, unless seepage control facilities are installed. The consequences can be important not only at the dam site but elsewhere on the reservoir rim, particularly where the natural barrier is thin.

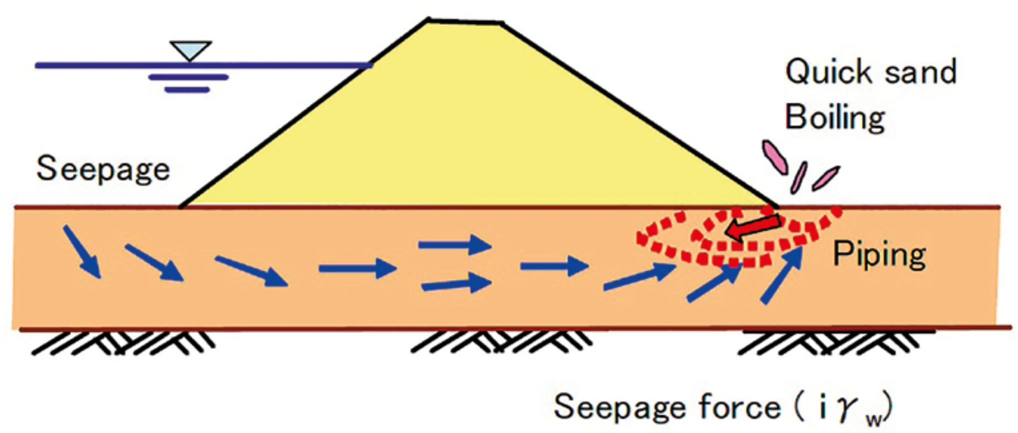
Seepage flow from embankment toe drains, concrete gravity or arch foundation drains and foundation relief wells are usually collected in a drainage system and routed to the downstream channel. Flow measurements should be taken near the system outfall where the combined flow can be measured. Additional measurements at intermediate locations may be appropriate on a case-by-case basis. Measurements of seepage or leakage from other sources should be made at locations where the flow is representative and readily measured. If the foundation has soluble strata, water quality tests should be considered.

Seeping water naturally tends to carry away constituents that may be vital to the integrity of the dam. Turbid flow issuing from a dam or from its foundation might be an indication of internal erosion. Such removal of material is typically progressive, so that the structure is gradually weakened. A sometimes more subtle attack can be launched through chemical solution of foundation rock. Some dam sites, for example, have large quantities of gypsum and other soluble minerals in the foundation. Appreciable volumes of such material might dissolve as water percolates.

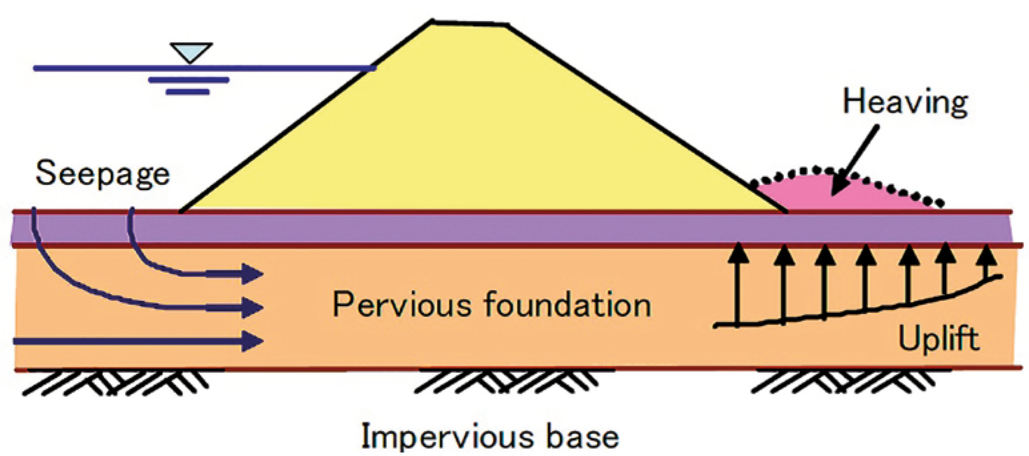
Adequate measurements must be taken of the piezometric surface within the foundation and the embankment, as well as any horizontal or vertical distortion of the abutments and the fill. Constant attention must be focused on any changes such as in the rate of seepage, settlement, or in the character of the escaping water. Generally, differentials caused by the dissolving of solid material develop slowly enough to provide early warning of the need for any remedies.

The presence of gap-graded materials such as openwork gravels or segregated nests of materials in a foundation, in drains or filters may be conducive to internal erosion.

Any leakage at an earth embankment may be potentially dangerous since rapid erosion might quickly enlarge an initially minor defect.

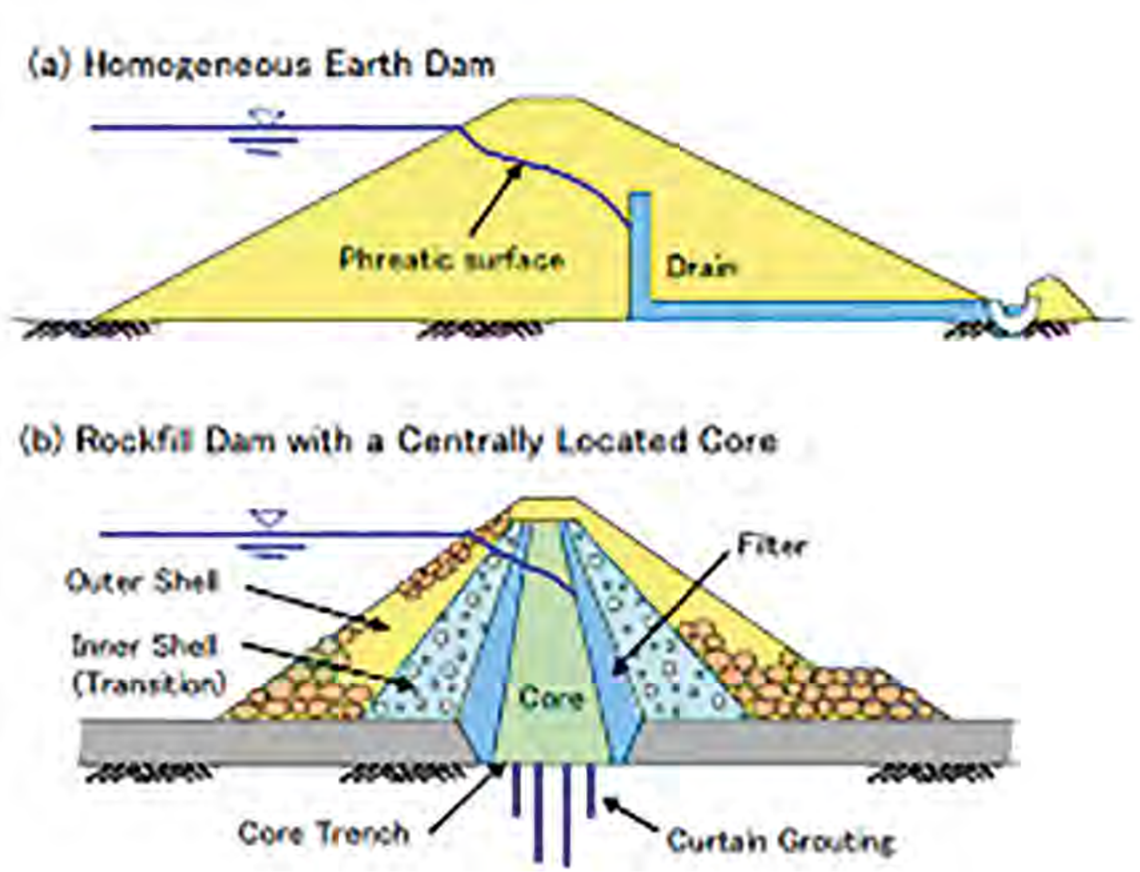


(b) Hydraulic Fracture
Concentration of flow lines at downstream toe leads to the increase in hydraulic gradient. Upward seepage force causes reduction in effective stresses in foundation, and quick sand and piping take place when counterweight loading is not enough.



(a) Seepage Through Pervious Foundation
Uplift pressure acts vertically on downstream side, so that counterweight fill or relief well are recommended to prevent heaving and local slide.

Pictures from [04-03]



Examples of dam section with vertical and horizontal drain filter to reduce pressure and flow at the base of the downstream zone. Pictures from [04-03].

Seepage paths may be opened by settlement cracks caused by weak material in the embankment or foundation and by shrinkage cracks in highly plastic clays in the embankment. Other dangerous water passages may be created by burrowing animals, decaying tree roots, and leakage along conduits improperly placed in an embankment.

Uncontrolled seepage may be accompanied by excessive embankment pore pressures and consequent weakening of the soil mass. High pore pressures can result from the placement of embankment too rapidly or too wet, because of seepage through pervious materials in the embankment, or along foundation joints and cracks.

4.2.4 Sliding

The possibility of sliding on the reservoir slopes, on the dam abutments or of the dam itself [04-04] must be taken into account when assessing safety at a water storage site. The consequences of landslides may include blockage or rupture of essential appurtenances or overtopping of the dam by waves. While the potential for landslides may exist in nearly any kind of rock, some slates and schists are notoriously susceptible to movement.

Shales and clay stones have also caused problems. Where such rocks are present in the foundations of concrete dams, special precautions must be taken. Many dams have failed where the sliding hazard was ignored or received inadequate attention. The concrete barrier, along with a layer of rock just below its base, slipped into one of these seams. The rock under the toe of the dam had been scoured, undermining the structure at that point and thus further lowering the resistance to sliding.

Excellent examples, considering the shear aspects, are described by ***Geol. Ricardo Abrahão*** as quoted:

> *"...Some geological constraints that occur in the foundations of concrete dams are extremely important and increasingly influential in project and construction decisions.*
>
> *These constraints relate to shallow discontinuities that occur in the rock mass which are flat surfaces, almost always sub horizontal or sometimes combined. This fact takes the problem of the foundation to lower levels already within the rock mass.*
>
> *The best first example is Malpasset, dam which was a double curvature arch structure, the thinner arch at that time, failed in 1959, five years after filling the reservoir described in Chapter 7.*

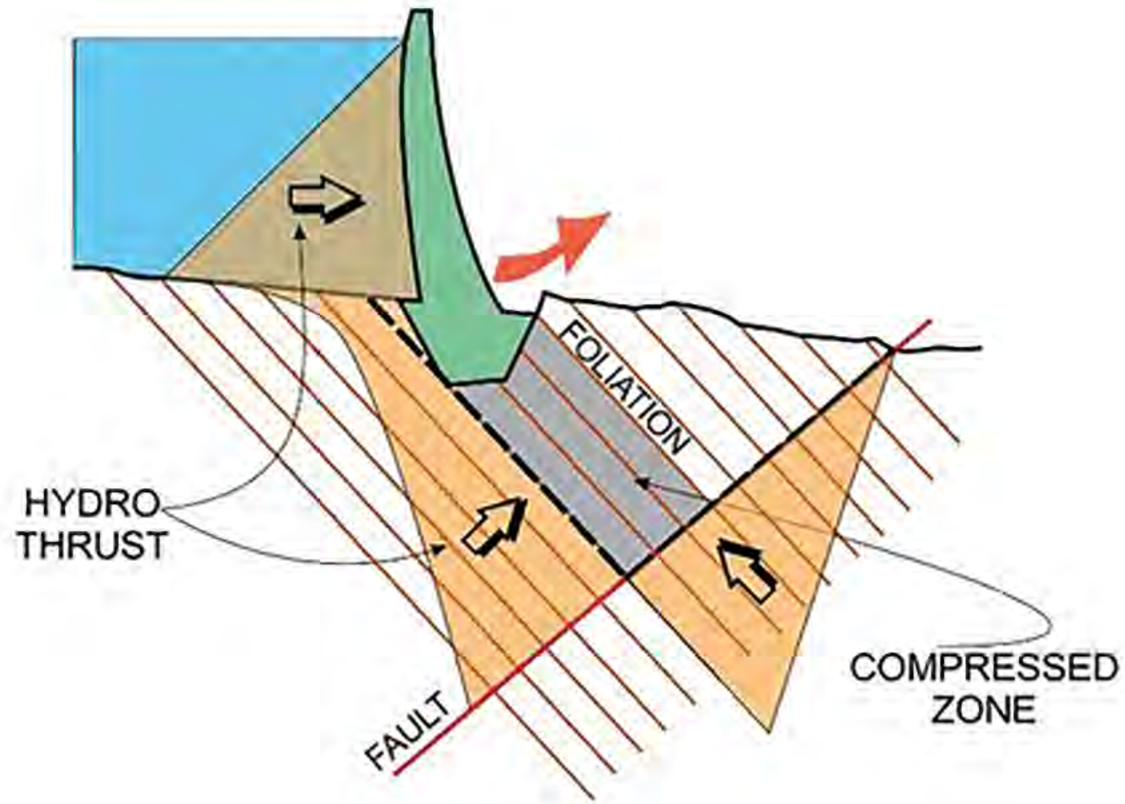
Present Malpasset situation in an image from Google Earth

For those who have keener eye it is possible to see on the left bank that there are two surfaces of discontinuities with the intersection forming a dihedral.

The dam was founded on schistose augen gneiss with sericite whose after-failure shape is shown in the next picture.

Malpasset failure surfaces seen from the ground

In this image it is possible to check the intersection of the 2 surfaces resulting from the discontinuities attitudes. The original interpretation of the diagnostic is shown schematically in the next diagram.



Simplified Malpasset failure diagnosis

The thrust built behind the compressed zone and uplift below the fault, both with low shear strength, led to failure.

In our 50 years' experience in dams we noticed several works that did not even know they had keys and we accumulated several experiences checking the discontinuities by the foundation, compromising the construction.The following images show some examples:

Very flat discontinuities in Brazilian sandstone

Discontinuities through chlorite schist with chlorite gauge whose influence was only known during excavation

The famous joint faults, in this case, one of Itaipu's low strength, sub horizontal discontinuities

Another feature that also draws attention are the relief joints, very common mainly in granites, gneisses, migmatites, and which follow the topographic shape and when close to the riverbed become sub horizontal

*The next case is a relief joint that underwent intense weathering creating a soil gauge which, in this case, suffered intense erosion causing the concrete supported on the sound rock above to collapse. I emphasize that in this case there was no rupture by shear at first. This is the case of Camará Dam also described in **Chapter 7**.*

Relief joint in Camará Dam

In sandstone it is possible to observe an intense anisotropy with low strength in the direction of the bedding

In the contact between flows of basic rocks it is likely to form zones of joint sets or weathered zones as shown in next figures, and that have a persistence that exceed the project magnitude.

Weathered contact between basic lava flows

This picture shows the same situation of contact between basaltic flows showing the formation of an important low strength joint whose persistence is much greater than the dam itself

The evaluation of sliding stability in rock+concrete contact is well known, and its stress distribution is evaluated by rigid block concepts and calculated by the limit equilibrium method, almost always in two-dimensional models.

However, in situations below this contact, involving diverse geometries and stiffnesses contrasts, these methods no longer apply effectively. One cannot simulate these distributions through rigid block considerations. The use of mathematical models to evaluate elastic-plastic stress-strain fields is mandatory.

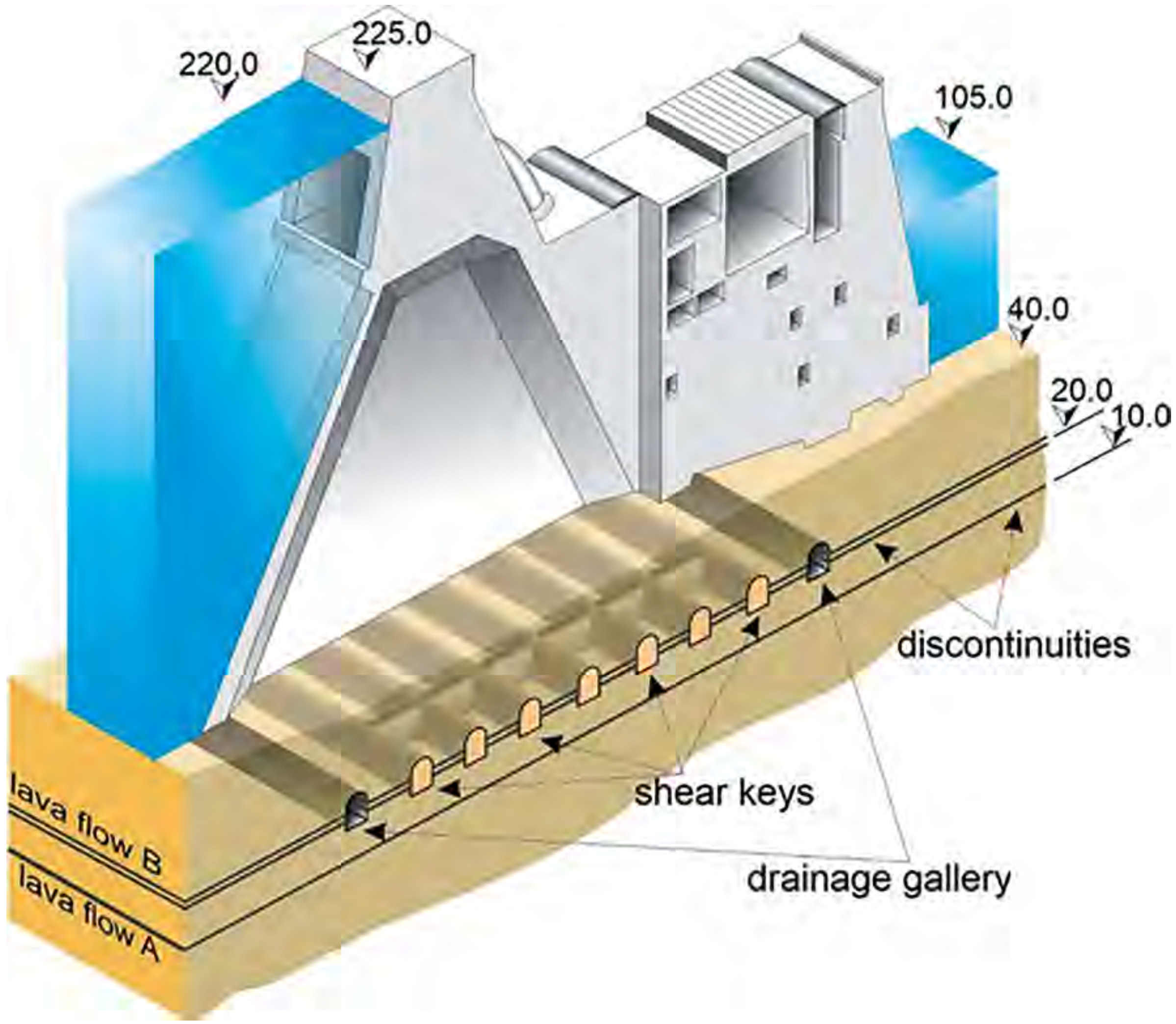
Whenever such a discontinuity occurs in the foundation and its strength and stiffness are not enough to comply with the requirements of the design criteria or the state-of-the art on this matter, some intervention is needed.

Normally, the removal of the rock above the discontinuity surface seems to be a very practical solution but however expensive or time consuming. In this case it is used to build rigid inclusions in the discontinuity in such a way this inclusion will take most of the shear stresses. The difference between discontinuity and concrete stiffnesses is called stiffness contrast.

To meet the current stability validation requirements, which I particularly consider obsolete, one can calculate the integrals of the stress curves taken from mathematical modelling whose resultant forces can be taken to the limit equilibrium method equations.

Two main emblematic cases are described below, although many other examples were already built and were under construction in Brazil during the period while this text was being written.

The ***Itaipu Main Dam*** *is founded on some basalt flows. One of the joints that occur in the contact between flows, the joint of elevation 20, is a surface of very low strength that gave rise to the treatments necessary for stabilization.*



Itaipu's main dam half block being a concrete hollow gravity structure

The shear keys tunnels were all filled with concrete in the longitudinal and transverse direction surrounded by drainage galleries that go around of the highest blocks of main dam.

For this case, the analysis through finite elements showed the distribution of tangential stresses along the critical surface. A small part of those stresses was taken in the discontinuities upstream and downstream of the reinforced area which supported the greatest part the tangential stresses.

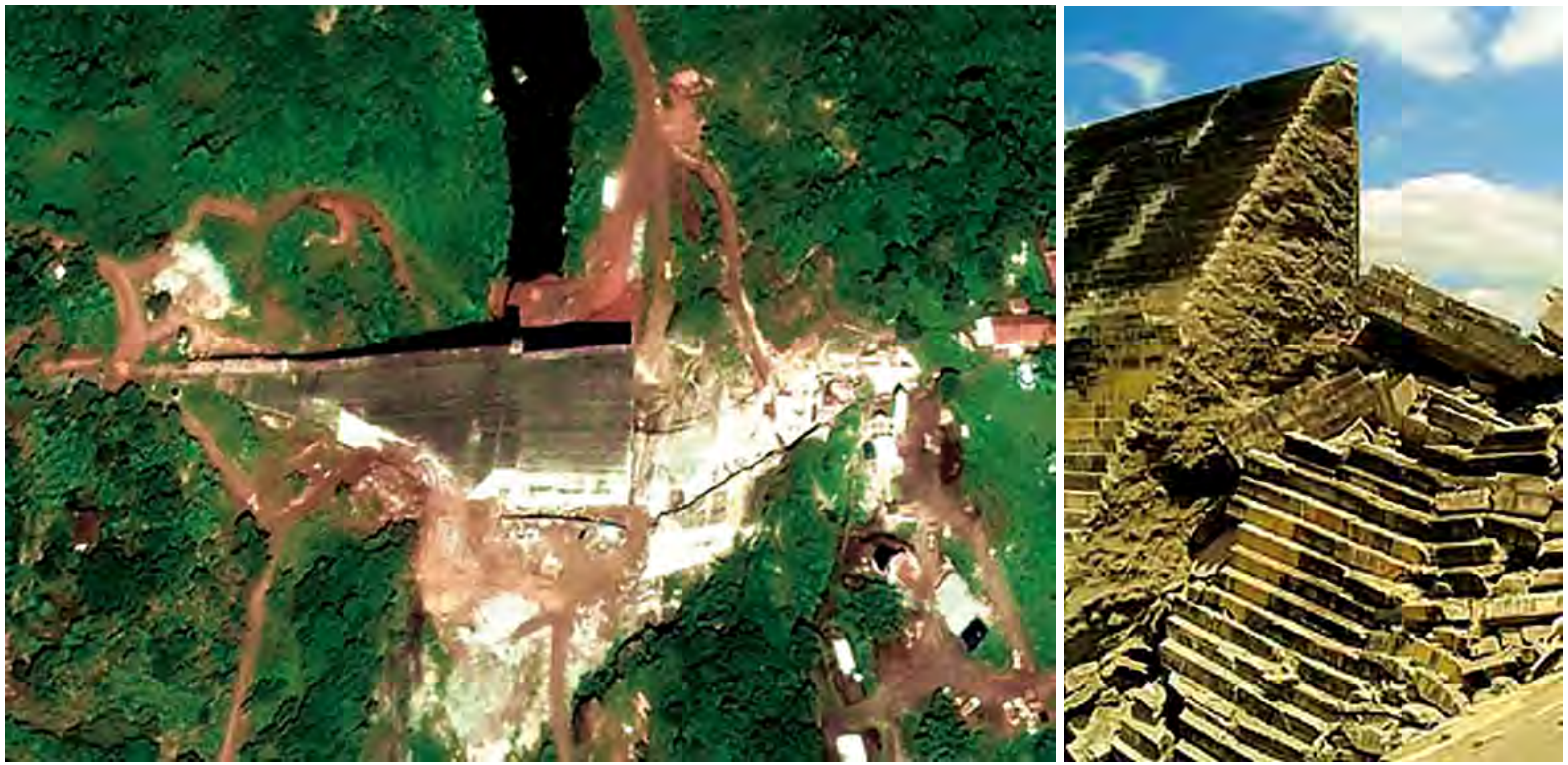
Distribution of shear stresses in the critical surface containing the rigid inclusions. It was found that the great part of the stresses was taken by the transversal keys

The picture shows one of the shear key tunnels partially concreted. The discontinuity is at half height of the tunnel

Itaipu main dam in operation since 1984, without any problem concerning the foundation

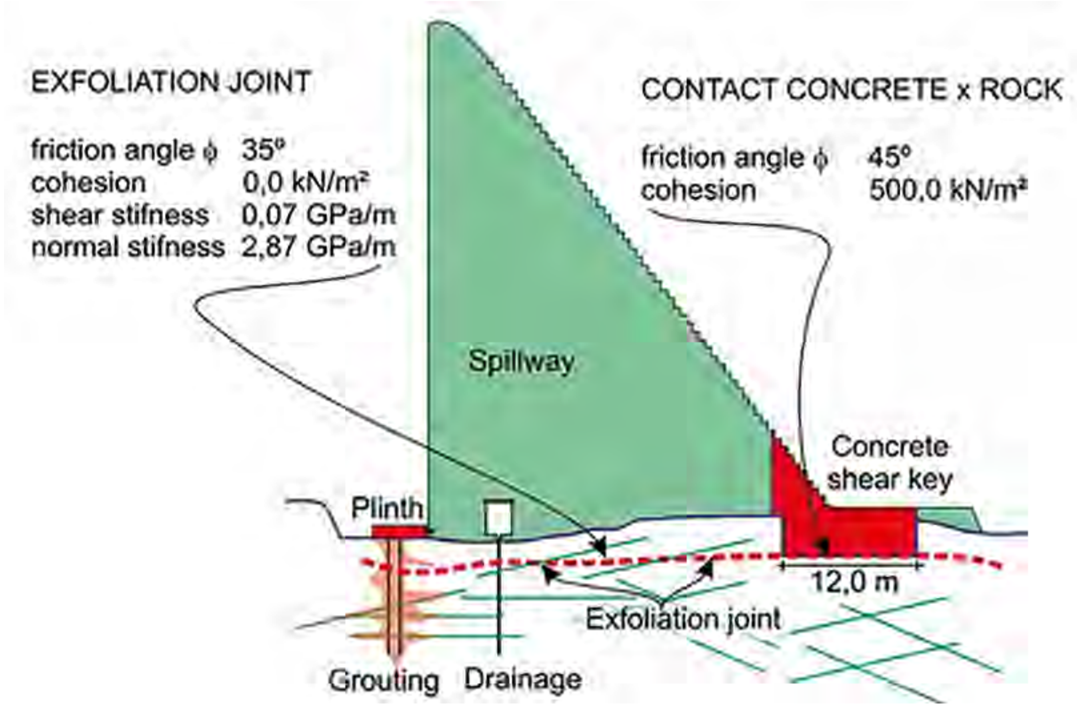
***Camará Dam** is a Brazilian 50m high roller compacted concrete structure founded on granite and migmatites with expressive weathered exfoliation joints.*

*In 2004 the left abutment failed due to the presence of such exfoliation joints (**Chapter 7**), which caused the dam to collapse, emptying the reservoir.*

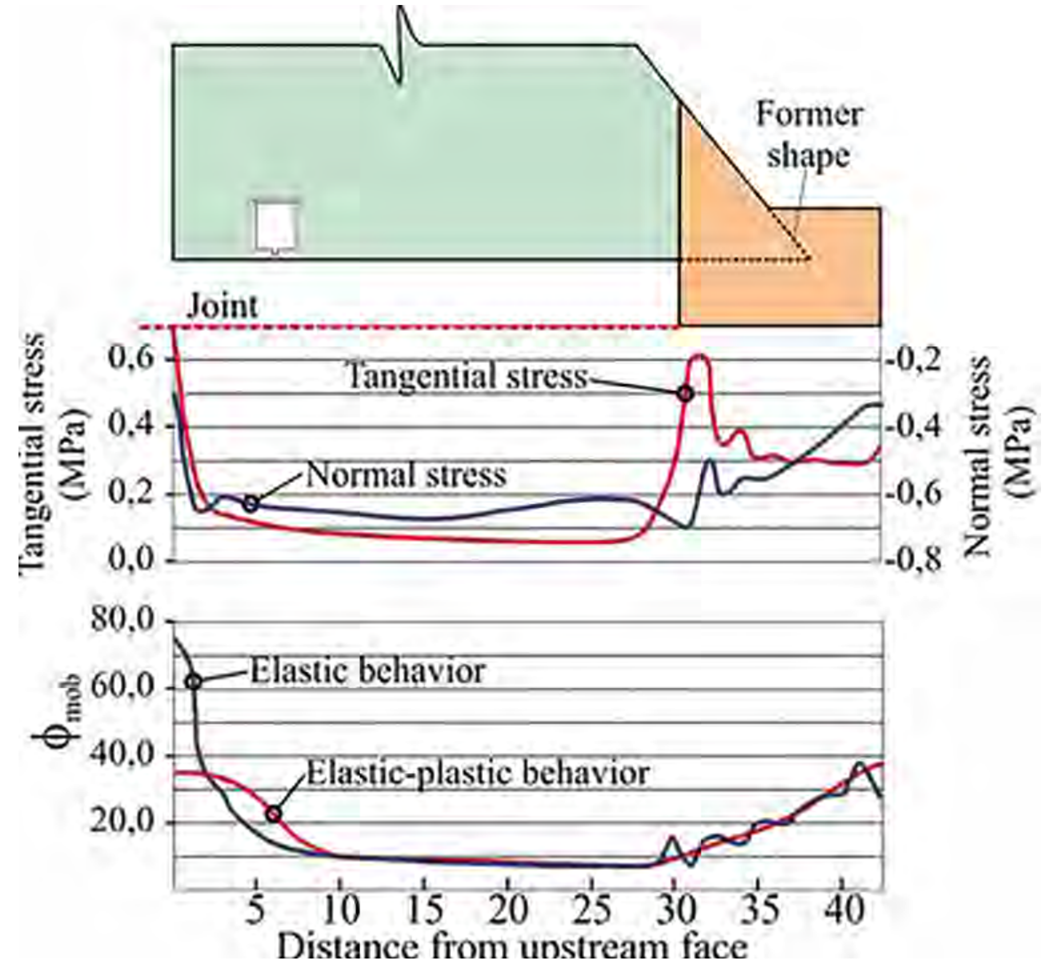


Camará dam seen from a Google Earth image in 2004 and after the total failure at the right

The rebuilding process started in 2011 and the new geo-mechanical model came up with a set of joints, parallel to the surface and some faults with a high degree of weathering producing a soft material that retains rock mass relics, as shown in next figure.



Expedite geomechanical model, based in innumerous investigations for Camará foundation



Normal and tangential stresses distribution along the critical surface. The stiffness contrast is very well illustrated here. The mobilized friction angle is 12° and the available friction angle is 35°

The reconstruction consisted in building new blocks in the left abutment and repairing the remaining ones. It started with the debris cleaning on the whole area. The surface mapping started at this time.

After the design setting, the area of the shear key downstream of the spillway started to be excavated by means of cable sawing to avoid major damage in the remaining concrete. As soon as the excavation reached the bottom, the concrete started to be poured. In the remaining blocks the older concrete had to be partially cut to give room to the shear key, while in the left bank, in the failure area, the shear keys were incorporated to the new structure.

Cable sawing in the concrete and in the rock in the left abutment

Camará dam in operation since 2016. No deleterious events were reported in the foundation until now

[A] *– R. Abrahão, Soft Rocks in Dam Foundation and Dam Sites, chapter 24 in "Soft Rock Mechanics and Engineering", Editors Milton Kanji, He Manchao and Luís Ribeiro e Souza. Springer. ISBN 978-3-030-29476-2, 2019;*

[B] *– R. Abrahão, F. Holanda, J. C. Degaspare. Camará Dam – Technical Aspects of Reconstruction. Third International Dam World Conference, Foz do Iguaçú, Brazil, 2018;*

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[D] *– Richard E.Goodman. On the Failure of Malpasset Dam, Univ. Cal., Berkeley, 2013-(https://docplayer.net/53797111-On-the-failure-of-malpasset-dam.html)*

[E] *– Pierre Duffaut. The traps behind the failure of Malpasset arch dam, France, in 1959. Journal of Rock Mechanics and Geotechnical Engineering 5 335–341, 2013;*

[F] *– V. M. Souza Lima et al. Rock Foundations with marked discontinuities, Criteria and assumptions for stability analyses. 14th ICOLD, Rio de Janeiro, Brazil, 1982."*

4.2.5 Erosion

Embankments may be susceptible to erosion unless protected from wave action on the upstream face and surface runoff on the downstream face. Groins are especially vulnerable to such damage. The downstream toe of the fill may also be subject to erosion if outlet or spillway flows are not kept at safe distances.

Riprap armors the upstream slope of an earth fill structure against wave erosion. Rockfill or gravel is also sometimes used on the downstream slope to protect from rain and wind attack. Seeding with grasses may be an acceptable alternative. Berms on the downstream face may also serve to control erosion by intercepting and diverting runoff.

The dislodging of riprap by wave action may leave the embankment exposed to erosion, but this deficiency can usually be detected and corrected before serious damage has developed.

4.2.6 Induced Earthquakes

The filling of a large reservoir behind a high dam may actuate an earthquake. Various factors can be contributory to such movement, including the superimposed water weight, reduction of frictional resistance in the underlying rock due to pore pressures, and decline in rock strength caused by chemical alteration. Infiltration of water into the foundation under high pressure can trigger the release of cumulative tectonic strain. Intensified pore pressures tend to diminish friction by reducing normal stresses on the planes of fracture. Consequent movement will extend until irregularities at the interface again and exert sufficient restraint.

There is experience showing that the high dynamic magnification at the crest of the dam resulting from the vibration mode at the site required special design emphasis. In such circumstances, the top of a dam may be the most vulnerable part during an earthquake.

4.2.7 Liquefaction

Improved methods for analyzing the stability of dams subjected to seismic loading provide reliable indications that many old dams may be vulnerable to earthquakes. Hydraulic fill dams especially have become suspect. The potential for development of “quick” conditions in such embankments is generally recognized. The possibility is acknowledged that such weaknesses may also exist in loose cohesionless soils in the mass or the foundation of other kinds of dam. Reevaluation of the stability of any embankment incorporating or founded upon such materials should be given high priority.

Hydraulic fills are now known to be characteristically vulnerable during an earthquake. Judging by these and other experiences, the most pronounced effect of severe seismic activity at a hydraulic fill is likely to be distortion of the embankment in response to low-frequency vibrations of comparatively long duration.

This would be manifested by settlement and lateral spreading. Such effects can be intensified by liquefaction. Susceptibility to this is highest in saturated low-density soils with uniform gradation and fine-grain size. Liquefaction is a potential problem in any embankment, such as a hydraulic fill, which may have continuous layers of such materials.

4.2.8 Concrete Deterioration

Aging of concrete dams can be attributed to both physical and chemical factors. The former is related to changes in forces acting on the structure, including those caused by temperature variations. The latter are associated with infiltration into the dam of aggressive waters containing inorganic acids, sulfates, and certain other salts.

Chemical reactions of these substances with constituents of concrete can result in leaching of the concrete. Soft water, for example, may attack concrete causing serious deterioration in a few years. Defective or inferior materials used in the construction of a concrete dam can result in deterioration and possible failure of the structure. Poorly bonded cement, weak aggregates, or mineral-laden are susceptible to freeze-thaw damage. Aggregate contaminated by soils, salts, mica, or organic material can also produce substandard concrete.

Concrete mixes for massive structures usually contain air-entraining agents. This appreciably improves the durability of the concrete and increases resistance to freezing and thawing. However, such distress still can occur where entrainment is insufficient or when the aggregate itself is vulnerable to freeze-thaw action.

Closely spaced parallel cracks at edges of concrete blocks may be symptomatic of freeze-thaw expansion. Entrance of water into the cracks and subsequent freezing are likely to further the deterioration.

Disintegration of concrete can be caused by freezing and thawing, thermal expansion and contraction, or wetting and drying. Freeze-thaw effects are most likely to be found in parapets, cantilever beams, slabs, and walls of appurtenant structures. Many gravity dams constructed in the 19th century were made of stone masonry with lime mortar. This is susceptible to deterioration and loss of strength over long periods of exposure to seeping water. Once its bond has been broken, water pressure in the joints may actuate a sliding or overturning failure.

Several concrete dams have suffered alkali-aggregate reaction. Typically, this chemical process is evidenced by upstream movement of an arch crown, by spalling of the concrete at extremities, and by characteristic pattern cracking and crazing of the dam faces. Expansion in the decomposing concrete can be substantial.

Alkali-aggregate reaction sometimes causes the disbonding of blocks at lift surfaces. Loss of strength by disbonding, and the accompanying increase in hydrostatic pressure along the lift surfaces, will reduce resistance to sliding and overturning. Alkali-aggregate reaction can cause expansion of a concrete dam with consequent cracking and deterioration, and possible binding of gates, valves, and metalwork. Once alkali-aggregate reactivity has developed in a relatively thin concrete dam, it cannot be stopped practically by any means known until now. Where deterioration has progressed to a dangerously advanced stage, the effective remedies are to remove and replace the defective concrete, or to build a new dam to replace the old one.

Settlement and cracking of concrete structures can be attributable to uplift, foundation displacement, ice thrust, or seismic forces. In spillways or outlet works conveying high velocity flows, offsets in the conduit surfaces may cause cavitation.

Vibration of structures by earthquake, water surges, or equipment operation may damage concrete. Damage due to the overstressing of a concrete dam often may be identified by examination. Clues include cracking, opening at joints or lift surfaces, seepage variations, and displacement. Erosion of concrete can be caused by flowing ice, rocks, logs, wind, traffic, or cavitation.

One of the most common problems reported at concrete gravity dams is clogging of drainage systems. The need for regular maintenance of drains is well recognized. Obstruction of dam and foundation drains may be attributable to various causes, including displacement, soil or rock deposits, biological growth, and leaching and deposition of chemicals.

4.2.9 Spillways

Overtopping of the dam may result from failure to make timely and adequate releases through the spillways and outlets. All spillway with gates must have two independent power systems for operation. In dams whose flood peaks occur in a few hours the consideration of free spillway is mandatory for safety.

Overtopping has been the most common cause of failure of embankment dams. Several failures attributable to overtopping have occurred while the dams were still under construction. Thus, the full design to be considered at this stage should consider the construction time and the consequences of a possible rupture, and not be adopted in advance for all dams, based in a certain Recurrence Time for this phase of construction.

The value of adequately sized and readily operable spillways has been convincingly demonstrated. However, the determination of the proper capacity may be difficult. Voluminous records of precipitation and runoff on watersheds have been collected since most dams were constructed. Also, more reliable methods for analysis of hydrologic data have been developed.

Inevitably, some existing spillways proved unable to pass the maximum floods that can now be predicted by new data. Where the risk of dam failure is unacceptable, the total discharge capacity should be increased. The comparatively limited time span of most meteorological and hydrological data suggests the probability that historical extremes eventually will be surpassed.

In all these events the largest anticipated flood flows were proven to be unrealistically low. However, even with the benefit of hindsight, the next forecaster of flows in those watersheds may not be assured of better error immunity. Aside from the very important consideration of discharge capacity, spillways must be checked also for such common flaws as slides or debris obstructing channels, erosion and undermining, broken linings, and inoperable mechanical equipment. Since the life of the dam depends upon safe functioning of the spillway during emergency, regular examinations and thorough maintenance are essential.

Maintenance of the facilities for conveying water past a dam is seldom difficult, yet sometimes receives too little attention. Even carefully designed and expensive equipment and structures have been known to suffer from neglect, especially when frequent operation is not required.

Malfunctioning gates, valves, or hoisting equipment may result from:

⇒ displacement of the structure;

⇒ corroded, worn, broken, or loose parts;

⇒ misalignment of parts;

⇒ binding due to infrequent operation;

⇒ insufficient lubrication;

⇒ improper operating procedures;

⇒ power outage;

⇒ electrical circuit failures;

⇒ icing;

⇒ silt or debris.

Inadequate maintenance of electrical and mechanical equipment may lead to operational failure at a crucial time.

The design criteria for most effective operation of conveyance works must be strictly followed. Some spillways and outlets require symmetrical operation. In others, water hammer, equipment vibration, and flow velocities must be carefully controlled. Guidelines for operators must be kept permanently at the dam.

4.2.10 Outlets

One of the most prevalent adverse conditions at reservoirs, particularly where small or medium-sized dams are involved, is a poorly constructed outlet or one that has deteriorated through lack of maintenance. And yet, the capability of rapid lowering or emptying of a reservoir during a crisis can be extremely important. In some cases, distress on a dam has been alleviated by reducing the pool elevation by just a few feet. On such occasions, a properly functioning outlet work is essential. The value of control at the upstream end of an outlet, to limit conduit water pressures within or under the dam, is generally recognized.

4.2.11 Demolition

Deliberate efforts have been made to destroy dams, including bombing, sabotage, and demolition for public safety. Of course, the number of dams which have failed from other causes is probably much greater than the number destroyed intentionally. The potential for hostile action, though, does warrant some examination. Military strategists can be expected to see the advantages of attacking any conspicuously vulnerable structure that may be of value to the enemy. In past wars, commanders have launched assaults on dams to flood out enemy forces or to cut off routes crossing rivers.

Although the consequences of hostile action against dams have been severe in some cases, the historical frequency of such events has been comparatively low. This is not necessarily reassuring, however. Looking to the future, the increasing potential of damaging attack cannot be disregarded.

4.3 Preventive and Remedial Engineering

4.3.1 General

As already mentioned, the authors will not go into the merits of debating the various Design Criteria adopted for each type of dam. The main objective of this text is to discuss aspects, hypotheses, and care that mitigate the risk and provide the Safety of Dams. The presenting suggestions aim to establish a scenario that can seek safety from the birth of a Project. Taking care and creating convenient and appropriate defenses in advance.

The authors have experience and awareness that a Project, without adequate defenses, will rarely survive the risk, even with a series of measures resulting from inspections and monitoring until measures and reparative actions are taken to reestablish safety. And these repairs require technologies, techniques, methodologies, and costs arising!

- ✓ ***What is the common thread, if any, among failures of dams?***

Some observers would suggest that the blame often lies on unwise economizing on structural dimensions and the limited amount of investigation done on foundations, riverflows, and materials. There is more than a little truth in this. ***For example, disastrous overtopping of***

dams can be prevented by spending money on a large enough spillway. Handling of floods is therefore not one of the most difficult problems to resolve. Other phenomena – particularly geologic hazards, earthquakes, seepage, and difficulties at conduits and structures – have more subtle aspects. A vital key to understanding them and coping with them is surveillance.

The failures and their dreadful toll emphasize the great responsibility that designers and constructors assume when creating a major dam, and how faulty their best efforts can be at times. A careful balance must be struck in reducing the risk to a tolerable minimum without raising the cost to a prohibitive level.

Moreover, hazard must be recognized as a variable. The condition of a dam can change, and the consequences of its failure will depend on developments in the area that might be threatened. An indeterminate degree of risk will always be present.

The history of dam disasters throughout the world reveals that problems often arise from undetected or inaccurately evaluated defects in the foundation. This dictates that engineering must be linked closely with geology in the design, construction, and continuing surveillance of a dam.

Reservoir safety cannot be assured by a uniform code of design practice. The designing of dams generally entails rigorous and sometimes complex studies of forces often based on assumed material characteristics and structural behavior. Results of these analytical efforts cannot always be precise. The proper margin of safety is assured by application of both mathematical logic and practical judgment.

Of course, the dam engineering does not end with the design. It may become crucial when the construction phase begins and some of the assumptions about foundations and materials are subjected to comparison with reality. The proudest engineer may grow progressively humble as he follows projects through design and construction into operation and sees how the conditions of dams can change – for some of them are like humans, meaning that they can become weaker with the advancing years. Tender care can make the difference between life and death in either case.

Dams may be the victims of various external and internal disorders not unlike the ailments of man, such as high pressure, sluggish drains, and dislocations. The syndrome in some instances may be less susceptible to diagnosis, but the consequences of ineffective remedies can be equally disastrous. To a Doctor of Medicine, each patient represents one human life.

The untreated sickness of a dam can threaten the lives of many people. The care and treatment of water storage facilities therefore involve heavy responsibility. The potentialities of deterioration of aging dams must be closely watched and analyzed. Many years of safe operation may pass before the attack of water on a faulty foundation becomes apparent. Attention must be given to monitoring the performance of the dam to detect adverse conditions so that remedial action can be taken in time to avert a disaster. Regular checkups are essential to the well-being of any reservoir.

Bigger and better dams are being built, and they are being placed necessarily on poorer sites. Maximum care is required in evaluating foundation conditions and construction materials to overcome site deficiencies.

Complete elimination of defects will not always be possible during construction. Not infrequently, some further work on the foundation will be needed after a period of operation. Openings in the rock may contain erodible or soluble matter and may remain closed only until reservoir pressures are imposed. Consolidation and deformation under structural and water loads also may be detrimental.

These changes can be subtle and difficult to detect. Until better devices can be developed for seeing inside and under dams to diagnose their ills, all prescriptions cannot be infallible. However, there is more that can and must be done to reduce the frequency and consequences of failures.

The work of protection of a dam begins with the first examination of the foundation and continues on the drawing board and through construction and operation. There can never be certainty that all problems have been solved. Also, the nature of the problems will change from time to time.

There have been cases of dams which have failed more than once, and sometimes for different reasons. The causes and processes of dam failure are varied. History discloses some of the most likely causes – overtaxing of spillways by unexpected floods, movement and deterioration of defective foundations, and piping of embankment materials caused by inadequate control of seepage.

Invariably, failures of dams have contributed to advancement of the specialized body of knowledge which is essential to their prevention. The case histories of the misfortunes of dams reveal some remarkable similarities in antecedent conditions and in the process of breakdown. Most troubles have developed over extended periods of time – in some cases months and years. Yet, these conditions went either undiscovered or improperly appraised. Otherwise, corrective measures could usually have been taken.

No one can say how rapidly a dam will fail once the limit of its resistance has been reached. Usually, embankments can be expected to fail more slowly than concrete structures. Failure times for fills have varied from a few hours to several days. Concrete dams have been known to collapse almost instantaneously.

Assuming that previous adverse trends had gone undetected, the guarding of a dam would have to include round-the-clock inspection to ensure the maximum time available for the evacuation of people in time of emergency. At critical sites where urban centers could be threatened, such close observation are highly desirable. Obviously, though, a monitoring program designed for early diagnosis and prompt therapy must be the cornerstone of any surveillance system. Coupled with the capability to lower the reservoir during a crisis, this should be as beneficial on the long run as a guard who can ring the siren or bell when he finds water gushing.

4.3.2 Design Criteria

There are Entities and Societies around the world that have Design Criteria Guidelines and/or Recommendations for the Design of the various types and purposes of Dams and Auxiliary Structures. There are also professionals, entities and technical societies and normative codes that can be adopted. Some can be listed:

Dam Type or Purpose	Country/ Entity	Guideline
Tailings	ICOLD	**Bulletin 45** – Manual on Tailings Dams and Dumps – 1982
		Bulletin 74 – Tailings Dams Safety-1989
		Bulletin 97 – Tailings Dams – Design of Drainage – 1994
		Bulletin 98 – Tailings Dams and Seismicity – 1995
		Bulletin 101 – Tailings Dams – Transport, Placement and Decantation – 1995
		Bulletin 103 – Tailings Dams and Environment-1996
		Bulletin 104 – Monitoring of Tailings Dams – 1996
		Bulletin 106 – A Guide to Tailings Dam and Impoundment – 1996
		Bulletin 139 – Improving Tailings Dam Safety – 2011
		Bulletin 153 – Sustainable Design and Post-Closure Performance of Tailings Dams – 2013
		Bulletin 181 – Tailings Dams – Technology Update – 2019
	ANCOLD-Australia	**ANCOLD** – Guidelines on Tailings Dams – Planning, Design, Construction, Operation and Closure – Revision – 1 july – 2019
	U.S. Environmental Protection Agency	Design and Evaluation of Tailings Dams

Dam Type or Purpose	Country/ Entity	Guideline
Earth Embankment	ICOLD	**Bulletin 54** – Soil –Cement for Embankment Dams – 1986
		Bulletin 91 – Embankment Dams Upstream Slope Protection – 1993
	Corps of Engineers – US Army	**EM 1110-2-2300 –** General Design and Construction Considerations for Earth and Rock-Fill Dams – 30 july 2004
	U.S. Department of the Interior Bureau of Reclamation	**Design Standards No. 13** – Embankment Dams -Chapter 2: Embankment Design – 2012
Hydraulic Fill	Missouri University – USA	Seismic Stability and Rehabilitation Analysis of a Hydraulic Fill Dam – 2001
	Berkeley University – CA-USA	Considerations in the earthquake-resistant design of earth and rock fill dams-Department of Civil Engineering, University of California, Berkeley.
Rock Fill Clay Core	Corps of Engineers – US Army	**EM 1110-2-2300** – General Design and Construction Considerations for Earth and Rock-Fill Dams – 30 July 2004
	Corps of Engineers – US Army	**EM 1110-2-2300** – General Design and Construction Considerations for Earth and Rock-Fill Dams – 30 July 2004
	U.S. Department of the Interior Bureau of Reclamation	Design Standards No. 13 – Embankment Dams – Chapter 2: Embankment Design – 2012

Dam Type or Purpose	Country/ Entity	Guideline
Rock Fill Asphalt Core	ICOLD	**Bulletin 42** – Bituminous Cores for Earth and Rock Fill Dams – 1982
		Bulletin 84 – Bituminous Cores for Fill Dams – 1992
		Bulletin 179 – Asphalt Concrete Cores for Embankment Dams – 2018
	U.S. Department of the Interior Bureau of Reclamation	**Design Standards No. 13** – Embankment Dams – Chapter 2: Embankment Design – 2012
	Corps of Engineers – US Army	**EM 1110-2-2300** – General Design and Construction Considerations for Earth and Rock-Fill Dams – 30 july 2004
Rock Fill Asphalt Face	ICOLD	**Bulletin 32** – Bituminous Concrete Facings for Earth and Rock Fill Dams – 1982
		Bulletin 114 – Embankment Dams with Bituminous Concrete Facing – 1999
	U.S. Department of the Interior Bureau of Reclamation	**Design Standards No. 13** – Embankment Dams – Chapter 2: Embankment Design – 2012
	Corps of Engineers – US Army	**EM 1110-2-2300** – General Design and Construction Considerations for Earth and Rock-Fill Dams – 30 july 2004

Dam Type or Purpose	Country/ Entity	Guideline
Rock Fill Geomembrane Face	ICOLD	**Bulletin 78** – Watertight Geomembranes for Dams – 1991
		Bulletin 135 – Geomembrane Sealing Systems for Dams – 2010
	U.S. Department of the Interior Bureau of Reclamation	**Design Standards No. 13** – Embankment Dams – Chapter 2: Embankment Design – 2012
	Corps of Engineers – US Army	**EM 1110-2-2300** – General Design and Construction Considerations for Earth and Rock-Fill Dams – 30 July 2004
Rock Fill Concrete Face CFRD)	ICOLD	**Bulletin 70** – Rock Fill Dams with Concrete Face – 1989
		Bulletin 89 – Reinforced Rock fill and Reinforced Fill for Dams – 1993
		Bulletin 141 – Concrete Face Rockfill Dams – Concepts for designs and Construction – 2010
	U.S. Department of the Interior Bureau of Reclamation	**Design Standards No. 13** – Embankment Dams – Chapter 2: Embankment Design – 2012
	Corps of Engineers – US Army	**EM 1110-2-2300** – General Design and Construction Considerations for Earth and Rock-Fill Dams – 2004
Concrete Gravity Dam	U.S. Department of the Interior Bureau of Reclamation	Design of Gravity Dams – Gravity Dam Design – 1995
	Corps of Engineers – US Army	**EM 1110-2-2200** – Engineering and Design-Gravity Dam Design – 1995

Dam Type or Purpose	Country/ Entity	Guideline
Concrete Arch Dam	U.S. Department of the Interior Bureau of Reclamation	Design Criteria for Concrete – Arch and Gravity Dams Engineering Monograph No. 19 – 1977
	Corps of Engineers – US Army	**EM 1110-2-2201** – Engineering and Design Arch Dam Design – 1994
Roller Compacted Concrete	ICOLD	**Bulletin 75** – Roller Compacted Concrete for Gravity Dams – State of the art – 1989
		Bulletin 126 – Roller Compacted Concrete Dams – State of the Art and Cases Histories – 2003
		Bulletin 177 – Roller Compacted Concrete Dams – 2019
	U.S. Department of the Interior Bureau of Reclamation	Roller-Compacted Concrete – Design and Construction Considerations for Hydraulic Structures – 2005
	Corps of Engineers – US Army	**EM 1110-2-2006** – Engineering and Design Roller Compacted Concrete – 2000
	American Concrete Institute – USA	**ACI 207.5R-11** – Report on Roller-Compacted Mass Concrete – 2007
General Concerns	ICOLD	**Bulletin 61** – Design Criteria – The Philosophy of Their Selection – 1988
		Bulletin 82 – Selection of Design Flood – 1992
		Bulletin 88 – Rock Foundation for Dams – 1993

Dam Type or Purpose	Country/ Entity	Guideline
General Concerns	ICOLD	**Bulletin 102** – Vibrations of Hydraulic Equipment for Dams-Review and Recommendations – 1996
		Bulletin 105 – Dams and Related Structures in cold Climate – 1996
		Bulletin 107 – Concrete Dams – Control and Treatment of Cracks – 1997
		Bulletin 111 – Dam Break Flood Analysis – 1998
		Bulletin 117 – The Gravity –A Dam for the Future – Review and Recommendations – 2000
		Bulletin 118 – Automated Dam Monitoring Systems – Guidelines and Case Histories – 2000
		Bulletin 120 – Design Features of Dams to Resist Seismic Ground Motion – Guidelines and Case Studies – 2001
		Bulletin 123 – Seismic Design and Evaluation of Structures Appurtenant to Dams – Guidelines – 2002
		Bulletin 124 – Reservoir Landslides: Investigation and Management – Guidelines and Case Histories – 2000
		Bulletin 129 – Dam Foundations – Geologic Considerations – Investigation Method – Treatment-Monitoring – 2005
		Bulletin 130 – Risk Assessment in Dam Safety Management – A Reconnaissance of Benefits, Methods, and Current Applications – 2005
		Bulletin 137 – Reservoir and Seismicity – State of Knowledge – 2011
		Bulletin 138 – Surveillance: Basic Elements in a Dam Safety Process – 2009
		Bulletin 142 – Bulletin on Safe Passage of Extreme Foods – 2012
		Bulletin 156 – Integrated Food Risk Management-2014
		Bulletin 158 – Dam Surveillance Guide
		Bulletin 160 – Dam Decommissioning Guidelines

Dam Type or Purpose	Country/ Entity	Guideline
General Concerns	ICOLD	**Bulletin 164** – Internal Erosion of Existing Dams – Levees and Dikes, and their Foundations – 2017
		Bulletin 166 – Inspection of Dams – Following Earthquake Guidelines – 2016
		Bulletin 170 – Food Evaluation and Dam Safety
		Bulletin 172 – Technical Advances in Spillway Design – 2016
		Bulletin 158 – Dam Surveillance

4.3.3 Engineering Geology

The safety of a dam is inseparable from the condition of its foundation. A large percentage of all dam failures have been caused by inadequate foundations. It is important to assess geologic hazards potentially affecting the site, including: the seismic setting, reservoir rim stability, potential adverse behavior of the foundation and abutments. Also to characterize the subsurface conditions in the foundation and abutments and identify suitable sources of construction material. Geologic investigation of the dam site and the reservoir area should include identification and evaluation of hazards from:

⇒ Landslides;

⇒ Subsidence;

⇒ Expanding soils;

⇒ Seismicity, including fault offset;

⇒ Soluble foundation rock;

⇒ Foundation caverns and channels;

⇒ Inherent rock stress;

⇒ High primary permeability;

⇒ Erodible rock;

⇒ Open fractures;

⇒ Low bearing capacity;

⇒ Weak shearing resistance in faults and fractures.

To be acceptable as a foundation for a dam, the rock must be sufficiently strong and bonded to remain intact under forces superimposed by the dam and reservoir, as well as by natural elements. It must also be impervious enough to preclude excessive seepage. To assure these qualities, determinations should be made of crushing strength, mineral composition, cementation, porosity, and resistance to cleavage and slaking.

Texture is usually one of the reliable indicators of rock integrity. Fine grained rocks such as shales, siltstones, and tuffs are generally not strongly bonded because water does not permeate them readily to deposit cementing agents. Some of these may be merely highly compacted and, although apparently competent in a stable environment, may come apart when exposed to alternate wetting and drying. In a dam foundation, such rock must be covered soon after exposure to minimize deterioration. The resistance of fine-grained sedimentary rocks to rapid seepage also makes them subject to high pore pressures. Coarse-grained sedimentary rocks generally are strongly bonded, but the interstices of some sandstones and conglomerates may be large enough to permit high rates of percolation.

Cohesion of rock particles varies with the type and quantity of the cementing agent. Silica, calcium carbonate, and iron oxide are relatively strong, insoluble, and durable; but clay and gypsum are not. Rock strength depends upon not only the cementation but also the size, shape, and arrangement of the particles. Compressive strength may range from about 3.5 megapascals for some tuff to more than 210 megapascals for basalt rock.

Excluding some of the weaker shales and tuffs, most rocks have enough intrinsic strength to resist the loads imposed by a dam. But the rock mass may have bedding and foliation planes, joints, shears, and faults. These can be natural channels for seeping water, which may carry away soluble materials and erode openings. The planes can also be deficient in shearing resistance and susceptible to weathering.

Foliation, the tendency to break into thin sheets, is a common characteristic of schists and slates. The cleavage may allow water, air, and other weathering agents to invade the rock mass. The foliation planes are generally conducive to slippage.

Practically all rock formations have joints, which are fractures along which there has not been any slipping. They form the boundaries of individual blocks in the mass. In a dam foundation, joints can be a cause of concern because the condition of the joint fillings is uncertain and the joint has the adverse potential of becoming a conduit for leakage under the dam.

Among the more dangerous elements at a dam site are faults and fractures which have slipped. These are of particular concern because they may have caused physical alteration of the rock to the extent that the load-bearing capacity has been reduced. The fault zone might have been so shattered and crushed that it is unable to support the heavy loads of a reservoir. Its soft filling could be susceptible to squeezing or blowing out. Fault gouge may also hinder the grouting of cracks. Faulting not only alters the condition of the adjoining rock but also displaces foundation blocks so that rocks of contrasting characteristics are side by side. This may bring a hard rock to bear on a soft rock, or a tight rock against one that might leak like a sieve.

Major faults at or around a dam site must be examined to assess the probability of their future movement. Dams constructed on active faults may be stressed severely during such slippage. Disclosure of geologically recent movement at a proposed dam site is usually enough reason for abandonment of the site. Dams have been built at such sites when there was no alternative, but in these cases almost invariably the design was ultraconservative, incorporating features that would allow accommodation of displacement.

Resistance to erosion is an important factor in determining suitability of the rock at a dam site. This may depend more on bedding, foliation, and jointing characteristics than on the inherent strength of the rock. Where the potential planes of breakage are closely spaced, vulnerability to disintegration under water forces can be high. Such weaknesses should be given special attention in areas where outlets and spillways will discharge.

Solubility of the rock underlying the reservoir should also be considered. Limestones and gypsums sometimes present problems when exposed to water under pressure. Limestones may have joints and bedding planes that provide paths of infiltration that facilitate rock solution. However, joint enlargement and cavern development in limestone are usually slow enough to be controllable during the life of a reservoir. The deterioration of gypsum may be rapid enough to create hazard.

At some sites it is practically impossible to discover and assess all geologic defects prior to construction. Moreover, there is little likelihood that drilling and sampling of the foundation materials will be so selectively accurate as to completely define the most critical zones. Only during construction and operation can there be assurance that the facility and its site have been fully tested.

Not infrequently, problems appear for the first time in the operational phase, despite conscientious efforts to detect them sooner. For example, some reservoirs do not hold water. One of these leaked immediately in the first attempt to impound. The water disappeared into sinkholes as fast as it could be delivered. After the holes are sealed, storage is still not successful. The reservoir can be found beneath a limestone formation with a multitude of solution channels that challenged the seal. Experiences such as this point to the need for a broad viewpoint when considering plans for water storage. The perspective required covers the dam site, the reservoir basin and generally much of the surroundings.

4.3.4 Hydrology and Hydraulic

Based on its hazard potential, a dam is normally classified into risk categories. In hazard-potential classification, potential adverse consequences should be considered, including deaths and the loss of major infrastructure elements—infrastructure whose loss may indirectly place such a burden on a community that lives would be at risk as a result.

Hazard assessment is also based on the potential economic risk associated with the flooding of industry, businesses, and infrastructure. This risk and the related regulatory issues are also handled within the confines of local flood protection regulations. A hazard-potential classification does not reflect any estimate of the likelihood that a dam may fail, but only reviews the consequences of the assumed failure.

To determine the potential of lowering the hazard classification from a conservative field evaluation, detailed studies including dam-breach analyses are to be performed for various hydrologic conditions to evaluate the effects of a dam.

A hydrologic and hydraulic investigation needs be prepared. The engineer should attempt to understand:

Main aspect	Information
Rainfall and Runoff Information	Characteristics for the entire watershed and all subbasins, as applicable to calculation methods
	Data used to develop parameters describing the watershed characteristics, including any available calibration data
	Design-flood inflow and discharge hydrographs
	Reservoir routing data and parameters
	Discharge-frequency relationships
	Determinations of hydraulic roughness
	Water-surface profiles

Main aspect	Information
Dam and Spillway Information	Spillway stage–discharge relationships
	Maximum height and reservoir storage values
	Elevation-area-storage relationship
	Key operational elevations for the dam and spillway
	Pertinent spillway dimensions
	Energy-dissipating facility features
	Results of hydraulic model tests when the hydraulic design is based on a model study
	Details of low-flow release structures
Breach-Analysis information	Breach parameters
	Profile of peak flood levels
	Profile of warning time versus distance downstream
	Delineation on the best available mapping base of the extent of inundation for the normal pool and design flood breach events for the project
	Identification of any potential loss of public services and of critical facilities
	Assessment of hazard-potential classification
Freeboard	Should include the expected wind effects that could occur during the design-flood event if the peak reservoir level occurs within the critical portion of the storm event itself
	Should include the expected future settlement and consolidation of the embankment after construction in addition to wave run-up

Main aspect	Information
Spillway Rating Curves	Important components of any design flood determination are the accurate representation of the elevation-area-capacity
Principal Spillways	Rating-curve development needs to reflect the unique characteristics of the individual spillway.
Emergency Spillways	Emergency spillways are generally cut into an abutment and have little or no erosion protection from flows discharging through them

4.3.5 Embankment Safeguards

An embankment dam must be an optimum product of the local materials from which it is constructed and must harmonize with its site. If the foundation is not strong enough to support the loads of the structure and water, the inferior materials must be removed or improved. If it is too permeable to serve as an adequate water barrier, it should be sealed by measures such as grouting, cutoffs, or blanketing. A foundation with openings that are difficult to seal may also be treated by drains or relief wells. The **ASCE** [04-05] recommends the following guidelines to protect against cracking and consequent piping of embankments:

⇒ Use of a wide transition zone or properly graded filter zones of adequate width.

⇒ Special treatment of foundation and abutment conditions to reduce sharp differential settlement.

⇒ Arching of the dam horizontally between steep abutment slopes.

⇒ Adjustment of construction sequence for the different zones or sections.

⇒ Requiring special placement methods for questionable materials.

⇒ Thorough compaction of rock shells to avoid inducing tensile stresses in adjacent core material.

The internal distortions that occur in embankments result from compression, shear strain, and/or plastic deformation of the materials in the dam and in its foundation. In an earth fill or rockfill structure with several internal zones with different material characteristics, degrees of compaction, and moisture content, there will almost inevitably be appreciable interzonal adjustments in response to the various forces imposed.

Irregular rock surfaces in the core foundation increase the potential for differential strain and consequent cracking in the core. Therefore, careful attention to foundation treatment under the core and the adjoining transitions is necessary. Overhangs should be eliminated, and rock protuberances should be trimmed. To preclude disturbing acceptably sound foundation rock, this excavation should be done preferably without blasting. In conjunction with rock excavation or as an alternative, concrete can be placed under overhangs or at other irregularities to give the foundation an acceptable shape.

Seepage through a rock joint or crack underlying erodible material in the embankment may cause fatal damage. Fine sands, silts, and dispersive clays are susceptible to such erosion. In some cases, an initial contact layer of plastic clay has been placed on the foundation for protection. While the benefits of this can be discussed, there should be no doubt about the value of the permanent sealing of foundation openings with grout or concrete to isolate the embankment from potentially damaging underflows. As common practice in many projects, this is accomplished effectively with slush grout, mortar, dental concrete, or shotcrete. An additional line of defense is provided by filters and drains in the downstream part of the embankment.

Some aspects of embankment design are necessarily dependent on assumptions and approximations and therefore require extensive safety factors. Since these are introduced to compensate for uncertainties, they should not be considered as strength reserves to support superimposed loadings. While less liberal safety factors may be used as confidence in data and methods increases, enough conservatism must be retained to cover the remaining unknowns. To cite an obvious but instructive example, the most rapid electronic computer cannot offset imperfections of input data from the field or laboratory. Personnel who tend to be fascinated by sophisticated analytical techniques must pause from time to time to appraise the value of the ingredients.

4.3.6 Materials

Inspection quality is also receiving more attention, as emphasized in **Chapter 3.**

4.3.7 Engineering for Usual Defenses and for Earthquakes

In the XXth century there was a trend towards bigger dams. Especially remarkable was the increasing size of embankment dams. The risk has increased proportionately and has been compounded at the same time by construction in marginal locations as good dam sites have become scarcer. This applies especially to seismically active areas.

4.3.7.1 Exposure to Earthquakes

Public confidence in dams is mainly based on the safe performance of thousands of reservoirs under less than the most severe conditions. Only a few dams have been exposed to major earthquakes, as can be seen in **Chapters 1 and 7**.

Overtopping water waves may be generated by landslides or oscillation of the reservoir or sudden movement of the dam foundation.

4.3.7.2 Seismic-Resistant Design

Advancements in design earthquake determination, finite element analysis, and dynamic testing of soils have enabled prediction of the behavior of embankments under vibratory loading. In the design of embankment dams, zoning is an important key to built-in protection against failure. Selection of the right materials for each zone, and ensuring their proper placement, will allow control of concentrated leakage arising from distortion of the fill or from foundation displacement.

One of the most effective lines of defense is a comparatively wide transition or filter zone composed of a well-graded mixture of sand and gravel. If a dam is sheared by an earthquake, the intermediate section between the core and the downstream zone can adjust to control leakage to tolerable amounts and to prevent detrimental piping of materials. With proper gradation, the sand and gravel will tend to seal the cracks which might open in the dam or its foundation.

The upper part of an embankment is especially vulnerable to seismic forces. It is susceptible to cracking and to separation at the contact with the abutment. Since seepage paths are shorter near the top of the dam, and because the internal embankment pressures are generally too low to close cracks, the potential for dangerous leaks is considerable. Therefore, in determining the zoning for this part of the embankment, a well-graded sand and gravel mixture placed on the upstream side of the impervious core should be favored as a stopper for cracks. Assurance against failure during an earthquake is also provided by a substantial freeboard between the normal water surface and the crest. This may be a decisive benefit in case of a slumping or cracking of the crest. It will also provide a measure of protection against overtopping by a water wave generated by a seiche or a landslide into the reservoir.

An embankment with an ability to adjust safely to differential movements would, therefore, be one which has an impervious zone composed of a well-graded mixture of clay, silt, sand, and gravel; ample transitions and drains; thoroughly compacted gravel or quarried-rock zones; and liberal freeboard. One of the least resistant would be a dam with a thin, sloping core of silt or other easily eroded soil, thin filter or transition zones, and dumped rockfill. Dumped rockfill may have questionable merit in a high dam because it is susceptible to considerable settlement under severe shaking.

4.3.7.3 Seepage Control

Consideration of seepage control should be factored into all aspects of the project's investigation, design, construction, and monitoring.

From a balanced risk point of view, this aspect of design should be receiving the same level of scrutiny as the design flood and that of static and seismic slope stability. Satisfactorily addressing seepage concerns is not simply a matter of constructing a suitable impervious zone along with adequate drainage features. One must address filter issues, embankment zoning, foundation geometry, among other factors.

The goal of seepage control is to ***prevent the development*** or ***mitigate the impact*** of the following:

- Cracks in the low permeability section of the embankment;
- Cracks at the embankment contact with appurtenance works, the abutments and the foundation;
- Piping due to uncontrolled flow through the dam, and through the foundation downstream toe of the dam, and;
- Excessive seepage beneath or around the dam through the abutments or the foundation.

A dam will alter the natural balance of conditions at its site. As water is brought into storage, an adjustment will begin, which develops a new flow net through the barriers that confine the reservoir.

Unless seepage is intercepted and safely conveyed away, it may exert detrimental pressures or remove erodible materials. The integrity of a dam, therefore, depends on the functioning of a properly designed and well-maintained filter-drainage system.

When excessive seepage conditions threaten the safety of a dam or reservoir, various procedures may be considered; the first being to lower the storage level. This will reduce the hydraulic gradient and is a prudent interim step until permanent corrective work is completed.

The measures for controlling seepage through pervious foundations depend upon several factors. In some cases, a combination of several kinds of seepage control measures may be adopted. A positive cutoff, achieved by excavation to an impervious foundation, is regarded as most desirable under an embankment. Such a cutoff should be sufficiently broad to ensure a seepage gradient low enough to avoid damaging the embankment material and should have excavation slopes flat enough to avoid stress concentrations. If such positive protection cannot be attained by excavation and backfilling with impervious material, consideration should be given to other seepage control measures singly or in combination such as:

⇒ Impervious earth blankets extending upstream from the embankment;

⇒ Slurry trenches:

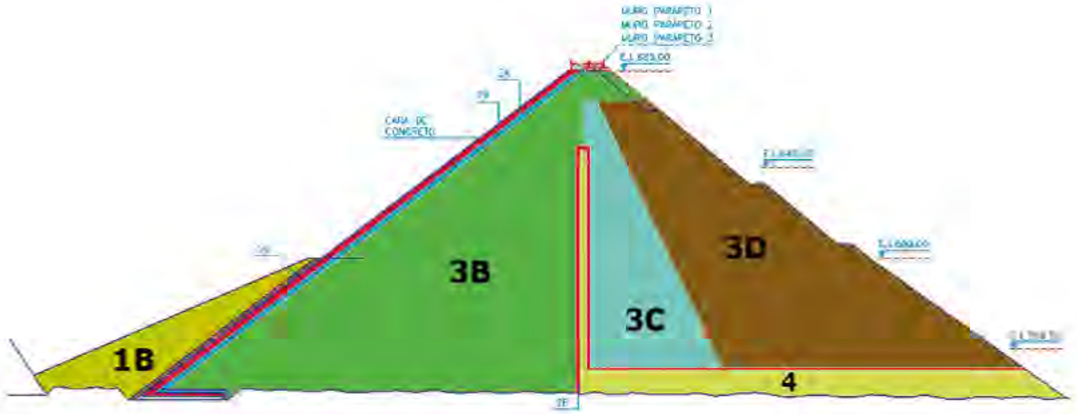
⇒ Grout curtains;

⇒ Concrete cutoff walls.;

⇒ Vertical drains.;

⇒ Relief wells.

Filters and Drains – Filters are considered as a "protection" that the various design features of which they form a sub-element will maintain their integrity and function as intended. At a site with soils of adequate strength and impermeability, the embankment may be constructed as a single homogeneous mass. However, in present practice, the embankment is more likely to consist of an impervious core enclosed by pervious shells. Internal filter-drains are often placed in the downstream of the impervious core shell to intercept and carry away seepage. These may be relatively narrow, vertical, or inclined zones immediately downstream of the core, a blanket on or near the foundation (including abutments) under the shell, a zone at the toe of the embankment, trenches filled with pervious material, perforated pipes, or combinations of these measures. Horizontal drain blankets should be preferably used as companions and extensions of inclined drain zones or chimneys placed just downstream of the core.



Porce III CFRD Dam Transversal Section in Colombia – H:151m; V:4,155,000 m^3 [04-06]

Transition zones properly designed and constructed should be able to control leakage through a crack in the impervious core. An effective defense will be provided by a zone of coarser material such as cobbles or rockfill just downstream of the transition. With its greater permeability and its filter compatibility with the transition (so that transition materials cannot enter the rockfill voids), this zone should convey leakage safely.

If a crack occurs in a fine-grained core, the filter must prevent transport of material through the opening. An ideal filter on the downstream side of the core will adjust rather than sustain the cracking. This capability is also important in the filter upstream from the core so that it can function as a "crack filler" if the core crack tends to remain open. Careful consideration must be given to the selection of permeable material for drainage of an embankment or of a natural reservoir barrier.

Aggregate drains must function as filters to retain soil or rock particles and as conduits to convey water safely to discharge points. To meet the first requirement, a graded filter – a coarse aggregate layer protected by one or more layers of finer aggregate – is effective. In controlling large seepage flows, filter aggregates fine enough to resist piping are not usually sufficiently coarse to meet the full discharge requirement. The necessary capacity can be provided either by pipes or by the coarse element of a graded filter. If the seepage outfall must extend over a relatively long distance, water can be collected by open-jointed, slotted, or perforated drainpipe and conveyed to a closed pipe discharge system. All pipe openings must be sized to prevent the entrance of the surrounding aggregates.

Trench or finger drains may be used as alternatives to continuous blankets, especially where drain materials are very expensive. If such drains are used, the material must be thoroughly compacted to ensure that it does not consolidate on saturation. Otherwise, an open seepage conduit may develop in the top of the trench, bridged by the overlying embankment.

Enough testing should be performed on the compacted drain material to ensure that it will not be subject to detrimental consolidation. In view of this potential weakness, finger drains probably should be avoided unless other alternatives are unavailable or prohibitively expensive. Care should also be taken to avoid the contamination of drain materials.

The possibility of gradual adulteration of originally cohesionless embankment zones cannot be disregarded. It could happen through migration of clayey fines or depositing of chemicals from seepage. Whether such conditions commonly develop enough to impair filtering and draining capability is not easily verified. A generally accepted view is that clean, hard crushed rock and sand and gravel in embankments will not undergo significant changes during the life of a reservoir. In contrast, however, some weathered alluvial materials and soft rocks susceptible to deterioration and/or recementation should not be used where cohesionless zones are specified.

A drain must be stable enough to withstand the surging which may be necessary to remove clogging by chemical deposits or bacterial growth. Drain stability tests should be conducted for vibration and surging effects.

In some cases, sinkholes have appeared on the crests and slopes of embankments composed of coarse, broadly graded soils of glacial or alluvial origin. The fines in the subject soils tended to be non-plastic or to have low-to-medium plasticity. The fines apparently were not compatible with the coarser particles from the standpoint of filter requirements. The sinkholes were believed to be caused by erosion at a concentrated leak, causing the finer soil particles to migrate out of the compacted soil mass, exiting through cracks in the foundation rock or through filters which were too coarse to retain the fines. Fine-to-medium sand filters should be considered for dams with thin cores of such materials. Emphasis must also be placed on the sealing of cracks in rock foundations under dam shells consisting of these materials.

The above information should caution designers to consider that such coarse, broadly graded soils may not necessarily possess the self-healing properties sometimes supposed. These soils may not be as well-graded as a concrete aggregate or many deposits of river sand and gravel. Theoretically, such well-graded materials may have just the correct quantity of each particle size to fill the voids of the progressively larger particles. The particle-size distribution of the typical coarse soils which have been associated with the sinkhole phenomenon shows that the volume of fine particles is greater than the volume of the voids of the coarse sand and gravel fraction, and the coarser particles, therefore, may be floating in a matrix of fines.

Another important observation is that construction of a coarse filter without some particle segregation is difficult.

Consideration should therefore be given to placing a sand filter downstream of the core, especially for major dams with thin impervious cores and thin filter zones. The difficulties described have occurred at only a small number of dams composed by the suspect soils. Internal erosion of coarse, broadly graded soil cores apparently develops only when an unfavorable combination of the following conditions exists:

⇒ thin core, usually vertical;

⇒ downstream filter of coarse sand and gravels, with little or no fine sand sizes;

⇒ not adequately sealed steep or jagged rock foundation.

Relief Wells – Foundation Drains – Pressure relief wells -foundation drains – are often placed under concrete dams, usually immediately downstream from the grout curtain. They are also used in the foundations of other dams. When they are drilled in erodible materials, their design must incorporate features to prevent piping. A combination of upstream impervious blanket and downstream drain wells can provide effective seepage control.

Relief wells are not only used in combination with upstream impervious blankets but also with various other schemes to control hydrostatic pressures in the downstream zones of the embankment that could lead to piping or slope instability. Relief wells are sometimes connected with a drainage gallery under the dam. There is need for regular surveillance and maintenance of relief wells.

Grouting – Grouting is done to seal subterranean channels as well as cracks in structures. It is not always effective by itself but is often a dependable safeguard when combined with adequate drainage systems. The grout must be mixed to proper proportions for the site conditions and must be injected under controlled pressures to prevent damage to the dam or the foundation. In establishing a grout curtain under an embankment, several rows of grout holes are generally preferable to a single row. The curtain should be supplemented with a drainage system and a series of piezometers to check the efficiency of the grout barrier.

Cutoffs – Seepage is controlled most effectively by extending a cutoff into impervious foundation. This should be combined with a drainage system to intercept any seepage that may still find its way through the rock and pervious foundations or the dam. Where a complete cutoff is not feasible, satisfactory control might be assured, in some cases, by adding relief wells or toe drains.

When a cutoff is to be constructed at an existing dam, its influence on stability must be carefully analyzed. If used in remedial seepage control for an embankment, the preferable location for the cutoff is at or near the upstream toe. This normally requires the draining of the reservoir.

Properly constructed slurry trench cutoffs are essentially impervious and plastic and have engineering capabilities similar to stiff clay. Their effectiveness has been demonstrated on many projects where they have adjusted to embankment or foundation deformations without cracking or any differential settlement.

Advances in slurry trench construction methods have broadened the applicability of cutoffs by enabling greater depths with limited volume of excavation. The slurry trench has been used successfully at major dams in several countries. Although it has been incorporated into the original design of the dam, it can also be an effective corrective measure on an existing structure. The common procedure involves excavation of a narrow trench, keeping it filled with bentonite slurry to support its vertical walls. After the trenching has been extended to final depth, it is backfilled by dumping earth materials into the slurry pool.

To obtain and retain a uniform slurry mix, backfill components of clay, well-graded sand and gravel, and bentonite preferably should be weight batched into mixers for blending with a predetermined amount of water. Although on some projects the trench backfill has been mixed by wind, mixers are generally superior. Careful control of the fine-grain content in the backfill of the slurry trench must be maintained. A generally acceptable range for materials passing a 75 μm (200-mesh) sieve is from 10 to 30 percent. This is intended to ensure impermeability without excessive settlement.

Techniques have also been developed for the installation of concrete walls or diaphragms through the use of slurry trenches. Tremie concrete has been successfully placed in such construction to achieve a positive cutoff.

One of the least effective alternatives for seepage reduction is sheet piling. Although this was installed in many previous dams, it has not been proven to be reliable. Steel sheet piling cannot be regarded as a positive way of controlling seepage. Vibrating pile hammers and other measures may improve pile alinement, and bentonitic slurry may be helpful in sealing the piling interlocks. However, sheet piling in most applications cannot be expected to provide a watertight barrier.

Blankets – Blanketing is another useful alternative for seepage control. A complete blanket would extend into an impervious contact along its full boundary. Partial blanketing is sometimes done to lengthen the path of percolation in the foundation. Blankets are most often constructed of earth but in some cases with an impermeable membrane.

Other materials, such as plastic sheets, have been used with varying results. Some of these liners have tended to be susceptible to damage and accelerated deterioration. Techniques of placement require careful attention. To be most effective, an earth blanket normally should have at least 1meter thickness and should be thoroughly bonded to the adjoining impervious elements. The mix of the earth should be designed to assure watertightness. In locations where the blanket may be subjected to erosion, it should be covered by a protective material.

4.3.7.4 Engineering of Conduits and Structures

Many of the defects disclosed at dams have been in appurtenant conduits or structures such as outlet works and spillways. One hazard which has been well demonstrated is when a rigid structure is placed upon a yielding foundation or across a shear or a fault zone. Voids or fractures at such places may result in uncontrolled release of water.

Conduits and structures under high fills may be subjected to seriously damaging movement and cracking, particularly where the foundation is relatively soft. All such facilities should be placed on sound rock if possible.

Even with firm support, structural elements may be broken by embankment adjustments, inducing lateral pressures. Accommodation of such movement must be enabled by proper location and shaping of the buried structure.

Parts that protrude considerably into the fill should have gradual changes in geometry to safeguard against rupture of either the soil mass or the structure.

A primary requirement for a conduit under a high embankment is that it should be strong enough to carry the most severe loads that may be imposed by the fill. Its strength can be enhanced by placement in a notch or trench in the foundation. The bottom and sides of this excavation must be thoroughly cleaned. Any earth backfill around the conduit must be compatible with the surrounding material. Both inside and outside of the core limits, backfill should be selected and compacted to minimize settlement. Often, the best practice is to backfill completely around the pipe with concrete.

Conduits which pass under an embankment must be constructed with an effective watertight barrier around them. Means of achieving this include tight bedding and installation of seepage collars. A common cause of failure is piping of material along the outside of the conduit. Not infrequently, this can be attributed to poor compaction of backfill around the conduit. A conduit represents a discontinuity [04-07 & 04-08] through an embankment dam and its foundation. This discontinuity can cause settlement adjacent to the conduit to be different from the rest of the embankment dam. Earth fill might also be compacted differently around a conduit than for the rest of the embankment dam. These factors can cause cracking of the earth fill and lead to other consequences. Failures of embankment dams caused by the uncontrolled flow of water through the dam or foundation are a common problem.

Failure of an embankment dam due to the discontinuity represented by the conduit[04-08]

A failure due to internal erosion often leaves a tunnel-shaped void along the conduit[04-08]

Anti-seep collars impeded the compaction of soils around the conduit. Hand tampers were used next to the anti-seep collar[04-08]

Outlets – Every reservoir should have an outlet with a capacity proportionate to the reservoir storage. Emergency draining time will often be the controlling factor in sizing these works. The capability of rapid lowering of a reservoir during a crisis can be extremely important. On such occasions properly functioning outlet works are essential. Just by being able to quickly lower the water level a few feet could make the difference between saving and losing a dam.

Where the conduit feeds directly into the distribution system, a blowoff or short bypass should preferably be installed close to the reservoir to release the full capacity of the outlet. Gate or valve control at or near the upstream end of an outlet is highly desirable so that conduit water pressures can be limited within or under the dam. This is especially important for an outlet under an embankment or through a reservoir rim that would erode readily if the conduit ruptured. Where such control is not provided, an upstream bulkhead shall be included to enable dewatering of the conduit under full reservoir head.

There are advantages in providing more than one mean of controlling the release through the outlet works. Facilities equipped with only one valve or gate require careful maintenance and periodic testing to assure that they are operable.

Location of outlet pipes within walk-in conduits is desirable. Where this is done, a ventilating system should be provided to reduce condensation and consequent corrosion of metal. Painstaking care is required to assure that the outlet pipes themselves are constructed properly. When a metal pipe is buried, concrete encasement loads. The reinforcing steel cage must be centered on the pipe. Poor workmanship can result in less encasement than provided in the design. The thickness of the encasement usually should not be less than 200 millimeters (8 inches) even for small conduits.

If conduits must cross faults or shear zones, some means of accommodating displacement should be provided. Protection against detrimental differential movement is also needed where a conduit must cross both fill and rock foundation. For buried pipe, one way is to place a closed jacket or carrier conduit around the pipe. Flexibility is an essential requirement for the pipes at the point where they leave any rigid encasement.

The need for seepage or cutoff collars around an outlet pipe warrants careful attention. In certain circumstances, they should not be used. Better protection against seepage is provided by placing the concrete encasement of the conduit to fill the whole space between the pipe and the trench.

Where seepage collars are subjected to embankment loading, one practice has been to place the collar integrally with the conduit, using reinforcing steel to tie the two elements together. Some designers have suggested that the collars should be separated from the conduit by means of asphaltic joint filler, so that the cutoff is free to move yet still maintain a water seal.

Collars are usually best protected against embankment distortions if they can be located in the center third of the dam base, where movement will be primarily vertical.

Spillways – Increasingly conservative criteria for sizing flood control works are tending to considerably raise some project costs. At some sites these facilities have been almost as expensive as the dam itself. But false economizing on spillways has led to many problems. Spillway chutes have been terminated too high and too close to the dam. Erosion from a perched spillway can be very hazardous. Flip buckets are poor substitutes for stilling basins where rock is not resistant to erosion. More than one dam has been endangered by lack of waterstops in spillway chutes. Even a small spillway discharge has been known to overtax underdrain systems where waterstops were omitted.

Oroville Spillway damage in 2017[04-09]

Oroville Spillway damage in 2017[04-09]

There was no single root cause of the Oroville Dam[04-09] spillway incident, nor was there a simple chain of events that led to the failure of the service spillway chute slab, the subsequent overtopping of the emergency spillway crest structure, and the necessity of the evacuation order. Rather, the incident was caused by a complex interaction of relatively common physical, human, organizational, and industry factors; starting with the design of the project and continuing until the incident. The physical factors can be placed into two general categories:

⇒ Inherent vulnerabilities in the spillway designs and as-constructed conditions, and subsequent chute slab deterioration;

⇒ Poor spillway foundation conditions in some locations.

Spillways preferably should not be placed across active faults nor below potential slide areas. Landslides are especially likely to be activated during storms in the wet season and have been known to clog spillways when they were most needed.

Outlets and spillways may be built as tunnels in the dam abutments or through other barriers forming the reservoir rim. From the standpoint of safety, this is one of the preferred methods of construction. However, the condition of the geologic formations may have an important influence on the selection of alinement. If tunneling is done in soft rock abutments, every precaution must be taken to prevent damage to the foundation through rock yielding. Where this is violated, by inadequate support of the excavated faces or by other negligence, the weakened zone may constitute a hazard of major proportion.

Galleries – In designing gallery systems within or under dams, consideration should be given to the need for working room for monitoring, maintenance, and repair. Economy-minded designers have provided galleries at some sites which will accommodate only small, strong-hearted inspectors. Most importantly, an access system should enable rapid movement and mobilization of men and equipment during an emergency. An alcove or two in the gallery system, for example, would be valuable for equipment storage and workspace.

Motorized conveyance devices can also pay dividends during emergency. Since future drilling for grouting and drainage can be expected from some dam galleries, the passageway should be sized to permit setting up drill rigs so that holes can be aligned at desirable angles.

Drains – Drainpipes under embankments and reservoirs deserve special attention. The type of pipe is important. Any conduit or structure buried under an embankment must not be susceptible to rapid deterioration. Since most drainage systems are buried permanently, any failure may be difficult to detect and to remedy.

In designing a pipe system for drainage of the abutments under an embankment, two preferred guidelines are:

⇒ provide two outfalls connected together, so that, if one outfall fails due to crushing under construction, or movement or plugging during operation, there will still be a reserve discharge line, and

⇒ extend the upper end of each abutment drain to serve as a cleanout access opening. This will permit the introduction of water into the drain system for cleaning and testing.

Underdrains in zones subject to movement should be divided into sections with separate outfall systems so that areas of leakage can be identified. Drains on one side of a foundation shear can be isolated from those on the other side to avoid possible fracturing of lines at the shear.

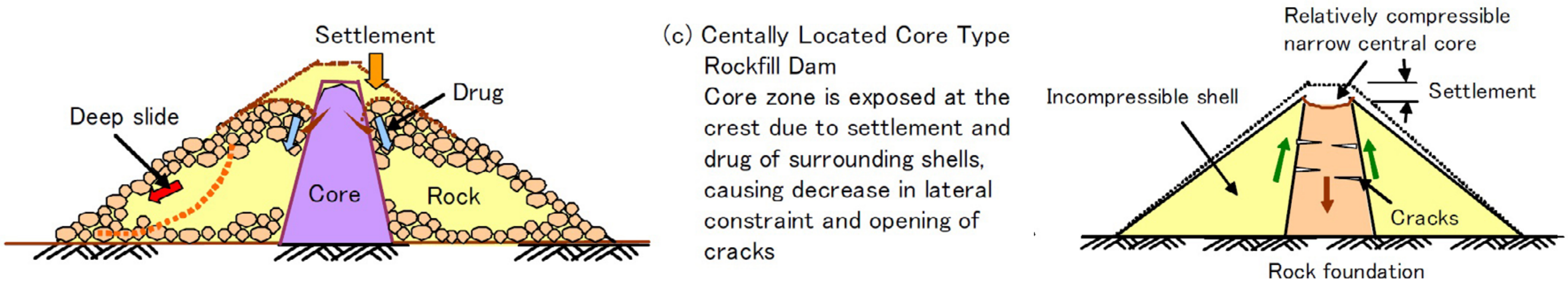
Rigid pipes commonly used for drains as such as clay tile and asbestos cement, require extra care in handling and bedding, since they are relatively brittle and easily damaged. Some metal pipes are very susceptible to corrosive attack, particularly when located in moist embankment.

Shear Keys – For many years shear keys have been commonly accepted features of joints in concrete structures. They look effective on a drawing, but many construction engineers can attest to the difficulties of building them properly. A joint in a relatively thin structural member such as a spillway wall can become quite cluttered by the time the waterstop and the reinforcing steel are in place. To further complicate the joint with a shear key, it may be inviting for honeycombed concrete, which defeats the effectiveness of the waterstop. Proper vibration of the concrete in a key is difficult. The resulting poor grade of concrete in the joint may offer less shear resistance than an unkeyed joint.

Shear keys in the concrete Tucurui Dam – Brazil – (Andriolo's Archive)

Foundation Projections – The use of concrete cutoff walls and other structures buried under embankments must be carefully considered. On a high embankment, on steep granitic abutments, low concrete walls were built over the abutments to provide a cutoff in case the non-plastic decomposed granite fill pulled away from the foundation. Slope indicators showed that the fill did indeed settle away from the abutments. There is a remaining question, however, whether such walls, projecting into the fill like knives, would not have a detrimental effect through shearing of the embankment and the creation of cavities as the embankment adjusts under load.

Core Walls – These walls had a tendency to crack and were not always dependably watertight. Today, there are very few designers who would advocate the use of a concrete core wall in an earth fill or rockfill dam.



Pictures From [04-03]

Superimposed Conduits and Structures – Wherever possible, construction of conduits through or over embankments should be avoided. Difficulties have been experienced with spillways, outlets, and fish ladders in such locations. Conduits can be expected to leak at least a little. Leakage may be obscured by the structure until it has caused damage.

Trenching into the dam, coupled with improper backfilling, may create a plane of weakness in the structure. Also, discharge from a ruptured pipe may quickly wash out a dam. Where no feasible alternatives exist, the utility conduit should be placed within a flexible carrier pipe, preferably located along the upstream face of the dam rather than buried in the fill. If the conduit operates under pressure, it should be provided with valve control so that the section of the dam can be shut off from the system in case of a break.

Emergency Access – No dam design, nor an operation plan, is complete without provisions for protection during an emergency. Outlet works and spillways should be designed and maintained so that they are always accessible. Auxiliary power should be provided. Equipment and supplies for handling adverse conditions are essential. Floodlighting of critical facilities should also be considered.

The safety of a dam during an emergency requires dependable means of access. Roads to the site must enable entry of equipment necessary for servicing the dam during any adverse conditions. The road grades and bridge spans should be above the projected high waterline. As additional safeguard, alternative means of access should be provided where possible.

4.4 Design Aspects Related to the Complacency and Tolerance

The following considerations or actions may be defined as ***Complacency Factor*** [04-10 & 04-11]:

⇒ Undue confidence in unproven theoretical concepts;

⇒ Subjective or wrong interpretations of results of mathematical or model analyses;

⇒ Underestimating the serious consequences of a physical incident at a dam;

⇒ Excessive extension of state of the art beyond the limits of experience, e.g. use of marginal materials and foundations;

⇒ Statistical analyses indicating very low probability or risk of failure of a certain type of structure;

⇒ Using typical, standard, or empirical designs of dams without adapting them to critical site conditions or materials.

Engineering decisions must rely on both sound science and quantifiable risk analysis. From a scientific and engineering perspective, disasters are failures, albeit very large ones. One thing fails. This failure leads to another failure. The failure cascade continues until it reaches catastrophic magnitude and extent. Some failures occur because of human error, some occur because of human activities that make a system more vulnerable, and some occur despite valiant human interventions. Some failures are worsened by human ignorance, and some result from hubris and lack of respect for the power of nature. Some result from forces beyond the control of any engineering design, irrespective of size and ingenuity.

Engineers and other scientists loathe failure. But all designs fail at some point in time and under certain conditions. The distinction between a successful and an unsuccessful design is the function of time. If what is designed performs as intended during its acceptable life span, it is a success. If not, it is a failure. A disastrous design is one that not only does not perform as intended, but also causes substantial harm when it fails.

Engineers can, with fair accuracy, predict the probability of failure due to natural forces such as rain in some zones, and they design the structures for maximum loading, but these natural forces can be exceeded. Engineers design for an acceptably low probability of failure, not for 100% safety and zero risk. However, tolerances and design specifications must be defined as explicitly as possible. The tolerances and factors of safety have to match the consequences. Risk is a function of time because it is a part of the exposure equation, that is, the more time one spends in contact with a hazard, the greater the exposure.

From the above you can ask questions:

- ✓ ***Is it tolerable that a cofferdam can be overtopped 5 or 6 times during the construction of a dam?***
- ✓ ***Wasn't there much complacency?***

It is standard practice in the civil engineering community that the degree of conservatism in design be commensurate with the intended use and the consequences of failure of a given system element. If the failure of a given system element does not pose a public safety concern, then the design-level loading is usually based on economic considerations and the effects of a disruption of operation of the system.

A contrasting situation is where the failure of a given element could pose a threat of loss of life. In these cases, the design events/loadings are typically very conservative to provide protection from the consequences of a failure. And, as the potential magnitude for loss of life and property damage resulting from a failure increase, the design levels/loadings become increasingly more stringent.

The physical size of a project element, its importance to project performance and the cost of replacement or repair are other characteristics which affect the choice of design levels and loadings. It is logical that a large dam represents a greater capital investment than a small dam and warrants greater protection by way of more stringent design levels. Thus, the size and importance of a project element and the consequences of failure of that element are primary considerations in establishing minimum design levels. These issues will be discussed in the presentation of the design considerations for the various project elements throughout the guidelines.

In particular, it will be seen that design levels and requirements are markedly more stringent for those critical elements whose failure could lead to an uncontrolled release of the reservoir and pose a risk to downstream inhabitants.

Special attention must be given to the design and construction of the critical elements. In particular, care must be exercised to achieve a balance in the level of protection provided by the design of the various critical elements. Application of excessive design conservatism to any one element without consideration of other elements will not necessarily result in increased project safety. Thus, a balanced approach is needed during the design phase of a project to provide assurances of acceptable reliability of the entire system.

There is great value in incorporating a systems approach into the design philosophy for the project. It is important that a conscious decision is made to examine the various design levels, and that efforts are made to strike a balance among the design levels/loadings used in design of the critical project elements.

Experience has shown that the causes of dam failures have typically been associated with three general categories of project elements. Approximately one-third of the failures have occurred in each of the three categories: spillways, outlet conduits, and the impounding barrier and foundation. These three general categories therefore comprise the primary critical elements. Failure mechanisms have typically been:

⇒ overtopping by floodwaters on inadequate spillways;

⇒ internal erosion along outlet conduits or through conduit joints;

⇒ internal erosion through earthen embankments and foundations or instability of impounding barriers and foundations.

Special emphasis has been given in the guidelines to providing reasonably consistent design levels and balanced protection to critical elements in these three general categories. In addition, the guidelines present information on various defense mechanisms for the failure mechanisms listed above.

The principal of ***Redundancy*** has always been a common feature employed in engineering design. Redundant elements provide backup protection for the primary element or system and increase the reliability of system operation. Redundant elements are necessary design features for many of the critical project elements to achieve the high levels of reliability required in dam design and construction.

The minimum design levels/loading conditions for critical elements of a project are usually very stringent for situations where the valley downstream of the dam is inhabited. This is particularly true for the design levels for Inflow Design Floods and Earthquakes. Frequently, the design levels are sufficiently stringent that it is prohibitively expensive to construct a project where there would be "zero damage" to the project if the design event(s) occurred.

One solution to this problem is to employ the principle of ***Survivability***, that is, to design project features which allow damage to occur to the project, provided that the structural integrity of the impounding barrier is not jeopardized, and control of the reservoir is maintained. The basic premise is that the design events are so rare that it is unlikely that they will occur during the project life.

Therefore, it is often economically attractive to accept the potential for future project damages and associated repair costs in those situations where the damages would not jeopardize project safety or public safety.

Survivability concepts are applicable to the design of several elements presented in the guidelines. Most notably, survivability concepts are appropriate for design of emergency spillways and energy dissipation basins where tolerable amounts of erosion may be acceptable. Likewise, some settlement and deformation may be allowable on earthen embankments following a major earthquake.

The design of some project elements is governed by the need to provide practical means for inspection and long-term monitoring. This is a constraint in addition to the usual considerations of design levels, loadings, and functionality. This is often the case when man-made materials are used in the construction of the element and proper operation and safety are dependent on maintenance and/or long-term durability of the construction materials. There are several project elements discussed in the Guidelines whose design incorporates the principal of ***Inspectability*** to allow proper inspection and monitoring.

Most dams have expected service life of 100 years or more. This lengthy life span and the frequently harsh service environment pose long term maintenance, repair, and upgrade problems. To the extent practicable, the design should anticipate these problems and include provisions to allow refurbishing or upgrading in the future. This is the principal of ***Serviceability***.

Where there is a variety of possible approaches and where a preference is warranted, recommendations are made based on past experience or current accepted practice. In a limited number of situations, requirements are identified. To avoid regulation misinterpretation between guidance, recommendations and requirements, all requirements are clearly identified by inclusion of the terms required in the subsection heading.

4.5 Dams Affected by Innapropriate Design or Insuficient Attention

A disaster can also be understood as the failure of engineers, construction managers, developers, planners, and other leaders to properly account for an environmental vulnerability. Although such a definition is harsh and strident, it is certainly a warning that engineers must be constantly aware of the first ethical canon of the profession: to hold paramount the safety, health, and welfare of the public. For problems that potentially affect large numbers of people or large geographic areas or that are otherwise substantial and irreversible, precaution is the basis for safety factors in engineering design.

Usually, a design flaw that can cause an accident comes accompanied by aspects characterized as having another origin -***not considered deeply in the design phase*** – as usually mentioned in the technical documents as:

⇒ resulting from exceptional flood;

⇒ resulting from inadequate foundation;

⇒ resulting from expected cracking;

⇒ resulting from an infiltration;

⇒ or other analogous.

Some examples can be cited below.

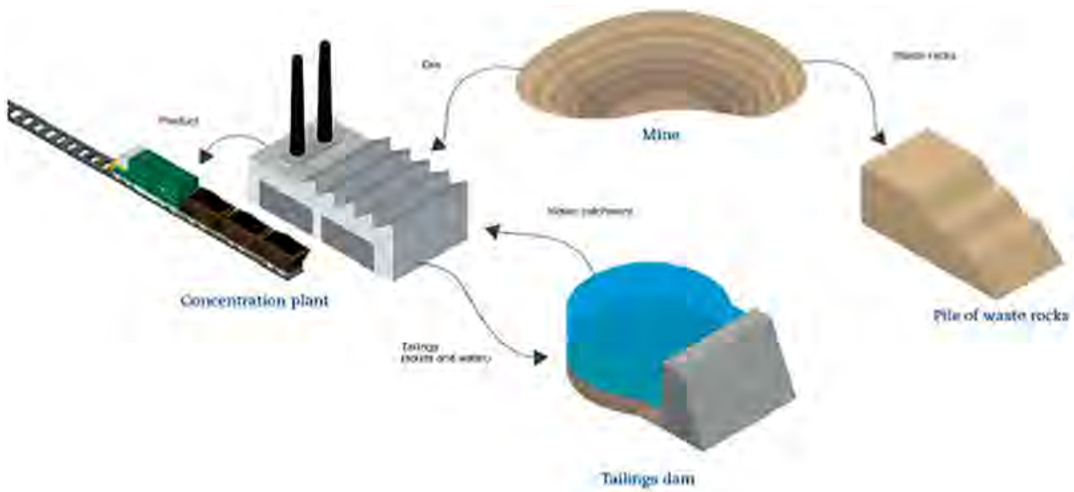
4.5.1 Tailings Dams

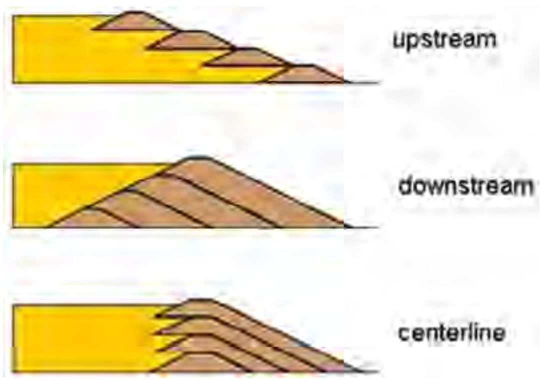
4.5.1.1 Conceptual Aspects

Tailings are the residue of the milling process used to extract metals of interest from mined ores or to clean coal. The extracted metal represents a small percentage of the whole ore mass and so, the vast majority of the mined material ends up as a finely-ground slurry. Tailings contain all other constituents of the ore except for most of the extracted metal. These consist of heavy metals and other substances at concentration levels that can be toxic to biota in the environment.

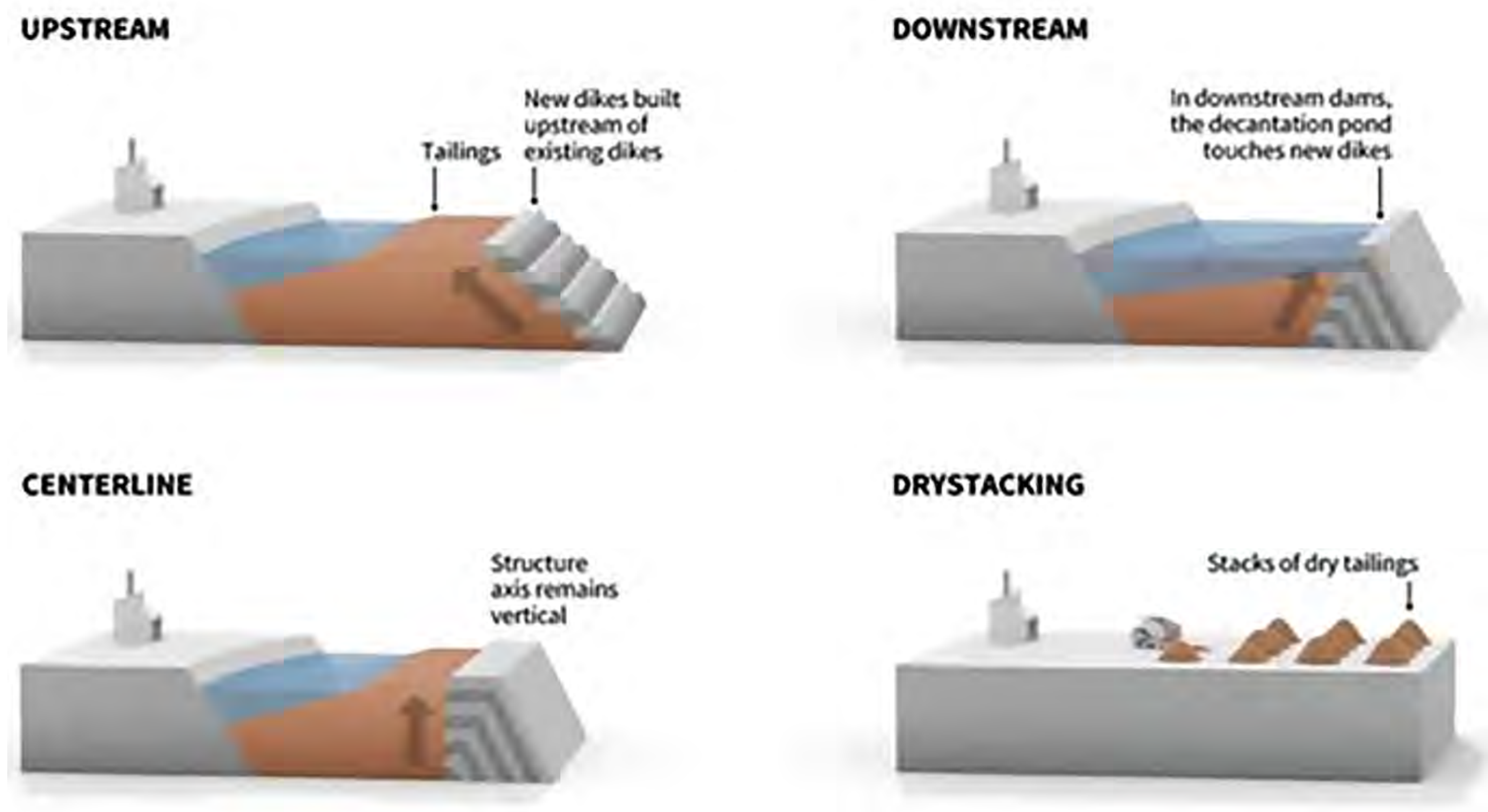
Tailings impoundments and most mill tailings produced worldwide are dumped in large surface impoundments, these being the tailings dams. In other cases, tailings are processed for use as backfill in underground mines. The embankments of these large impoundments are typically constructed as earth-fill dams.

A tailings dam is typically an earth-fill embankment dam used to store byproducts of mining operations after separating the ore from the gangue. Tailings can be liquid, solid, or a slurry of fine particles, and can be toxic and potentially radioactive. Solid tailings are often used as part of the structure itself.





There are three raised tailings dam designs, the *upstream*, *downstream* and *centerline*, named according to the movement of the crest during raising. An alternative for the tailings is the dry stacking.


UPSTREAM
Tailings
New dikes built upstream of existing dikes
DOWNSTREAM
In downstream dams, the decantation pond touches new dikes
CENTERLINE
Structure axis remains vertical
DRYSTACKING
Stacks of dry tailings


Types of Tailings Dams
As the volume of tailings grows, new levels of the dam—often made of sandy, dried tailings—are added to increase its capacity.
Upstream
Built in
In the upstream design, these new embankments rest directly upon the 'beach' inside the reservoir. This saves money, since it requires little earthmoving.
Centerline
Built up and out
Downstream
Built out
In the centerline and downstream designs, new levels of the dam are placed atop previous levels and built outward. This results in a bulkier—and often sturdier—structure.

The specific design used is dependent upon SAFETY, topography, geology, climate, the type of tailings, and cost. An upstream tailings dam consists of trapezoidal embankments being constructed on top on one side but toe to crest of another, moving the crest further upstream. This creates a relatively flat downstream side and a jagged upstream side which is supported by tailings' slurry in the impoundment.

The downstream design refers to the successive raising of the embankment that positions the fill and crest further downstream. A center lined dam has sequential embankment dams constructed directly on top of another, while fill is placed on the downstream side for support and slurry supports the upstream side.

Tailings dams are built to retain impoundments of tailings, and when possible, material extracted from the tailings themselves is used in their construction. They have many features in common with embankment dams built to retain water reservoirs, and in many cases are built as water retaining dams, particularly where there is a requirement for the storage of water over the tailings, or the stored tailings must be protected by a covering of water to prevent aerial pollution.

While the methods used for the design and construction of embankment dams can be applied to tailings dams, there are major differences between the two types. Embankment dams are prestigious structures used to profitably store water, whereas tailings dams are required for the storage of unwanted waste, desirably at minimum cost. Embankment dams are usually built to full height during their period of construction, being designed and the construction supervised by competent engineers (controlled by law in many countries).

Similarities between tailings dams and embankment dams designed to retain water, have enabled many of the design techniques used with embankment dams to be applied to produce safe tailings dams, but despite great improvements, there has been a reported failure of a tailings dam almost every year for the past three decades. The damage caused by these failures in the form of human casualties, destruction of property, disruption of communications, pollution of the environment and economic loss to the mining industry is enormous.

4.5.1.2 Tailings Dams and Relevant Information

The mining industry has learnt from many tailings storage failures and incidents in recent decades that are helping to develop leading tailings management practice. The main causes of failures and incidents identified were:

⇒ Mistake as not properly considering the control of percolation through the dam and foundation;

⇒ Lack of control of the water balance and in the sizing of the spillway;

⇒ Lack of control of construction;

⇒ A general lack of understanding of the features that control safe operations especially in materials subject to dam liquefied in the upstream construction method, and

⇒ Lack of responsibility and ownership by operators.

The safety aspects of the design of a tailing dam need to be considered. Due to these aspects the upstream construction method for tailing dams is refused in some countries.

Tailings containment wall failures were caused by (in order of prevalence):

⇒ poor water control e.g. overtopping, and in the sizing of the spillway;

⇒ slope instability;

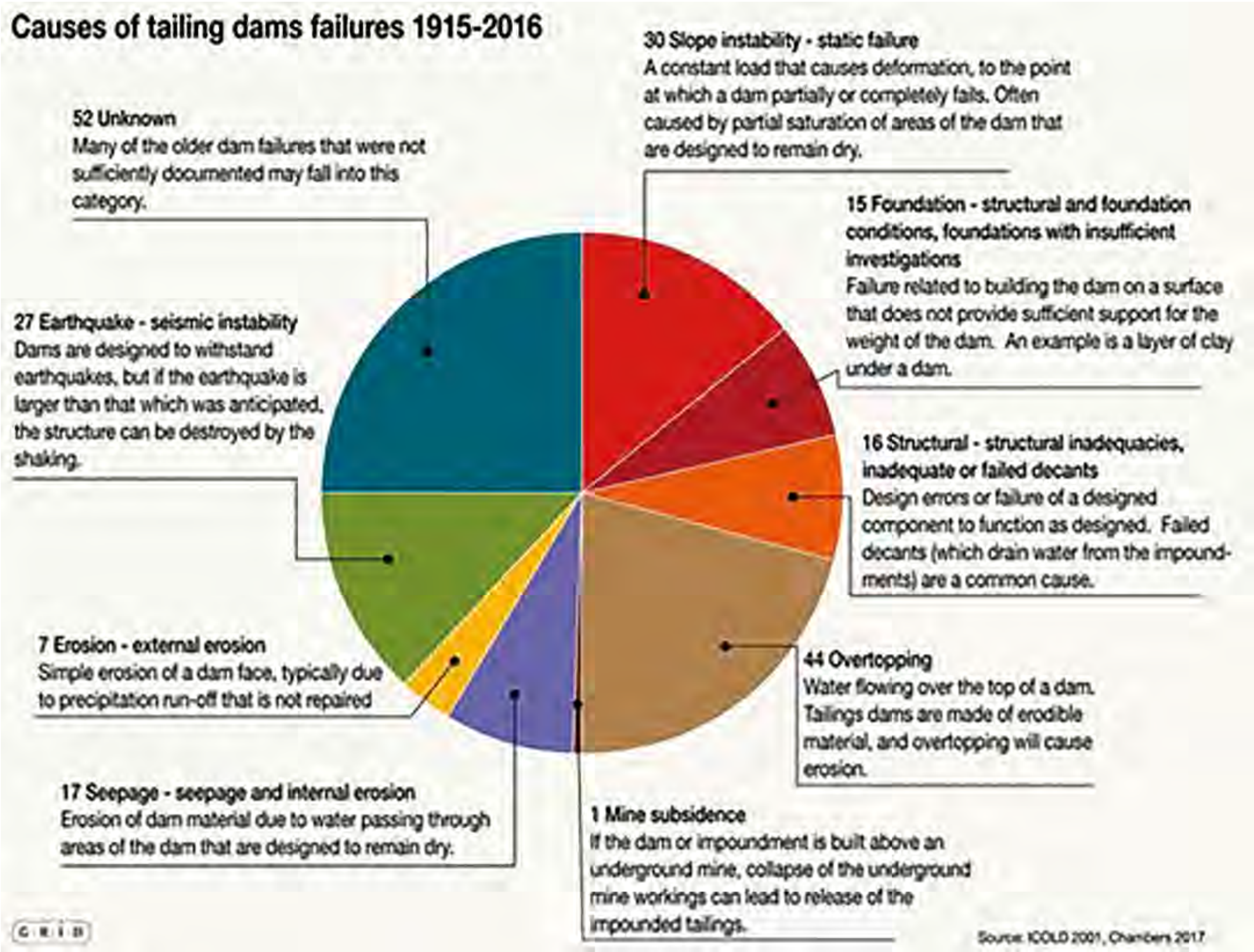
⇒ earthquake loading;

⇒ inadequate foundations;

⇒ tailings liquefaction, associated with the upstream construction method, and

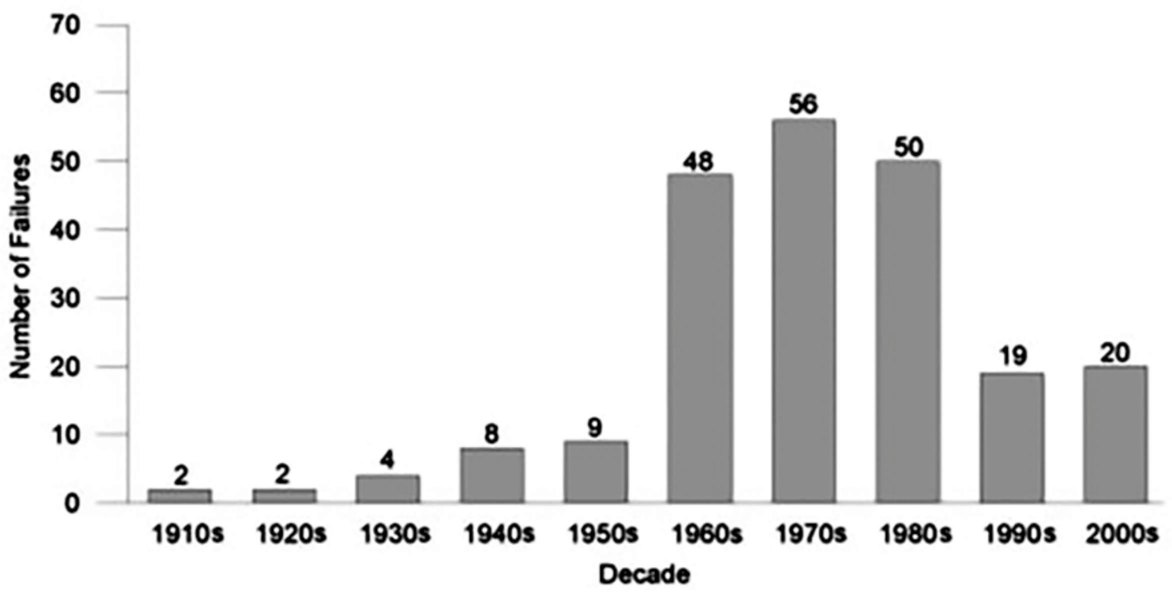
⇒ seepage.

Historically, tailings incidents appear to have been more common where upstream construction was employed compared with center line or downstream construction. This could be due to poor practices in design and construction in the past, and modern design methods should have improved this imbalance. Tailings containment walls constructed using the downstream method appear to have performed similarly to water-retaining embankments, but in reality, shows the statistics as follows (From ICOLD).

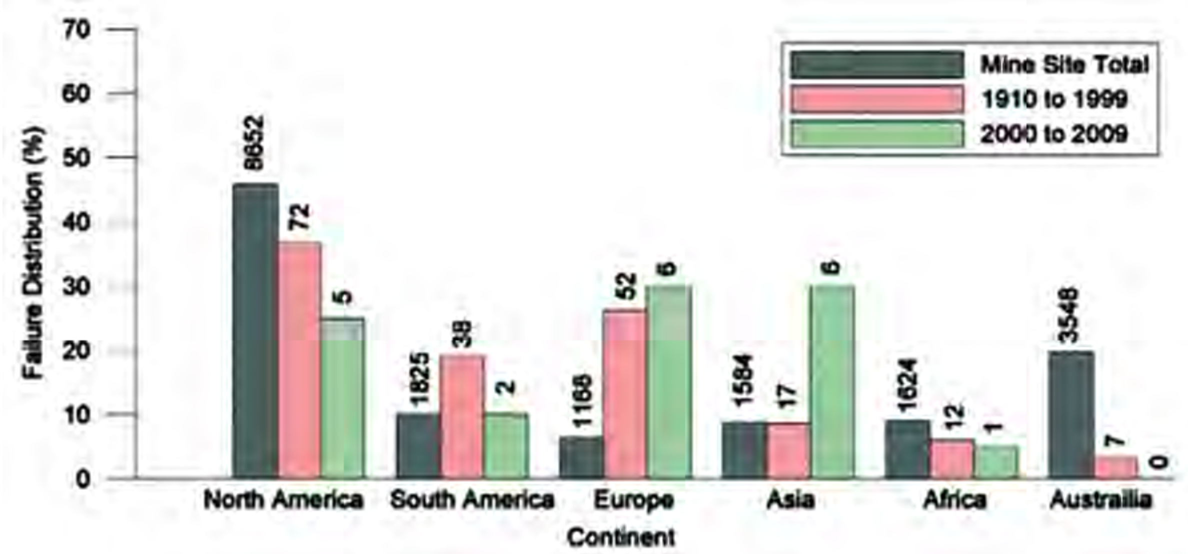


A large number of tailings dam failure incidents remain unreported or lack basic information when reported. This has seriously hindered the development of safety regulations in such areas. Despite insufficient data, a generalized statistical analysis can show some number of failures.

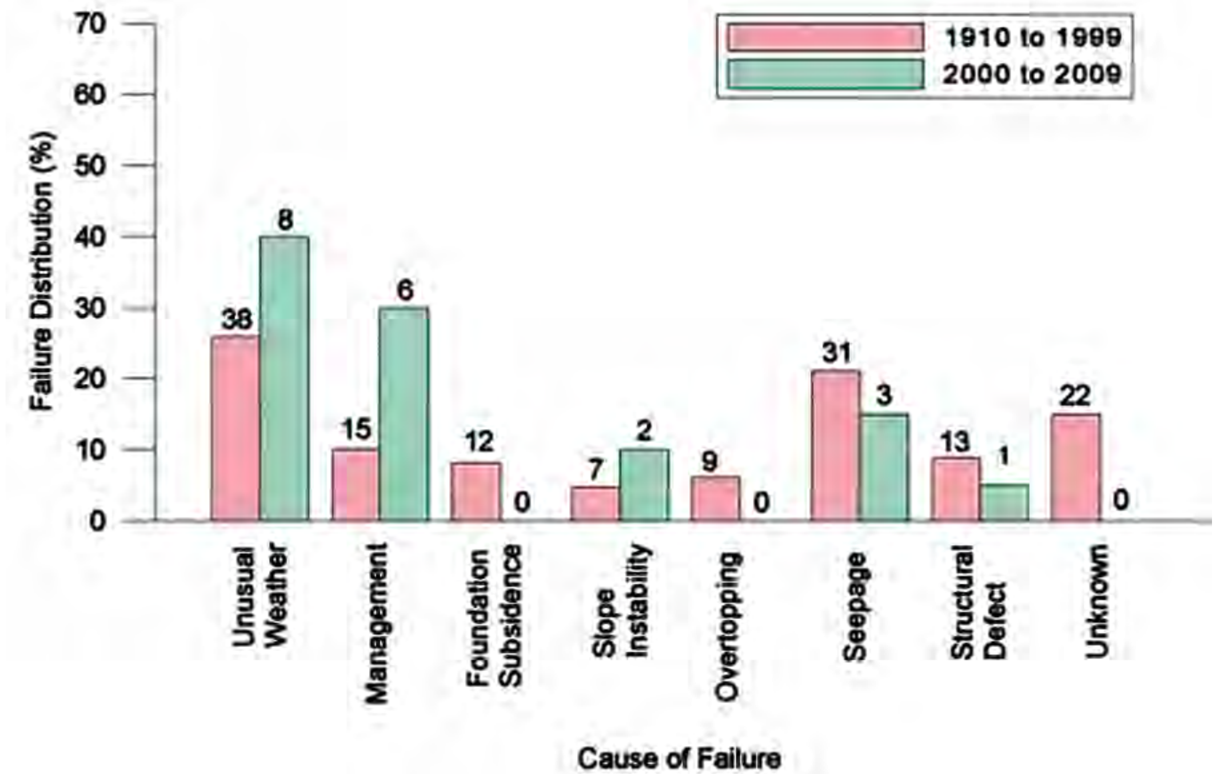
From the beginning of the twentieth century to the 1950s, the number of tailings dam breaks was small, and the occurrence was mainly concentrated in the United States and Chile, but also happened in other countries[04-12]. In addition, the construction requirements of the tailings dam are low, resulting in the occurrence of the tailings dam failure. Tailings dam failure events usually occur in developing countries with rapid economic development (e.g.,Brazil, Chile, and China) and associated with the type of upstream construction method.



The following figure shows that accidents in tailings dam breakages mostly occur in North America. In North America, the countries with the most accidents are the United States and Canada. The proportion of accidents in South America, Asia, and Europe is relatively small in comparison with North America.



The image above highlights the reasons for the occurrence of tailings dam breakage in the last 100 years. One scholar divided the causes of tailings dam breakage into 11 categories, namely, seepage or piping, foundation failure, overtopping, seismic liquefaction (earthquake), mine subsidence, unusual rain, snowmelt, structural, slope instability, maintenance, and unknown cause. But many accidents are the result of a combination of multiple causes, and this classification has some overlapping parts, such as unusual rain, snowmelt, and overtopping. It can be seen from the collected data that extreme weather causes serious damage to the safety and stability of tailings dams. As human activities cause climate warming, the tailings dam failure ratio caused by extreme weather may gradually increase.



The main causes of tailings dam failures in the world can be summarized as seepage, foundation failure, overtopping, and earthquakes. Poor understanding of the materials properties and the liquefaction action, as well as mechanisms of the classic examples for tailings dam failures. In order to understand the reason for the tailings dam failure, the height of the failure, building type, geographical location, and time distribution, a brief discussion of the collected data should be carried out.

To keep such impoundments standing is one of the most challenging tasks in mine waste management. Generally, these containment facilities are vulnerable to failure because of the following reasons:

1) dyke construction with residual materials from the mining operations;

2) sequential dam raise (upstream side) along with an increase in effluents;

3) lack of regulations on design criteria, especially in developing countries;

4) high maintenance cost after mine closure.

Whereas a significant portion of failure incidents fell into the "unknown" category, some general trends were developed regarding time and space, causes, and consequences. The main findings of this work can be summarized as follows:

1. The frequency of such incidents has recently shifted geographically from developed countries to developing countries.

2. The main reasons for dam failures are "unusual rain or poor hydrological analysis" as well as "poor management" and these causes have a profound effect on failure mechanisms. The inclusion of climate change effects in the initial design and the observational method during construction, maintenance, and monitoring are highly desirable.

3. Failures predominantly occur in "small to medium" size dams that are up to 30m high. Such incidents can be minimized by employing proper engineering standards and knowledge.

4. Upon dam breakage, the released tailings generally amount to about one-fifth of those contained within the facilities. Environmental pollution and infrastructure damage can be managed in "intermediate failures". Loss of life and health issues are associated with large catastrophic seepage. Each tailings dam must consider the available scenario and consider a knowledge management.

Tailings dams comprise structures to store unwanted waste from a mineral extraction or manufacturing process. This gives rise to the following particular features which differ from conventional dams:

⇒ The embankments must store solids, usually deposited as a slurry, as well as manage free water. Due to many tailings are susceptible to liquefied even under to low-intensity seismic actions, or any vibrations in the surrounding:

⇒ The dams should have a well-planned end-filter drainage system;

⇒ Both the solids and water stored in tailings dams may contain contaminants which have the potential for environmental harm if not contained both now and in the future;

⇒ Their operating life may be relatively short, but they are potentially required to safely store the tailings for extremely long periods of time, possibly "in perpetuity";

⇒ They are often built in stages over a number of years;

⇒ The construction, particularly any subsequent raising, sometimes may be undertaken by mine personnel without the level of civil engineering input, or control, applied to conventional water dams;

⇒ The materials, both those used for embankment construction and the tailings themselves, are likely to vary during mine life;

⇒ Water management is crucial, particularly if harmful materials are contained;

⇒ Seepage and dust may have a major impact on the environment;

⇒ Daily operations such as placement of tailings and recovery of water may be critical:

- The safety of the storage;
- The filling rate, the ultimate height and even the overall storage configuration may well change in unforeseeable ways during construction and operation;
- The storage must be designed with mine closure in mind, so as to create a permanent, maintenance free deposit that does not pose any unacceptable long-term environmental impact or risk.

4.5.1.3 Case Histories Illustrating Tailings Dam

Case	Identification	Country	Since	Damage	References
4.3.1.3-A	Mount Polley	Canada	1959	08/2014	[04-13]

The disaster of Mount Polley mine happened in British Columbia, Canada. It began with a breach of the Imperial Metals-owned Mount Polley copper and gold mine tailings pond, releasing its water and slurry with years' worth of mining waste into Polley Lake.

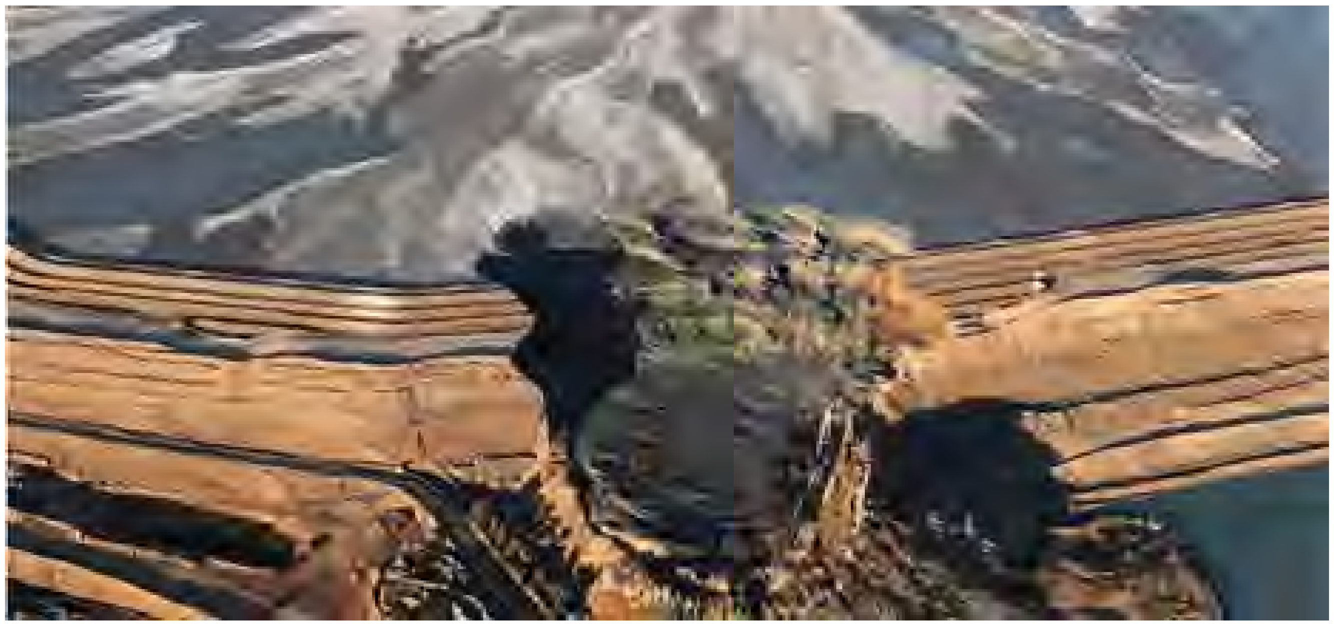
Mount Polley mine disaster – Alchetron, the free social encyclopedia

The Mount Polley open pit copper and gold mine disaster began in the early morning of August 4, 2014, with a partial breach of the tailings pond dam, releasing 10 million cubic meters of water and 4.5 million cubic meters of slurry into Polley Lake. By the end of the day the four square kilometers sized tailings pond was "virtually empty". Mine safety experts and media articles have called this spill one of the biggest environmental disasters in modern Canadian history. The cause of the dam breakage was investigated with a final report published January, 31-2015 .

The investigation ***of the cause of the spill revealed that mine engineers failed to account for glacial silt underneath the tailings containment pond***, leading to structural insufficiencies that caused the dam's collapse.

The government described the purpose of the local state of emergency was to provide “exceptional” powers in the interest of public safety, and an equitable distribution of potable water to the residents of Likely.

Case	Identification	Country	Since	Damage	References
4.5.1.3-B	Cadia's Northern Tailings	Australia	2017	2018	[04-14]



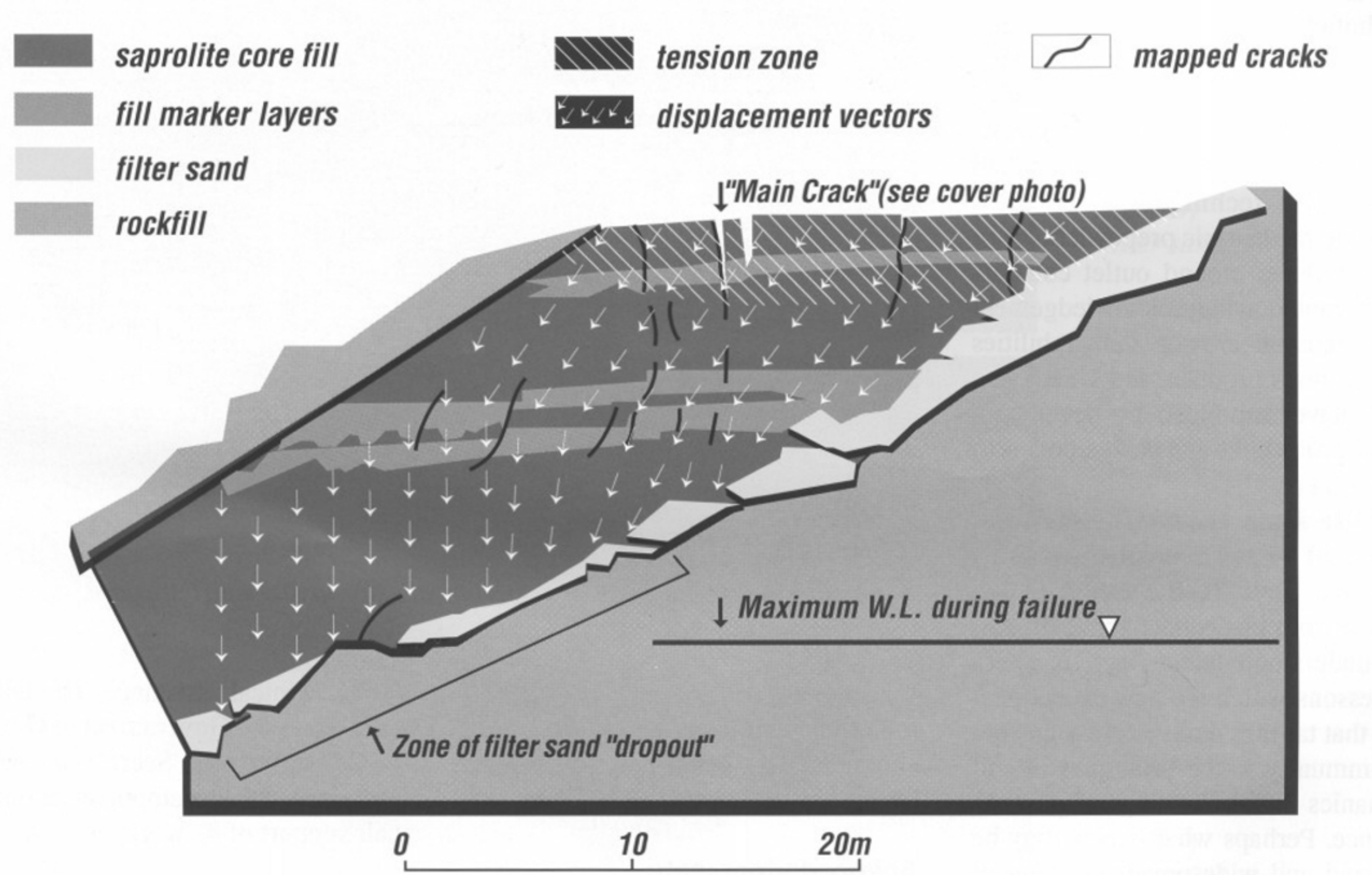
The slump occurred on March 9 in the southern wall of Cadia's Northern Tailings Storage Facility, causing it to lose containment of the section's tailings.

The Independent Report ***concluded that the dominant factor determining the location of the Cadia tailings dam failure was the existence of a low-density foundation layer in the vicinity of the slump***. Other factors that contributed were the local height of the dam, the prevailing phreatic conditions, and excavation at the toe of the structure in the area of the slump. The low-density foundation layer material, which had not been previously identified, is relatively weak and highly compressible and brittle when subjected to significant load.

It was determined that the failure of this weak foundation material, when placed under load accumulated through the construction history, resulted in deformation of the wall. This then triggered liquefaction of part of the tailings behind the embankment, causing it to slump forward. The report noted that this material has to date only been found in close proximity to the area of the slump. The layer material was found to be relatively weak and highly compressible, and brittle once subjected to a significant load.

Case	Identification	Country	Since	Damage	References
4.5.1.3-C	Omai	Guyana	1992	1994	[04-15]

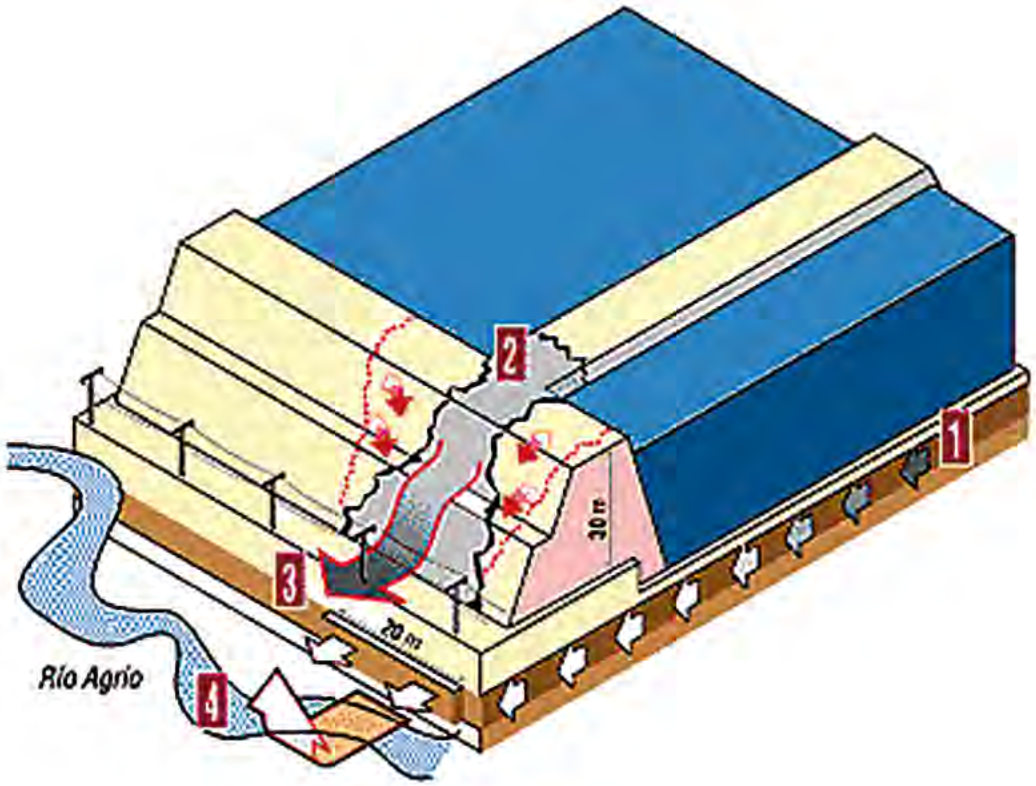
In 1994, the Omai tailings dam in Guyana broke down due to internal erosion which resulted in the release of sewage into nearby rivers. The dam contained an upstream sloping core and a downstream rockfill section, with foundation materials having the classic weathering profile of residual saprolite soils derived from parent andesite/diabase rocks. These clayey, low-permeability soils provided fill material for the dam core, and they also comprised a major component of the mine waste materials excavated as pit overburden. This saprolite mine waste was deposited in a wide zone adjacent to and contiguous with the downstream rockfill section of the dam, extending outward 400 m to the Omai River and confining the rockfill zone in all except the two limited areas near the abutments where the failure discharges emerged.



The Omai Tailings Dam case demonstrates yet again that no dam, tailings or otherwise, without adequate seepage protection around conduits or without adequate filters can be expected to survive for long. Even with the factors specific to the Omai situation, these failure mechanisms are by no means unique or new.

Case	Identification	Country	Since	Damage	References
4.5.1.3-D	Los Frailes	Spain	1995	1998	[04-16]

The Aznalcóllar Disaster or Guadiamar Disaster, was an industrial accident in Andalusia, southern Spain. On April 25, 1998, a holding dam burst at the Los Frailes mine, near Aznalcóllar releasing 4–5 million cubic meters of mine tailings. The acidic tailings, which contained dangerous levels of several heavy metals, quickly reached the nearby River Agrio, and then its affluent the River Guadiamar, travelling about 40 kilometers along these waterways before they could be stopped.



The embankment that failed at Los Frailes

1. **Soil slab beneath the dam;**
2. **The dam cracked and broke;**
3. **Contaminated slurry spilled through the gap;**
4. **The river Agrio rose 3 meters.**

Around 3 AM, an electrician inspecting the line noticed cracks in the dam crest and only a little ponded water in the pyroclastic section of the impoundment, indicating most of the tailings outflow occurred before 3 AM. The release of tailings solids and water occurred through a breach in the eastern side of the impoundment, in the southeastern corner of the pyroclastic section. This was initiated by a failure in the dam along the pyrite section just to the south, which resulted in a 700-m-long section of dam, alluvium, and marl moving as much as 67 m laterally to the east with a maximum reduction in dam-crest elevation of 2.4 m. The breach was later enlarged by the water and solids flowing through it.

- ✓ ***The loss of tailings from the pyrite section was attributed primarily to liquefaction, whereas the pyroclastic-section loss was primarily from tailings-water erosion.***

The 25-m-high dam rests on roughly 4 m of river-terrace alluvium, which is underlain by 70 m of blue marl (composed of roughly 25% carbonate). At a depth of approximately 10 m into the marl, overstressing of the marl beyond its strength peak by construction-induced pore pressures allowed the dam, alluvium, and shallow marl to slide along a near-horizontal bedding plane to the east. This resulted in liquefaction of the pyrite tailings, which in turn increased the loading on the dam as the foundation resistance was decreasing. These processes account for the 60 m horizontal displacement of the dam, which is considered unusually high. Other factors like earthquakes, blasting, acidic drainage, and seepage of groundwater have been ruled out as contributors to the dam failure.

Case	Identification	Country	Since	Damage	References
4.5.1.3-E	Merriespruit	South Africa	1978	1994	[04-17]

The Merriespruit tailings dam, located in Virginia area, South Africa, failed in 1994, releasing 600,000 m^3 of tailings and 90,000 m^3 of tailings water.

Aerial of the Merriespruit failure

In 1994, the Merriespruit tailings dam broke after a few hours of thundershowers. It is worth mentioning that this tailings pond is basically an upstream structure with less freeboard length and less reservoir area. When the flow rate of the overtopping water flow was greater than the starting flow rate of the tailings, the tailings dam continued to cause downward and bilateral erosion.

The hydraulic erosion caused the breach of the tailings dam to expand, and the slope became steep, which caused the tailings dam to collapse locally and completely. At the early stages of flooding over the dam, the dam break process can be divided into the following 5 steps:

⇒ a small gully appears on the tailings dam after a rainstorm,

⇒ erosion of loose tailings in the lower slope,

⇒ ***local instability of the lower slope*** (tailings butter),

⇒ the water level in the tailings pond is high and the flood erodes the tailings dam,

⇒ local instability on a central slope, the failed material is washed away.

At the later stages of flooding over the dam, the dam break process can be divided into the following 3 steps:

a) after the erosion, the tailings dams slope began to be unstable overall, and the tailings sand was taken away by the water:

b) the tailings dam slope continues to be unstable under the domino effect, and the tailings sand is taken away, and

c) a large amount of tailings flow causes the slope to be unstable.

Case	Identification	Country	Since	Damage	References
4.5.1.3-F	Kayakari	Japan	1951	2011	[04-18]

An earthquake occurred in eastern Japan in 2011, and the Kayakari dam at the Ohya mine liquefied because of the tailings material, releasing a large amount of clay and causing damage to the downstream environment. ***Studies have shown that liquefaction leads to a significant reduction in the safety factors of tailings dams.*** In addition, the construction method of the dam body, the particle size of the tailings, and the magnitude of the earthquake affects the stability of the tailings dam during an earthquake.

The Kayakari dam at the Ohya mine was close to Akayushi Port in Japan.

The reasons for the damage of the Kayakari dam during this earthquake were the following:

⇒ The accumulation material of the tailings pond itself was inferior in strength and unable to resist the attachment force generated by the earthquake;

⇒ Finer tailings particles had lower plasticity and were easier to liquefy;

⇒ The contact surface between the mountain body and the dam body was not well protected, and the groundwater seeped into the reservoir area, causing the tailings to remain saturated;

⇒ The earthquake (the order was 300 Gal at its peak), which lasted for 2 min, caused the tailings to liquefy and the tailings dam to break;

⇒ The protection of the smaller tailings pond was ignored.

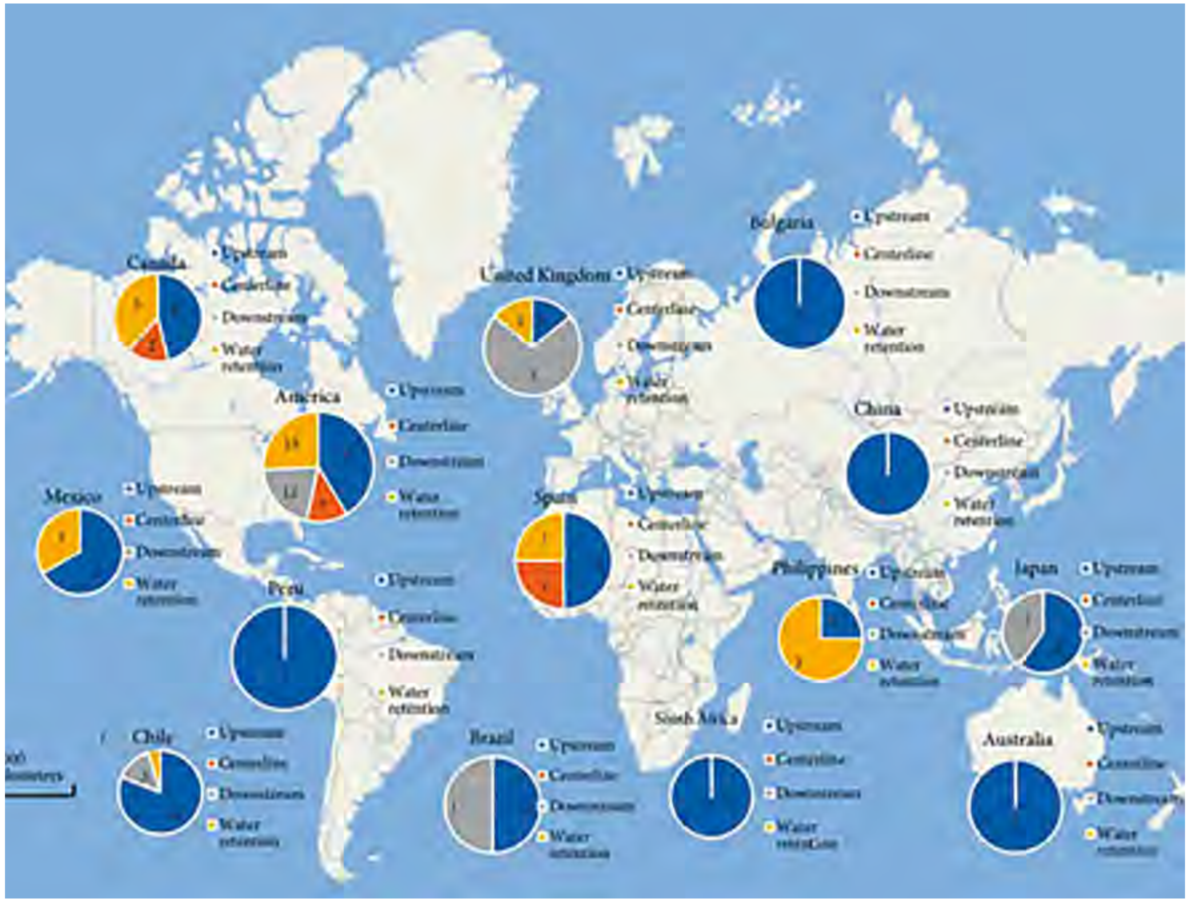
Case	Identification	Country	Since	Damage	References
4.5.1.3-G	Mishor Rotemi	Israel	1989	2017	[04-19]

The flood began, by June 2017, when the 60 m high wall of a reservoir at a phosphate factory partially collapsed, letting loose 100,000 cubic meters of highly acidic wastewater in the Ashalim riverbed.

The Mishor Rotem tailings dam failure in Israel on 30th june, 2017

4.5.1.4 Key Examples List of Tailings Dams

Key examples of tailings dam failures are summarized (from the available information in the internet-Wikipedia) in the table ahead. It is not difficult to infer that each tailings dam failures involve engineering and human factors and that these factors can be avoided. Tailings dam failure is extremely harmful to people's health and living environment.



From [04-12]

One should prevent the occurrence of tailings dam damage events, instead of repairing after the accident. For example, tailings dams should design with special attention given important factors that have a major impact on the stability of the dam including site conditions (hydrological conditions, geological conditions, and climate), choice of the embankment, and risk prediction (heavy rains and typhoons). In the operation and maintenance stage of the tailings dam, the medium and low tailings dam should be given more attention, and problems should be dealt quickly. Finally, the review of global dam failure information is beneficial to the management of tailings storage facilities and can effectively reduce the probability of tailings dam failures. The safety and stability of tailings dams require the joint effort of the government, design units, construction units, and supervision units. Due to limited availability of data, this compilation can be quite incomplete.

Date	Dam/Mine	Country	Type of Incident	Deaths
2020, may 1	San José de Los Manzanos	México	Tailings dam failure	
2020, mar. 28	Tieli, Yichun City	China	Overflow well of the tailings dam tilted	
2019, oct. 1	Nossa Senhora do Livramento	Brazil	Tailings dam failure	
2019, july 10	Cobriza San Pedro de Coris	Peru	Tailings dam failure	
2019, apr. 22	Hpakant	Myanmar	Waste heap failure	354
2019, apr. 9	Muri	India	Failure of red mud tailings pond	
2019, mar. 29	Machadinho d'Oeste	Brazil	Failure of inactive tailings dam after heavy rain	
2019, jan. 25	Córrego de Feijão	Brazil	Failure of tailings dam No. 1	259
2018, june 4	Cieneguita mine	México	Tailings dam failure	4
2018, mar. 9	Cadia	Austrália	Tailings dam failure, mainly due to the existence of a low-density foundation layer in the vicinity of the slump.	

Date	Dam/Mine	Country	Type of Incident	Deaths
2018, mar. 3	Huancapatí	Peru	Collapse of embankment of tailings dam after heavy rain	
2018, feb. 17	Barcarena	Brazil	Overflow of red mud basin after heavy rain	
2017, sep. 17	Kokoya Gold Mine	Liberia	Rupture of a section of the geo-membrane layer/overflow after heavy rain	
2017, june 30	Mishor Rotem	Israel	60 meter high wall of a reservoir at a phosphate factory partially collapsed.	
2017, mar. 12	Tonglvshan Mine	China	A partial dam failure occurred, opening a gap	
2016, dec. 28	Satemu	Myanmar	Waste heap failure	
2016, oct. 27	Antamok mine	Philippines	Tailings flow through drain tunnel of underground mine after heavy rains	
2016, aug. 27	New Wales plant	USA	A 14-meter-wide sinkhole appeared in a phosphogypsum stack, opening a pathway for contaminated liquid into the underground.	
2016, aug. 8	Dahegou	China	Failure of a tailings dam	
2015, dec. 14	Lamaungkone	Myanmar	Waste heap failure	1
2015, nov. 21	San Kat Kuu	Myanmar	Waste heap failure	> 113
2015, nov. 5	Germano mine	Brazil	Failure of the Fundão tailings dam due to insufficient drainage, leading to liquefaction of the tailing sands shortly after a small earthquake.	> 17
2014, sep. 10	Herculano mine,	Brazil	Tailings dam failure	2
2014, aug. 7	Buenavista del Cobre mine,	México	Tailings dam failure	
2014, aug. 4	Mount Polley mine,	Canada	Tailings dam failure due to foundation failure	
2014, feb. 2	Dan River Steam Station	USA	Collapse of an old drainage pipe under a 27-acre ash waste pond	
2013, nov. 15-19	Zangezur Copper Molybdenum	Armenia	Damage of tailings pipeline	

Date	Dam/Mine	Country	Type of Incident	Deaths
2013, oct. 31	Obed Mountain Coal Mine,	Canada	Breach of wall in containment pond	
2012, dec. 17	Gullbridge mine	Canada	Embankment dam failure, width 50 m	
2012, nov. 4	Sotkamo	Finland	Leak from gypsum pond through a “funnel-shaped hole”	
2012, aug. 1	Padcal mine	Philippines	“Breach” in tailings pond No.3 during heavy rains	
2011, jul. 21	Mianyang City,	China	Tailings dam damaged from landslides caused from heavy rains	
2011, may	Bloom Lake mine	Canada	Dam breach of Triangle tailings pond	
2010, oct. 4	Kolontár	Hungary	Tailings dam failure	
2010, jun. 25	Huancavelica	Peru	Tailings dam failure	
2009, aug. 29	Karamken	Russia	Tailings dam failure after heavy rain	>1
2009, may 14	Huayuan County	China	Tailings dam failure (capacity: 50,000 cubic meters)	3
2009, april 27	Barcarena	Brazil	Overflow of drainage channels around red mud basin after heavy rain	
2008, dec. 22	Kingston fossil plant	USA	Retention wall failure	
2008, sep. 8	Taoshi, Linfen City	China	Collapse of a waste-product reservoir at an illegal mine during rainfall	277
2007, jan. 10	Miraí	Brazil	Tailings dam failure after heavy rain	
2006, nov. 6	Nchanga	Zambia	Failure of tailings slurry pipeline	
2006, april 30	Miliang, Zhen’an County,	China	Tailings dam failure	17
2005, april 14	Bangs Lake, Jackson County	USA	Phosphogypsum stack failure, because the company was trying to increase the capacity of the pond at a faster rate than normal	

Date	Dam/Mine	Country	Type of Incident	Deaths
2004, nov. 30	Pinchi Lake	Canada	Dam collapses during reclamation work	
2004, sep. 5	Riverview	USA	A dike at the top of a gypsum stack broke after waves driven by Hurricane Frances bashed the dike's southwest corner	
2004, may 22	Partizansk	Russia	A ring dike, made of coal ash, broke. The break left a roughly 50-meter-wide hole in the dam.	
2004, march 20	Malvési	France	Dam failure after heavy rain in preceding year	
2003, oct. 3	Cerro Negro	Chile	Tailings dam failure	
2002, aug. 27/ sep. 11	San Marcelino	Philippines	Overflow and spillway failure of two abandoned tailings dams after heavy rain	
2001, jun. 22	Sebastião das Águas Claras	Brazil	Mine waste dam failure	>2
2000, oct. 18	Nandan Tin mine, Dachang	China	Failure of upstream dam	28
2000, oct. 11	Inez, Martin County	USA	Tailings dam failure from collapse of an underground mine beneath the slurry impoundment	
2000, sep. 8	Aitik mine, Gällivare	Sweden	Tailings dam failure from insufficient perviousness of filter drain	
2000, mar. 10	Borsa, Romania	Romania	Tailings dam failure after heavy rain	
2000, jan. 30	Baia Mare	Romania	Tailings dam crest failure after overflow caused from heavy rain and melting snow	
1999, apr. 26	Placer,	Philippines	Tailings spill from damaged concrete pipe	
1998, dec. 31	Huelva	Spain	Dam failure during storm	
1998, apr. 25	Los Frailes, Aznalcóllar,	Spain	Dam failure from foundation failure	

Date	Dam/Mine	Country	Type of Incident	Deaths
1997, dec. 7	Mulberry Phosphate	USA	Phosphogypsum stack failure	
1997, oct. 22	Pinto Valley,	USA	Tailings dam slope failure	
1996, nov. 12	Amatista	Peru	Liquefaction failure of upstream-type tailings dam during earthquake	
1996, aug. 29	El Porco	Bolivia	Dam failure	
1996, mar. 24	Marcopper	Philippines	Loss of tailings from storage pit through old drainage tunnel	
1995, dec.	Golden Cross	New Zealand	Dam movement	
1995, sep. 2	Placer	Philippines	Dam foundation failure	12
1995, aug. 19	Omai	Guyana	Tailings dam failure from internal dam erosion (preliminary report on technical causation)	
1994, nov. 19	Hopewell Mine, Hillsborough County	USA	Dam failure	
1994, oct. 2	Payne Creek Mine, Polk County	USA	Dam failure	
1994, oct.	Fort Meade	USA	Spill into Peace River near Fort Meade	
1994, june	IMC-Agrico	USA	Sinkhole opens in phosphogypsum stake	
1994, feb. 22	Harmony, Merriespruit	South Africa	Dam wall breach following heavy rain	17
1994, feb. 14	Olympic Dam, Roxby Downs	Australia	Leakage of tailings dam for 2 years or more	
1994	Daye Iron Ore mine	China	Failure of upstream dam	31
1993, oct.	Gibsonton	USA	Fish killed when acidic water spilled into Archie Creek	
1993	Marsa, Peru	Peru	Dam failure from overtopping	6

Date	Dam/Mine	Country	Type of Incident	Deaths
1992, mar. 1	Maritsa Istok 1		Dam failure from inundation of the beach	
1992, jan.	No.2 tailings pond	Philippines	Collapse of dam wall (foundation failure)	
1991, aug. 23	Sullivan mine	Canada	Dam failure (liquefaction in old tailings foundation during construction of incremental raise)	
1989, aug. 25	Stancil, Perryville	USA	Dam failure during capping of the tailings after heavy rain	
1988, apr. 30	Jinduicheng	China	Breach of dam wall (spillway blockage caused pond level to rise too high)	
1988, jan. 19	Tennessee Consolidated No.1, Grays Creek	USA	Dam wall failure from internal erosion, caused from failure of an abandoned outlet pipe	
1988	Riverview	USA	Thousands of fish killed at mouth of Alafia River	
1987, april 8	Montcoal No.7, Raleigh County	USA	Dam failure after spillway pipe breach	
1986, may	Itabirito	Brazil	Dam wall burst	
1986	Huangmeishan	China	Dam failure from seepage/slope instability	19
1985, aug. 25	Niujiaolong	China	Failure of upstream dam after debris inflow caused by heavy rainstorms	49
1985, july 19	Stava, Trento	Italy	Dam failure, caused from insufficient safety margins and inadequate decant pipe construction	
1985, mar. 3	Veta de Agua No.1	Chile	Dam wall failure, due to liquefaction during earthquake	
1985, mar. 3	Cerro Negro No.4	Chile	Dam wall failure, due to liquefaction during earthquake	
1985	Olinghouse, Wadsworth	USA	Embankment collapse from saturation	
1982, nov. 8	Sipalay, Negros Occidental	Philippines	Dam failure, due to slippage of foundations on clayey soils	

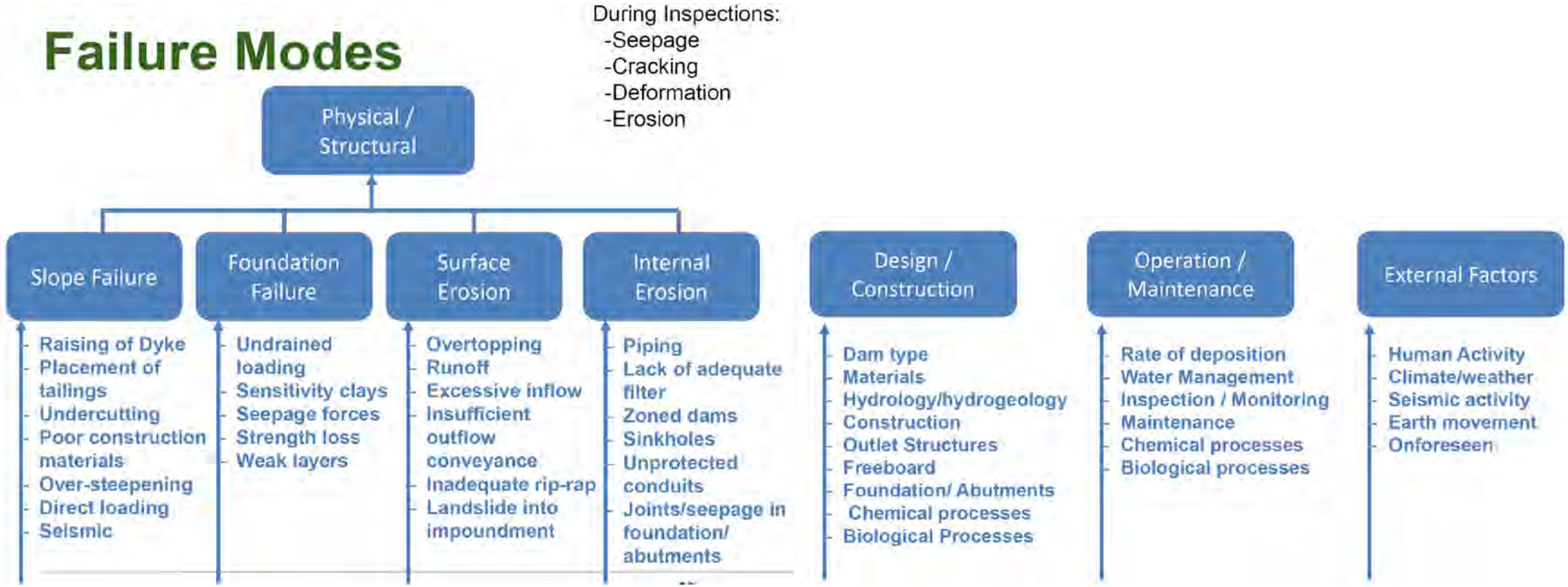
Date	Dam/Mine	Country	Type of Incident	Deaths
1981, dec. 18	Ages, Harlan County	USA	Dam failure after heavy rain	
1981, jan. 20	Balka Chuficheva	Russia	Dam failure	
1980, oct. 13	Tyrone, New Mexico	USA	Dam wall breach, due to rapid increase in dam wall height, causing high internal pore pressure	
1979, july 16	Church Rock, New Mexico	USA	Dam wall breach, due to differential foundation settlement	
1979 or earlier	(unidentified)	Canada	Piping in the sand beach of the tailings dam	
1978, jan. 31	Arcturus	Zimbabwe	Slurry overflow after continuous rain over several days	1
1978, jan. 14	Mochikoshi No.1	Japan	Dam failure, due to liquefaction during earthquake	1
1977, feb. 1	Homestake, Milan	USA	Dam failure, due to rupture of plugged slurry pipeline	
1976, mar. 1	Zlevoto	Yugoslavia	Dam failure, due to high phreatic surface and seepage breakout on the embankment face	
1975, june	Silverton, Colorado	USA	Dam failure	
1975, apr.	Madjarevo,	Bulgaria	Rising of tailings above design level caused overloading of the decant tower and collectors	
1975	Mike Horse, Montana	USA	Dam failure after heavy rain	
1974, nov. 11	Bafokeng,	South Africa	Embankment failure by concentrated seepage and piping through cracks	12
1974, jun. 1	Deneen Mica, North Carolina,	USA	Dam failure after heavy rain	
1973	(unidentified), Southwestern	USA	Dam failure from increased pore pressure during construction of incremental raise	
1972, oct. 20	Brunita, Cartagena	Spain	Dam failure after heavy rain	1

Date	Dam/Mine	Country	Type of Incident	Deaths
1972, feb. 26	Buffalo Creek, West Virginia	USA	Collapse of tailings dam after heavy rain	125
1971, dec. 3	Fort Meade, Florida	USA	Clay pond dam failure, cause unknown	
1970	Mufulira	Zambia	Liquefaction of tailings, flowing into underground workings	89
1970	Maggie Pie	UK	Dam failure after raising the embankment and after heavy rain	
1969 or earlier	Bilbao	Spain	Dam failure (liquefaction) after heavy rain	
1968	Hokkaido	Japan	Dam failure (liquefaction) during earthquake	
1967, mar.	Fort Meade, Florida	USA	Dam failure, no details available	
1967	(unidentified)	UK	Dam failure during regrading operations	
1966	(unidentified), East Texas	USA	Dam failure	
1966	Derbyshire	UK	Dam failure from foundation failure	
1966, oct. 21	Aberfan, Wales	UK	Dam failure (liquefaction) from heavy rain	144
1966, oct. 9	Geising/Erzgebirge	German Democratic Republic	Collapse of stream deviation tunnel located under the Tiefenbachtal tailings dam	
1966, may 1	Mir mine, Sgorigrad	Bulgaria	Dam failure from rising pond level after heavy rains and/or failure of diversion channel	488
1965, mar. 28	Bellavista	Chile	Dam failure during earthquake	
1965, mar. 28	Cerro Negro No.3	Chile	Dam failure during earthquake	

Date	Dam/Mine	Country	Type of Incident	Deaths
1965, mar. 28	El Cobre New Dam	Chile	Dam failure (liquefaction) during earthquake	200
1965, mar. 28	El Cobre Old Dam	Chile	Dam failure (liquefaction) during earthquake	
1965, mar. 28	La Patagua New Dam	Chile	Dam failure (liquefaction) during earthquake	
1965, mar. 28	Los Maquis	Chile	Dam failure (liquefaction) during earthquake	
1965	Tymawr,	UK	Dam failure from overtopping	
1962, sep. 26	Huogudu, Gejiu	China	Failure of upstream dam after three days of moderate rainfall	171
1962	Almivirca	Peru	Dam failure (liquefaction) during earthquake and after heavy rainfall	
1961	Tymawr	UK	Dam failure, no details available	

4.5.1.5 Defensive Design Measures

Attention in the design stage to the critical issues that can affect the long-term safety of a tailings dam, as summarized:


Failure Modes
During Inspections:
-Seepage
-Cracking
-Deformation
-Erosion
Physical / Structural
Slope Failure
- Raising of Dyke
- Placement of tailings
- Undercutting
- Poor construction materials
- Over-steepening
- Direct loading
- Seismic
Foundation Failure
- Undrained loading
- Sensitivity clays
- Seepage forces
- Strength loss
- Weak layers
Surface Erosion
- Overtopping
- Runoff
- Excessive inflow
- Insufficient outflow conveyance
- Inadequate rip-rap
- Landslide into impoundment
Internal Erosion
- Piping
- Lack of adequate filter
- Zoned dams
- Sinkholes
- Unprotected conduits
- Joints/seepage in foundation/ abutments
Design / Construction
- Dam type
- Materials
- Hydrology/hydrogeology
- Construction
- Outlet Structures
- Freeboard
- Foundation/ Abutments
- Chemical processes
- Biological Processes
Operation / Maintenance
- Rate of deposition
- Water Management
- Inspection / Monitoring
- Maintenance
- Chemical processes
- Biological processes
External Factors
- Human Activity
- Climate/weather
- Seismic activity
- Earth movement
- Onforeseen

Conceptual item	Criteria
Design Philosophy	Tailings dams have somewhat different storage capacity and water management requirements to normal water storage dams. That allowance needs to be made for both dam safety and environmental safety in an operational situation where the remaining water storage capacity is continually being reduced by the deposited tailings solids, and water quality may be unsuitable for release to the environment. The dam safety requirements will determine the spillway design to avoid overall embankment failure, whereas the environmental issues will determine the storage allowance to be provided to reduce the risk of spill from the dam. The purpose of a tailings dam is primarily to store solids, but this is often complicated by: a) Staged construction; and b) Uncertainty as to the tailings dry density that will be achieved in the dam. The Design Criteria can be summarized as follows: ⇒ Climate and hydrologic data; ⇒ Embankment Consequence Classification; ⇒ Seismicity; ⇒ Slope and foundation Stability Criteria; and ⇒ Freeboard (contingency freeboard due to poor hydrologic information).
Minimum Decant Storage Capacity	There is normally some minimal level of decant storage required to allow settlement of decant water or chemical equilibrium development prior to water removal from the tailings dam. This will vary depending on production rates, the tailings settlement characteristics, and the climate. It is likely that this volume will need to be determined by experience. Normally it is desirable to minimize the pond size to maximize the extent of tailings beach development to achieve good drying and consolidation. However, during wet weather the pond size will need to be increased to prevent carry-over of tailings solids. This will require a decant system which can be controlled, either by operation of a valve on gravity flow systems or by controlling the pump output for pumped systems.

Conceptual item	Criteria
Non-Release Dams – Design Storage Allowance	Where water quality within the storage is unsuitable for release during normal conditions, appropriate wet season storage, extreme flood storage, and appropriate contingency storage allowances are made to ensure that the risk of spillage is reduced to an acceptable level. The design storage capacity must be sufficient to accommodate the solids and liquid inputs until such a time as excess accumulated water can be recovered, or until additional storage capacity can be provided by constructing a new dam or raising the embankments of an existing dam. Where ongoing storage capacity is provided by incremental raising of existing dams, it is a good practice to provide the contingency storage capacity.
Spillways	The design flood requirement for spillway design can preferably be determined by risk assessment methods and should take into account the risk of over the expected operating life of the dam and also the spillway should always be provided – even where “no spill” design requirements are in force, to guard against overtopping in extreme, or unexpected, events that could lead to failure of the dam embankment. Where short-term extreme flood storage is provided, the spillway sizing may be determined based on routing calculations taking the extreme flood storage allowance and any contingency freeboard into account. It may also be appropriate to add additional freeboard to allow for wind set-up in larger storages and for uncertainties of calculation, particularly, if erosion has the potential for embankment breaching. In addition, on the freeboard closure, consideration must be given to the the potential settlement of the embankment due to consolidation and earthquake induced deformation.
Non-release Dams – Emergency Spillways	In addition to the provision of a conservative dam storage allowance for no-spill tailings dams, it is also good risk management practice to provide an emergency spillway. An emergency spillway is a strong preventative control against overtopping and hence against the potential for extreme consequences associated with catastrophic failure of the dam embankment.

Conceptual item	Criteria
The Water Balance	An important design task is the development of a water balance model for the tailings dam. The water balance model will help understand the ways water might affect the design and subsequent operational limitations and risks. Water used in tailings transport is likely to make up a significant proportion of water use at a mine site. Much of this water will be retained in the tailing storage trapped within the pores. A portion will be returned to the process or released if environmental conditions allow. Some water will be lost through evaporation and/or seepage, particularly from lake areas. Water gains from the natural environment into the disposal area that can include surface streams, groundwater inflow and rainfall. The total of water inputs into a tailings dam will be balanced by recovery, disposal, or losses from the area. The “water balance” will determine the performance characteristics of the tailings disposal system, including flows and losses such as seepage that would need to be managed during its operation and final abandonment. Any imbalance can lead to progressive changes in the volume stored in the pond.
Stream Management	The tailings area is often separated from the surrounding storm water streams to minimize flood design requirements, to maximize settling of tailings and to minimize the volume of water which may need special management due to water quality issues. Tailings dams should ideally be located away from significant streams or at the head of valleys where catchment outside the storage is limited. The potential failure of a diversion system is likely during extreme flooding and the added inflow to a tailings dam should be considered. Tailings dams design criteria normally require consideration of ultimate abandonment. An additional channel around the dam can be adopted to support some flow.
Rainfall Run-Off	Rainfall can be a major component of water inflow, with catchment runoff mixing with decant water in the pond area. Run-off from the contributing land surfaces, either as direct or indirect (pumped) catchments, any tailings beaches and from the pond area itself, will need to be taken into account. In regions with highly seasonal rainfall, runoff coefficients need to consider pre-existing soil moisture conditions.

Conceptual item	Criteria
Tailings Decant Water	Tailings normally settle on beaches, thus decanting a proportion of the transport water over a short time frame. This would be followed by a long-term release of transport water as consolidation of the tailings takes place for both sub-aerial and sub-aqueous methods of discharge. Further water is lost where there is evaporation from exposed beaches.
Evaporation	Evaporation from tailings beaches and ponds can lead to significant water loss from the system. Losses from ponds can be evaluated from pan-evaporation data using appropriate adjustment factors or by calculations utilizing wind speed, temperature, solar radiation, etc. Losses from beaches can similarly be evaluated.
Water Recovery	Excess water within the tailings dam is either removed by evaporation or collected for recycling in the process plant, depending on environmental and process considerations. In some case water quality may allow direct discharge to the environment, possibly including the need for treatment.

Conceptual item	Criteria
Seepage	Seepage from tailings dams will potentially develop through the embankments, foundations, and floor of the impoundment. The amount of seepage loss will depend on the permeability of the various materials and will be greatly influenced by the permeability of the tailings themselves, which in many cases is quite low. Seepage losses may not be significant in the overall water balance, but the environmental impact of contaminated seepage may be a significant factor. Seepage, as conventionally defined, is not the only mechanism responsible for the generation of pore water pressures within tailings impoundments. Normal loading consolidation (dissipation of excess pore pressure generated by undrained loading of the tailings material) and shear induced pore pressure are equally important mechanisms that should be considered in the analysis of pore pressure in tailings. The combination of seepage and consolidation pressures often culminates in non-hydrostatic conditions which need to be considered in the design. If pore pressure is not properly considered, the potential failure may be underestimated affecting the stability during construction. The water stored behind a dam always seeks a mean of escape. Control of this seepage presents a challenge to the designer because water will always find the path of least resistance for its escape route. This will take the seepage through pervious strata, joints, fissures, and cracks as they really exist, in and beneath the structure, rather than as assumed for purposes of the design analyses. For this reason, seepage control measures should always be conservatively designed and for important structures, instrumentation to measure piezometric pressures and seepage flows should be included as part of the design. It is important to consider the percolation zones that can cause piping and consider the defenses against the potential failure. Seepage through dams may give rise to three basic problems that can create serious difficulties and, in the extreme may lead to failure. These three problems are: ⇒ Piping occurs where exiting seepage flows pick up soil particles and move them out of the foundation or embankment. The continued removal of soil particles causes the unseen development of channels or pipes in the embankment or foundation. When these pipes connect back to the free water in the reservoir very large flows develop along the pipe and complete failure of the dam may occur. ⇒ Slope Instability and Heaving Seepage forces caused by the flow of water through the embankment or its foundations can cause instability of downstream slopes. If excessive upward seepage forces develop in the foundation soils immediately downstream of the toe of the dam, heaving may occur. ⇒ Excess Water Losses occur when the embankment or its foundations are highly pervious.

Conceptual item	Criteria
Stability Evaluations	Stability evaluations of tailings dams differ from those for conventional dams in the following aspects: ⇒ tailings dam embankment zones may be thinner and smaller, especially for the upstream method of construction and are typically constructed in stages over many years; ⇒ upstream construction relies on the strength of the tailings which can vary over time due to consolidation and potential liquefaction; ⇒ the pore pressures within the tailings are a combination of seepage pressures and consolidation pressures which generally culminate in non-hydrostatic conditions requiring specialized modelling techniques.
Earthquake Considerations	Most tailings comprise fine sand, gravel, ash, or filter cake, which are placed in a relatively loose state. Beaches or stacks formed from these materials often appear solid, however, it is important to consider whether such apparently solid material may liquefy under either static or dynamic loading conditions. If liquefaction does occur, the strength of the liquefied portions of the tailings is significantly reduced and can lead to failure. The design of a tailings dam for earthquake or blast-induced vibration, should take into consideration: ⇒ the level of seismic activity that may occur at the site appropriate for design during operations; ⇒ the level of seismic activity that needs to be considered for closure design.
Design – Embankment	Following an earthquake, the stability of a slope might be diminished because the cyclic loading has reduced the shear strength of the material – this is especially true for tailings. The reductions in shear strength are generally treated differently depending on whether or not liquefaction occurs. The first step into evaluating strength loss is to determine if the material will liquefy. The procedures for doing this are semi-empirical, based on consideration of particle size grading, the degree of saturation, results of field tests and case histories.

<table>
<tr><th>Conceptual item</th><th>Criteria</th></tr>
<tr><td>Planning and management activities should include</td><td>⇒ Staff training;
⇒ Planning of deposition cycles and positions;
⇒ Planning for dam geometry control;
⇒ Planning for maintenance activities;
⇒ Planning of measurement and monitoring activities;
⇒ Planning for responses to emergencies and for contingencies;
⇒ Recorded measurements made during dam construction will include:
o The volumes and properties of delivered tailings slurry;
o Levels of the dam crest and of the water pool, giving freeboard values;
o Position of the phreatic surface;
o In situ properties of the deposited tailings;
o Drains.
⇒ Record of any uncontrolled toe seepage or other signs of distress.</td></tr>
</table>

Conceptual item	Criteria
Additional Points to Consider	The following points are made specifically in reference to the use of limit equilibrium methods to analyze the stability of tailings dams. In the majority of applications, non-circular failure surfaces may need to be considered. Critical failure surfaces are defined as those which give the lowest factor of safety, and which would likely cause significant damage if sliding occurred. Shallow failure surfaces are often identified by computer analyses using automatic search routines as giving the minimum factor of safety but do not lead to the critical breaching of the dam. Situations which can lead to an overestimation of safety factor can usually be related to the assumptions made regarding shear strength and pore pressures, not to problems in the analysis itself, e.g.: ⇒ incorrect assessment of location of phreatic surface and pore water pressure conditions; ⇒ anisotropic conditions in the fill or tailings, giving relatively high horizontal permeability and elevated phreatic surface levels; ⇒ non-recognition of bedding plane shears or landslip surfaces in the foundation; ⇒ non-recognition of fissuring in the soil/rock foundation; ⇒ 'liquefaction' under earthquake loading, leading to loss of shear strength; and ⇒ static liquefaction as stress conditions changes e.g., by upstream construction where failure occurs at stresses lower than those provided by effective stress parameters. This occurs when the loose tailings generate positive pore pressures during shearing.
Progressive Failure	Consideration should be given to the risk of progressive failure, where, for example, the slip surface passes through high plasticity clay which exhibits brittle or strain softening behavior. Progressive failure, associated with large slip surfaces, with a near vertical face/scarp within the embankment is a critical case. Such slip surfaces may not directly indicate potential loss of containment, but subsequent progressive failures of the vertical scarp may.
Settlement	Tailings densities are low when deposited, but will increase under the effects of surface drying or from consolidation under self-weight, the weight imposed by ongoing deposition or the weight of a capping layer. Consolidation rates may be quite slow, sometimes taking many years, particularly for fine grained, clayey tailings.

Conceptual item	Criteria
Design – Embankment	As the material consolidates, the permeability also reduces with the lowest layers being most dense and having the lowest permeability. This restricts downwards flow necessitating much of the consolidation water to move upwards through a longer distance than consolidation of normal soils. This in turn causes a slower consolidation than might be expected. Detailed analyses take into account the changing characteristics of the tailings as they consolidate. The consolidation of tailings may result in settlements of many meters in some cases. The effects of such settlement on the embankment or any structures near or within the tailings are to be considered carefully.
Durability of Construction Materials	The durability of all construction materials must be considered in the design of tailings dams intended to safely retain tailings into the long-term post-closure phase. Examples of materials that should be avoided in tailings dam construction could include: ⇒ riprap or armour rock subject to break-down by weathering; ⇒ rockfill containing sulphides that could be prone to oxidation, breakdown and release of acid drainage; ⇒ drain material that may react with the process solution; ⇒ synthetic materials such as geotextile and pipes that do not have proven long-term performance.
Construction	The integrity of a tailing embankment is as critical as for any water dam. Assuming a sound design, the success or failure of a tailing embankment will depend heavily on the manner in which it is constructed. Construction management, technical supervision, and quality assurance/quality control (QA/QC) are essential for the successful construction of a tailings dam and ancillary works. The requirements for successful construction management of a tailings dam are as set out below, together with other construction related issues.
Quality Control/ Quality Assurance	Quality Assurance (QA) comprises management of the design, construction, and operation process to ensure that the systems in place are capable of delivering the quality objectives of a project. Quality Control (QC) comprises inspection of the work and testing of materials prior to incorporation in the Works to verify compliance with the specifications. This work comprises the testing of potential borrow areas, filter materials, concrete aggregates etc., inspection of membrane liners, pumps, pipelines etc., during or soon after manufacture and prior to installation or incorporation into the works.

Conceptual item	Criteria
Site Inspection Manual	At that presents QA methodology and the types and frequency of QA/QC test work, inspection, recording and reporting requirements, in accordance to the construction specification, should be prepared, maintained and amended when required. The Manual should include a site organization chart showing lines of communication and responsibilities for the construction management team. The manual should include protocols for acceptance and rejection of components of the work, re-work and re-testing requirements.
Instrumentation	Instrumentation is placed to monitor response of the tailings dam to construction and operation. Instrumentation can be delicate and relies on accurate installation to the specifications of the instrument manufacturer and the Designer. In cases where multiple installations are required, particular attention must be given to correct labelling and identification of the output points. The instruments require protection during construction from earthmoving machinery, etc. Particular care is required to protect existing instrumentation and monitoring equipment during staged construction or construction of embankment raises.
Operations, Maintenance and Surveillance	An Operation, Maintenance and Surveillance (OMS) Manual should be completed, normally prior to the commissioning of a tailings dam. The Manual should cover design intent, predicted behavior of tailings, daily operations and inspections, water management procedures, criteria for mechanical and electrical works (including pumps), surveillance, maintenance, and reporting requirements. Operational Management Plans within the OMS Manual should specifically highlight all designer requirements for operation and response actions that must be met to ensure the ongoing safety of the dam.
Monitoring and Surveillance	The operational procedures for the tailings facility should include provisions for surveillance (i.e., regular inspection, monitoring and evaluation) and documentation thereof. Conditions can develop during operations which, if not detected early, could lead to loss of containment or unsuitable conditions for undertaking plans for extension or closure of the facility.

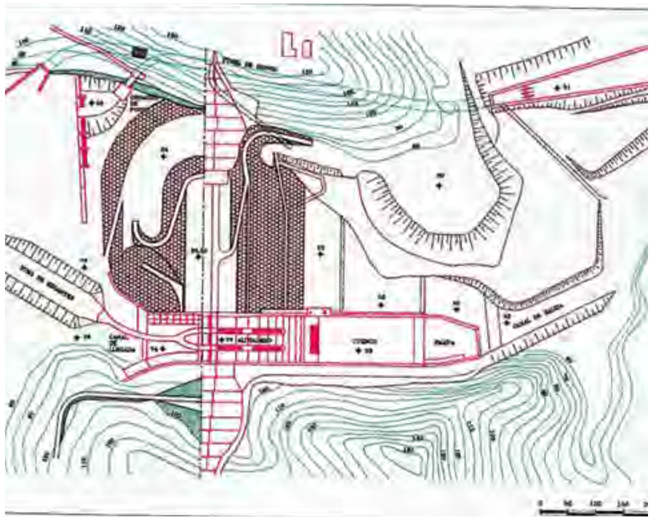
4.5.2 Earth Fill Dams

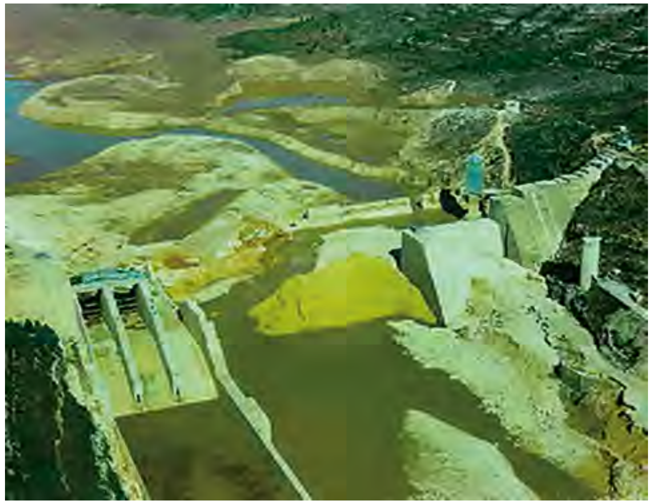
A dam, designed by the U.S. Bureau of Reclamation, failed just as it was being completed and filled for the first time. This failure of a modern dam so soon after construction was a shock to the engineering community. It prompted one of the most intensive investigations of any dam failure. A panel of experts investigated that ***the failure of dam was related to erosion and piping phenomena which occurred in the key trench fill on the right abutment possibly caused by seepage through cracks. The Teton Dam failure in June 1976, is mentioned in many papers and books, so it is not necessary to mentioned it again in this text.***

Case	Identification	Country	Finished	Damage	Actions	References
4.5.2-A	Tous	Spain	1978	1982	Rebuilt	[04-20]

Tous dam was a 70-m-high rockfill dam with a central clay core located near Valencia, Spain, ***failed due to overtopping. It was designed and built as a flood defense*** structure being also used for regulation and irrigation. Its construction was started in 1958 following a project of a concrete 80-m-tall dam. During foundation works, geotechnical conditions revealed a problem, and the construction was stopped in 1964. It was continued in 1974 with a modified project, in which the central part had been changed to a loose material design with clay core and finally finished in 1978. It was an earth-gravity 70-m-tall dam with 400 m crest length. The dam was provided with radial gates to regulate the spillway whose capacity was 7000 m3/s; the bottom outlet had a capacity of 250m3/s. During October 19 and specially 20, 1982, a heavy rain took place in the Jucar basin close to Tous dam. The heaviest rain was recorded in the Cofrentes area, about 25 km north-west of Tous dam. The total rainfall in Cofrentes exceeded 550 mm with 285 mm of precipitation in only 3 hours. The estimated Inflow was 5000 m3/s and the gates of the spillway were to be opened. Unfortunately, the electric network was out of order due to the weather conditions; moreover, of the two emergency diesel generators, one was under repair and the other could not be started. Efforts to raise the gates manually were fruitless.

The overtopping started at 17.00 PM; the water overcame the dam reaching about 1.10 m above the crest at 19.15 PM. About 16 h after recognizing the impossibility of overtopping the flood gates, the dam was overtopped and washed out after 1 h by erosion of a greater part of the shoulders and of the central rockfill. After such an extraordinary flood, in the downstream basin, 8 people lost their lives and about 100,000 people had to be evacuated. The damages were estimated to reach $400 million, even though some of that damage was likely caused by flooding before the breakers arrived. (fig. 2). A new Tous dam was built on the same site and part of the clayey core material, which had shown a relatively high resistance to water flow, was reused for constructing the new dam.





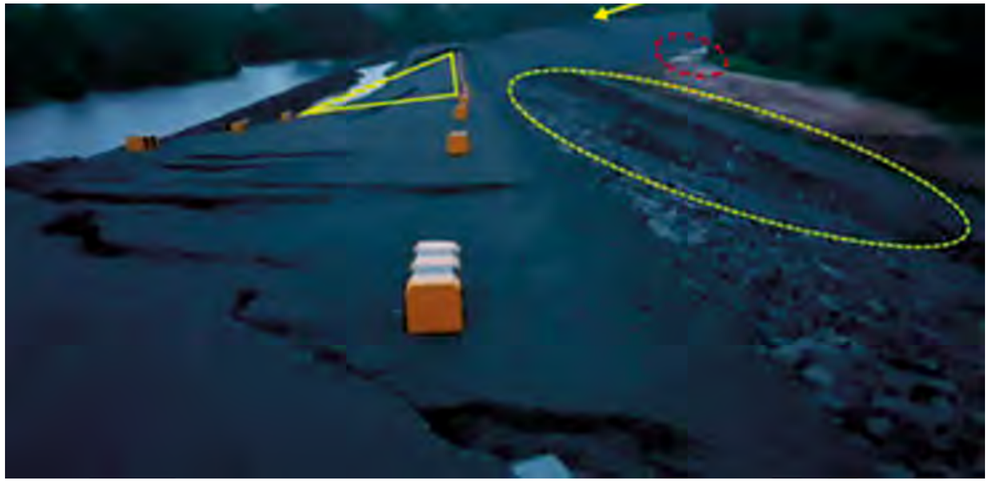
The Tous dam Design and after failure

Case	Identification	Country	Finished	Damage	References
4.5.2-B	Xe-Pian Xe-Namnoy – Saddle Dam	Laos	2018	2018	[04-21]

This final report on the failure of Saddle Dam D of Xe-Pian Xe-Namnoy hydropower project summarizes the findings of the Independent Expert Panel (IEP) based on the available supporting information and the observations made by the IEP during the site visits carried out in the beginning of October 2018 and end of November 2018.

The mechanism of failure of the Saddle Dam D was most probably triggered by the following successive sequences:

1. Due to the presence of high ***permeability horizons in the foundation***, as confirmed by the investigations, groundwater level at the downstream toe was close to the surface generating resurgence in the vegetated area where topography declines rapidly. This hypothesis is supported by the observation made downstream of the very similar Saddle Dam E, where evidence of resurgence with some internal erosion was observed.
2. With continuing resurgence in the vegetated area downstream of the dam toe, ***regressive erosion*** has developed in the foundation resulting in the formation of ducts that collapsed from time to time, especially in the deepest section of the saddle where the highest seepage gradients occur. The resulting softening of the laterite triggered the speeding up of the settlement and the appearance of the first cracks on the dam crest.
3. When the erosion and softening in the foundation reached a certain extent, the ***static dam stability was no longer ensured*** and a deep rotational sliding at the highest section of the embankment developed. Simultaneously, converging embankment movements occurred from the lateral border of the sliding mass towards the middle, resulting in a bumping up of the downstream embankment face and the subsidence of the track in front of the dam toe.
4. When the remaining thin upstream edge of the embankment crest breached, theembankment was overtopped and the catastrophic uncontrolled release of water from the reservoir washed away the central section of the Saddle Dam D and its foundation.



Initiation of the failure (23 july 04:30)

Beginning of water crossing the embankment (23 july 11:46)

Thus, it was considered that the root cause ***of the incident is related to the presence of high permeability and erodible horizons combined with the existence of canaliculus interconnected paths in the foundation***. Such conditions can lead to internal erosion and softening of the lateritic soil, if no efficient filtering and draining system is installed.

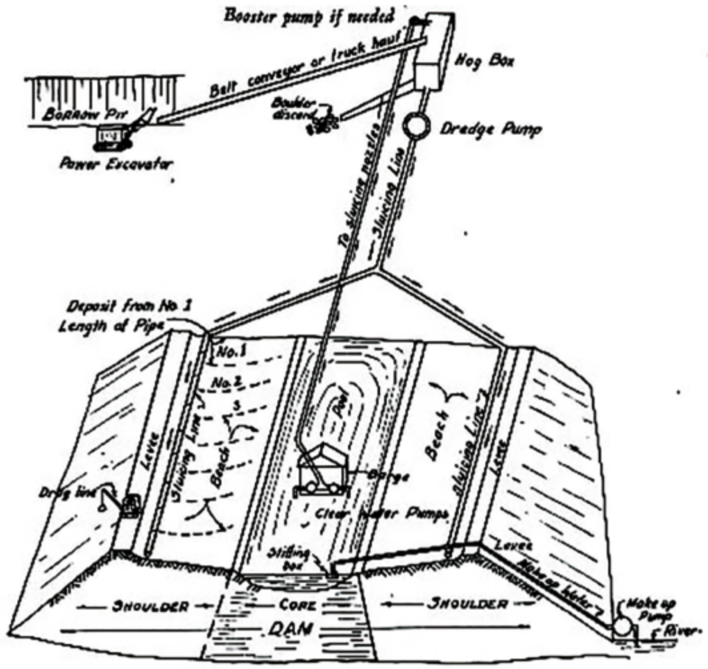
4.5.3 Hydraulic Fill Dams

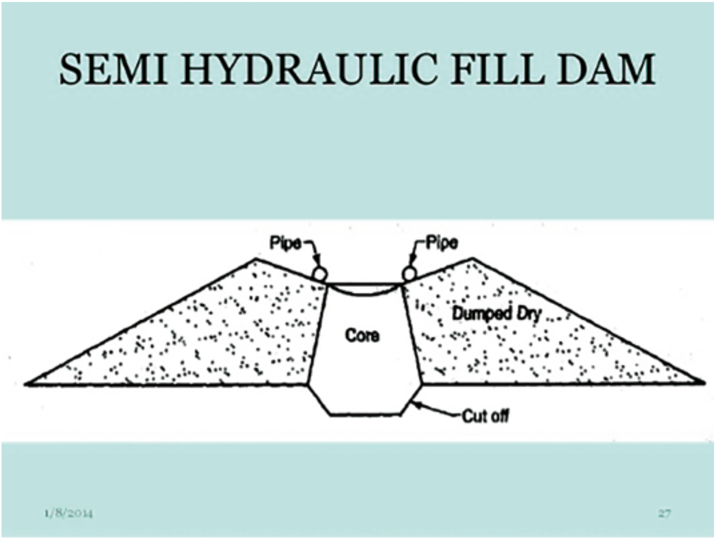
4.5.3.1 Introduction

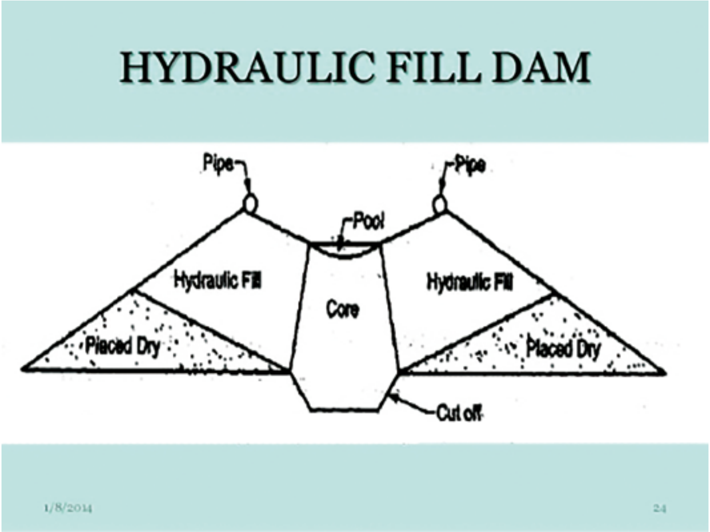
A **hydraulic fill** is an embankment or other fill in which the materials are deposited in place by a flowing stream of water, with the deposition being selective [04-22]. It can be a suitable dam in valleys of soft material and is constructed by pumping soft material duly consolidated up to moderated heights up to 30 m. But it is important to remember that this dam type design and construction was reduced since some failures due to earthquake damages.

Gravity coupled with velocity control, is used to affect the selected deposition of the material. While flowing from the sluices, coarse material is deposited first and then finer material is deposited (fine material has a slower terminal velocity thus takes longer to settle, see ***Stokes' Law***) as the flow velocity is reduced towards the center of the dam. This fine material forms an impervious core to the dam. The water flow must be well controlled at all times, otherwise the central section may be bridged by tongues of coarse material which would facilitate seepage through the dam later.

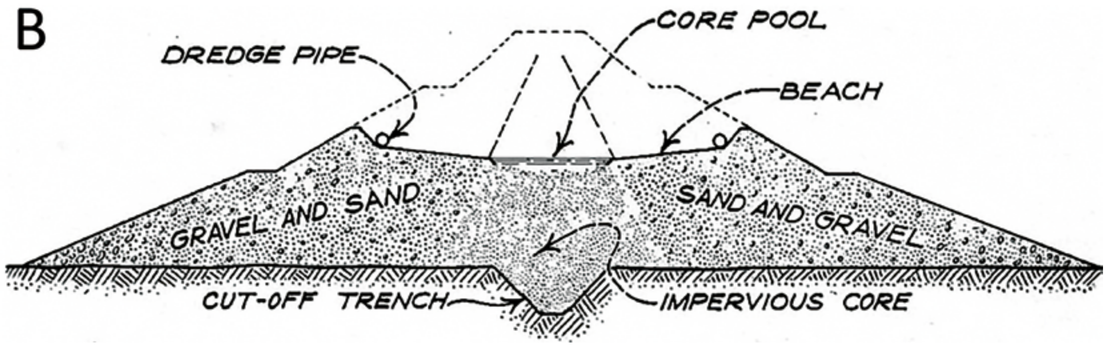
A


Booster pump if needed
Hog Box
Belt conveyor or truck haul
Borrow Pit
Power Excavator
Boulder discard
Dredge Pump
To sluicing nozzles
Sluicing Line
Deposit from No. 1 Length of Pipe
No. 1
No. 2
3
Levee
Sluicing Line
Beach
Pool
Barge
Beach
Sluicing Line
Levee
Drag line
Clear Water Pumps
Stilling box
Levee
Make up Water
SHOULDER
CORE
SHOULDER
DAM
Make up Pump
River


SEMI HYDRAULIC FILL DAM
Pipe
Pipe
Core
Dumped Dry
Cut off
1/8/2014
27


HYDRAULIC FILL DAM
Pipe
Pipe
Pool
Hydraulic Fill
Hydraulic Fill
Core
Placed Dry
Placed Dry
Cut off
1/8/2014
24

B


CORE POOL
DREDGE PIPE
BEACH
GRAVEL AND SAND
SAND AND GRAVEL
CUT-OFF TRENCH
IMPERVIOUS CORE

A hydraulic fill dam is one in which the material is transported in suspension in water to the embankment where it gets placed by sedimentation. The sorting effect of flowing water is utilized in creating a fine-grained core at the center of the embankment with coarse shells on the sides. In a semi-hydraulic fill dam, the material is transported by hauling units and dumped at the edge of the embankment. It is then washed to its final position by water jets. The use of this type of dam is rare, because:

⇒ The cost of rolled earth has dropped rapidly with the development of larger, more economical earth moving equipment.

⇒ It is difficult to control the quality which makes them less dependable than other types of dams.

Drainage of the core takes place in two ways, some of the water percolates horizontally into the more pervious shell. The remainder moves upward to the surface, allowing the center of the dam to subside. The downward movement eventually develops arching in the core and prevents its full consolidation.

In the construction of a hydraulic fill dam, the edges of the dam are defined by low embankments or dykes which are built upward as the fill progresses. Since safety concerns for earth dams have increased in recent years all over the world, especially in seismically active zones, it has become necessary to reevaluate existing dams for new codes and regulations.

The construction method of the dam, hydraulic filling, consisted of mixing the soil with large quantities of water, conveying the mixture to the construction site through pipes and flumes, then depositing it at the desired location. This method was popular for earth fill dams during the years 1900 and 1940, because the earthmoving equipment of that time was too small and underpowered for large earthmoving operations.

The sluices discharge their water-earth mixture at intervals, the water fanning out and flowing towards the central pool which is maintained at the desired level by discharge control. While flowing from the sluices, coarse material is deposited first and then finer material is deposited (fine material has a slower terminal velocity thus takes longer to settle, see ***Stokes' Law***) as the flow velocity is reduced towards the center of the dam. This fine material forms an impervious core to the dam. The water flow must be well controlled at all times, otherwise the central section may be bridged by tongues of coarse material which would facilitate seepage through the dam later.

4.5.3.2 Cases Illustrating Hydraulic Fill Dam

Case	Identification	Country	Finished	Damage	Actions	References
4.5.3.2-A	Lower San Fernando	USA	1917	1971	Rebuilt	[04-22] & [04-23]

Lower San Fernando Dam is a hydraulic fill earth dam in San Fernando, California. It was constructed between 1912-1917, followed by several raises to max height of 140 ft by 1930. This case history was a milestone to renew all seismic design and evaluation process. Had the reservoir level been a little higher, or the earthquake lasted a few seconds longer, a major disaster would have occurred.

The February 9, 1971, earthquake in San Fernando Valley, California, caused slides in the embankments of two old adjacent hydraulic fill. It was concluded that the slide in the Lower dam resulted from the development of an extensive zone of liquefaction near the base of the embankment. Some liquefaction is also believed to have occurred in the Upper dam; however, since a significant body of the sand in the upstream and downstream shells of this dam retained considerable strength, complete failure could not occur, and the movements were limited in extent.

The embankment construction was:

⇒ Founded on recent alluvium consisting of stiff clay with sand and gravel lenses.

⇒ Hydraulic fill between upstream and downstream starter dikes.

⇒ Rolled earth fill on top of hydraulic fill and in downstream berm.

What happened by earthquake is:

⇒ In 1971 a M=6.6 San Fernando earthquake (Feb 9, 6:00 a.m.) produced about 0.55 g peak acceleration at the dam crest.

⇒ The dam had 10,5 m of freeboard before the earthquake, and only 1 to 1,5 m afterward.

⇒ During the earthquake a major slide occurred on the upstream face, taking with it the crest and the upper 9.2 m of soil on the downstream slop.

⇒ About 80,000 people living in the downstream valley had to be hastily evacuated.



Before and after earthquake, Lower San Fernando dam, ASOD
Lower San Fernando Dam after 1971 earthquake, ASOD

The original San Fernando Reservoir was constructed by the City of Los Angeles between 1911-17 using hydraulic “puddled fill technique”

San Fernando Dam and Reservoir– – This view shows the dam in 1920, as originally completed.

The embankment was raised 2,1 m in four stages using rolled earth fill (over hydraulic fill). The last raise was completed in 1924-25, increasing its storage capacity and was renamed Lower Van Norman Reservoir in 1945.

Case	Identification	Country	Finished	Damage	References
4.5.3.2-B	Calaveras	USA	1918	1918	[04-24]

A slide occurred in the upstream shell of Calaveras Dam during its construction in 1918. The dam was constructed in part using hydraulic filling techniques, a technique that was common in that era but is seldom used today.

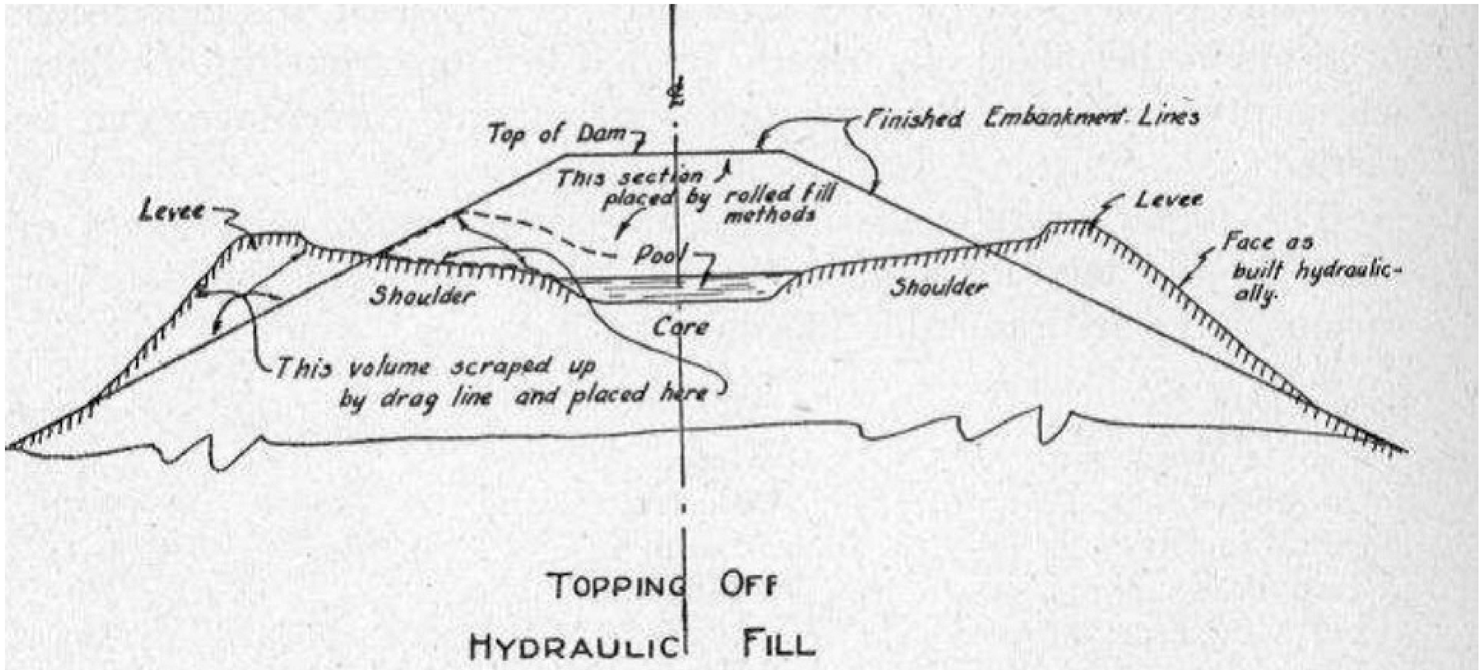
Calaveras Dam was intended to be 73 m high

On March 23, 1918, the fill slid upstream in five minutes, destroying the intake tower

Case	Identification	Country	Finished	Damage	References
4.5.3.2-C	San Pablo	USA	1920	1971	[04-24]

The San Pablo Dam near Oakland, California was a hydraulic fill embankment 67 m high, constructed in 1918-20. Buttress fill zones were placed up and downstream of the original dam in 1967 and 1979-80 to increase seismic stability.

The alluvium just downstream of the dam's toe was stabilized using Cement Deep Soil Mixing in 2008-10 to increase resistance to liquefaction of the alluvium.



The embankments of hydraulic fill embankments were raised by constructing temporary levees on either side and allowing the fines to "puddle" in a central "core pool"

This central zone became the impervious core of the dam (San Pablo Dam is shown at right)

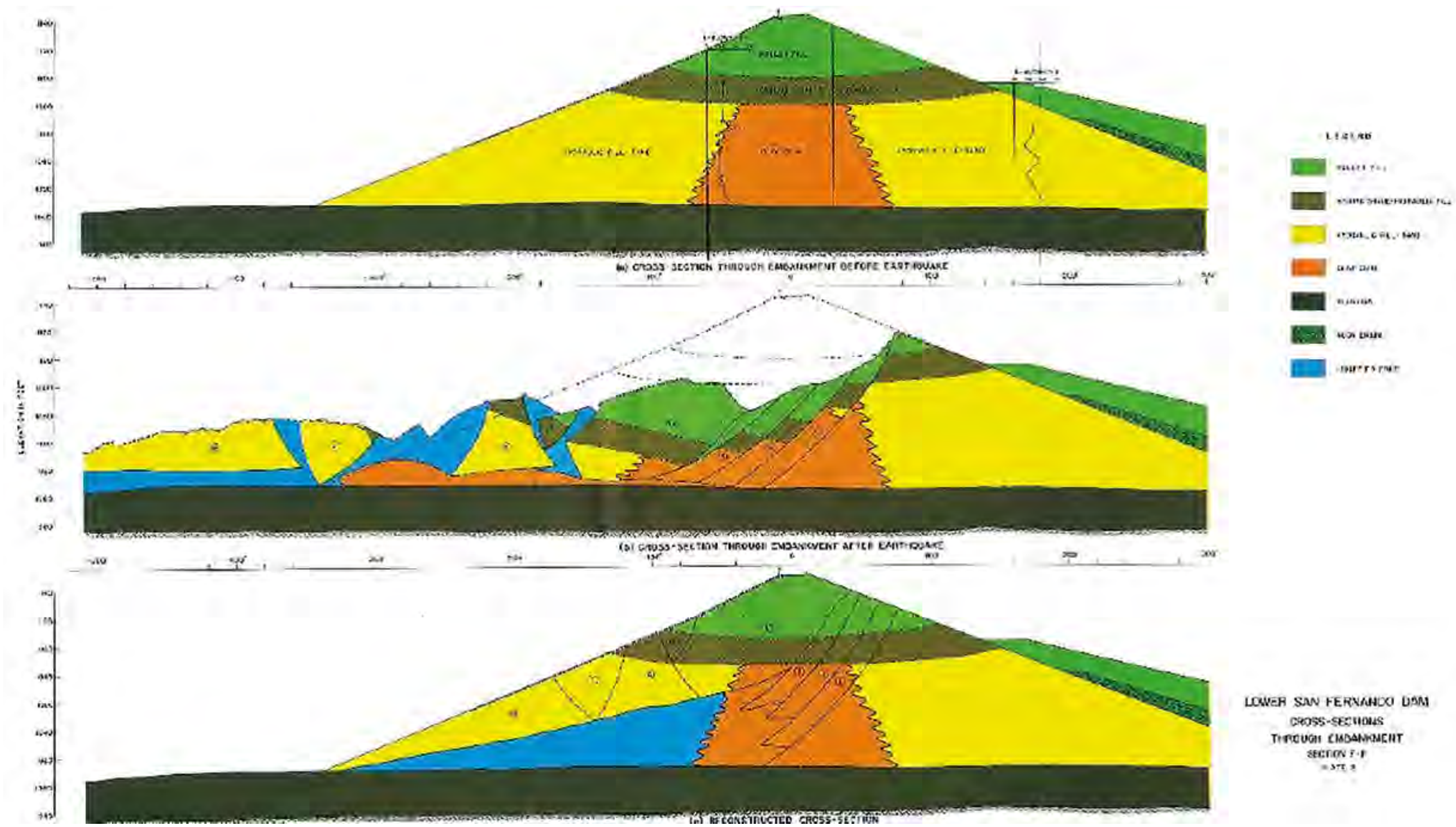
In the case of San Pablo Dam, the compacted earth eroded completely immediately after a breach in the concrete occurs, i.e., instantaneous complete dam failure. Therefore, it is apparent that a large amount of water is released almost immediately after the dam failure.

Case	Identification	Country	Finished	Damage	References
4.5.3.2-D	Lower Van Norman – Lower San Fernando	USA	1918	1971	[04-22] & [04-23]



The Lower San Fernando Dam (LSFD) was built as part of the terminal storage system for the Los Angeles Aqueduct that included the adjacent Upper San Fernando Dam and several other dams in southern California.

The LSFD was a hydraulic and rolled fill dam constructed beginning in 1912 at the northeast corner of the San Fernando Valley near Granada Hills. At the time of design and construction, hydraulic fill techniques were considered to produce "soundly engineered" earth dams. The embankment failed during the Feb 9, 1971, Mw6.7 San Fernando Earthquake, but no water was released.



Careful forensic evaluations by the geotechnical engineering group at U.C. Berkeley unraveled the dam's failure by liquefaction of a zone of low density sandy hydraulic fill (shown in blue) in the above sections. The relative density of hydraulic sand fill was later determined to be between 40 and 70 percent. The hydraulic fill section was capped, and the dam raised with rolled earth fill in four epochs.

Aerial view of Lower Van Norman Lake and LSFD (lower left) looking northeast towards San Gabriel Mountains prior to earthquake; Upper Van Norman Lake and Upper San Fernando Dam are in background. (Photo Credit: H.B. Seed)

This aerial view shows how the crest of the dam disappeared under the reservoir as a result of the slide in the upstream shell. The slide occurred shortly after earthquake shaking ended and was attributed to loss of strength in the hydraulic fill due to liquefaction.

The dam was operated many years with the reservoir (Lower Van Norman Lake) near full design (*spillway*). However, in 1966, following technical reviews and engineering studies involving the evaluation of seismic hazards of this and many other dams in California.

The 1971 San Fernando (a.k.a. Sylmar) earthquake (Mw = 6.6) occurred in the early morning hours of February 9. The earthquake was generated by thrust faulting on the Sierra Madre fault, and the researchers concluded there was no significant amplification between the foundation and the crest of the dam.

The earthquake ground shaking caused most of the upstream slope of LSFD, offset towards the left abutment, to fail, sliding into the reservoir and resulting in a substantial loss of freeboard. The embankment spread approximately 250 feet beyond the toe of the embankment. Further examination of the seismoscope on the crest indicated that the upstream slide developed after the earthquake had continued for some time and not during one of the peak motions.

After the failure, the resulting freeboard created by the upper edge of the slide mass was approximately 1,5 m. Within minutes of ground shaking and failure, a caretaker of the dam made observations and found the reservoir to be perfectly quiet with no observable waves or sloshing. Sandbags were rushed to the site to build up freeboard. As a precaution, 80,000 residents living below the dam were immediately evacuated and kept out of the area for four days while the reservoir was lowered with pumps.

A post-failure investigation was conducted, and the focus of their investigation was liquefaction triggered by ground shaking using an approach involving a comparison of seismic shear stresses and the results of cyclic triaxial shear tests on tube samples. This earthquake-induced liquefaction and the estimated in situ undrained steady state strength was substantially lower than the undrained strength measured in conventional laboratory tests due to sample densification via various means. The incident at LSFD had far-reaching impacts on the evaluation of seismic safety of earth dams in the United States, starting with federal dams and focusing on hydraulic fill dams.

✓ ***Although rare in the 1970's, the use of hydraulic fill was effectively no longer considered for embankment dams in seismic zones after the LSFD incident. This incident provided an important basis for the evaluation of residual strengths for liquefied deposits.***

To replace the failed LSFD, the Los Angeles Dam and Reservoir were built in 1976-78 about 920 m feet up the valley from LSFD. The old LSFD was reconstructed to provide a holding basin for storm water and to back up the new dam. In 1994, the Northridge earthquake (Mw=6.7) struck nearby. The remnant LSFD again suffered heavy damage on the upstream slope whereas the Los Angeles Dam performed well.

Case	Identification	Country	Finished	Damage	References
4.5.3.2-E	Fort Peck Dam	USA	1938	1938	[04-24]

The **Fort Peck Dam** is the highest of six major dams along the Missouri River, located in northeast Montana in the United States, near Glasgow, and adjacent to the community of Fort Peck. At 6,409 m in length, over 76 m in height, and width 15 m in crest, it is the largest hydraulically filled dam in the United States. The spillway capacity (controlled overflow, with 8 bulkhead gates) is 7.500m^3/s.

The Missouri riverbed at the site consisted of approximately 49 m of alluvial deposits, varying from coarse, pervious sands and gravels to impermeable clays. Beneath these deposits lay a thick (approximately 300 m) deposit of Bear Paw shale. This shale is classified as a firm shale and contains thin (2.5 to 15.2 cm) layers of bentonite. The topmost layer of soft clay was removed from the alluvium in order to found the dam on the stable sandy deposits beneath, at an elevation of approximately 620 m. The remaining deposits consisted of the alluvial materials mentioned above. These deposits had many interconnecting layers of coarse sands and gravels, necessitating the installation of a steel sheet pile wall down to the firm shale, from the left to the right abutment. The ***Fort Peck Dam is an example of a hydraulic fill dam that failed during construction where the hydraulic filling process may have contributed to the failure. The Lower San Fernando Dam is an example of a hydraulic fill dam that failed during an earthquake.***

A view of the intact Fort Peck Dam during construction before the disastrous slide of September 22, 1938, which occurred at the far eastern end, located top center in this image. June 29, 1938. Courtesy, estate of Robert A. Midthun.

The slide took the lives of 8 men on September 22, 1938. Fort Peck Dam, Fort Peck, Montana. Courtesy, estate of Robert A. Midthun.

An aerial view of the main Fort Peck Dam structure looking westward with Milk Coulee Bay in the foreground. Just out of view to right would be the intake for the spillway. June 29, 1938. Courtesy, estate of Robert A. Midthun.

The upstream face was designed with an average slope of one vertical on four horizontal and included three horizontal shelves built into the slope. A flatter (1 on 7.5) berm was to be placed between some stations.

Since the construction method of hydraulic fill was chosen, four electric dredges were built. Because of the distance of the site from the nearest shoreline, a shipyard was started on the site, affectionately dubbed "The Fort Peck Nav" and "The Biggest Shipyard in Montana" by the workers. These dredges would pump material from nearby borrow pits to the dam site where it was discharged by pipes along the outside edges of the fill. The coarser material settled out quickly, while the fines were carried downhill toward what would eventually become the core of the dam. Samples were taken from all zones regularly to ensure that the material had the gradation and consolidation characteristics specified by the design.

At this point, the danger of the core pool overtopping or bursting the shell became greater because the beaches became narrower. For this reason, an extensive alarm system was implemented along the narrower upstream shell. This alarm system could immediately shut off the dredge pumps if a shell breach was detected. Part of this alarm system involved monitoring the elevations of the core pool and the pipelines carrying the dredged fill.

In the testing and analysis done by the Corps of Engineers and others[04-25] to determine the cause of the slide, several modes of failure were considered. These were: movement along a weak zone in the shale in the abutment, movement along the shale surface, bursting of the shell due to excessive core pressure, and temporary liquefaction of the shell or foundation sand.

Extensive laboratory testing of the shale, both weathered and unweathered indicated strengths leading to a factor of safety greater than one. Also, portions of the weathered shale were found in the slide mass, indicating that the slip surface was located somewhere in the shale, but probably at a shallow depth. The core material turned out to be much stronger than expected (having a friction angle of approximately 29°) and was carried out into the slide nearly in a solid mass, making it unlikely that the core was the weak point in the slide. Laboratory testing was done on the shell material and the foundation sand, and it was determined that both materials were denser than the critical state for liquefaction.

There was no evidence of ground vibration, seismic or otherwise. Some liquefaction may have occurred after the sliding was initiated, but it was unlikely that it caused the slide.

The major weak point in the dam seemed to be the bentonite seams in the Bear Paw shale. Very high water pressures were reported at some points in the shale during the construction. This was likely caused by consolidation due to the overburden of the fill being placed for the dam. The excess pore pressures could not be relieved due to the low permeability of the surrounding shale. This resulted in a low effective stress in the bentonite and a very low shear strength.

Hydraulic fill dams can be dangerous in areas of seismic activity due to the high susceptibility of the uncompacted, cohesion-less soils in them to liquefaction. The vulnerability of hydraulic fill dams under strong earthquake shaking has long been recognized. When located in areas of high seismic hazard, seismic upgrading of these types of dams requires careful consideration of seismically induced deformations when the hydraulic fill is to remain as part of the dam. It is important that a conservative and robust design was developed based on well-established engineering principles and multiple lines of defense. Poorly design/built hydraulic fill dams pose a risk of catastrophic failure.

4.5.4 Rock Fill Clay Core

Case	Identification	Country	Finished	Damage	Actions	References
4.5.4 -A	Carsington	UK	1984	1984	Rebuilt	[04-26]

The dam – height 33 m, had a rolled clay core with an upstream extension (the boot) and shoulders of compacted mudstone with horizontal drainage layers of crushed limestone about four meters apart. Observations of pore pressure and settlement were made during construction at four sections and horizontal displacements were observed from August 1983. The failure started in the early hours of June 4, 1984, with a 50 mm crack on the crest over a length of about 120 m. During the night of June 5^{th}, a major upstream slip occurred. The slip propagated along the embankment in both directions extending to a length of nearly 500 m, with the embankment crest dropping 11 m and the upstream toe moving 13 m horizontally by June 6, 1984.

Faced with one of the largest geotechnical failures of a structure in Britain, the owners sought independent advice on the cause to report technical issues relating to the slip. Reconstruction of the failed dam was commenced in February 1989 and was completed in 1991, seven years after the start of investigations.

The scale of the failure was so great and the public concern so high, that an independent of any interested parties reported the actions being taken to investigate the failure. ***Sulphate attack on concrete was discovered when investigating the partial collapse of Carsington Dam in 1984***. In this case, pyritic mudstone had been used to form the outer shoulders of the dam and, in order to prevent standing water, limestone drainage layers were added into that mudstone. Unfortunately, these drainage layers allowed for increased movement of water through the material, which meant that the acidic groundwater had easy access to buried concrete structures that subsequently suffered sulphate attack. Other problems linked to the pyrite at this site included blockage of drains due to precipitation of minerals, such as gypsum, and acid water runoff that required treatment before it could enter the local water system.

Degradation of concrete caused by sulphate (thaumasite) attack

Partial collapse of Carsington Dam in 1984

However, sulphate attack on concrete is only rarely seen in the Irish pyrite cases. Indeed, there was only one case that I looked at as part of my research where sulphate attack was confirmed to have occurred. In that case, both ettringite and thaumasite were found in the upper few millimeters of the concrete ground beams. However, in the cases that were the focus of the research, there were no confirmed cases of sulphate attack on concrete.

The problem with these properties, instead, leads back to the mention above about the mudstone material being organic-rich. The majority of the organic matter in the mudstone comes from decomposed micro-organisms that are primarily made of calcium carbonate ($CaCO_3$). Calcium carbonate reacts in the presence of acids to release carbon dioxide gas and calcium ions into solution. The calcium ions, in turn, react with the sulphate from the acid to form gypsum ($CaSO_4.2H_2O$). The pyrite crystals found in the mudstone are generally on the scale of tens of microns in size. By contrast, the gypsum crystals can be around 100 times larger at a few millimeters in size. This means that the very process of replacing the pyrite with gypsum causes expansion of the material. This expansion is increased by the way in which the gypsum preferentially precipitates along layers in the mudstone. These forces open these pre-existing lines, making the material expand and also allowing better access for air and moisture through the material, which furthers the reaction process

4.5.5 Rock Fill Asphalt Core

On Asphaltic Concrete Faces, asphaltic concrete has been used as the impervious element of many dams. It is particularly popular as a lining to the upper pond in pumped storage plants, where the frequent and rapid rate of the rise and fall of the water level is an important ageing factor. Among the causes of deterioration of asphaltic concrete faces are oxidation and brittleness under the influence of atmospheric oxygen combined with sunlight and hot temperatures. Such a brittle material is less able to resist the fluctuating stresses. Early designs incorporated two impervious bituminous layers. Air bubbles sometimes developed at the interface, leading to deformation and cracking of the asphalt surface. Vertical joints between strips carried out by finisher equipment are prone to rapid deterioration if they have not been carefully executed. Rehabilitation of asphaltic concrete facings require specialist contractors. The work often involves the removal of ageing and damaged asphaltic facings and their replacements with new bituminous layer and mastic coating.

In principle, the asphalt core must have the characteristics: impervious, flexible, resistant to erosion, workable, and free of construction joints. In addition, it presents viscoelasticity and ductile properties, a self-sealing ability if cracks occur in the core. "Asphaltic cores are, therefore, recommended for dams built in areas subject to earthquakes".

Case	Identification	Country	Finished	Damage	Actions	References
4.5.5-A	**Megget**	**UK**	**1982**	**1984**	**Repaired**	**[04-27]**

The dam is a gravel fill embankment, 56 m height, 570 m long, with a central asphaltic core. The upstream slope is 1:1.5 and its protection is 1.8 m thick, with the upper 1.2 meters of heavy riprap containing rocks up to 900 mm.

Damage occurred to the riprap upstream slope protection ***during the first filling in a severe storm in January 1984. The damage has taken the form of a shallow displacement of individual or groups of stones***. No emergency action was required but repairs are ongoing. Five alternatives were considered for the remedial works. It may also lead to the reinforced layer being unable to dissipate uplift pressures. To minimize these effects, pattern grouting was done which involved grouting square blocks of riprap while maintaining ungrouted areas between the blocks for drainage. Pattern grouting has been used on sea defense work where the wave attack is generally more extreme than in inland reservoirs.

The simple prediction methods used to determine the design wave heights underestimated the wave heights at Megget.

Megget Asphalt Core Rockfill Dam

4.5.6 Rock Fill Asphalt Faced

Case	Identification	Country	Finished	Damage	Actions	References
4.5.6-A	Winscar	UK	1975	1976-1980	Repaired	[04-28]

It was the second largest dam in Britain to have an upstream facing of asphaltic concrete although many had been built in Europe and elsewhere prior to Winscar Dam. Two layers of DAC (dense asphaltic concrete) were used. The dam is founded on jointed sandstone, sandy shales, and mudstone-laminated sandstone of the Carboniferous Millstone Grit Series. A grout curtain continues beneath the upstream toe to depths of up to 70 m. A permeable sandstone formation outcrops in the valley floor. The dam is made of compacted sandstone rockfill. ***Although this incident mainly concerned the performance of the asphaltic lining, leaks through the abutments contributed to flows in the drains.*** A pattern of rising seepage was recorded during first filling, with flows disproportionately high above a certain reservoir level.

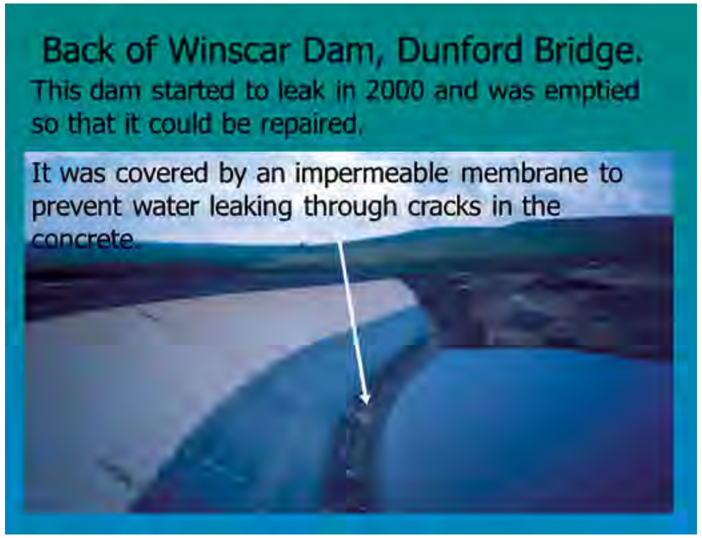
Leakage through the left abutment resulted in two stages of grouting in January 1978 and 1979 with the aim of reducing permeability at the contact between two rock strata. A third phase of grouting in 1980 involved emptying the reservoir, which led to the discovery of a series of cracks in the asphaltic concrete in the vicinity of the toe wall and concrete collar surrounding the draw-off culvert. One crack penetrated the full depth of the lining, and the hole was "no bigger than a match box". Fluorescence tests confirmed the connection to the drainage system. Damage had occurred from differential settlement between the rigid concrete collar and culvert, both of which were founded on rock, and the adjacent poorly compacted and inadequately graded rockfill.

Repair involved removal and replacement of around 12 m^2 of lining and the introduction of a flexible joint between the concrete collar and asphaltic lining using copper sheets.

The formation of blisters and debonding of the two layers of asphalt occurred over the following years. During late 2000, leakage increased and the appearance of a large spring at the downstream toe in January 2001 with a flow of 15 l/s led to a precautionary reservoir drawdown: leakage flow reduced at half-depth of the reservoir.

The defects detected during the 1996 inspection included 20 cracks within the upper layer of DAC varying in length up to about one meter, eight blisters which also had cracks, and debonding between the upper and lower layers of membrane. Inspection of the membrane in 2001 revealed 60 new defects, with several large cracks at the base of the dam, one of which had opened into a hole through the membrane. In December 2002, a Carpi composite PVC/fabric membrane liner was constructed over the DAC.

It was always recognized that connections between the lining and toe wall and culvert entry to the embankment were areas where large differential settlement between the concrete and rock fill could occur. The long-term blistering problems at Winscar Dam have not occurred to the same extent at other British dams with asphaltic linings, although regular maintenance has been required.



4.5.7 CFRD – Concrete Face Rock Fill Dam

The slab thickness designing and the specifications have been empirically established based on experiences presented by Barry J. Cooke and James L. Sherard and ASCE – 1985 and 1987[04-29].

In about 50 years there are more than 500 concrete face rock fill dams (CFRDs) completed or under construction in the world. But the design of the CFRD is empirical and is based on experience and precedent. Some serious damages, as follows, have happened at several high CFRDs since 1990's.

Case	Identification	Country	Finished	Damage	Actions	References
4.5.7-A	Tiasenqqiao-1	China	1998	2003	Repaired	[04-29]

Some cracks of cushion zone happened at Tianshengqiao No.1 Dam (178 m high). The top of concrete face slabs separated mostly from cushion layer and then more than 5000 cracks of concrete face slab occurred at Tianshengqiao No.1.

The following problems occurred during the construction and initial operation of the dam.

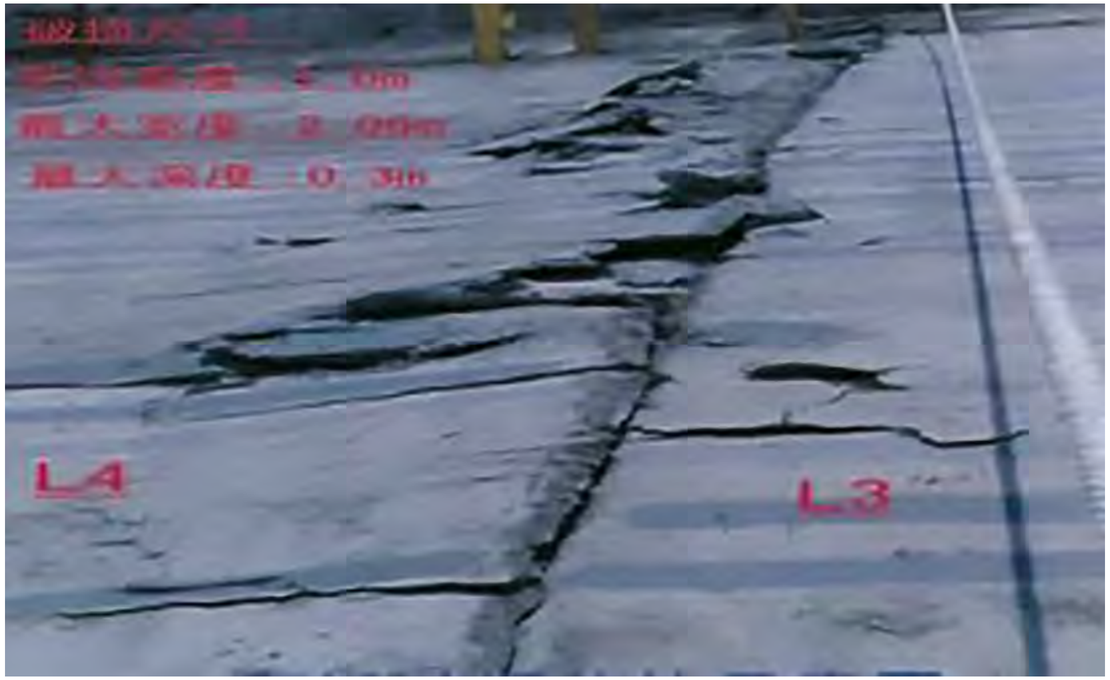
Firstly, cracks formed in the cushion layer. During the sixth filling stage, 37 cracks were found in the cushion layer among these cracks, the largest length, width, and depth were 79 m, 5 cm, and 1.5 m, respectively. ***Excessive differential settlement between upstream and downstream caused by the incorrect filling sequence of upstream and downstream rockfill was considered to be the main reason***.

Secondly, there was separation of the face slab from the cushion layer, and horizontal cracks formed on the face slab. Influenced by both excessive deformation of the rock fill and separation from the cushion layer, the face slabs lost effective support, thus resulting in horizontal cracks. The number of cracks on face slabs in the area reached 4537.

Thirdly, a face slab rupture damage occurred. The concrete on both sides of the vertical joint between the longest face slabs, was damaged in July 2003 due to the excessive compression stresses. The damage zone with a maximum width of 4 m, average width of 1 m, maximum depth of 30 cm, and average depth of 24 cm.

Later, this damage zone was repaired and the joint was filled with embedded rubber plate, which showed good performance during the subsequent operation.

Finally, the leakage rate was large. It reached 80–140 l/s and fluctuated with changes in the reservoir water level.



The damages at Tianshengqiao no.1 Dam

Case	Identification	Country	Finished	Damage	Actions	References
4.5.7-B	Barra Grande	Brazil	2005	2005	Repaired	[04-29]

Some serious cracks, squeezed ruptures, and horizontal overlaps of concrete face slabs occurred at Barra Grande Dam (185 m high).

The damages at Barra Grande CFRD

Case	Identification	Country	Finished	Damage	Actions	References
4.5.7-C	Campos Novos	Brazil	2006	2006	Repaired	[04-29]

As in Barra Grande Dam, some serious cracks, squeezed ruptures and horizontal overlaps of concrete face slabs also occurred at Campos Novos Dam (202 m high).

The damages at Campos Novos CFRD

The damages at Campos Novos CFRD

The damages at Campos Novos CFRD

The damages at Campos Novos CFRD

Case	Identification	Country	Finished	Damage	Actions	References
4.5.7-D	Mohale	South Africa	2004	2006	Repaired	[04-30] & [04-31]

The cracks, squeezed ruptures, and horizontal overlaps of concrete face slabs occurred at Mohale Dam (145 m high), then the seepage discharge increased to twice.

The damages at Mohale CFRD

The dam was visited on February 13, 2006, with no anomalies detected. ***In February 2006 heavy rains hit the Mohale region, resulting in a rapid rise of the reservoir to spilling conditions. This resulted in significant dam settlements downstream and cross valley movements of the crest, which in turn increased the already high compressive stresses within the center portion of the concrete slab, resulting in spalling failure of the slab***.

The incidents have been reported as slab crushing along the vertical joints of the face slabs, horizontal bending, and tension cracks developing in the upper portion of the face slabs.

Compaction parameters must be evaluated using odometers and plate load tests not to obtain final modulus but the differences among them. Fill design must be optimized based on available materials hailing distances should be optimized. This is standard practice even for dams in narrow canyons where variable rock conditions are expected in quarries. For the final design it is required to develop a three-dimensional model, construction sequence, modeling the structural elements, constitutive models for geomaterials, and incorporation of interface behavior between different elements of the structure.

Case	Identification	Country	Finished	Damage	Actions	References
4.5.7-E	Tokwe Murcosi	Zimbabwe	2016-2017	2014	Rebuilt	[04-32]

The **Tokwe Mukorsi Dam** is a concrete-face rockfill dam on the Tokwe River, just downstream of its confluence with the Mukorsi River, about 72 kilometers south of Masvingo in Masvingo Province, Zimbabwe. It is 90.3 m tall.

Heavy flooding in February 2014, caused a partial failure during construction, on February 4, on the downstream face of the dam. By late February the dam had not been fully breached but the unplanned rising reservoir behind the dam caused evacuations upstream. The Dam was eventually completed in December 2016, and commissioned in May 2017.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4.5.8 Rock Fill Geomembrane Faced

Upstream facings to waterproof earth and rock dams offer several advantages. Among the many materials used for decades, modern polymers (Geomembranes) proved to possess substantial advantages and were successfully applied to dams of increasing height[04-33]. Deformations are inevitable and relevant in high rock fills. Facings should therefore have low permeability, large deformability, and be joint-free.

It is very well known that leakage through embankment dams can not only degrade the dam materials but also may cause stability issues. Three reasonable precautions need to be taken to minimize the adverse effects of these problems:

⇒ leakage through liners should be reduced;

⇒ water leaks through and around the liner should be prevented, and;

⇒ excess pore pressure should be removed from the dam body.

All in all, a good liner, especially a geomembrane, is required for the first activity while a proper drainage system is needed for the second and third actions. Therefore, leakage through the geomembrane liners can be carefully considered in dams and particularly in embankment dams.

Geomembrane Holes "***Defect***" is generally used to define a hole on geomembrane liners. However, this is not the proper term to refer to the passage of liquid through the liners since defects cannot create a corridor for liquid. Holes in geomembrane liners could occur during the construction stage or in operation by the adjacent fill materials. Therefore, the frequency and size of the holes are very critical for the evaluation of leakage through geomembrane liners. Defect size is also an important factor affecting leakage through the geomembrane liners.

The selection of thickness and permeability of the geomembrane liners is important in the design stages of embankment dams. It is shown that a geomembrane thickness with a typical ranging from 1 to 5 mm will have more or less the same performance in earth dams with respect to stability when they are placed in the dam core. On the other hand, it is important to note that increasing the geomembrane thickness will have positive impacts on the mechanical properties of geomembranes such as tensile behavior, tear, and puncture resistance.

Rapid drawdown would also be a significant concern in the case of internal geomembrane

systems due to the excessive pore pressures developed on the upstream side. Therefore, the upstream slope should be carefully considered in internal geomembrane systems when rapid drawdown is a critical concern in the dam performance.

4.5.9 Roller Compacted Concrete Gravity Dam Geomembrane Faced

Due to natural characteristics of RCC-Roller Compacted Concrete dams such as permeability, are not as uniform as expected to be. The considerable problems of RCC dams are high permeability due to dry concrete that contains low amount of cement and leads to low density zones, the permeability between lifts, and the high risk of joint's separation on upstream which will develop by thermal reaction. This problem can be solved by using concrete with high cementations content, however, it can affect thermal cracking in plain concrete.

High cementitious concrete in some RCC will complicate construction due to mixing temperature control, placement and elevation lift control to avoid cold joints. The other problem of this kind of dams is seepage that can be deadly by leaching out of cement by the seeping water.

Designing an upstream system can carefully be the solution, for this purpose, geomembrane and integral concrete of upstream and RCC can be the turning part of the solution. The concrete of the upstream facing is made by internally vibrated concrete placed at the same time by RCC and will enrich upstream concrete facing. In addition, the placement of concrete requires being different from mix design of the RCC body.

Using artificial materials is the other part for protecting upstream permeability which can be named by watertight sealing element and embedded water-stops. These instruments have negative influence on time and cost during the construction procedure through entire dams. In order to overcome this problem, selecting geomembrane system has significant benefits in terms of cost and schedule which can provide upstream impermeability. The uplift reduction is therefore a function of the water tightness of the upstream facing. The uplift can be reduced in dam foundation using a tight connection for foundation sealing system such as cut-off wall or grout curtain.

The other way to reduce the uplift is face drainage system. They are accepted by many experts, due to reduction abilities at the design uplift in the part of designing. The advantages of face drainage system during service life of dams are: the monitoring which can control the performance of waterproofing system by measuring fluctuations; the dams safety which can control the capacity of drained upstream facing for impervious geomembrane to avoid the damage of waterproofing liner due to the behind water; the reservoir safety can drain the water of behind liner and makes the liner impervious.

In general, the cover system is not vital unless the cracks appear to the surface and then it became serious concern which can cause failure. As an additional precaution against such events, cover can be provided in the vulnerable horizontal zones, or in the zone of reservoir fluctuation, and can consist of a steel plate or a layer of concrete or shotcrete. [04-34]

The introduction of RCC construction techniques sought to reduce the cost of the form materials and the high labor costs of setting, stripping, and resetting the forms. This led to innovations for building both the upstream and downstream faces of RCC dams. The innovations were intended to speed construction and to avoid the sunk costs of the forms and the labor costs of stripping and resetting of forms.

As a result, engineers began to consider the dam faces as a separate design element and to break out the portion of costs allocated to building so-called “facing systems” from the single unit cost of the mass concrete.

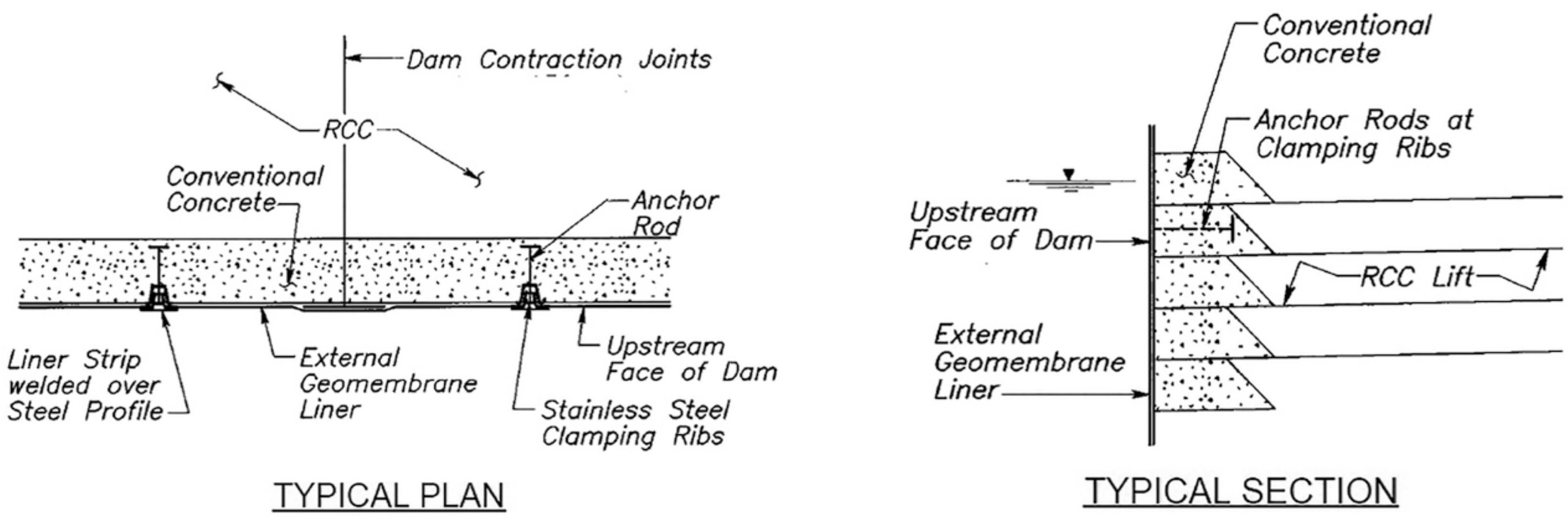
A great number of RCC dams experienced significant seepage, either through horizontal lift joints and/or vertical transverse cracks. As a result, more sophisticated upstream facing systems using conventional concrete, precast concrete, geomembranes, or combinations of these systems have been incorporated in recent RCC dams with greater success.

Larger and higher RCC dams than those which have been constructed since the 80’s are scheduled for design and construction in the near future. As the body of RCC experience has increased, the cost, constructability, and performance of various upstream and downstream facing systems have been closely studied and reported. As a result, some facing systems have gained wide acceptance and use, while others have been abandoned. Most facing systems that have performed well and are widely used, continue to be improved and refined with each new dam.

Although the type of facing system selected for a new dam is site specific and is based on a few some criteria, all successful facing systems for RCC dams have one feature in common – they do not impede the potential for high RCC placement rates.

This should always be a consideration in selecting a facing system for a RCC dam. Selection of the facing system(s) for a RCC dam must also consider the intended purpose of the facility, operation and performance criteria, local climatic conditions, materials availability, dam size, owner preferences, and public perception.

For this method, the RCC is formed, and the liner or membrane is installed after the forms are removed, or the RCC dam is completed. A liner or membrane provides the primary water barrier. A richer conventional concrete mix is placed adjacent to the forms. Formed RCC without conventional concrete is generally not used because it is extremely difficult to compact RCC on an upstream vertical face. In addition, it is difficult to get vibratory rollers near the vertical face, and smaller compaction equipment is usually required. The forms also must be designed to handle the transfer of the load due to compaction and construction equipment.



Typical plan and section of formed conventional concrete placed concurrently with RCC, with external liner, upstream facing system[04-34]

Case	Identification	Country	Finished	Damage	Actions	References
4.5.9-A	Balambano	Indonesia	1999	2002	Planning	[04-33]

An example is Balambano Dam that just completed a 95 m high roller compacted concrete (RCC) dam on the island of Sulawesi in Indonesia. The dam which includes 528,000 m^3 of RCC was completed in September 1999 and will provide hydro-electric power for a nearby nickel smelting operation.

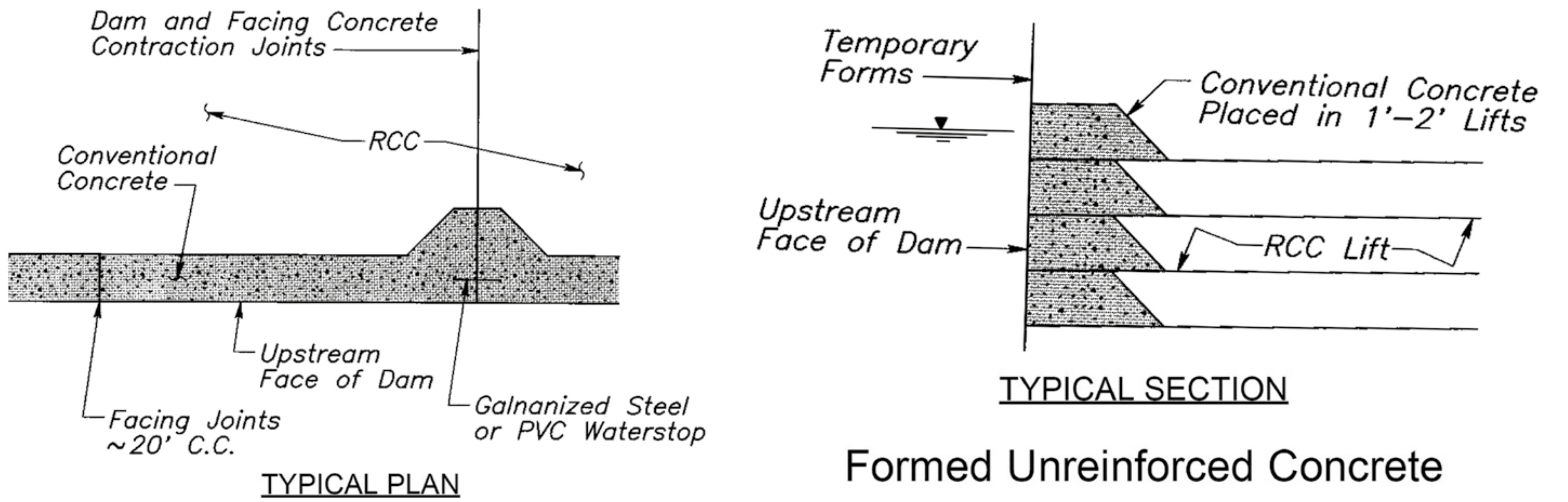
One of the largest RCC dams built in the region in recent times, the construction presented a number of unique challenges, in particular, placing techniques to cope with the heavy rainfall in the area as well the logistics to this remote location. ***After early problems with the river diversion, the works were accelerated and completed to a very tight program***. To enable dam construction to commence prior to river diversion the wall was advanced as a series of separate monoliths which led to a number of RCC placing innovations.

For the formed RCC with exposed liner or membrane, the RCC is formed and the liner or membrane is installed after the forms are removed or the RCC dam is completed. A liner or membrane provides the primary water barrier. A conventional concrete mix is placed adjacent to the forms. Formed RCC without conventional concrete is generally not used because it is extremely difficult to compact RCC on an upstream vertical face. In addition, it is difficult to get vibratory rollers near the vertical face, and smaller compaction equipment is usually required. The forms also must be designed to handle the transfer of the load due to compaction and construction equipment.

4.5.10 Roller Compacted Concrete Gravity Dam CVC and RCC Faced

As mentioned in **4.1.5**, the adoption of Design Defenses to ensure the durability of a Dam, should consider, among others that act in a structure the element, the watertightness, that is, the face of the dam.

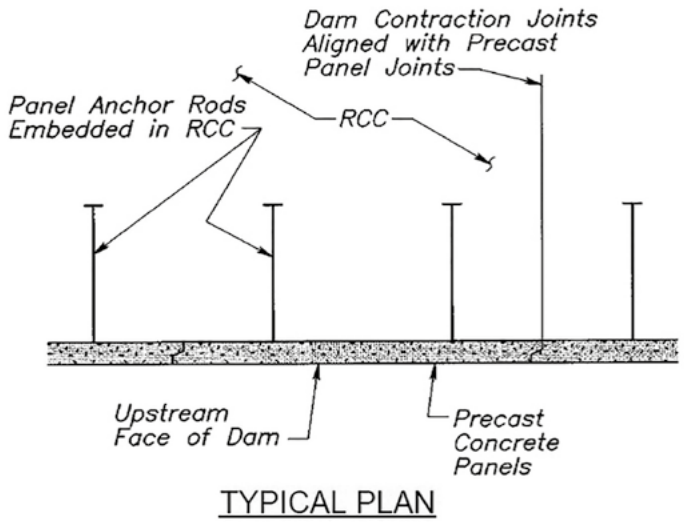
Some early RCC dams experienced significant seepage through lift joints and/or vertical cracks. As a result, many facing systems consisting of conventional concrete, precast concrete, geomembranes, and combinations thereof have been used and refined during the past two decades. In the case of the use of Conventionally Vibrated Concrete-CVC as the face used for all Japanese RCC/RCD Dams and mostly in Brazilian dams, there are cases of total success, such as those in Japan. However, in Brazil there are cases of a number of dams where the seepage is resulted from deficient construction procedures.

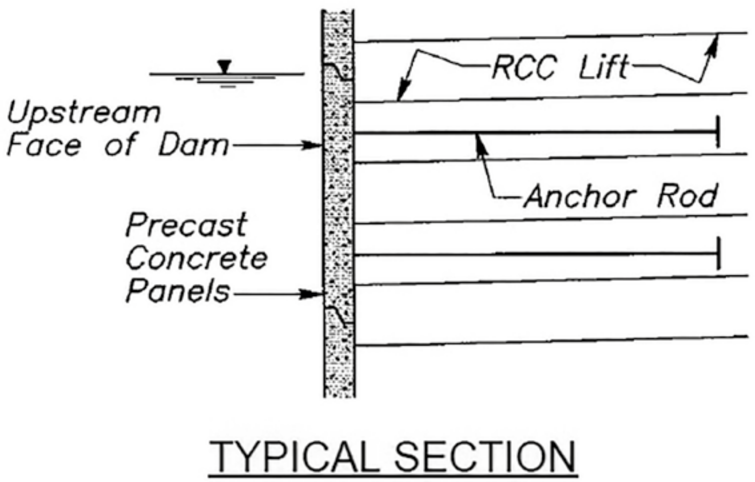


Typical plan and section for formed unreinforced conventional concrete upstream facing system[04-36]

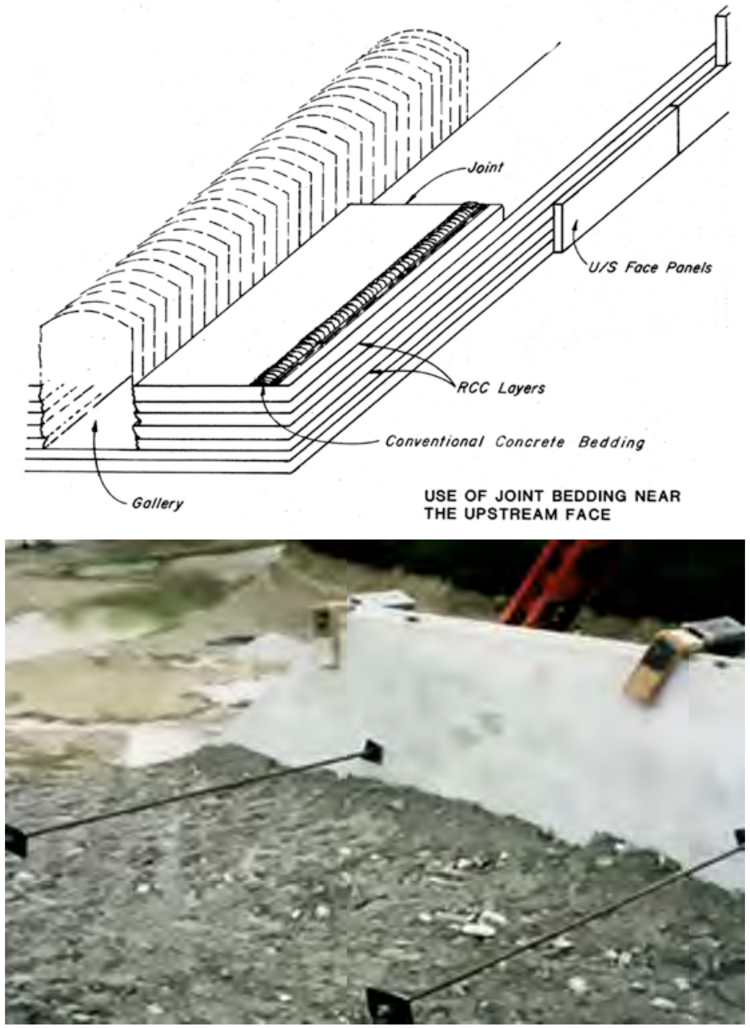
Case	Identification	Country	Finished	Damage	Actions	References
4.5.10-A	Willow Creek	USA	1983	1983	No actions	[04-34] to [04-37]

In this method, the RCC is placed directly against formwork. Relatively good finish and a durable RCC face may be achieved by placing workable, high-cementitious RCC mix in a mild climate. However, in severe climate conditions, freeze-thaw cycles may significantly damage the RCC face. Segregation near the formwork often creates labor-intensive repairs. As a result, this method is not usually used on dams. There may, however, be some applications where appearance is not a concern and a sacrificial RCC thickness can be provided. The methodology adopted for Willow Creek Dam was constructed the face with CCR directly against pre-casted panels as bellow.





Typical plan and section of RCC against precast concrete panels



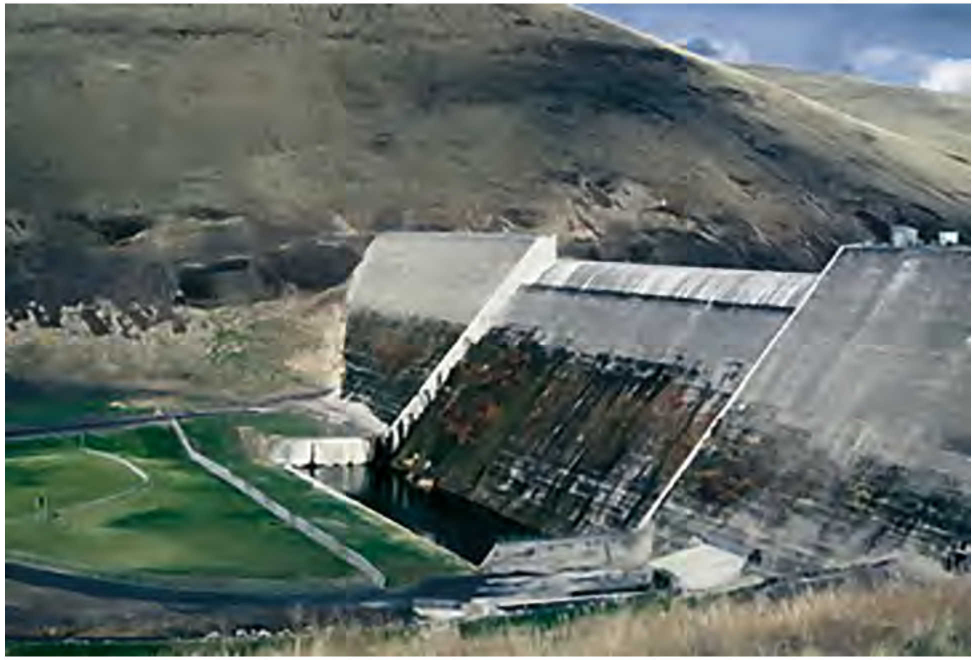
Typical plan and section of RCC against precast concrete panels

Soon after the reservoir was filled in the spring of 1983, seepage in the drainage gallery and at the downstream face was noticeable. The Tender Documents, had informed as follows:

> (10) Even with these modifications, perfect joints should not be expected. But, to repeat, they are not necessary. Some seepage could be tolerated just as is the practice on lift joints in isolated locations of essentially all conventional concrete gravity dams. With time this seepage will probably seal itself through calcification or "natural healing", or by being plugged with silt as commonly occurs on low head dams in the Northwest. At any rate, seepage along lift joints would be an aesthetic rather than a structural problem if it did occur, and it could be remedied if later deemed necessary by drilling and grouting the affected area. Because Willow Creek Dam is a flood control structure which has a low permanent reservoir and because the base of the dam is being built wider than structurally necessary for reasons of construction practicality, the ratio of normal flow path to reservoir head is about three times higher than normal. This will help eliminate or reduce any lift joint seepage.

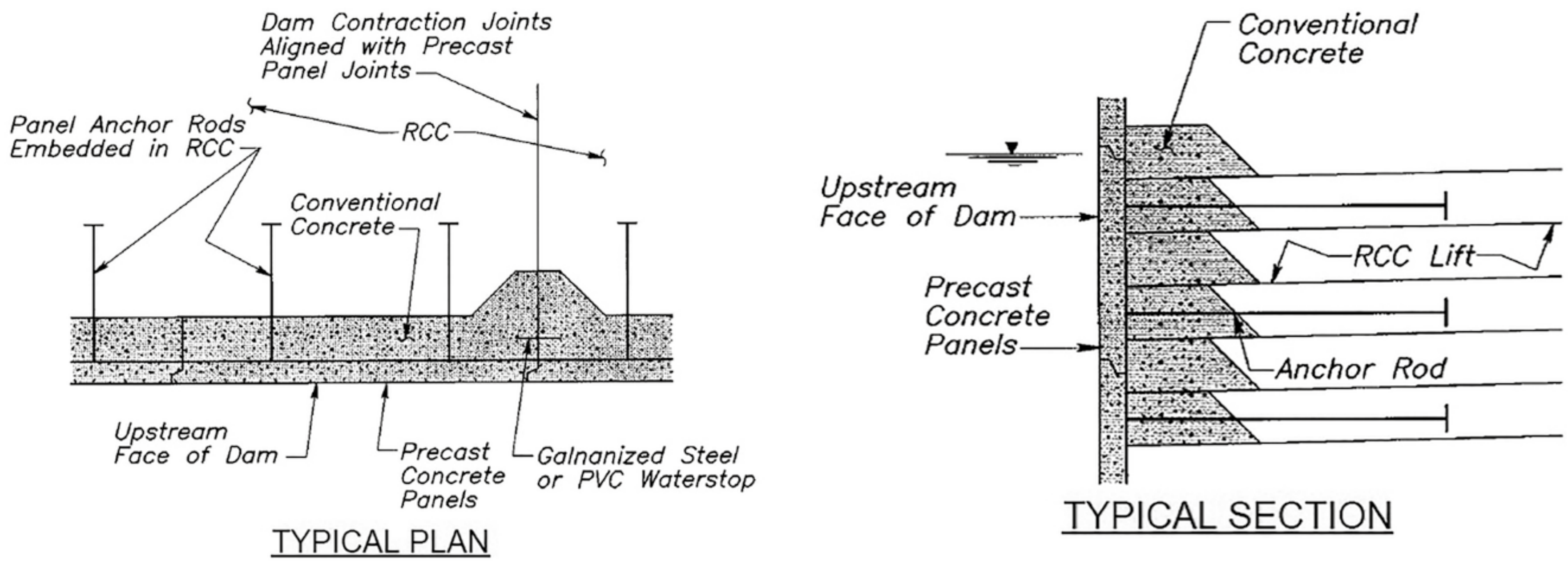
The Final Report Concrete Report Willow Creek Dam – World's First All Roller Compacted Concrete Dam – US Army Corps of Engineers – Walla Walla District – July 198[04-37] 3 – mentioned:

"... Original design concepts did not include a gallery. One of the reasons was that the resulting short seepage path from the upstream face to it would allow significant leakage, especially because the continuity of placement in this zone would be disrupted. Because of the unprecedented nature of the dam and the desirability of inspecting the interior of the RCC, the gallery was included and, in fact, significant leakage to it developed as anticipated..."



The conventional facing concrete is usually placed in 30 cm lifts against vertical upstream forms, followed by the RCC. Contraction joints can be provided and consist of formed crack control notches with embedded PVC waterstops. Additional vertical crack control notches can be provided within the conventional concrete between the contraction joints to control temperature and shrinkage cracking expected in the higher paste, exposed, conventional concrete mix. A similar procedure is usually the preferred approach for forming downstream facing concrete. The downstream face can be constructed as formed steps, which can be incorporated into the spillway design to facilitate the energy dissipation.

There are other alternatives to the execution of the face, as illustrated below.



Typical plan and section of unreinforced conventional concrete against precast panels upstream facing system

Precast concrete panels, with a liner or membrane between panels, placed on the vertical upstream face of the RCC dam is a common method of forming the upstream face of an RCC dam and providing a continuous water barrier. The precast concrete panels are anchored to the RCC with anchor rods. The liner or membrane is either preinstalled on the panels or installed from rolls with the panels in place. Conventional concrete is usually used on the concrete panel/RCC interface because compaction is difficult at this location.

The design for this small municipal water supply Winchester dam[04-36] was similar to Willow Creek Dam in that precast concrete panels were used as stay-in-place forms for the vertical upstream face. However, there was one major difference that led to improved seepage performance through the RCC dam. A 65-mil thick PVC membrane was attached to the downstream side of the panels during casting. Then, following installation, both the horizontal and vertical joints were heat-welded together with the use of a strip of the membrane material. Conventional concrete was then placed between the panel and the RCC as a precaution against damage to the membrane during RCC placement and compaction.

Case	Identification	Country	Finished	Damage	Actions	References
4.5.10-B	Passagem das Trairas	Brazil	1994	2005	Repair by 2020	Private Report from Andriolo

The inspections showed the face of the CCR dam executed simultaneously with CVC, ***with porosities, honeycombs and infiltrations to the downstream face, resulting from methodology and execution of poor quality.***



Case	Identification	Country	Finished	Damage		References
4.5.10-C	Umari	Brazil	2001	2005	Private Report from Andriolo	

The same as 4.5.10-B, the inspections showed the face of the CCR dam executed simultaneously with CVC, with porosities, honeycombs and infiltrations to the downstream face, ***resulting from methodology and execution of poor quality***.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Case	Identification	Country	Finished	Damage	Actions	References
4.5.10-D	Santa Cruz do Apodi	Brazil	2002	2005	Repairs by 2006	Private Report from Andriolo

The same as 4.2.11-B and C, the inspections showed the face of the CCR dam executed simultaneously with CVC, with porosities, honeycombs and infiltrations to the downstream face, resulting from methodology and execution of poor quality.


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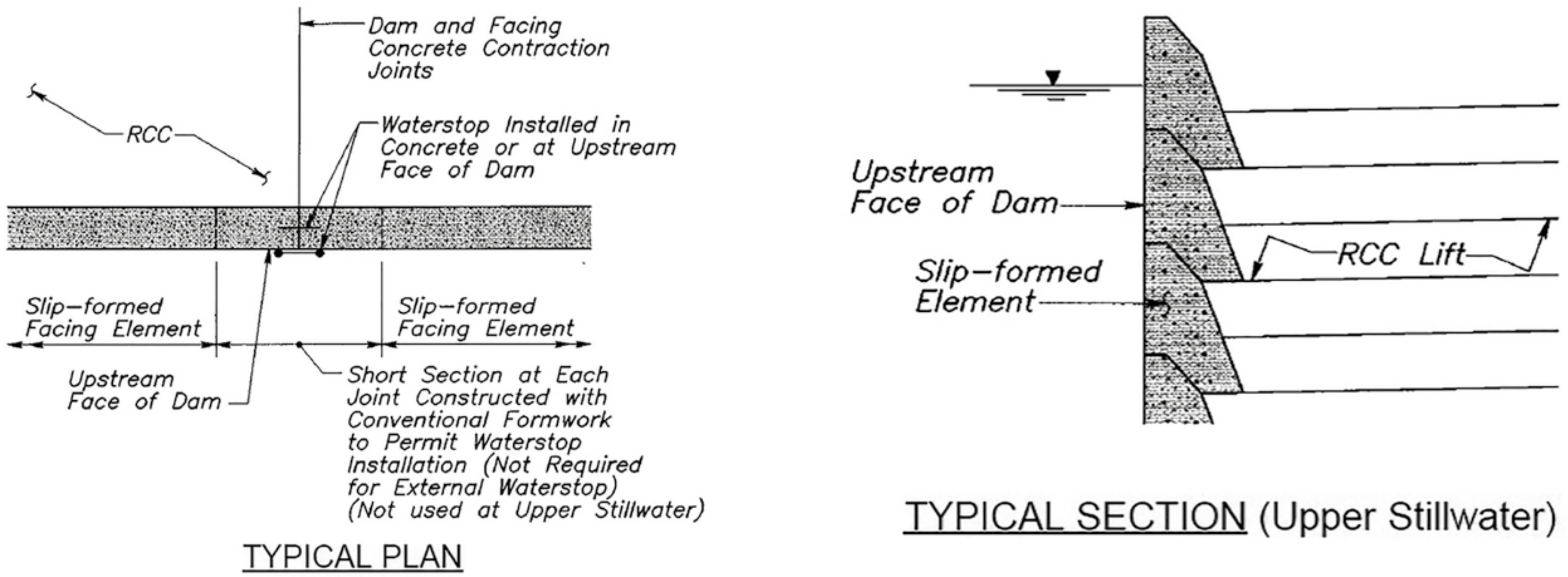
Key factors related to seepage control include the permeability of the facing system, whether or not the facing system is drained or undrained, and the performance of the facing system, should the dam experience minor movements or cracking. A drained upstream facing system can accomplish the removal of water migrating through lift joints in the body of the dam, thus lowering saturation levels and pore pressures in the dam, with beneficial effects on the stability safety factors, on AAR phenomena, and on appearance.

A drained upstream facing system also permits more accurate monitoring and control of seepage. For screening purposes, seepage control is categorized as "Good," "Fair," and "Poor" as ahead presented.

Case	Identification	Country	Finished	References
4.5.10-E	Porce II	Colombia	2000	[04-34] & Private Report from Andriolo

A richer conventional concrete (CVC) mix may also be used near the upstream face of the dam with slip-formed facing elements. It is very difficult, however, to provide joints in slip-formed facing elements. Because of the time required for the facing element concrete to gain strength, this method usually limits the placement of RCC to two or three lifts per day. Both faces of Upper Stillwater Dam were formed of 3-foot-high, slip-formed facing elements. Slip-formed facing concrete has been used on a very small number of RCC projects.

The methodology adopted for Porce II Dam was constructed to face with CCR against slip formed elements, as bellow.



Typical plan and section of RCC against slip-formed/extruded facing elements upstream facing system

The author's technical visit (by October/1999) may observe, even yet just during the construction, that there was seepage due to cracks in the elements of the face, together with poor contact between layers of the RCC.





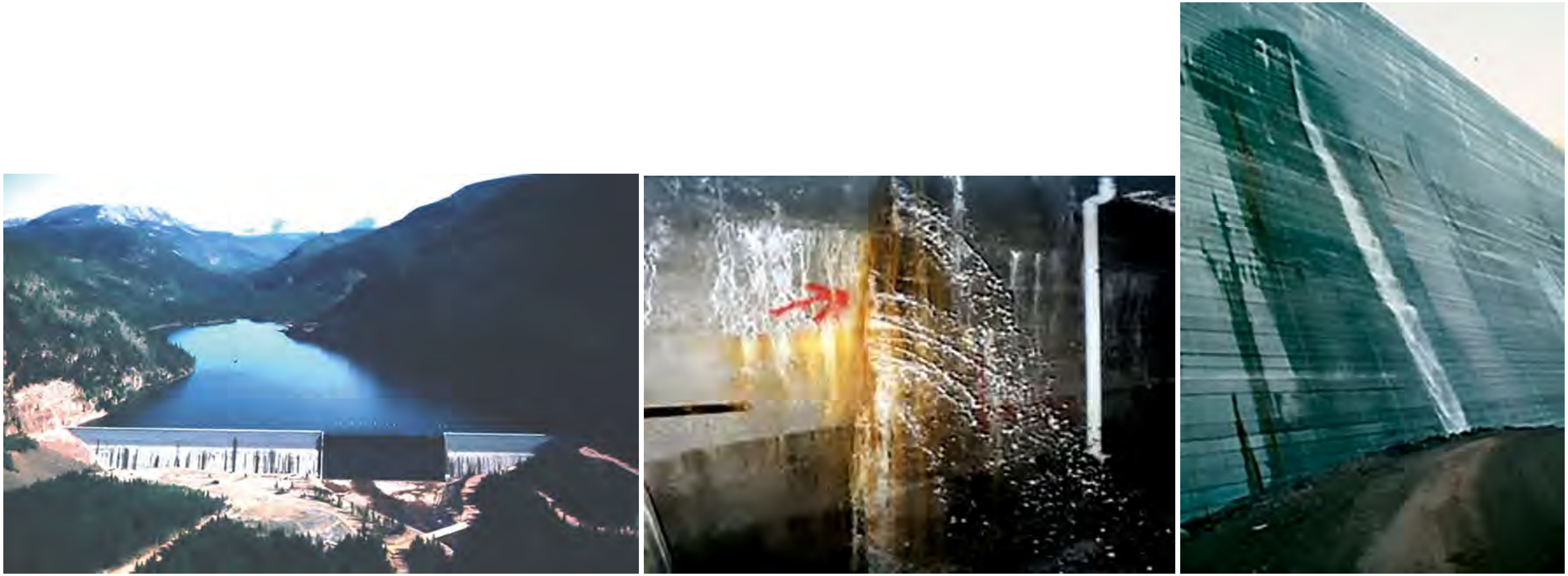

Case	Identification	Country	Finished	Damage	Actions	References
4.5.10-F	Upper Stillwater	USA	1987	1988	Groutings	[04-38] to [04-40]

Upper Stillwater Dam was the first from Bureau of Reclamation concrete gravity dam constructed with RCC. In 1987, at the time of its completion, Upper Stillwater Dam was the largest RCC dam in the world. Upper Stillwater Dam is located on Rock Creek in eastern Utah. The upstream and downstream faces of Upper Stillwater Dam consist of slip formed concrete, while the interior mass of the dam consists of RCC placed and compacted in 30 cm lifts using earthmoving equipment and a vibratory roller.

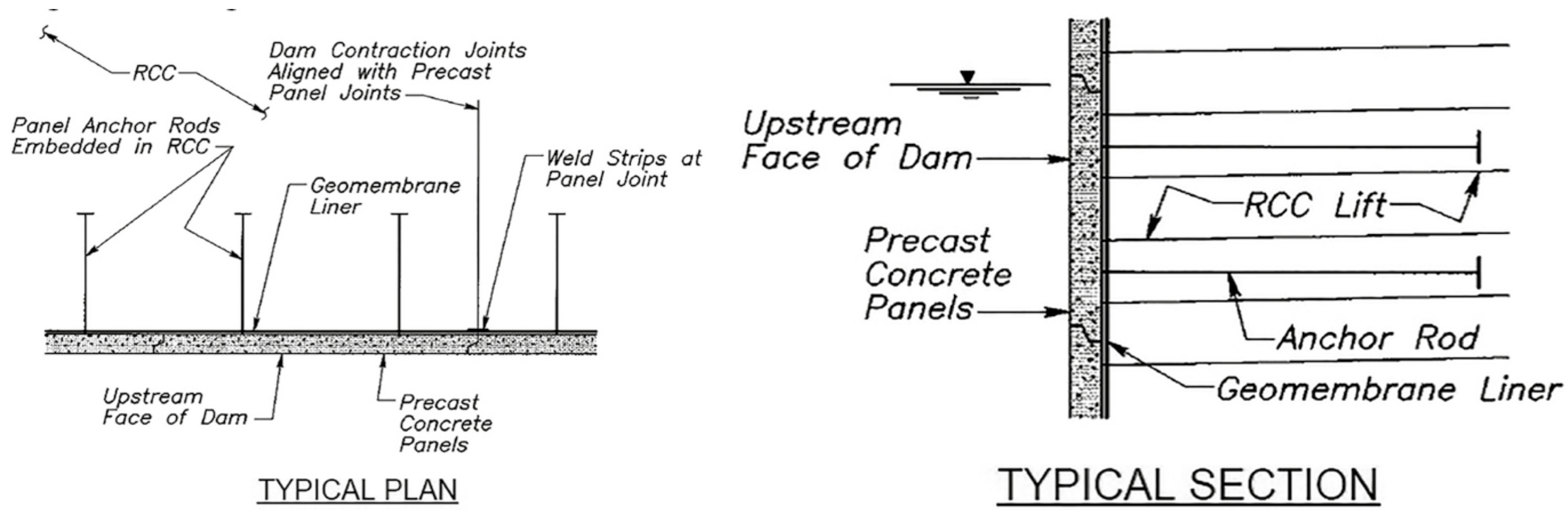
The dam was constructed continuously from abutment to abutment ***without contraction joints or artificial cooling, which resulted in the development of thermally induced vertical cracks at several locations and leakage into the gallery and downstream face***. Both the upstream and downstream faces of the dam were constructed by extruding concrete using a conventional, horizontal, slipform paver and a side-hung mold.

Supplemental grouting was performed using both cement grout and polyurethane chemical grout, but it was only partially successful because significant leakage persisted at several cracks.

Thermal expansion studies were performed on the RCC mix. The analysis included air temperature, solar radiation and heat of hydration, and a maximum specified placement temperature of 10°C. The analysis of the thermal behavior of the dam indicated that the dam could crack at 15 m spacing. The dam was designed without any contraction joints or crack inducers through the RCC, although contraction joints were placed on the conventional concrete on the crest of the dam. Structural cracking, due to thermal stresses, initiated on the crest contraction joints.



Aerial view of the completed Upper Stillwater Dam, showing the downstream face and seepage from cracks following the first winter and first filling

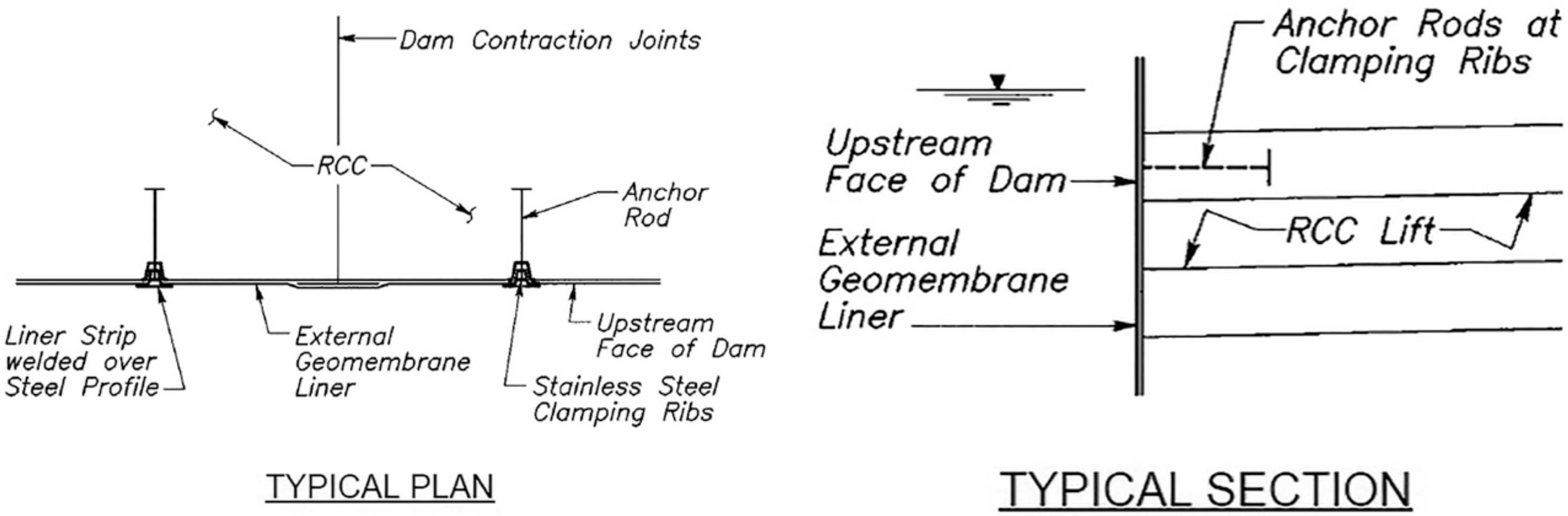


Typical plan and section of RCC against precast concrete panels with liner upstream facing system[04-36]

This improved upstream facing system effectively stopped any measured or noticeable seepage through the dam after filling. Some dams as Urugua-i (Argentina); Capanda (Angola); Cindere and Beidag (Turkey) had adopted this system.

Case	Identification	Country	Finished	Damage	Actions	References
4.5.10-G	Galesville	USA	1985	1988	Groutings	[04-34]

Galesville Dam is another example of the rapid placement of RCC. The 161,000 m^3 of RCC was placed in about 1.5 months, basically in June and the first half of July, 1985. Placing all conduits through the dam in a concrete encasement on one abutment helped to speed the construction. The vertical upstream face is conventional concrete with no transverse contraction joints. Unformed RCC was used for the downstream slope with overbuild allowed by the contractor. The overbuild was allowed to ravel and served as a sacrificial layer of poorly compacted RCC.

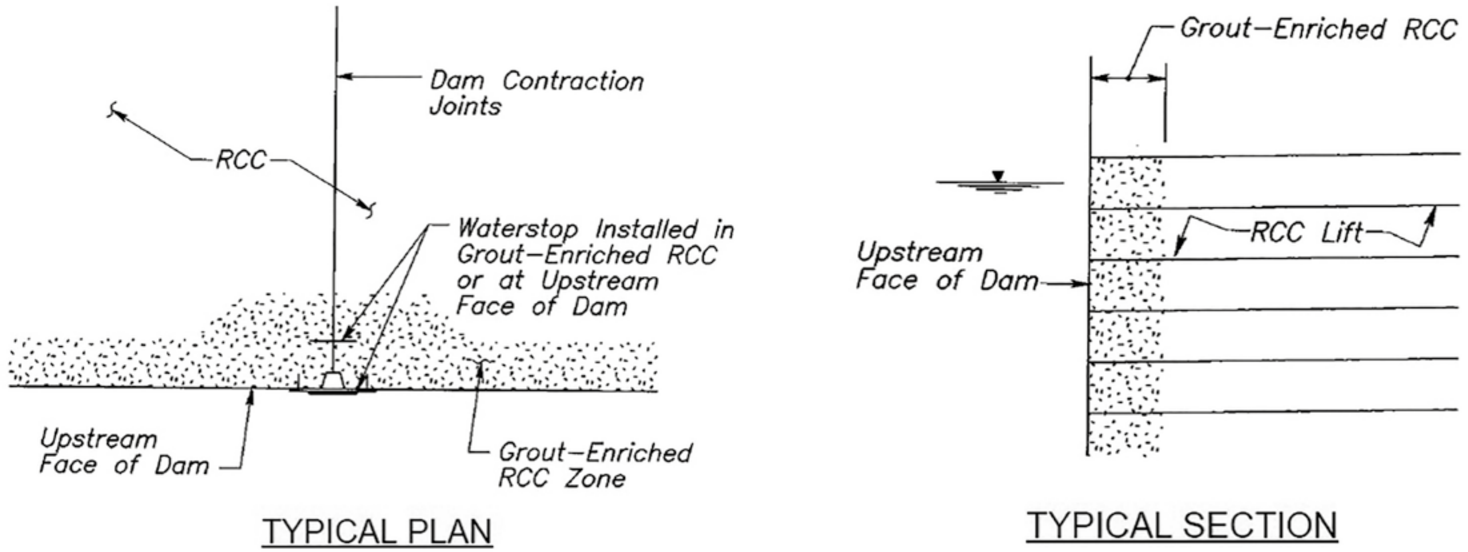


Typical plan and section of formed RCC with external liner upstream facing system[04-36]

For seepage control, two 20-mil thick layers of a coal-tar based elastomeric membrane was sprayed on the upstream face. A delay in the start of the RCC placement to warmer weather helped contribute to the initial formation of seven thermal related cracks that continued through the entire gravity structure. Following completion of the dam, unusually cold weather hit the site causing a reduction in volume and thus cracking. The sprayed-on membrane did not have sufficient elasticity to bridge the cracks.

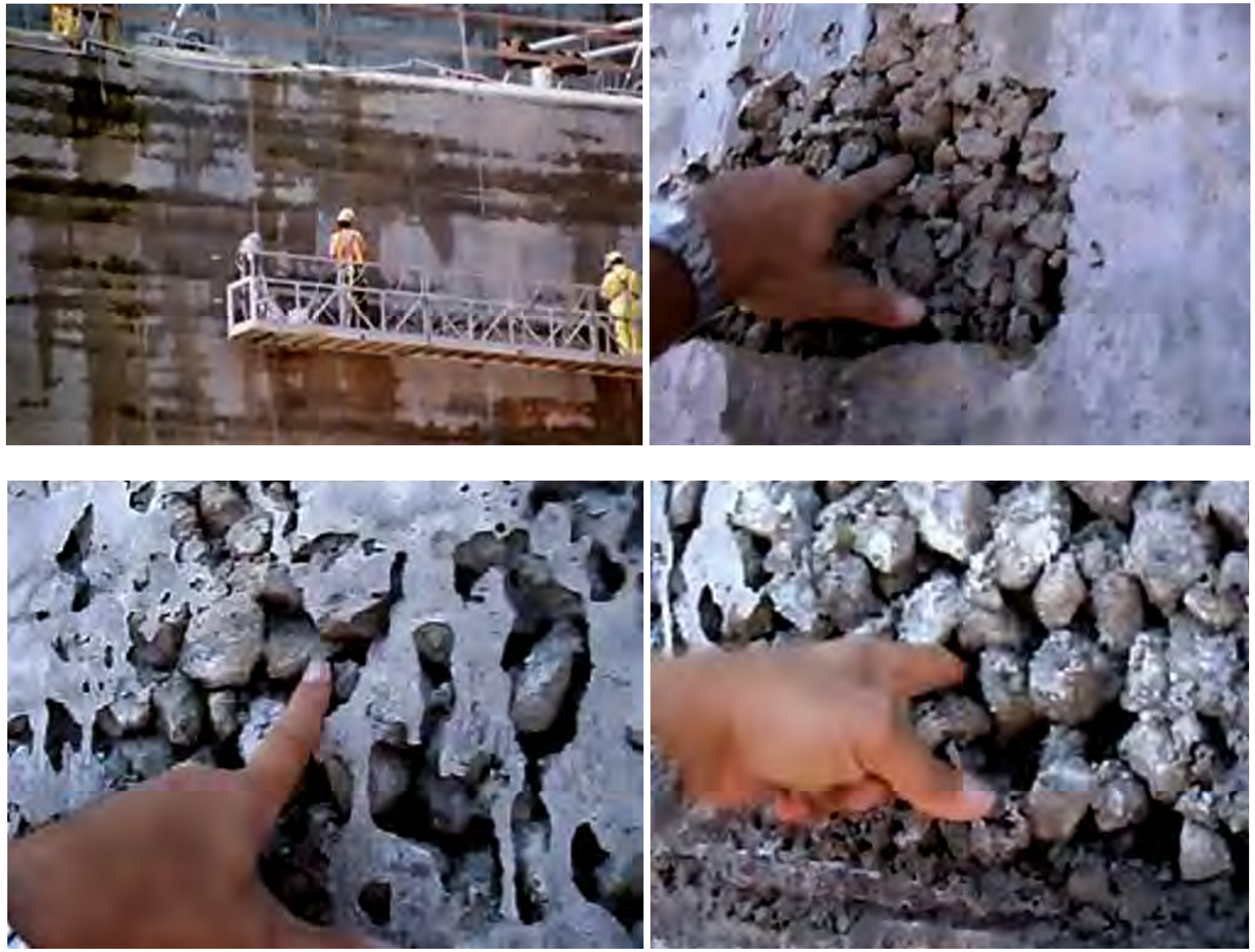
4.5.11 Roller Compacted Concrete Gravity Dam GE-RCC Faced

The formed grout-enriched RCC (GERCC), sometimes referred to as grout-enriched-vibratable RCC (GEVR), consists of first placing unconsolidated RCC near the upstream and downstream forms and then adding a grout mix that is vibrated into the RCC using immersion vibrators prior to RCC compaction. The RCC lift is then compacted adjacent to, and just overlapping, the consolidated GERCC.



Typical plan and section of Grout-Enriched RCC (GE-RCC) against formwork upstream facing system[04-36]

In this alternative, the vibration procedure must be controlled in order not to obtain a porous face as illustrated below.



Honeycombs in the Grout-Enriched RCC (GE-RCC) (Andriolo´s Archive)

Durability can be influenced by several site-specific factors including:

⇒ chemical attack,
⇒ solar radiation,
⇒ thermal expansion and contraction,
⇒ wave and ice loading,
⇒ freeze/thaw cycles,
⇒ seismic loading, and
⇒ vandalism.

The relative weight of consideration placed on the ice loading and freeze/thaw cycle factors should be climate dependent. Other durability considerations include maintenance requirements and the anticipated service life of the facing system. Durability also includes an assessment of what would be involved to repair or replace the facing system once its design life is exceeded or should a defect in, or failure of, the facing system occur. For screening purposes, durability is categorized as "Good," "Fair," and "Poor", in the table as follows[04-36].

Order	Upstream Facing System	Appearance	Watertightness	Durability	Constructability
A	RCC Against Precast Panels Without A Liner	Good	Poor	Good	Routine
B	RCC Against Slip-formed Facing Elements	Fair-Good	Poor-Good	Good	Moderate Difficult
C	Formed Conventional Unreinforced Concrete	Fair	Good	Good	Moderate
D	RCC Against Precast Panels With Liner	Good	Good	Good	Routine-Moderate
E	GE-RCC simultaneously with RCC cast against formwork	Fair-Good	Fair-Good	Fair-Good	Routine
F	Exposed Liner on Formed RCC	Good	Good	Fair	Proprietary

Design Factor Ratings for Downstream Facing Systems[04-36]

The perceived problems included excessive seepage through the RCC mass, leakage through transverse cracks, cracks due to differential settlement, deterioration at the downstream face due to freeze-thaw and wet-dry cycles, and the leaching of calcium hydroxide to form calcium carbonate deposits where it meets the air. In no case did the problem encountered jeopardize the safety of the dam.

Many of these problems required maintenance following completion of the dams. The performance of this first generation of RCC dams in the US was usually well publicized. The designers of future RCC dams owe a great deal of gratitude to the pioneering efforts of these early RCC dam designers. Lessons were learned that would be applied to more recent RCC dam designs.

Since 1982, 29 roller compacted concrete (RCC) dams 50 ft (~15 m)or more in height have been built in the US, and there are two others under construction. Lessons learned from these projects over the last 30 years have led to significant changes in the design and in the means and methods of construction, particularly in the area of seepage control and collection and crack control.

The earliest dams were generally built as a monolithic structure with no joints and few, if any, crack inducers. Additionally, lift quality was frequently compromised because equipment had to be hauled on and off the lift surface. Both of these factors have contributed to uncontrolled seepage.

The instances of uncontrolled cracking and seepage have not been a safety concern, but they have created an aesthetic and maintenance problem at several of the projects. Repairs have generally consisted of sealing the individual large cracks and grouting the mass of the dam by drilling through the crest in an attempt to seal cracks and any voids along lift lines.

Today, designers of RCC dams place greater emphasis on evaluating the potential for cracking due to thermal and foundation considerations. They are minimizing uncontrolled seepage by providing upstream facing systems designed to be near-watertight and/or providing means to collect the seepage before it exits at the downstream slope. The performance level of RCC dams has improved from the early days because the design community have been willing to exchange information on how their projects have performed and have developed the expertise to address past performance deficiencies.

In the early years, seepage through those RCC dams that maintained a normal pool were generally controlled by using a conventional concrete facing, placed concurrently with the RCC.

The latest generation of conventional concrete-facing designs include waterstop contraction joints, not only at the location of the crack inducers in the mass sections of the RCC, but also at ~6-10 m intervals along the length of the facing element. The joints aligned with the crack inducers may have a double row of waterstops, with a drain located behind them to collect any water that bypasses it.

Some designers have introduced a series of face drain holes that are drilled diagonally from the top of the completed dam, intersecting the drainage galley, to collect any seepage through the dam's mass or through any uncontrolled cracking.

The performance of the geomembrane facing systems have been excellent.

In almost every case, seepage flow rate through RCC dams have decreased with time. Siltation and calcification are the major natural reasons for seepage reduction. Calcium carbonate is formed when calcium hydroxide released from the cement hydration process is carried by seepage to a surface in contact with air. The calcium hydroxide combines with the carbon dioxide in the air to form calcium carbonate, which seals small cracks and reduces overall seepage through the RCC. However, two negative side effects result from this chemical process.

Most cracking in RCC dams can be attributed to abrupt changes in the dam's foundation profile and/or material properties, or to thermally induced stresses. Considerable insight has been gained into why cracking occurs and the analytical tools to evaluate cracking potential have improved to a point that crack spacing and widths can be fairly accurately estimated. The most common cause of cracking in RCC dams is thermal stress, which develops as a result of the differential in temperature — within the RCC mass and the exposed face, and between the mass and the ambient air temperature.

4.5.12 Roller Compacted Concrete Arch Gravity Dam CVC Face

Case	Identification	Country	Finished	Damage	Actions	References
4.5.12-A	Knellpoort	South Africa	1988	After the reservoir was filled	Grouting	[04-41]

The 50-m-high dam is an asymmetric arch with a straight gravity left flank. The upstream faces is Vertical and the downstream face: 0.60:1 (H:V). ***After the filling some cracks and seepage were observed from the downstream face.***

Case	Identification	Country	Finished	Damage	References
4.5.12-B	Wolwedans	South Africa	1989	After the reservoir was filled	[04-41]

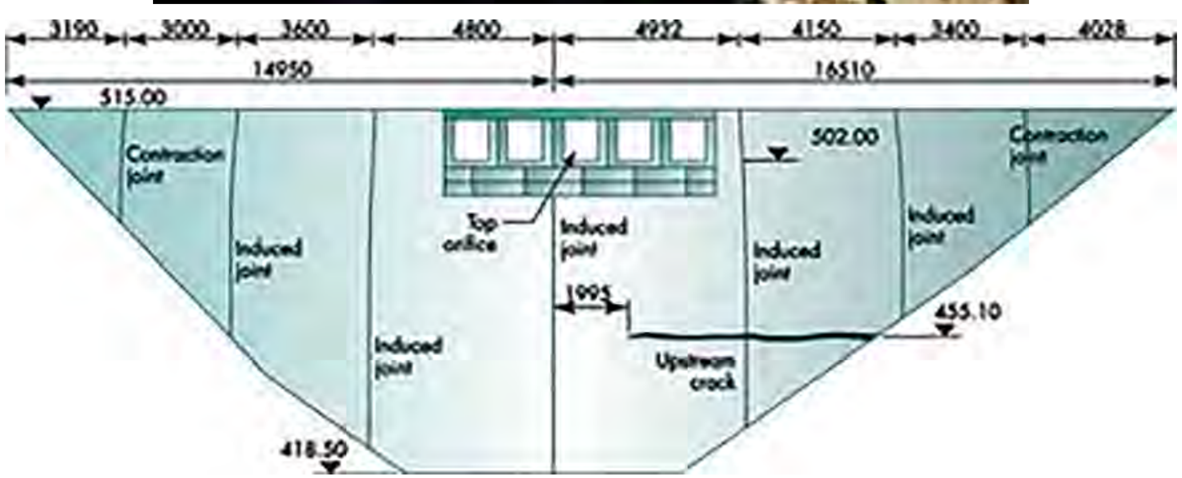
The Wolwedans Dam is situated on the Great Brak River near George in the Southern Cape Province of South Africa. The 70-m-high dam is a near symmetric arch with upstream face with CVC concrete: Vertical and downstream face: 0.50:1 (H:V). ***As for a Knellpoort dam, after the filling some cracks and seepage were observed from the downstream face***.

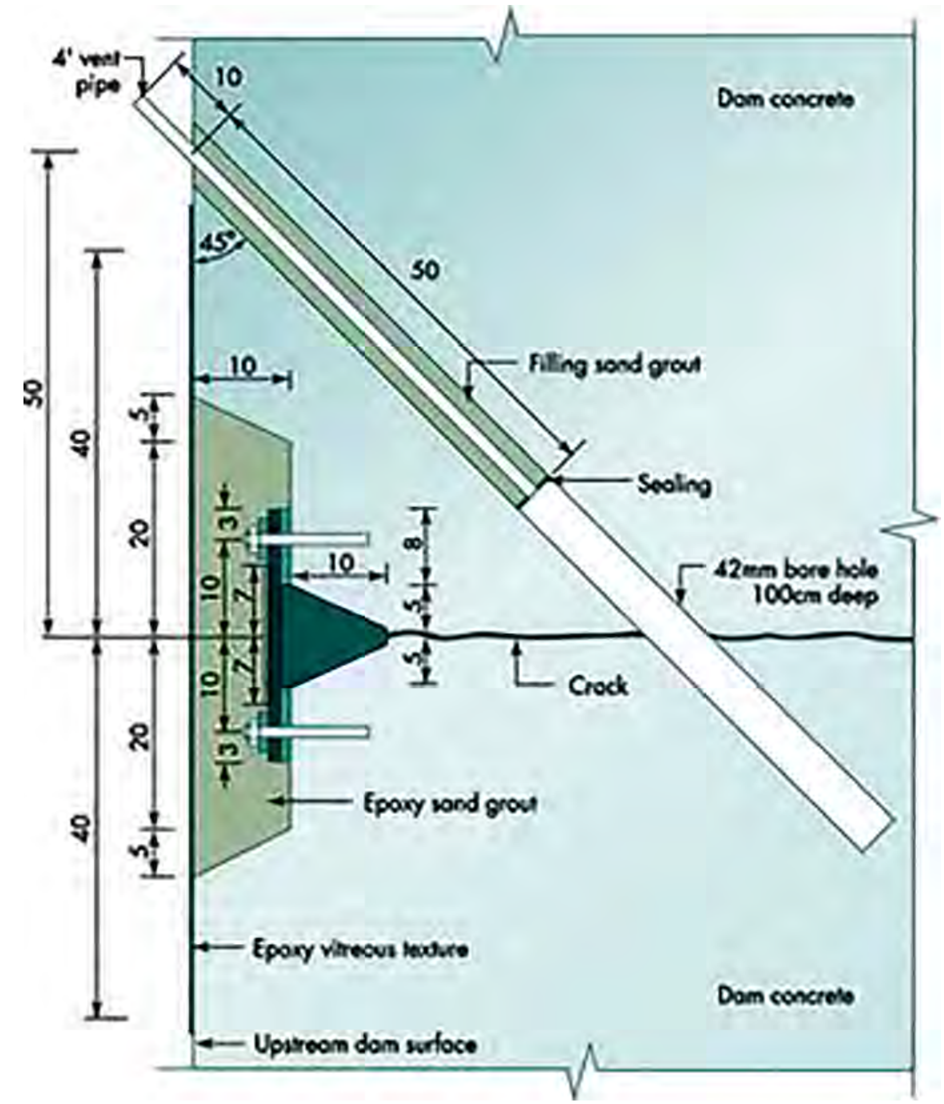
4.5.13 Roller Compacted Concrete Double Arch Gravity Dam

Case	Identification	Country	Finished	Damage	Actions	References
4.5.13-A	Linhekou	China	2003	2002	Grouting	[04-42]

The project features an RCC arch dam with peak height of 96.5 m. The contractor began to place RCC on December 23, 2001, at a compacted thickness of 30 cm, and dam construction was completed on June 25, 2003. The dam began to retain water on October 27, 2003, and electricity generation began on May 1, 2004.

On August 8, 2002, a horizontal crack was found on the upstream face of the dam. Water pressure tests and bored dam concrete cores indicated that the crack was along the surface between placing lifts. The crack had developed from the dam upstream face to the downstream face, and had a total cracking area of nearly 1000 m^2, with a width less than 0.3 mm. After careful observation, indoor tests, and field experiments – measures including chemical grouting into the crack surface, sealing the crack boundary, and installing anchor steel piles through the crack – were carried out twice for the arch dam.


3190
3000
3600
4800
4932
4150
3400
4028
14950
16510
515.00
Contraction joint
Induced joint
Induced joint
Top orifice
Induced joint
Induced joint
502.00
Induced joint
Contraction joint
1995
Upstream crack
455.10
418.50


4' vent pipe
10
Dam concrete
50
45°
50
40
10
Filling sand grout
5
Sealing
20
3
8
10
10
7
5
42mm bore hole 100cm deep
10
5
7
Crack
20
3
Epoxy sand grout
40
5
Epoxy vitreous texture
Dam concrete
Upstream dam surface

After the discovery of the crack, which may have appeared previously but remained unnoticed, another horizontal fracture was found at the same elevation on the dam's downstream face. A simple water pressure test was carried out on August 16, 2002, resulting in water leaking out of both the upstream and downstream cracks, and water splashed out from several other locations. Also, $Ca(OH)_2$ emitted from both cracks. After chemical grouting was undertaken for the first time on 21 October 2002, it was found that water still leaked out of the cracks, and the cracks were extending toward the crown cantilever. This clearly indicated that the first chemical grouting was not successful.

Crack treatment for the second time began on November 20, 2002. During the drilling of chemical grouting holes, especially when high-pressure winds drove water into the grouting pipe system and the crack surface, the cracks continued to further extend toward the crown cantilever, which was evident in the wet cracking trace. After surveying, it was found that the upstream crack extended from the right abutment to a location 19.95 m right from the reference plane, and the downstream crack extended from the right abutment to a location 28.6 m right from the reference plane. The crack ran through the upstream face to the downstream face and the total crack area was about 1000 m^2. This damage is an infrequent occurrence in RCC dams, and required a very difficult treatment process to fix the problem.

- ✓ ***Damage can occur from a weak interface, even from the initial crack from the tensile stress caused by the temperature drop.***

4.5.14 CVC Mass Gravity

Case	Identification	Country	Finished	Damage	Actions	References
4.5.14-A	Mullardoch	UK	1951	1986	Postension	[04-43]

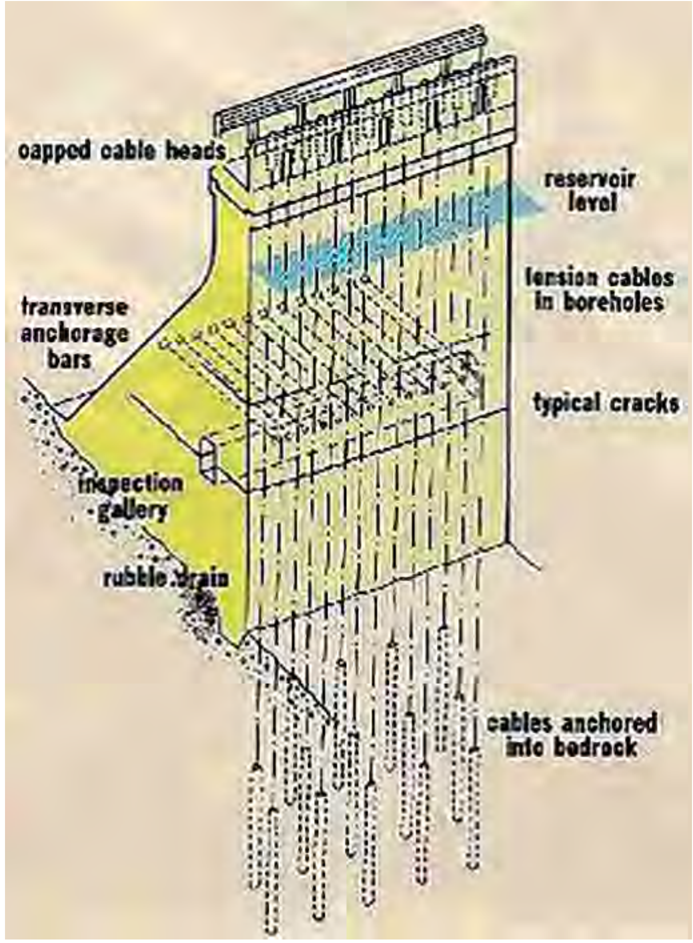
On July 4, 1986, it was reported that leakage into the longitudinal gallery had increased from 0.16 l/s to 5.2 l/s. Pre-existing nearly horizontal cracks in the gallery walls were found to have opened as much as 1.5 mm. This was mainly evident in the two blocks extending about

15 m either side of the central buttress where the two flanks of the dam meet. There was particular concern about the suddenness of the increase and the opening of the cracks.

The reservoir level was lowered to seven meters below top water level. Existing instrumentation was monitored twice daily, and the results were assessed. Three-dimensional modelling showed the observed pattern of cracking to be consistent with a build-up of longitudinal compressive stress within the structure, leading to downstream tilting of the central buttress under high temperature loads. The build-up of compressive stress was thought to be the result of progressive deposition of calcium carbonate in the vertical construction joints resisting thermal expansion and closure of the valley sides.

Improvement of drainage and pressure relief to reduce uplift pressures was achieved by drilling low-level outlets to intersect the longitudinal rubble drain in the foundations.

After examining several options, it was decided to post-tension the four central blocks of the dam, to improve stability against overturning, and to hold the cracks closed under all foreseeable loading conditions. The most severe being that of high temperature and valley closure movements. Twenty-six vertical tendons were installed. The tendons were provided with double corrosion protection and were re-stressable and fully detensionable. Transverse tendons were also installed to counteract induced tension on the roof of the inspection gallery.



The layout of the post-tensioning is shown above

Case	Identification	Country	Finished	Damage	Actions	References
4.5.14-B	Rio Descoberto	Brazil	1974	1981, 1989, 1993	Diaphragm	[04-44]

The dam, mass concrete gravity type, was finished in 1974. Some leaching water started to be observed at the downstream face a few years after the end of the construction, filling the reservoir.

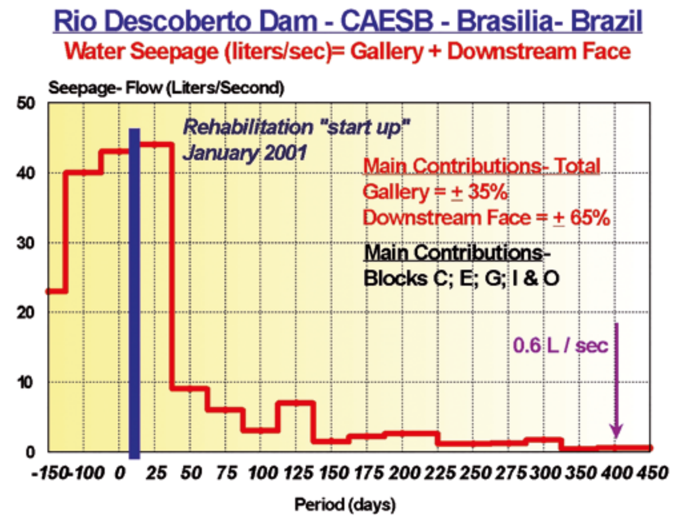
Some remedial works were adopted in different periods, adopting grouting and drainage systems, with no remarkable success. After several analyses, the problem origin diagnosis was the presence of pyrite on the concrete aggregate combined with the acidic water action.

A diaphragm wall was adopted as the rehabilitation methodology. This “In the wet” technique, permitted the water supply for Brasilia (1.5 million people) not to be interrupted or affected in the course of the rehabilitation works. The reservoir’s water quality was continuously controlled during the process and kept at the same level. The adopted methodology is described in this book.

The consequences of pyrite composed concrete aggregate was known by the Descoberto Dam designers by the time of construction, but the pale local experience with that kind of problems allowed the use of a low-level pyrite concrete aggregate in this construction work. From that time, until the performance of this project in 2000, the water leakage increased strongly, becoming long horizontal leaching planes across the dam section.

At that time, it was constituted a Consultant Committee that ordered the collect of samples of inner inspection gallery drains sediment, dam’s concrete, and reservoir and drain water analyses. Those analyses indicated the presence of pyrite on the concrete aggregate and foundations. The combination of the presence of that mineral with the action of acidic (pure) water, was contributing to the degeneration of the concrete structure of the Descoberto Dam. The main pathologies observed were pyrite reactions. The best solution was to implant a waterproof barrier, avoiding the contact between the reservoir water and the body of the dam.


BL


Rio Descoberto Dam - CAESB - Brasilia- Brazil
Water Seepage (liters/sec)= Gallery + Downstream Face
Seepage- Flow (Liters/Second)
Rehabilitation "start up"
January 2001
Main Contributions- Total
Gallery = ± 35%
Downstream Face = ± 65%
Main Contributions-
Blocks C; E; G; I & O
0.6 L / sec
50
40
30
20
10
0
-150 -100 0 25 50 75 100 125 150 175 200 225 250 275 300 350 400 450
Period (days)

With the execution of the diaphragm the seepage was reduced. Currently (years 2019-2020) there are news that the small seepage has increased was observed again

4.5.15 CVC Arch Gravity

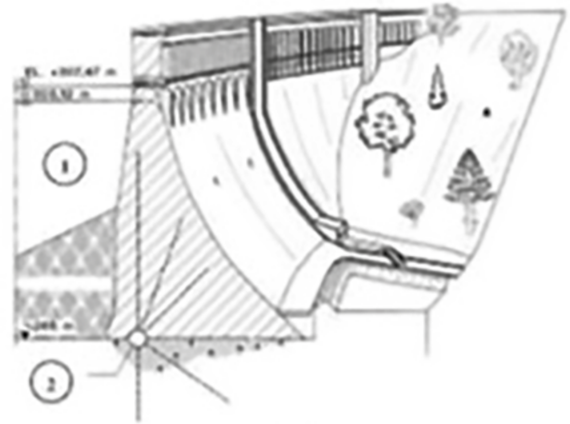
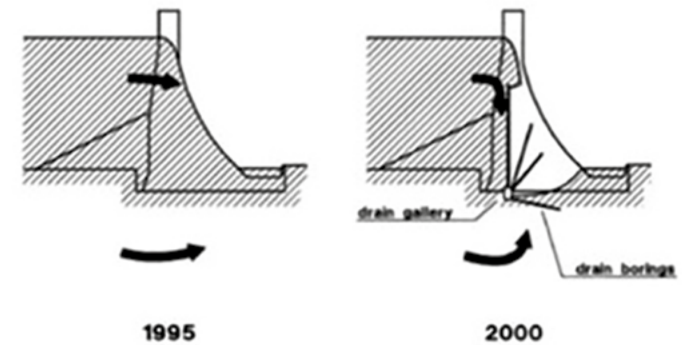
Case	Identification	Country	Finished	Damage	Actions	References
4.5.15-A	Ennepe	Germany	1907	1912	Drainage	[04-45] & [04-46]

Between 1909 and 1912 the dam was raised by adding a 10 m high masonry block on the crest to increase the storage capacity. Therefore, all remedial measures have had to be done during normal reservoir operation.

The Ennepe Dam must be adapted to the established technical standards and safety regulations. ***The construction of a drainage – and inspection gallery with a Tunnel Boring Machine has been the most spectacular part of the rehabilitation work so far and has been successfully finished in August 1998.***

This was considered as a difficult task for a TBM due to the curved axis of the gallery and a distance of only 3.5 m to the upstream face of the dam. In October 1997 the TBM began the driving of the access tunnel. From the tunnel, fans of drainage holes were bored within a test section.





drain gallery
drain borings
1995
2000



Case	Identification	Country	Finished	Damage	Actions	References
4.5.15-B	Lost Creek	USA	1977	1993	Membrane	[04-33] & [04-47]

The Lost Creek Dam is an arch gravity dam whose reservoir cannot be emptied. The permeability of the concrete, and the consequent deterioration as a result of alternate freezing and thawing, resulted in progressive loss of concrete and decreasing strength of concrete at the downstream face. The stability of the dam was not an issue.

The installation underwater of an upstream PVC membrane system was the preferred option. To install internal profiles underwater, divers worked from swing platforms that were controlled from a materials barge. They used grid lines as guides to ensure the internal profiles were installed in a perfect vertical line. Gasket material was placed on the installed vertical profiles to provide a watertight seal at the membrane joints.

4.5.16 CVC Double Arch

Case	Identification	Country	Finished	Damage	Actions	References
4.5.16-A	Kolnbrein	Austria	1979	1989	Massive block downstream	[04-48]

The dam foundation rock consists of gneiss formations, layered at the left abutment, schistose on the left flank of the valley and massive elsewhere. Each rock type has a different bulk modulus. During construction the quality of the rock abutment had been improved by injecting 480 t of cement from 20 000 m of bored holes.

On first filling in 1978, when the reservoir level reached 1890 m, 42 m below the normal full storage level, the seepage into the drains just above the base of the dam increased suddenly. ***The cause was considered to be a new set of inclined cracks in the foundation rock***

running from elevation 1750 m downstream between the control gallery and base of the dam. The cracks were assumed to be a consequence of high shear stresses in the base of the slender dam.

Ad hoc measures were carried out to reduce the high pressure and the seepage:

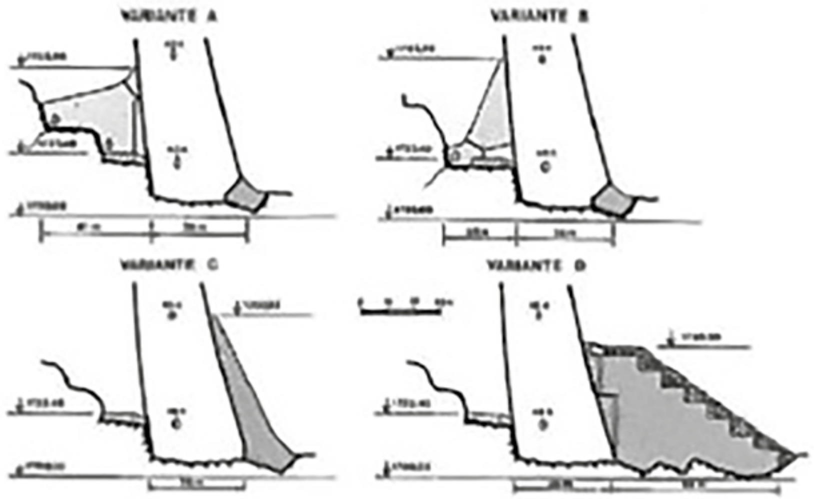
⇒ grouting with epoxy resin;

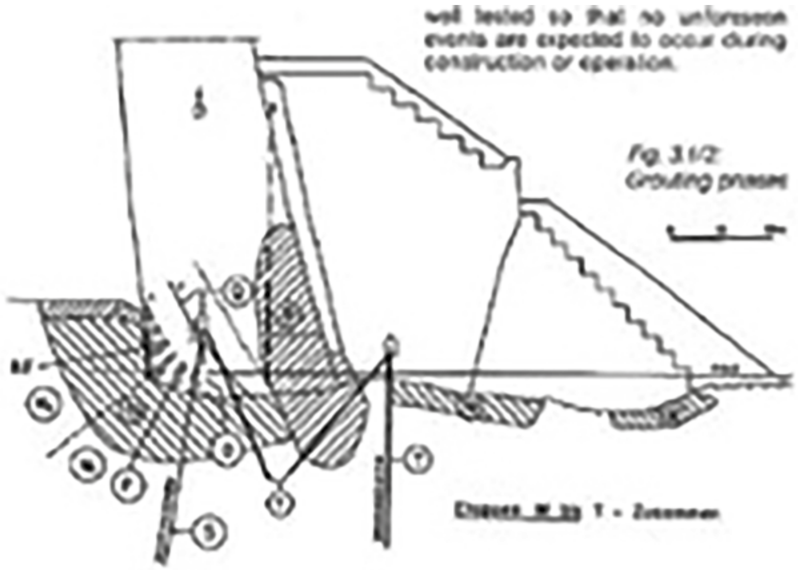
⇒ a freezing zone had been installed as a temporary measure in the cracked zone at the base of the dam;

⇒ a concrete apron had been installed on the valley floor upstream of the dam in order to cover the crack zone in the abutment. Although the desired reduction of uplift and seepage had been achieved, no satisfactory improvement of the dam behavior had been gained. A concept for the rehabilitation was developed comprising the following measures:

- As the high shear stresses in dam and abutment were considered responsible for the development of cracks, the lower parts of the dam were to be horizontally supported by a massive concrete block;
- Grouting with cement and with epoxy resin was planned to stabilize the cracked zones and to provide a watertight abutment;
- Grouting measures were necessary to improve the abutment below the upstream toe, especially for the empty reservoir condition.

The rehabilitation work began in 1989 and was finished successfully in 1994. The adopted solution was to install a 70 m high supporting block of concrete downstream of the dam. Its function is to support the lower third of the dam, but only when the water in the reservoir exceeds a certain level. It was therefore necessary to bring the two elements together only after a certain water load had been applied. The problem was solved by installing reinforced neoprene cushions at nine levels at concrete consoles. Each cushion was connected to a double steel wedge construction that could be calibrated in height from adits below and above their horizon.


VARIANTE A
VARIANTE B
VARIANTE C
VARIANTE D


well tested so that no unforeseen events are expected to occur during construction or operation.
Fig. 3.1/2
Grouting phases

Case	Identification	Country	Finished	Damage	Actions	References
4.5.16-B	Gibson	USA	1929	1982	Piers for overtopping	[04-49]

The Gibson Dam is a concrete arch dam on the Sun River, that was built by the U.S. Bureau of Reclamation (USBR) between 1926 and 1929.

BuRec decided to rehabilitate the dam to meet a new PMF. ***In a new approach, piers were constructed on the crest of the dam. In the event of overtopping, the piers would divide the flow and provide aeration beneath it***. The piers extend to the height of the PMF (3.7 m) and are placed at intervals of 30.5 m.

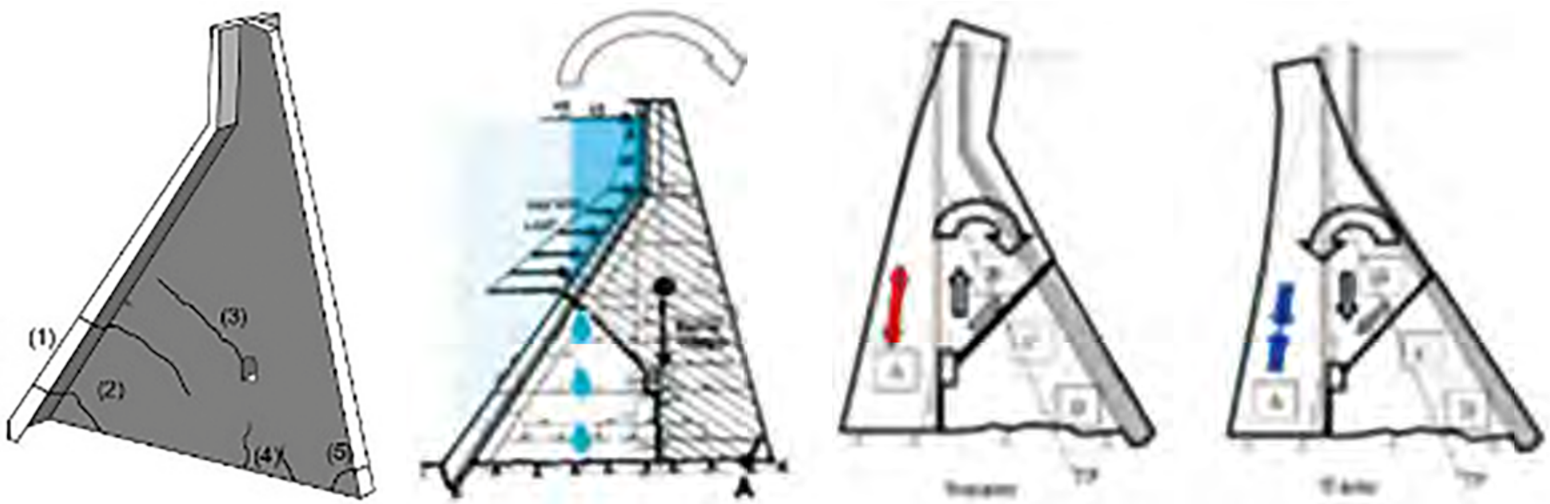
The upstream pier edges are project into the roadway, and the downstream edges are flushed with the parapet walls. To prevent plucking erosion, rock bolts and concrete caps were installed on downstream rock abutments.

4.5.17 CVC Buttress and Hollow Gravity Dams

Case	Identification	Country	Finished	Damage	Actions	References
4.5.17-A	Storfinnforsen	Sweden	1954	1992	Insulation and Post-tensioning	[04-50] & [04-51]

A few years after completion, ***horizontal cracks were found in the lower parts of the front-plates and freeze-thaw damage was detected on the upstream side of the front-plates***. This resulted in a structural rehabilitation program where cracks were grouted and an insulating wall was installed to reduce the thermal gradient over the thickness of the front-plate. The program consisted of moving the insulating walls, improving the stability with ground anchorage tendons, strengthening the front-plates and, in addition, to widen the road on the dam crest to allow for heavy traffic.

Post-tensioned anchors were the practical and cost-effective method of strengthening the dam. They were used to stabilize the concrete and to combat the effects of alkaline and aggregate reaction. The post-tensioning technique requires minimum demolition, has only a minor impact on the dam, and was relatively inexpensive using a small number of anchors.


(1)
(2)
(3)
(4)
(5)

Case	Identification	Country	Finished	Damage	Actions	References
4.5.17-B	Olef	Germany	1955	1992	Prestressed bars	[04-52]

This Dam is an example ***where it was found necessary to strengthen the dam because of the combined influences of creep, shrinkage, and thermal cycling***. During construction shrinkage cracks appeared in the buttresses. Additional reinforced concrete support was provided on the inner side of each buttress. A concrete thermal protection wall was installed at the downstream face of the dam between the buttresses in order to reduce the magnitude of the temperature variations associated with climate and season.

After 10 years of operation of the reservoir, hair cracks were discovered in the upstream face of the dam. Measurement confirmed that the cracks were nearly closed in winter and up to 0,5 mm wide in summer. The cracks were concentrated in the area of the face subject to fluctuating water level. On average the cracks were 200 mm to 250 mm deep, but one was measured to be 800 mm deep. Prestressed anchors were used to compress the cantilevers to eliminate the tensile stresses.

Fig. 3.3.4

Olef Dam. Typical crack pattern in the buttresses

1. Air circulation holes
2. Access hole

Fig. 3.3.7

Olef Dam. Rehabilitation of the upper part

1. Load distribution
2. Reinforced concrete shell
3. Thermal insulation wall
4. Supporting concrete
5. Prestressing force
6. Mass concrete

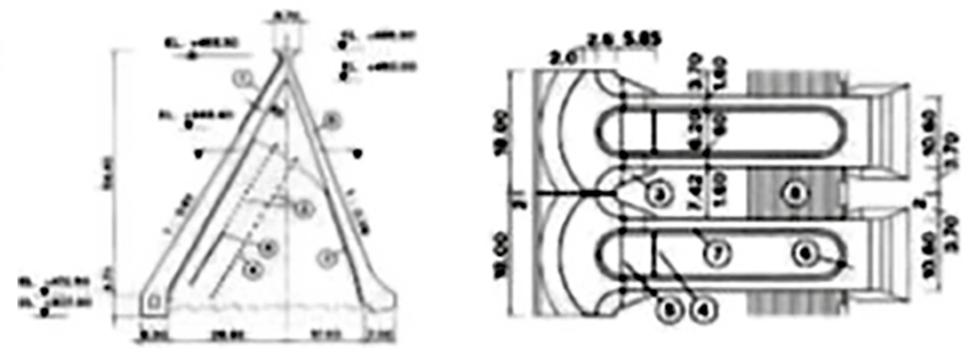


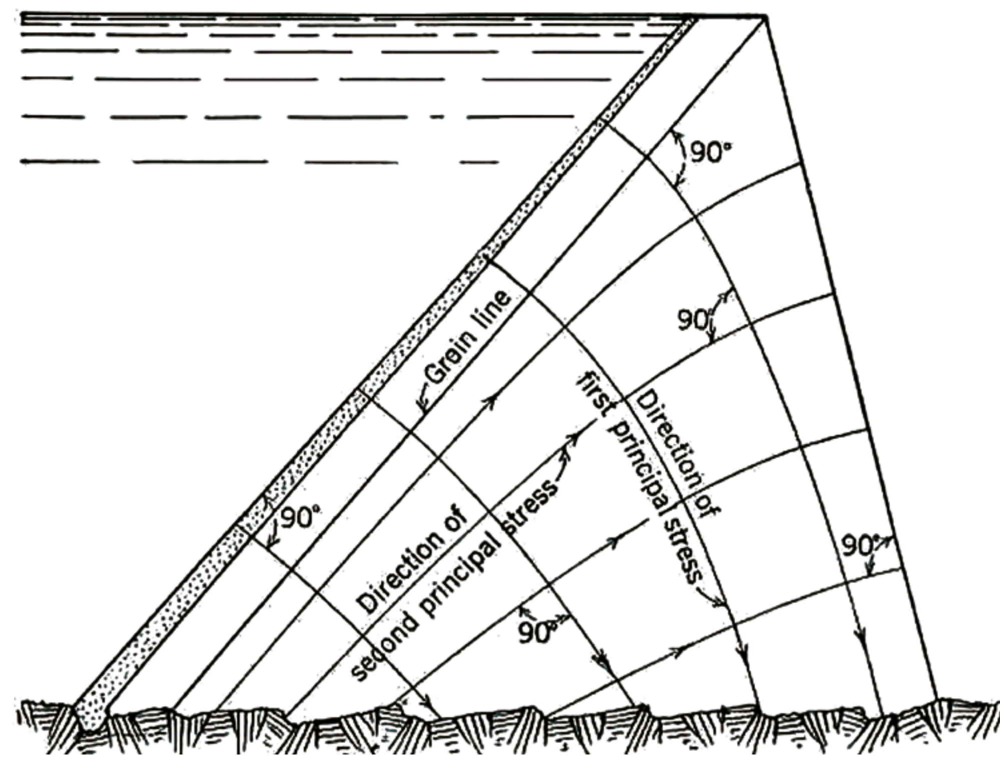
Fig. 3.3.8

Olef Dam. Rehabilitation of the lower part

1. Reinforced concrete shell
2. Precast concrete beams
3. Supporting concrete
4. Strut
5. Tension element
6. Mass concrete
7. Reinforced concrete strengthening
8. Thermal insulation wall

Case	Identification	Country	Finished	Damage	Actions	References
4.5.17-C	Lake Hodge	USA	1918	1992	Repair	[04-24] & [04-53]

Lake Hodges Dam and Reservoir is located in Southern California. Lake Hodges Dam was designed as an inclined multiple-arch, which became vertical in the top 4,5 m.



The buttress supports developed cracks parallel to the minimum stress trajectories. ***A professional debate erupted as to the cause of these cracks, being induced tension, or caused by shrinkage of the concrete. This cracking problem was not explained until after instrumentation and study of similar cracks in Rodriguez Dam in 1929, by Fred Noetzli, Hubert Woods, and Roy Carlson.***

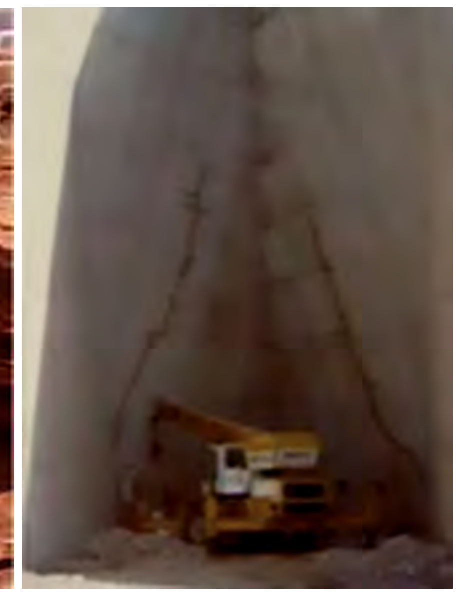
Case	Identification	Country	Finished	Damage	Actions	References
4.5.17-D	Itaipu	Brazil	1983	1980	Epoxy Grouting	[04-54] & [04-55]

During the construction of the Right Lateral Dam, some blocks, which were under the cableway cranes, were poured slowly, and at the other side of the cranes, were poured in a faster sequence (5 or 6 layers per month). The blocks that were poured in a faster sequence exhibited some cracking. Some professionals discussed thermal cracks when first analyzing this dam. However, an additional analysis using a finite element system and based on some laboratory tests on geometrical models indicated the occurrence of a large shear tension in the same zone as the real structure. In addition to these analyses, the strain meter spider installed displayed compressive stresses, not tensile stresses.

Virtually all cracks were verticals or sub-verticals and began at the foundation. If the cracks were characterized from micro-cracks of small depth and extension, they were even between 10 and 20 m in length. The opening media of these cracks were around of 0,3 and 0,9 mm, and some cross the entire buttress, but none achieved the complete separation of the foothills and the head of the blocks. The cracks were injected with resins and special equipment.






4.5.18 CVC Multiple Arches

Case	Identification	Country	Finished	Damage	Actions	References
4.5.18-A	Waddell	USA	1926	1993	Demolition	[04-56]

The Waddell Dam is a concrete multiple arch dam that was constructed during 1924 through 1926. It's function has been replaced by New Waddell Dam, a 104 m high rockfill embankment dam, which is located about 0.8 km downstream of Waddell Dam, and which inundated the old dam.

It was required that Waddell Dam be breached to ensure access to the full reservoir pool at New Waddell Dam and to provide access for boat traffic to a marina located between the two dams. It was decided to create a channel through the existing dam that would be large enough to pass flood flows with minimum restriction and would also be large enough and deep enough to allow for boat traffic at minimum reservoir level. The required breach through the dam was 68 m wide and 21 m deep.

Case	Identification	Country	Finished	Damage	Actions	References
4.5.18-B	Daniel Johnson	Canada	1970	~1970	Geomembrane & Epoxy Resin	[04-57]

The Daniel-Johnson dam is located 800 km northeast of Montreal, PQ, and is 1314 m in length and 214 m high. Just after completion of the dam construction, different types of cracks started to appear on the upstream and downstream faces. ***During and after the construction of the dam, numerous cracks and joints were grouted*** in order to reduce water infiltration. In some cases, because of high injection pressures and inaccurate methods, the injections provoked the propagation of the existing cracks or the initiation of new ones. Because of this situation and to determine the contribution of injection to dam safety, in 1985, Hydro-Quebec applied a moratorium on all future injection work on the dam. Research work was initiated in 1986 in the areas of grouting materials, methods, equipment, and behavioral analysis to establish a safe method for the injection of the cracks.

In 1997, as a result of the progress of the structural analysis studies and the injection research project, a decision was made to proceed with the injection of the dam. ***For twenty years, leakage marks have appeared on the downstream buttresses, and also some degradation of the concrete due to freeze-thaw cycles along the vertical joints were observed.*** This situation led to replace the joint sealing for enhancing the watertightness and appearance of the downstream face of the dam. So, a new and more effective solution was required to restore the watertightness and appearance of the joints.

The solution chosen in 2008, was to use a flexible waterproofing sheet geomembrane system to stop infiltration and freeze-thaw action affecting the buttresses. The solution developed to reduce freeze-thaw damage on the downstream buttresses of the dam consists of external waterstop over the vertical joints in the upper part of the downstream face. The waterproofing system used for the dam consists of:

⇒ Waterproofing liner, geocomposite, consisting of a 2.5-mm-thick PVC geomembrane;

⇒ Vertical and horizontal watertight stainless steel perimeter seal anchoring the PVC geocomposite to the concrete face; The flat profiles are anchored to the face of the dam via chemical anchor bolts;

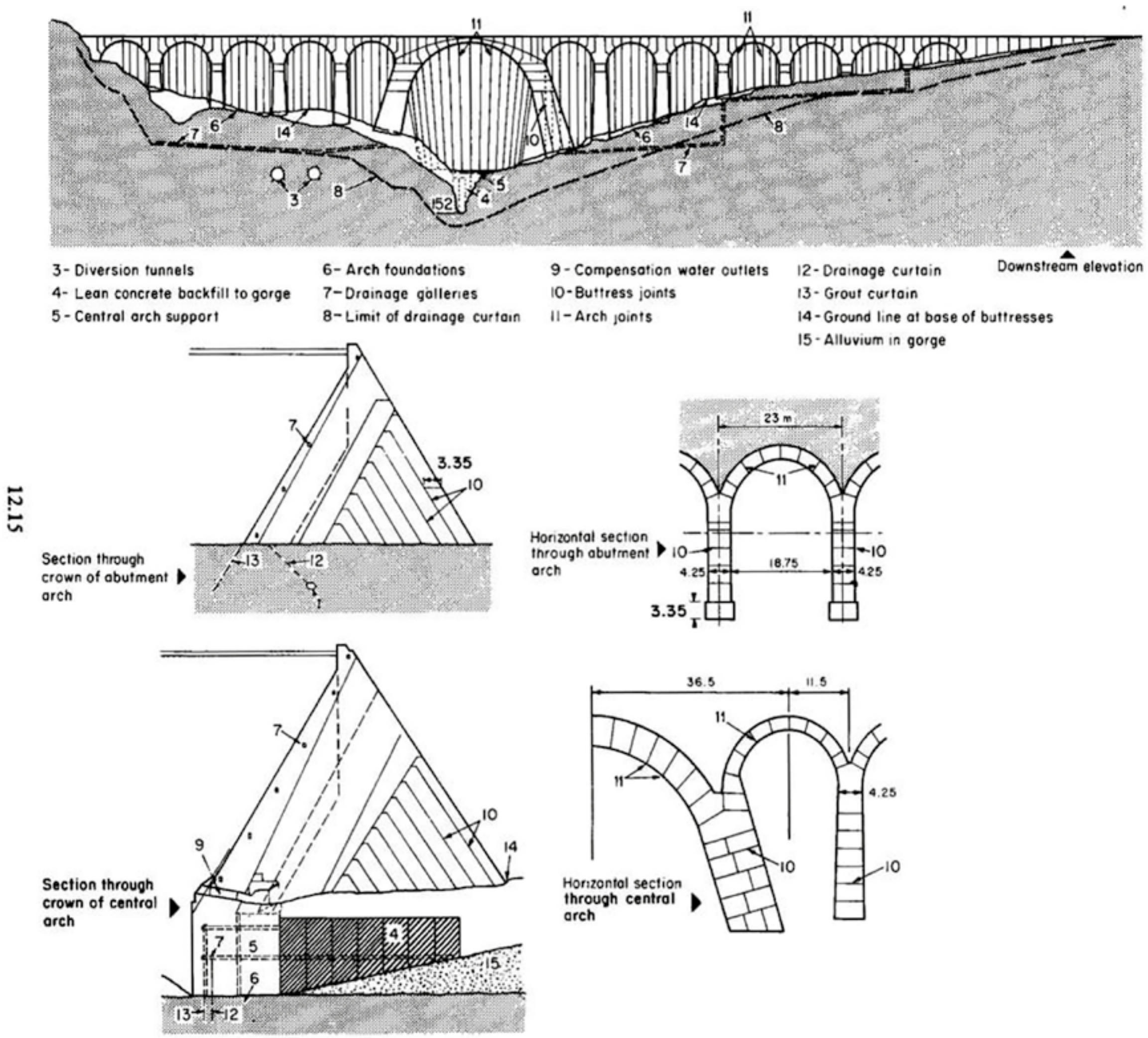
⇒ A rubber gasket was used to ensure even and adequate compression;

⇒ An epoxy resin was applied to the face of the dam along the perimeter seal;

⇒ Horizontal stainless steel flat profile for the top and bottom perimeter seal; The profile was bolted to the concrete of the crest wall with mechanical anchors;

⇒ Two strips of geonet are placed under the geocomposite for ventilation.

All flat profiles, nuts, washers, couplers, anchor bolts and other metal items used in the perimeter anchor seal are made of stainless steel.


3- Diversion tunnels
4- Lean concrete backfill to gorge
5- Central arch support
6- Arch foundations
7- Drainage galleries
8- Limit of drainage curtain
9- Compensation water outlets
10- Buttress joints
11- Arch joints
12- Drainage curtain
13- Grout curtain
14- Ground line at base of buttresses
15- Alluvium in gorge
Downstream elevation
12.15
Section through crown of abutment arch
Horizontal section through abutment arch
23 m
18.75
4.25
3.35
Section through crown of central arch
Horizontal section through central arch
36.5
11.5


© Photo Hydro-Québec

Case	Identification	Country	Finished	Damage	Actions	References
4.5.18-C	Gleno	Italy	1923	1923	Water activated foam	[04-04]

The failure of a power dam at Gleno (Italy) is an emblematic case of disastrous break in a multiple-arch dam. It occurred on 1st December 1923 and there was a consequent flood. The Gleno dam, built immediately after the First World War and completed during the spring of 1923, was a reinforced concrete structure of multiple-arch type, resting on a gravity base of stone masonry. It was 43 m high above the stream and 263 m long on top. According to the original plan, a gravity dam was to be built. Subsequently, the company which held the franchise applied for a change in its franchise to permit the construction of a multiple-arch dam on the ground.

The dam was built on a solid masonry base, filling the lower part of the valley, and consisted of a superimposed concrete multiple-arch structure. The curved part of the superimposed structures mainly extended over the masonry base, whereas the straight flanking portions were founded directly on the rock of the valley. The buttresses of the structure at the junction of the straight and curved portion were made of extra thickness. The multiple-arch superstructure consisted of semi cylindrical arches.

As reported, the cause of the failure was well defined by the engineers who first observed the Gleno structure: the work had been badly executed. The reinforced concrete part of the dam on the sides was placed directly on the rock surface, without being trenched into the rock. The masonry of the gravity base was made of lime mortar, whereas the specifications required cement mortar. The lime was burned near the site by the builders and transported to the dam by cableway. The gravel aggregate used in the concrete was

not washed, and the concrete in the structure was porous. The reinforcement of the buttresses had been used during the war for protecting against hand grenades.

During construction, some of the arches leaked, and part of the frame timber remained embedded in the concrete cast. Hand-mixed concrete was used for the arches, and the usual precaution of vibrating it in the forms was omitted. Summarizing, the following faults in the work were listed:

⇒ Failure to cut footings in the rock for the buttresses of the dam;

⇒ Use of improper materials and lack of inspection;

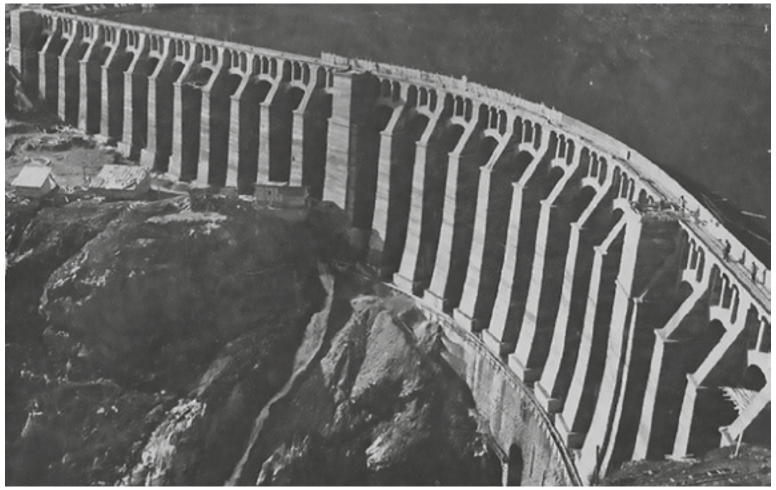
⇒ Poor mixing and lack of inspection of the concrete;

⇒ Use of unwashed aggregate;

⇒ Lack of inspection in pouring the concrete;

⇒ Failure to ram the concrete in the forms;

⇒ Generally incompetent direction and supervision.



Gleno dam immediately before the filling and Gleno dam immediately after the failure

4.6 Hydraulic Circuits

The authors note that in the case cited in this item, it is interesting to observe the others shown in **Chapter 7** of this text.

4.6.1 Diversion Circuits

Case	Identification	Country	Finished	Damage	Actions	References
4.6.1-A	Campos Novos	Brazil	2005	2006	Drop down reservoir and Repair	[04-58]

In October of 2005, construction of the Campos Novos CFR-dam was completed. The diversion tunnel failed in June/2006, causing an uncontrolled release of the water from the huge upstream reservoir. The flow of water through the tunnels pushed back the plans to plug the tunnels and complete the construction of the dam. Construction began in August of 2001. The river was deviated through the two diversion tunnels in October of 2003. Two tunnels of 860.9 meters and 915.8 meters in length were dug to divert the water from the river around the dam during construction. The tunnels were roughly square in shape 16 meters high and about 4 meters wide. The leakage in the longer of the two tunnels began on October, ten days after the construction of the dam was completed. Water flowed into the tunnel at the rate of 50 m^3/s until a plug was installed that limited it to 1 m^3/s.

On June 20, the pressure of the ***water damaged two of three steel gates installed in the tunnel and allowed the water in the reservoir to flow through the diversion tunnel. The entire reservoir***, which was near its 1.3 billion cubic meter capacity at the time of the incident, flowed through the tunnel within the span of days.

After the failure of the gates and pier structures, the most critical evidence associated with the initial damage at TD-02 was destroyed. However, substantial evidence still exists in the remaining structure of TD-02. More importantly, the critical structural members (i.e., the second stage concrete members) in TD-01, which corresponds to the initial damage area in TD-02, manifests consistent crack patterns. ***They indicate incipient structural failure and provide the most significant and reliable evidence for the investigation.***

Conclusions*: **The primary causes of the failure are defective design of reinforcing steel in the second stage concrete***, including:

⇒ There is no steel continuity across the joint above the second stage concrete. Although the first stage concrete is adequately reinforced, none of them extends into the second stage concrete;

⇒ The reinforcement across the joint is located far away from the concrete surface and; therefor provides little constraint on the crack initiation and propagation in the second stage concrete or the joint. The problem is further aggravated by the poor joint between the first and second stage concrete.

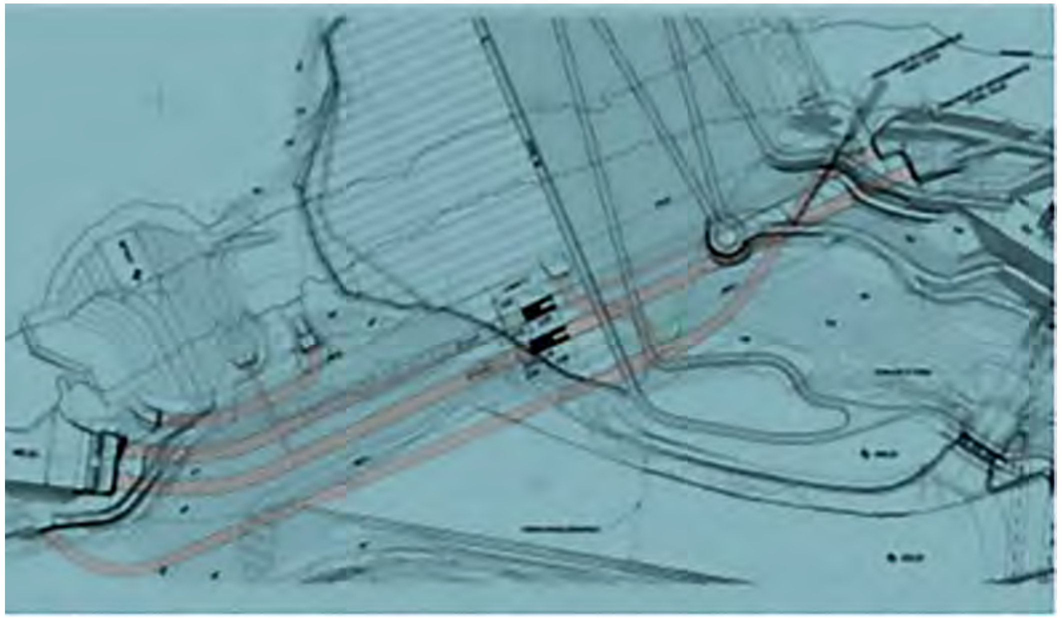
⇒ The amount of the reinforcing steel across the joint is grossly inadequate to resist the hydrostatic load in the joint;

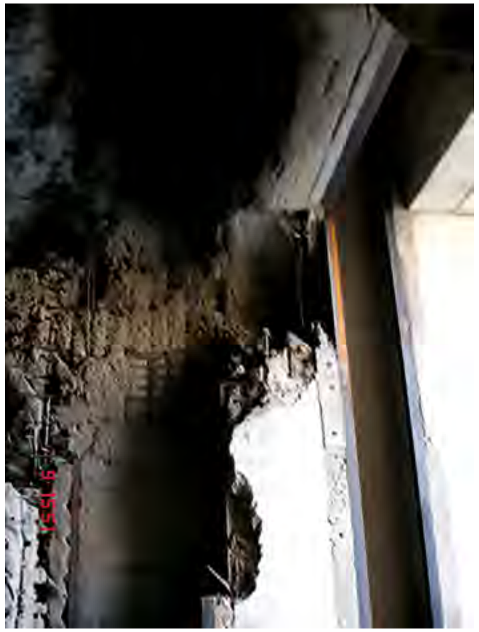
⇒ The reinforcement in the second stage concrete is inadequate to prevent shear failure. More importantly there is discontinuity (gap) of the reinforcement which allowed the crack propagation through a weak failure surface in the concrete without effective restraint of reinforcing steel;

⇒ The precast concrete panels are not adequately anchored to the first stage concrete.

The fundamental reason for these design defects lies in the designer's assumption that the concrete structure is watertight and behaves as a monolithic structure. The hydrostatic pressure at cracks and joints is a realistic and active force that must be included in structural analysis. This fact is confirmed by extracted cores that showed the presence of water flow in the joint.

The concrete defects in the first stage concrete, second stage concrete, and the construction joints had significant contributions to the failure and final collapse of the TD-02. The evidence shows that the construction joints in the edge members were poorly constructed and numerous voids and honeycombs existed in the concrete. The concrete defects facilitated penetration of water into the concrete and probably contributed to a significant size of damage.





4.6.2 Bottom Outlets

Case	Identification	Country	Finished	Damage	Actions	References
4.6.2-A	Glen Canyon	USA	1964	1980/1983	Aeration slot	[04-59]

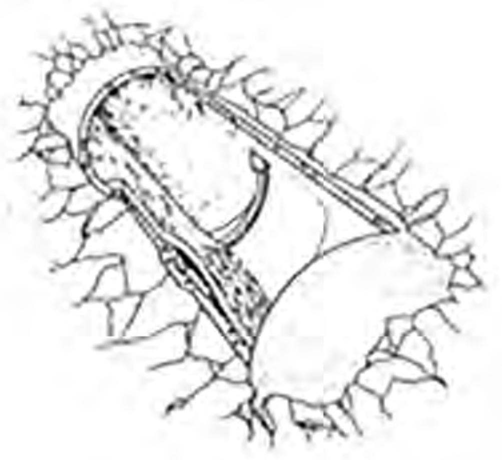
After several days, noticeable vibrations were felt in the dam wall and surrounding rock. Water exiting the spillways contained noticeable debris, including sandstone, signaling severe erosion taking place within the tunnels.

Bureau of Reclamation (BuRec) responded by reducing releases by half, however, the rumblings continued. The engineers soon closed the spillways for inspection crews who were lowered down the spillway tunnels and ***found that cavitation had severely damaged and eroded***

the 0.91 m-thick concrete tunnel lining. In some locations the cavitation had exposed the soft sandstone.

The tunnels could not be kept closed as more rain fell in the Colorado River Basin and the reservoir continued to rise. After analyzing the spillway flow, BuRec staff members decided to construct an aeration slot in each tunnel. ***The aerators were located in the conical reducing section of the tunnel about one-half of the way down the tunnel between the intake and the vertical bend.***

Repair work began with the removal of the entire tunnel lining, including sections that were not damaged, to improve safety, speed construction, and produce satisfactory, long-lasting results. Damaged and missing reinforcement was replaced. New reinforcement was manually welded to existing reinforcement in most cases. In areas where drainage water prevented welding, steel dowels were epoxied into drill holes in the liner and then wired to the existing reinforcing in a splicing technique.



4.6.3 Spillway – Discharge Conduits – Bridges

Case	Identification	Country	Finished	Damage	Actions	References
4.6.3-A	Ute	USA	1963	1984	Provide labyrinth spillway	[04-60]

The original structure consisted of a main embankment dam, an ungated ogee-type concrete spillway located to the left of the main dam; and an embankment dike located to the left of the spillway. ***The dam did not provide sufficient storage capacity to permit use of its full storage allotment.***

Ute Dam was well suited for an approach flow from the dam parallel to the spillway center line; this configuration is required for greatest efficiency of a labyrinth spillway. This cantilever-type free overflow structure can provide reservoir storage capacity of a standard spillway economically without the necessity of manual or mechanical operation.

Case	Identification	Country	Finished	Damage	Actions	References
4.6.3-B	Canton	USA	1948	2002	Addition of Fuse Gates	[04-61] & [04-62]

The dam consists of a rolled earth fill embankment with a gate controlled, concrete gravity chute-type spillway located in the right abutment. The outlet works consist of three sluices through the spillway weir, which are controlled by broome-type gates. ***The Dam Safety Assurance Report, approved in 2002, indicated two serious and interrelated hydrologic deficiencies occurred at the existing Canton Lake***. The deficiencies included inadequate factors of safety against spillway sliding and uncontrolled embankment overtopping by the Probable Maximum Flood.

The recommended plan for resolution of the dam safety deficiencies consisted of anchoring the existing spillway to improve sliding stability, relocating Highway 58A, constructing an auxiliary spillway to increase the discharge capacity required during a probable maximum flood event, and placing the excavated material from the spillway excavation at the toe of the earthen dam to resolve the seismic and seepage deficiencies as an additional benefit.

For a retrofit on an existing spillway, a portion of the ogee crest is removed and provided with a flat surface. ***If the goal of the retrofit is only to increase spillway capacity, the crest of the Fusegates is set near the original ogee crest elevation***. If the purpose is to increase storage, then the crest of the Fusegates is set above the original ogee crest elevation. For discharges up to the design flood, the Fusegate functions like an aerated labyrinth weir.

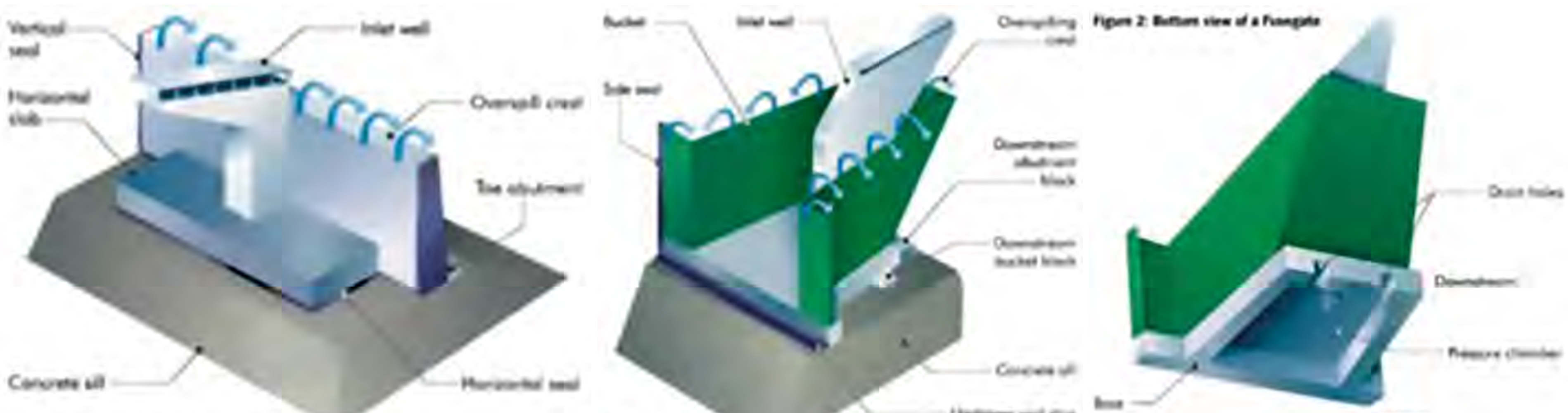


Figure 4: 3-D view of a straight crested Fusegate

Figure 1:
3-D view of a Fusegate

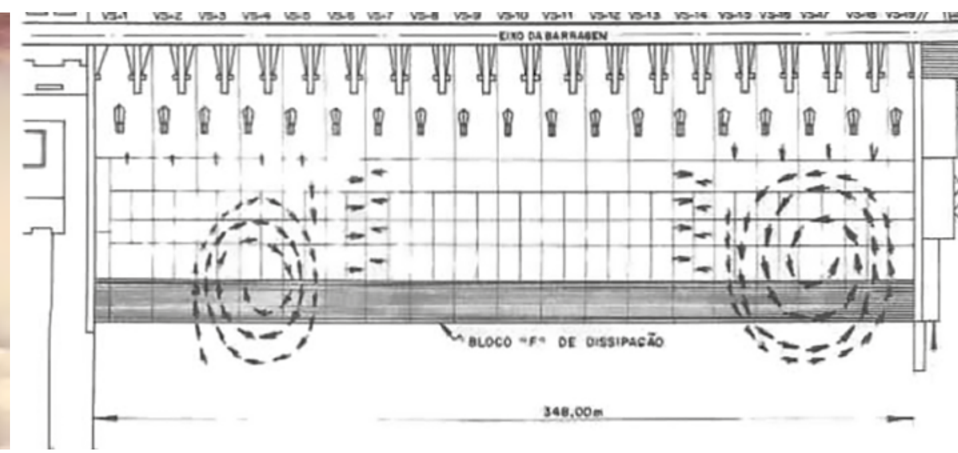
Figure 2: Bottom view of a Fusegate

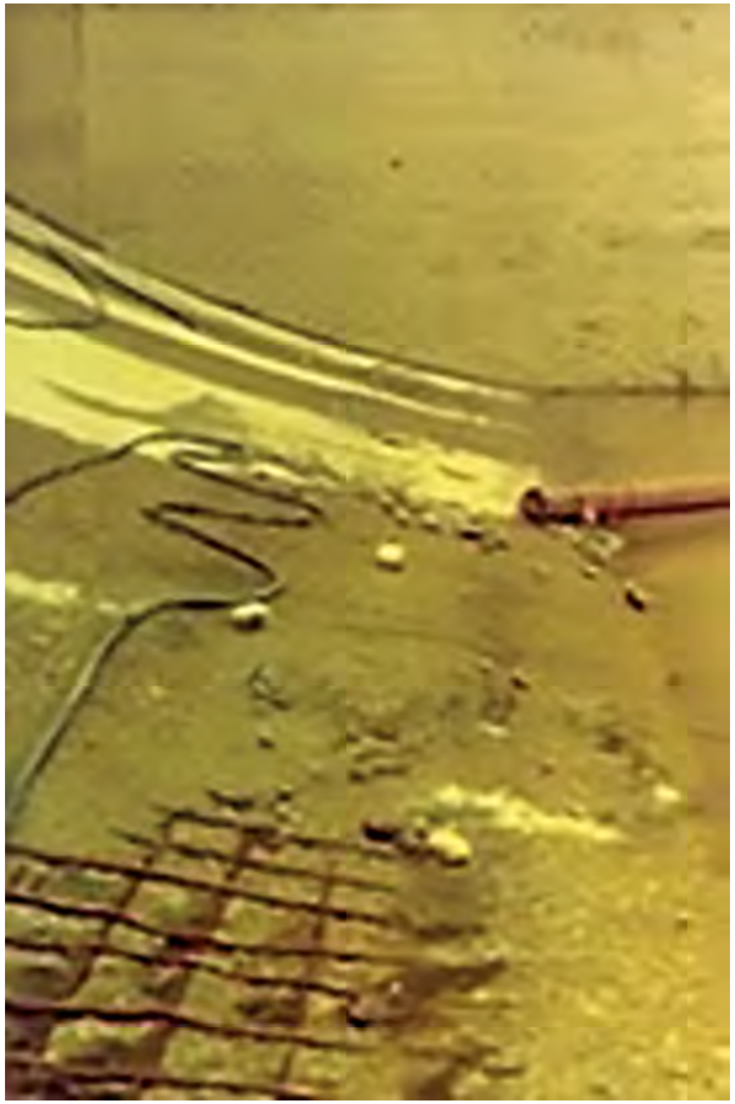
4.6.4 Stilling Basin

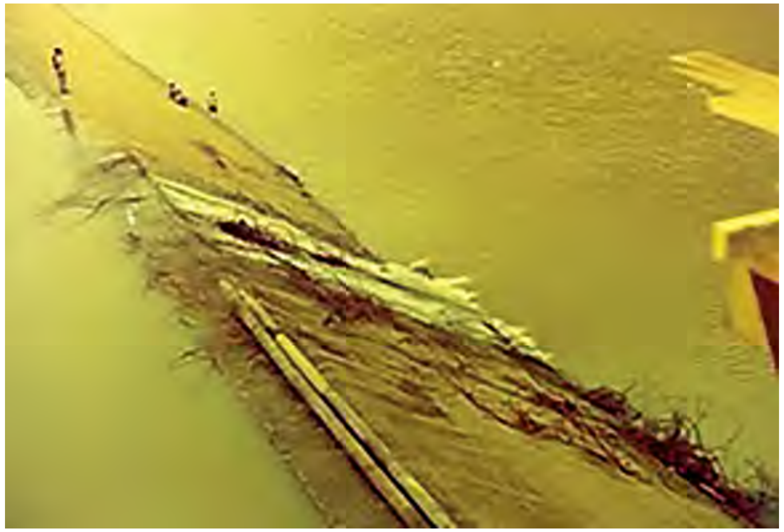
Case	Identification	Country	Finished	Damage	Actions	References
4.6.4-A	Ilha Solteira	Brazil	1974	1974	Repairs	[04-63] & [04-64]

Due to the energy demand, the owner sought to anticipate the power generation, and with these 4 spillway gates (of 19) they were assembled on supports on the pillars allowing the flow of water, from the pre-filling, to pass under them. This caused an asymmetric flow in the spillway basin.

There was abrasion observed in the stilling basin because of the erosive action of the rock blocks carried from downstream into the basin next to the defector teeth erosion due to cavitation. The following measures were taken: underwater concrete in the critical areas of the basin before a partial reducing of the reservoir level; study on hydraulic model; and repair of the eroded area with epoxy mortar and concrete.





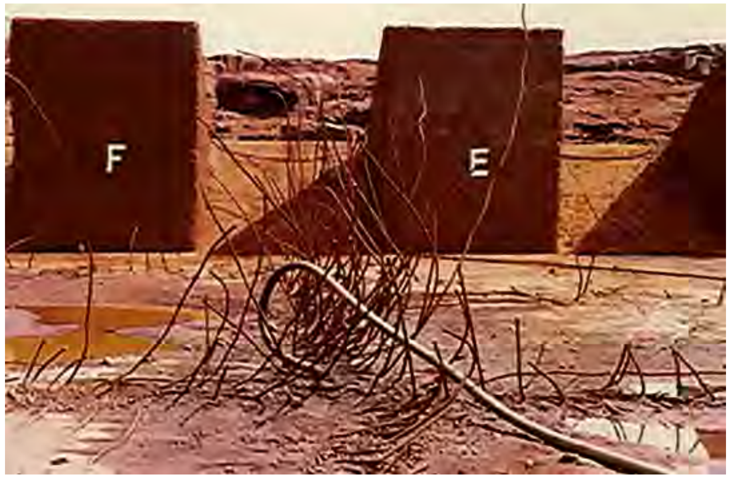

Case	Identification	Country	Finished	Damage	Actions	References
4.6.4-B	Marimbondo	Brazil	1975	1975	Repairs	[04-63] & [04-65]

In May 1975, after the river closure, it was observed an erosion of the spillway chute and dissipation basin. There was a great amount of solid material deposited inside the stilling basin (around 3800 m^3).

The stilling basin was dewatered in 1980, for the recovery of the eroded concrete. The horizontal bottom slab was with widespread erosion observing surface damage, reinforcement, and erosions. Spillway chute presented with gradual abrasion with no major wear compared to those seen in 1975 and 1978.

The rock downstream of the dissipation basin was irregular due to erosion of the current return flows and the effect of the rock cracks. In 1980 and 1982 the stilling basin was dewatered for concrete repairs.



Case	Identification	Country	Finished	Damage	Actions	References
4.6.4-C	Porto Colombia	Brazil	1974	1983	Repairs	[04-63]

Erosion on surface of the blocks and slab of the spillway with the reinforcement exposed. The repair was performed with concrete and epoxy mortar.

4.6.5 Channels

Case	Identification	Country	Finished	Damage	Actions	References
4.6.5-A	Juba I	Brazil	1996	2005	Repairs	Andriolo´s Private Report

The Jubas Hydroelectric Complex, in Mato Grosso-Brazil, has intakes and power plants that are supplied by channels. In an inspection carried out in 2005, it was seen the need to repair the Channel that feeds the Juba I HPP, ***due to leaks and deteriorations***.


Google Earth




4.6.6 Water Intakes

Case	Identification	Country	Finished	Damage	Actions	References
4.6.6-A	Zipingpu	China	2006	2008	Repairs	[04-66]

Several dams and power plants damaged by the earthquake which occurred in China's Sichuan province on 12 May 2008.

In the afternoon of May 12, 2008, ***a magnitude 8 earthquake occurred*** in China's Sichuan province with the epicenter at a distance of 17 km from the Zipingpu CFRD. The earthquake ruptured a 240 km long segment of the Longmenshan fault system separating the Tibetan Plateau from the Chengdu Basin and is referred to as the Wenchuan earthquake. In the case of Zipingpu Dam the water intake tower was damaged as shown bellow.

Damage of reinforced concrete building on top of the intake towers of the Zipingpu reservoir, after the May 12, 2008, Wenchuan earthquake[04-66]

4.6.7 Powerhouses – Pump Houses

Case	Identification	Country	Finished	Damage	Actions	References
4.6.7-A	Shapai	China	2002	2008	Repair	[04-66]

The Shapai Dam powerhouse located several kilometers downstream was severely damaged by high velocity rock falls and the movement joint of the penstock failed, causing flooding of the powerhouse. In the case of Shapai Dam the powerhouse was damaged as bellow.

Damages in Shapai Powerhouse after the May 12, 2008 Wenchuan earthquake[04-66]

4.7 Other Damages

In this item, other cases of failures that deserve to be remembered to have defensive actions are presented.

Case	Identification	Country	Finished	Damage	Actions	References
4.7-A	Zeiuzier	Switzerland	1957	1979	Repairs	[04-67] & [04-68]

At the end of 1978, after more than 20 years of trouble-free operation, abnormal deformations were detected during the regular inspection of the dam. Although the deficiencies originated in the rock mass of the foundation, they affected the dam body itself. They increased for two years, until May 1980, and then tended to slow down. Finally, they almost stopped. In comparison to the geodetic measurements made in 1976, a settlement of 100 mm and an upstream displacement of 90 mm were observed at crest level, as well as a 60 mm shortening of the distance between the abutments of the crest arch.

Owing to these deformations, some of the vertical contraction joints in the upper part of the upstream face opened and cracks developed along the downstream toe. The major cracks are located mainly in the lower third of the dam and along the foundation. Other cracks also appeared in the inspection galleries and shafts.

A program was established for examination of the condition of the dam and its foundations and for evaluation of methods suitable for repairing the damage to it. Three zones were defined: grout curtain, abutment, and dam body.

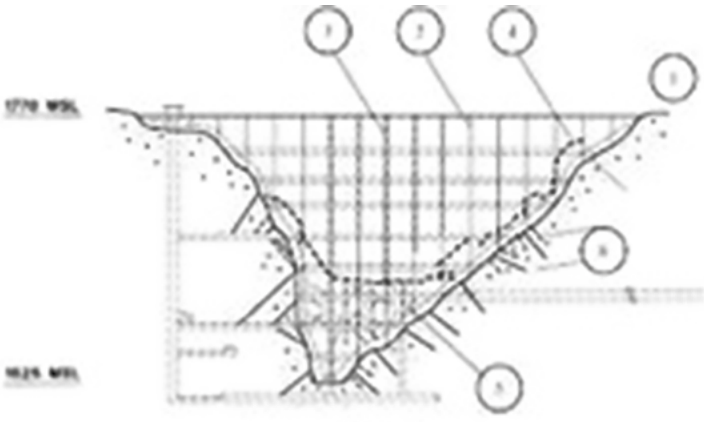


Fig. 3.2.2

Zeuzier Dam. Longitudinal section

1. Left abutment
2. Vertical joints
3. Opening of the construction joints
4. Cracks on downstream face
5. Test and injection drill holes
6. Check holes

Case	Identification	Country	Finished	Damage	Actions	References
4.7-B	El Atazar	Spain	1972	1979/1983	Groutings	[04-69]

El Atazar Dam is an example of underwater treatment of a large crack developed on the upstream face, at great depth. Important repair works of that crack were first carried out by caulking the crack at the face and then grouting resin from the neighboring galleries. Monitoring of the dam revealed abnormal movement. Although dams normally move, the left side of the dam was moving more than the right because a support built on the dam's right made that side less flexible. In 1977, a crack was noticed in the dam. The crack was repaired.

Inspection in 1983 revealed that the ***settling in the foundations and the movements of the dam had caused fracturing in the rock, resulting in significantly increasing the foundation's permeability***. The crack has been treated and since then the problems have abated. The increase of leakage and the inspections made, pointed out to the need for a new treatment. These were made by divers and included the detection and sealing of the suction points at the upstream face. Grouting was also carried out with a highly fluid resin.

Case	Identification	Country	Finished	Damage	Actions	References
4.7-C	Venda Nova	Portugal	1951	1984	Improving the Foundation	[04-70]

A monitoring system installed in the dam showed the seepage remaining and the uplift pressure increasing. ***This was due to the opening of faults and sub-horizontal joints at the left bank and valley bottom***. It was accompanied by washing out and the dissolution of filling materials. Repair work was carried out to improve the hydraulic behavior of the foundation. This aimed at improving the strength and watertightness at the lower zone of the foundation rock mass.

Case	Identification	Country	Finished	Damage	Actions	References
4.7-D	Lister	Germany	1911	1965	Adoption of a Gallery	[04-71]

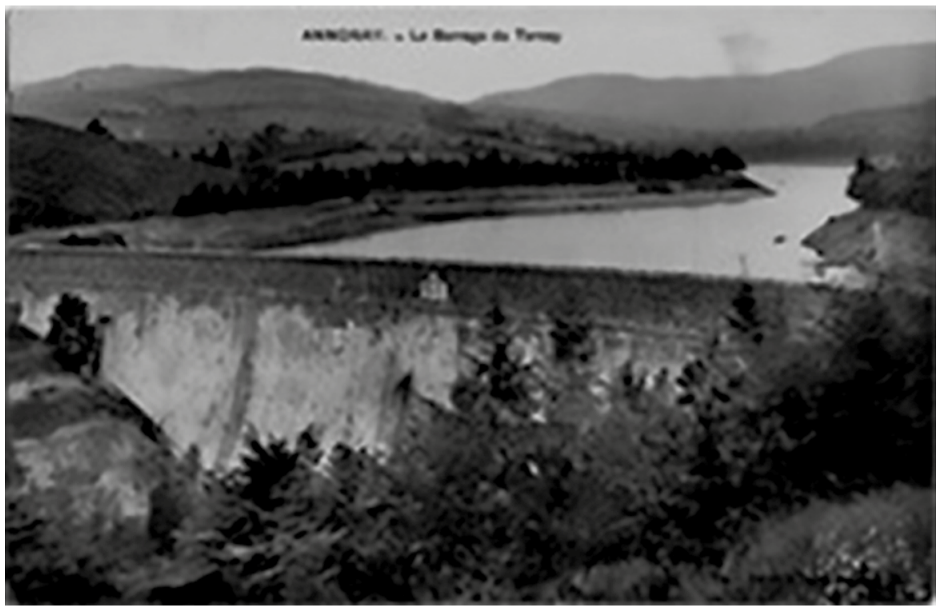
To ***improve the stability of the dam, a drainage gallery was excavated at the bottom of the dam, to reduce the uplift pressure.*** After some years it was observed that joint filling material was transported to the gallery, increasing the permeability of the rock below the dam. Additional calculations proved the dam to be stable with the gallery flooded from the downstream side and the gallery was allowed to fill up, preventing further erosion.

Case	Identification	Country	Finished	Damage	Actions	References
4.7-E	Schelegeis	Austria	1973	1983	Adding a cut off wall	[04-71]

The volume of seepage water emerging in the inspection gallery at the dam base increased markedly during the final stage of reservoir filling. Ninety percent of the seepage was concentrated over a 150 m length of the foundation. Investigations showed that the grout curtain, situated between the upstream toe and the inspection gallery, was cracked due to tension. Cracked grout curtain repaired with a new 5 m deep cutoff wall.

Case	Identification	Country	Finished	Damage	Actions	References
4.7-F	Ternay	France	1867	1990	Adding a rockfill	[04-71]

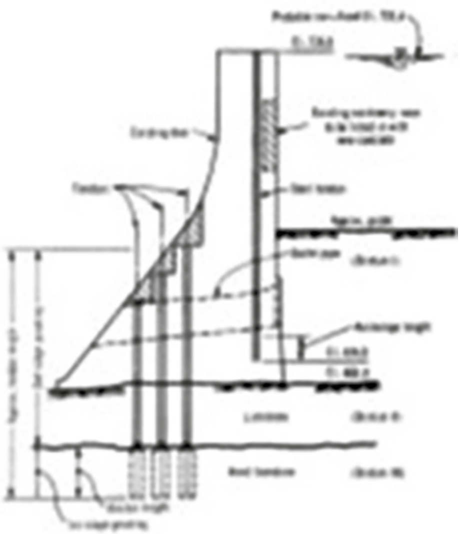
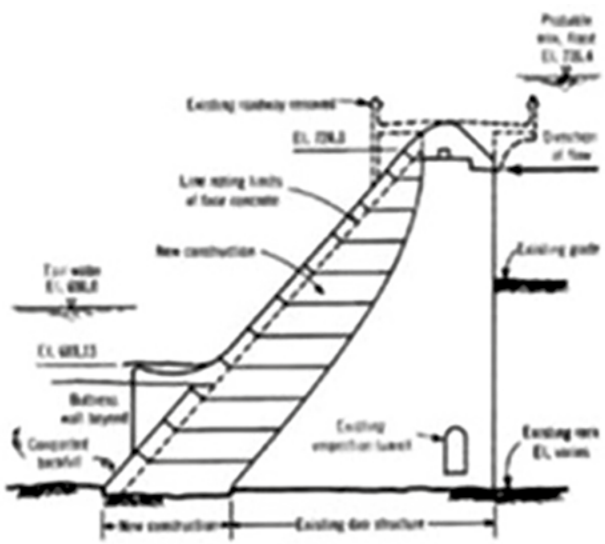
Stability problems and cracks were repaired by strengthening and by shape correction. An earth and rockfill embankment was placed downstream.



Case	Identification	Country	Finished	Damage	Actions	References
4.7-G	Olmos	USA	1975	1979	Prestressed Anchors	[04-71]

A major dam rehabilitation program had to be implemented in order to prevent damage during maximum overflow.

The alternative selected was to strengthen the two non-overflow sections with prestressed anchors installed in 2 – to 3-m thick, hard limestone 15 m below the base of the dam and to increase the stability of the spillway with mass concrete. For construction of the 39-m-long ogee spillway crest, the topmost portion of the dam had to be removed.


Case	Identification	Country	Finished	Damage	Actions	References
4.7-H	Arlanzon	Spain	1933	1996	Grouting and sealants	[04-72]

Arlanzon concrete dam was constructed without contraction joints. Fifteen large vertical cracks developed, from the upstream to the downstream faces, causing leakage that damaged the dam, particularly at the downstream face, owing to frost.

The rehabilitation works included the treatment of the cracks, by grouting with an epoxy resin, as well as the treatment of the dam faces and the consolidation and drainage of the dam body.

Repairs on the Arlanzon dam upstream face (courtesy from Group Teimper)

Case	Identification	Country	Finished	Damage	Actions	References
4.7-I	Urft	Germany	1904	1989	Addition of a Gallety	[04-73]

The dam was founded on sandstones, siltstones, and slate. No gallery was provided in the original design. In the eighties, lime encrustation from the mortar was observed on the downstream face of the dam, and this prompted an investigation of its behavior.

Further work was needed for the dam to meet current German standards. For this, two control galleries were excavated.

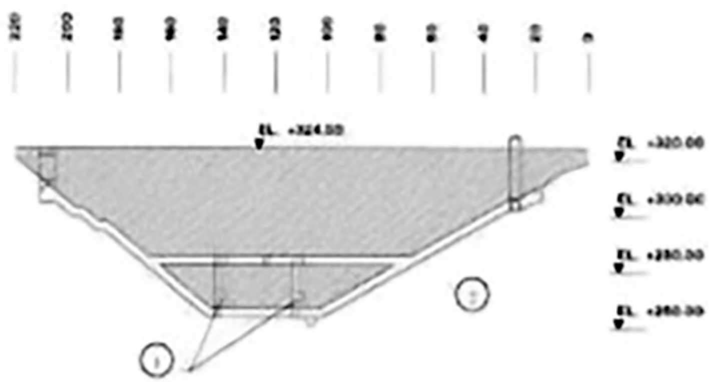


Fig. 3.4.6

Urft Dam. Longitudinal section

1. Bottom outlets
2. Right abutment

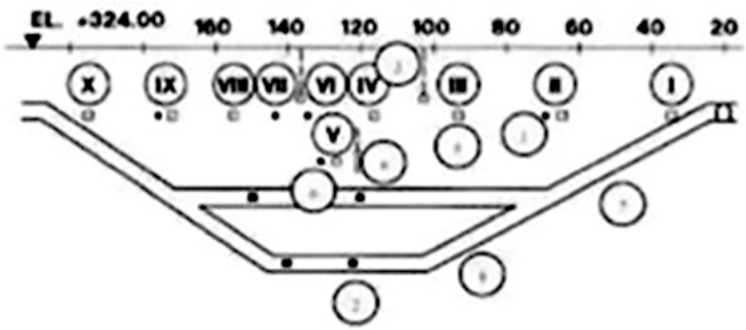


Fig. 3.4.7

Urft Dam. Instrumentation

1. Extensometer
2. Flat jack
3. Pendulum
4. Inverted pendulum
5. Piezometer
6. Thermometer
7. Upper gallery
8. Lower gallery

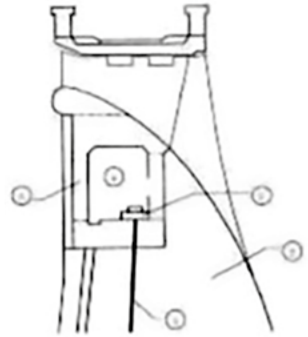


Fig. 3.4.4

Eder Dam. Final crest configuration

1. Anchor head
2. Masonry
3. Post tensioned anchor
4. Gallery
5. Concrete

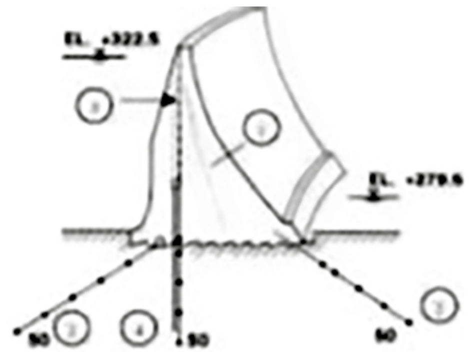


Fig. 3.4.8

Urft Dam. Instruments at cross sections V to VII

1. Drain holes
2. Extensometer
3. Pendulum
4. Inverted pendulum

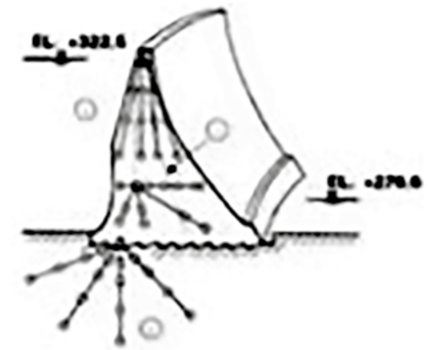


Fig. 3.4.9

Urft Dam. Instruments at cross section IV

1. Drain holes
2. Piezometers
3. Thermometers

Case	Identification	Country	Finished	Damage	Actions	References
4.7-J	Center Hill	USA	1948	2008-2012	Adoption of a cut off	[04-74] & [04-75]

The construction of Center Hill Dam was completed in 1948. The dam is a combination of earth and concrete dam and provide valuable flood damage reduction, hydropower, water supply, recreation, and the water quality benefit the region.

***The main earth dam and saddle dam were built on highly solutioned limestone with open and clay-filled features. During the time of construction, designers had limited understanding of adequate earth dam foundation preparation techniques in karst* geology.** Seepage problems have plagued the project for many years. Indicators of serious seepage through the foundation of the main dam and saddle dam include abnormal piezometer levels, wet areas, and springs.

An approved 2006 Major Rehabilitation study recommended foundation concrete cutoff walls along the entire length of the main and the saddle dam and grouting of the rims. Initial construction work elements began in 2008, preliminary grouting was completed in late 2010 and main dam barrier wall construction began in 2012. During construction, additional information was obtained, and a formal risk assessment completed, which altered the recommendation**.**

Less grouting along the rims and a roller compacted concrete (RCC) reinforcing berm downstream of the saddle dam (in lieu of a barrier wall) is recommended in a Supplement to the original Major Rehabilitation study. Aggregate used for the concrete was taken from an onsite quarry in the Ordovician Cannon Formation, but no limitation was placed on the alkali content of the cement. Until 1947, all concrete used in the structure was non-air entrained.

A detailed engineering inspection in August 1967 found several horizontal lift joints to be leaking excessively. Two of these joints were located near the center of the spillway near crest elevation. The conclusion reached by this investigation was that the cause of the leakage was poor bond resulting from deficient construction. The joints were reinforced with anchors/bars to assure monolithic action of the lifts. In the late summer of 1983, cores were taken from the dam, galleries, adits, powerhouse, spillway piers, and spray walls, and were sent for petrographic examination and testing. The mineralogical composition of most of the rock was calcite with some dolomite and quartz and some clays and feldspars.

Some of the rock types were identified as potentially reactive. The concrete cores contained many aggregate particles with reaction rims left in relief when the more soluble carbonate particles were acid etched. The tests on the concrete cores and petrographic examinations led to the conclusion that some potentially reactive aggregates were used in the concrete. There was no proof that shortening the bridge spans and spillway gates was more than a short-term solution to operational deficiencies and that the structure might not continue to grow.

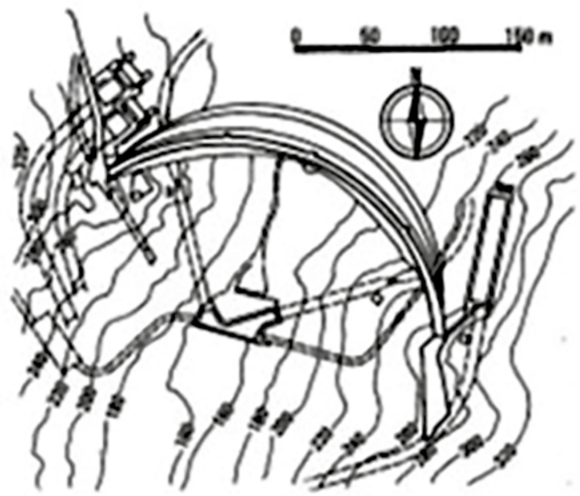
Case	Identification	Country	Finished	Damage	Actions	References
4.7-K	Bluestone	USA	1949	2011	Installation of Anchors	[04-76]

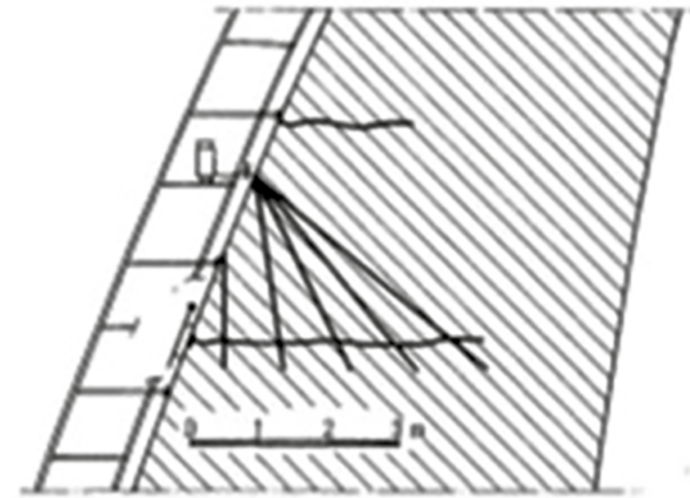
New calculations identified the possibility for dam failure due to the monoliths sliding on the bedrock. As a result, a total of 216 high-strength anchors, comprising high strength multi strands, were installed at critical monoliths to stabilize the dam.




Case	Identification	Country	Finished	Damage	Actions	References
4.7-L	Flumendosa	Italy	1957	1995	Epoxi Resin Grout	[04-77]

In the Flumendosa Dam, ***cracks developed along the construction lift joints***, at the highest elevations of the upstream face. These were grouted with epoxy resin.



Case	Identification	Country	Finished	Damage	Actions	References
4.7-M	Koyna	India	1962	1990	Epoxi Resin Grout	[04-78] to [04-81]

The dam **was designed with a seismic coefficient of 0.05**, constant over the entire height corresponding to maximum water level in the lake. The dam constructed in 1962 across river **Koyna has experienced an earthquake of magnitude 6.5** in the Richter scale on December 11, 1967. Through measurements in the gallery located in the dam, the leakage through the dam body and foundation was monitored. This showed an increasing trend after the earthquake. ***The Koyna dam developed some surface cracks.***

Immediately after experiencing the earthquake an expert committee recommended several temporary and permanent measures for strengthening of the dam. These measures were:

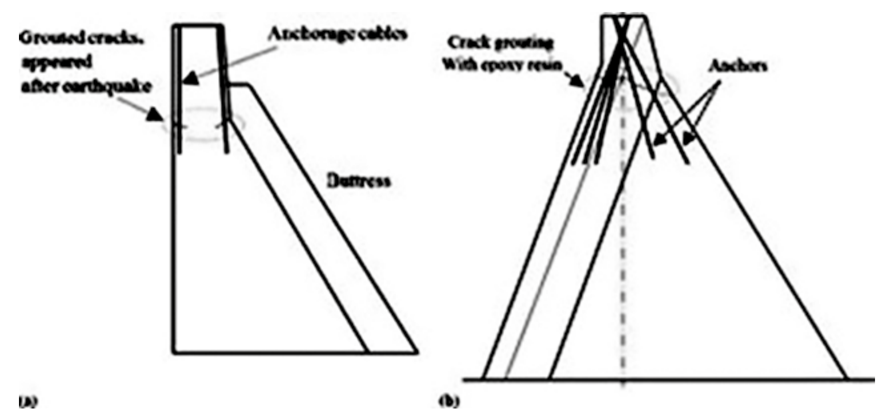
⇒ Grouting the cracks with epoxy resin, polyester grouting, and sealing of crack upstream with grouting and guniting, thus reestablishing the monolithicity of the dam to the extent that the epoxy grout can penetrate through the face and at the same time prevent the water ingress into the dam body;

⇒ Strengthening of 7 high monoliths by pre-stressed cables was carried out because it was not possible to assert that:

- o the crack did not extend beyond the grouted face;
- o the crack did not continue from upstream to downstream face;
- o the resin grout has bonded the whole width of the dam.

It was therefore decided that cracked and deep monoliths should be stitched across the crack by pre-stressed cables, so that the bodies above and below the crack act together in unison under dynamic forces.

The end blocks did not require strengthening because they were buried shallow in the ground and were not cracked.

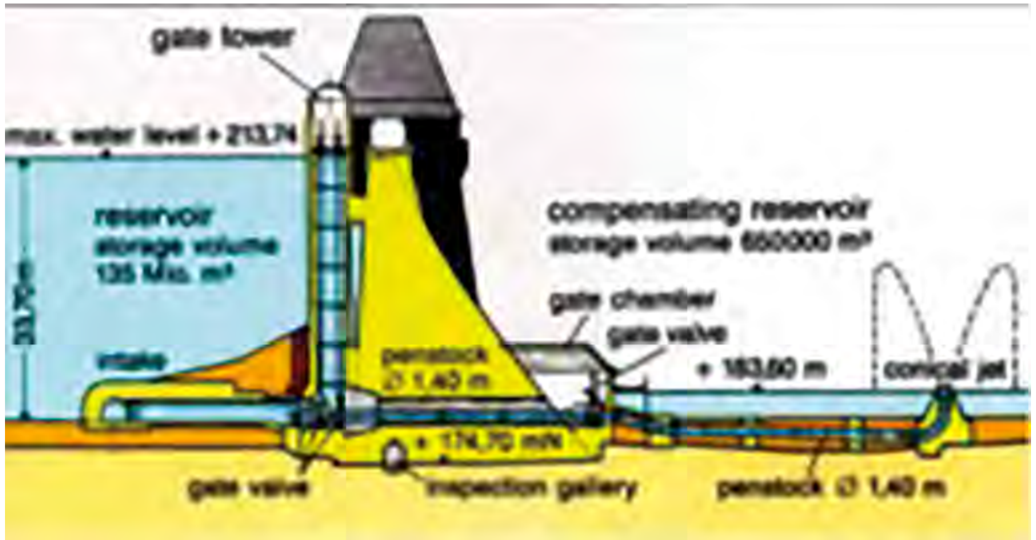


Case	Identification	Country	Finished	Damage	Actions	References
4.7-N	Möhne	Germany	1913	1943-1990	Repaired	[04-82]

The dam was damaged by bombing in 1943 and repaired rapidly in the same year. The downstream face of the dam had not been investigated since the reconstruction in 1943. ***In the early nineties, a detailed inspection was made on the downstream face using specialized access platforms***.

It revealed that extended rehabilitation work was necessary. The masonry was repaired by replacing face stones and by renewing the mortar in joints. Afterwards the faces of the two towers of the dam were rehabilitated in the same way and this was followed by rehabilitation of the pillars between the flood escape openings at the crest. ***At the Möhne Dam in Germany, the low-level outlet gates were found by inspection to have suffered corrosion and to be unacceptably leaking.***

The rehabilitation of the Möhne Dam provides a valuable case history describing the replacement of the low-level outlet valves underwater. Inspections by divers showed that the culverts were in poor condition. It was decided therefore to rehabilitate the masonry culverts and to provide a support for the emergency gates by installing steel liners within the culverts.


gate tower
max. water level + 213,74
reservoir
storage volume
135 Mio. m³
compensating reservoir
storage volume 650000 m³
gate chamber
gate valve
+ 183,60 m
conical jet
intake
penstock
∅ 1,40 m
+ 174,70 mN
gate valve
inspection gallery
penstock ∅ 1,40 m

Case	Identification	Country	Since	Damage	Action	References
4.7-O	Castlewood Canyon Dam	USA	1890	1933	Repairs	[04-83]

Castlewood Canyon Dam was constructed in 1890 across Cherry Creek, 40 miles southeast of Denver, Colorado. The masonry and rockfill structure, built from local materials, was around 180 m long with a height of 21m measured from the reservoir floor, 2,5 m wide at the crest, and 15 m wide at the base.

The dam was controversial from the beginning. Just after construction, Castlewood Dam showed ***signs of settlement***, ***with cracks and seepage*** visible on the face of the dam. Safety was questioned by downstream citizens and a committee of engineers determined that improvements to the dam were necessary. Meanwhile, Denver Water Storage Company, owner of the dam, and the dam's designers argued that the dam was safe. In 1897, a section of the dam washed out prompting multiple repairs. Following the repairs, leakage remained visible, but to a lesser degree.

During the 1933 thunderstorm the reservoir rapidly filled until water flowed over the central spillway and eventually overtopped the remainder of the dam by a little over a foot. Prior to the build-up of tailwater, erosion likely initiated at the toe of the central spillway section. The masonry apron in this location was washed away and deep erosion of the underlying mudstone quickly ensued. ***At the same time, scour may have started along the groins due to overtopping flow***.

Castlewood Canyon Dam as completed
(Photo source: Colorado History Museum)

Castlewood Canyon Dam after the rupture
(from internet)

Case	Identification	Country	Since	Damage	Action	References
4.7-P	Camará Dam	Brazil	2002	2017	Rebuilt	[04-84] and the item 4.2.4 on this text

On the night of June 17, 2004, the dam broke after a ***foundation failure***, reaching part of the territories and inhabitants of the municipalities of Alagoa Nova, and the urban sites of two other cities, where the disaster gained greater dimension. The dam was rebuilt by 2017.



Camará Dam before failure (*)

Camará Dam after failure (*)

Additional rupture (*)

Rupture aspect [04-84]

Local of the foundation Rupture (*)

After the dam was rebuilt (*)

Case	Identification	Country	Since	Damage	Action	References
4.7-Q	El Guapo Dam	Venezuela	1999	2009	Rebuilt	[04-85]

El Guapo dam reservoir was at its peak **when it was unable to contain the floods due to the great magnitude and thus a rupture occurred.** A new RCC concrete spillway was constructed, and the embankment was repaired.



Sequency of the failure

Spillway as rebuilt (courtesy from the Contractor)

Case	Identification	Country	Since	Damage	Action	References
4.7-R	Tarbela Dam	Pakistan	1968	1974	Repaired	[04-86] to [04-89]

The Tarbela Project was built over the River Indus by Tarbela Dam Joint Venture, which was led by Italian contractor Impregilo. The joint venture was a consortium of three Italian and three French heavy civil engineering contractors. Five German and two Swiss companies joined the consortium in 1969.

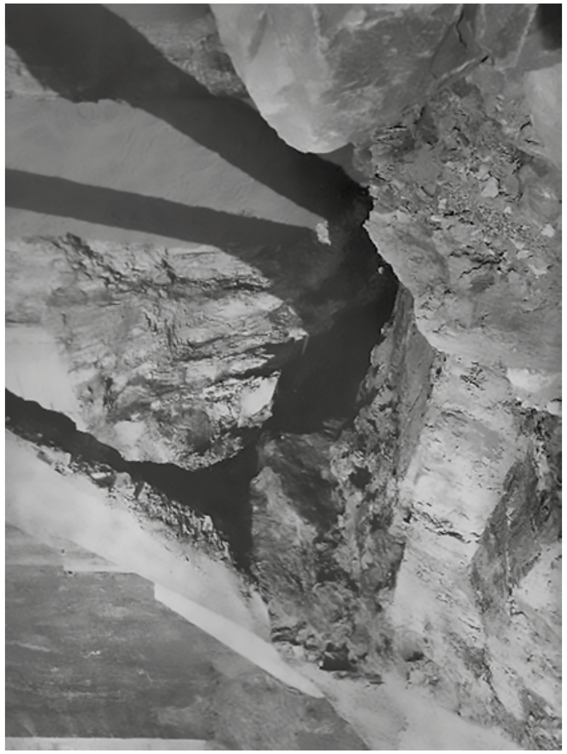
Members of the joint venture led by Impregilo S.p.A (Impresit-Girola-Lodigiani) included Compagnie de Constructions Internationales S.A. (Citra-ECB-GTM-SFEDTP-BGE), Construzioni Generali Farsura Cogefar S.p.A., Impresa Astaldi Estero S.p.A., Compagnie Française D´Enterprises S.A., Spie-Batignolles S.A., Hochtief AG, Philipp Holzmann AG, Strabag Bau AG, Ed. Züblin AG, S.A. Conrad Zschokke, Losinger & CO. AG, C. Baresel AG.

General view of Facilities and Structures of the Tarbela Project

Illustration where the tunnel that collapsed (picture from Internet)

The water conveyance structures for the Tarbela Dam Project consist of two spillways (Service and Auxiliary), five large diameter tunnels, and one small tunnel for irrigation. Tunnel **1** was 13,3 m in diameter and served as river diversion tunnel prior and during the initial filling of Tarbela reservoir in 1974. On the August 21, 1974, while discharging flows under high heads from Tarbela reservoir, tunnel **2** suddenly collapsed.

Cavitation was a factor that led to the collapse of tunnel **2** in August 1974. The flow situation that led to the cavitation in tunnel **2** was caused by the operation of the central gate (one of three), which stuck at part-gate-opening at heads that steadily increased up to a maximum of 109m. In tunnel **1,** damage occurred when each of the three gates could be opened only partly during emergency drawdown of the reservoir.



Tunnel 2 collapse/ suspended air vent to gates (courtesy R. Allione)

Tunnel 2 collapse, diameter 13,3 m and 6 inches steel ribs HEM 360 (courtesy R. Allione)

The part-gate operation was the result of accidental jamming of the gates due solely to structural failures in the gate track systems and was forced by circumstances that could not be foreseen. The original design basis for the intakes, tunnels and gates was that the gates should only be used to shut off the flow completely when the time came to discontinue diversion through the tunnels. **Later, after additional studies, design review and some modifications were made.**

4.8 Monitoring and Inspection Planning

4.8.1 Basics

The importance of monitoring programs for dam safety is widely accepted. A well designed, planned, and executed instrumentation monitoring program can provide information that is needed for a solid understanding of the ongoing performance of a dam and may help detect early warning signs of trouble. Monitoring design and programs, including instrumentation and visual inspection, provide dam owners with the knowledge that a dam is performing as expected and the ability to detect a change in performance. This knowledge and ability are critical because the dam owner is directly responsible for the consequences of a dam failure.

The use of instrumentation to monitor the performance of dams is widely accepted as a prudent component of a successful dam design and safety program to manage and minimize the risks to the public posed by dams. Instrumentation observations are used to supplement and complement visual inspections to verify the integrity of the dam and appurtenant features, assuring protection of life and property.

In order to support the instrumentation system and to be effective to verify the behavior of the structures, it is necessary that the designer indicate the levels of Normality, Attention and Alert for each instrument. Each of these corresponding to a given safety factor.

It is important to note that these Safety Requirements should be reevaluated after a given period of operation of the Dam. In addition to these Safety Levels, any small or rapid variation in the measurement, even below the Level of Attention, is an indication of abnormal.

The function, purpose, and type of instruments may vary widely, depending on the specific application, from a simple v-notch weir to a complex network of automated vibrating wire piezometers. Data acquisition methods can also vary widely from manual readings to automated data acquisition with periodic data recording capabilities. If in-house expertise is not available, engineering consultants, instrument manufacturers, or suppliers can be consulted to help identify an appropriate instrumentation program to the project. Therefore, it is imperative that each project is evaluated independently to assess the objectives of the instrumentation program. The evaluation should be part of a structured process that identifies plausible failure modes unique to a dam and develops appropriate responses, including instrumentation requirements. Dam owners should carefully evaluate the need for instrumentation, periodically review the need, and modify the program accordingly when specific issues of performance arise.

The authors consider that the theme of monitoring and inspection of dams is so relevant, that this aspect is addressed in this item as well as widely considered in more detail in **Chapter 10**.

Taking this into account, attention should be paid to the following issues, whether in new or existing projects:

⇒ Why and how can your dam fail?

⇒ Why instrument and monitor?

- Are some points or zones in doubt?
- Can an emergency condition be developed?
- Are the current conditions safe?
- Will the dam perform as expected?
- Can conditions and materials deteriorate and become unsafe?
- Is a critical failure mode likely to develop?

- o Will the dam remain safe for future changes due to loads, deformations, properties?
- o Are there some remedial action that can be taken to preserve or restore the safety of your dam?

⇒ Effective performance monitoring

⇒ What and where can you monitor?

- o Link this to potential failures modes.
- o What measurements are available to indicate?
- o What are the optimal locations for these measurements?
- o What measurements can help indicate that a potential failure mode is developing in time?
- o How often should measurements be adopted to sufficiently indicate rate of change of a failure mode?

4.8.2 Responsibilities

Most successful organizations, in any endeavor, clearly define the roles of their personnel; certainly, this is an important procedure in the management of dam safety instrumentation design and programs. Personnel involved in an instrumentation monitoring program need be experienced and the most important concept is that responsibilities for acquisition of data, maintenance of instrumentation, interpretation and reporting of data should be clearly defined (this may be filled by one person or a full crew of dedicated personnel).

The selection of personnel for the monitoring of dams must be done carefully. The inspector and the analyst must be practical and dedicated diagnosticians who thoroughly examine every clue in their scrutiny of the behavior of the dam. A person who becomes uninterested, complacent, or overwhelmed when surrounded by voluminous collected data should not be assigned to this demanding duty. On the other hand, an analyst concerned with quantity rather than quality of data or fascinated with overly sophisticated techniques might overlook obviously adverse trends that may be apparent by scanning data or by simple charting. The key to striking a proper balance is the selection of someone who knows what to look for and is perseverant in their search, discerning in their interpretations, and communicative of their findings.

Responsibility for surveillance should be clearly designated. The need for results determined from an unvarying basis requires that, whenever possible, the same people be assigned each time to specific tasks, although the findings must be checked independently. Fragmented or dispersed responsibility is not conducive to obtaining reliable measurements and accurate analyses. A competent observer guided by established operating and instrumentation criteria must be assigned to each major dam to detect abnormal behavior and to analyze promptly the significance of deviations.

To assure that a dam remains in good health, surveillance must be professional and continuous. The designer cannot walk away as operation is begun; they must share their valuable knowledge of how it was intended to perform. With the help of instrumentation, the designer, the operators, and the professional inspectors can judge its actual performance against the design expectations and the other contingencies that have been considered. If further protective measures are needed after the first stage of operation, the designer will have the necessary background and insight to tailor them to design requirements.

Construction and operations engineers are usually best positioned to recognize the unexpected. They must understand how the design is intended to work. Otherwise, the significance of conditions that vary from design assumptions may not be noticed. While they must enforce compliance with plans and specifications, they should advise the designer when revisions are necessary.

The importance of well-informed operations and maintenance personnel must be stressed. The value of their presence and of their routine inspections will depend upon how well they understand the design and the vulnerability of the structures. Unless they are trained to distinguish the important indicators from the unimportant, they may tend to be unperceptive even as conditions worsen. If a dangerous defect develops slowly, a resident inspector who is not attentive may not notice subtle changes.

A regular examination by experienced personnel is an indispensable element. The inspector must be able to recognize signs of possible distress such as:

⇒ structural joint movement;

⇒ piezometric fluctuations;

⇒ seepage variation;

⇒ settlement and horizontal misalignments;

⇒ slope movement;

⇒ cracking of the dam and the structures;

⇒ erosion;

⇒ and corrosion of equipment and conduits.

4.8.3 Surveillance

In the engineering of dams, provisions should be made to cope with changing conditions over the years of operation. The potentialities of deterioration must be closely watched. Attention must be given to these possibilities during design and should be reflected in access systems, maintenance facilities, and instrumentation. Surveillance should cover the entire reservoir area.

Engineers responsible for a new dam have opportunities to know its foundation and its materials, and to determine and execute their treatment, processing, and placement. They know where the site and the structure are strong and where they may be weak. In addition to the possibility that complete design and construction records may be lacking, it is not likely to have much instrumentation to indicate its condition.

There may be some survey data that offer clues to its history of movement, but the reliability of such records may be doubtful. New instrument installations may be advisable.

Evaluations of the safety of existing dams must pursue all aspects of design, construction, and operation. The task may be more comprehensive, more demanding, more tedious, and sometimes, more puzzling than the original design effort. Visual examination is a fundamental and reliable way to detect malfunctioning or deterioration. Uneven settlement, discoloration or increase in seepage, and embankment sloughing are manifestations of potential failures and should be investigated by an experienced engineer.

4.8.4 Monitoring Planning

Planning of instrumentation, whether for an existing dam, or during the design phase for a new dam, includes several essential considerations. Considerations include selecting the parameters for monitoring; defining the purpose of the instrument; predicting the life cycle of the instrument and its replacement challenges; predicting the influences that drive fluctuations; predicting the range of measurements expected; and establishing thresholds for safe performance. After logically evaluating these considerations, an appropriate instrumentation system may then be selected. The Potential Failure Mode Analysis procedure is a valuable tool for planning and selecting the parameters for monitoring.

4.8.5 Project Specific Knowledge

While general knowledge of dam design, analyses, and parameters measured at dams is desired for personnel engaged in an instrumentation program, site specific knowledge is imperative. Interpretation of data to determine the performance of dams can vary significantly based on site location, condition and maintenance of instrumentation, geology, foundation conditions and treatment, seepage control features, construction, and design details. Personnel who have consistently monitored projects over long periods of time have project-specific knowledge that makes them an extremely valuable resource for dam safety programs.

4.8.6 Instrument Specific Knowledge

Instrument specific knowledge, i.e., types of instruments, their purpose, and installation details are critical in the identification of potential problems and in the evaluation of the performance of dams. For example, dam owners may install a variety of piezometers: standpipe; vibrating-wire; pneumatic; or hydraulic. If personnel involved in the instrumentation program understand the differences in response, accuracy, and weaknesses of these types of piezometers, more accurate interpretations of performance will be realized. Knowledge of the installation details of each type of piezometer will provide insight to the function of the instruments, e.g., open standpipe or observation wells which measure an overall water surface versus those piezometers which are screened at levels to measure pore water pressure in specific zones.

4.8.7 Monitoring Procedures

Before filling a major reservoir, records of piezometric levels, ground elevations, and background seismic activity at the site should be compiled so that comparison can be made with the effects of water loading. For high dams and large reservoirs, installation of a sensitive seismograph network may be justified. As soon as water impoundment begins, which might happen before construction is complete, an inspection and maintenance program for structures and operating equipment must be instituted. During the first filling, this will include daily patrol of the dam and its abutments and daily observation and graphing of seepage flows and piezometric levels. Instrumentation to detect structural or foundation movement should be read monthly. These readings should be plotted and correlated with concurrent reservoir water surface levels.

Dams are especially susceptible to failure during the first 2 or 3 years after the initial filling of the reservoir. Surveillance should be aimed at detection of any tendency toward change in behavior of the dam. The search must focus on the anomalies as opposed to the norm. This requires establishment of an observational data base as early as possible in the life of the structure. Emphasis must be placed on quick processing of data.

During the initial impoundment, reservoir water may penetrate and flush out foundation openings that were not discovered during construction. This may be signaled by increases in seepage flow and turbidity which should alert surveillance forces.

Although the most critical time in the life of a reservoir may be during its first filling, several years may pass before foundation and structures have fully adjusted to loading. Thereafter, deformation will continue in response to cyclical load variations. Attention should be focused on examination and data collection during relatively rapid changes in reservoir water surface elevations. Conditions year-to-year at high and low seasonal levels should be compared. Special monitoring should be conducted when the pool exceeds the historic high level. Abnormalities indicative of deteriorating conditions must be met with quick corrective action.

Failures may develop very slowly, and the adverse conditions might not be apparent for a long time. This may be misleading and conducive to careless surveillance. The failure of a dam is likely to be preceded by observable or measurable deformations. If its materials are brittle, however, the final rupture may be sudden, with minimal advance warning. Foundations may also fail abruptly and thus deprive the dam of vital support. These possibilities demand that surveillance systems to be developed painstakingly and be strictly enforced.

Anomalies in observational data must be subjected to relentless scrutiny. Nothing should be taken for granted or explained away by casual assumptions. In the surveillance of dams, any observation that appears unusual should be reported to someone who can analyze it properly. The judgment of its significance should not be left to those who may misunderstand it and dismiss it.

Performance data should be examined not only for deviations from reading to reading, but also – and especially – for slow trends which may have subtle meanings. The implications of such long-term changes are sometimes overlooked.

The value of timely and painstaking data analysis in search of changing trends cannot be overemphasized. On larger projects where numerous instruments must be read, data retrieval and processing systems should be designed so that rapid evaluations can be made. The importance of timely actions in all parts of the surveillance process needs to be emphasized again and again. The reading of instruments must not be allowed to lag. The channels for communicating the data should be kept short, and the information provided must be examined when it arrives. Anything unusual must be called to the immediate attention of those in responsible charge.

To assure timely and perceptive analysis, those who read surveillance data must be selective. They must be able to sort out what may be important and study it quickly. Otherwise, there might be a tendency to bog down in the voluminous detail that can be generated by a comprehensive system of observation. After initial review, these data that might indicate questionable trends should be examined in depth.

Engineers who analyze data from dam instrumentation must strive for a clear perspective that enables prompt recognition of adverse conditions as they sift through the sometime voluminous records. Quality of data can be more important than quantity. A single fragment of information may not be meaningful in itself, but when grouped with other data, it may establish a norm. Departures from the norm can then serve as indicators of the condition of the dam. The graphical summarization of data often facilitates understanding the significance of factors that might adversely affect the dam.

Once established, a monitoring regimen must still be given periodic professional review. The surveillance system should be adaptable to changing circumstances, and revisions should be promptly made to cover unforeseen variations. Measuring devices should be recalibrated on a regular basis.

4.8.8 Routines

A dam's routine instrumentation and visual monitoring program can be adopted as suggested in some guidelines[04-90 & 04-91].

4.9 Tips to Mitigate the Risk of Failures in Dam Design

A large number of dams have been built on many rivers, since thousands of years. From the last century, the criteria for dam design and manuals for materials, dam construction, and about quality control were available.

But, besides these, some failures occur, and it can be asked:

- ✓ ***Why?***

From these accidents and incidents, the technical society had developed a huge number of papers, new approaches, new codes, legislations. In the contemporaneous moment, the **Media** and the **Internet** put all the technical material available for the society.

From this availability, it is important that the engineers can adjust the knowledge and understand some summarized "tips" as follows:

Dam-Subject	Concern	Tip
General	Documents	Designs for construction of high-hazard dams must conform to accepted practices and procedures of the engineering profession.
		Design as well as preparation of the construction plans and specifications must be prepared by or under the direction of an engineer experienced in dam design and construction.
	Organization & Planning	Coordination between geologists, designers, and contractors is important.
		Effective communication with emergency responders is important when responding to a dam emergency.
		Peer review and collaboration during dam design can prevent design-attributed failures.
		Seemingly small changes to dam details can cause failure of a dam.

Dam-Subject	Concern	Tip
General	Organization & Planning	Emergency design and construction of dam modifications requires proactive involvement between the owner, engineer, regulatory agencies, and the contractor to achieve the most effective combination of constructability, conservative design, and flexibility.
		Delays during dam construction can expose a dam to a higher risk of failure.
	Concept	For high and significant hazard dams, elements that are critical for the safe operation of the dam should be designed using the “belts and suspenders” approach.
		Static equilibrium, including uplift pressures, must be considered during all phases of construction and service.
		Reservoir sedimentation can increase destabilizing forces acting on a dam and have other detrimental effects that could contribute to a dam failure.
		Differences in the stiffness of structural materials can lead to unforeseen stress concentrations.
		Unique force systems must be anticipated when designing foundations on rock that have complex systems of faults and joints.
		Dam failure by acts of terror should be considered as potential failure modes.
		Proper development of site-specific loading diagrams and related assumptions are an important aspect for any dam design. Key assumptions include selection of dam and foundation material properties that are defensible.
		Due to inherent uncertainties relating to both design and construction, appropriate factors of safety need to be applied.
		Improperly designed or anchored spillway slabs may fail long before a spillway discharges at its designed maximum capacity.
		A very well-maintained dam is not a guarantee against failure when a dam and its design is dated and does not meet current design standards.
		Fish containment structures must be located and designed such that they function properly in extreme runoff events without limiting the outflow capacity of the dam’s spillway.

Dam-Subject	Concern	Tip
General	Concept	The design life of key components of a dam (e.g., outlet works) may be much shorter than that of the dam structure; therefore, major maintenance or replacement of such components may be required on a shorter time interval.
		Dam modifications need to be designed by a professional engineer.
		For new dams, the as-built conditions of critical elements should be verified through direct observation and/or testing. This is particularly important for critical elements that are constructed "blindly".
	Hydrology/ Hydraulics	PMF magnitude floods do occur. High and significant hazard dams should be designed to pass an appropriate design flood. Dams constructed prior to the availability of extreme rainfall data should be assessed to make sure they have adequate spillway capacity, considering an additional freeboard and also confidence limits when applying some statistical method.
		During floods that greatly exceed the design flood, spillway failure (due to exceedance of the spillway capacity) may be a more critical potential failure mode than dam overtopping.
		Dams may overtop to floods more frequent than the design flood if the spillway capacity is reduced (due to debris plugging or gate malfunction) or if a gated spillway is not operated as assumed in design studies.
		Raising the normal pool or crest of an existing dam requires evaluation of existing and new potential failure modes as well as the stability of the dam for the new loading condition.
		Aeration of the underside of the nappe is often needed to mitigate vibrations in spillways.
		Siphons can be an effective method to lower reservoir pool levels during emergencies when outlet works are inoperable, undersized, or missing.
		Under certain conditions at a dam site, flows exiting spillways can double back and erode and breach the dam embankment. Dam designers and inspectors need to be aware of this potential failure mode.

Dam-Subject	Concern	Tip
General	Hydrology/ Hydraulics	Landslides around the rim of a reservoir can cause dam overtopping. The stability of the hillsides around the rim of the reservoir as well as the impact of potential slope failures should be evaluated.
		Rapid filling of clay dams after long dry periods should be avoided.
		Proper management of runoff and pool water is essential to the safe operation of tailings dams.
		Flooding resulting from a dam failure may extend further than noted in inundation maps.
		Flood control dams may not provide an opportunity to observe developing seepage and piping.
		Failure of upstream reservoirs should be considered in the design of closely spaced dams.
		Reservoir impoundments and operation variation of the reservoir level can reduce the stability of natural slopes.
	Foundation	Stability of the dam foundation and other geologic features must be considered during dam design.
		Most concrete dam failures are the result of foundation stability problems.
		Concrete dams founded on bedrock require subsurface investigations and testing of rock properties.
		Dams built of or on loose granular soil can be susceptible to liquefaction of the foundation material.
		Concrete dams on rock foundations are not immune to failure during flood overtopping.
		Prior to cement grouting of rock zones that are highly permeable and have high piezometric gradients, it is important, when possible, to reduce the flow and the piezometric gradient in the area where the grout is to be injected.
		Construction of a cutoff in alluvial foundation materials if often needed to prevent potential internal erosion.
		The foundations and abutments for an arch dam should be properly treated by replacement of poor rock with concrete, grouting, and drainage.

Dam-Subject	Concern	Tip
General	Foundation	Foundation approval should be documented by designers and geologists.
		The presence of weak zones in natural foundation materials must be evaluated in design.
		Zones of permeable soil, such as old riverbed deposits in dam foundations, should be addressed.
		Grouting of earth fill or overburden material should not be used as a long-term/permanent solution to prevent internal erosion.
		Fault activation and subsequent dam failure can be caused by high-pressure injection of fluid into subsidence-stressed sub surfaces.
		Grout curtains in a formation where potential seepage paths (joints, fractures, etc.) are filled with either erodible or soluble materials are not permanent and may require periodic maintenance grouting to remain effective.
		Foundation and formed drains for concrete dams should be inspected regularly and their performance verified by drain flows and uplift pressure measurements. When drains begin to plug and performance is reduced, a cleaning program should be initiated.
		Stress distribution in an arch dam is critically influenced by excessive deformation of the foundations and abutments.
		Supporting a dam on piles makes it more vulnerable to foundation erosion and piping.
		Gravity dams on soil foundations require special features to address potential erosion of the foundation.
	Earthquake & Landslide	Dams located in areas of potential seismic activity need to be evaluated for liquefaction, cracking, potential fault offsets, deformations, and settlement due to seismic loads.
		Dams constructed by hydraulic fill methods can be susceptible to liquefaction during seismic events.
		There is magnification of seismic accelerations not only in the upper parts of a concrete dam but also along its abutments.
	Access	Safe access to high and significant hazard dams is important at all times.

Dam-Subject	Concern	Tip
General	Materials	Historic installations of copper waterstop may fail due to corrosion from acid rain or other influences on the chemical composition of runoff.
		Quality control of waterstop installations is critical to assure adequate embedment of waterstop materials into the concrete on either side of joints
		Geotextiles should not be used as the primary means of filtration in drainage systems for dams.
	Conduits & Spillways	Drainage conduits for dams should be designed with cleanouts to accommodate future cleaning and inspection.
		Trash racks need to be appropriately sized and cleared after large flow events.
		Spillways should be designed to prevent clogging by debris.
		Principal spillways should be designed to convey high frequency floods without incurring significant erosion damage
		Moments and stresses caused by friction within the trunnion pin connection must be considered in the structural design and maintenance of radial gates. Trunnion pin connections must also be lubricated and maintained in accordance with design assumptions.
	Instrumen-tation	Conventional instrumentation may provide early detection of conditions within a dam that could lead to failure.
		Some Conventional instrumentation can induce or accelerate internal erosion.
		Dam instrumentation can provide early detection of a dam safety problem and can provide an opportunity for intervention.
	Operation	Dam operators may operate a gated spillway at release levels less than those specified if there is the potential for downstream consequences.
		Spillway gates should be tested to the maximum extent possible on a regular basis to verify the performance of the electrical/mechanical system and to ensure that the gates can travel freely without binding or being restricted.
		Loose rockfill should not be used as structural support in locations where it can be easily eroded.

Dam-Subject	Concern	Tip
Embankments	Material	The use of corrugated metal pipes in embankment dams is discouraged.
		To the practicable extent, dispersive soils should not be used in the construction of embankment dams.
		Non-plastic soils are far more likely than soils with some plasticity to experience internal erosion. This needs to be considered in the design phase in order to find an adequate defense (filter and drain).
		Karstic foundations are difficult to treat and can cause internal erosion issues.
		Brittle materials, such as asphalt and Portland cement concrete, should not be used as reservoir liners without high-capacity filtered underdrains.
		Compatibility of materials to prevent piping of materials through embankment and foundation materials needs to be considered.
		Special consideration is necessary for broadly graded and variable soils deposits (glacial, alluvial, and colluvial).
		Lime treatment can be used to stabilize dispersive soils used to construct embankment dams.
	Outlets	Outlet works and pressurized conduits in embankment dams should be provided with means for upstream closure.
		Outlet conduits at dams need to be inspected regularly to confirm their structural integrity and conveyance capacity.
		Outlet works conduits with joints in embankment dams should be watertight to prevent internal erosion of the embankment.
		Drainage conduits in embankment dams should be video inspected using a pipe camera after they have been installed and before construction work is completed.
	Seepage	Seepage along penetrations through embankment dams should be controlled using a filter diaphragm instead of antiseep collars.
		Installation of an under-slab drainage system can help avoid detrimental frost action while providing a method for monitoring seepage quantities over time.

Dam-Subject	Concern	Tip
Embankments	Seepage	Reduction in minor principal stresses due to drying or differential settlement can lead to hydraulic fracturing and piping failure in embankment dams. This also needs to be considered in order to search for a design defense (filter and drain).
		Erosion through a breach in erodible fill cannot be controlled.
		A concrete encasement or cradle around or under conduit penetrations through earthen embankments allow for better compaction of earth fill using an adequate compaction equipment.
		Treatment of fractured foundation rock for embankment dams is important to prevent internal erosion of embankment material that is in contact with the foundation.
		High and significant hazard embankment dams should have internal filter and seepage collection systems.
		Filters and drains for embankment dams must be compatible with adjacent fill or in-situ materials.
		Earth/rock cut spillways can fail by erosion and breaching and should be evaluated for integrity during passage of the design flood.
		Internal erosion can occur at relatively low hydraulic gradients. Internal erosion can take decades to progress. This must also be considered in order to find a design defense (filter and drain).
		Cutoff walls can concentrate gradients and seepage flows.
		Some dams may not have included the clear out of the stream channel under the embankment. This can be a source of uncontrolled seepage under the embankment.
		Pressurized pipes in embankment dams require special design features.
		It is prudent to provide very high discharge capacity for seepage collection and control systems for dams constructed on glacial foundations.

Dam-Subject	Concern	Tip
Embankments	Seepage	In order to control seepage in glacial foundations, sand filters and other drainage zones should be limited to minimum dimensions that can be reliably constructed, thereby providing as little resistance to concentrated seepage flows as practical.
		A properly designed and executed foundation grouting program in rock or fractured foundation can provide an effective seepage cutoff.
		Excessive head loss in inlet piping can be a failure mode.
		Severe piping of embankment materials can occur through a dam into the abutments or its foundation without any deficiencies being observed by dam inspection.
		Special care is needed in placing embankment materials to prevent preferential seepage paths due to material variability, segregation, and partial fill surfaces.
	Filters – Drains	In order to reduce uplift pressures in sand aquifers overlain by clay layers in earth fill dams, granular filters – drain installed directly on the underlying foundation can be an effective solution.
	Deformation	Settlement of earth fill embankment dams can reduce freeboard and increase the risk for overtopping. New embankment dams should be designed with allowances for settlement.

Dam-Subject	Concern	Tip
Embankments	Construction	An earth fill dam must be safe and stable during all phases of construction and operation of the reservoir. To accomplish this, the following criteria must be met: a) the embankment must be safe against overtopping during occurrence of the inflow design flood by the provision of sufficient spillway and outlet works capacity; b) the slopes of the embankment must be stable during construction and under all conditions of reservoir operation, including rapid drawdown of the reservoir; c) the embankment must be designed so as not to impose excessive stresses upon the foundation; d) seepage flow through the embankment, foundation, and abutments must be controlled so that no internal erosion or piping takes place and so there is no sloughing in the area where the seepage emerges; e) the embankment must be safe against overtopping by wave action; f) the upstream slope must be protected against erosion by wave action, and the crest and downstream slope must be protected against erosion due to wind and rain; g) the design must be such that the most severe earthquake that can be reasonably anticipated will not cause catastrophic failure and loss of life; h) and construction of the dam and its appurtenants must be constructed utilizing proper methods and control.
		Except as otherwise specified earth dams retaining a flood water capacity of less than the limit adopted by the rules or a total capacity of less than the area from the rule's limits, the primary emergency spillway must be designed and constructed in accordance to principles adopted.
		Moisture content and compaction of embankment fill material must be carefully monitored for acceptance during construction.
		Special attention must be given to the compaction of earth fill around discontinuities, such as, along outlet structures and other penetrations through embankment dams.

Dam-Subject	Concern	Tip
Concrete Dam	Design and Actions	Concrete dams must be designed and constructed in accordance to principles at least equivalent to the Standards adopted in each Country.
		Concrete gravity dams should be evaluated to accommodate full uplift.
		Structural underdrains can lead to internal erosion under or along stilling basins and conduits.
		Hard rock spillway channels and hard rock concrete dam foundations may erode under the right flow conditions combined with unfavorable joint orientations and other joint characteristics.
		Because of their need to transfer load to surrounding rock, the abutments and foundations of arch dams require special geologic exploration, evaluation, and treatment.
		Concrete dams should be evaluated for and protected from foundation and/or abutment scour.
		Extensive and progressive cracking can seriously impair the safety and durability of a thin arch dam.
		In order to reduce tensile stresses in thin arches, the structure should be thickened toward the abutments and riverbed.
		Grouted interlocking keys, if adopted, are an effective means to construct contraction joints in arch dams.
		For new dams, weak features in rock foundations can be mitigated using concrete shear keys and dental concrete.
		Vertical interlocking keys in the transverse contraction joints are highly effective in maintaining stability of individual blocks of an arch dam during an earthquake when the reservoir is partially full.

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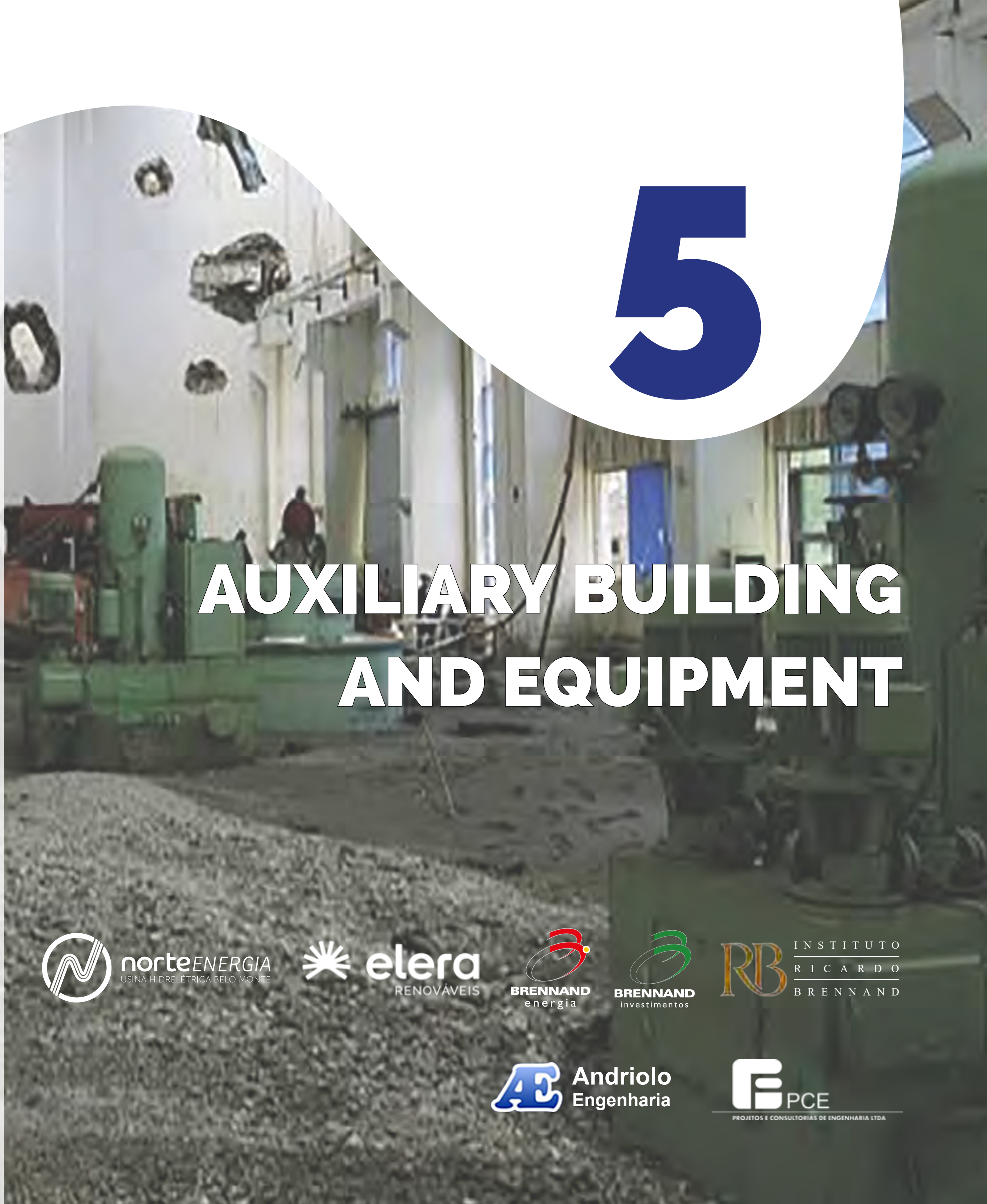
5

AUXILIARY BUILDING AND EQUIPMENT



5.1 Introduction

The most of the Manuals and Guidelines on Dam Safety, present statistical and resulting recommendations on Safety of the ***civil works*** of the dams. Almost nothing is said about the facilities and auxiliary structures, such as Water Intakes, Switchyards, Transformers, Power House, Pump House, etc.,

The information in **Chapters 4 and 7** of this text, shows that other structures and their equipment can cause hazard to Society, so the authors consider it prudent to draw attention to the need for care about them.

5.2 Appurtenant Structures and Equipment

5.2.1 Appurtenant Structures

It is important to understand that:

Appurtenant Structures are structures such as outlet works and associated gates and valves; water conveyance structures such as spillways channels, fish ladders, tunnels, pipelines or penstocks; intake and powerhouse sections; and navigation locks, either in the dam or separate there from.

An appurtenant structure is a structure at the dam site, other than the dam itself, which is designed and is required for the safe containment and control of the reservoir contents and reservoir discharges under all loading conditions. As such, appurtenant structures are required to fulfil functions necessary for the ***safety of dams*** and may include, but are not limited to, spillway, intake, outlet and sluice facilities together with their associated gates/valves and control equipment. Spillway facilities enable the management of flood flows and intake, outlet and sluice facilities enable reservoir lowering or dewatering in response to a dam safety emergency. Depending on the specific requirements of a site, other conduits or structures (e.g. tunnels, pipelines, surge chambers, penstocks, power stations) may fit the appurtenant structure Understanding if they fulfil dam safety functions.

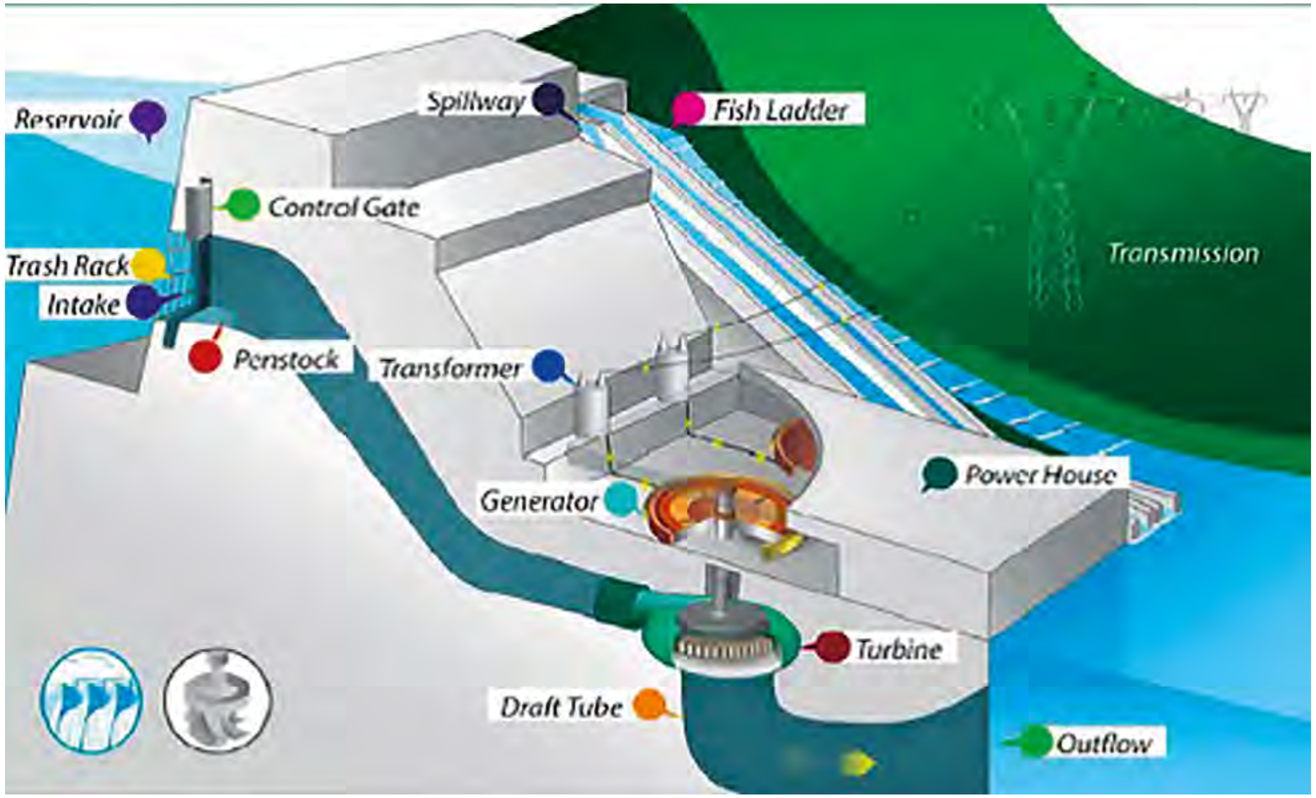
Dam safety deficiencies in appurtenant structures can include insufficient spillway capacity, susceptibility to spillway and sluice blockages, erosion and abrasion damage, and scour. Aging can lead to dam safety deficiencies that are not apparent at commissioning.

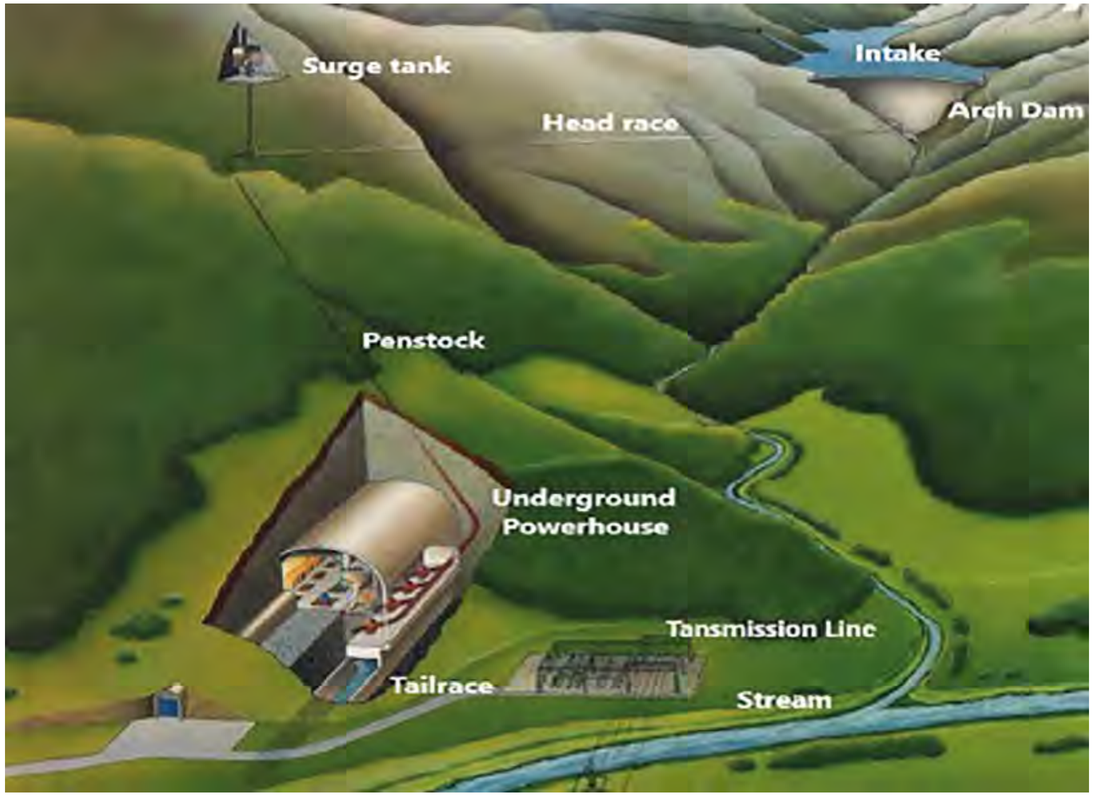
Inappropriate operation of mechanical and electrical equipment installed in appurtenant structures can also affect dam safety and, as such, operational procedures and personnel training must be in place to ensure the equipment is appropriately operated during normal, unusual and emergency loading conditions. Under seismic action, gates are subjected to hydrodynamic loads.

Dam and powerhouse operation sustainability is a major concern from the hydraulic engineering perspective. Powerhouse operation is one of the main sources of vibrations in the dam structure and hydropower plant; thus, the evaluation of turbine performance at different water pressures is important for determining the sustainability of the dam body. Draft tube turbines run under high pressure and suffer from connection problems, such as vibrations and pressure fluctuation. Reducing the pressure fluctuation and minimizing the principal stress caused by undesired components of water in the draft tube turbine are ongoing problems that must be resolved.

5.2.2 Elements and Equipment

Most plants are dependent on dams that retain water; this water retention results in the existence of a large water reservoir that is used as storage. The storage can be a part of the dam body or constructed separately and located upstream of the dam. The essential parts of the dam must be identified as the dams' material, the form of the dam, and spillway and powerhouse locations with types and sizes, quantities, and types of turbines with inlet and outlet locations, length of penstock and draft tube, and purpose of dam construction.





Schematic of the main equipment in a Dam and Power House [05-01]

Interestingly, Hydro mechanical equipment i.e. Gates and their associated equipment are often not given due importance in the dam safety reports. This results in serious anomalies in the overall planning of the project later on. The common reasons given for ignoring these vital components of the project are:

⇒ Hydro mechanical equipment are not site specific. One size fits all.

⇒ Hydro mechanical equipment can be designed later at the time of detailed planning.

⇒ Cost of Hydro mechanical equipment is only a small part of overall project cost.

But a designer can ignore the importance of hydro mechanical equipment at his own peril. Often these are the components of a project whose trouble free performance is essential for the success and safety of the project. Progress of many projects is held up due to them. And many projects have failed (partially or wholly) due to their malfunctioning.

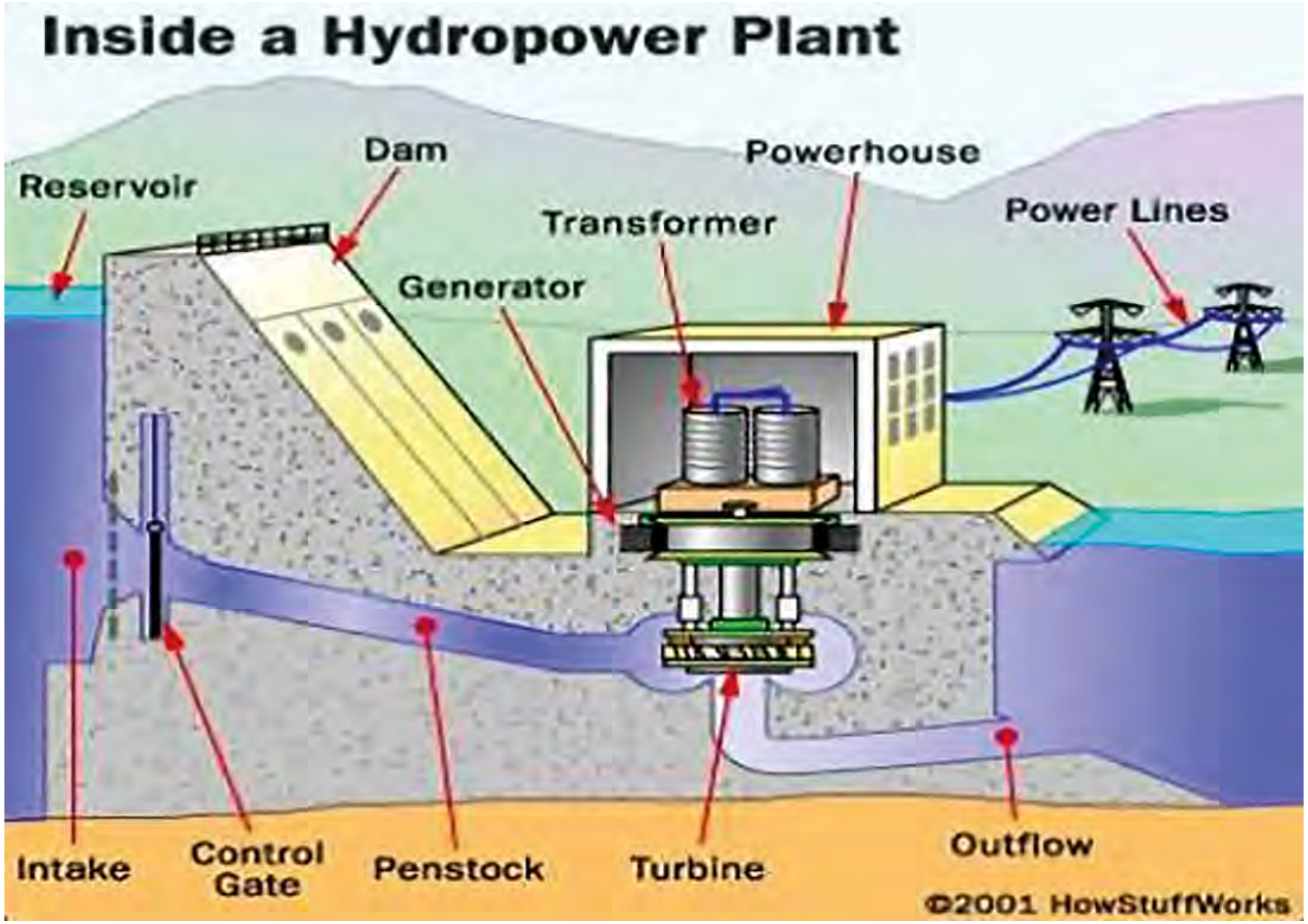
Sometimes an improper selection of gates makes the project unsafe and/or costly substantially inadequate (as mentioned in Chaper 4). In today's world of water scarcity, the importance of these equipment has increased as these regulate pond level and discharge. A brief description of various types of Hydro mechanical equipment shall be provided in the following pages.

5.2.2.1 Intake, Penstock, and Surge Chamber

Water delivery from the penstock to the turbine is controlled by controlling the opening and closing of the gates or intake structure which controls water movement on the upstream face of the dam or central part of the tailing dam. Normally, headrace is conducted which transports water from the river channels to the penstock constructed with the surge tank; a surge tank is used to reduce the sudden water surge, which can cause harm or increase the stress level on the turbine.

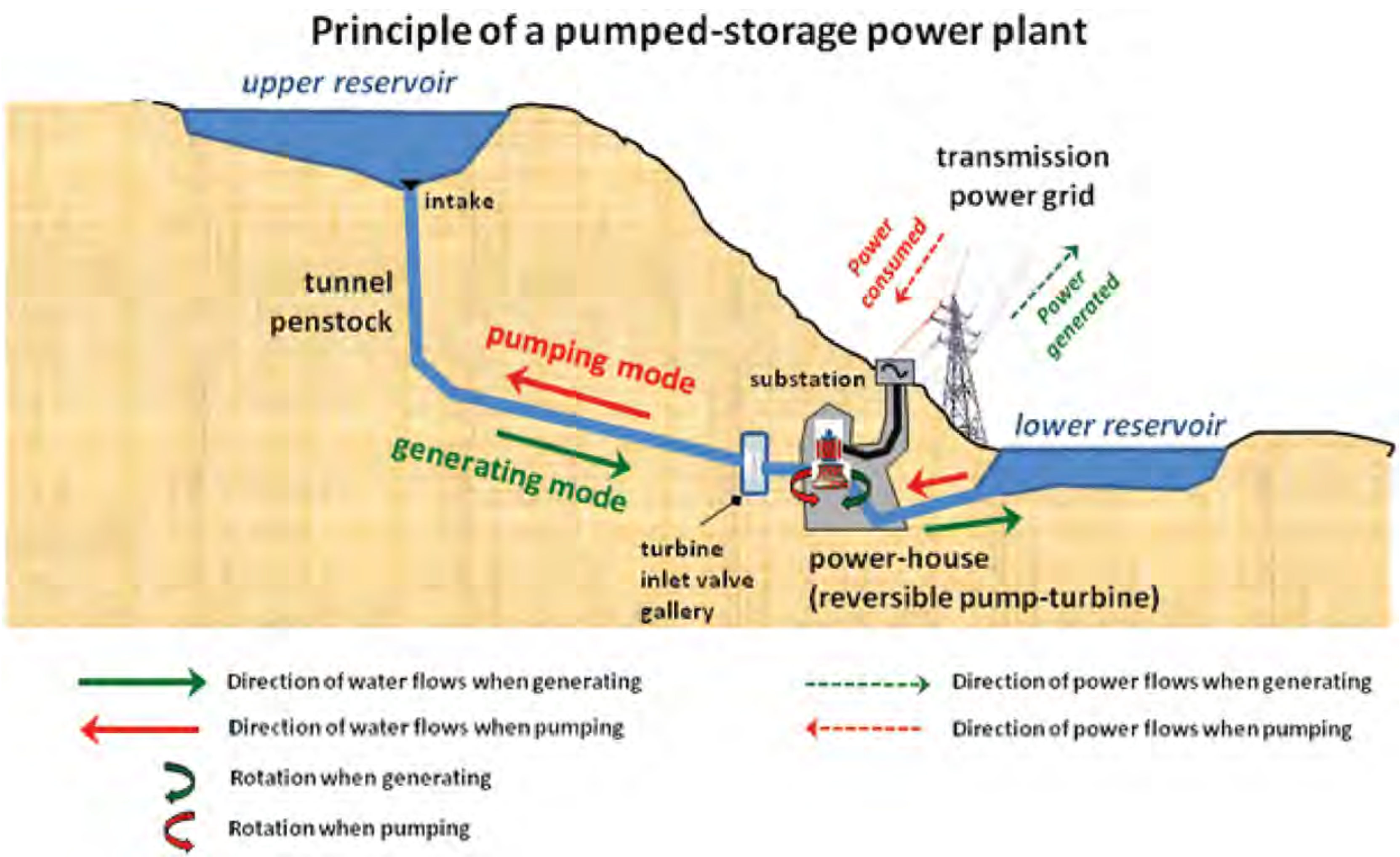
5.2.2.2 Powerhouse Facilities

Conventional powerhouse plants can be classified into four types of facilities: power generation, storage plants, pumped storage plants, and micro plant.



A pumped storage plant pumps water from a downstream reservoir to the reservoir instead of the storage and only is used during peak electric demand. This storage technique utilizes the gravitational potential energy of water when pumped from a low-level to high-level reservoir, as in run-of-the-river dams.

Storage plants have a reservoir to allow for more flexible adaptation to electricity demands, whereas the pumped storage plants have a reservoir but can also operate in reverse through pumping water back into the reservoir to be stored when demand is higher. The run-of-river plants must adapt to the variability of inflow conditions on generation; storage plants are not that vulnerable. The increased control of water by a storage plant results in a greater environmental impact than that caused by run-of-river plants.


Principle of a pumped-storage power plant
upper reservoir
intake
tunnel
penstock
pumping mode
generating mode
transmission
power grid
Power consumed
Power generated
substation
lower reservoir
turbine
inlet valve
gallery
power-house
(reversible pump-turbine)
Direction of water flows when generating
Direction of water flows when pumping
Rotation when generating
Rotation when pumping
Direction of power flows when generating
Direction of power flows when pumping

From[05-03]

5.2.2.3 Turbines

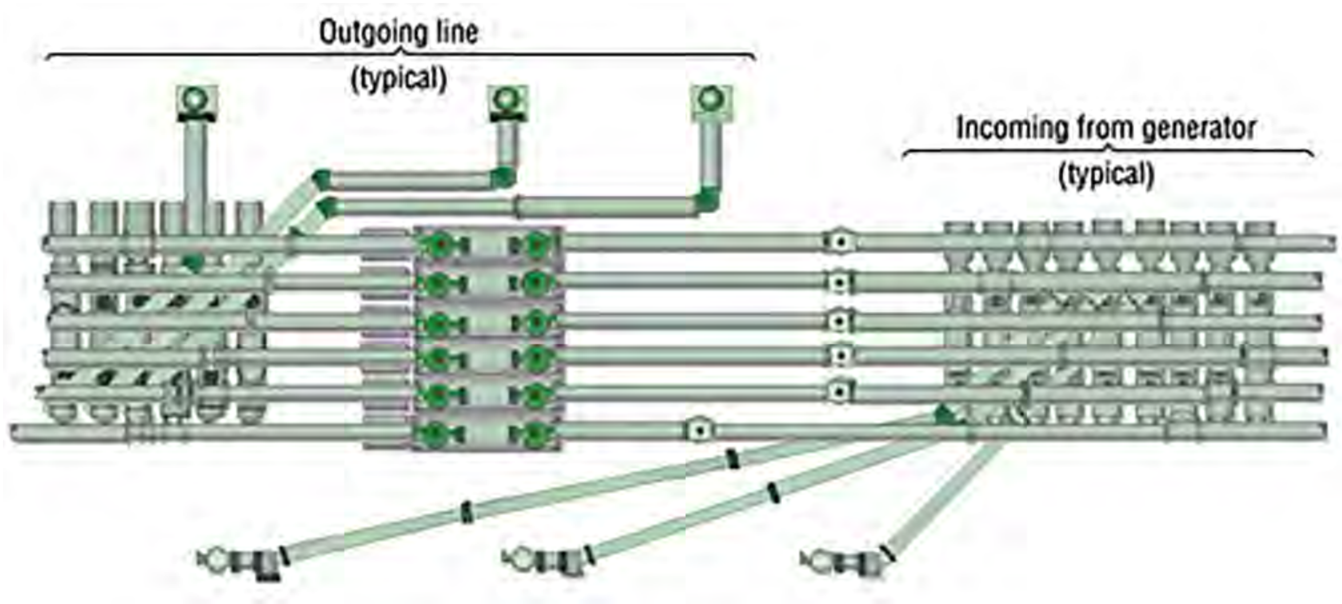
As the flowing water hits the blades of the turbine (connected via a shaft to the generator), the turbine rotates. With the generator, several configurations are possible (either above or next to the turbine).

Itaipu Turbine[05-04]

5.2.2.4 Generators, Transformers, Transmission Lines, and Outlets

The turbine shaft is directly connected to the shaft of the generator; hence, the rotation of the turbine blades drives the rotor of the generator, leading to electrical current generation from the rotation of the magnets within the constant coil generator. The continuous rotation of the magnets provides alternating current (AC), which will be converted by the transformer within the powerhouse into a higher voltage for onward long-distance transportation via the transmission lines. For feeding the electrical power to the distribution network, it is first transformed back to a lower voltage. The water used during power generation (called tailraces) is re-channeled back via pipelines – Draft Tubes – into the river.

Generator rotor and the axis connected to the Turbine- Itaipu[05-05]



Isolated SF6 Gas Substation in Itaipu[05-05]

5.2.2.5 Hydraulic Gates and Valves

Hydraulic gates are structures or devices to control the flow of water as desired. These are essentially closure devices in which a leaf or a closure member is moved across the fluid way from an external position to control the flow of water. In case of valves, the closure member is generally rotated or moved from a position within the fluid to restrict discharge passage.

Radial gates do not require grooves in the piers. They move on side guide plates which are in flush with the concrete surface. For spillways, simplicity of operation and smooth flow pattern past the gate and avoidance of flow disturbance due to absence of grooves are positive features for radial gates.

5.2.2.6 Gates for Outlets

The basic function of any outlet is to provide an efficient, economical means of releasing water from a reservoir to obtain the desired downstream use or uses. The conduits, pipes or penstocks for high head outlets are usually metal, and have gates or valves located at the upstream entrance, at an intermediate point or at the downstream end. Such outlets may also utilize a combination of these arrangements, and have a guard gate at the entrance or at an intermediate point with a regulating gate or valve at the downstream end.

Each outlet should be provided with two gates or valves capable of closing under flow. An upstream guard gate or valve is required primarily to ensure the safety of the conduit and equipment downstream and also to permit inspection and maintenance of the downstream pipe and the equipment.

Guard gates must be capable of closing under the full head and maximum possible flow, but are normally operated under balanced pressure/ no flow conditions. In addition to gates or valves which can be closed with water flowing, most outlets are provided with a bulkhead gate or stoplogs at the upstream end to permit inspection or repair at the entrance of the conduit. Bulkhead gates and stoplogs are normally designed to be placed and removed under balanced head no flow conditions.

The slide gates are usually adopted where high pressure application is called for. They are used for both guard and regulating services. Basically, a slide gate consists of a leaf which is either closed by being positioned across the fluid-way in the body or opened by being withdrawn into the bonnet by a hoist mounted on the bonnet cover. The mating seats on the gate leaf, body and bonnet serve as sliding surfaces for carrying the hydrostatic load on the leaf and as the sealing surfaces when the gate is closed. The body and bonnet are sufficiently stiffened to eliminate any distortion when the gate's frame/embedment are embedded in concrete. The bonnet cover is designed to resist internal water pressure

5.2.2.7 Gates for Spillways

A spillway may be controlled or uncontrolled. A controlled spillway is provided with gates or other facilities so that the outflow rate can be adjusted. The most widely used type of gate for large installations is the radial (or tainter) gate. A gated spillway provides for greater flexibility in reservoir operation than a dam having an uncontrolled spillway. Uncontrolled spillways have no gates. The uncontrolled spillways should be used in limited drainage areas where the peak time of floods are smalls.

The failure, misoperation, or use of spillway gates may cause downstream flooding that can range from minor to catastrophic. Downstream flooding is possible from any of the following[05-06]:

⇒ Spillway gates fail to open when directed. This could be caused by loss of electrical power; undersized motors; failure of automatic control systems; corrosion of wire ropes, rope connections, or bolted connections; failure of cart-mounted hoist equipment; displacement of concrete structural components; lack of maintenance; or other design or operational defects. If gates cannot be opened during a major inflow at a reservoir, dam overtopping and possible dam failure may result. If dam failure does not occur, the reduced outflow from the dam may have the benefit of reducing downstream flood damage;

⇒ Spillway gates open accidentally through failure of automation equipment or some other unexpected occurrence;

⇒ Spillway gates are opened intentionally during a major flood in accordance with a flood operating plan. The downstream level is considered in the planning and design, and will reduce the chance of dam overtopping and possible failure. The flooding may impact many people, and those affected may question whether the spillways were operated correctly.

⇒ Spillway gates fail structurally because of a deficiency in gate design or lack of maintenance, causing a sudden increase in discharge downstream from the dam;

⇒ Debris blockage of spillway gates impedes outflow, possibly leading to damage to spillway gates and/or overtopping and dam failure;

⇒ Spillway gates are operated incorrectly. It is possible that some cases of misoperation go unreported. One case study of misoperation is contained in this document.

5.3 Lessons to be Remembered

From the References **[05-07 to 05-16]** it can be summarized the following information.

5.3.1 Small List of Damages

Order	Dam	Country - Location	Failure	Technical Information
5.3.1-A	San Teresa	Tormes River in Spain	1963	Construction of the 59-meter high earthfill dam was completed in 1960. In 1963, the ***malfunction of automatic controls of five 16-meter long tainter gates led to overtopping*** and foundation erosion (LAA et al., 1979).
5.3.1-B	Picote	Douro River in Portugal	1966	On February 16, 1966, during a flood, ***the hoist chains failed when the gates were being opened by remote control***. The cause of the accident was later determined to have been a lack of articulation in the chain links on the left side of the gate (caused by the accumulation of debris). The lack of articulation of the chain led to failure of the motor on the left side. The motor on the right side of the gate continued to operate, causing the gate to warp. The friction resulting from warping of the gate led to the failure of the right motor. The gate descended from its own weight, causing the gate to land forcibly on the sill. This resulted in the trunnion girders being torn from the fan, causing the gate to wash downstream. The accident put the two adjoining gates out of use and in the up (open) position because of lack of support of one end frame. Dam failure did not occur, and downstream damage was not reported (LEMOS et al., 1973).

Order	Dam	Country - Location	Failure	Technical Information
5.3.1-C	Belci	Tazldu River in northeast Romania	1991	During the night of July 28-29, 1991, torrential rainfall of an exceptional magnitude occurred. The spillway at the dam was composed of radial and flap gates. ***The supply of electricity to the dam failed, preventing the full opening of the gates. One radial gate had been lifted by only*** 40 centimeters at the time of the power outage, and the other radial gate never opened. Dam operating personnel tried to unblock and lower the flaps manually. After the dam failure, it was found that three of the four flap gates remained blocked. A total of 78 people were killed, and 19 were reported missing (DIACON et al., 1992).
5.3.1-D	Seton	British Columbia in Canada	1989	In 1989, the forebay radial gate ***opened automatically when the hoist motor energized itself without warning***. Water in an electrical conduit had frozen around the 460-volt, three-phase power supply leads. ***The expanding ice in the conduit pushed the leads upward, forcing the contacts closed, thus energizing the motor. The hoist raised the gate past the fully open position, causing the gate to hit the upper stop-beam.*** This caused the fuses in the circuit to blow, but not before structural damage had occurred to the gate arms and skin plate. The extent of downstream damage, if any, was not reported (M. WATSON, 1997).
5.3.1-E	Guernsey	Wyoming	1986	In 1986, one of two drum ***gates inadvertently opened at the southern spillway*** of Guernsey Dam in Wyoming. Debris left inside the gate by a painting contractor resulted in plugged drain lines. The interior of the gate filled with water, resulting in a loss of buoyancy. The gate reportedly opened approximately half way in 7 hours before the debris was cleared from the drain (READ, 2000).
5.3.1-F	Singur	Andhra Pradesh, India	1990	In October 1990, 1 of 17 radial spillway gates failed. This failure occurred during initial filling of the reservoir when the water level was 3 meters below design level. ***The gate became dislodged due to a detachment of the left side trunnion girder***.

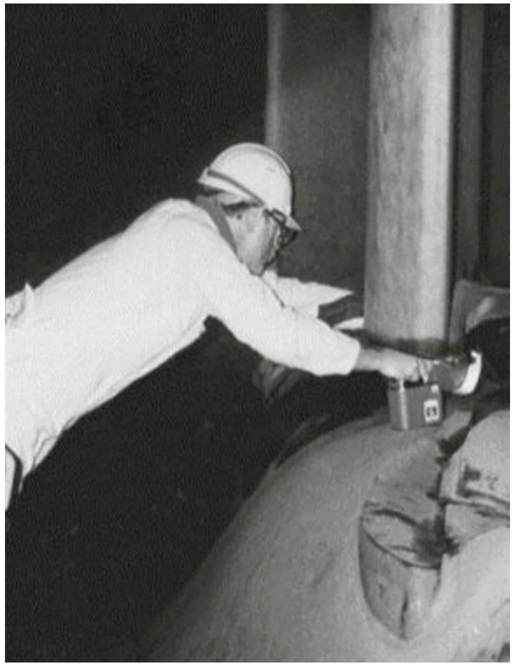
5.3.2 Examples of damages

Case	Identification	Country	Finished	Damage	References
5.3.2-A	Dartmouth Dam	Australia	1979	1990	05-07 to 05-16

Dartmouth Dam is a large rock-fill embankment dam with an uncontrolled chute spillway across the Mitta Mitta, Gibbo, and Dart rivers. The dam is located near Mount Bogong in the north-east of the Australian state of Victoria. The dam's purpose includes irrigation, the generation of hydroelectric power, water supply and conservation.

On 2 May 1990, the 180MW Francis turbine-generator running at full speed was instantaneously stopped by a foreign body left in the penstock following maintenance. The turbine casing and concrete machine block surrounding the power station ***were destroyed in May 1990 when two steel beams entered the turbine***. The resulting force ruined the power station and the dam's control systems, making it impossible to gradually release water from the near-capacity dam by conventional means.

An improvised system, placing large pipes over the spillway to siphon water over it, was soon installed, but the inflow from an unusually wet spring was such that the dam would have overflowed anyway, leading to a spectacular cascade over the huge rock steps formed when the rock used for the dam itself was quarried from the valley walls. The station was subsequently re-built and recommissioned in 1993.



One of the twelve stay vanes fractured at the base.

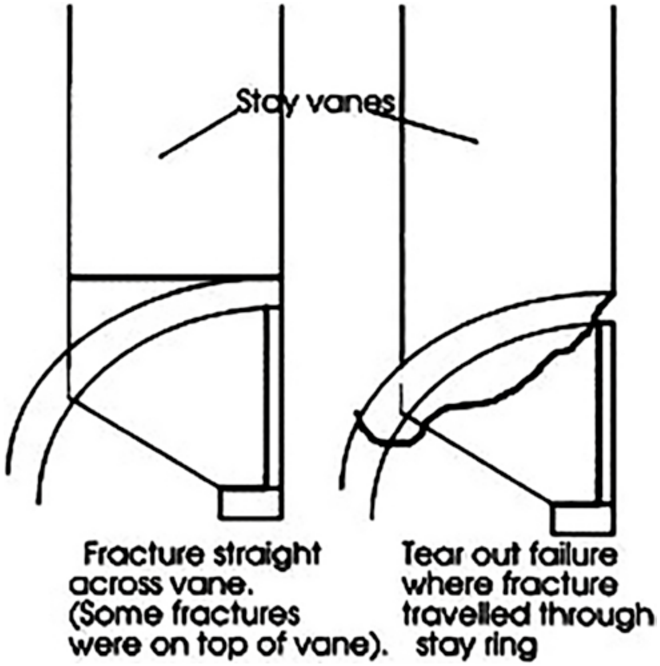


Illustration of fracture locations

Fracture surface

Case	Identification	Country	Finished	Damage	References
5.3.2-B	Folsom Dam	USA	1956	1995	05-07 to 05-16

The dam was built by the US Army Corps of Engineers in North California. Five gates, 13 m wide by 15.2 m high, are normally used for flood control. Three additional gates on the dam crest are only used for emergency. The design loading for the two arms that support the skin plate of the gate comprise the hydrostatic load and the load from the chain when raising the gate. The two arms each comprise four struts, with vertical bracing between the struts and diagonal bracing between the two lower struts. The gates are operated by mechanical hoists with two chains attached to the upstream face of the skin plate.

On 17 July 1995 one of the radial spillway gates failed during raising, resulting in an uncontrolled release of 1,133 m3/s and the breach was closed by stop logs. There were no provisions for stop logs, so they had to be designed, fabricated and installed.

Prior to the failure, there had been no indication of any structural problems, although there had been concern about rusting of the gates over the six years before the failure.

Examination of the failed gate indicated that the diagonal brace joint adjacent to the trunnion was the initial point of failure. Failure of the first brace caused the next diagonal brace to be overloaded and failure of the struts in column bending. Trunnion friction moment was the key factor in the overloading and failure of the gate, and had been omitted in the original design calculations. Over the years, corrosion had built up on the trunnion pins, increasing the friction and resulting in higher trunnion moments on the gate arms.

Inherent weaknesses in the original gate design were corrected by adding bracing and reinforcement. A preventative maintenance program was introduced which includes a full-cycle operation of the gates with grease applied to the trunnions.

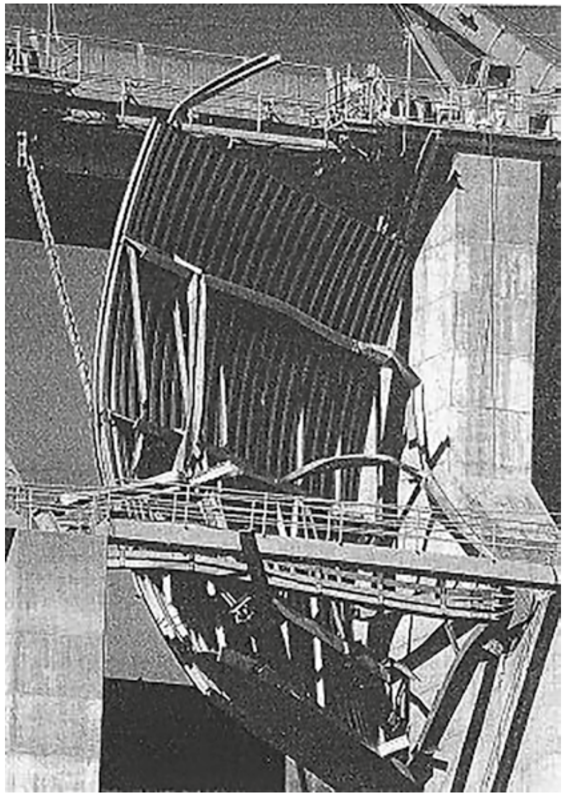
The failure was due to inadequate structural design, aggravated by corrosion on the loaded side of the steel trunnion pins and vibration. As a result of the incident, the following recommendations were made:

⇒ All radial spillway gates that could involve loss of human life in the event of failure should be inspected thoroughly and design calculations reviewed to ensure the gates meet current design standards;

⇒ Trunnion moments were not considered in many gate designs prior to the mid- 1960s and therefore reinforcement may have to be added where a trunnion moment was overlooked;

⇒ To prevent possible self-excited vibrations which can cause fatigue damage and damage to the hoisting system, gates should be made adequately stiff;

⇒ Monitoring of a gate's condition over time should be undertaken every five years and could include loading on the hoist, changing geometry of the arms and strain gauge data to check changes in the trunnion moment caused by corrosion.



Radial gate at Folsom dam during and after the failure

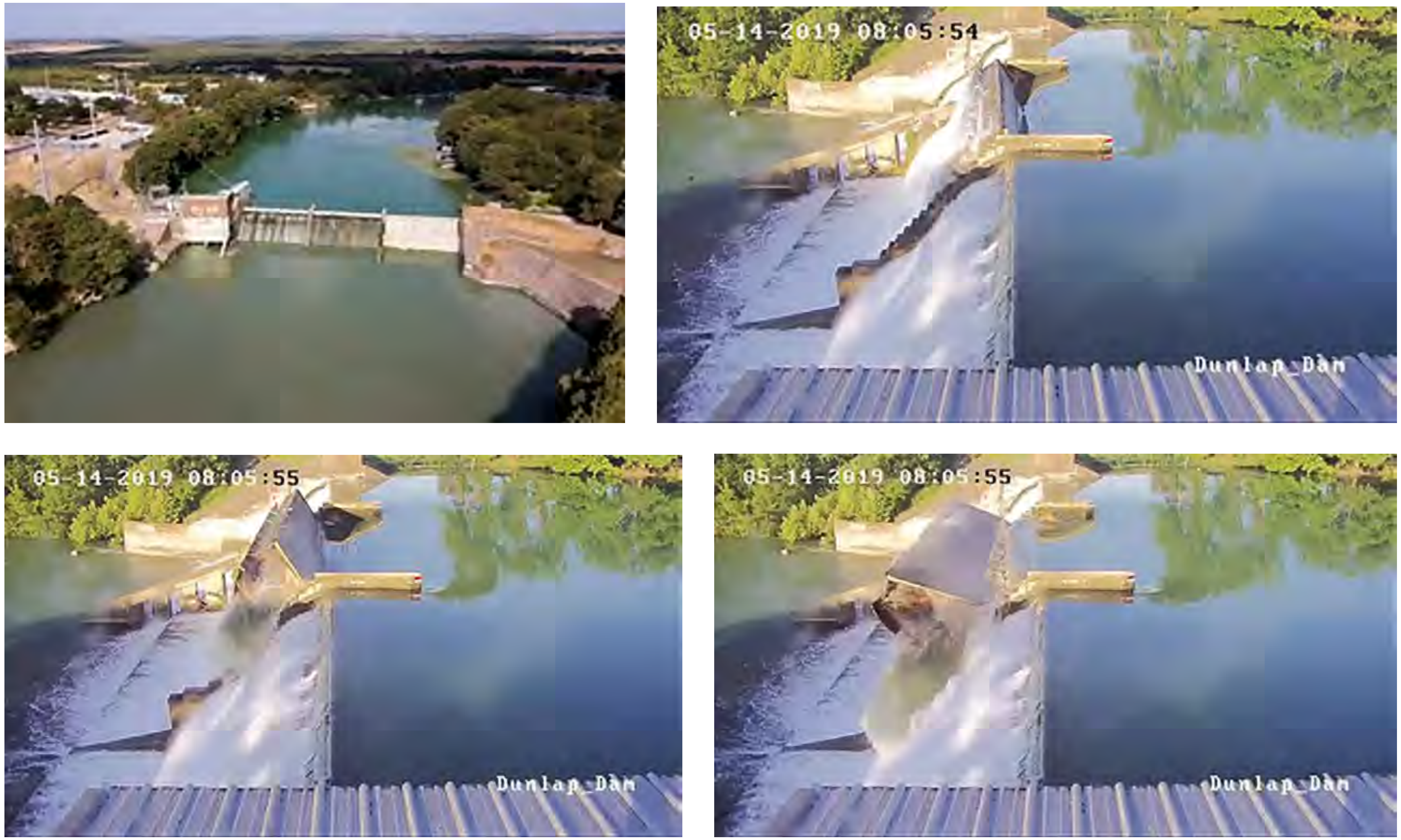
Case	Identification	Country	Finished	Damage	References
5.3.2-C	Lake Dunlap Dam	USA	1931	1995	05-07 to 05-16

The Lake Dunlap dam was finished in 1931 to provide hydroelectric power to the area of New Braunfels, Texas.

On the morning of May 14, 2019, at 8:05AM local, the dam's 90-year-old middle spillgate unexpectedly collapsed, nearly draining the lake by day's end. ***The collapse was due to aging structural steel.*** The collapse caused a large quantity of water to be driven downstream and, as a result, the lake's water level dropped by almost 3 meters in the following hours.

The failure has triggered severe concerns about the stability of aging dams, which raises a major issue since 1,263 dams at high risk exist in Texas, according to the American Society of Civil Engineers (ASCE). In particular, 67 dams that are over 50 years old are located in Williamson County. The problem does not only concern the degradation of the mechanical properties of the dam's components, but also the fact that they were constructed with obsolete safety codes.

Moreover, the dams that are considered vulnerable are required to have an emergency plan in case of a failure. The plan includes guidelines about how residents and officials should react in order to prevent any accident. However, according to ASCE, 20% of those dams do not have such plans.



Lake Dunlap dam spillway gate damage sequence (Disponível em: https://youtu.be/WrTp3JDG9Fs - Access: 17 jan. 2022)

Case	Identification	Country	Finished	Damage	References
5.3.2-D	Taiping Dam	China	1987	2008	05-07 to 05-16

Several dams and power plants damaged by the earthquake which occurred in China's Sichuan province on 12 May 2008.

In the afternoon of 12 May 2008, a magnitude 8 earthquake occurred in China's Sichuan province, with the epicenter at 17 km from the Zipingpu CFRD. The earthquake ruptured a 240 km long segment of the Longmenshan fault system separating the Tibetan Plateau from the Chengdu Basin and is referred to as the Wenchuan earthquake.

The Wenchuan earthquake has confirmed that earthquakes are multiple hazards, which may have the following features in the case of storage dams:

⇒ Ground shaking causing vibrations in dams, appurtenant structures and equipment, and their foundations;

⇒ Fault movements in the dam foundation or discontinuities in dam foundation near major faults which can be activated causing structural distortions;

⇒ Fault displacement in the reservoir bottom causing water waves in the reservoir or loss of freeboard;

⇒ Mass movements (rock falls, landslides);

⇒ Ground movements and settlements due to liquefaction, densification of soil, causing distortions in dams;

⇒ damage to spillway piers (cracks);

⇒ Retaining walls (overturning) ;

⇒ ***Powerhouses (cracking and puncturing and distortions);***

- ***Electro-mechanical equipment;***
- ***Hydro-mechanical equipment such as gates***;

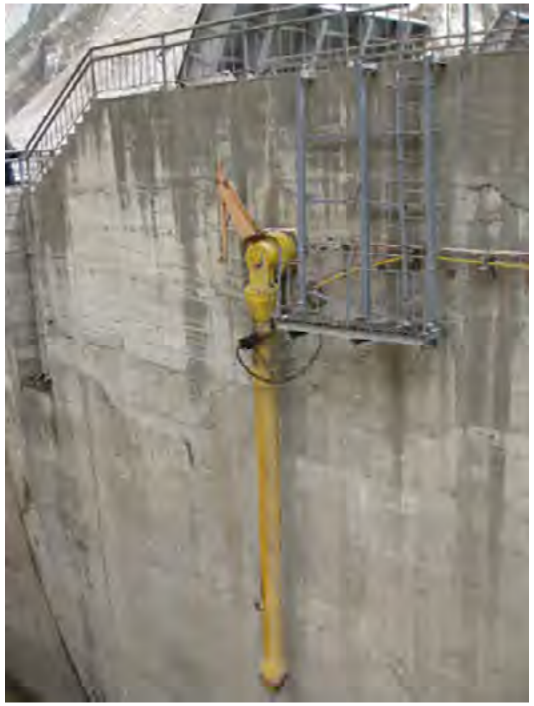
⇒ Mass movements into the reservoir causing impulse waves in the reservoir;

⇒ Mass movements blocking rivers and forming landslide lakes whose failure may lead to overtopping of run-of-river power plants or the inundation of powerhouses with equipment;

⇒ Mass movements blocking access roads to dam sites and appurtenant structures.

In the case of Taiping Dam Spillway, the Radial gate was damaged as below.

Radial gate of Taiping before the Earthquake



Failure of radial gate of run-of-river power plant due to rock falling on arm whose support has not been designed for transverse loads (May 12, 2008, Wenchuan earthquake)

Case	Identification	Country	Finished	Damage	References
5.3.2-E	Shapai Dam	China	2003	2008	05-07 to 05-16

In the case of Shapai Dam, the penstock was damaged as bellow due to the Earthquake

Failure of penstock near Shapai powerhouse: detail of damaged expansion joint (Wenchuan Earthquake)

Damaged crane, end wall and roof of powerhouse of Shapai arch-gravity dam project caused by rockfall; sediments were deposited due to penstock failure and powerhouse earthquake, China)

Case	Identification	Country	Finished	Damage	References
5.3.2-F	Sefidrud Dam	Iran	1962	1990	05-07 to 05-16

At Sefidrud dam, the radial gate of the intermediate level spillway shown was damaged during the 1990 Manjil earthquake

Sefirud Dam

Damage of the radial gate of intermediate level spillway of Sefidrud dam caused by June 21, 1990, Manjil earthquake, large hydrodynamic pressures caused inelastic buckling of gate arms, gate distortions and leakage

Non-structural elements falling on panel in control room of powerhouse of Sefidrud dam project and electrical cabinet attached to infill wall (June 21, 1990, Manjil earthquake)

Overturned switchyard equipment with high center of mass caused by amplified ground shaking on fill, and ground movements (Sefid Rud dam, June 21, 1990, Manjil earthquake)

Case	Identification	Country	Finished	Damage	References
5.3.2-G	Cleuson-Dixence Bieudron Hydro Plant	Switzerland	1998	2000	05-07 to 05-16

Engineers from Energie Ouest Suisse are examining the Cleuson-Dixence hydroelectric plant in Switzerland to attempt to determine the source of a 9 m rupture in the penstock. The rupture, which took place on 13 December, was in the penstock on the newest power house at Bieudron, and resulted in flooding and landslips in the local area.

The Bieudron powerhouse went into operation in 1998, drawing water from the Cleuson dam through a tunnel that falls some 1800 m from the reservoir. The water pressure in the tunnel varies from 26.5 bar at the top to some 210 bar at the bottom, and the tunnel was completely steel lined. The original construction of the penstocks was completed by a consortium of Giovanola of Italy (consortium leader), Sulzer Hydro and the then GEC Alsthom Neyrpic. In the fabrication, 6 m and 9 m lengths were assembled at site into sections 12 m long, before being lowered into the shaft. Members of the consortium assembled different parts of the penstocks, using several welding methods and automatic, semi-automatic or manual techniques as appropriate.

On 15 December engineers had not yet been inside the penstock to examine the damaged area in detail and speculation as to the cause was wide-ranging. ***A faulty weld was an immediate possibility, which may have been caused by inadequacies during the original construction or by corrosion in the two years since the hydro plant started up***. Rumours also blamed an earthquake said to have taken place on the day of the accident.

Whatever the cause, the effects were both dramatic and hazardous. Eyewitnesses described a mass of water being driven out of a crevice in the rock near to the foot of the tunnel at Nendez. The water was said to have damaged several buildings and some people had to be evacuated from the area. Landslips caused by the water blocked a local road and more flooding was caused when material from the landslip landed in the Rhone river. The situation is now said to be stable.

Case	Identification	Country	Finished	Decommissioning	References
5.3.2-H	Buntzen Power Plant	Canada	1914	2000	05-07 to 05-16

Old Buntzen Powerplant ***is a decommissioned hydroelectric dam***. According to BC Hydro, water from Buntzen Lake flows through penstocks down the steep mountain slope to two power plants located on Indian Arm. This station is Buntzen No. 2, which was completed in 1914 with three pelton wheels delivering a total of 26,700 kilowatts to meet Vancouver's continually increasing demand for secure electricity.

Buntzen Hydro Dam - Damaged Penstock - City of Vancouver Archives

Case	Identification	Country	Finished	Damage	Actions	References
5.3.2-I	Barra Bonita	Brazil	1962	1982/2006	Repair	05-17

Part of the tailrace guide wall on the right bank was damaged. In several other locations were observed cracks and the structure was not in contact with the foundation. The gates had to be repaired, also. Recently, the equipment for the supervision and control of the power house and locks have been updated.

Barra Bonita Dam, Power House and Lock

Damages in the guides of the tailrace - Barra Bonita Dam

Case	Identification	Country	Finished	Damage	Actions	References
5.3.2-J	Pepperell Dam	USA	1918	2012	Repair	05-18

The Pepperell dam was constructed in 1918 when the Pepperell Paper Company was formed to purchase the Nashua River Paper Company and constructed a new powerhouse on the opposite side of the river using a dedicated wood stave penstock to deliver all the flow to three new turbines located in a new powerhouse whose power output was delivered to the new paper mill. The 1918 concrete dam has an ogee shaped spillway, which was starting to crack and was repaired during the summer of 2012 ***when the penstock was replaced a second time since 1918***.



Penstock being replaced in Pepperell Dam

Case	Identification	Country	Finished	Damaged	References
5.3.2-K	Uhl III Dam	India	2012	2020	05-19

During the trial run as the 3×33.3 MW generating units were loaded for generation of 16 MW, the penstock 150 meters above the powerhouse burst and water gushed inside, badly damaging the machines. Penstock of the power house is about 8 km long and runs overground down the hill from the storage dam. A hydropower expert, having remained associated with many large power projects in Himachal Pradesh and other states, claiming anonymity, informed that the penstock bursting was not the first such accident in Himachal Pradesh.


Penstock of the power house that was burst during the trial step

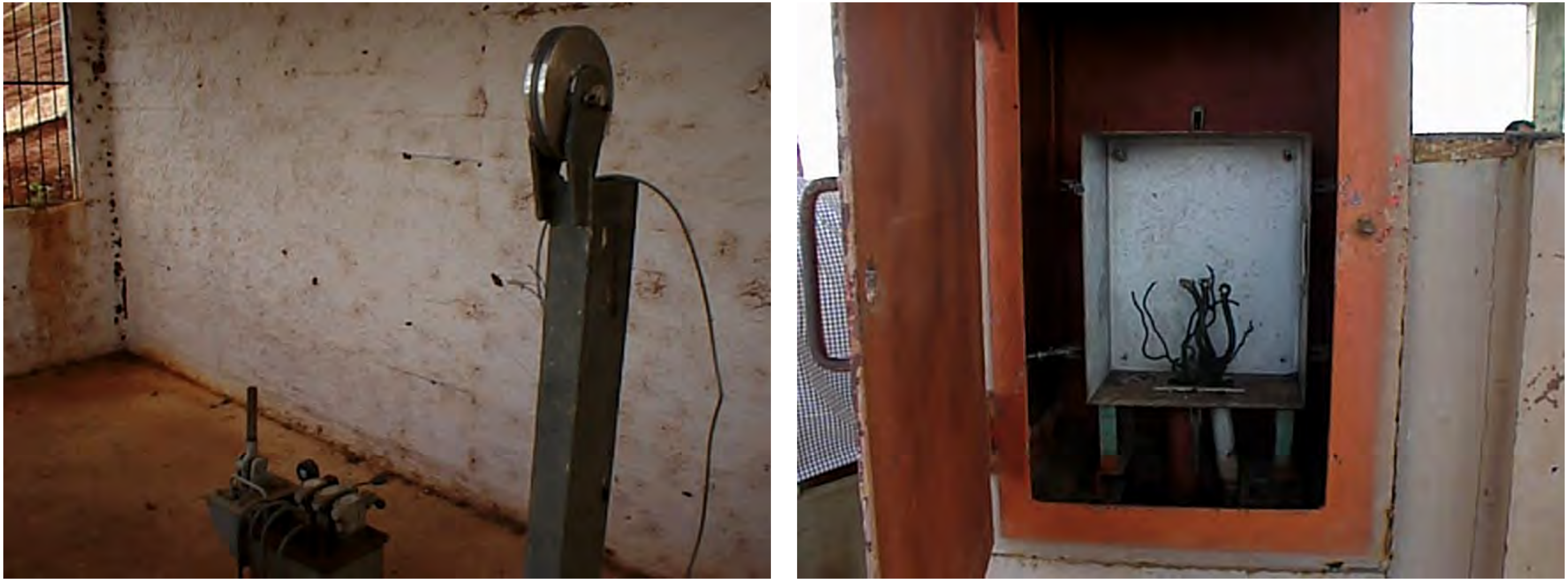
Case	Identification	Country	Construction	Damage	References
5.3.2-L	Ype Dam	Brazil	2016	2017	05-19

One of the gates of the spillway of the Ype dam of the Verdão River, in the municipality of Santa Helena de Goiás, broke and in September 2017.

Moment of the Rupture of the Ype Dam Spillway

The following are photos (File and Private Reports of Andriolo) evidencing vandalism and/or poor maintenance of the equipment.

Vandalism on equipment (Andriolo´s Archive)



Vandalism on equipment (Andriolo´s Archive)

Vandalism on equipment (Andriolo´s Archive)

Vandalism on equipment (Andriolo´s Archive)

Vandalism on equipment (Andriolo´s Archive)

5.3.3 Coincidence

The authors consider it important to remember that in item **7.1.1 - Chapter 7**, it is mentioned the coincidence of dam accidents that occurred in on 2020/may-20th, when the text of this book was in its beginning. However, during the period of completion and revision of this text, the authors obtained information that on 2020/august- 22nd, part of the concrete conduit of adduction to the pentstock in the Jati Dam, in Brazil, had failed.

As this **Chapter 5**, considers ***Auxiliary Buildings and Equipment***, the authors chose to consider this example of damage in this item.

Case	Identification	Country	Finished	Damage	References
5.3.4-A	Jati Dam	Ceara State-Brazil	June/26th-2020	August/22nd-2020	See Notes below

Notes: The Information were obtained from:

Order	Information from
A	https://www.youtube.com/watch?v=nprbYsU4yLc
B	https://diariodonordeste.verdesmares.com.br/regiao/erro-de-empresa-em-montagem-de-valvulas-causou-vazamento-na-barragem-de-jati-aponta-pericia-1.3017854
C	https://www.youtube.com/watch?v=Q9eGl3DPsEg&t=431s

The project is part of the northern axis of the transposition of the São Francisco River - Inter Basin Transfer Project - which was put into operation on 2020/June-26th. On 2020/August- 22nd, the damage occurred in the concrete conduit that fed the flow of water from the water intake to the adduction of the valve system to supply a Basin Transfer channel and a future hydroelectric plant.

An analysis was prepared by a group of five experts, hired by the Government Agency, and evaluated on site the affected structures and analyzed the documentation provided by the companies involved in the project. This report was available by the government agency on 2020/December-2nd, 2020, reported:

⇒ That there was a ***failure in the assembly and commissioning of the valve assembly***. The operation of the spherical valve, whose installation and subsequent operation did not occur according to the standards and standards determined by the manufacturer itself, caused its inopportune closure and, as a consequence, ***the hydraulic transient that exceeded the design values***, leading to the collapse of the concrete conduit;

⇒ The sequence of failures points to ***a sum of errors made in the operation of the dam, under the responsibility of the Construction Consortium***, at the time of the incident, with the following information:

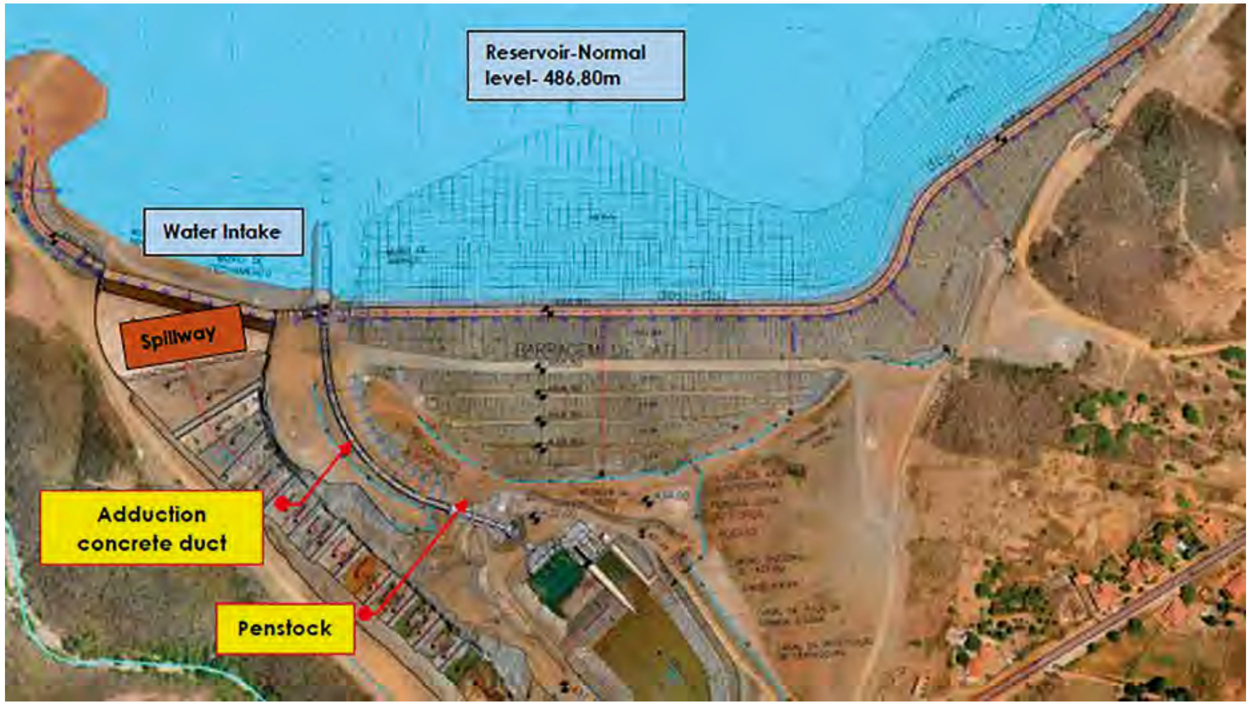
- Failures in the phases/activities of assembly and commissioning of the valve assembly (spherical and dispersing) ***impacted the safe conditions of Operation of the Jati Dam;***
- ***The incomplete assembly prevented the automatic operation of the valve assembly, which would ensure the safety of operation*** due to the automated interlock provided in its design;
- The option of a manual marking of the position indication of the spherical valve (open/closed), instead of the correct installation of the set of sensors indicators of its position, potentiated the insecurity for the operation, as it imposed the need for a visual verification of the open/closed position, ***transferring to the operator the responsibility of this check, a procedure that can be failed***. The manual marking itself, made inaccurately, has by itself already promoted a visual verification error.

⇒ It is observed that the ***commissioning activity was not performed, an activity that is crucial for the safety of the operation, because it is precisely in the pre-operation, verifying all possible failures that could have occurred in previous phases***.

⇒ This assembly and commissioning should have been carried out by the consortium contracted for the operation.

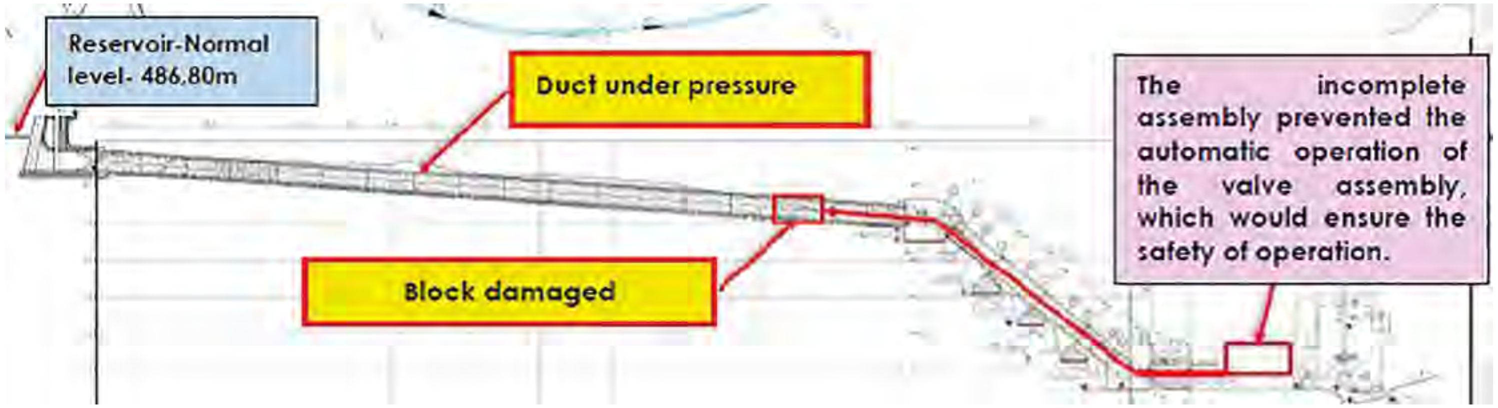
⇒ The results of the studies present satisfactory stability conditions for the upstream and downstream of the ***Jati Dam***, i.e. no additional interventions are necessary with regard to the repair of the downstream dam slope.

Jati Dam - General view



Jati Dam and the Water Intake, Spillway, Conduit and Penstock

Jati Dam - Auxiliary Structures and damaged area - From the References



Jati Dam and damage information - From the References

Concrete conduit failure, and concrete aspect after the damage - From the References

5.4 Preventive and Protective Actions

The reliability of mechanical and electrical equipment and components installed in appurtenant structures that fulfil a dam and reservoir safety **function is critical to dam safety**. The installed equipment usually has a significant shorter life than the associated civil works and replacement is usually necessary within 30 to 40 years of installation. ***Shorter lifespans can result from the combined effects of corrosion, erosion, excessive vibration and poor maintenance, and communication and control systems can become outdated and unsupported within a few years.***

The aging gates and guides as rails deteriorate faster. Such installations need to be monitored for their strength more often, especially if the installations are more than 30 years old. Before executing the rehabilitation of aged equipment or installations, assessment of the deterioration of the structure needs to be monitored with reference to its original design parameters. The integrity of the equipment under question is required to be assessed by measurement of thicknesses of skin plate, horizontal girders, and vertical stiffeners etc. after removal of rust, scales etc. by grit/sand blasting.

Aspects like maintenance requirements; safe operating procedures etc. need to be documented in operation & maintenance manuals, and inspections reports.

A regular schedule of operation, inspection and maintenance can restore the damages and deficiencies to a great extent and postpones the requirement of rehabilitation by extending its useful life.

Having established the structural weaknesses, process of strengthening the structure is proposed for restoration of its strength to withstand safely the water pressure and hydrodynamic forces encountered by the structure.

A primary driver for the rehabilitation of appurtenant structures, which include spillway and outlet facilities together with their gate and/or valve systems, is the effects of aging and deterioration of mechanical and electrical equipment. Other primary drivers include a requirement for additional capacity (e.g. spillway capacity, generation capacity), additional diversity and redundancy in power supply and/or control systems, and damage to the civil works by appurtenant structure discharges (e.g. cavitation damage in surface spillways, abrasion damage in low level outlet structures, scour immediately downstream of discharge facilities).

The following lists [05-20 & 05-21] can be useful for a check-up during the design step and for the inspection and maintenance routines.

Equipment and Type	Main Application	Advantages	Disadvantages
Gates in open channels			
Radial gate- Motorized operation	Sluice installations. River control. Spillways. Dams.	No unbalanced forces. Absence of gate slots. Low hoisting force. Mechanically simple. Bearing out of water. Can be fitted with overflow section. Some inspection with gate in service possible	Extended flume walls. High concentrated load. Increased fabrication complexity.
Radial gate – automatic	Sluice installations, River control.	No outside source of power required. Absence of machinery. Low maintenance	Wide piers to accommodate displacers. Counterbalance visually intrusive. Can malfunction due to incorrect design. Can malfunction due to blockage of inlet of control system.
Vertical – lift gates	Sluice installations. River control. Old installations. Spillways. Dams.	Can be fitted with overflow sections. Short piers. Wide span gates can be engineered to provide good navigation openings. Up and over gates can reduce height of supporting structure.	Gate slots required. Load roller underwater. Can jam due to debris. High hoisting load unless counterbalanced. Overhead support structure visually intrusive
Flap gate – Bottom hinged	Tidal dams. Sluice installation. River control	Complete separation of saline and fresh water. Overflow to clear debris. No visually intrusive overhead structure. Can in some cases be designed to open under gravity in emergency.	Requires extensive side staunching for side sealing or very accurately constructed pier walls. Hinge bearings not easily accessible and permanently immersed
Flap gate – Top inged	Tidal outlets.	No outside source of power required, automatic in operation. Absence of machinery. Little maintenance. Simple construction.	Cannot control water levels. Will not entirely exclude tidal water if D/S water level rises above sill. Gate slam can occur.

Equipment and Type	Main Application	Advantages	Disadvantages
Gates in open channels			
Drum and sector Gates	Spillways.	No outside source of power required, automatic in operation.	Complex gates. Require civil works. Require zero d/s water level. Control system critical. Can silt up. Not preferred.
Gate in submerged outlets			
Vertical lift intake gate – Hydraulic hoist operated	Control and emergency closure.	Reliable control gate. Good load distribution in the slide version. Damped.	Gate slots required. Load rollers/ slide operate underwater. Requires stem connection between hydraulic hoist cylinder & gate. Possible cavitation problems. Slow operation to raise to the maintenance position. Require air admission.
Vertical lift Intake gate – Rope drumhoist operated	Bulkhead gate.	Can be roller or slide type. Does not require air admission.	Cannot be used as a Control or emergency closure gate. Requires balanced head for operation. Guide slots required. Possible cavitation problems. Requires bypass system.
Caterpillar or coaster gate	Control and emergency closure.	Control gate for very high heads.	Wide gate slots required. Caterpillar train operates underwater. Requires stem connection between hydraulic hoist cylinder & gate. Cavitation problems. Slow operation to raise to the maintenance position. Very costly. Require air admission
Radial – intake gate	Control and emergency closure gate. Intake gate	Absence of gate slots. Requires no load rollers or slides.	Require chamber to retract. High concentrated load. Lintel seal critical. Require dewatering of tunnel to carry out maintenance. Require air admission.

Equipment and Type	Main Application	Advantages	Disadvantages
Gates in open channels			
Slide gates	Control gates in conduit. Back-up gate for a control gate	Reliable control gate or emergency closure gate. Inherently damped due to sliding friction.	Gate slots required. Require bonnet for withdrawal. Require air admission.
Radial gates	Control gates in conduit.	Absence of gate slots Requires no load rollers or slides. Lower hoisting force required	Require chamber to retract. High concentrated load. Lintel seal critical. Require dewatering of tunnel to carry out maintenance. Require air admission.

Element	Check and Action List
Vertical Lift Wheeled Gates	⇒ Surface cracks on steel works & on surrounding concrete works, especially in load bearing locations & welds; ⇒ All bolts & nuts are tight (loosened bolts & nuts need to be tightened); ⇒ Crack damages like boils or blisters in painted surfaces; ⇒ Surface cracks on steel works & on surrounding concrete works, especially in load bearing locations & welds; ⇒ All bolts & nuts are tight (loosened bolts & nuts need to be tightened); ⇒ Crack damages like boils or blisters in painted surfaces; ⇒ Accumulation of water & silt on horizontal girders & other members of the gate structure, ask the Project to provide drain holes, if not provided or these need to be enhanced in numbers or size at appropriate location; ⇒ Surface cracks on steel works & on surrounding concrete works, especially in load bearing locations & welds; ⇒ All bolts & nuts are tight; ⇒ Surface cracks on steel works on surrounding concrete works, especially in load bearing locations & welds; ⇒ Crack damages like boils or blisters in painted surfaces; ⇒ Accumulation of water & silt on horizontal girders & other members of the gate structure, require providing drain holes, if not provided or these need to be enhanced in numbers or size at appropriate locations; ⇒ Gate operation for lifting & lowering cycles is seen. Notice if the movement of gate is smooth or jerky & without vibrations; ⇒ Downstream side of skin plate T members of radial gates watch that inside faces of T-beams are painted, as such difficult locations (or painting) are generally left out for surface; ⇒ preparation as well as painting; ⇒ Free rotation of wheels of vertical lift gates by hand movement.

Element	Check and Action List
Radial Gates & Hoists	⇒ Seals for damages, damaged/ loose seal bolts & nuts, missing seal portions for replacement by a new set of seals & fasteners; ⇒ For any damage to lifting attachments, pulleys and pins; ⇒ For ongoing structural steel fabrication/ welding works, arrangement of detection on structural fabrication work as well as on welds be insisted.
Mechanical Rope Drum Hoists – Wire Rope	⇒ Inspect the wire rope for wear and tear, the rope strands for cracks, broken & damaged wires, visible oxidation/ rusting; ⇒ Trash, sediments and any foreign material sticking to the lifting rope and lifting attachment for cleaning; ⇒ If the wear and tear / broken wires are found to be more than permissible or marked corrosion is noticed, the project should be advised to get it replaced; ⇒ Besides, it should also be done whenever the wire rope is found to be dry; ⇒ Adjust the rope tension of wires, if both side ropes are found unequal; ⇒ All greasing points like trunnions, gear trains/ gear boxes, wheels etc. for re-greasing; ⇒ The expansion provision in case of independent unbonded anchorages; ⇒ All approach ladders, walkways, hand railings, rung ladders, chequered plates are not badly rusted & are of good strength & safe for usage; ⇒ The condition of Motor, Brake, gear boxes, Electrical panel, rope drum, etc. for cleanliness, serviced/un-serviced condition; ⇒ Oil level in gear boxes and get it noted for replenishment wherever required with oil of proper grade; ⇒ For Lubrication of all bearings, bushings, pins, linkages, etc.

Element	Check and Action List
Gantry Crane	⇒ Oil level in the gear boxes. It is very important to ensure that the correct oil level is maintained. Over filling causes overheating and leakage, therefore, care should be taken that the breather holes are not clogged by any foreign material like dust, paint etc.;
	⇒ Insulation resistance of motor winding;
	⇒ All the electrical connections;
	⇒ Lubrication of each part of the crane;
	⇒ Removal of any loose/foreign material along the rail track;
	⇒ Actuating tests of limit switches;
	⇒ Actuating tests of brakes;
	⇒ All fuses in the control panel should be checked and if necessary it should be replaced;
	⇒ Necessary terminal connections of motors, brakes etc. is to be checked;
	⇒ Overload relay should be checked;
	⇒ Visual inspection of wire ropes for any snapped loose wire and its proper lubrication;
	⇒ Checking of rope clamps on the drum and tightening of bolts if required;
	⇒ Gearbox assembly should not have any leakage of oil;
	⇒ Unusual noise/vibration if any should be checked and rectified before operation.

Element	Check and Action List
Mechanical Hoists	⇒ All the fuses on power lines for damages, if any and ensure closure of panel board covers to avoid entry of dust and moisture; ⇒ All bolts and nuts on gear boxes, hoist drum and shaft couplings for tightness; ⇒ That the starters should are cleaned & free of moisture and dust; ⇒ All the geared couplings are greased; ⇒ Bearings for damages; ⇒ Gears and pinions for damage; ⇒ Plummer blocks for damage; ⇒ Check for any painting damage.

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6

DOCUMENTS

6.1 Historical Remarks

Marcus Vitruvius Pollio a famous Roman architect from the 1st century BC in his work "***De Architectura***"[06-01], which is a summary of his own experience in the field of architecture, consisting of 10 volumes, and that was written around 15 BC and dedicated to the emperor, had mentioned in the Book IV, an introduction that mentions:

"...I have observed, Emperor, that many in their treatises and volumes of commentaries on architecture ***have not presented the subject with well-ordered completeness, but have merely made a beginning and left, as it were, only desultory fragments. I have therefore thought that it would be a worthy and very useful thing to reduce the whole of this great art to a complete and orderly form of presentation, and then in different books to lay down and explain the required characteristics of different departments****...*

(***note– Bolded emphasis added***)

...Hence, Caesar, in my first book I have set forth to you the function of the architect and the things in which he ought to be trained. In the second I have discussed the supplies of material of which buildings are constructed. In the third, which deals with the arrangements of temples and their variety of form, I showed the nature and number of their classes, with the adjustments proper to each form according to the usage of the Ionic order, one of the three which exhibit the greatest delicacy of proportion in their symmetrical measurements. In the present book I shall speak of the established rules for the Doric and Corinthian orders, and shall explain their differences and peculiarities..."

The report of the history of the dam provides valuable information concerning the safe of its structure, the chronology documentation (letters, diaries, reports) including ordering of materials, construction, unusual equipment and or methodology may be necessary to clarify some subject.

Written documentation should be maintained in standardized format on all design-related information of the project. Planning design documentation should cover the project objectives and the studies made to locate, size, classify as to potential hazard, and select the type of dam and auxiliary facilities. Site investigation documentation covering geologic mapping and studies made of the geologic and geotechnical explorations and conditions for the various dam sites considered and the detailed investigations for the chosen site.

Geological, seismological, and geotechnical features and considerations, whether specifically identified during the investigation, interpretations from the data and experience at other sites, or suspected by experienced personnel, should be available for the ***Dam Safety*** analysis. Design documentation should include all design criteria, data and qualitative information, assumptions, analyses and computations, studies on discarded alternatives, and derived judgments and decisions.

As-built drawings should be available, considering the facilities that were adopted, and the routines that were considered for operation and maintenance and inspection.

6.2 Government Regulations and Responsibilities

Dams are structures that differ from many other engineering creations. What makes them different is the longevity of service, and thereby, the exceptional length of their economic life. The typical life cycle of a ***properly engineered dam*** can exceed 100 years.

Since the safety impacts of dam presence or operation may affect people, property and the environment, these principles and policies must be in agreement with the general interest of the population. These Interests are usually protected by the country's laws and government regulations.

The fundamental safety objective applies to all dams and dam operational activities and to all stages over the lifetime of a dam including planning, design, construction, commissioning, operation, maintenance, and either the long-term sustainability of the dam or decommissioning of the dam.

The Project Company or Engineer in charge of the design of a dam must be a registered and have the training and experience to properly apply the knowledge to the specifics of the site and the needs of the owner. Dams are complex structures that typically require a multidisciplinary analysis and design approach.

Because each project requires site-specific considerations, these texts should not be viewed as a cooking recipe for the design, repair, modification, or construction of a dam. The intent of this text is to outline the general technical data, engineering computations, and plans that need to be analyzed concerning the ***Dam Safe***. It is important that the documents consider archaeological and environmental issues in the design or modification of a dam.

The storage of water is a hazardous activity that creates increased risk to lives and property located downstream of the dam. The owner of a dam is responsible for operating and maintaining the dam safely.

A property owner of a dam should retain the data of the services during the design and construction of dams and waterways. It is common practice for the owner and the engineer to discuss the owner's needs, the intended purpose of the dam, and the project budget before any design work is performed, these information are important to the safety analysis. During the design process, the owner remains in close contact with the engineer to periodically review the design and the desired project goals. These aspects must be reported and in hands during the operational dam life.

During construction, the owner works closely with the engineer, supervision and the contractors. After construction, an owner assumes the role as the primary caretaker of the project. Routine inspection and maintenance allow early detection of many problems that could occur with a dam. The owner should inspect the dam often, keep records of observations and measurements and learn as much as possible about the operation and maintenance of the dam.

Although a dam can be designed and constructed to be a ***safe structure***, lack of routine maintenance and repair, or changing conditions, can eventually cause the dam to become unsafe. If a dam is not in compliance with government law, the owner will be required to improve the dam to bring it into compliance.

There are several things to consider about the ***Dam Safety***, including understanding the government regulations about harvesting water. The primary focus a government regulation is to ensure that dams are designed, constructed, operated and maintained in a safe and responsible manner.

The regulations had been established to ensure that the responsible for a dam can sufficiently demonstrate that reasonable measures have been incorporated into the project's design to address the impacts associated with constructing and operating a dam at the proposed location.

These requirements are intended to provide with sufficient information regarding the scope, potential, scale and complexity of the project, to identify conditions which must be met for the dam, region and population be in a safe use.

The *ICOLD Bulletin 154 – Dam Safety Management – Operational Phase of the Dam Life Cycle – 2017*, mentioned[06 02]:

"...The prime responsibility for operational integrity and safety of a dam should rest with the Dam Owner. The Dam Owner is ultimately responsible of assuring the safety of the public, property and environment around and downstream of dams. However since dams are often not owned and operated by a single individual company or organization the term Responsible Entity is used In this Bulletin. Usually the dam owner is the Responsible Entity. Sometimes a government Institution or agency is responsible for the safety of the dam and the public either directly or through oversight over the safety management activities of the bodies that operatehe dam.

The safety arrangements established by the Responsible Entity must conform to the requirements and expectations of government and the prevailing laws regardless of how they are established and implemented. Therefore, the Responsible Entity's values and principles that govern safety management reside within the overarching legislative and regulatory value system of the Country were the dam is located.

In some instances, for dams the responsible entity may be a branch of government with significant internal dam engineering and safety management capability, and which is responsible of all aspects of the operational integrity and safety management of the dam over its entire life-cycle. Conversely, the Responsible Entity may have no engineering capability and in the absence of prescriptive regulatory requirements it will be the legislative and judicial arms of government where the safety of dams is implied by existing legislation and precedents with all responsibility for meeting the intent of the law resting with the Responsible Entity.

In order for the Responsible Entity to be confident that it is meeting all obligations in relation to the safety of its dams, a systematic approach to dam safety management activities is needed. This means that the Responsible Entity is responsible at a minimum for:

1) *Establishing and maintaining the necessary competencies;*
2) *Providing adequate training and information;*
3) *Establishing procedures and arrangements to maintain safety under all conditions;*
4) *Verifying appropriate design and the adequate quality of facilities and activities and of their associated equipment;*
5) *Ensuring the safe control of all inflows, outflows and stored volumes;*
6) *Ensuring the safe control of all sediments and deleterious materials that arise as a result of the dam.*

Dam safety management covers the full spectrum of hazardous conditions, including dam Failure, which can arise from the activities of storing and discharging water. Since dam management can span many human generations, considerations1 should be given to the fulfilment of the responsibilities of the Responsible Entity and the regulator in relation to both present and future operation. Provision should be made for the continuity of responsibilities and the fulfilment of funding requirements in the long term.

These responsibilities should be fulfilled in accordance with applicable safety objectives and requirements as established or approved by the regulatory body, and their fulfilment is to be ensured through the implementation of a management system…"

6.3 Design Report

6.3.1 Conceptual Aspects and General Site Conditions

For the analysis of a **Dam Safety**, one of the documents to be available to understand the dam and reservoir aspects is a Design Report. Documentation should cover investigation and design, construction plans and construction history, operation and maintenance instructions.

The design report must contain information considering the site conditions as resource areas: biological resources (wildlife, vegetation, and special status species); water resources (ground water, surface water, water quality, and wetlands); earth resources (geology, topography, and soils); cultural resources; recreation; air quality; socioeconomics; and environmental justice.

A design report, submitted to the owner, should include an evaluation of the foundation conditions, the hydrologic and hydraulic design and a structural stability analysis of the dam. The report should include calculations and be sufficiently detailed to accurately define the final design and proposed work as represented on the construction plans. Any deviations from the guidelines should be fully explained. A Design Report can be understood as a document that provides:

- ⇒ An overview of the general site conditions that are relevant to the dam design;
- ⇒ Considerations about the environmental aspects;
- ⇒ Design criteria and assumptions related with calculations;
- ⇒ Geotechnical and hydrotechnical analyses;
- ⇒ Materials availability and quality;
- ⇒ Construction approach for the dam design;
- ⇒ Considerations concerning the system for quality control;
- ⇒ Considerations of the dam operation, maintenance, and monitoring;
- ⇒ Considerations and advices related to the dam impoundment;
- ⇒ Assumptions associated with additional recommendations.

The main purpose of a safety review is to obtain an overall view of the actual state of safety of the dam system, considering all the available documents, determine whether any modifications (organizational. managerial and structural) are necessary to ensure that the level of safety is appropriate. and ensure that the principle of continuous improvement is observed. The safety review constitutes a comprehensive assessment of the dam system and provides answers to the following questions:

- ⇒ Does the dam system conform to current regulatory requirements, current national and international standards and practices, and to current requirements with respect to acceptable and tolerable risk criteria?
- ⇒ Are the managerial and organizational arrangements currently in place sufficient to maintain the levels of safety in conformance with the above requirements until the next safety review?

The safety analysis should assess expected or planned (if the assessment takes place in the design phase) performance of the dam system against the entire range of operational states and operating conditions, to obtain complete understanding of how the dam is expected to perform.

6.3.2 Design Criteria

All around the world there are many available design criteria for dams, but many times the authors are faced that some engineers had adopted a part of each criteria. It is important that these situations be explained and justified when the dam is being analyzed under its safe condition.

If an existing design criteria and guidance from past projects and experience were used for design of the hydraulic appurtenances, their sufficiency should be documented. When a sufficient criteria and guidance are not available for analytical design of the hydraulic appurtenances, physical hydraulic model studies could be performed.

For non-gravity structures such as arch dams, the designer is required to present calculations based on appropriate elastic techniques as approved by the ***Dam Safety***.

The loads that were considered in stability analyses need to be considered the external water pressure, internal water pressure (pore pressure or uplift) in the dam and foundation, silt pressure, ice pressure, earthquake, weight of the structure. The uplift hydrostatic pressure from reservoir water and tailwater that were considered acting on the dam. The efficiency of the drains must be verified through piezometer readings.

Different load conditions must be shown, including the seismic condition, reservoir water surface at different levels, plus a seismic coefficient applicable to the location.

The resultant from an overturning analysis should be informed. Additionally, if some tension cracks could not be accepted in the design or if it was acceptable in an exceptional condition, it needs to be informed. Sliding safety factors must be informed related the shear characteristics that were adopted. Additional data should be available for dam under rehabilitations or dam modifications.

6.4 Technical Specifications-Standards

This is an important aspect that the authors had observed in various set of documents for a dam design and inspections for ***dam safety*** procedures. There are situations that a technical specification requires properties of materials and for some works, with different standards. There are no consistency between different standards adopted, that comes from different organizations and countries. Sometimes this aspect can cause conflicts.

Where the contract and the documents established specific standards for the design and construction of projects this must be demonstrated that these standards have been complied with in the project proposal and required properties and works.

In the absence of some standards, it was important to ensure that all applicable standards used are based, so far as reasonably practicable, on accepted engineering and scientific principles and practices and have been developed and/or reviewed by qualified persons with the necessary qualifications, knowledge and experience to evaluate their suitability.

The concepts of ***Durability***, ***Uniformity*** and ***Limits*** must be very well described and understood by all the entities involved and as possible as described in the standards

The environmental effects of water impoundment vary greatly with the characteristics of the region as well as the type of reservoir to be constructed (area and depth of reservoir, ratio of water inflow to storage). Due to this, it is important that a special report be available considering the reservoir impoundment planning, operations and inspections. The potential impact of altered flow regimes, siltation, reduction in beach formation and nutrient enrichment at the mouths of rivers, and the possibility of saltwater encroachment should receive careful study.

A thorough description of the plants and animals to be affected by inundation should be made to determine the possible loss of rare or key organisms, as well as the potential development of "nuisance species". Included in this report should be a detailed study of existing fish and the potential for commercial fishery development in the proposed reservoir.

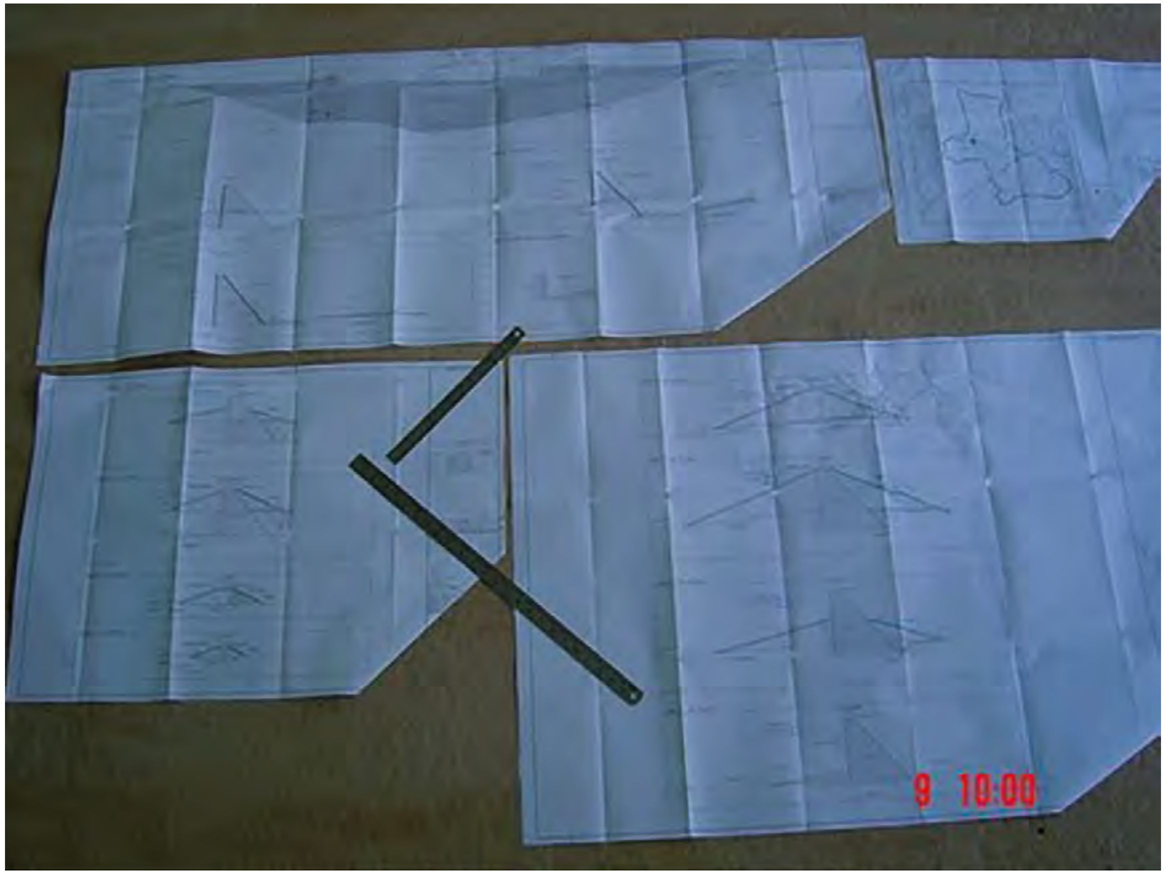
Consideration should be reported to vegetation removal in the reservoir basin prior to inundation, since decaying vegetation can result in deoxygenation, formation of hydrogen sulfide, possible development of suitable habitats for undesirable species and snagging of fish nets.

Sanitation and land use practices as well as erosion in the watershed surrounding the reservoir must be controlled to prevent accelerated eutrophication caused by increased nutrient loading. Inundation in tropical areas can have serious sociological and human health implications including the increase of diseases, e.g., malaria, schistosomiasis, onchocerciasis, and dysentery, and the probable resettlement and alteration of land use practices.

Census information and surveys concerning land use, housing and health standards and the social and economic structure of the community to be affected must be reported in order to anticipate and avoid potential problems.

6.5 Drawings

To verify if a dam is safe a set of drawings provided by the owner need be available in plan, profile and cross-section view, with dimensional data appropriately labelled with length, width, horizontal and vertical dimensions. The drawings should include the entire dam structure, showing the entire extent of the dam and construction site, including construction access.



Drawings in different and no Standard format-dimensions, showing a “poor” discipline-organization (From Andriolo’s Archive)

The technical drawing is a form of graphic expression that aims to represent the shape, dimension and position of objects according to the different needs required by the various modalities and engineering. Using a set consisting of lines, numbers, symbols and internationally standardized written indications, the technical design is defined as the universal graphic language of engineering and architecture. The interpretation of the graphic language of the technical design requires specific training because flat (two-dimensional) figures are used to represent spatial shapes.

In works involving technological knowledge of engineering, the feasibility of good ideas depends on calculations, economic studies, risk analysis, among others, which, in most cases, are summarized in drawings that represent what should be executed or constructed or presented in graphs and diagrams that show the results of the studies done. All the process of development and creation within engineering is closely linked to graphic expression. Technical design is a tool that can be used not only to present results, but also for graphical solutions that can replace complicated calculations.

The standardization of all drawings of the dam project must comply with internationally accepted technical standards.

6.6 Plan for Initial Filling of the Dam Reservoir

First filling of a reservoir is the first indication that the dam is safe and will function as designed. Therefore, first filling of a reservoir should be carefully planned and implemented to ensure safety of the dam and future success of the dam. The initial filling of a reservoir is the first test that the dam will perform the function for which it was designed.

Specifications regarding the rate of reservoir rise should be described to allow the dam to adjust to the forces it will experience as the water level behind it increases. These plans should be documented in a document that may also include reservoir regulations for the water control plan, project surveillance, cultural site surveillance, flood emergency plan, public affairs, safety plan, and transportation and communications. In addition to dam failure, it is common for design, construction, and/or material deficiencies of a new dam to become apparent during the first filling. For example, evidence of seepage, cracking, and erosion are often noted when the reservoir is raised to new levels for the first time. Inspection and assessment of these potentially hazardous conditions prior to the completion of filling is important and it may be necessary to halt filling or in some cases lower the reservoir before the desired operating water level is completed to investigate signs of seepage, cracking and erosion.

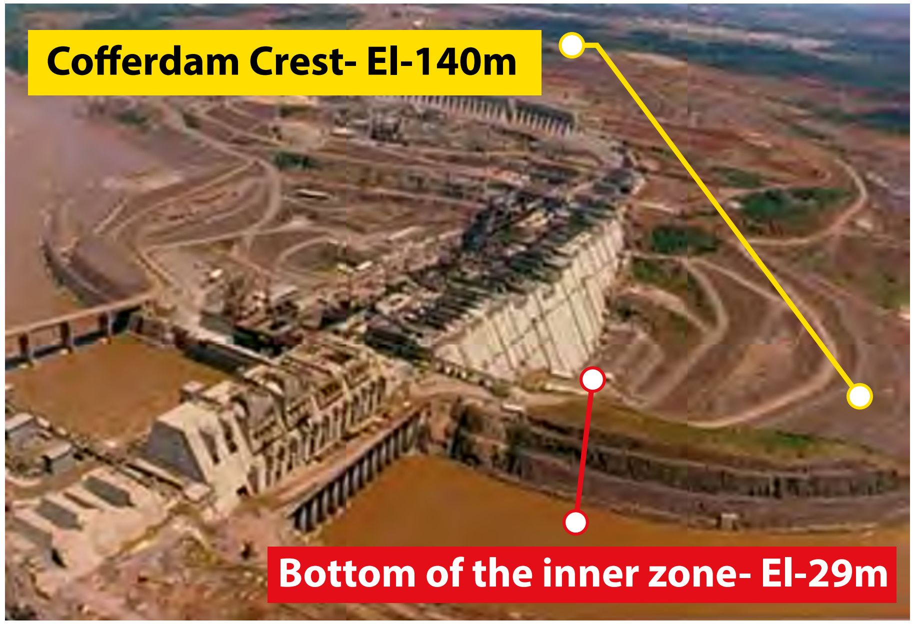
Thus, it is vital for dam operators and engineers to have as much control over the first filling as possible, allowing as much time as needed for appropriate surveillance, including the observation and analysis of instrumentation data.

> *"...Approximately two-thirds of all failures and one-half of all accidents occurred on first-filling or in the first 5 years of reservoir operation. Therefore, approximately one-half of all incidents included in this evaluation occurred after 5 years of reservoir operation..."*[06-03]

As an example, the authors can mention what was planned during the construction of Itaipu Project as measures for filling the reservoir. Between the crest of the upstream cofferdam and the riverbed next to the foundations of the Main Dam, there was one of about 110 m. In view of this, it was planned (by 1981/1982) to fill the pool in between the cofferdam and the front zone of the Main Dam and verify all aspects of the dam, with a view to a load of more than 50% of the final hydrostatic load. All contraction joints, drains, and monitoring instruments were checked, necessary repairs were performed, and the Designers, Itaipu's Supervisory Team and the Advisory Panel (Board of Consultants) evaluated the information, and the Advisory Panel Board attested [06-04 to 06-06]:

> *"...Based on information provided and discussions held during the present meeting, the Panel agrees with the Projetistas (understanded as* ***Designers's****) conclusion that the structures performed satisfactorily during the pre-filling test. The Panel also accepts that the approach that the pool level maintained at El. 139, with monitoring continuing until and through reservoir filling...*
>
> *...The filling of the reservoir between El. 190 and 205 will impose a faster increase in the loading of the structures and foundations. We do not expect any abnormal behavior of the structures...*
>
> *...The Panel agrees that the revised range of reservoir filling is an acceptable and satisfactory program..."*

The program, for the filling, was followed in a safe way, and the structures had performed satisfactorily.



Phases of the Itaipu reservoir filling (pictures from Andriolo's Archive)

Phases of the Itaipu reservoir filling (pictures from Andriolo's Archive)

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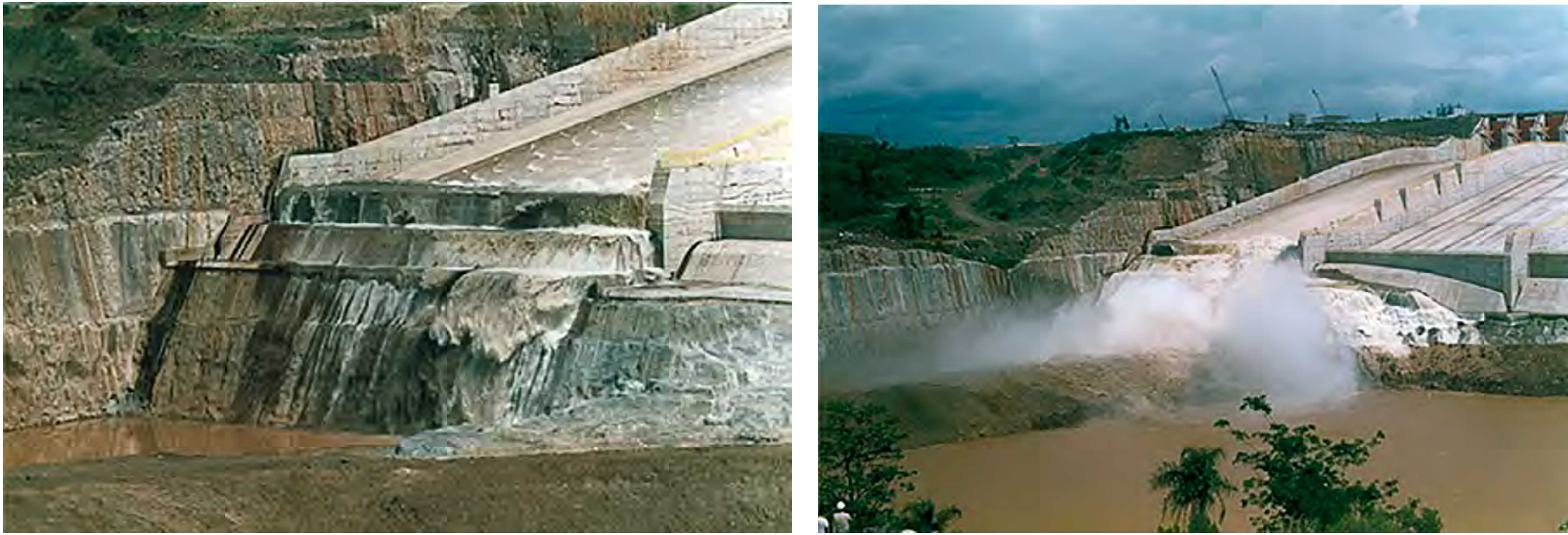


Water flow passing through the Itaipu Spillway during the first filling (pictures from Andriolo's Archive)

Dams are constructed primarily to impound and store a large body of water. The first filling of a reservoir can be defined as the increase in water level behind the dam from the time construction is complete until it reaches the desired operating level. Depending on the location, type, size, and intended purpose of a dam, the duration and rate of its first filling can vary. Regardless of whether it takes several months, several years, occurs naturally, or with the aid of pumping units, the first filling of a reservoir should be planned, controlled, and closely monitored to reduce the risk of failure.

Specifications regarding the rate of reservoir rise should be described to allow the dam to adjust to the forces it will experience as the water level behind it increases. These plans should be documented in a document that may also include reservoir regulations for the water control plan, project surveillance, cultural site surveillance, flood emergency plan, public affairs, safety plan, and transportation and communications. In addition to dam failure, it is common for design, construction, and/or material deficiencies of a new dam to become apparent during the first filling. For example, evidence of seepage, cracking, and erosion are often noted when the reservoir is raised to new levels for the first time. Inspection and assessment of these potentially hazardous conditions prior to the completion of filling is important and it may be necessary to halt filling or in some cases lower the reservoir before the desired operating water level is achieved to investigate signs of seepage, cracking and erosion.

Thus, it is vital for dam operators and engineers to have as much control over the first filling as possible, allowing as much time as needed for appropriate surveillance, including the observation and analysis of instrumentation data.

6.7 Contracts

There are many steps involved in taking a hydro project from the initial concept to construction[06-07].

A contract is an agreement entered into between two or more people with the intention of creating legally enforceable obligations. Once properly concluded, a contract is binding on each party. This means that each party has a legal obligation to do the things which the contract requires him or her to do. If a party does not do so, he or she may be in breach of the contract and the other party will have certain remedies, such as claiming for additional costs caused by the breach (called damages). They are also able to get a court order to force the party in breach to do what is required of them under the contract.

The contract should describe the following:

- ✓ ***What will be done;***
- ✓ ***How long it will take to complete;***
- ✓ ***How much it will cost and the payment terms;***
- ✓ ***What will be done if either party defaults; and***
- ✓ ***The extent to which the common law, which would usually apply, is adhered to.***

Ensure that all responsible have read the entire contract and understand the terms and conditions contained therein before signing

It is important that the contracting process, for the design and for the construction, be synchronized with the other development processes to ensure elements of the project are ready when needed. For example, entities needed to support licensing and permitting activities or engineering must be contractually brought on board at appropriate times to ensure that they produce the needed deliverables. In reality, contracting is the first process an owner needs to define and initiate so that the philosophy, approach, and processes for successfully procuring goods and construction are clearly defined from the start.

A general approach to contracting the work and identifying the various parameters affecting the contracts must be defined. In addition, the overall scope of the project should be subdivided into separate contract bid packages, such as land clearing, pumps, valves, turbine-generator equipment procurement, cofferdam installation and excavation, general construction, and transmission line and substation construction. Then, principal risks associated with the work included in each package need to be developed, along with mitigation measures to be incorporated into the contracts.

There are numerous ways to approach development of ahydro project. One of the approaches to be considered should take into account the risk tolerances, whether associated with environmental or other aspects, and how well site conditions are defined.

Another aspect to be understood and set responsibility and legal know how licenses, is concerned the knowledge development that is a key issue for the continuation of technological progress in the 21st century.

Technological advances in construction have been changing the way almost everything is done. One of the most noticeable areas of change is the materials used. New technologies are allowing for innovative steps as for a construction material. Tech tools are also changing how construction companies work with these materials. For example, concrete prefabrication is nothing new in this Century, but how to fix the elements and assure its safety, must be very clear in the documents.

The contract needs to consider the penalties rates that must be clearly described and understood by all the entities.

6.8 Insurance – Responsibility – Liability

6.8.1 General Aspects

This discussion is intended solely to provide a basis to consider liability potentials and to encourage dam owners to seek competent legal counsel and/or technical experts to help resolve any specific problems.

In this item is designed to provide both laypersons overview of the law concerning the liability for the failure of major Water Control Facilities, and discussions in conducting legal research in this area of the law.

The authors try to call the attention of the people, owners, public administration to examine the standards used by courts to assess liability for damage due to the failure of a flood control structure.

Considering that “flood control structure” includes dams, levees, and other major non-natural structures that store, divert, or transport large volumes of water. Determining who will pay for such damage involves a fundamental conflict between two of the most important beneficial incidents of land ownership: the right of exclusive occupation and the right of utilization.

The owner of the land on which the flood control structure is situated desires to utilize fully his or her land, and often to help provide beneficial services such as flood control and water supply to the community.

The damaged property owner wishes to exclusively occupy and enjoy her land without serious injury from adjacent property owners. Either right carried to an extreme requires one owner to surrender valuable property rights to the other.

The legislature or the courts must draw a line between each party’s property rights. Exact placement of that boundary line between the property rights of owners will be a reflection of existing social, political, and economic conditions that prevail in society. Strict liability for damage caused by the release of water from a water control facility is the general rule of law in some countries.

From the perspective of a water control facility owner, the outlook is not as grim as it might seem at first glance. Failure of a major water control facility during a storm is likely to lead to the imposition of strict liability. However, advances in hydrology, hydraulics and ***Dam Safety Engineering*** procedures can offer protection to the water control facility owners as well as to the public at large.

Investigations of potential for failure undertaken by the owners of water control facilities before that failure may well provide an owner with the unwelcome and unpleasant news about the safety of these facilities. At the same time, awareness of any deficiencies should give early warning of problems while they can be corrected.

Dam ownership carries with it significant legal responsibilities. Dam owners should be aware of the potential liabilities and how to effectively minimize their exposure to these liabilities. ***A dam owner should first be familiar with the legal obligation to maintain a dam in a***

safe condition. The common legal understanding is that the dam owner is the prime benefactor of the impounded waters behind his dam, and is therefore responsible for the potential impacts, which the impoundment of waters may have on upstream or downstream properties.

The dam owner is responsible for flood damages incurred to upstream properties by the storage of floodwaters and is responsible for damages caused by the sudden release of stored water from a failure of the dam or intentional rapid draining of the impoundment.

The general rule is that a dam owner is responsible for the dam's safety. Liability can be imposed upon a dam owner if he or she fails to maintain, repair, or operate the dam in a safe and proper manner. This liability can apply not only to the dam owner, but also to any company that possesses that dam, or any person who operates or maintains the dam. If any unsafe condition existed prior to ownership of the dam, the new dam owner may not be absolved of liability should the dam fail during his term of ownership.

Dams and impoundments are popular places, even if located in remote areas. Employees, contractors, invited visitors, or trespassers may visit a dam. The presence of these persons is a potential liability to the dam owner. Liability insurance or workers compensation insurance should cover employees, contractors or invited guests. However, trespassers present a unique problem. Most trespassers at a dam site are probably members of the public who wish to use the site for fishing, picnicking, boating or swimming. While they may mean no harm, their unauthorized use of the site may be a serious liability problem for the dam owner.

The dam owner is responsible for making and keeping his premises safe. The general rule is that the dam owner must avoid conduct or conditions that could injure any person, even one who trespasses. If the dam owner knows that an unsafe condition exists, he is responsible to correct it and/or post warnings. Typical dangers at a dam site include fast moving water, open spillways (pipes) and thin ice.

Owners of dams can be charged with greater responsibility when the trespassers are children. By reason of children's inability to understand the danger, which a condition may pose, a dam owner is expected to protect children from the dangers of a dam site. In effect, this rule requires actions to anticipate what parts of the facility would be particularly attractive to children. Since signs may not adequately warn children, security fencing may be necessary. Dam sites located near state or county roads, campgrounds or picnic areas, or near populated areas will attract many more people. These popular dam sites require frequent visits by the dam owner to inspect and assure safety. Potential Liability due to Operation of the Dam In addition to liability problems arising out of dam ownership, operation of a dam has legal ramifications

For both upstream and downstream users, this responsibility includes a duty to avoid negligent flooding of their property. In times of high runoff, the dam owner must assess the effects of operations that alter prevailing conditions. Increasing discharge may create flooding downstream, while decreasing discharge may protect downstream property but cause flooding or other damage upstream. The dam owner must always consider the maximum discharge capacity of the structure relative to prevailing hydrologic conditions and weather forecasts. Overtopping of a dam due to insufficient or untimely operations must be avoided. In situations where there is no specific duty to protect downstream owners from flooding, the dam owner must still operate the dam conscientiously. Should damages occur, the dam owner must be able to clearly show that his dam did not increase flooding. Upstream users may also have the right to be protected from damage caused by operation of the dam. Therefore, the dam owner is advised to assess the legal as well as the physical impact of any change in the level of the impoundment, including dam removal.

- ✓ ***Thus, the owner or his engineer must carefully inspect the structural integrity of any dam prior to purchase and then provide inspection, maintenance, and repair thereafter.***

6.8.2 Special Aspects

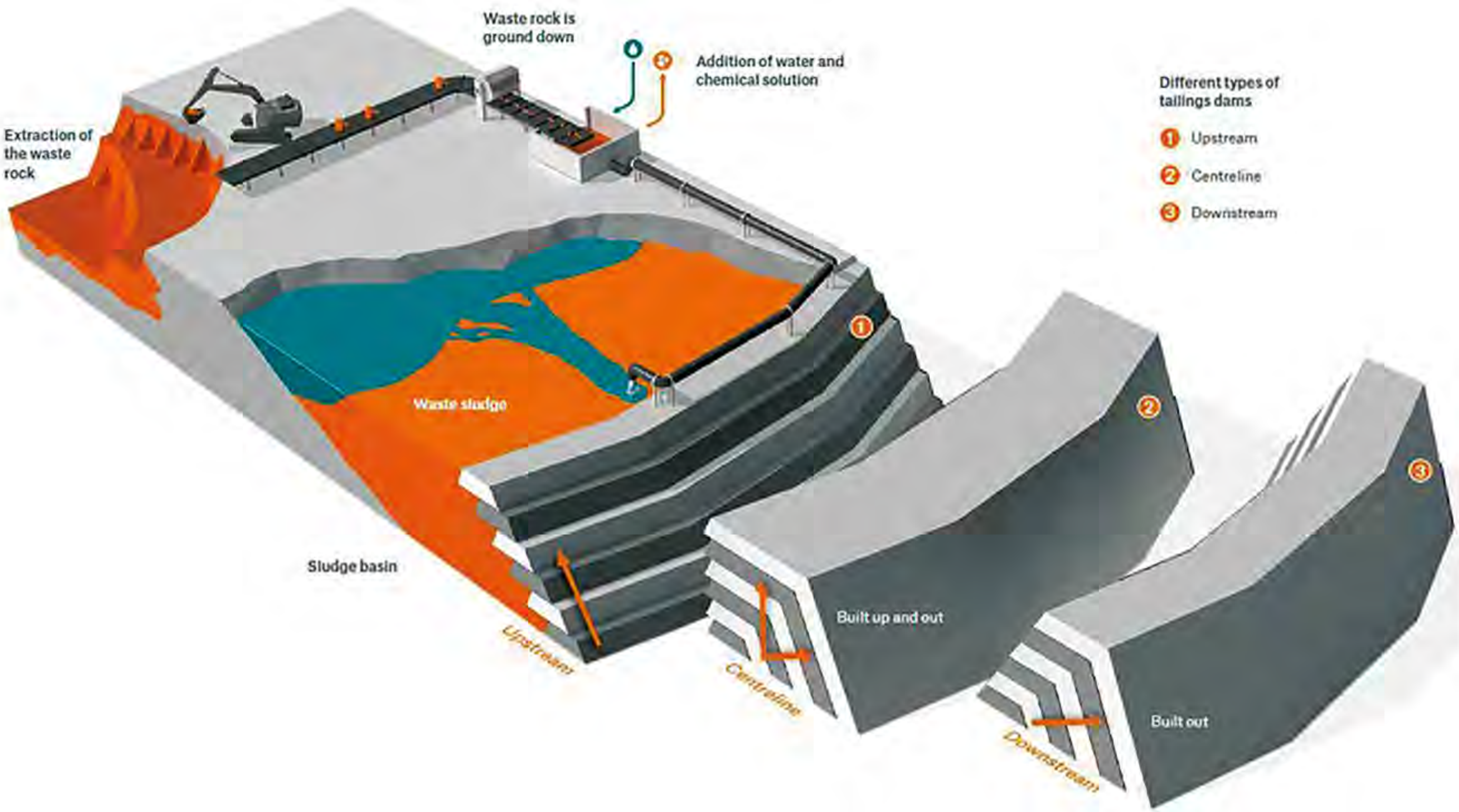
A rethink has also begun in the insurance industry after dam failures over the last few years triggered several major losses. It would be sensible in this context to separate the insurance of the special risks that involves: standard property insurance, and the different functions of dams (fishing; hydroelectric; flood control; water supply; tailing; private use....)

There is a need, however, considering a different approach: risks must be correctly assessed if they are to be insured commensurately. This should help calculate the critical risk scenarios, based on which the scope of cover and limits of indemnity can then be determined. The relevant factors include the age of the dam, its probable service life, and the expected output of the operations

Insurance policies are simply adapted from the policy forms for "standard" property risks in other industries by adding specific amendments for mining. As a result, product development has failed to keep pace with the industry's needs and risks.

Unlike reservoirs, which can be drained for maintenance, tailing dams must remain reliable over their entire operational life. In principle, they are built to last forever, and ideally will be revegetated after a mine has closed. While the mine is in operation, they must be stable enough to withstand the pressure from the tailings they hold. Unfortunately, this is not always the case. Lump-sum covers for risks emanating from tailings dams harbor substantial risks for insurers because clients are requesting ever-larger sums insured.

Tailings dams are of varying stability, depending on their design – elevation by upstream, center line and downstream. The most frequent incidents are in the upstream type and caused by are earthquakes. Others causes, to all types of tailing dams are overflow (spillway deficient capacity) and landslides. In the case of quakes, either the dam itself can become unstable, or it can fail because of what is known as liquefaction. But tailings from mining operations are a product of no value, and thus cannot be covered under generic property insurance. This means that mining companies have no way to insure against business interruption if the dam on a sludge basin fails. On the other hand, it is impossible to operate a mine without a functioning the tailing dam since operations would have to close if the processing residue cannot be disposed in the area.



Usual Types of Tailings Dams [06-09]

6.8.3 Role of Governments

The role of the Government includes defending the general interest of the population and to do so, it writes laws and regulations specific to protection of people property and the environment. The legal and governmental framework for all industrial activities, including operation of dams, provide the overarching structures for operational integrity and safety assurance. For activities that are hazardous, laws and regulations are often enacted to protect third parties against the harmful effects of misoperation or failure of the specific activity.

In some cases, within the general legal framework, specific laws and regulations may be established to the type of the tailing dam and to protect against the misoperation or failure of dams and reservoirs. The legal and governmental framework provides for the governance of dams, reservoirs and operational activities that give rise to dam breach and other inundation risks. The framework typically includes the clear assignment of Responsibility for Operational Integrity and Safety.

The government is responsible for the adoption of such legislation, regulations and other standards and measures, within its national legal system, as may be necessary to effectively fulfil all its national responsibilities and any international obligations. In terms of the modem view of safety governance, this includes establishment of an independent regulatory body to assure the safety of dams.

Government authorities should ensure that arrangements are made for reduction of risks from dams, including emergency actions, monitoring of high discharges to the environment and disposing of reservoir silt waste. This does not require that the governments establish and maintain all arrangements, although they may choose to do so. In addition, government authorities must address the safety of dams, for which no other organization has responsibility.

The main purpose of the safety process or system is to obtain an overall view of the actual state of safety of the dam system, determine whether any modifications, as organizational, managerial and structural, are necessary to ensure that the level of safety is appropriate. and ensure that the principle of continuous improvement is observed.

The safety process-review constitutes a comprehensive assessment of the dam system and provides answers to the following questions:

✓ ***Does the dam system conform to current regulatory requirements, current national and international standards and practices, and to current requirements with respect to acceptable and tolerable risk criteria?***

✓ ***Are the managerial and organizational arrangements currently in place sufficient to maintain the levels of safety in conformance with the above requirements until the next safety review?***

As an example of actions to establish the safety of Dams one can cite the sequence of legislative acts adopted in the United States of America to protect the society, as describe in **Chapter 02**.

The safety analysis should assess expected or planned (***if the assessment takes place in the design phase, construction controls and plannings***) performance of the dam system against the entire range of operational states and operating conditions, in order to obtain complete understanding of how the dam is expected to perform.

The process for **Dam Safety** must include suitable and sufficient systems for the control and management of all documents and data related to management of dam safety risks. The system has to ensure that:

⇒ All dam safety records are identified, created since the early beginning and properly managed;

⇒ The records should include all available dam safety related reports, rationale for delaying or not carrying actions recommended by them, and a summary report of all important data, sources of data as hydrological and climatic and geotechnical parameters:

⇒ Storage and maintenance of records provides easy retrievability and appropriate maintenance prevents loss or deterioration:

⇒ Language is accurate and clear, ensuring good quality and minimizing misunderstandings:

⇒ Appropriate document control and release procedures are in place, ensuring that current status of documents and history of changes are recorded;

⇒ Obsolete documents are either properly identified if retained for knowledge preservation, or are removed from circulation:

⇒ An appropriate system is in place, ensuring that all staff Involved in dam safety related activities is updated on changes in relevant documentation in a timely and reliable manner;

⇒ Appropriate means of accessing the records and documents are in place, including provisions to have the access from various locations at times of emergency.

The procedures must include suitable and sufficient processes, ensuring that all components of the dam system important to the system safety remain in accordance with the conclusions and requirements of the current dam safety review. The process should ensure that a systematic approach is taken to identify which maintenance activities are to be performed and at what intervals.

The process should establish how maintenance activities are initiated managed, assessed, prioritized, planned and scheduled. The identification, selection and frequency of maintenance activities should consider:

⇒ Magnitude of risks involved;

⇒ Guidelines and requirements of applicable codes and standards;

⇒ Design and operation conditions.

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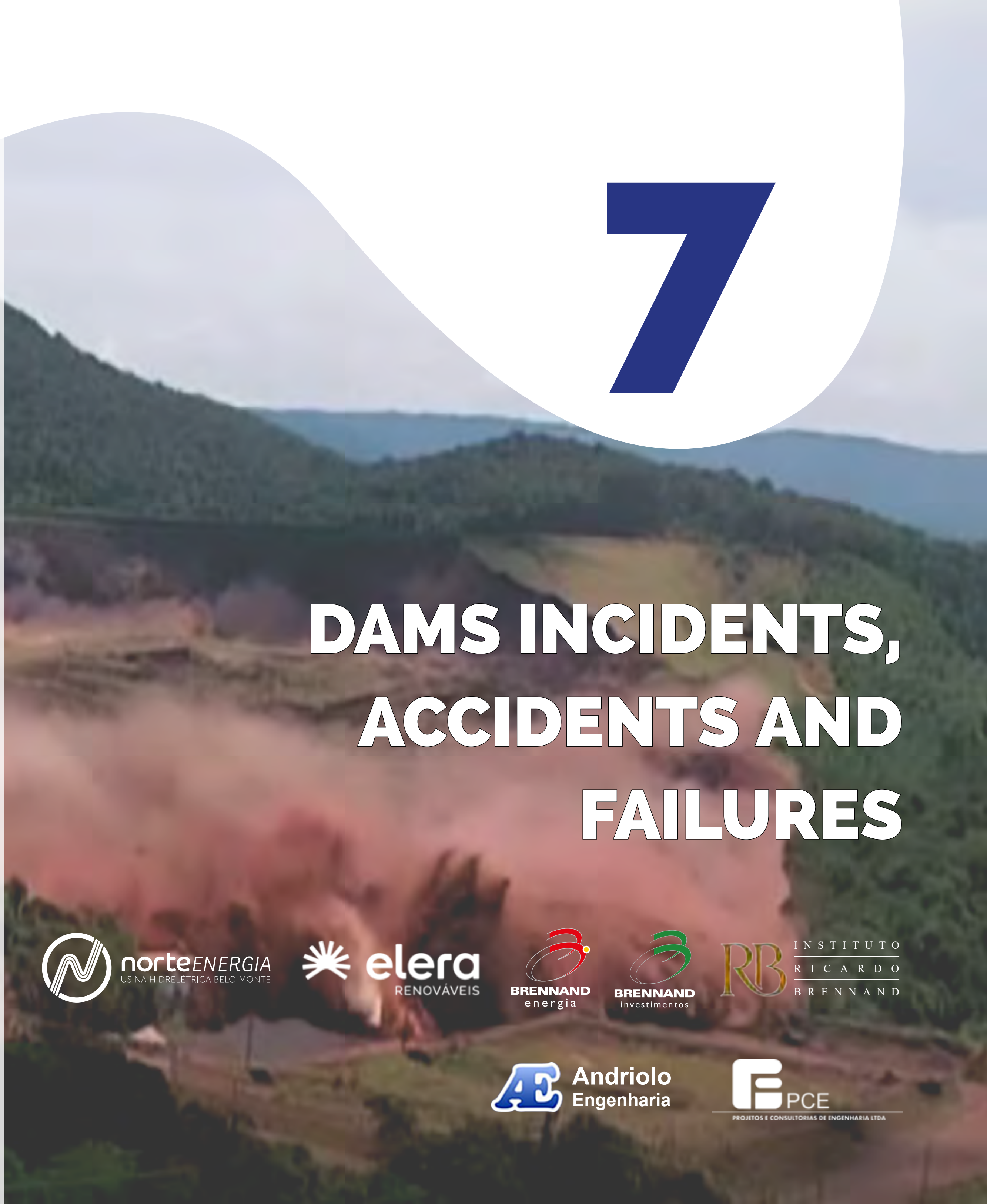
7

DAMS INCIDENTS, ACCIDENTS AND FAILURES



7.1 Introduction

7.1.1 Coincidence

On May 20, 2020, coincidently when the authors were writing the draft of this Chapter, the Television News **(*Source: WJRT/CNN –* https://www.youtube.com/watch?v=XpZMb5TR-hU)** was showing that:

About 10,000 residents have been evacuated in the US state of Michigan after two dams breached following days of heavy rain, officials say. The National Weather Service issued a flash flood emergency for areas near the Tittabawassee River after the Edenville and Sanford dams failed.

The following pictures were also presented:

Edeville Dam

Sanford Dam

⇒ **Edenville Dam –** was built in 1924 for hydroelectric power and for flood control. The dam was equipped with two 2.4 MW turbines capable of generating 4.8 MW of electricity in total. In May 2020, after heavy rains, the Edenville Dam breached and the downstream Sanford Dam overflowed, which caused major flooding in Midland County, including the city of Midland. On May 19, 2020, 5:46 p.m., due to flooding on the Tittabawassee River, the eastern side of the dam collapsed, prompting immediate evacuations in the town of Edenville and the city of Midland. The Sanford Dam, about 16 km downstream of the Edenville Dam and 9.7 km upstream of the city of Midland, subsequently overflowed.

The newspaper had mentioned:

*“...**(CNN** – May 21, 2020**)** Federal regulators have warned for more than 20 years of inadequate spillways at a Michigan dam that was breached Tuesday, sending floodwaters raging into a city of more than 40,000.*

Documents available on the Federal Energy Regulatory Commission website show federal regulators warned multiple companies that the Edenville Dam was not ready to handle a massive flood. The federal government threatened large fines against one private company that operated the dam until eventually revoking its license in 2018. Although federal regulators repeatedly warned about the dam’s inability to handle a large flood, it took years for federal authorities to crack down on the dam’s operator after more than 13 years of cajoling them to abide by the terms of their license...”

⇒ **Sanford Dam** – was built in 1925. Following a period of heavy rain, immediately upstream the Edenville Dam overtopped and failed and more water was released into the Tittabawassee River which feeds into Sanford Lake. Then it overran Sanford Dam, washing out its fuse plug and escaping around the sides of the dam.

The ***Federal Emergency Management Agency*** (FEMA) approved the request to add Gladwin County to the federal emergency declaration, which will provide additional resources to respond to a 500-year flooding event caused by failures in century-old dams.

7.1.2 General Aspect and Understanding

An accident is the opposite of the fundamental intentions of a safety program, which is to find hazards, fix hazards, and prevent incidents. When we accept that accidents have no cause, we assume that they will happen again.

Some organizations don't believe it is possible to foresee every hazard or danger present in the workplace. Often, the cause of these accidents is said to be a fluke, a one in a million chance of equipment failure or wrong place at the wrong time. These incidents lead to the creation or improvement of safety procedures and policies which are intended to stop the same scenario from playing out again in the future.

It also means that management teams are looking to reduce the number of injuries or illnesses that occur, not trying to prevent them outright.

⇒ **Accidents** are understood as: an unexpected event that may result in property damage and ***does result in an injury or illness to an employee***.

⇒ **Incidents** are understood as: an unexpected event that may result in property damage but ***does not result in an injury or illness***. Incidents are also called, "near misses," or "near hits."

⇒ **Failure** can be understood as: a state of inability to perform a normal function

So, these events are unplanned and can present damage to places or things, ***but only accidents result in illness or injury to a person***. Basically, by definition, all accidents are incidents, but not all incidents are accidents.

Dams are important because they provide water for domestic, industry and irrigation purposes. Dams often also provide hydroelectric power production and river navigation. Domestic use includes everyday activities such as water for drinking, cooking, bathing, washing, and lawn and garden watering.

Dams and their reservoirs provide recreation areas for fishing and boating. They help people by reducing or preventing floods. During times of excess water flow, dams store water in the reservoir; then they release water during times of low flow, when natural flows are inadequate to meet water demand. When engineers design and maintain dams, they consider all these purposes.

But as mentioned above, some dams can be damaged, and about hundreds of dam failures have occurred throughout world history.

It is very clear that the Owners and the Engineers consider, day after day, a better knowledge management to mitigate the risks.

7.2 Incidents, Accidents and Failures

Throughout history, a large number of dam failures have caused immense disagreements, but as previously mentioned, society needs the benefits of the dams. Along with that, dam failures over the years have claimed thousands of lives, and Engineering needs to develop so that the society has ***Safe Dams***.

Based on the available documents (see below[07-01]) it can be seen that the dams and powerhouses that fail with accidents and/or incidents can be used for learning and development. The table shows the main causes of failures.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Marib Dam	575	Sheba – Yemen	Unknown	Unknown causes, possibly neglect. The consequent failure of the irrigation system provoked the migration of up to 50,000 people from Yemen.
Döda fallet/1796 Ragunda lake	1796	Jämtland – Sweden	0	Natural dam of glacial till had a canal dug through it for purposes of navigation. As the till was hard to dig, water was used to erode the channel. That canal then led to the failure of the dam.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Puentes Dam	1802	Lorca – Spain	608	1,800 houses[07-02].
Hogs Back Dam	1829-04-03	Ottawa – Canada	0	Inexperience with cold weather engineering allowed for a small leak in a wall to form on March 28 and the dam to slump on April 2. The following day, on April 3, the dam failed and washed away the Rideau River [07-03].
Bilberry reservoir	1852-02-05	Holme Valley – United Kingdom	81	Failed in a heavy rain. The inquiry concluded that the construction was culpably negligent.
Dale Dike Reservoir/Great Sheffield Flood	1864-03-11	South Yorkshire – United Kingdom	244	Defective design and construction. A small leak in a wall grew until the new dam failed. More than 600 houses were damaged or destroyed. Led to regulation.
Iruka Lake Dam	1868	Inuyama, Aichi Prefecture – Owari Province-Japan	941	Under the influence of a heavy rain from late April, this soil dam collapsed on May 13. Water accumulated in Lake Iruka overflowed downstream, causing severe damage in the region.
Mill River Dam	1874	Williamsburg, Massachusetts – United States	139	Lax regulations and cost cutting led to an insufficient design, which fell apart when the reservoir was full. 600 million gallons of water were released, wiping out 4 towns and making national headlines. This dam break led to increased regulation of dam construction.
South Fork Dam/ Johnstown flood	1889-05-31	Johnstown, Pennsylvania – United States	2.208	Blamed on poor maintenance by owners, who lowered crest by a meter or more[07-04]. Court deemed it an “Act of God”. Followed by exceptionally heavy rainfall, 1,600 homes were destroyed.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Walnut Grove Dam	1890	Wickenburg, Arizona – United States	100	Heavy snow and rain following public requests by the dam's chief engineer to strengthen the earthen structure [07-05].
Gohna Lake dam	1894-08-25	Garhwal – India	1	Failure of a landslide dam. Authorities were able to evacuate the valley.
Austin Dam	1900-04-07	Austin, Texas – United States	8	In an extreme current, two sections of the dam slid intact about 20 m downstream. The town was left without electrical power for months.
Hauser Dam	1908-04-14	Helena, Montana – United States	0	Heavy flooding coupled with poor foundation quality. Workers managed to warn people downstream.
Broken Down Dam	1908-09-24	Fergus Falls, Minnesota – United States	0	Design flaw: dam built on water springs. Four downstream dams and bridge destroyed; a fourth dam was opened and saved.
Austin Dam	1911-09-11	Austin, Pennsylvania – United States	78	Poor design, use of dynamite to remedy structural problems. Destroyed paper mill and much of the town of Austin. Replacement failed in 1942.
Desná Dam	1916	Desná – Austria / Hungary	62	Construction flaws caused the dam failure.
Lower Otay Dam	1916	San Diego County, California – United States	14	Over-topped from flooding. Rainmaker blamed but not charged.
Sweetwater Dam	1916-01-27	San Diego County, California – United States	0	Over-topped from flooding; spillway inadequate, water rose over a meter higher than the dam and fell over its surface. The dam was raised after a similar earlier overtopping. Partial failure.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Lake Toxaway Dam	1916-08-13	Transylvania County, North Carolina – United States	0	Heavy rains and lack of water-level controls caused the dam to give way. Private lake destroyed, and resort area failed. Dam was later rebuilt in the 1960s
Tigra Dam	1917-08-19	Gwalior – India	1.000	Failed due to water infiltrating through sandstone foundation. Possibly more fatalities.
Gleno Dam	1923-12-01	Province of Bergamo – Italy	356	Poor construction and design, inferior materials.
Llyn Eigiau dam and Coedty reservoir	1925-11-02	Dolgarrog – United Kingdom	17	The outflow from Llyn Eigiau destroyed Coedty reservoir.
St. Francis Dam	1928-03-12	Santa Clarita, California – United States	451(*)	Geological instability of canyon wall. Designer inspected it hours before it failed.
Castlewood Dam	1933	Franktown, Colorado – United States	2	Bad design and maintenance, with proximate cause of heavy rain. Dam failed at 1 a.m. on 3 August 1933, with dam waters just 15 miles from the City of Denver. Warnings to the city at 4 a.m. allowed most people to move out of the way of the flood waters[07-06 to 07-08].
Granadillar Dam	1934	Canary Islands – Spain	8	Bad design and foundation.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Secondary Dam of Sella Zerbino	1935	Molare – Italy	111	Geological unstable base combined with flood.
Horonai Dam	1941	Ōmu, Hokkaido – Japan	60	A torrential rain struck around Horonai River area. The dam collapsed in the sequence, and according to official confirmation, the number of lost houses reached 32.
Nant-y-Gro dam	1942	Elan Valley – United Kingdom	0	Destroyed during the preparation for Operation Chastise in World War II.
Edersee Dam	1943-05-17	Hesse – Germany	70	Destroyed by bombing during Operation Chastise in World War II.
Möhne Dam	1943-05-17	Ruhr-Germany	1.579	Destroyed by bombing during Operation Chastise in World War II.
Xuriguera Dam	1944	Barcelona – Spain	8	Heavy rain.
Heiwa Lake Dam	1951	Kameoka, Kyoto Prefecture – Japan	117	Under heavy rain, the dam swallowed the muddy stream from the village in the downstream portion and collapsed the irrigation ponds. 80 houses were damaged in Kameoka and the surrounding area.
Tangiwai disaster	1953-12-24	Whangaehu River – New Zeland	151	Failure of Mount Ruapehu's crater lake. Natural tephra dam failed.
Taisho Lake Dam	1951	Ide, Kyoto Prefecture-Japan	108	Under the influence of heavy rain, the Ninotani Lake Dam outburst.
Schoellkopf Power Station	1956	Niagara Falls, New York – United States	1	Destruction of the plant as it fell from the Niagara Gorge wall and collapsed into the Niagara River, caused by water seeping into the back wall of the power station.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Vega de Tera	1959-01-09	Ribadelago – Spain	144	According to dam workers testimonies, the grounds had serious structural deficiencies due to poor construction. On the night of January 9, a 150-meter-long portion of the containing wall collapsed[07-09].
Malpasset dam	1959-12-02	Côte d'Azur – France	423	Geological fault possibly enhanced by explosives work during construction; initial geo-study was not thorough. Two villages were destroyed.
American Falls Dam	1960	Idaho – United States	0	American Falls Dam was completed in 1927. A core-drilling program in the early 1960s revealed that the concrete in portions of the dam was in a relatively advanced stage of deterioration due to a chemical reaction between alkalis in the cement and the aggregate. By congressional act of December 28, 1973, it was authorized to finance and contract for the replacement of American Falls Dam. The new dam, completed in 1978, replaced the concrete portion of the original structure and was built immediately downstream from the old dam.
Kurenivka mudslide	1961-03-13	Kiev – Ukrania	145	Impoundment of the clay slurry reservoir (storing the waste of the local brick factories) failed after heavy rains, inundating the Kurenivka neighborhood with meters of mud.
Panshet Dam	1961-07-12	Pune – India	1.000	Dam wall burst due to pressure of accumulated rainwater[07-10].
Huogudu	1962-09-26	Gejiu, Yunan Province – China	171(*)	A tailings pond at a tin mine operated by Yunnan Tin Group collapsed. Foundation Failure.
Baldwin Hills Reservoir	1963-12-14	Los Angeles – United States	5	Subsidence caused by over-exploitation of local oil field.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Vajont Dam	1963-10-09	Monte Toc – Italy	2.000	Strictly not a dam failure since the dam structure did not collapse and is still standing. Filling the reservoir caused geological failure in valley wall, leading to 110 km/h landslide into the lake; water escaped in a wave over the top of the dam. The valley was incorrectly assessed as stable. Several villages completely wiped out.
Spaulding Pond Dam (Mohegan Park)	1963-03-06	Norwich – United States	6	It had rained heavily on March 5, 1963.
Swift Dam	1964-06-10	Montana – United States	28	Failed during heavy rains. Another nearby dam did likewise.
El Cobre	1965-03-28	Chile	300(*)	Failure of two tailings dams due to earthquake at the El Soldado copper mine.
Mina Plakalnitsa	1966-05-01	Vratsa – Bulgaria	107	A tailings dam at Plakalnitsa copper mine near the city of Vratsa failed. A catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water or the likelihood of such an uncontrolled release. The official death toll is 107 [07-11 & 07-12].
Aberfan Tailing Dams	1966-10-21	Walles – United Kingdom	144(*)	The collapse and landslide of a spoil tip accumulated above the mining town on geologically unstable ground.
Sempor Dam	1967-11-29	Central Java Province – Indonesia	138	Flash floods overtopped the dam during construction[07-13].

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Mufulira	1970	Zambia	89(*)	A tailings reservoir breached as result of the underground hanging walls collapsed into the copper mine below it.
Certej dam	1971-10-30	Certej Mine – Romania	89	A tailings dam built too tall collapsed, flooding Certeju de Sus with toxic tailings [07-14].
Buffalo Creek Flood	1972-02-26	West Virginia – United States	125	Unstable loose constructed dam created by local coal mining company collapsed in heavy rain.
Canyon Lake Dam	1972-06-09	South Dakota – United States	238	Failure of structural steel members inside the gate dam outlets clogged with debris.
Banqiao and Shimantan Dams	1975-08-08	Zhumadian – China	171.000	Extreme rainfall, beyond the planned design capability of the dam, dumped in China by Typhoon Nina. Dam would later be rebuilt between 1986 and 1993.
Teton Dam	1976-06-05	Idaho – United States	11	Geological problems including unsuitable bedrock, seismic activity, and caves.
Laurel Run Dam	1977-07-19	Johnstown – United States	40	Heavy rainfall and flooding that overtopped the dam. Six other dams failed on the same day, killing five people.
Kelly Barnes Dam	1977-11-06	Georgia – United States	39	Unknown, possibly design error as dam was raised several times by owners to improve power generation.
Machchu-2 Dam	1979-08-11	Morbi – India	5.000	Heavy rain and flooding beyond spillway capacity[07-15].
Wadi Qattara Dam	1979	Benghazi – Libya	0	Flooding beyond discharge and storage capacity damaged the main dam and destroyed the secondary dam in the scheme.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Lawn Lake Dam	1982-07-15	Rocky Mountain National Park – United States	3	Breaching of the dam was due to piping which initiated an erosion; dam under-maintained due to location.
Tous Dam	1982-10-20	Valencia – Spain	8	Heavy flooding coupled with poor quality of the dam wall, lack of qualified staff and negligence of a warning of heavy rain in the area.
Val di Stava dam	1985-07-19	Tesero – Italy	268	Poor maintenance and low margin for error in design; outlet pipes failed leading to pressure on dam.
Kantale Dam	1986-04-20	Kantale – Sri Lanka	180	Poor maintenance, leakage, and consequent failure. Dam was 1400 years old, and heavy modern vehicles were driven across it (rebuilt).
Upriver Dam	1986-05-20	Spokane – United States	0	Lightning struck power system, and turbines shut down. Water rose behind dam while trying to restart. Backup power systems failed, could not raise spillway gates in time. Dam overtopped (rebuilt).
Dartmouth Dam	1990	Victoria – Australia	0	The 180 MW Francis turbine-generator running at full speed was instantaneously stopped by a foreign body left in the penstock following maintenance.
Belci Dam	1991-07-29	Belci – Romania	25	The embankment dam collapsed after record rainfall firstly overtopped the structure, followed by its breach later on.
Peruća Dam detonation	1993-01-28	Split-Dalmatia County – Croatia	0	Not strictly a dam failure as there was a detonation of pre-positioned explosives by retreating Serb Forces.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Merriespruit tailings Dam	1994-02-22	Free State – South Africa	17	Dam failed after a heavy thunderstorm. The dam was in an unacceptable condition prior to failure. Widespread devastation and environmental damage.
Meadow Pond Dam	1996-03-13	New Hampshire – United States	1	Design and construction deficiencies resulted in failure in heavy icing conditions.
Saguenay Flood	1996-07-19	Quebec – Canada	10	Problems started after two weeks of constant rain, which severely engorged soils, rivers, and reservoirs. Post-flood enquiries discovered that the network of dikes and dams protecting the city was poorly maintained.
Opuha Dam	1997-02-06	Canterbury – New Zelana	0	Heavy rain during construction caused failure, dam was later completed.
Virgen Dam	1998	Matagalpa – Nicaragua	0	In 1998 heavy rains and flooding from Hurricane Mitch severely damaged the Mancotal and El Dorado Dams, over-topping their spillways and nearly destroying the dams. The Virgen Dam was destroyed but later rebuilt[07-16 & 07-17].
Srisailam Dam	1998	Andhra Pradesh – India	0	Due to poor reservoir operation, flood water overflowed into the semi underground powerhouse. Flood water deluge caused the complete submersion of powerhouse.
Doñana	1998-04-25	Andalusia – Spain	0	Oversteepened dam failed by sliding on weak clay foundation, releasing acidic mine tailings into the River Agrio, a tributary of the River Guadiamar,
Shihgang Dam	1999-09-21	Taichung – Taiwan	0	Caused by damage sustained during an earthquake.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Bieudron Hydroelectric Power Station	2000	Valais – Switzerland	0	The failure appears to have been due to several factors including the poor strength of rock surrounding the penstock at the rupture location.
Martin County coal slurry spill	2000-10-11	Martin County – United States	0	Failure of a coal slurry impoundment. The water supply was contaminated. The spill was 30 times larger than the Exxon Valdez oil spill.
Vodní nádrž Soběnov	2002	Soběnov – Czechia	0	Extreme rainfall during the 2002 European floods.
Zeyzoun Dam	2002-06-04	Zeyzoun – Syria	22	Cracks were noticed in the embankment[07-18 & 07-19].
Silver Lake Dam	2003-05-14	Michigan – United States	0	Heavy rains caused earthen Fuse plug dam and bank to be washed away.
Hope Mills Dam	2003-05-26	North Carolina – United States	0	In heavy rains, floodgate held bay water pressure shut.
Ringdijk Groot-Mijdrecht	2003-08-23	Wilnis – Netheralands	0	The peat became lighter than water during the 2003 drought. The real cause was new wooden piling along the canal.
Big Bay Dam	2004-03-12	Mississippi – United States	0	A small hole in the dam grew, spouted higher, and eventually led to failure.
Camará Dam	2004-06-17	Paraiba – Brazil	3	Poor geologic understanding and poor maintenance. A second failure happened 11 days after.
Shakidor Dam	2005-02-10	Pasni – Pakistan	70	Sudden and extreme flooding caused by abnormally severe rain.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Taum Sauk Hydroelectric Power Station	2005-12-14	Lesterville, Missouri – United States	0	Computer/operator error; gauges intended to mark when the dam was full were not respected; dam continued to fill. Minor leakages had also weakened the wall through piping. The dam of the lower reservoir withstood the onslaught of the flood.
Ka Loko Dam	2006-03-14	Kauai, Hawaii – United States	7	Heavy rain and flooding. Several possible specific factors to include poor maintenance, lack of inspection and illegal modifications[07-20].
Campos Novos Dam	2006-06-20	Campos Novos – Brazil	0	Diversion tunnel collapse.
Gusau Dam	2006-09-30	Gusau – Nigeria	40	Heavy flooding, lack of maintenance.
Lake Delton	2008-06-09	Lake Delton – United States	0	Failure in June 2008 Midwest floods; nearby highway washed out, creating a new channel which drained the lake.
Koshi Barrage	2008-08-18	Koshi Zone – Nepal	250	Neglection of barrage and the building of barrage itself. The region however saw weak monsoon and multi-year drought preceding the barrage failure.
Taoshi	2008-09-08	Linfen, Shanxi Province, China	254(*)	Iron mine tailings.
Kingston Fossil Plant coal fly ash slurry spill	2008-12-22	Roane County – United States	0	Failure of a fly ash slurry pond.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Itaipu Dam	2009	Parana-Brazil/ Paraguay	0	Power generation loss due to storm damage of transmission lines.
Algodões Dam	2009-05-27	Piaui – Brazil	7	Heavy rain [07-21].
Situ Gintung Dam	2009-03-27	Tangerang – Indonesia	98	Poor maintenance and heavy monsoon rain.
Sayano-Shushenskaya Dam	2009-08-17	Sayanogorsk-Russia	75	The power station accident where the turbine 2 broke apart violently due to the metal fatigue caused by overlooked vibrations, flooding the turbine hall and causing the ceiling to collapse.
Srisailam Dam	2009-10-02	Andhra Pradesh – India	9	An earth dam burst above the Srisailam reservoir creating a record inflow which threatened the dam.
Kyzyl-Agash Dam	2010-03-11	Qyzylaghash – Kazakhstan	43	Heavy rain and snowmelt. Causes and death toll were disputed.
Hope Mills Dam	2010-06-16	North Carolina – United States	0	Sinkhole caused dam failure. Second failure of the dam, will be replaced.
Testalinda Dam	2010-06-13	Oliver – Canada	0	Heavy Rain, low maintenance.
Delhi Dam	2010-07-24	Iowa – United States	0	Heavy rain, flooding, malfunctioning spillway, and structural problems.
Niedow Dam	2010-08-07	Lower Silesian Voivodeship – Poland	1	Heavy rain, overtopped from flooding[07-22].
Ajka Alumina Plant	2010-10-04	Ajka – Hungary	10	Failure of concrete impound wall on alumina plant tailings dam.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Kenmare Tailings Dam	2010-10-04	Topuito – Mozambique	1	Failure of tailings dam at titanium mine.
Fujinuma Dam	2011-03-11	Sukagawa – Japan	8	Failed after 2011 Tōhoku earthquake. Japanese authorities state that the dam failure was caused by the earthquake, making these the first earthquake-caused dam failure fatalities since 1930, worldwide[07-23].
Campos dos Goytacazes Dam	2012-01-04	Campos dos Goytacazes – Brazil	0	Failed after a period of flooding[07-24].
Ivanovo Dam	2012-02-06	Biser – Bulgaria	8	Failed after a period of heavy snowmelt. A crack in the dam went unrepaired for years[07-25].
Köprü Dam	2012-02-24	Adana Province – Turkey	10	A gate in the diversion tunnel broke after a period of heavy rain during the reservoir's first filing[07-26 & 07-27].
Dakrong 3 Dam	2012-10-07	Quảng Trị Province – Vietnam	0	Poor design, Typhoon Gaemi flood surge.
Vishnuprayag Hydroelectric Station	2013	Uttarakhand – india	0	Flash floods resulted in accumulation of huge quantity of muck and debris in the dam reservoir.
Dhauliganga Hydroelectric Station	2013-06	Uttarakhand – India	0	Unprecedented flash floods in June 2013, in the State of Uttarakhand, causing the complete submergence of powerhouse.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Uri-Ii Power Station	2014	Jammu and Kashmir – India	0	A large fire incident happened in one of the transformers of the power station.
Tokwe Mukorsi Dam	2014-02-04	Masvingo Province – Zimbadwe	0	Downstream slope failure on a 90.3m tall embankment dam, possibly as the reservoir was being filled.
Mount Polley Tailings Dam	2014-08-04	British Columbia – Canada	0	Tailings dam collapse due to negligent operation; reservoir was overfilled beyond design parameters despite repeated warnings of the danger combined with a minor dam breach a few months before and fundamental design flaws. [07-28 to 07-32]
Hpakant Jade Mine	2015-10-25	Myanmar	113(*)	A slag heap reportedly used by multiple operators in this jade-mining region became unstable and flooded into nearby residences.
Mariana Dam	2015-11-05	Mariana, Minas Gerais – Brazil	19	Tailings dam collapsed.
Maple Lake	2017-10-05	Paw Paw, Michigan – United States	0	A heavy rainstorm caused a section of a dam to crumble because of the weight of a pond above, which happened around 5 a.m.[07-33].
Patel Dam	2018-05-10	Solai – Kenya	47	Failed after several days of heavy rain.
Panjshir Valley dam	2018-07-11	Panjshir Valley – Afghanistan	10	Dilapidated dam crumbled under heavy summer rains.
Xe-Pian Xe-Namnoy Dam	2018-07-23	Attapeu Province – Laos	36	Saddle dam under construction collapsed during rainstorms.
Swar Chaung Dam	2018-08-19	Yedashe – Myanmar	4	Breach in the dam's spillway. 3000 evacuated, 3 missing, 85 villages affected.

Dam/Incident	Date	Location – Country	Fatalities (*Inaccurate)	Details
Sanford Dam, Patricia Lake	2018-09-15	Boiling Spring Lakes, North Carolina – United States	0	Overtopping after heavy rainfall during landfall of Hurricane Florence.
Brumadinho dam disaster	2019-01-25	Brumadinho, Minas Gerais – Brazil	270	Tailings dam suffered a catastrophic failure releasing 12 million cubic meters of tailings slurry.
Spencer Dam Failure	2019-03-14	Near Spencer, Nebraska – United States	(*)	Ice run flooding and human cause.
Tiware Dam	2019-07-02	Ratnagiri District – India	23	Heavy rains overtopped and breached the dam.
Edenville Dam	2020-05-19	Edenville, Michigan – United States	None reported [07-34]	Heavy rains overtopped and breached the dam[07-35].
Sanford Dam	2020-5-19	Sanford, Michigan – United States	None reported	The failure of the Edenville Dam immediately upstream caused a large inflow into Sanford Lake, which overtopped the dam[07-36].

From the list above, with more than one hundred accidents, the following percentages of the occurrences of causes can be obtained:

Collapse Causes	Occurrences (%)
Climatic – Hydrological – Snow melted – Floods	46
Geological – Geotechnical	9
Poor Design	11
Poor Construction	5
Poor Maintenance	8
Other: War (bombing) – Poor Operation – Unknown – Fire – Earthquake	21

7.3 Remarkable Aspects

Several reports describe failures of dams, some had shown impressive facts and consequences, that had induced the society, the owners, and the governors to adjust rules and/or laws. Some of these remarkable facts are presented ahead.

The following examples are shown to help get the facts about dam failures in mind and then in 7.4 to discuss likely statistical aspects.

Order	Dam Identification	Type	Location-Country
7.3-A	South Fork	Earth and Rockfill	Pennsylvania – USA
Finished	**Height (m)**	**Length (m)**	**References**
1853	22	284	[07-37]

Event: The dam's discharge works consisted of a stone-lined culvert with five valves for releasing varying amounts of flow as well as a spillway created by cutting into the rock along the east abutment. As a result of *poor maintenance*, the outlet works culvert collapsed and a portion of the dam washed out in 1862.

South Fork Dam after failure in 1889 (Picture from Internet)

Order	Dam Identification	Type	Location-Country
7.3-B	Austin	Curved concrete gravity	Austin – Pennsylvania – USA
Finished	**Height (m)**	**Length (m)**	**References**
1911	15	160	[07-37]

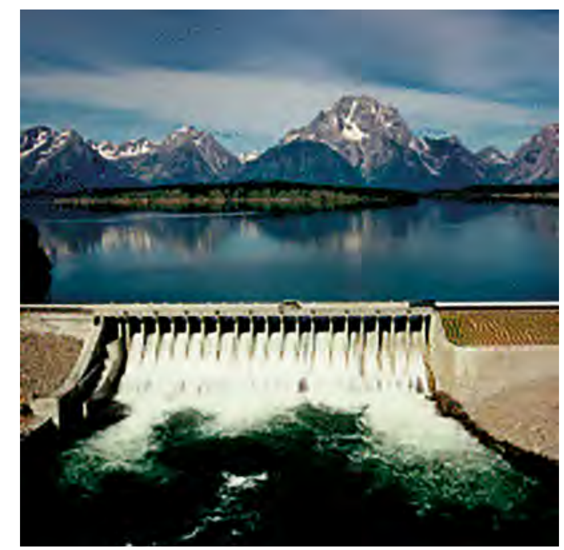
Event: Austin Dam was designed to *be thirty feet thick but was built only twenty feet thick*. Within only a few months of its completion, problems were detected. The dam bowed more than 36 under the pressure of the water it was holding, and the concrete started cracking. The bowing was alleviated by using dynamite to blast a 4 m space for the excess water to spill over. The cracking was claimed to be normal because of the drying cement. On September 30, 1911, the dam failed and destroyed the Bayless Pulp and Paper Mill as well as much of the town of Austin. It also resulted in the deaths of 78 people. The Paper Mill and Dam were subsequently rebuilt, but the mill was lost in a fire in 1933. The new dam failed in 1942 with no loss of life. The dam was not replaced after the second failure.

Remnants of Austin (Bayless) Dam one day after failure and recently (Pictures from Internet)

Order	Dam Identification	Type	Location
7.3-C	Jackson Lake	Earthfill and concrete	Wyoming – USA
Finished	**Height (m)**	**Length (m)**	**References**
1916	20	1.500	[07-38]

Event: The first Jackson Lake Dam was a log-crib dam constructed in 1906–07 across the outlet of Jackson Lake, a natural lake. That dam raised the lake level by 6.7 m, but the dam failed in 1910. A new concrete and earthen dam was constructed in stages between 1911 and 1916, raising the maximum lake level to 9 m above the lake's natural elevation. The U.S. Bureau of Reclamation conducted studies on dams in 1976 and determined that Jackson Lake Dam was susceptible to failure in case of an earthquake of magnitude 5.5 or greater. Following the Borah Peak earthquake of 1983 in Idaho, the dam was upgraded during 1986-1989, and the Bureau of Reclamation believed it could withstand the "maximum credible earthquake", a magnitude 7.5 quake on the Teton fault. Since then, various studies have cast doubt on this belief.





Jackson Lake Dam views (Pictures from Internet)

Order	Dam Identification	Type	Location-Country
7.3-D	St. Francis Dam	Curved concrete gravity	Los Angeles – California – USA
Finished	**Height (m)**	**Length (m)**	**References**
1926	62	210	[07-37 & 07-39]

Event: Water began to fill the reservoir on March 12, 1926. It rose steadily and rather uneventfully, although several temperature and contraction cracks did appear in the dam and a minor amount of seepage began to flow from under the abutments. At 11:57 p.m. on March 12, 1928, the dam catastrophically failed, and the resulting flood took the lives of an estimated at least 431 people. The collapse of the St. Francis Dam is considered to be one of the worst American civil engineering disasters of the 20th century and remains the second-greatest loss of life in California's history, after the 1906 San Francisco earthquake and fire.

Initial views of St. Francis dams before the collapse and after the damages (Picture from the references)

Initial views of St. Francis dams before the collapse and after the damages (Picture from the references)

Order	Dam Identification	Type	Location-Country
7.3-E	Spencer	Earth and rock-fill	Nebraska – USA
Finished	**Height (m)**	**Length (m)**	**References**
1927	8	1.127	[07-40]

Event: The dam was constructed in several sections. The powerhouse was located on the north bank of the river. The spillway consisted of four tainter gates and five sto-plog gates to the south of the powerhouse. In 1935 the dam was partially breached after an ice jam broke upstream. It was reconstructed in 1940. Both after its initial construction and after its rebuilding in 1940, the dam was filled with sediment within a few years. Heavy precipitation during an early morning of March 14, 2019, the dam was breached by snowmelt and ice breakage caused the Niobrara River to swell. The earth embankment was washed out in two locations, while the spillway remained partially intact.

Views of Spencer Dam and Spillway after the collapse

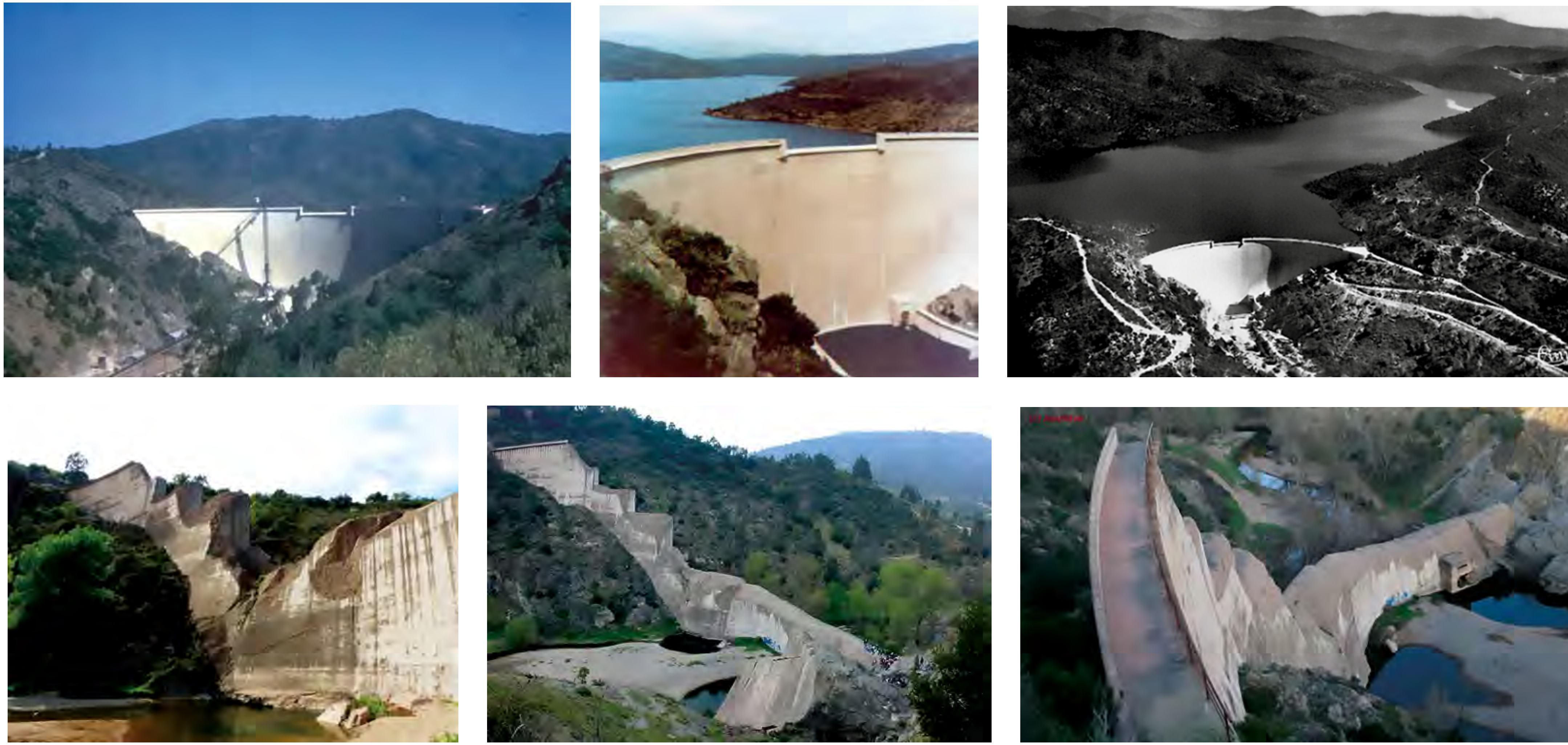
Order	Dam Identification	Type	Location-Country
7.3-F	Salt Springs	CFRD	California – USA
Finished	**Height (m)**	**Length (m)**	**References**
1931	101		[07-41 & 07-42]

Event: The dam has a history of settlement problems caused by poor consolidation of the rocks during construction. The concrete face has been cracked many times by the movement, causing leaks. The surface of the dam consisted of cracks, craters and shotcrete overlays. It was decided to use a flexible geomembrane to cover the portions of the dam with the greatest leakage. The installation of the membrane was completed in 2005.

Views of the damages of the concrete face on Salt Springs Dam and the repair using a PVC Membrane

Order	Dam Identification	Type	Location-Country
7.3-G	Malpasset Dam	Concrete arch dam	French Riviera – Côte d'Azur – France
Finished	**Height (m)**	**Length (m)**	**References**
1954	66	222	[07-43], [07-44] and item 4.2.4 – Chapter 4

Event: It collapsed on December 2, 1959, killing 423 people in the resulting flood. During November 1959, there were the first warning signs: a "trickle of clear water observed high on the right [side]" and then cracks were noticed later in the month in the concrete apron at the dam toe.
The dam was breached at 09:13 p.m. on December 2, 1959. The breach created a massive dam-break wave, or wall of water, 40 meters high and moving at 70 kilometers per hour, destroying two small villages, Malpasset and Bozon. It was reported that the death toll of the dam breach was 423. Other damage included 155 buildings destroyed, 796 buildings damaged, and 1350 hectares destroyed.
Geological and hydrological studies were conducted in 1946 and the dam location was considered suitable. Due to lack of proper funding, however, the geological study of the region was not thorough. The lithology underlying the dam is a metamorphic rock called gneiss. This rock type is known to be relatively impermeable, meaning that there is no significant groundwater flow within the rock unit, and it does not allow water to penetrate the ground.
A tectonic fault was later found as the most likely cause of the disaster. Other factors contributed as well; the water pressure was aimed diagonally towards the dam wall and was not found initially. As a consequence, water was collected under a wall and was unable to escape through the ground due to the impermeability of the gneiss rock underneath the dam. Weeks before the breach, some cracking noises were heard, but they were not examined. It is not clear when the cracking noises started. The right side of the dam had some leaks in November 1959.



Views of the Malpasset Dam after construction, as operating, and after the collapse

Order	Dam Identification	Type	Location-Country
7.3-H	Aberfan	Tailing	Wales – Great Britain
Finished	**Height (m)**	**Length (m)**	**References**
1958	34	Not informed in reference	[07-45]

Event: After three weeks of heavy rain the tip was saturated and approximately 110,000 m^3 of spoil slipped down the side of the hill over a distance of about 500 meters and onto a village. In total the Aberfan Disaster claimed 144 lives.



Views of the Aberfan Tailings Dam after the disaster

Order	Dam Identification	Type	Location-Country
7.3-I	Vajont or Vaiont	Concrete arch dam	Erto/Caso – Italy
Finished	**Height (m)**	**Length (m)**	**References**
1959	262	191	[07-46]

Event: It was described as *'the tallest dam in the world'*, intended to meet the growing demands of industrialization.
On 9 October 1963, during initial filling, a landslide caused a mega-tsunami in the lake in which 50 million m^3 of water overtopped the dam in a wave of 250 m leading to the complete destruction of several villages and towns, and 1.917 deaths. This event occurred when the company and the Italian government dismissed evidence and concealed reports describing the geological instability of Monte Toc on the southern side of the basin, and other early warning signs reported prior to the disaster. Numerous warnings, signs of danger, and negative appraisals had been disregarded, and the eventual attempt to safely control the landslide into the lake by lowering its level came when the landslide was almost imminent and was too late to prevent it. Although the dam itself remained almost intact, and two-thirds of the water was retained behind it, the landslide was much larger than expected and the impact brought massive flooding and destruction to the Piave valley below.



Views of the Vajont Dam before and after the disaster

Order	Dam Identification	Type	Location-Country
7.3-J	Fontenelle	Earthfill	Wyoming – USA
Finished	**Height (m)**	**Length (m)**	**References**
1964	42	1.652	[07-47]

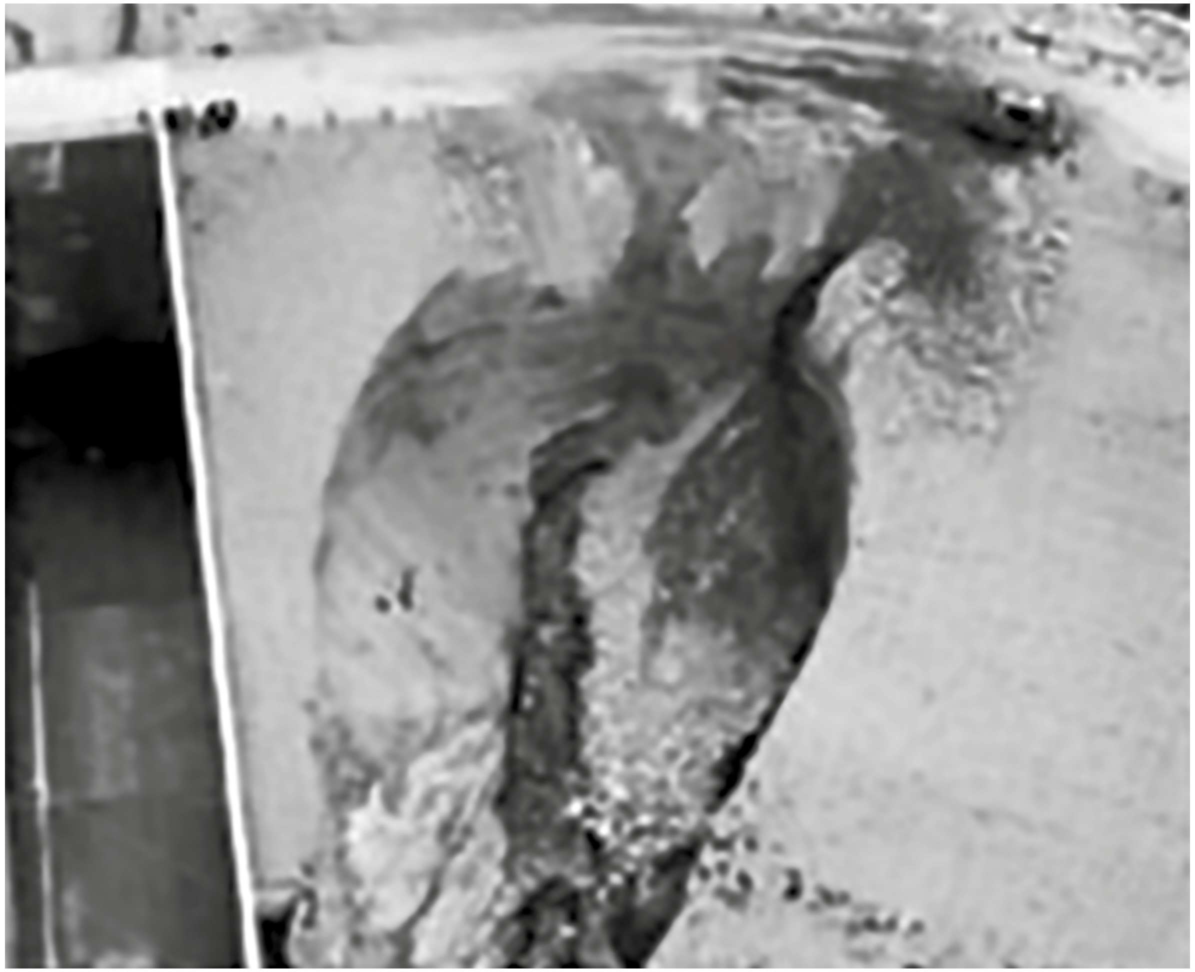
Event: The dam suffered a significant failure in 1965, when the dam's right abutment developed a leak. Emergency releases from the dam flooded downstream properties, but repairs to the dam were successful. However, in 1983 the dam was rated "poor" under Safety Evaluation of Existing Dams (SEED) criteria, due to continuing seepage, leading to an emergency drawdown. A concrete diaphragm wall was built through the core of the dam to stop leakage.

The second embankment slide to the right of the spillway on June 27, 1965

The third embankment slide on July 27, 1965

Third embankment slide. Seeps issuing from vertical cracks in sandstone.

The erosion hole about noon on Saturday September 4. Note 1,2m-diameter leak exit tunnel adjacent to the right abutment rock.



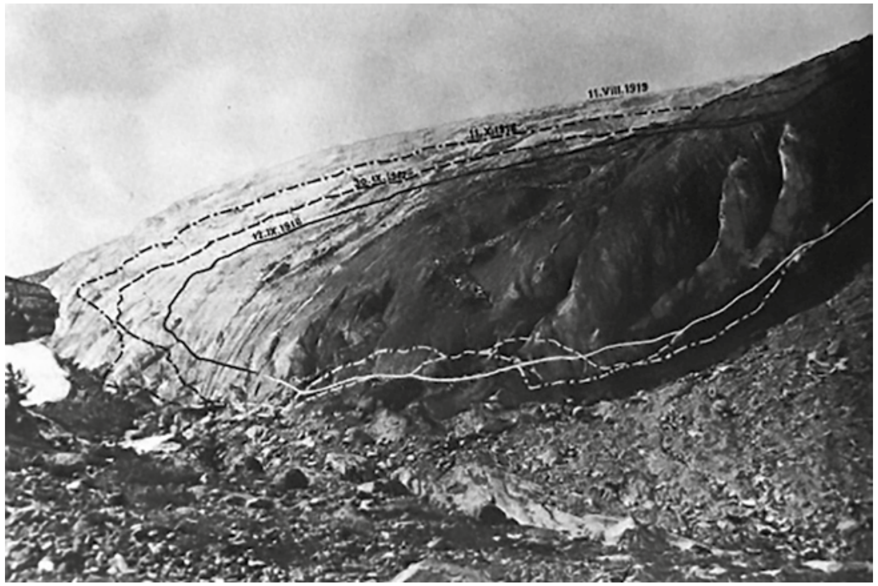
By Sunday morning September 5th a large rock berm was created in the left side of the erosion hole.

Section of dam removed for investigation and repair.

Fontenelle Dam after repairs

Order	Dam Identification	Type	Location
7.3-K	Mattmark	Earthfill	Sass Valley – Switzerland
Finished	**Height (m)**	**Length (m)**	**References**
1965	93	3.200	[07-48]

Event: On August 30, 1965, 2.000.000 m^3 of ice and debris broke off the Allalin glacier in canton Valais, engulfing the Mattmark dam construction site. Eighty-eight people lost their lives. Many questions remain unanswered about the worst disaster in recent Swiss history. Its wild and unpredictable nature has repeatedly threatened the existence of the Saas population. The glacier originates on the 4,190-meter-high Strahlhorn, which, along with the Allalinhorn, the Alphubel, and the Rimpfischhorn, belongs to the Allalin group.



The Allalin glacier ice tongue, as seen on August 11, 1919, with information on its historical movement, on Mattmark Dam

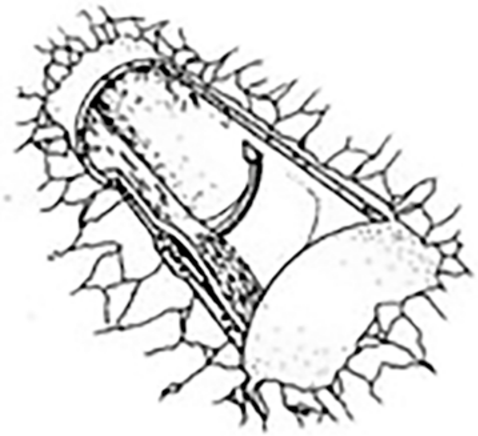
Mattmark Dam after repairs

Order	Dam Identification	Type	Location-Country
7.3-L	Glen Canyon	Concrete Arch	Arizona – USA
Finished	**Height (m)**	**Length (m)**	**References**
1966	216	476	[07-49]

Event: An inspection of the tunnels following the test revealed minor cavitation damage to the liners. Vapor cavities occur in liquid when water pressure in a high-velocity flow is reduced by an irregularity in the flow surface. As these cavities move into a zone of higher pressure, they collapse, sending out high-pressure shock waves that cause cavitation.

After analyzing the spillway flow, Bureau of Reclamation staff members decided to construct an aeration slot in each tunnel. The aerators were located in the conical reducing section of the tunnel about one-half of the way down the tunnel between the intake and the vertical bend.

Repair work began with the removal of the entire tunnel lining, including sections that were not damaged, to improve safety, speed construction, and to produce satisfactory, long-lasting results. Damaged and missing reinforcement was replaced. New reinforcement was manually welded to existing reinforcement in most cases. In areas where drainage water prevented welding, steel dowels were epoxied into drill holes in the liner and then wired to the existing reinforcing in a splicing technique.



Downstream view of the Glen Canyon Dam and a schematic view of the aeration outlet on the spillway tunnel

Order	Dam Identification	Type	Location-Country
7.3-M	Oroville Dam	Earthfill	Oroville – California – USA
Finished	**Height (m)**	**Length (m)**	**References**
1968	235	2.109	[07-50]

Event: In February 2017, Oroville Dam's main and emergency spillways were damaged, prompting the evacuation of more than 180,000 people living downstream along the Feather River and the relocation of a fish hatchery.

Heavy rainfall during the 2017 California floods damaged the main spillway on February 7, so the California Department of Water Resources (DWR, created in 1956) stopped the spillway flow to assess the damage and contemplate its next steps. The rain eventually raised the lake level until it flowed over the emergency spillway, even after the damaged main spillway was reopened. As water flowed over the emergency spillway, headward erosion threatened to undermine and collapse the concrete weir, which could have sent a 10 m wall of water into the Feather River below and flooded communities downstream. No collapse occurred, but the water further damaged the main spillway and eroded the bare slope of the emergency spillway.

There was no single root cause of the Oroville Dam spillway incident, nor was there a simple chain of events that led to the failure of the service spillway chute slab, the subsequent overtopping of the emergency spillway crest structure, and the necessity of the evacuation order. Rather, the incident was caused by a complex interaction of relatively common physical, human, organizational, and industry factors, starting with the design of the project and continuing until the incident. The physical factors can be placed into two general categories:

- Inherent vulnerabilities in the spillway designs and as-constructed conditions, and subsequent chute slab deterioration;
- Poor spillway foundation conditions in some locations.

Oroville Dam and Spillway as constructed and before the damages

The large flow and the damage in the Oroville Spillway

The large flow and the damage in the Oroville Spillway

Oroville Spillway repair development since the damage (Courtesy from California Department of Water Resources)

Oroville Spillway view after repair (Courtesy from California Department of Water Resources)

Order	Dam Identification	Type	Location-Country
7.3-N	Teton	Earthfill	Idaho – USA
Finished	**Height (m)**	**Length (m)**	**References**
1975	940	1.000	[07-51]

Event: The Teton Dam was built by the Bureau of Reclamation (established in 1902, and is responsible for the construction for more than 600 dams and reservoirs including Hoover Dam on the Colorado River and Grand Coulee on the Columbia River), one of eight federal agencies authorized to construct dams, and completed in November 1975. The collapse of the dam resulted in the deaths of 11 people.

The dam was completed in November 1975 and filling the reservoir began at the standard rate of 0.30 m a day. However, snows were heavy that winter and five months later the project's construction, engineers requested permission to double the filling rate in order to deal with the additional spring run-off, while continuing to inspect for leaks and monitor the groundwater. A month later, even though monitoring showed that groundwater was flowing a thousand times faster than it had been originally anticipated, the filling rate was doubled again, to 1.2 m a day.

On June 3 and 4, 1976, three small springs were discovered downstream of the dam, although the water running through the leaks was clear and such leaks are not unexpected for an earthen dam. At the time, the reservoir was almost at capacity, with a maximum depth of 73 m. The only structure that had been initially prepared for releasing water was the emergency outlet works, which could carry just 24 m3/s. The main outlet works and spillway gates were not yet in service: the gates were cordoned off by steel walls while they were being painted.

On Saturday, June 5, 1976, at 7:30 a.m., a muddy leak appeared, suggesting sediment was in the water, but engineers did not believe there was a problem. By 9:30 a.m. the downstream face of the dam had developed a wet spot which began to discharge water at 0,57 to 0,85 m3/s and the embankment material began to wash out.

At 11:55 a.m., the crest of the dam sagged and collapsed into the reservoir; two minutes later the remainder of the right-bank and a third of the main dam wall disintegrated. Over 57.000 m3/s (many times the average flow rate of Niagara Falls) of sediment-filled water emptied through the breach into the remaining 10 km of the Teton River canyon, after which the flood spread out and shallowed on the Snake River Plain. By 8:00 p.m. that evening, the reservoir had completely emptied, although over two-thirds of the dam wall remained standing.https://en.wikipedia.org/wiki/Teton_Dam – cite_note-NoFinger-10

Study of the dam's environment and structure placed blame for the collapse on the permeable loess soil used in the core and on fissured (cracked) rhyolite in the abutments of the dam that allowed water to seep around and through the earth fill dam. The permeable loess was found to be cracked. It is postulated that the combination of these flaws allowed water to seep through the dam and led to internal erosion, called piping, that eventually caused the dam's collapse.

An investigating panel had quickly identified piping as the most probable cause of the failure, then focused its efforts on determining how the piping started. Two mechanisms were possible. The first was the flow of water under highly erodible and unprotected fill, through joints in unsealed rock beneath the grout cap and development of an erosion tunnel. The second was "cracking caused by differential strains or hydraulic fracturing of the core material". The fundamental cause of failure may be regarded as a combination of geological factors and design decisions that, taken together, permitted the failure to develop.

The sequence of the Teton Dam collapse (Courtesy from Bureau of Reclamation)

The sequence of the Teton Dam collapse (Courtesy from Bureau of Reclamation)

Order	Dam Identification	Type	Location-Country
7.3-O	Shih-Kang	Concrete Gravity	Taichung – Taiwan
Finished	**Height (m)**	**Length (m)**	**References**
1977	25	352	[07-52 & 07-53]

Event: On September 21, 1999, an earthquake happened in the central region of Taiwan. Shih-Kang Dam was damaged by marvelous surface ruptures of Che-Lung-Pu fault, strong surface deformation, and great ground motion.
Since the Shih-Kang dam is the first concrete dam to be directly damaged by the active fault in the history of the hydraulic structures, the damage of Shih-Kang dam becomes very unique.
The Shih-Kang Dam design was based on the traditional design concept of the pseudo static earthquake acceleration. The design horizontal earthquake acceleration coefficient was Kh=0.15 and the effect of the vertical motion was neglected.
Considering the existing active fault on the dam site, the long-term solution to the damaged Shih-Kang Dam and Tai-Chung area water resource is to build a new reservoir in the upstream of Shih-Kang dam to substitute the damaged one.

The damage caused by earthquake in the Spillway Shih-Kang Dam

Order	Dam Identification	Type	Location-Country
7.3-P	American Falls	Concrete Gravity	Idaho – USA
Finished	**Height (m)**	**Length (m)**	**References**
1978	29	1.608	[07-54]

Event: Core samples taken in the early 1960s of the concrete of the original structure revealed deterioration resulting in impaired durability and strength caused by a chemical reaction (alkali aggregate reaction) between components of the concrete. A second dam was completed in 1978 and the original structure was demolished.

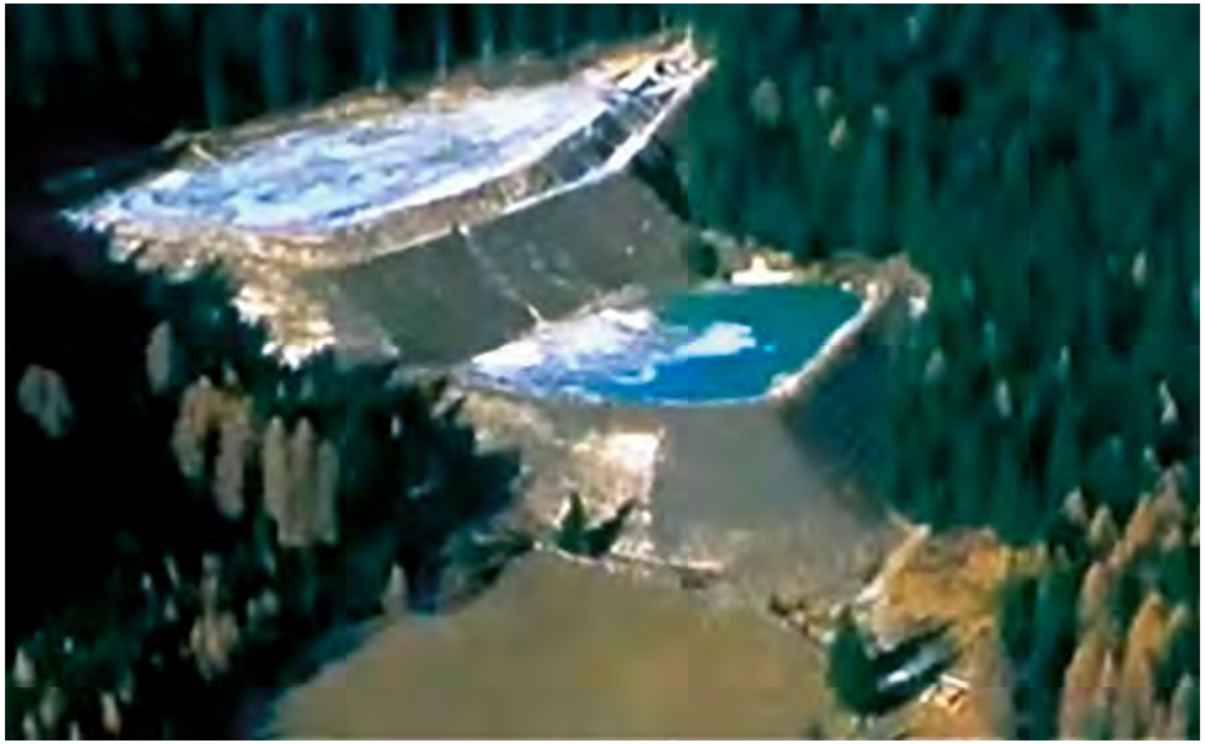
Original view of the American Falls Dam and Spillway.

American Falls after being rebuilt (pictures courtesy from Bureau of Reclamation)

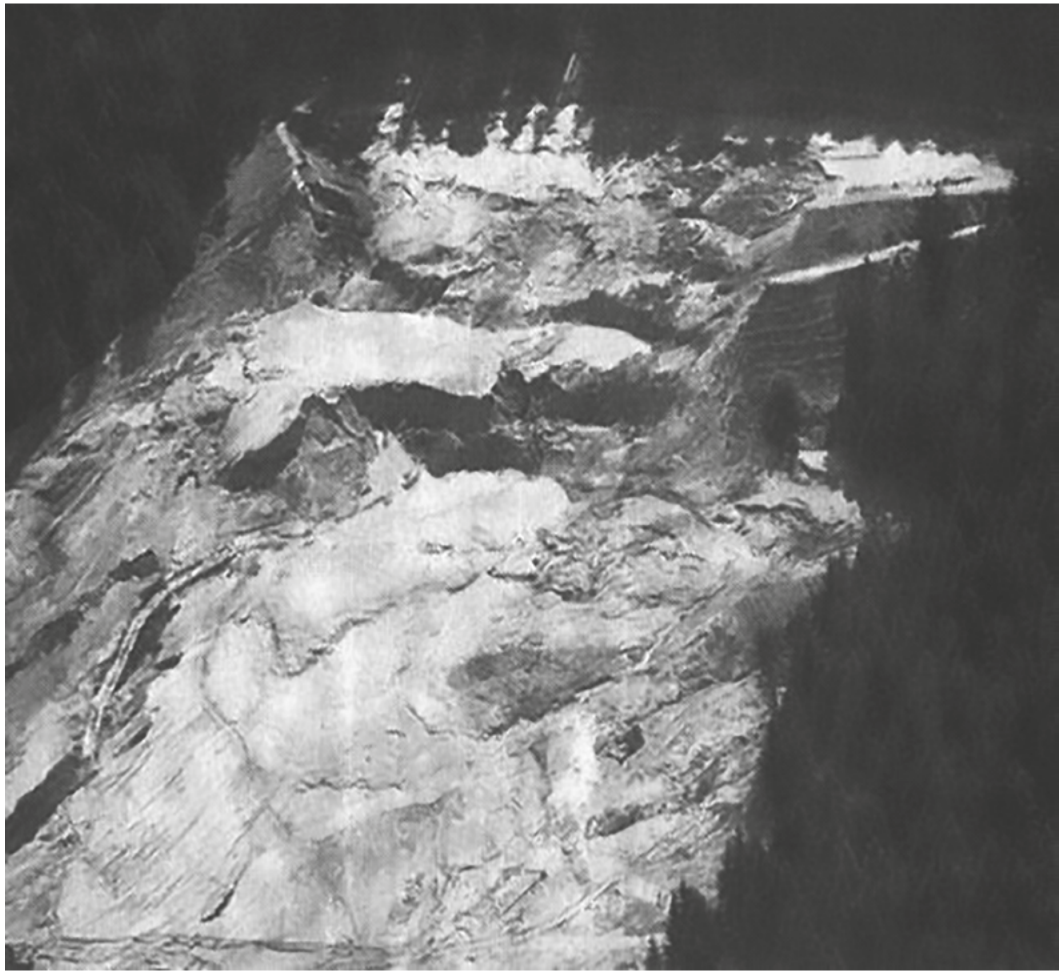
Order	Dam Identification	Type	Location-Country
7.3-Q	Val di Stava	Tailings	Tesero – Italy
Finished	**Height (m)**	**Length (m)**	**References**
1981	Not informed in reference	Not informed in reference	[07-55]

Event: The dam collapse occurred on July 19, 1985, when two tailings dams above the village of Stava-Italy failed, killing 268 people, destroying 63 buildings, and demolishing 8 bridges. The upper dam broke first, leading to the collapse of the lower dam. Around 180.000 m^3 of mud, sand, and water were released into the Rio di Stava valley and toward the village of Stava at a speed of 90 km/h.

Graphical representation of the Prestavel basins: (A) upper basin; (B) lower basin; (1) cyclone, (2) sandy deposit, (3) silty deposit, (4) drainage service, (5) emergency drainage, (6) service road, (7) sand cone, (8) silty deposit, (9) drainage from the upper basin, (10) caretaker´s house.



1981-1982: bottom view of the basins almost completely replanted. It is possible to notice the progressive levels of growth achieved by hydrocyclone and the caretaker´s house in the foreground (courtesy of Fondazione Stava, 1985).



Pictures and schematic view of Stava Tailings Dam, and after the collapse (From [07-55]).

Order	Dam Identification	Type	Location-Country
7.3-R	Quail Creek	Earthfill replaced by RCC	Utah – USA
Finished	**Height (m)**	**Length (m)**	**References**
1983	42	610	[07-37 & 07-56]

Event: As the reservoir filled in June 1987, seepage at the downstream toe began to increase. Additionally, a two-foot diameter *sinkhole* was discovered at the downstream toe on June 25th. During the summer of 1988, as the reservoir was held, seepage continued to increase. On September 21, a major opening was identified. With the seepage apparently under control the owner began to fill the reservoir through the month of December. On the morning of December 31, 1988, cloudy seepage was observed at the downstream toe. Between 11:00 and 11:30 p.m., a wedge 15 m wide suddenly dropped, blocking flow temporarily until flow resumed and began removing the collapsed material. Erosion continued toward the reservoir until at 12:30 a.m. on January 1, 1989, the Quail Creek Dike failed. A new roller-compacted concrete (RCC) dam was built to replace the failed Quail Creek Dike.

Quail Creek Embankment collapse

Quail Creek was rebuilt using RCC concrete (pictures Courtesy from Bureau of Reclamation)

Order	Dam Identification	Type	Location-Country
7.3-S	Sayano Shushenskaya	Concrete Arch Gravity	Russia
Finished	**Height (m)**	**Length (m)**	**References**
1985	242	1.066	[07-57; 07-58 & 07-59]

Event: On August 17, 2009, a catastrophic accident took place in the turbine and transformer rooms of the hydroelectric plant of the Sayano-Shushenskaya dam. Initially, the accident was lightly reported in the west, both in the mainstream and the technical press. Over the ensuing months, the early internet postings of photographs, videos and narratives from witnesses and technical experts in Russia were supplemented with studies, opinions, and speculations from writers both inside and outside of Russia about the causes. Both the official reports issued after the incident, and several technical discussions that followed, have drawn very general conclusions that attributed the incident to heavy vibration and poor maintenance associated with failed studs in the turbine head cover of a turbine in the plant.

Pictures from Sayano Shushenskaya (Andriolo's Archive) during the Study Tour planned during the Seventeen ICOLD Congress



Pictures from Sayano Shushenskaya before the damages



Pictures from Sayano Shushenskaya after the damages (from Internet)

Order	Dam Identification	Type	Location-Country
7.3-T	Upper Stillwater Dam	RCC Gravity	Duchesne County – Utah – USA
Finished	**Height (m)**	**Length (m)**	**References**
1987	91	815	[07-60, 07-61 & 07-62]

Event: The first reservoir filling, during the fall of 1987, provided the downstream hydrostatic force which instigated the foundation movement. Unusually, high piezometer readings were also recorded early in the filling process. Horizontal movement of the foundation on the argillite layer was recorded by multiple point borehole extensometers beginning in June 1988.

Shrinkage/temperature cracks, some of which extended continuously through the parapets, crest, galleries, and downstream face, resulted in significant leakage in at least 15 distinct locations.

These cracks, one of which was up to a 6 mm wide, was probably aggravated by the relative downstream foundation movement since some displacement could be seen at the large crack. Leakage rates at the worst crack reached 126 l/s, while others recorded leakage rates around 9.5 l/s. Extensive remedial grouting and crack repair was required to reduce the leaks.

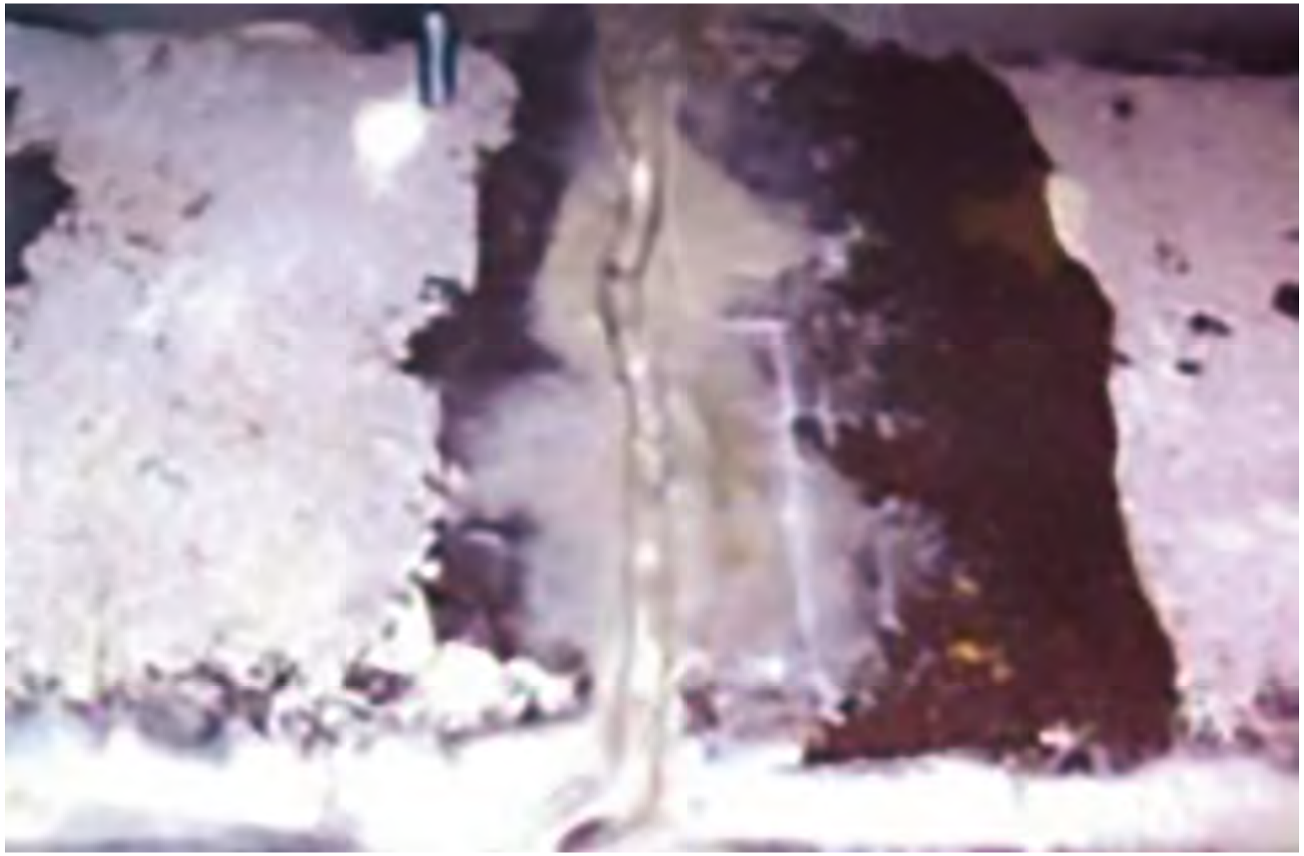
In addition to seepage from cracks in the dam, there was also significant flow from the foundation drains. In 1988, during the first filling of the reservoir, a continuous crack was discovered in the foundation gallery.

The Bureau of Reclamation repaired this and other similar but smaller cracks at various stations. Due to the potential for crack movement with seasonal reservoir level changes, a flexible hydrophilic polyurethane resin was selected for injection into the cracks. The selected repair procedure was to inject the crack with polyurethane resin in 3 stages.

Work for the first two stages was executed from the gallery and the downstream face at elevations below the reservoir water level. When the flow of water was controlled, a urethane resin pump system was connected to the injectors, and resin was pressure injected into the crack.

Aerial view from downstream of Upper Stillwater Dam (Pictures from the references above)

Remedial actions on Upper Stillwater Dam (Pictures from the references above)



Remedial actions on Upper Stillwater Dam (Pictures from the references above)

Order	Dam Identification	Type	Location-Country
7.3-U	Chavimochic	Gravity	Trujillo – Peru
Finished	**Height (m)**	**Length (m)**	**References**
1993	20	70	[07-63]

Event: The rainy period of 1993/1994, was characterized by being long and with flows of the order of 300 to 400 m^3/s. In addition, the three floodgates remained open for long time, based on works that were being carried out on the water intake spillway.

As a consequence, there was an intense erosion on the pillar between the gates 1 and 2, in function of the impact of sediment in high speed. This increased the effect of abrasion caused by the action of the vortices that formed from its base. These efforts provoked a cesspool deep around the base of the pillar, which stretched downstream in the greater inclination of the profile of the Spillways 1 and 2, causing wear and removal of the protective coating. This protection was done with plates of 0.40 x 0, 40 x 0, 20 m high granite abrasion resistance.

Chavimochic Dam Spillway before the damages (Pictures from Andriolo's Archive)

Damages in the structures and gates of Chavimochic Dam Spillway (Pictures from Andriolo's Archive)

Order	Dam Identification	Type	Location-Country
7.3-V	El Guapo	Earthfill	Miranda – Venezuela
Finished	**Height (m)**	**Length (m)**	**References**
1999	60	138	[07-64]

Event: During heavy rainfall in 1999, the dam on the Guapo river suffered serious damage and collapsed. A new RCC concrete spillway was constructed, and the embankment was repaired.

Damages in the El Guapo Dam around the Spillway (Pictures from the reference above)

The repairs at El Guapo Dam with a new Spillway (Pictures from the reference above)

Order	Dam Identification	Type	Location-Country
7.3-X	Brumadinho	Tailing	Minas Gerais – Brazil
Finished	**Height (m)**	**Length (m)**	**References**
Operation up to 2016	86m	720m	[07-65]

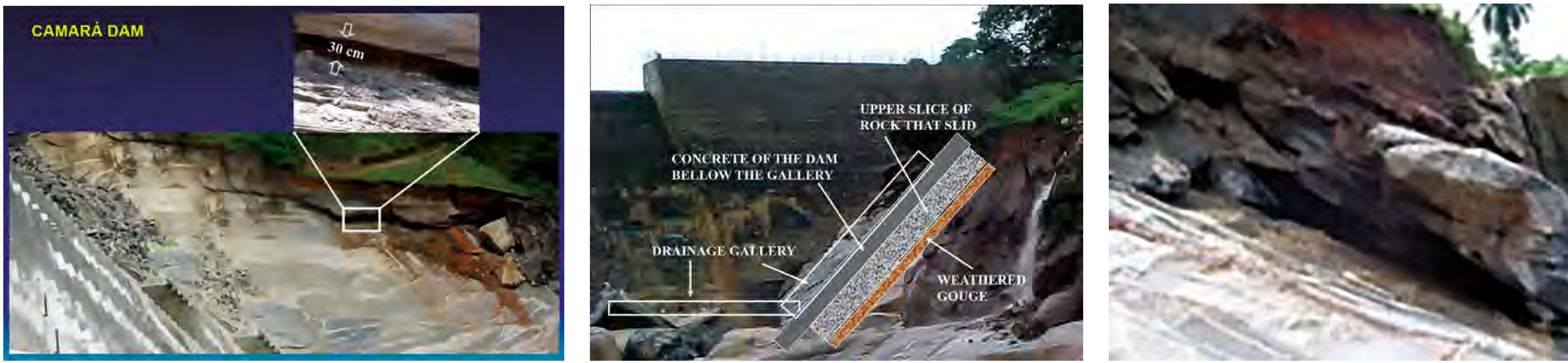
Event: The Brumadinho dam disaster occurred on January 25, 2019 when Dam I, a tailings dam at the Córrego do Feijão iron ore mine, suffered a catastrophic failure**.** The dam released a mudflow that advanced through the mine offices, including a cafeteria during lunchtime, along with houses, farms, inns, and roads downstream. 270 people died as a result of the collapse, of whom 259 were officially confirmed dead.
A Review Panel Board concluded that the rupture occurred due to structural instability with liquefaction. The most relevant technical aspects for the rupture were inadequate internal drainage and high groundwater level in the reservoir; slow deformation of the rejects reaching the peak of resistance in the non-drained condition and loss of suction in the material above the groundwater level; dam structure not designed to contain liquefied material; and inadequate consideration of stability issues identified during dam existence.

The Brumadinho Tailings Dam collapse (Pictures from Internet)

Order	Dam Identification	Type	Location-Country
7.3-Y	Camara	RCC Gravity	Paraíba – Brazil
Finished	**Height (m)**	**Length (m)**	**References**
2002	50	465	[07-66] and item 4.2.4 – Chapter 4

Event: On the night of June 17, 2004, the dam broke after a foundation failure, reaching part of the territories and inhabitants of the municipalities of Alagoa Nova, sand and the urban sites of two cities, where the disaster took on bigger dimension.

The Camará Dam as was constructed (at left above) and the damages due to the foundation collapse (Pictures from the Reference)



The Camará Dam as was constructed (at left above) and the damages due to the foundation collapse (Pictures from the Reference)

Camará Dam after being rebuilt (Pictures from the Internet)

Order	Dam Identification	Type	Location-Country
7.3-Z	Campos Novos	CFRD	Santa Catarina – Brazil
Finished	**Height (m)**	**Length (m)**	**References**
2006	202	600	[04-58]

Event: A major rupture caused the water to begin to run out, after a tunnel collapsed on June 20, 2006, and the reservoir was droped down.

Campos Novos Dam at the end of construction and after the damage, and reservoir as drop down (Pictures from Internet)

Order	Dam Identification	Type	Location-Country
7.3-W	Zipingpu	CFRD	Dujiangyan, Sichuan – China
Finished	**Height (m)**	**Length (m)**	**References**
2006	156	663	[01-17 & 01-18]

Event: Zipingpu CFRD failures were caused by the 8.0R Earthquake on May 12, 2008, and the following failures were recorded:
Subsidence of the crown in the central part of the dam, of the order of 50 cm in relation to the side survey control points;

- Deformation of the lower face of the dam, an area of approximately 1000 m^2;
- Deviations and deformations of the construction elements throughout the face of the dam;
- Widening of construction joints (approximately 15 cm on the upper face);
- Extended massive landslides throughout the reservoir; and
- Landslides on both left and right abutments of the dam causing further damages to secondary constructions.

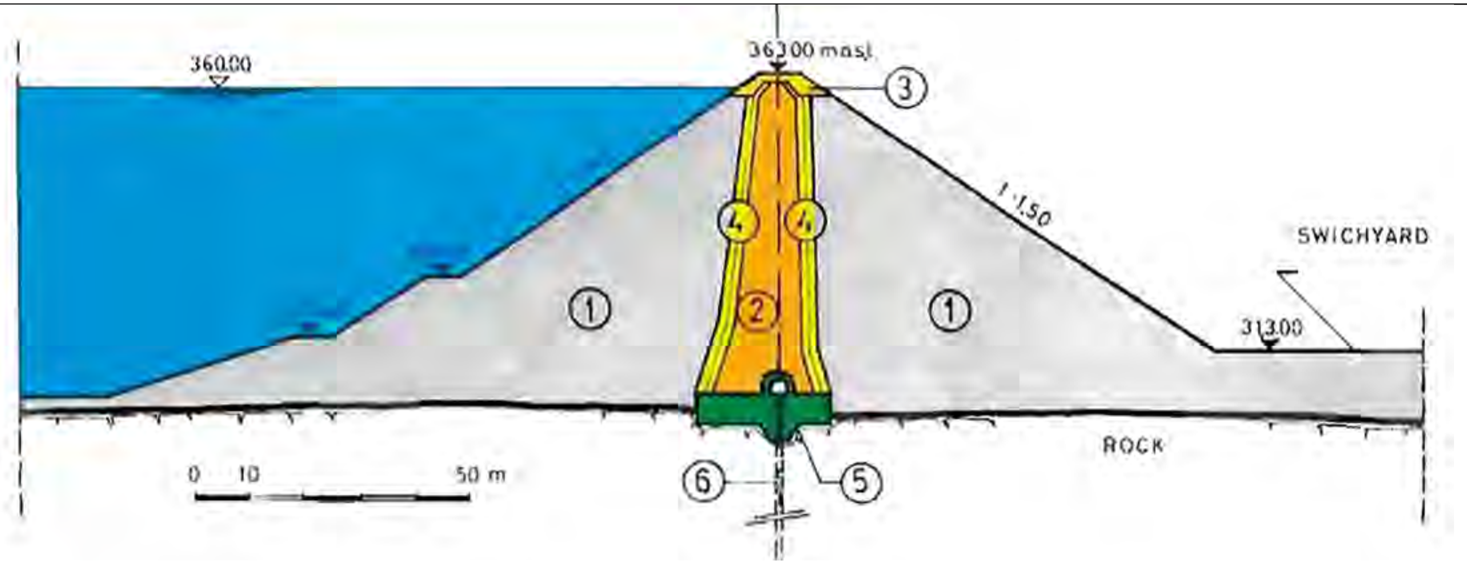
The Earthquake hit Zipingpu Dam hard and rendered a maximum permanent settlement of 100 cm and a horizontal displacement of 60 cm to the dam.

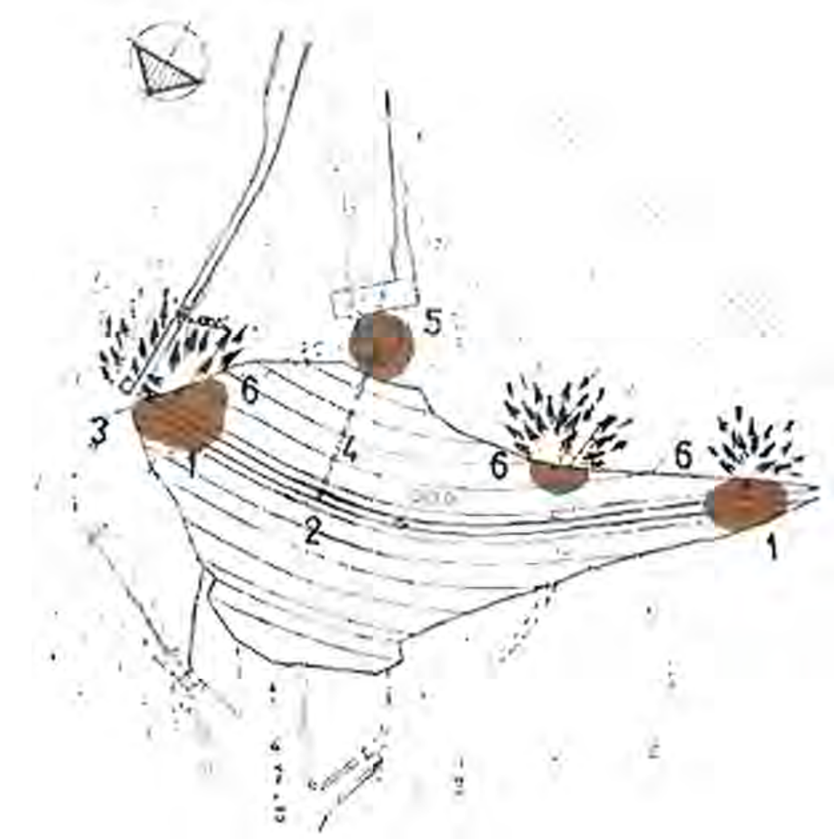


Damages on Zipingpu Dam (pictures from the References)

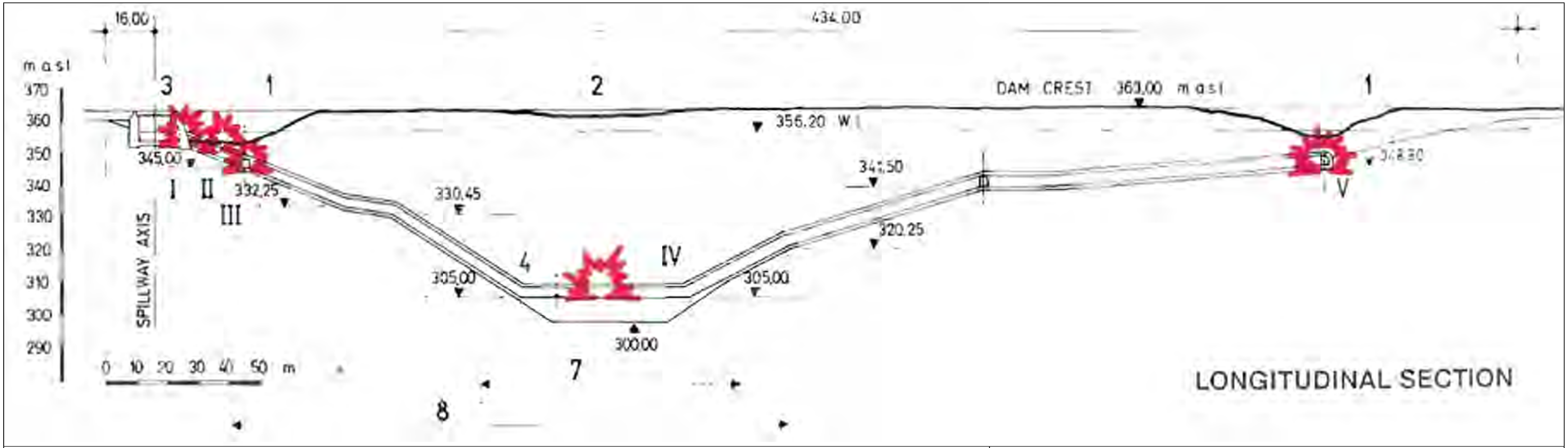
Order	Dam Identification	Type	Location-Country
7.3-&	Peruca	Embankment Clay Core	Split-Dalmatia County, Dalmatia – Croatia
Finished	**Height (m)**	**Length (m)**	**References**
1958	63	450	[07-69]

Event: The Peruca Dam, together with the reservoir and hydroelectric power plant, is a part of the hydropower scheme constructed in the Cetina River catchment. The Peruca Dam reservoir has a significant effect on water regime regulation and consequently on power generation in this hydropower scheme which is in average about 3,000,000 MWh per year and presents the main energy source for the southern part of Croatia.
The dam is of rockfill type, with zoned cross-section consisting of centrally placed clay core, filtering layers, and upstream and downstream crushed stone shells. The dam is 63 m high and 450 m long at the crest. Since the dam is founded on the permeable limestone, the watertightness of the dam profile and the reservoir was achieved by construction of 200 m deep and 1,600 m long grout curtain with total surface area of 260,000 m^2. The explosive set in the Peruca Dam by the former Yugoslav Army was blasted at 10:48:55 a.m. on January 28, 1993. The reservoir level was at 356.20 m.a.s.1. The exact explosion time was recorded by the seismic stations. The seismogram analyses have proven that the explosions took place in approximately 10s intervals; that 2030t of TNT explosive charges were blasted; and that the energy released during the explosion corresponded to the energy of an earthquake of magnitude 2.4.





1 – Rockfill
2 – Clay Core
3 – Top Fill
4 – Filter Layers
5 – Grouting Gallery
6 – Grout Curtain



1 – Craters on the right and left dam ends	5 – Chunks of clay core
2 – Subsidence in the central dam section	6 – Caved -in gallery entrances
3 – Spillway	7 – Gallery completely destroyed
4 – Drain age outlet	8 – Gallery completely filled with clay
I, Ii, 111. IV. V – ASSUMED BLASTING POINTS	

Peruca dam layout and longitudinal section[07-69]

Peruca dam damages due to war[07-69]

7.4 Understanding the Causes and Discussion

7.4.1 Understanding

Dam failures not only risk public safety, they can also cost our economy millions of dollars in damages. Failure is not just limited to damage to the dam itself. It can result in the impairment of many other infrastructure systems, such as roads, bridges, and water systems. When a dam fails, resources must be dedicated to understanding the reasons for failures and the measurements to the prevention and mitigation of the consequences.

In order to improve public safety and resilience, the risk and consequences of dam failure must be lowered. Progress requires better planning for mitigating the effects of failures; increased regulatory oversight of the safety of dams; improving coordination and communication across governing agencies; and the development of tools, training, and technology.

The actions need to be in the direction to understanding the causes and looking for the technical defenses or improvement that can be adopted.

The common causes reported (and which are observed in the list on **item 7.2**) of dam failure include:

Main Cause	Specific	Conceptual understanding	
		Specific	General
Climatic & Hydrological	Heavy Rain	Poor (*) statistical data	
	Extreme Inflow – Overtopping	Poor statistical data	
	Spillway Design Error		Poor knowledge management
	Low Dam crest height		Poor knowledge management
	Transport of debris and/or sediments		Poor knowledge management
Geological Instability	Inadequate Foundation	Poor statistical data	
	Instability/ Defects		Poor knowledge management
	Erodible zones downstream and/or upstream abutments	Poor statistical data	
	Displacement of Rock and/or Soil Mass		Poor knowledge management
Earthquake	Shaking, Cracks, Displacements; Seepages	The actual fault associated with an earthquake can be complex, and it is often unclear whether in a particular earthquake the total energy comes from a single fault plane	
Materials Uses	Substandard quality and/or preparation		Poor knowledge management
	Poor Quality Control		Poor knowledge management
Constructability and/or Methodology	Poor Construction Practices		Poor knowledge management

Main Cause	Specific	Conceptual understanding	
		Specific	General
Human Design Errors	Design Concept and/or Hypothesis		Poor knowledge management
	Computational Mistakes		Poor knowledge management
	Poor Documentation – technical Specification; Drawings		Poor knowledge management
	Environmental Concerns		Poor knowledge management
	Poor Contract and no Legal understanding		Poor knowledge management
Erosions	Internal erosion, seepages, and/ or piping		Poor knowledge management
	Concrete surfaces		Poor knowledge management
	Tunnels and/or Penstocks		Poor knowledge management
Equipment	Gates	Excessive vibration and seepage	Poor knowledge management
	Turbines	Excessive vibration	Poor knowledge management
	Maintenance	Poor routine and/or attention	Poor knowledge management
(*) Poor	*Reduced; Modest; Insufficient*		

7.4.2 Discussions after the Accidents

When a dam impounds a body of water, it will experience a load or force commonly referred to as hydrostatic pressure. A variety of other forces such as uplift pressure, earth pressure, silt pressure, wave pressure, wind pressure, ice pressure, seismic acceleration, hydrodynamic pressure, and thermal stress from ambient temperature changes can also act on the dam depending on site conditions. The planed and required properties adopted for the dam body and its foundation must support the actions. Though it is imperative to analyze all applicable force combinations specific to a given site when evaluating an existing dam or designing a new one.

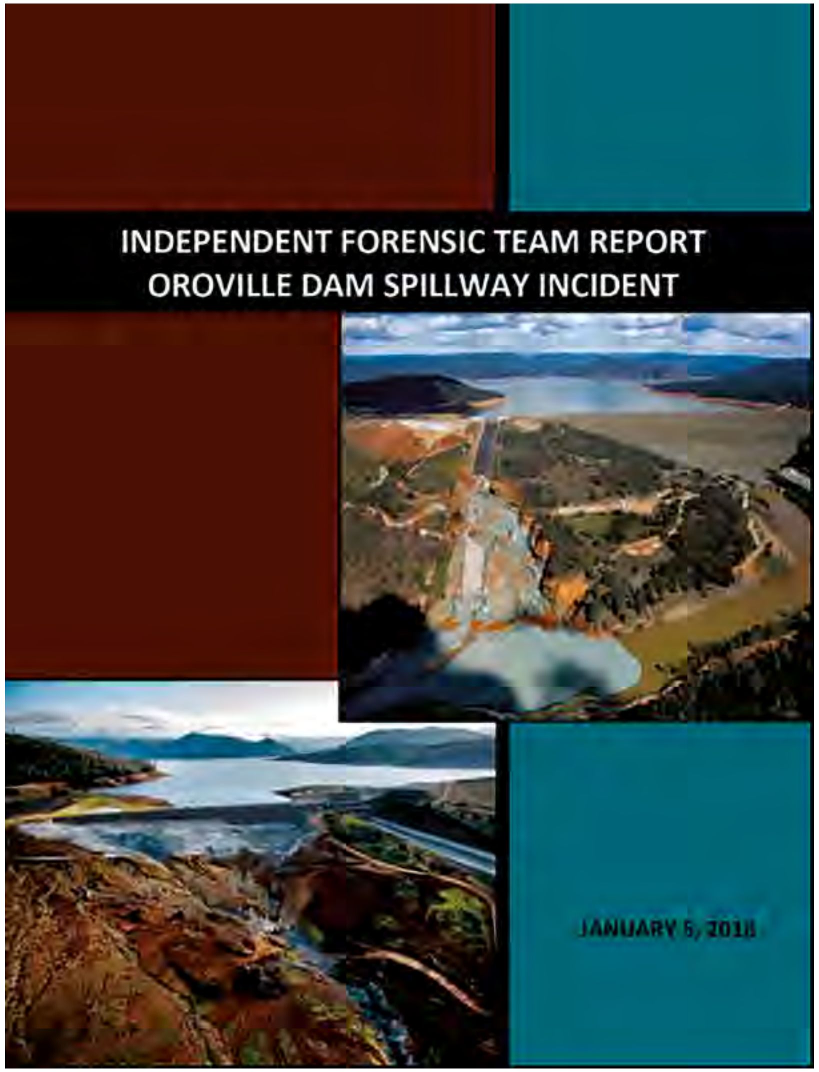
To address the potential for highly variable nature of foundation rock and materials properties as well as construction quality within a given structure **the current design practice** relies heavily on simple empirical rules.

In order to improve public safety and resilience, the risk and consequences of dam failure must be lowered. Progress requires better planning for mitigating the effects of failures; increased regulatory oversight of the safety of dams; improving coordination and communication across governing agencies; and the development of tools, training, and technology. Failure is not just limited to damage to the dam itself. It can result in the impairment of many other infrastructure systems, such as roads, bridges, and water systems. When a dam fails, resources must be devoted to the prevention and treatment of public health risks as well as the resulting structural consequences.

To help understanding the potential causes of accidents, some reports and opinions of post-occurrence analyses can be cited bellow:

See Dam on 7.3 – M		Location-Country	References
7.4.2-A	Oroville	Oroville – California – USA	[07-50]

Relevant information from de Investigation Team/or Panel Board



Oroville Dam was initiated in 1961 (under the responsibility of **California Department of Water Resources (DWR)**, that was created in 1956), and despite numerous difficulties encountered during its construction, including multiple floods and a major train wreck on the railway line used to transport materials to the dam site, the embankment was topped out in 1967 and the entire project was ready for use in 1968.

In February 2017, the main and emergency spillways threatened to fail, leading to the evacuation of 188,000 people living near the dam. After deterioration of the main spillway *largely stabilized and the water level of the dam's reservoir dropped below the top of the emergency spillway, the evacuation order was lifted. The Independent Forensic Team Reports mentioned:*

> *"...The Oroville Dam spillway incident was caused by a long-term systemic failure of the California Department of Water Resources (DWR), regulatory, and general industry practices to recognize and address inherent spillway design and construction weaknesses, poor bedrock quality, and deteriorated service spillway chute conditions. The incident cannot reasonably be "blamed" mainly on any one individual, group, or organization.*

During service spillway operation on February 7, 2017, water injection through both cracks and joints in the chute slab resulted in uplift forces beneath the slab that exceeded the uplift capacity and structural strength of the slab, at a location along the steep section of the chute. The uplifted slab section exposed the underlying poor quality foundation rock at that location to unexpected severe erosion, resulting in removal of additional slab sections and more erosion.

Responding to the damage to the service spillway chute necessitated difficult risk tradeoffs while the lake continued to rise. The resulting decisions, made without a full understanding of relative uncertainties and consequences, allowed the reservoir level to rise above the emergency spillway weir for the first time in the project's history, leading to severe and rapid erosion downstream of the weir and, ultimately, the evacuation order.

There was no single root cause of the Oroville Dam spillway incident, nor was there a simple chain of events that led to the failure of the service spillway chute slab, the subsequent overtopping of the emergency spillway crest structure, and the necessity of the evacuation order. Rather, the incident was caused by a complex interaction of relatively common physical, human, organizational, and industry factors, starting with the design of the project and continuing until the incident. The physical factors can be placed into two general categories:

- *Inherent vulnerabilities in the spillway designs and as-constructed conditions, and subsequent chute slab deterioration*
- *Poor spillway foundation conditions in some locations*

A simplified overview of how human, organizational, and industry factors interacted with these two general categories of physical factors is given in and is broadly outlined below.

The inherent vulnerability of the service spillway design and as-constructed conditions reflect lack of proper modification of the design to fit the site conditions. Almost immediately after construction, the concrete chute slab cracked above and along underdrain pipes, and high underdrain flows were observed. The slab cracking and underdrain flows, although originally thought *of as unusual, were quickly deemed to be "normal," and as simply requiring on-going repairs. However, repeated repairs were ineffective and possibly detrimental.*

The seriousness of the weak as-constructed conditions and lack of repair durability was not recognized during numerous inspections and review processes over the almost 50-year history of the project. Over time, chute flows and temperature variations led to progressive deterioration of the concrete and corrosion of steel reinforcing bars and anchors, with likely loss of slab strength and anchor capacity.

There was likely also some shallow underslab erosion and some loss of underdrain system effectiveness, which contributed to increased slab uplift forces. The particularly poor foundation conditions at the initial service spillway chute failure location contributed to likely low anchor capacity and shallow underslab erosion.

Due to the unrecognized inherent vulnerability of the design and as-constructed conditions and the chute slab deterioration, the spillway chute slab failure, although inevitable, was unexpected.

Once the initial section of the chute slab was uplifted, the underlying poor quality foundation materials were directly exposed to high velocity flows and were quickly eroded. Undermining and uplift of other portions of the chute slab resulted in further removal of slab sections and more foundation erosion.

Although the poor foundation conditions at both spillways were well documented in geology reports, these conditions were not properly addressed in the original design and construction, and all subsequent reviews mischaracterized the foundation as good quality rock. As a result, the significant erosion of the service spillway foundation was also not anticipated.

Following the unexpected chute slab failure and erosion, and subsequent closure of the service spillway gates to examine the damage, delicate and difficult risk tradeoffs, involving myriad considerations, were necessary over the next few days in order to *manage the incident. Either the gates would need to be re-opened, with the potential for further service spillway damage and/or damage to a transmission tower, or the lake levels would rise and the emergency spillway weir would be overtopped, with the potential for erosion at the emergency spillway. In addition, erosion had transported a tremendous amount of debris into the river channel, and the resulting high tailwater was threatening to flood the powerhouse. The decision-makers attempted to find a "sweet spot," such that the service spillway would continue to be used, but with discharges no greater than necessary to just prevent the lake from rising above the emergency spillway weir.*

There were decision points during the incident when discharge through the service spillway was specifically limited, even though risks to the powerhouse from further discharge were clearly diminishing. These decisions ultimately resulted in the lake rising high enough to initiate flow over the emergency spillway weir. The decisions were made with the best of intentions, but against the advice of civil engineering and geological personnel, who had by then recognized the poor bedrock conditions and the potential for unsatisfactory performance of the previously untested emergency spillway. In limiting service spillway discharge to reduce the likelihood of powerhouse flooding, the additional dam safety risk associated with use of the emergency spillway was not appropriately considered. Once the emergency spillway was allowed to overtop, this additional risk was soon realized, and the evacuation order became a necessary precaution.

There were many opportunities to intervene and prevent the incident, but the overall system of interconnected factors operated in a way that these opportunities were missed. Numerous human, organizational, and industry factors led to the physical factors not being recognized and properly addressed, and to the decision-making during the incident. The following are some of the key factors which are specific to DWR:

- *The dam safety culture and program within DWR, although maturing rapidly and on the right path, was still relatively immature at the time of the incident and has been too reliant on regulators and the regulatory process.*

- *Like many other large dam owners, DWR has been somewhat overconfident and complacent regarding the integrity of its civil infrastructure and has tended to emphasize shorter-term operational considerations. Combined with cost pressures, this resulted in strained internal relationships and inadequate priority for dam safety.*
- *DWR has been a somewhat insular organization, which inhibited accessing industry knowledge and developing needed technical expertise.*
- *DWR's ability to build the appropriate size, composition, and expertise of its technical staff involved in dam engineering and safety has been limited by bureaucratic constraints.*
- *In addition to lessons which are specific to DWR, as described in this report, the following are some of the general lessons to be learned by the broader dam safety community:*
  - *In order to ensure the safe management of water retention and conveyance structures, dam owners must develop and maintain mature dam safety management programs which are based on a strong "top-down" dam safety culture. There should be one executive specifically charged with overall responsibility for dam safety, and this executive should be fully aware of dam safety concerns and prioritizations through direct and regular reporting from a designated dam safety professional, to ensure that "the balance is right" in terms of the organization's priorities.*
  - ***More frequent physical inspections are not always sufficient to identify risks and manage safety**.*
  - *Periodic comprehensive reviews of original design and construction and subsequent performance are imperative. These reviews should be based on complete records and need to be more in-depth than periodic general reviews, such as the current FERC-mandated five-year reviews.*
  - *Appurtenant structures associated with dams, such as spillways, outlet works, power plants, etc., must be given attention by qualified individuals. This attention should be commensurate with the risks that the facilities pose to the public, the*

environment, and dam owners, including risks associated with events which may not result in uncontrolled release of reservoirs, but are still highly consequential.

- *Shortcomings of the current Potential Failure Mode Analysis (PFMA) processes in dealing with complex systems must be recognized and addressed. A critical review of these processes in dam safety practice is warranted, comparing their strengths and weaknesses with risk assessment processes used in other industries worldwide and by other federal agencies. Evolution of "best practice" must continue by supplementing current practice with new approaches, as appropriate.*
- *Compliance with regulatory requirements is not sufficient to manage risk and meet dam owners' legal and ethical responsibilities.*

Some of these general lessons are self-evident, and have been noted by others previous to the IFT's investigation of this incident. The question is whether dam owners, regulators, and other dam safety professionals will recognize that many of these lessons are actually still to be learned. Although the practice of dam safety has certainly improved since the 1970s, the fact that this incident happened to the owner of the tallest dam in the United States, under regulation of a federal agency, with repeated evaluation by reputable outside consultants, in a state with a leading dam safety regulatory program, is a wake-up call for everyone involved in dam safety. Challenging current assumptions on what constitutes "best practice" in our industry is overdue…."

See Dam on 7.3-S		Location-Country	References
7.4.2-B	Sayano Shushenskaya	Russia	[07-67]

Relevant information from de Investigation Team/or Panel Board

From the reference [07-67] it can be mentioned:

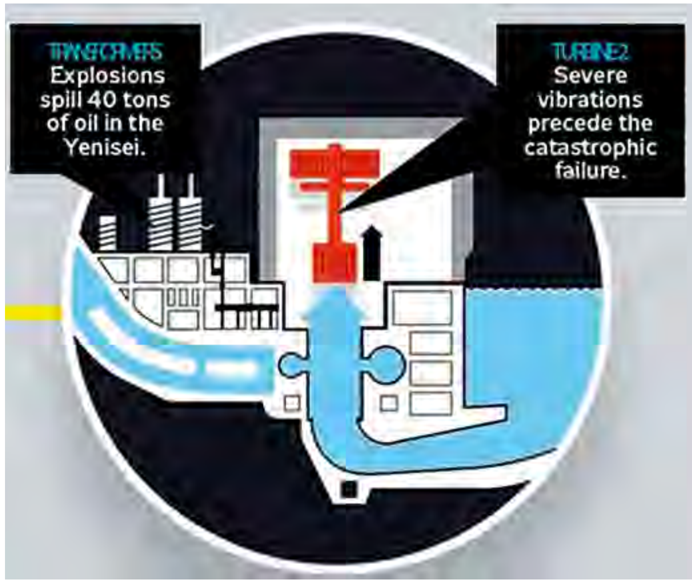
"...On August 17, 2009August, a major failure occurred at Sayano-Shushenskaya hydroelectric dam in Russia. 75 people were killed, many were injured, and 40 tons of oil were spilled in the Yenisei River.

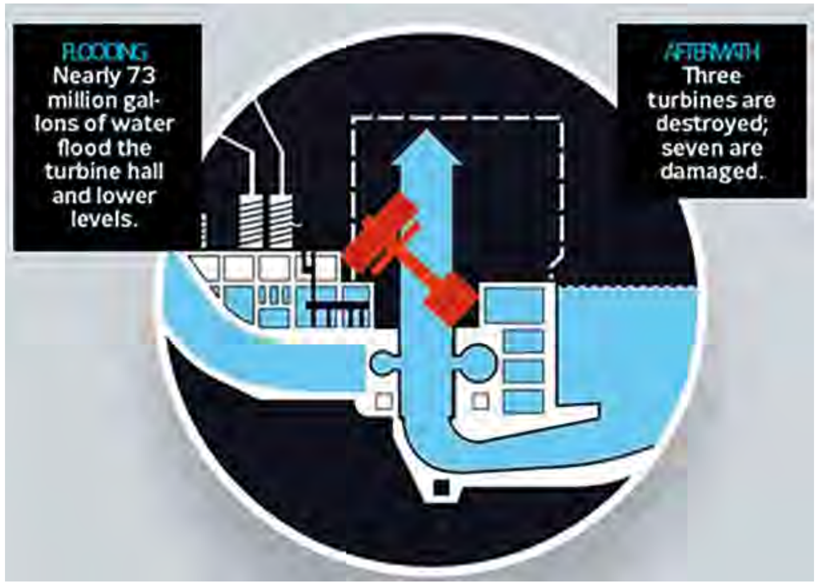
Immediately after the accident, Russia's Federal Service for Ecological, Technological, and Nuclear Supervision launched an investigation. The official report, released on Oct. 3, blamed poor management and technical flaws for the accident.

According to the report, repairs on Turbine 2 were conducted from January to March 2009, and a new automatic control system--meant to slow or speed up the turbine to match output to fluctuations in power demand--was installed. On March 16, the repaired turbine resumed operation. But the amplitude of the machine's vibrations increased to an unsafe level between April *and July. The unit was taken offline until Aug. 16, when the Bratsk fire forced managers at Sayano-Shushenskaya to push the turbine into service.*

Back in operation, Turbine 2 vibrated at four times the maximum limit. As the control system decreased the turbine's output on the morning of Aug. 17, the vibrations increased. The unit acted like the engine of an automobile being downshifted on a hill, shuddering violently, and stressing the fatigued metal pins holding it in place.

In a normal procedure at the first sign of abnormal performance, and redundant automatic systems are in place a routine if a unit were experiencing violent or abnormal vibrations it would shut down, and the gate at the top of the penstock would close. If it's not safe, if there's a risk of failure, all other benefits--be they economic, environmental or anything else--those all go away."





"The general arrangement and size of the facilities at Sayano Shushenskaya are displayed in the photographs in Figures 1 and 2. Figure 3(not presented in this text) is a reproduction of a drawing showing a vertical cross section through dam, penstock, and powerhouse. It shows the relative locations and sizes of intakes, penstocks, turbines, generators, transformers, and power take-off facilities. Figure 4 is an interior view of the machine hall looking across Unit 2 towards Units 3 through 10. Figure 5 is a photograph of a cutaway model of one of the turbine generator units showing its main components. Figure 6 is a cross section drawing through a turbine. It contains some key dimensions, and it clarifies the arrangement of the head cover, its structural support for the thrust bearing, and the location of the studs connecting the head cover to the upper stay ring.

Other information (see Figure 6) has indicated that these studs were located at the extreme outer edge of the head cover, where it rests on a narrow flange which is part of the upper turbine stay ring. Both mating flanges at the location of the studs are narrow and relatively thin, as evidenced in the photographs (Figures 8 and 9).

In this peer-reviewed paper, F. A. Hamill presents a hypothesis of the underlying direct cause of the accident.

At 08:13 local time on 17 August 2009, Unit 2 experienced a load rejection, which was followed immediately by a loud bang heard in the administration and control building adjacent to the powerhouse. The load rejection precipitated a massive failure involving the lifting of runner, shaft, head cover, turbine and generator bearings vertically upward into the umbrella generator rotor spider, destroying it. Full penstock head was then released into the turbine pit, resulting in an enormous geyser and massive destruction.

At least a half minute after the geyser blew the roof away, another very loud bang was recorded by a cell-phone video which showed events as seen from a substantial distance downstream from the powerhouse. Three units (2, 7 and 9) were totally destroyed. The rest of the units were severely damaged, with the exception of Unit 6, which was under refurbishment and not in operation.

During the night of 16-17 August 2009, Sayano Shushenskaya experienced large and rapid load swings, with the total varying from 2800 to 4400 MW. Unit 2 at the plant, with both a new governor and a new automated joint load control system, had been set as the lead unit, and experienced the largest load swings. The accident itself followed in the morning.

Very soon after the event, the Russian industrial safety agency had attributed the cause to heavy vibration of Unit 2 in the plant, which, combined with lax maintenance and inspection practices, resulted in fatigue failure of the studs securing the turbine head cover to the unit stay ring. Although two other units in the plant were similarly destroyed.

The stud fatigue failure was attributed to the large vibration which had plagued Unit 2 for a very long time, both before and after the refurbishment in the first quarter of 2009. It appears that the runner repairs that year were made in place, without removal of the head cover, so the studs would not have been replaced.

In summary, there was evidence that the failure events sequence seems to be very powerful. That the wicket gates were blown outward after their lower trunnions were pulled out of their bushings. Thus, it seems unavoidable to conclude that the very large pressure spike originated on the inside of the gate ring, which leads to the hypothesis that it started in the draft tube.

Observations at hydroelectric installations over the past 40 years have indicated that plant operators sometimes try to improve the responsiveness of their generating units by various adjustments to the equipment. One such adjustment is to modify the orifice control of the wicket gate servomotor oil pressure system in order to speed up the wicket gate movement. Occasionally, this has resulted in cases where draft tube column separation has occurred causing loud banging sounds, pressure spikes, and sometimes damage to the machines. Normally, governors are designed with considerable margin allowance in the sizing of oil piping, leaving the speed control up to the orifice plates (or needle valves in some cases) that are installed to limit the velocity of oil flow. How much margin is allowed is determined by the governor designer, but oil piping is normally not a large portion of the cost of a governor, so designers can be conservative with piping sizes and remain competitive.

Nevertheless, the importance of this incident to the safety of hydroelectric installations everywhere demands that this evaluation, however imperfect and incomplete, be made available to everyone in and around this industry.

a) *The fundamental conclusion from this examination is that the explosion of Unit 2 and the destruction of Units 7 and 9 were very probably caused by water column separation in the turbine draft tubes during unit load rejection. This hydraulic transient* *phenomenon was probably caused by turbine governors that had been speeded up (probably unknowingly) to an unsafe level in an attempt to improve frequency stability under changing electrical loads.*

b) *This project serves to re-emphasize the need to stress both model and field testing of hydraulic turbomachinery. Although the rough operating zones of the Sayano Shushenskaya turbines were able to be identified in the laboratory, the problem of resonance in the penstocks as excited by draft tube pulsations at overload conditions could only be identified in the field under full scale operating conditions. Such testing was done early on and established limits to safe operating zones which prevented resonance problems in operation. Had these limits not been established or been violated in practice, consequences as dire as those experienced on 17 August could have occurred. Fortunately, they did not, due to adequate field testing and implementation of results. Much progress has been made in recent times in the field of computational fluid dynamics (CFD), however, the fluid mechanics of turbomachinery, especially in unsteady flow regimes, still remains beyond the abilities of present day CFD modeling.*

c) *If the turbine governors in this plant were adjusted in recent times to increase wicket gate operating speed above safe levels, this may have been done in good faith by operations personnel who were not familiar with hydraulic transient phenomena, and the attendant limitations that the design of this installation imposed on operation.*

d) *This sort of adjustment has been observed on other plants, both in the USA and in other countries. Operators, left to their own devices, will attempt to maximize the output of their plant, while ensuring that it reacts to load changes in the fastest way possible. In this case, the plant operators were clearly under pressure from the owners and grid operators to improve system frequency stability, and, therefore, load following capability. Starting with the first implementation of automated and fast joint load control, the operators of this plant had a strong incentive to speed up the governors, which could have been accomplished easily by replacing orifice plates or adjusting needle valves. Full load rejections in hydro plants are not very common. There may not have been any severe ones at Sayano Shushenskaya prior to August 2009.*

e) *Turbine mechanical designs should be carefully evaluated relative to the safety and redundancy of connections. This mechanical design, which exposed a significant head cover area to static penstock pressures at the outer periphery of each, placed a great burden on a set of relatively small and rather inaccessible studs. Inspection of the studs was not easy due to their location in recesses that were small and not particularly visible. This could be considered a deficiency on the part of the machine designers*

f) *Plant designers typically prepare Operating and Maintenance Manuals as part of the design documentation. These manuals are for the use of operations personnel, and they include both equipment manufacturer recommendations and limitations and those of the overall plant designers. A vital responsibility of the designers of these plants is to state clearly in the O&M manuals the design limitations inherent in the plant and its equipment. Clear warnings should be stated about such matters as speeding up governor times without allowing for the hydraulic transient effects thereof. Operators may not be trained in the mechanics of hydraulic transients, and their understanding of these phenomena must not be taken for granted. They must be warned what not to attempt and why, as well as what good practices to follow. It must be kept in mind that operators may be widely separated from designers by both distance and time, and additionally in technical knowledge. The O&M manual may be the only link between the two.*

g) *The importance of hydraulic transient phenomena cannot be overemphasized, as witnessed by the tragic outcome of this spectacular failure. Designers must be cautious and must impart that caution to operations people. Hydro plants are inherently safe structures, and hydro machinery is robust, conservative, and safe. All that can be negated by misoperation and by lack of maintenance and inspection, so these must be avoided through every avenue available. The continued safety of our hydro resources depends on it."*

See Dam on 7.3-X		Location-Country	References
7.4.2-C	Brumadinho	Minas Gerais – Brazil	[07-65]

Relevant information from de Investigation Team/or Panel Board

"...The Team concluded that the rupture occurred due to structural instability with liquefaction. The most relevant technical aspects for the rupture were:

- *inadequate internal drainage and high groundwater level in the reservoir;*
- *slow deformation of the rejects reaching the peak of resistance in the non-drained condition and loss of suction in the material above the groundwater level;*
- *dam structure not designed to contain liquefied material, and;*
- *inadequate consideration of stability issues identified during dam existence..."*

"...The Investigation Team also concluded that, at least since 2003, if it had information that indicated the fragility condition of the dam The measures adopted to remedy the weaknesses and improve safety were limited and unsuccessful or, if they had been implemented, they would not be short-lived in that despite the knowledge of the weaknesses of the Dam and the impact of its eventual rupture, no evidence of studies and/or measures aimed at the removal of administrative facilities downstream of the dam were identified..."

"...The independent investigation conducted by the Investigation Team evaluated the role of other areas in the company risk management and found that the organized culture of "silos" between different areas of the Company made other areas, which could also have played a relevant role in ensuring comprehensive and robust dam safety management, not fully acted..."

"...Moreover, there was a tendency of excessive deference to the area of geotechnic to deal with dam issues – understood as purely technical – in relation to which other areas that, not geotechnics, supposedly would have nothing to contribute. The research found a preponderant emphasis on financial aspects. In the case of employees in the area of operational management, no specific safety targets of geotechnical structures were identified for variable compensation purposes and the safety goals consisted mostly of conducting external auditing..."

"...In geotechnical risk management in turn, the specific dam safety targets had little weight compared to financial components, in total variable remuneration. In addition, it was observed that dam safety targets are essentially linked to regulatory compliance. Finally, we sought to analyze the expenses incurred for safety and maintenance. However, it was observed that Vale's budget and financial registration systems do not have mechanisms to identify or relate the values incurred for each geotechnical structure..."

"...The themes and problems were dealt with in the area and were not exposed outside it. In addition, it was verified that there was no environment of transparency, with a stimulus that employees could raise or reveal problems and/or question decisions by their leaders. This cloistered and watertight corporate formatting meant that relevant and understood information as unfavorable, in general, remained restricted..."

See Dam on 7.3-Y		Location-Country	References
7.4.2-D	Camará	Paraíba – Brazil	[07-66]

Relevant information from de Investigation Team/or Panel Board

"...A Panel Board Report concluded that the dam was supported on fractured rocks with weathered material between the blocks, and the proposed solution was ineffective because there was inadequate judgment in the geological interpretation of the extent of the fault. Besides these there was a lack of responsibility, absence of supervision by the owner, erroneous assessment of a geological problem and sporadic visits of the person responsible for the control of materials, without correction of non-conformities when detected. The dam was rebuilt by 2017..."

See Dam on 7.3-E		Location-Country	References
7.4.2-E	Spencer	Nebraska – USA	[07-68]

Relevant information from de Investigation Team/or Panel Board

In the early morning hours of March 14, 2019, Spencer Dam on the Niobrara River in northern Nebraska failed during a major flood and ice run on the river. An independent investigative panel was formed to examine the failure on April 2020.

"... The Panel identified two key, human factors contributing to the dam failure and consequences:

1. *There is a notable lack of knowledge about ice-run – related potential failures modes generally in the dam safety industry...*
2. *The Panel believes that the ... underestimated the potential of the dam to cause life-threatening flooding at the downstream house and property in the event of dam failure..."*

"...Beyond the human factors noted ... which contributed to the risk posed to and from the dam, several other human factors had the potential to influence the judgment and decision-making related to the dam, and thereby contributed to the failure of the dam." These other human factors are described below (summarized by the author of this book):

⇒ *Fatigue and Stress;*

⇒ *Complexity;*

⇒ *Safety Concerns;*

⇒ *Cost Pressures;*

⇒ *Pressure from Non-Dam Safety Goals;*

⇒ *Overconfidence;*

⇒ *Unclear Rules.*

The following lessons should be learned from this failure, as could be summarized from the Report:

⇒ Engineers working on dams, bridges and other infrastructures facilities in cold weather regions need to access whether the rivers are susceptible to periodic severe ice runs. It should be addressed in design. Dam facilities should be designed to be operated safely during these extreme weather events;

⇒ More research needs to be done on the dynamic nature of rivers in cold weather regions, including ice run formation, frequency, movement, damage, and how infrastructure like dams should be designed, maintained and operated to withstand ice run loading;

⇒ Designers must incorporate knowledge of local conditions;

⇒ Dam inspections while valuable, are not adequate dam safety evaluations in themselves. Evaluations must include review of critical documentation and records;

⇒ Dam owners should maintain a complete and organized set of electronic records for their Dam(s);

⇒ One of the most important responsibilities dam safety regulators have, is to periodically assess the areas downstream of low and significant hazard dams to evaluate whether the hazard classification is appropriate;

⇒ For dams with people at risk downstream, Emergency Action Plans should be developed and exercised;

⇒ Dams should be designed and have operation plans that include operations during adverse weather conditions and extreme events.

7.4.3 Observations and Comments

The accidents mentioned in this text, as well as the information of the potential causes that led to events and disasters lead to the following comments:

⇒ Lack of information to establish hypotheses and adopt possible solutions;

⇒ Poor management of available information;

⇒ Overconfidence;

⇒ Unclear Rules;

⇒ Complacency in tolerating the insecure and/or unknown.

Of the above, it can all be summarized in the lack of **knowledge management**. Otherwise, one can ask:

✓ ***What about the actions of the Public Administration/Government, to protect the Society against Risks and Catastrophes?***

The role of the Government includes defending the general interest of the population and in order to do so it writes laws and regulations specific to protection of people's property and the environment. The legal and governmental framework for all industrial activities, including operation of dams, provide the overarching structures for operational integrity and safety assurance. For activities that are hazardous, laws and regulations are often enacted to protect third parties against the harmful effects of misoperation or failure of the specific activity.

In some cases, within the general legal framework, specific laws and regulations may be established to protect against the misoperation or failure of dams and reservoirs. The legal and governmental framework provides for the governance of dams, reservoirs and operational activities that give rise to dam breach and other inundation risks. The framework typically includes the clear assignment of Responsibility for Operational Integrity and Safety.

The government is responsible for the adoption of such legislation, regulations, and other standard measures within its national legal system as it may be necessary to effectively fulfil all its national responsibilities and any international obligations. In terms of the modem view of safety governance this includes establishment of an independent regulatory body to assure the safety of dams.

Government authorities should ensure that arrangements are made to reduce the risks of dams. This includes emergency actions, monitoring of high discharges to the environment, and disposing of reservoir silt waste. This does not require that the governments establish and maintain all arrangements, although they may choose to do so. In addition, government authorities must address the safety of dams for which no other organization has responsibility.

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8

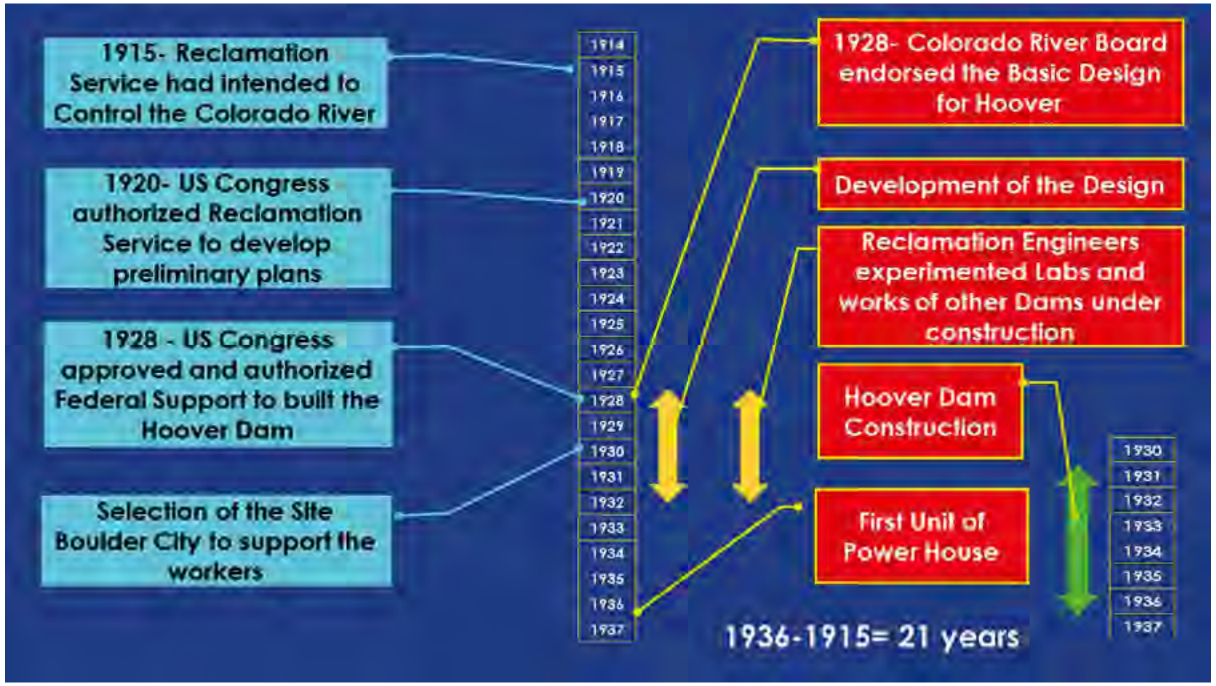
PROJECT DEVELOPMENT

8.1 Preliminary Actions

The needs of a country's society must be foreseen by its Government intelligence agencies, or by professionals who can predict difficulties. Thus, **Infrastructural Projects** such as water and sewage treatment systems, roads, bridges or viaducts, dams, hydroelectric plants or other energy sources may be necessary for the welfare of society. They depend on foresight, studies, technical, environmental and financial resources, as well as on Government authorizations that establish the social balance between ***Necessity, Benefits, and Coexistence***.

- ✓ ***A Project is not established in the blink of an eye. It requires maturation.***

In this **Chapter**, the authors recall the course of two large Dam Projects that can be cited as useful and have been constructed and operated with quality and without any drawbacks. These are, comparatively, the **Hoover (USA)** and **Itaipu (Brazil-Paraguay) Projects** – the latter is a binational development based on the understanding and sovereignty of two countries.



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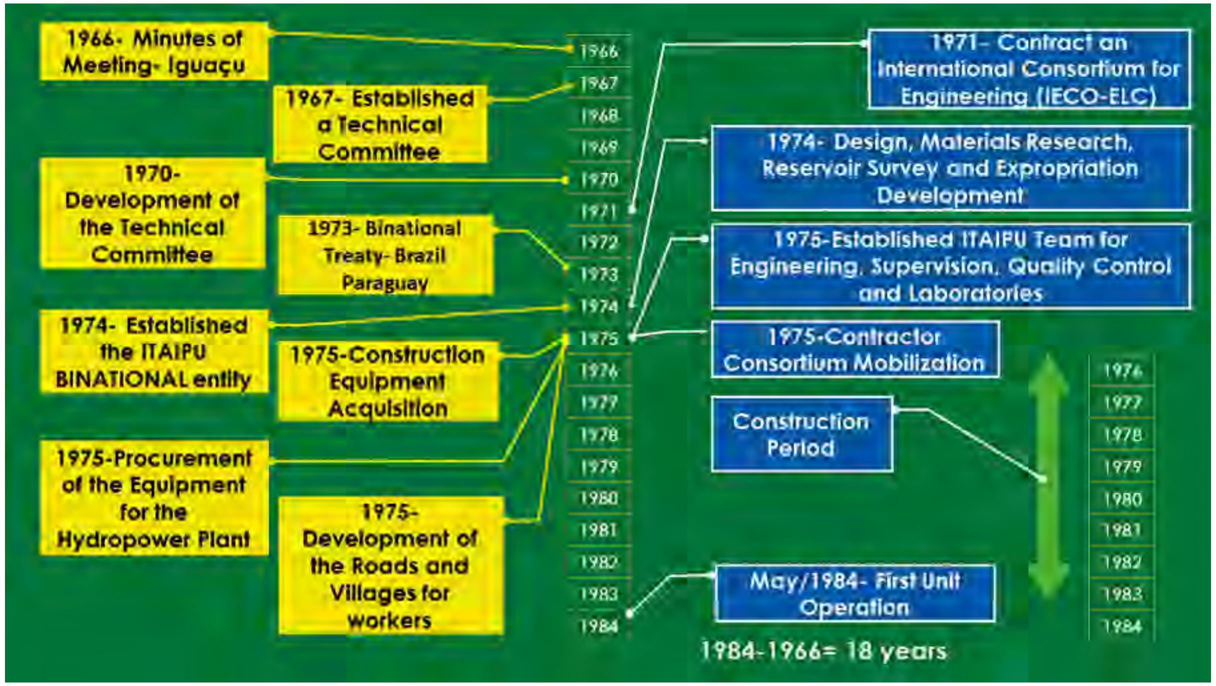


Itaipu Project Development – Data obtained from [08-02] and Andriolo's archives

These two Projects – **Hoover and Itaipu** – were developed based on an ***Organizational Line*** that allowed their developers to anticipate potential problems and search for timely solutions to enable their execution without adversity and in their normal course.

8.2 Organization and Planning

A successful project begins with its owner. Two major contributors to project quality are the owner's development and documentation of complete and realistic expectations and requirements for the project and a thorough understanding of the owner's role and responsibilities among the other team members.

The key to fulfilling an owner's expectations and requirements is knowing and understanding what they are. If on the one hand requirements are likely to be easily understood and quantified; on the other hand, expectations – though very important to the owner – are abstract and difficult to define and understand.

A relationship where the design professional is working with the owner as an adviser during the project's conception and definition phases is beneficial to both parts (the designer and the owner), and is recommended. It allows the design professional to suggest various alternatives, estimate the order of magnitude of costs, and identify trade-offs and other related aspects of the project. This function helps owners solidify their requirements.

An owner cannot expect poorly communicated requirements to be met. Owners and design professionals should develop satisfactory communication and agree on how requirements will be met and which expectations are reasonable.

Discussing relevant facts, concerns, and necessities will enhance the likelihood that expectations will become met requirements.

For designers, most projects involve more than one professional discipline. The goal of each multidiscipline design team is to provide a facility that meets the project's requirements. Team members from each design discipline integrate their technical knowledge with that of the practitioners from other disciplines to satisfy the overall design objectives.

For multidiscipline projects, three organizational levels are generally applied:

⇒ The design team consists of members from disciplines needed to complete the project.

⇒ Each team member needs to understand the project's requirements and apply their specialty to achieve a portion of the completed design under the management and guidance of the design team leader.

The design team, in any multidiscipline project, consists of practitioners of principal and support disciplines. Key members of the design team are the lead practitioners of each discipline. They should ensure that the design professional provides the services, adhering to the project's requirements, echnical accuracy, quality in design, and managing resources to meet the schedule and budget. They are should also jointly coordinate their services with those provided by the team members from other disciplines.

In this respect, the leadership should be, at least, acculturated with the following concepts:

Concept	Main Aspect	Additional Consideration	Specific
Construction period	Local Availabilities and Conditions	Materials	Regular availability to Support the needs
		Labor force	
		Cities or villages	
		Health Condition	
		Entertainment	
		Communication	
		Industrial Capabilities	
	Available Funds		
Laws-Rules – Administration	Protective aspects, responsibilities, Liabilities	Social	
		Environmental	
		Contractual	
		Business understanding	
Technical	Conceptual Criterion Statistical data	Design Criteria	Updated
		Hydrological information	With no doubts
		Geological information	
	Properties	Materials information	
	Engineering availability	Engineers	With professional ambition
		Technical Team	
		Training	

Concept	Main Aspect	Additional Consideration	Specific
Procurement and Supplying	Contractual Criteria	Requirements, Responsibilities and needs	
Quality Control System	Technical Specification	Design Requirements	Updated
		Standards	Preferably from a single Association
		Laboratories	Trustable
	Construction	Experience – Knowhow	To make decisions
		Conformity and Non-Conformity actions	Judicious
	Monitoring	Instrumentation	Proper and suitable
	Cost Control	Judgment – Criteria – Approval	Judicious, to minimize the conflicts and claims
Commissioning	Operational criteria	Trained Staff	
Maintenance	Operational Life	Regular procedures	Trained professionals
		Monitoring/Inspection	Limits

8.3 Quality Control System

For the purposes of this aspect, the following definitions are used:

⇒ **Quality Assurance (QA)** comprises all planned and systematic actions needed to ensure that items are designed and constructed according to applicable standards and as specified by contract.

⇒ **Quality Control (QC)** comprises examination of the services provided and work performed, together with the management and documentation needed to demonstrate that these services and work meet the contractual and regulatory requirements.

QA or **QC** programs previously formulated by the design professional and the constructor are adjusted to meet the specific requirements of the project as defined by the owner/design professional agreement and the owner/constructor contract, as well as by applicable regulatory requirements.

Project-specific **QA** programs are the responsibility of the owner. While most owners are desirous of having a quality project, many will need assistance in stating project QA requirements. Early involvement with the selected design professional often provides the assistance needed in stating these requirements, defining the services required, and negotiating the agreement for project services. As the **QA** or **QC** program affects the performance of the design professional, it is agreed upon during this phase.

The **QA** or **QC** program expected by the constructor is formulated by the owner, usually with the assistance of the design professional at a later date, during preparation of the construction contract documents. The requirements of the **QA** or **QC** program are often developed in the form of a written QA manual.

Effective use of computers and computer systems can assist design professionals, constructors, and owners planning, designing, and constructing a project, and the QA or QC systems, ***but is important to understand that computers do not think for themselves!***

Computer systems are capable of reducing the time required to perform many construction and design-related functions and, in many projects, computers and computer methods assist in improving elements of quality, including design quality and total life-cycle costs.

When computers are employed, managed, and maintained to their maximum, they can provide the project team with considerable data processing.

Effective use of computers and computer systems can assist owners, design professionals, and constructors in planning, designing, constructing, and operating the project. Computer systems help reduce the time required to perform many construction and design-related functions and, when properly managed, they can assist in achieving quality.

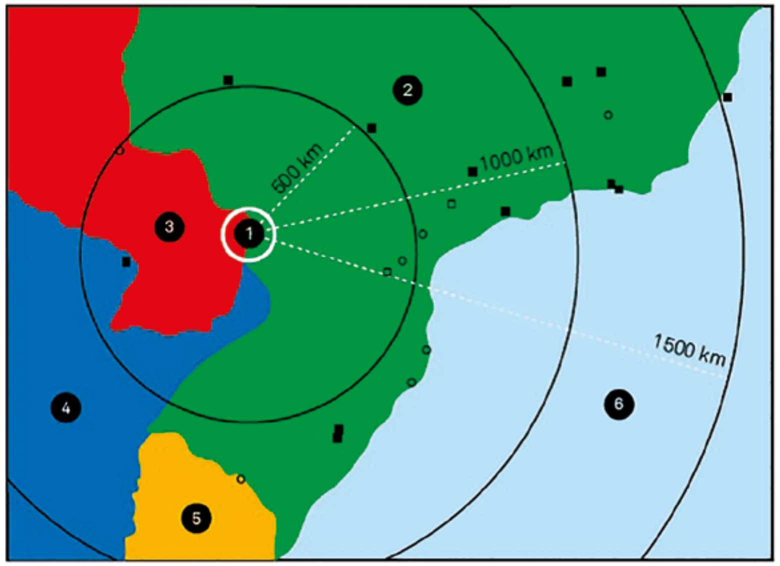
There is a trend in the construction industry toward statistical analysis for quality control by constructors and suppliers, and for statistically based acceptance criteria by owning agencies. Organizational efficiency can be fine-tuned, job estimating can be made more accurate, and out-of-sequence work can be curtailed.

The control organization adopted during the construction of approximately 14.000.000 m^3 concrete in the Itaipu Project, based on Ref. **[08-03]**, can be used as example:

"… 3.1. THE NEED FOR A QUALITY PLAN

Obedience to the timetable of services, the magnitude of these activities, production rates, and the distances to the various suppliers led to the following questions:

- *How to ensure that all materials provided would meet ITAIPU's technical specifications at their time of delivery?;*
- *How to verify the properties of materials and concrete in such a way as not to create chronological impediments?;*
- *How to ensure that the project details would be obeyed during construction?;*
- *How to guarantee the functionality of monitoring instruments?;*
- *How to assure the nations involved the desired level of quality and safety?*



1	ITAIPU	6	Atlantic Ocean
2	Brazil	■	Supplying Steel Mills
3	Paraguay	□	Cement suppliers
4	Argentina	○	Fly ash suppliers
5	Uruguay		

Project location and its access and distances from the production sites of cement, fly ash, steel and admixture.

The set of possible answers to these questions has led to the following scenario of actions:

- *Qualification of professionals to perform control functions;*
- *Ability to perform all tests in order to clear any possible doubts;*
- *Establishment of conditions for the self-motivation of employees, in a perennial way, given the long period they would be living together;*
- *Creation of information routines, with impersonal systematics compatible with the dynamics of the project's development and construction;*
- *Establishment of strict control over the basic materials (binder, admixture, aggregate, steel, etc.) at their production origin.*

3.2. PROFESSIONALS TO SUPPORT THE ENTERPRISE

Planning for the organization of the professional team to support the several areas of expertise (Administration; Engineering; Cost Estimate/Procurement; Supervision; Analysis and Control) led to the creation of guidelines to conceptualize the ITAIPU Treaty, as cited forth (relevant aspects of what is herein described):

"*Annex 'A' of the ITAIPU Treaty (STATUTE)*

I – DESIGNATION AND OBJECT

ARTICLE 1 – *ITAIPU is a binational entity created by Article III of the Treaty signed by Brazil and Paraguay on April 26, 1973, comprising the following parts:*

a) 'Centrais Elétricas Brasileiras S.A.' – ELETROBRÁS, Brazilian mixed-economy corporation;

b) 'Administración Nacional de Eletricidad' – ANDE, Paraguayan autarkic entity.

ARTICLE 2 – *The object of ITAIPU is the hydroelectric exploitation of water resources of the Parana River, belonging in condominium to the two countries, from and including the Salto Grande de Sete Quedas or Salto de Guaíra to the mouth of the Iguaçu River.*

ARTICLE 3 – *ITAIPU shall be governed by the rules established in the Treaty of April 26, 1973, in the Statute, and in the other Annexes.*

ARTICLE 4 – *ITAIPU will have – according to what is described in the Treaty and its Annexes – legal, financial and administrative capacity, as well as technical responsibility to study, design, and manage the works of its object, enable their operation, and exploit them. To this end, ITAIPU may acquire rights and contract obligations.*

ARTICLE 5 – *ITAIPU will have headquarters in Brasilia, capital of the Federative Republic of Brazil, and in Asuncion, capital the Republic of Paraguay ... .*

....ARTICLE 27 – *"Employees rendering services to ITAIPU may be civil servants, employees of autarkies and mixed-economy corporations, Brazilian or Paraguayan, with no loss of their original bonds and the benefits of retirement and/or social security, under the respective national legislation ..."*

This allowed ITAIPU to recruit qualified employees – from several agencies of the Brazilian and Paraguayan hydroelectric system, as well as from other entities – interested in cooperating in the construction of this mega project. In an agreed and measured way, this selection was conducted based on other similar developments in the Brazilian and Paraguayan territories.

3.3. GUIDELINES FOR THE QUALITY SYSTEM OF CONCRETE WORKS

3.3.1 General information

Considering the aspect of the bi-nationality, between 1975 and 1976, 138 testing methods were prepared based on the norms by ***ASTM*** *(American Society for Testing and Materials),* ***CRD*** *(US Army Corps of Engineers),* ***ACI*** *(American Concrete Institute),* ***RILEM*** *(Reunion Internationale des Laboratoires et Experts des Materiaux), and* ***ABNT*** *(Associação Brasileira de Normas Técnicas) to facilitate the understanding by the part of the technicians and make routines and procedures more precise, therefore minimizing possible errors.*

[illegible] ADOTADOS PELA DIVISÃO DE CONTROLE DE CONCRETO.

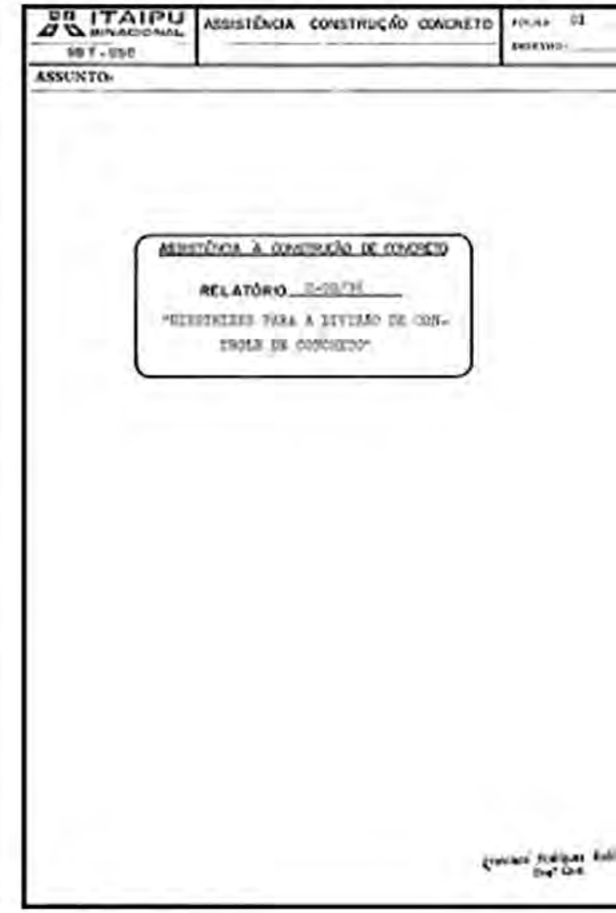
Os Métodos de Ensaios, aqui referendados, foram preparados a partir das Publicações da A.B.N.T. - CORPS OF ENGINEERS - A.S.T.M. - U.S.B.R. - A.C.I., e outras fontes de pesquisa.

Tais Métodos serão revisionados, periodicamente, em função das revisões dos Métodos Básicos, bem como a partir de pesquisas desenvolvidas pela Divisão de Controle de Concreto da ITAIPU BINACIONAL.

Foz do Iguaçu - Janeiro/1977

Engº [illegible]
Chefe Divisão de Controle de Concreto

Engº [illegible]
Chefe Departamento de Solos, Concreto e Geologia



ITAIPU BINACIONAL | ASSISTÊNCIA CONSTRUÇÃO CONCRETO | FOLHA 01

ASSUNTO:

ASSISTÊNCIA À CONSTRUÇÃO DE CONCRETO

RELATÓRIO [illegible]

"DIRETRIZES PARA A DIVISÃO DE CONTROLE DE CONCRETO"

Set of Test Methods for the Control of Materials and Concrete Guidelines for the Concrete Control Division

The guidelines for the Concrete Quality Control System were also prepared in the same period.

Beginning of the training of professionals for the control system – November 1975

During the discussions about the need to implement this comprehensive quality control system, suggestions found in the ACI Manual of Concrete Inspection Publication SP 2 were several times used:

"... The quality of concrete depends largely on labor in construction. The best of material and design practice would not be effective unless the construction was well performed. Inspection is provided to ensure satisfactory work according to the plans/ specifications and good practice. It also secures a record of the job for future reference ....

... The cost of competent inspection is relatively little compared with the resulting quality assurance of the structure.

Often, the cost may be more than offset, because competent inspection prevents mistakes and permits more economical and workable mixes to be used ...

... It is the responsibility of the engineer or architect to elect qualified professionals or agencies as inspectors, pay them adequately, train them well, encourage continued study, provide them with appropriate equipment and technical references, define their responsibility and authority clearly, and back them up on the job ...".

In general, monitoring and/or control would mean responding to the following questions:

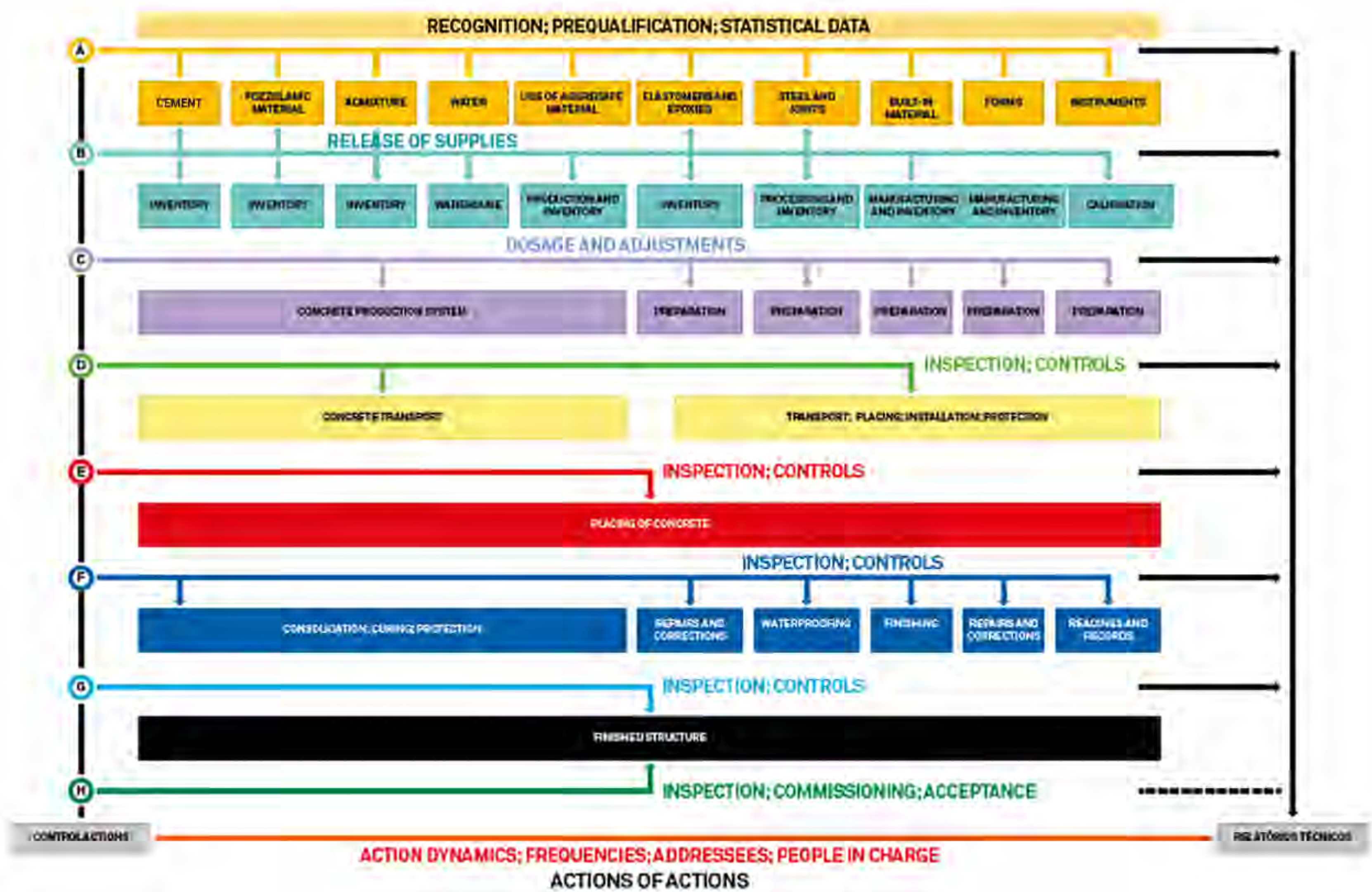
- *What should be controlled?*
- *Where to control it?*
- *How to control it?*
- *When to control it?*
- *How should data be processed?*
- *How to report or inform?*

3.3.2 What should be controlled?

The system established for the Control of Materials and Concrete comprised the topics summarized ahead:

- *Aggregate materials:*
  - *Dredging of natural sand*
  - *Deposit of material for crushing*
  - *Crushing*
  - *Washing set*
  - *Cooling system and concrete plants*
- *Cement:*
  - *Clinker/cement suppliers*
  - *Clinker/cement reception and milling*
  - *Production*
  - *Reception and processing of gypsum*
  - *Reception and handling of cement in the concrete plants*
- *Pozzolanic material:*
  - *Suppliers*
  - *Reception, storage, and processing in the concrete plants*
- *Admixture*
  - *Suppliers*
  - *Reception, storage, and processing in the concrete plants*
- *Steel*
  - *Suppliers*
  - *Reception at the mounting patio of the construction site*
  - *Processing*
  - *Placing of reinforcement*
- *Steel joints*
  - *Joints on work benches*
  - *Joints on the spot*
- *Elastomeric material (joints and support material)*
  - *Suppliers of finished materials*
  - *Reception at the construction site*
  - *Placement and use*

- *Epoxies and Resins*
  - *Suppliers of finished materials*
  - *Reception at the construction site*
  - *Placement and use*
- *Water used in the processing of ice production aggregates and concrete batching and curing*
  - *Source*
  - *Industrial facilities*
  - *Curing*
- *Concrete*
  - *Proportioning (dosing) of mixtures*
  - *Monitoring of dosing and production at the concrete plants*
  - *Inspection of foundations, forms, reinforcement, joints, and other items*
  - *Verification of the adequacy of the execution and placing processes*
  - *Monitoring of the concrete transport system*
  - *Monitoring of placing and consolidation*
  - *Concrete curing control*
  - *Statistical monitoring of concrete*
- *Monitoring of the Concrete Structures and their foundations since the implantation of the monitoring instruments:*
  - *Verification of the adequacy of the instruments with the designer*
  - *Procurement of tools and equipment*
  - *Calibration of instruments*
  - *Installation of instruments*
  - *Reading and monitoring of data and information*
  - *Calculation, processing and discussion of values with the designer*


RECOGNITION; PREQUALIFICATION; STATISTICAL DATA
A
CEMENT
ADMIXTURE
WATER
FORMS
INSTRUMENTS
RELEASE OF SUPPLIES
B
INVENTORY
INVENTORY
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INVENTORY
CALIBRATION
DOSAGE AND ADJUSTMENTS
C
CONCRETE PRODUCTION SYSTEM
PREPARATION
PREPARATION
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D
INSPECTION; CONTROLS
TRANSPORT; PLACING; INSTALLATION; PROTECTION
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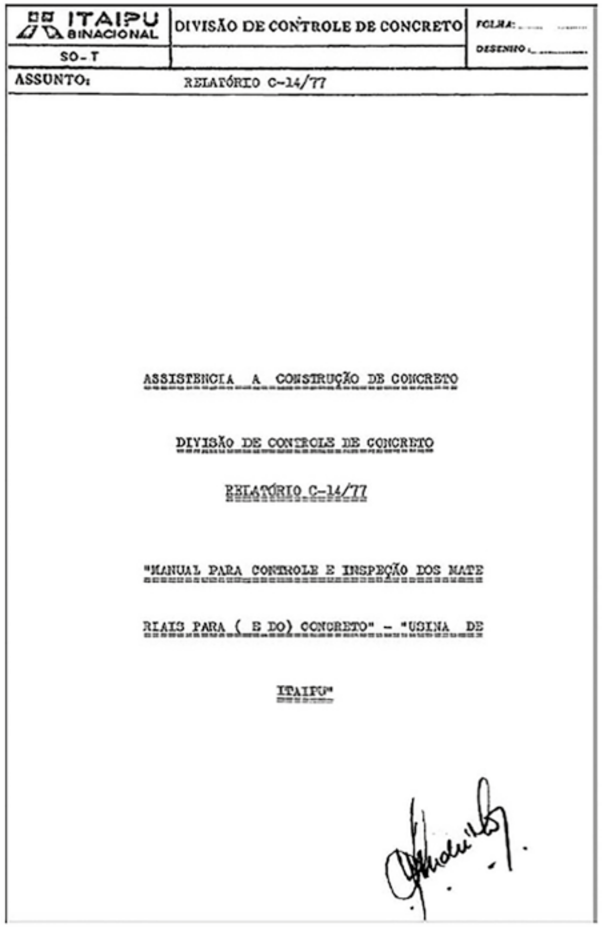
WATERPROOFING
FINISHING
REPAIRS AND CORRECTIONS
G
INSPECTION; CONTROLS
FINISHED STRUCTURE
H
INSPECTION; COMMISSIONING; ACCEPTANCE
CONTROL ACTIONS
RELATÓRIOS TÉCNICOS
ACTION DYNAMICS; FREQUENCIES; ADDRESSEES; PEOPLE IN CHARGE
ACTIONS OF ACTIONS

Analysis of the set of materials evidenced the necessity of a laboratory, adequate in size and resources, to provide technological support to the various areas. In addition, the dynamics of the actions suggested that this laboratory be located in the construction site.

3.3.3 How to control it?

'How to control' involved the need to know the definitive arrangement of the industrial facilities and technical specifications.

From the definitive establishment of such facilities, technical specifications and knowledge of suppliers, and the equipment of industrial plants that produced materials and concrete, between 1976 and 1977, it was possible to write a Control Manual where the whole sampling routine, sample collection sites, tests to be performed, and data processing and reporting were described.



ITAIPU BINACIONAL | DIVISÃO DE CONTROLE DE CONCRETO | FOLHA:
SO-T | | DESENHO:

ASSUNTO: RELATÓRIO C-14/77

ASSISTENCIA A CONSTRUÇÃO DE CONCRETO

DIVISÃO DE CONTROLE DE CONCRETO

RELATÓRIO C-14/77

"MANUAL PARA CONTROLE E INSPEÇÃO DOS MATERIAIS PARA (E DO) CONCRETO" - "USINA DE ITAIPU"

Report RC-14/77 – Itaipu Laboratory – Manual for the Control and Inspection of Materials and Concrete – Itaipu Power Plant – Issued in August 1977, prior to the beginning of the concrete works.

The manual indicated routines, sampling and testing sites, formats for records, information flow, and procedures and guidelines for statistical analysis and action taking. The following may be cited as an example:

View of the aggregate processing installations on the left bank of Parana River in September 1977, before beginning the concrete works of the diversion structures

View of the Concrete Plants and the Silage System of Binders on the left bank of Parana River, next to the diversion canal, in September 1977, before beginning the concrete works of the diversion structures

View of the assembling of the installations for the Production of Aggregate Material and Concrete Plants on the right bank of Parana River in April 1978

3.3.4 When to control it?

The following actions were established as the basic premise of 'when to control':

- *The following actions should be taken before the use of any material:*
  - *Verify binders (cement and pozzolanic materials), admixture, steel, resins, and joints with their suppliers before they are sent to the construction site to avoid the hypothesis of rejection;*
  - *Dose the concrete in advance to the necessity of its use;*
  - *Evaluate rock flows before excavation and storage or supply of crushed aggregates with respect to integrity and physical indices of durability;*
  - *Assess the aggregate material during production and before and during storage to enable its use without unexpected technical problems;*
  - *Inspect all external material upon arrival at the construction site.*

- *The following actions should be taken during the processing and handling of materials and production of concrete:*
  - *Monitor the processing of joints and reinforcement on the work bench;*
  - *Control the fresh concrete mixture to ensure uniform placing, without setbacks and/or unexpected technical problems, seeking to anticipate climatic variations such as rain, sunlight and temperature; standing ready for actions;*
  - *Install monitoring instruments in a timely manner to meet the design requirements without creating chronological difficulties for the concrete works;*
  - *Be attentive to the application of concrete classes (strength, control age, durability, workability, maximum aggregate size), compatible with the site and project requirements, for each region of each structure;*
  - *Provide support to the areas of measurement and costs concerning the use of various materials and products.*

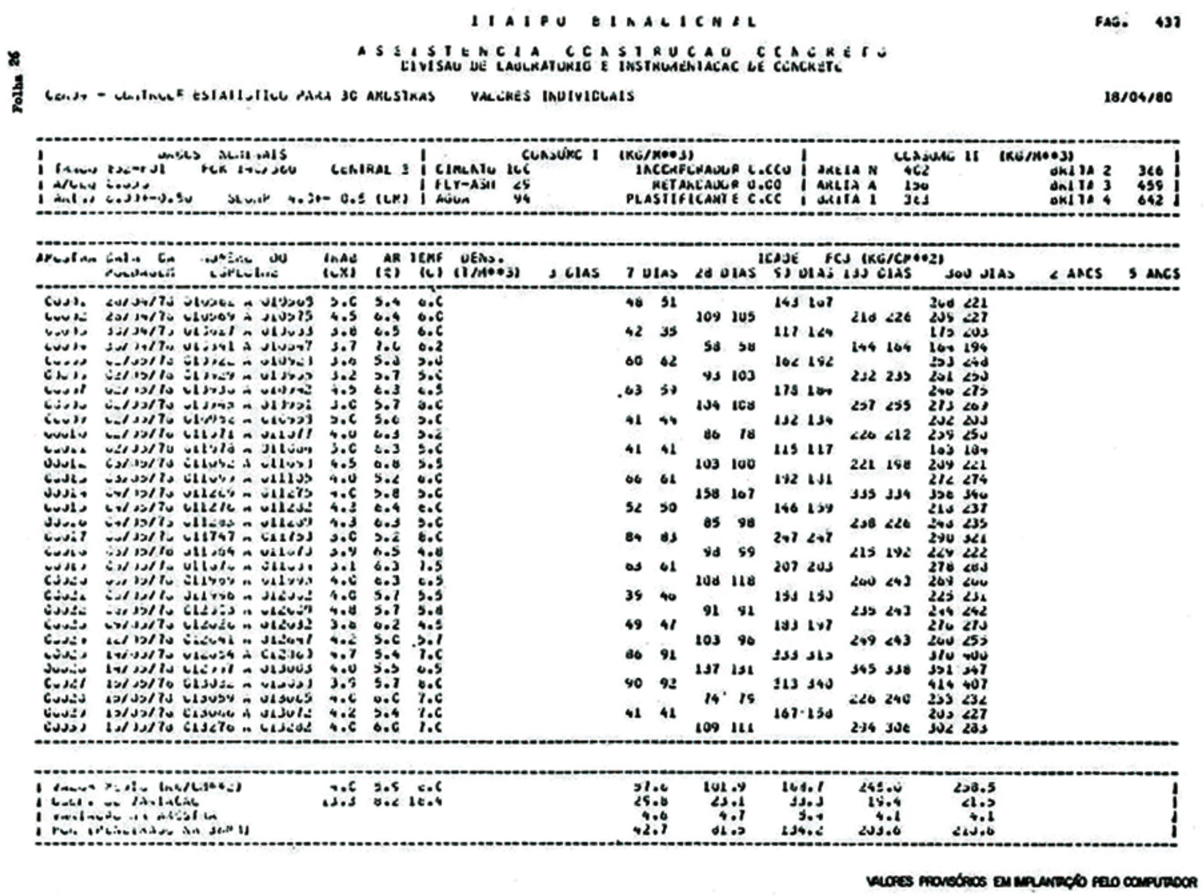
3.3.5 How should data be processed?

The planning established in the control system considered that the test data and technical information should be processed by a team of professionals in the laboratory area and be stored in a separate file.

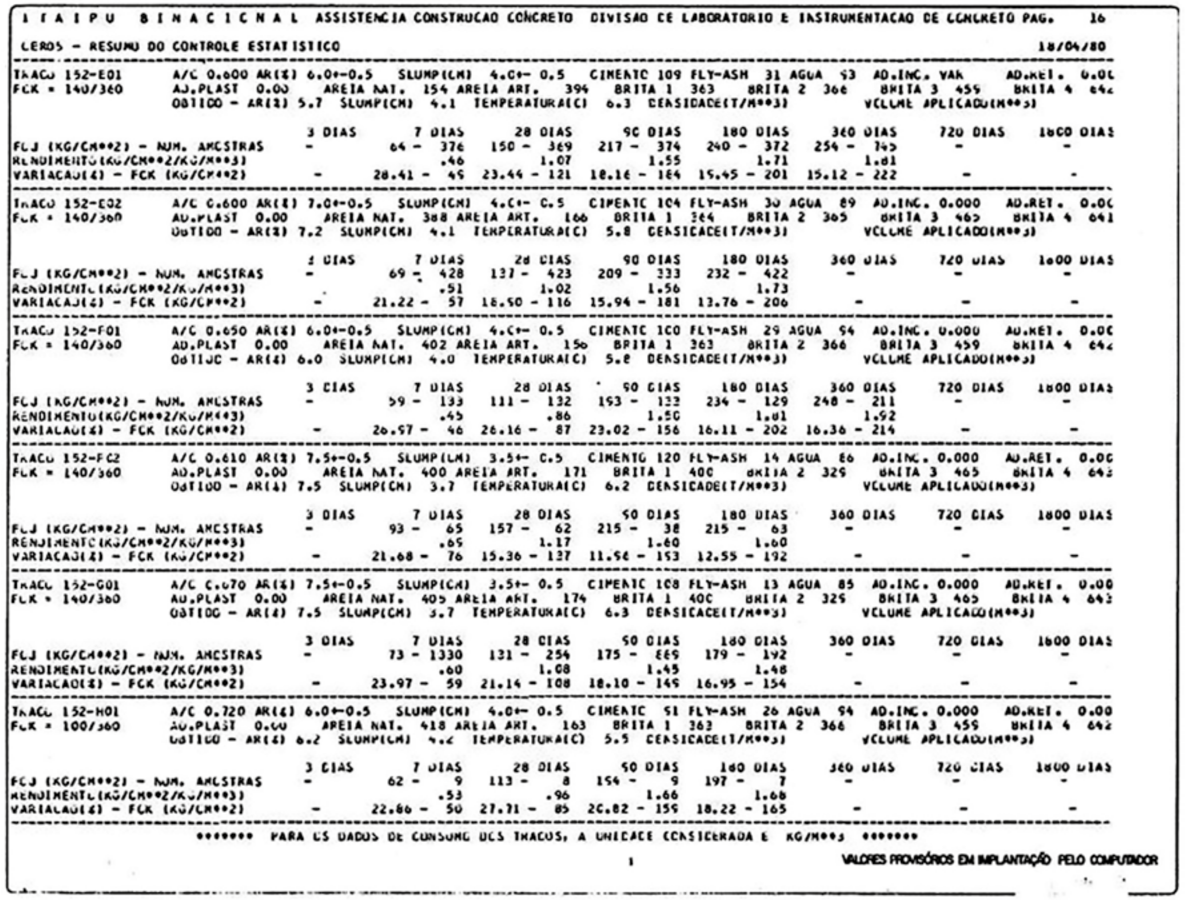
The magnitude of the ITAIPU works demanded the use of a computer (or a computer terminal) for processing the data, both for

- *the statistical values of the concrete controls, which would be the final product;*
- *the instrumentation values, which would provide a track record of information and data:*
  - *transient, at the time of construction, and*
  - *perennial, throughout the operational lifetime of the structures.*

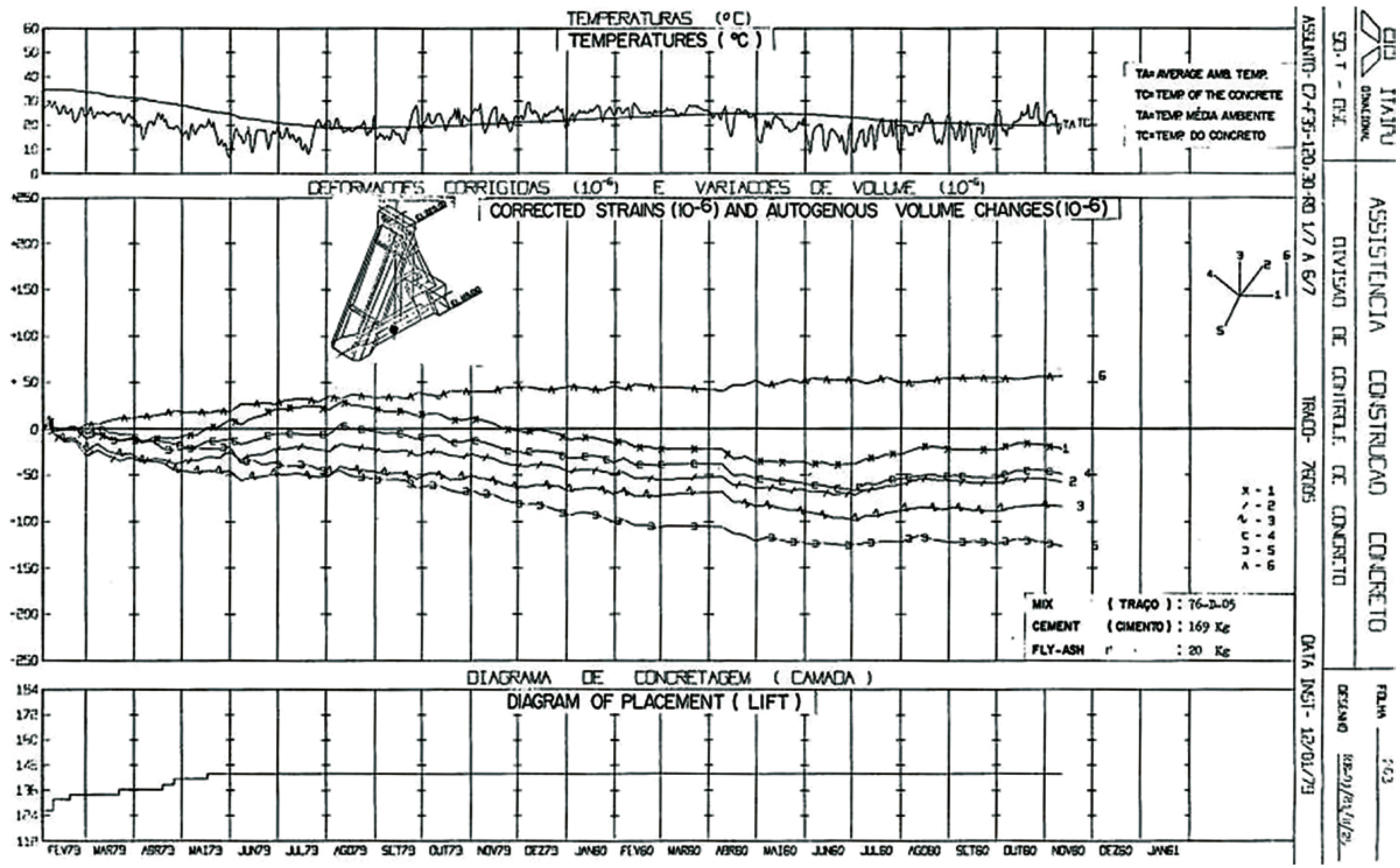
To meet this demand, the Eletrobras computer, located in Rio de Janeiro, was used; it processed the data of concrete mixtures (dosages) generating two types of report, as follows:



Processing of individual control data of each concrete dosage



Processing of control data of all dosages up to the age of 5 years



Typical data processing from the instruments installed during the construction, including the time diagram indicating the concrete placement lifts on the installation spot

We also had to rely on desktop computers for the expeditious processing of immediate data and transient routine, such as particle size analyses.

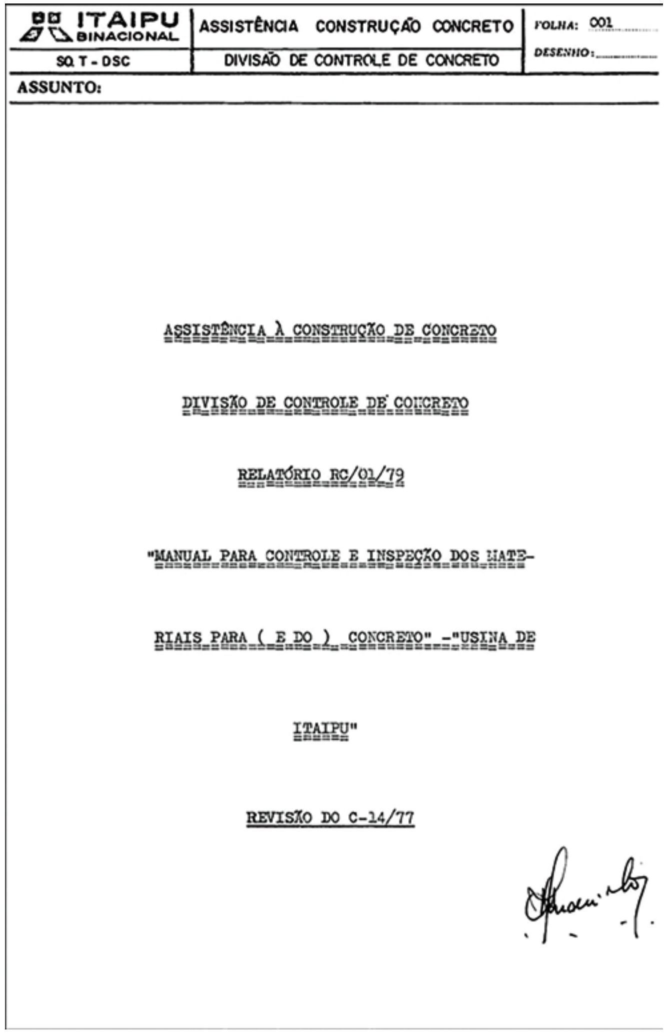
This system was developed this way until the end of the construction; it was adapted owing to the availability of computers in the 1980s.

*The data storage planning also aimed at the periodic use of the same data and the preparation of periodic reports (monthly – called **RT**) or at special times, depending on meetings or special needs (called **RE**), and a Final Report at the end of the work.*

At the time of this planning, among other things, the standardization and development of printed forms that would be used for the control to be performed were also prepared.

Planning for data processing also oriented for periodic and systematic assessment of the Control Manual because of evaluation that could lead to implement or reduce the number of samples, or focus on details that led to more comprehensive and detailed control measures.

These revisions of the Control Manual occurred in early 1979 and early 1981.



ITAIPU BINACIONAL	ASSISTÊNCIA CONSTRUÇÃO CONCRETO	FOLHA: 001
SQ T - DSC	DIVISÃO DE CONTROLE DE CONCRETO	DESENHO:

ASSUNTO:

ASSISTÊNCIA À CONSTRUÇÃO DE CONCRETO

DIVISÃO DE CONTROLE DE CONCRETO

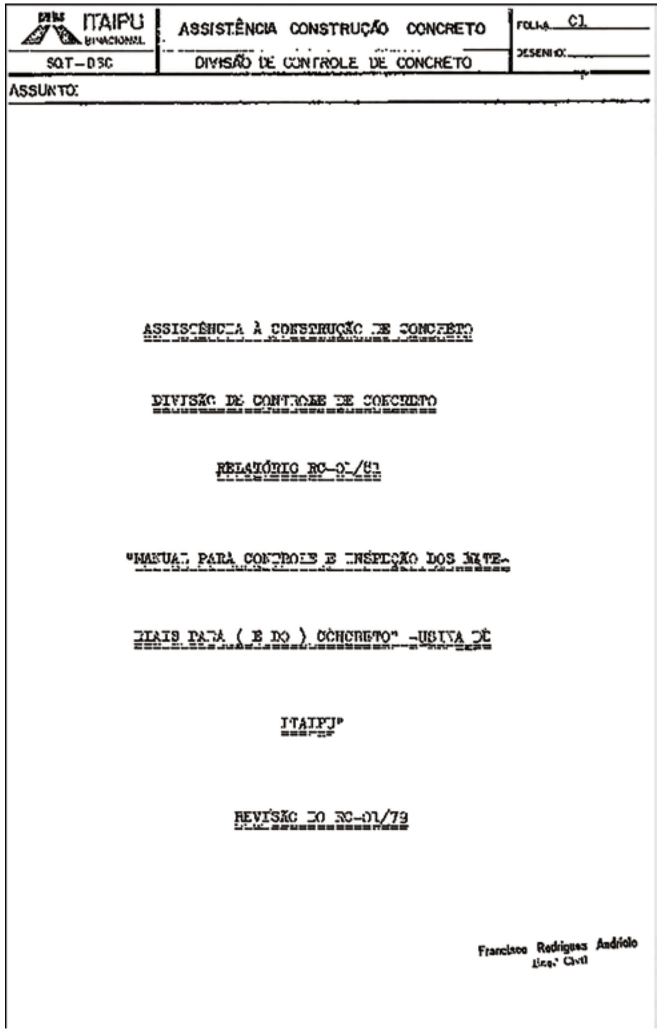
RELATÓRIO RC/01/79

"MANUAL PARA CONTROLE E INSPEÇÃO DOS MATE-

RIAIS PARA (E DO) CONCRETO" -"USINA DE

ITAIPU"

REVISÃO DO C-14/77



ITAIPU BINACIONAL	ASSISTÊNCIA CONSTRUÇÃO CONCRETO	FOLHA: 01
SQT-DSC	DIVISÃO DE CONTROLE DE CONCRETO	DESENHO:

ASSUNTO:

ASSISTÊNCIA À CONSTRUÇÃO DE CONCRETO

DIVISÃO DE CONTROLE DE CONCRETO

RELATÓRIO RC-01/81

"MANUAL PARA CONTROLE E INSPEÇÃO DOS MATE-

RIAIS PARA (E DO) CONCRETO" -USINA DE

ITAIPU"

REVISÃO DO RC-01/79

Francisco Rodrigues Andriolo
Eng.º Civil

Revisions of the Control Manual conducted in early 1979 and early 1981

3.3.6 How to report or inform?

Planning for the Control System established that the data and results of tests, controls and analyses should be reported and informed using the following system:

Type of Document	Identification	Contents/Objective	Issuance	Addressees
Study Reports	**RC**-0x/Year	Non-routine tests, new dosages; qualification of materials; clarification of technical questions; report of study programs	At the end of the activity	Internal to the areas of Itaipu, or external when formalized by Itaipu
Technical Reports for Construction Control	**RT**-0x/Year	Monitoring, testing, controls and systematics on the materials received at the work site (Cement, Fly Ash, Admixture, Steel, Joints, Epoxies); on the materials produced in the work site (Aggregate material, Joints; Parts of precast concrete); and on the concrete produced individually at the Production Center and Installation Site). Monitoring of the execution of all structures, with details of concrete placing, damage and repairs; preparation, calibration, installation, readings and records of monitoring instruments; systematic inspection of structures, drains and events.	Monthly until the 5th day of the month following the control period	➦ Measurement and Cost Areas of Itaipu e; ➦ Engineering Staff of e Itaipu; ➦ Project Coordination IECO/ELC; ➦ Designers; ➦ Construction Companies (Único/Conempa)

Type of Document	Identification	Contents/Objective	Issuance	Addressees
Special Reports	RE-0Y/Year	a) Summarized Control Reports issued especially for the meetings with the construction companies, including information on controls within the time period between meetings; sb) Special reports not included in the preceding routines, but justified by their relevance; c) Reports containing technical publications produced by professionals of the Control for congresses and technical events.	Usually every six months, given to the participants one week before each meeting; At the end of verification; Event Registration	Members of the Advisory Panel; Representatives of the Designers; Engineering Staff ofe Itaipu; Construction Companies; Engineering Staff ofe Itaipu, ands Entities designated by Itaipu; Internal to the areas of Itaipu.a
Letters	Designated by e Itaipu	Communication to suppliers and external companies without common interface	When instructed bypor Itaipu	Under the guidance of Itaipu e

Two subtypes were systematically considered within the RC type Report:

- ***RC** of Division Activities (in certain periods between 1976 and 1978), reporting the controls performed during the installation of the work site, originally prepared on the same basis of the RTs, aiming to train the labor force, overseeing the construction of the temporary works;*
- *RC of Inspection of Cement Plants (systematically, from September 1977 until the end of the construction), containing the control data for cement production in each of the plants selected to supply cement to the construction.*

ITAIPU BINACIONAL | DIVISÃO DE CONTROLE DE CONCRETO

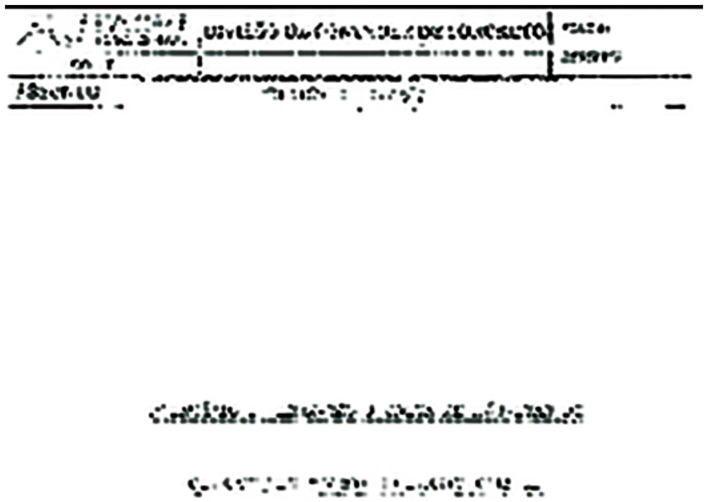
ASSUNTO:

RC-06/76 – Initial studies on concrete dosages

ITAIPU BINACIONAL | DIVISÃO DE CONTROLE DE CONCRETO

ASSUNTO:

RC-09/76 – Control of the Construction Site Activity



RC-22/77 – Inspection in Cement Plants


ITAIPU BINACIONAL | ASSISTÊNCIA CONSTRUÇÃO CONCRETO | DIVISÃO DE CONTROLE DE CONCRETO

ASSUNTO:

APROVEITAMENTO HIDROELÉTRICO DE ITAIPU

RELATÓRIO TÉCNICO

MES DE OUTUBRO DE 1977

DIVISÃO DE CONTROLE DE CONCRETO

PARTES: A :

B :

C :

D :

E :

F :

G :

H :

I :

RE-01/78 – Special Report for the Advisory Panel meeting in March 1978

ITAIPU BINACIONAL | ASSISTÊNCIA CONSTRUÇÃO CONCRETO
DIVISÃO DE CONTROLE DE CONCRETO
ASSUNTO:

RT-01/77 – Monthly Technical Report, October 1977, beginning of concrete pouring of the final structures – 1983

3.4. CAPACITY ESTIMATED TO MEET THE QUALITY CONTROL SYSTEM OF THE CONCRETE WORKS

Estimates for the system planning led to the following considerations:

- *Condition to perform approximately 10,000 tests per month (this estimate was considered from the controls carried out during the construction of the Ilha Solteira-CESP project);*
- *Condition to run Service Simulated and Load Tests;*
- *Condition to perform non-routine testing of materials and concrete, such as thermal and long-term elastic characterizations;*
- *Response to all requests for clarification in minimum time;*
- *Condition to supervise the placing of concrete during all activities (form, reinforcement, built-in, surface preparation, production, transport, placing, consolidation, curing, installation and reading instruments) in more than 30 simultaneous fronts, 24 h a day, every day throughout the year.*

- *Supervision of the use and maintenance of aggregate material and concrete production equipment, as well as of the concrete handling equipment, acquired by ITAIPU and made available to the construction consortium.*

It is clear that the authors did not want **All Works** to adopt the same Control and Supervision schemes. The size and spectrum of each project depend on its magnitude, contractual conditions, and responsibilities.

However, the characterization of Risk and associated damage of a Dam depends – based on the various codes adopted – on the existence and availability of data obtained and controlled during the Project's Development and Construction, as well as on the Inspections and Maintenance conducted, that is, each Dam Project must have records to preserve the "**Public Good"** and ensure its longevity.

The project representative is responsible for implementing procedures for documenting review and evaluation of quality requirements specified in the contract documents. Construction quality generally involves two broad aspects:

⇒ specified properties of materials and

⇒ labor.

Materials can be further subdivided into *in situ* materials and procured materials.

In situ (natural or original) materials typically include native soils and rocks and often require laboratory testing and engineering evaluation of properties to determine acceptability for project needs. Such laboratory reports and engineering evaluations become part of the project file. Retesting and other necessary follow-up analyses also become part of the file.

Procured materials are manufactured items, such as structural steel, asphalt, concrete, paint, glazing, mechanical and electrical equipment, and distribution systems, and can be evaluated **and** accepted by several considerations.

Specifications outline the level of quality and the manner of qualification, if any, that will be required. Procurement specifications state minimum standards. These standards clearly outline the specific qualification procedures required, and include acceptance requirements and testing frequency.

Each procured item of material or product should be represented by a file listing the qualification procedure and minimum requirements and include the type of tests performed; the date the test was performed according to procedures of an updated Standard; the signature of the person responsible for the test, test results, any nonconformance reports and, if required, the location in the structure where the tested material or product was incorporated.

8.4 Construction and Inspection/Supervision

The Project of a Dam develops, to meet certain needs, following rules, laws, standards and contract. Based on these needs and concepts, construction should be conducted with discipline and order. The builder must follow the guidelines of a Clear Contract-Specifications and Designs, and have no doubts. The control of a dam work may be exercised by different representatives of the Concessionaire/Owner, and may be of a Government Entity or Contractors for this purpose

The design professional, acting under the terms of the owner's agreement, is usually responsible for producing the complete design for approval. This effort is documented in plans, specifications, and other construction contract documents used for the project.

Design professionals usually follow the design report approved when planning and executing the design effort, and are primarily responsible for design activities such as:

⇒ planning and managing the design;

⇒ coordination and communication during the design phase;

⇒ monitoring and controlling design costs and schedule;

⇒ providing professionally qualified staff;

⇒ performing design-related quality control functions;

⇒ designing in compliance with codes and standards, laws and regulations, and regulatory agency requirements;

⇒ arranging for appropriate design, constructability, operability and maintainability reviews.

In addition to responsibilities under the owner/design professional agreement, the design professional also bears responsibility to protect the public health, safety, and welfare under State licensing laws, and to conform to the ethics codes of the design profession.

Quality in the constructed project is achieved by the project team and all other project participants working together to reach common goals.

The design professional has prime responsibility for the planning and design, the preparation of the construction contract – including plans, specifications and other documents, and for providing the owner with services during the project construction phase, including construction observation and technical review of submittals prepared by the constructor.

The constructor has prime responsibility for construction of the project facilities as specified in the contract documents, job-site safety, and for protecting public health, safety, and the environment as impacted by the construction activities.

Each project has its own unique set of circumstances, and requires careful structuring of the contract terms that define the roles and responsibilities of each team member and the way other team members assist in the effort to reach the common goal quality in the constructed project.

The owner must ensure that the construction comprises the necessary activities of technological control and safety, environmental impacts are minimized, and that the work schedule, when necessary, includes all activities, means, and procedures, aiming at:

⇒ Mobilization of technical means and equipment inherent in the execution of quality control tests of construction materials put on site to control the foundation treatment and carry out the reception tests of hydro – and electro-mechanical equipment;

⇒ Acquisition, storage, performance of tests, and installation and operation of instrumentation, according to the Monitoring and Instrumentation Plan, under adequate conditions of accessibility and operability, as well as according to an adequate collection, treatment, transmission and recording of information, making them available for the necessary human and technical means;

The procedures and activities involved in safety control should be subject to rigorous monitoring and validation by the Work supervision. Information about and significant changes in the project that prove necessary during the construction, as well as all occurrences of interest, from the point of view of safety, should be recorded in an organized manner and incorporated into the Dam Safety Plan.

Considering the importance, complexity and specificity of the work, the owner should constitute a technical staff aiming to supervise the execution of the construction accordin$_g$ to the project and technical specifications. The main duties of this technical staff responsible for supervision are:

⇒ Monitor the construction so that the quality and safety of the work is guaranteed;

⇒ Ensure the coordination of the construction work, according to the project and technical specifications, considering the adaptations resulting from the actual conditions of the work and the constraints inherent in the Monitoring and Instrumentation Plan;

⇒ Suspend any work being performed that does not comply with the project requirements and technical specifications.

The main objectives of this control during construction are to ensure the safety of structures and equipment, through inspections, as well as to develop, adapt, and implement the Monitoring and Instrumentation Plan established in the project.

Generally, this Plan needs to be developed and adjusted not only to consider the actual conditions of the work, but also to include:

⇒ Specifications relating to instrumentation and accessories used to determine the quantities to be observed, as well as all other elements necessary for the placement of instrumentation and its use;

⇒ Specifications relating to the collection and processing of information.

The procedures and communication scheme to be used in the case of adverse events, whether extreme events or accidents or incidents, when establishing the project quality requirements begin at the project inception. It is essential that a careful balance be made between the owner's requirements regarding project cost and schedule, the desired operating characteristics, construction materials, etc., and the design professional's need for adequate time and budget to meet those requirements during the design process.

Owners balance their requirements against economic considerations and, in some cases, against the chance of failure. The design professional must ensure public health and safety throughout the project. The constructor is responsible for the construction means, methods, techniques, sequences and procedures, as well as for safety precautions and programs during the construction process.

A list of important themes for the project should include definition and assignment of responsibilities, principles of good communication, importance of teamwork, owner's selection processes for project team members, and other elements that help achieve quality.

Quality is defined as meeting the requirements of the owner, design professional, constructor and, where appropriate, of regulatory agencies.

The requirements are usually related to project safety, costs, and schedules for all team members; project functions, appearance, and operation for the owner; provision of a well-defined scope of services for the design professional; a clear definition of responsibilities (contract documents) for the constructor. Other requirements include, for all team members, appropriate risk sharing, reasonable remuneration, timely decision making, good communication, and rapid resolution of misunderstandings, conflicts, and disagreements.

Quality in the constructed project is produced by the three team members – owner, design professional, and constructor – working amicably toward common goals.

However, the Main Principal is that everyone should **KNOW**:

⇒ What to do;

⇒ When to do it;

⇒ How to do it;

⇒ How much to do.

In a complementary way, it is opportune to have routines and procedures for:

⇒ How to report;

⇒ What to report;

⇒ For whom to report;

⇒ When to report;

⇒ How to archive information.

Quality in the constructed project is achieved when all those involved in it put quality in first. It requires a major communication effort during the entire process to keep all parties informed of the vital elements of the work and of the concerns of the owner, design professional, and constructor. It also requires mutual understanding of these concerns and awareness that few, if any, construction jobs have no problems. Finally, it requires determination of all parties to resolve these problems equitably as they occur.

Quality in the constructed project is achieved if the completed project conforms to the stated requirements of the principal participants (owner, design professional, constructor) while conforming to applicable safety codes, requirements and regulations. Quality can be characterized as:

⇒ Meeting the requirements of the owner as to:
  - function and appearance;
  - completion on time and within the budget;
  - life cycle costs;
  - operability and maintainability;
  - impacts on the environment, health, safety, and people;
  - other features.

⇒ Meeting the requirements of the design professional as to:
  - defined scope;

- adequate budgets;
- reasonable schedules;
- timely decisions by the owner;
- interesting work for the staff;
- realistic risk sharing;
- reasonable profit;
- satisfied client;
- finished project that results in positive recognition and recommendations for future work.

⇒ Meeting the requirements of the constructor as to:

- well-defined set of plans, specifications, and other contract documents;
- reasonable schedule;
- timely decisions by the owner and the design professional;
- fair treatment;
- realistic risk sharing;
- reasonable profit;
- satisfied owner;
- positive recognition and recommendations for future work.

⇒ Meeting the requirements, where appropriate, of regulatory agencies as to:

- public health and safety;
- environmental considerations;
- protection of public property, including utilities;
- conformance with applicable laws, regulations, codes, standards, and policies.

The probability of achieving quality in the constructed project will be enhanced by complete and open communication among participants, selection of qualified personnel for all phases of the project, and rapid resolution of misunderstanding conflicts, and disagreements.

It is important to understand that quality is not necessarily measured by appearance, durable materials, or other physical parameters.

The constructor's role is to plan, manage, and accomplish the construction activities necessary to build the project according to the plans, specifications, and other contract documents prepared by the design professional. The constructor's objective is to build a quality project safely and in compliance with the provisions of the owner/constructor contract.

The constructor assembles a team of material and equipment suppliers, specialty subcontractors, material fabricators, and others to assist with the construction effort. These team members report directly to the constructor, who is responsible for them. The constructor's responsibilities include:

⇒ Enhance communications;

⇒ Build a quality project;

⇒ Perform according to the owner/constructor's contract and approved change orders;

⇒ Plan, implement, and take responsibility for job safety;

⇒ Make timely decisions;

⇒ Be responsible for the performance of subcontractors and suppliers;

⇒ Provide skilled labor force;

⇒ Coordinate and cooperate with other project team members;

⇒ Comply with applicable codes, regulations, and laws.

⇒ Act with care and competence.

The constructor must comply with the contract documents during the work execution. To achieve quality in fulfilling this objective, the constructor should maintain a program designed to provide quality labor and compliance with the contract documents.

Successful construction projects are conceived, planned, designed, and built by a project team consisting of an owner, a design professional, and a constructor. In this context, quality is achieved when each team member's obligations are fulfilled competently and in a timely fashion in cooperation with the other members. In most projects, each team member can rely on functionally selected experts to assist with project activities.

The roles of the owner, design professional, and constructor may be integrated through a traditional organizational arrangement where the owner has independent contracts with the other two parties. In other arrangements, the owner may issue only one contract to a design-construction firm, or all of the functions may be performed by the owner's staff, with an outsourced design professional or constructor employed for unusual projects.

Owners are responsible for administering their contracts with the other project team members and monitoring and coordinating the activities of all parties involved in the planning, design, and construction of a project. The owner may fulfill these responsibilities more effectively by delegating authority to a project manager.

In addition to the specific responsibilities listed, others apply equally to all team members. These consist in accepting responsibility, striving for economy and efficiency, cooperating and coordinating with other team members, adhering to the established budget, schedule and program, and insisting on quality.

In the structuring of contracts and the roles and responsibilities of individual team members, care must be taken to avoid adversarial relationships that interfere with the production of a quality project. With appropriate care and understanding, there will be harmony among team members.

8.5 Dam Commissioning

Commissioning (please see **Chapter 11**) can be understood as formerly authorizing the operation.

A dam must be built with good practices. Construction shall proceed as required in the plan and be conducted by experienced and competent personnel. The quality control of construction work shall be independent of the building contractor, and the person responsible for supervising the work shall have the right to suspend it if necessary.

The dam safety authorities should be informed of the commencement of its construction at an early date to ensure that all dam safety aspects are considered in time. Any impact on dam safety arising from modifications or repair work shall be taken into account when assessing alternatives at the design and construction stages. Should the changes affect dam safety, they shall be reviewed as required during commissioning. For this purpose commissioning should begin on the day of the first filling (impounding) of the reservoir.

As a rule, several field inspections are undertaken during construction; for instance, reviews of structures and foundations conducted at different stages of the work. In every case, a field inspection must be made before impounding commences (commissioning inspection).

A commissioning inspection must be undertaken in an old dam when significant alterations or repair work are scheduled. The dam safety authority participates in the field inspections as necessary, but is not responsible for the inspections or their organization. The responsibility for undertaking inspections lies on the dam owner and associated experts. The dam owner must provide a commissioning plan containing the commissioning timetable, the associated monitoring measures and official inspections, and how impounding will occur when the dam is put into operation.

The dam owner must give the dam safety authority the opportunity to verify fulfilment of the safety requirements at the various construction stages, including inspections during the dam impounding and throughout its operational life. Before the dam is put into use, the owner must make sure that the technical requirements have been met and that other dam safety factors have been taken into account as required.

The field inspection is based on the design and quality control reports of the dam. The decision process for dam classification and documentation is normally required. The commissioning procedure is completed when all the structures are operationally ready, have been brought into full-scale use, and have had their planned operation verified. At the end of commissioning inspection, the records are collected in field and completion documents, and a summary is written and included in the Dam Safety Document.

When a project is completed, many agencies require some sort of statement or affidavit, or both, certifying that work has been done substantially in accordance with the contract documents, and that no outstanding payments are due. Furthermore, information on the location or completeness of record drawings may be required.

The owner/design professional agreement and the construction contract need to place emphasis on:

⇒ Maintaining quality of materials and labor;

⇒ Considering and taking timely action regarding the planned activities;

⇒ Maintaining current estimates and agreements;

⇒ Monitoring construction progress and maintaining current schedules and

⇒ work activity charts;

⇒ Revising change-order proposals and making timely decisions to approve,

⇒ modify, or reject them;

⇒ Building the project record, including all forms of written communication.

The operational and maintenance characteristics of the work after completion and acceptance by the owner should meet the project requirements. Operation and Maintenance (**O&M**) factors influence life-cycle costs, continuity of service, durability, public health and safety, environmental impact, and other features of the completed facility.

After the facility is completed, the owner is responsible for its O&M. Experienced operators should be responsible for implementing quality operation and maintenance activities. The owner, when making contractual arrangements for the project, may select from a number of options to provide for consideration of Q&M problems, as they are influenced by design and construction.

8.6 As Built

An as-built document of an existing structure can be provided to a contractor or other professional group upon request of the owner to ensure an understanding of the final dimensions of a project. An as-built document is the final result of a new or refurbished installation. As-built means exactly what it states, the as-built dimensions of a project, either new or refurbished.

Construction projects are not simple, with many parts that must correlated. Issues inevitably arise during construction, and the best contractors prove their skill by adjusting to necessary deviations from the original design.

At the end of construction, the contractor must provide an As-Built document including:

⇒ All elements of the work, as it was executed, including their calculations;

⇒ Representation of the geological and geotechnical aspects of the dam foundation and possible underground works, as well as the results related to their treatment;

⇒ Photographs showing the excavation of the foundations and their treatment and other aspects of the construction;

⇒ The test results of the materials used (concrete, soils, embankments, rockfills, rock mass, and other materials) and other laboratory studies carried out and their reports;

⇒ Work plan;

⇒ Updated monitoring and instrumentation plan;

⇒ Records of instrumentation readings and inspections performed during construction.

This is where as-built documents (reports, drawings, tests results, etc.) come in. While they are not always mandatory, most clients will require a complete set of as-built documents at project completion. Providing these documents is part of the conclusion of the construction management process, and they often prove useful in the future. As a result, all contractors should be familiar with what clear and useful as-built documents should contain.

An as-built document is a revised set of information created and submitted by a contractor after a construction project is finished. They contain any changes made in the initial drawings during the construction process, and provide an exact rendering of the building and property as it is upon completion. Any modifications, whether minor or major, should be included, along with a record of approvals to go along with them.

Even small details, such as materials used, should be documented if they differ from those indicated in the original plan, with the intended but unused materials simply crossed out to allow future reference to the changes that emerged throughout the construction process.

The contractor will most often be responsible for the accuracy of the final as-built drawing. This makes sense, as the contractor is responsible for the actual construction and is able to clearly document changes as they occur.

Contractors are well aware that, in most situations, the determination of any accuracy in the as-built document, is not realized until well after the contractor's warranty period is over. By definition, an as-built document is a revised set of drawings submitted by a contractor upon completion of a construction project. As-built drawings show the dimensions, geometry, and location of all components of the project. One of the main purposes of an as-built document is to describe any changes made during construction that strays away from the original design.

As-built drawings are an essential part of every construction project. The main purpose an as-built drawing is to replicate how the contractor has performed the project and identify the changes made throughout the course of construction. The final sets of as-built drawings hold important information, such as changes in shop drawing, design, field, approved and disapproved changes during construction, and any minor or major modification in the final resulting project.

Throughout the course of any construction project, a set of as-built documents is kept in the construction office. As items are installed, measurements are taken and recorded in the as-built documents of the project. Theoretically, at the end of the project, all the final dimensions relating to the actual installed items that make up the total project will have been recorded in the as-built documents.

The importance of an accurate as-built document can never be underestimated. It is also important that as-built drawings include:

⇒ explanations describing the modifications made;

⇒ dates on the corner of all drawing sheets;

⇒ clear and concise written language;

⇒ use of the same scale when adding to as-built drawings or recreating as-built drawings on different sheets;

⇒ logical order organization, such as primary colors, if applicable, when important items are added, deleted, or changed.

References

[08-01] – Hoover Project Development: Hoover Dam-75th Anniversary-History Symposium – ASCE – Las Vegas-Nevada – October, 2010.

[08-02] – Itaipu – Hydroelectric Project – "Engineering Features" – Itaipu Binacional, Curitiba, PR, 1994.

[08-03] – ANDRIOLO, FRANCISCO RODRIGUES (Organizer); BETIOLI, IDEVAL. **Itaipu Project** – Concrete Works – Development, control quality, durability-40 years later – Publisher Cubo, Itaipu, 2015.

9 MAINTENANCE

9.1 General and Conceptual Understanding of Maintenance

People often associate an accident with equipment maintenance failure, for instance, of a vehicle or an airplane. Approximately 12% of aircraft accident reports describe a maintenance factor. When failure or malfunction of aircraft equipment is part of an accident or incident, one third of these problems are related to maintenance errors.

One rarely imagines the interconnection of an accident with a lack of maintenance in a dam; however, as mentioned in **Chapter 7**, nearly 8% of dam accidents result from poor or inadequate maintenance.

- ***How important is maintenance?***
- ***If designed and constructed properly, should not all dams be maintenance free?***

✓ ***The answers to these questions may seem obvious, but several small dams fail as a result of lack of timely maintenance. In most cases, failure could have been prevented if these structures had been properly maintained.***

Maintenance can be briefly defined as the considerations, constraints, and plans for operational support of a system/equipment under development. Preventive maintenance is a schedular type of service that aims at preventing failures, loss, or reduction of function. Prevention is always the prime objective of management.

In most cases, dam failure could have been prevented if the structures had been properly maintained. Maintenance is an ongoing process that involves not only observing routines such as mowing the grass and clearing the trashrack, but also regularly inspecting the structure and properly operating its components.

A good maintenance program provides protection not only for the dam owner, but also for the general public. Furthermore, the cost of a proper maintenance program is small compared with that of major repairs or the loss of life and property and resultant litigation against the dam owner. A dam owner should develop a basic maintenance program based primarily on systematic and frequent inspections.

Major rehabilitation of a dam will not be necessary if it was designed according to good engineering practices, built using good construction standards, and operated and maintained properly. Design engineers should inspect their dams periodically after construction to ensure that the design is working and the structure is being properly operated and maintained.

A dam failure may result in loss of life, considerable loss of capital investment, loss of income, and property damage. A loss of a reservoir can cause hardships for those who depend on it for their livelihood or water supply, and can have an impact on the ecological balance of the area. In the event of a failure, the owner can be subject to a barrage of liability claims and, possibly, criminal charges.

Dam owners should be aware that they are legally liable for their operation, maintenance, and inspection. Negligence by owners in fulfilling their responsibilities can lead to the creation of extremely hazardous conditions to downstream residents and properties.

A good maintenance program will protect a dam against deterioration and prolong its life. A poorly maintained dam will deteriorate, and can fail. Nearly all the components of a dam and the materials used in its construction are susceptible to damaging deterioration if not properly maintained. Lack of proper maintenance can lead to deterioration, hinder inspection, cause critical components such as flood gates to be inoperable when needed, and ultimately cause the dam to fail.

9.2 Trained Labor Force

It is essential to keep the dam owner informed about matters related to the timely completion and cost of the construction; quality is usually the engineer's responsibility, and only in special circumstances is this discussed in detail with the owner. To achieve good communication, dam owners should set up an organization office in the site to monitor the contract and assist clearing bottlenecks on which they may have special competence, such as customs payments, housing, licensing, and access.

This can be achieved by strengthening the existing operation and maintenance organization. The owner's representative in the site is usually responsible for the welfare of staff seconded to the engineer, but not for their actions in supervising the contractor.

The professionals selected by the dam owner or the governmental entity to carry out maintenance must be trained and oriented to perform the functions. They should:

⇒ Be aware of aspects that are not tolerable and/or allowed;

⇒ Have notions of properties of materials and equipment;

⇒ Have knowledge about the dam project;

⇒ Be aware of the current legislation on the responsibilities of the dam owner;

⇒ Be aware of the features the dam must have for public protection;

⇒ Know how to report the facts and abnormalities observed.

Training professionals in different countries (pictures from Andriolo's archives)

The work entailed in the rehabilitation of reservoirs, dams, hydroelectric plants, and irrigation, drainage and water supply systems is often complex, and calls for a range of skills and experience in the water sector. It can provide a training vehicle for the owner's wider institutional development program.

To supplement technical staffing, agency management should provide internal personnel training. A rotational training program should be established to familiarize new personnel with all major aspects of the agency functions and the interrelationships of its organizational units. Provisions should be made for technical personnel to observe and participate in decision-making meetings and make visits to the site accompanied by more experienced staff.

Technical personnel concerned with all phases of project development should have broad exposure to a variety of field conditions. Training should be conducted by experienced observers and the engineers responsible for analyzing the structure effects. Operation and maintenance personnel should be trained by personnel experienced in the operation of similar projects, covering all the operation and maintenance features of the facility. This training should ensure that all inspectors know the expected requirements in detail. Onsite instruction sessions for inspection of new construction features should be developed and given by supervisors or lead inspectors prior to work commencement.

Technically qualified operating personnel should be trained in problem detection and evaluation and application of appropriate remedial (emergency and non-emergency) measures. This is essential for proper evaluation of developing situations at all levels of responsibility, which should initially be based on observations of the project by trained operating personnel. Training should cover the problems that experience has shown to be the most likely to occur with the type of dam and facilities, and should include the types of monitoring best suited to early detection of those problems. Such training will allow prompt action when time is a critical factor.

Sufficient personnel should be trained to ensure adequate coverage of all tasks at all times. If a dam is remotely operated, training must include procedures for dispatching trained personnel to the site at any reported indication of distress. Personnel involved in inspections should be trained to perform these duties. Training should cover the types of information needed to prepare for the inspections, critical features that should be observed, inspection techniques, and preparation of inspection reports.

Agency management should establish and maintain a program for continuing formal education and training aimed at increasing and broadening the agency's base of professional expertise in areas related to safe design and construction of dams. Programs should be designed to further the development of younger personnel and provide refresh training or reviews for senior personnel. Supervisory construction, inspection, and operation and maintenance staff should be kept up to date on modern methods and techniques by attending technical courses.

Professional growth of personnel should be encouraged by policies that ensure adequate training, support participation in technical and professional societies, and establish attractive career promotion for technical specialists. Provision should be made for the establishment of procedures to screen and disseminate information on technical advances relating to the design, construction, and operation of dams.

Structured training is needed to meet today's social, business and professional needs. Information technology demands considerable training if its benefits are to be realized. Not only greater technical skills, but also interpersonal and management skills are required. Whether in a government department or in private corporation, the level of skill required in planning, technical, contracts and finance departments is greater than ever, as we seek to use the world's resources to satisfy the needs of growing populations.

In developing countries, government departments carry major responsibilities and are particularly vulnerable. If they cannot satisfy the development needs of their personnel, they lose staff to the private sector, do not attract replacements, and cannot carry out their duties effectively. It is in this context that major financing agencies encourage significant, often stand alone, training programs.

Development programs can be designed to meet a significant range of needs, from planners, designers, construction, operation and maintenance staff to top management. All development programs have a common structure. This comprises definition of what a person needs to be able to do, a schedule of experience they need to have to meet these performance goals, and a mechanism to monitor their progress.

Encouraging the staff to take any course is an important ingredient of success. If job descriptions and the skills needed to do it are available to participants, they can see how their study will enable them to progress in their career path. A requirement to demonstrate their newfound skills upon return from training, either through presentations or training of others, induces performance. Consistent failure to take a course, particularly when it is offered abroad, should be punished.

9.3 Routines and Planing

Routine maintenance must be performed on the dam and its appurtenant structures. Any unusual conditions noticed when performing maintenance that may adversely affect the dam safety should be immediately reported to the site superintendent.

Dams must not be thought of as part of the natural landscape, but as man-made structures that should be designed, inspected, operated, and maintained accordingly.

Major rehabilitation of a dam normally will not be necessary if the dam was designed according to good engineering practices, built using good construction standards, and operated and maintained properly. Engineers generally agree that the design of a dam is not complete until after it has been built and impounded. Design engineers should inspect their dams periodically after construction to ensure that the design is working and the structure is being properly operated and maintained. However, this objective cannot be accomplished without the continued cooperation of owners and their personnel, engineers, and contractors.

Commissioned sections of work should be handed over to the owner for maintenance as soon as practicable. Defects that become apparent can then be rectified. At the end of the period for which the contractor is responsible for defects, the engineer's project manager reviews and tests the project together with the owner and the contractor. It may often be useful to the owner if the engineer provides continuing services to monitor the performance of the rehabilitated project.

Maintenance is a task that should never be neglected. If so, several areas will ultimately need attention – some of greater concern than others. A schedule should be established that includes both daily tasks and tasks performed less frequently troughout the year. Such a schedule serves to formalize inspection and maintenance procedures and makes it easy to determine when a task should be performed. The following list outlines, by order of priority, the various problems or conditions that might be encountered in a deteriorated dam.

9.3.1 Immediate maintenance

The following conditions are critical and call for immediate attention:

⇒ A dam about to be overtopped or being overtopped;

⇒ A dam about to be breached (by progressive erosion, slope failure, or other circumstances);

⇒ A dam showing signs of piping or internal erosion indicated by increasingly cloudy seepage or other symptoms;

⇒ A spillway being blocked or otherwise rendered inoperable, or having normal discharge restricted;

⇒ Evidence of excessive seepage appearing anywhere at the dam site (an embankment becoming saturated, seepage exiting on the downstream face of a dam) and increasing in volume.

Although the remedy for some critical problems may be obvious (such as clearing a blocked spillway), the problems listed above generally require the services of a professional familiar with the construction and maintenance of dams.

9.3.2 Required maintenance at earliest possible date

The following maintenance tasks should be performed as soon as possible after the defective condition is identified:

⇒ All underbrush and trees should be removed from the dam, and a good grass cover should be established;

⇒ Eroded areas and gullies on embankment dams should be restored and reseeded;

⇒ Defective spillways, gates, valves, and other appurtenant features of a dam should be repaired;

⇒ Deteriorated concrete or metal components of a dam should be repaired as soon as weather permits.

9.3.3 Continuing maintenance

Several tasks should be performed on a permanent basis:

⇒ Routine mowing and general maintenance;

⇒ Maintenance and filling of any cracks and joints on concrete dams;

⇒ Observation of any springs or areas of seepage;

⇒ Inspection and monitoring of the dam (**as discussed in Chapter 10**).

Monitoring devices are frequently computerized and specialized maintenance contracts are often used to assist the owner in the initial years.

Trees and vegetation along the spillway that can create concentrated flow that can cause erosion (pictures from Andriolo's archives)

Regular operation and maintenance as well as thorough and consistent inspection must be practiced throughout the lifetime of a dam. In addition to maintaining proper functioning, cost efficiency, and compliance with safety regulations, such habits can lead to early detection of deficiencies and prevention of failure. Standard practices for both preventive and extraordinary maintenance are provided in this section.

⇒ Preventative maintenance is performed routinely, and includes the servicing of the dam and its appurtenances, with the intention of avoiding over-vegetation, animal impacts, equipment deterioration, mechanical malfunction, flooding, or failure.

⇒ Extraordinary maintenance comprises the repairs required to correct these damages when they occur.

In addition to consistent and documented operation and maintenance, regular inspection is essential to preserv the proper functioning of a dam. Formal dam safety inspections and routine assessments should be conducted regularly. Dam assessments are thorough investigations of a dam by licensed professionals in which design documents are consulted and the current conditions are compared with those considered state-of-the-art.

Inspections are conducted on a more frequent basis by dam operators or maintenance personnel. These inspections include simple observation of the dam, its appurtenances, reservoir, and surrounding area. With the implementation of consistent operation, maintenance, and inspection comes a record of baseline conditions at the dam. As a result, deviation from normality becomes apparent. A forward planning of rehabilitation procedures concurrently with operation is necessary so as not to delay and to allow smooth operation of the dam and associated works.

Most power plants are connected to the electric grid; therefore, alternative electricity supplies should be arranged when there is need to take generating equipment out of service for rehabilitation. Alternative arrangements for water supply or for irrigation are seldom practicable. The demands have to be met, and have a major influence on the way rehabilitation can be carried out.

9.4 Operation and Maintenance Tips

9.4.1 General

The maintenance of structures and equipment, including their respective rules, procedures, records and responsibilities, aims to ensure that the dam, its associated structures and equipment are kept in fully operational and safe conditions. To this end, maintenance plans should be organized in particular, seeking to minimize possible constraints on the project operation. A list of items to be maintained at a dam can be adopted as follows[09-01]:

REQUIRED MAINTENANCE AND REPAIRS	EARTHWORKS	RIPRAP	VEGETATION	LIVESTOCK	RODENT DAMAGE	TRAFFIC DAMAGE	MECHANICAL PARTS	ELECTRICAL PARTS	CLEANING	CONCRETE	METAL COMPONENTS
FEATURE											
EMBANKMENT DAM											
Upstream Slope	X	X	X	X	X				X		
Downstream Slope	X		X	X	X	X					
Abutments	X	X	X	X	X	X					
Crest	X		X	X	X	X					
Internal drainage system										X	
Relief drains							X		X	X	X
Riprap & Slope protection		X	X	X	X	X				X	

REQUIRED MAINTENANCE AND REPAIRS	EARTHWORKS	RIPRAP	VEGETATION	LIVESTOCK	RODENT DAMAGE	TRAFFIC DAMAGE	MECHANICAL PARTS	ELECTRICAL PARTS	CLEANING	CONCRETE	METAL COMPONENTS
FEATURE											
CONCRETE DAM											
Upstream Slope									X	X	
Downstream Slope										X	
Abutments	X	X	X	X	X	X					
Crest										X	
Internal drainage system											X
Relief drains							X		X		X
Galleries								X		X	
Sluiceways/controls							X	X	X	X	X

REQUIRED MAINTENANCE AND REPAIRS	EARTHWORKS	RIPRAP	VEGETATION	LIVESTOCK	RODENT DAMAGE	TRAFFIC DAMAGE	MECHANICAL PARTS	ELECTRICAL PARTS	CLEANING	CONCRETE	METAL COMPONENTS
FEATURE											
SPILLWAYS											
Approach channel	X	X	X	X	X				X	X	
Inlet/outlet structure							X	X	X	X	X
Stilling basin		X							X	X	
Discharge conduit/channel	X	X	X				X	X	X	X	X
Control features							X	X	X	X	X
Erosion protection	X	X	X	X	X	X				X	
Side slopes	X	X	X	X	X	X				X	
OUTLETS & DRAINS											
Inlet/outlet structure							X	X	X	X	X
Stilling basin									X	X	
Discharge conduit/channel		X	X	X	X	X			X	X	
Trashrack/Debris Control							X	X	X		X
Emergency systems								X	X		X

REQUIRED MAINTENANCE AND REPAIRS	EARTHWORKS	RIPRAP	VEGETATION	LIVESTOCK	RODENT DAMAGE	TRAFFIC DAMAGE	MECHANICAL PARTS	ELECTRICAL PARTS	CLEANING	CONCRETE	METAL COMPONENTS
FEATURE											
GENERAL AREAS											
Reservoir surface									X		
Mechanical/Electrical systems								X	X		X
Shoreline		X	X		X				X		
Upstream watershed		X	X						X		
Downstream Channel	X	X							X	X	

List of items to be maintained at a dam and the maintenance tasks to be performed[09-01]

⇒ All visible portions of the lake and drain system should be inspected at least annually, preferably during the periodic operation of the drain. Look for and make note of any cracks, rusted and deteriorated parts, leaks, bent control stems, separated conduit joints, or unusual observations;

⇒ The reservoir and dam drain should be operated at least twice a year to prevent the inlet of clogging with sediment and debris, and to keep all movable parts working easily. Most manufacturers recommend that gates and valves be operated at least four times per year. Frequent operation will help ensure that the drain will be operable when needed;

⇒ All valves and gates should be fully opened and closed at least twice to help flush out debris and obtain a proper seal. If the gate gets stuck in a partially opened position, gradually work the gate in each direction until it becomes fully operational. Do not apply excessive torque, as this could bend or break the control stem, or damage the valve or gate seat. With the drain fully open, inspect the outlet area for flow amounts, leaks, erosion, and anything unusual;

⇒ A properly designed reservoir and dam drain should include a headwall near the outlet of the drain conduit to prevent undermining of the conduit during periods of flow. A headwall can be easily retrofitted to an existing conduit if undermining is a problem at an existing dam;

⇒ A properly designed layer of rock riprap or other slope protection will help reduce erosion in the reservoir drain outlet area;

⇒ Drain control valves and gates should always be placed upstream of the dam centerline. This allows the drain conduit to remain depressurized except during use, thus reducing the likelihood of seepage through the conduit joints and saturation of the surrounding earth fill;

⇒ All gates, valves, stems, and other mechanisms should be lubricated according to the manufacturer's specifications. If you do not have a copy of the specifications and the manufacturing company cannot be determined, then a local valve distributor may be able to provide assistance;

⇒ For accessibility ease, the drain control platform should be located on shore or be provided with a bridge or other structure. This becomes very important during emergency situations if high pool levels exist;

⇒ Vandalism can be a problem at any dam. If a reservoir drain is operated by a crank, wheel, or other similar mechanism, locking with a chain or other device, or off-site storage may be beneficial. Fences or other such installations may also help ward off vandals;

⇒ The recommended rate of reservoir drawdown is one foot or less per week, except in emergencies. Fast drawdown causes a build-up of hydrostatic pressures in the dam upstream slope that can lead to slope failure. Lowering the water level slowly allows these pressures to dissipate.

9.4.2 Operational Components

✓ ***Stoplogs***

There is no regularly scheduled maintenance for stoplogs. Replace a stoplog if it becomes excessively deteriorated. When not in use, store the stoplogs on a flat, hard surface, elevated with blocks. Maintain the hoisting equipment according to the manufacturer's recommendations.

There were water leaks from the stoplog concrete structure (from Ref. [09-02])

The rubber seal damaged

The stoplog gate leaf was in sound condition

Figures from Ref. [09-02]

✓ ***Slide Gate(s)***

To ensure good operation and maintenance of slide gates, all gates should be operated and inspected regarding all of their components as part of the normal dam and reservoir operations. The recommended procedure to ensure the smooth operation of outlet gates is to operate them through their full range at least once a year, preferably more often. Some manufacturers recommend operating the gates as often as four times a year. Because operating gates under full reservoir pressure can result in large outlet discharges, schedule gate testing during periods of low storage, if possible, or else operate them during periods of low stream flow. If large releases are expected, only have the outlets tested after coordinating releases with the local floodplain administrator and other dam owners located downstream, and after notifying downstream residents and water users.

Operation of the gates minimizes the buildup of rust in their operating mechanism and, therefore, the likelihood of their seizure. During this procedure:

⇒ Check the mechanical parts of the hoisting mechanism—including drive gears, bearings, and wear plates—for adverse or excessive wear;

⇒ Check all bolts, including anchor bolts, for tightness;

⇒ Replace worn and corroded parts;

⇒ Make mechanical and alignment adjustments as necessary.

The way the gate actually operates should also be observed. Rough, noisy, or erratic movements could be the first signs of a developing problem. The causes of operational problems should be investigated and corrected as soon as possible.

Excessive force should be neither needed nor applied to either raise or lower a gate. If excessive force seems necessary, something may be binding the mechanical system. Excessive force may result in increased binding of the gate or damage to the outlet works. If there does seem to be undue resistance, the gate should be worked up and down repeatedly in short strokes until the binding ceases or the cause of the problem should be investigated.

If a gate does not properly seal when closed, debris may be lodged under or around the gate leaf or frame. Raise the gate at least two to three inches to flush the debris, then attempt to reclose it. This procedure should be repeated until proper sealing is achieved. However, if this problem or any other problem persists, consult the manufacturer's representative or an engineer experienced in gate design and operation.

If, at any time, a sluice gate will not close, open, or malfunction, stop operating it and determine the cause of malfunction. Do not try to force a malfunctioning gate to open or close; this may damage it and/or its lifting mechanism.

An outlet gate operating mechanism should always be well lubricated according to the manufacturer's specifications. Proper lubrication will not only reduce wear in the mechanism, but will also protect it against adverse weather.

Brass, stainless steel, bronze, or other rust resistant alloys are the metals usually used in gate seats. Older or smaller gates may not be fitted with seats, making them susceptible to rust formation on the contact surfaces between the gate leaf and frame. Operation prevents excessive rust buildup or seizure in gates.

Any operational adjustments or repairs of damaged components should be performed immediately. All mechanical parts of slide gates should be periodically lubricated according to the manufacturer's instructions. All gates should be repainted periodically.

Many outlet gates are equipped with wedges that hold the gate leaf tightly against the gate frame as the gate is closed, thus ensuring a tight seal. After years of use, gate seats may become worn, causing the gate to leak increasingly. If an installation has a wedge system, the leak may be substantially reduced or eliminated by readjusting the wedges. Because adjustment of these gates is complicated, inexperienced personnel can cause extensive damage to the system. Improper adjustment could cause premature seating of the gate, possible scoring of the seats, binding, vibration, leaks, uneven closing, or damage to wedges or gate guides. Thus, only experienced personnel should perform adjustments.

Radial gates should be operated semi-annually as part of the normal dam and reservoir Operations Schedule. When operated, radial gates should be lifted through both up and down cycling to verify their functioning. A radial gate cannot be fully opened because this would result in excessive downstream flow discharge. Distribute the discharge flow equally among the gates that are to be opened.

Gate leaves in apparently good conditions

Gates presenting water leak

Figures from Ref. [09-02]

Occasionally, manufacturers will recommend that radial gate trunnion and hoist bearings be lubricated to prevent dirt and moisture buildup. In cases where lubrication is recommended, this service should be performed according to the manufacturer's instructions.

Some radial gate trunnion and hoist bearings are maintenance-free, and should not be lubricated for two reasons:

⇒ the bearing lifespan exceeds that of the project design because they are rated for loads 7 to 8 times the actual loads in the application;

⇒ lubricants that are not pure lithium-based will cause the plastic in the bearing materials to dissolve. Do not lubricate radial gate trunnion and hoist bearings unless this is recommended by the manufacturer.

✓ ***Diffusers & Valves***

Most energy dissipation structures in outlet works are partially or completely constructed using concrete. Valves and gates are made of various other materials, but repairs are usually performed by the manufacturers. Various causes of damage in energy dissipation structures in outlet works requiring repairs are cumulative in nature. If not addressed, these damages can lead to erosion or loss concrete floors or walls, resulting in increased erosion and eventual undermining of the entire structure.

The maintenance and repair of energy dissipators that are either partially, completely, or periodically under water present many complex problems. Many energy dissipators are kept in operation well beyond their original design lives. Experience has shown that many of these older structures require significant maintenance, repair, and rehabilitation.

Energy dissipators must be properly maintained to ensure their continued operation and that repairs, when needed, be made as efficiently as possible while addressing the cause of the problem, rather than just the symptom presented, to prevent problem recurrence. Effective ongoing maintenance is best achieved by developing a formal inspection and maintenance program for the structure that documents future requirements, identifies personnel responsible for performing it, and ensures that they are included in annual maintenance budgets.

Diffuser Valve Types in good operational condition and in poor maintenance (pictures from Andriolo's archives)

Sealing rings must be replaced whenever necessary. The replacement intervals depend on the operating conditions of the discharge valves. Stainless steel sealing faces equipped with an additional elastic auxiliary seal (profile seal ring) ensure that the in closed position of a discharge valve. A separate seat ring transmits the sealing pressure. This threaded sealing ring can be removed, thus allowing replacement of the damaged elastic seal.

After the seat ring is disassembled, the profile ring on the pipe cone can be removed. In order to move the cylindrical sleeve beyond the sealing ring, the rear and front sliding shoes first need to be removed from it. Installation of the cylindrical sleeve must be adjusted to the parallel plane(this can be done via the lateral fixing of the stem nuts). Remove the cover of the double-bevel gearbox. Fill the gearbox hollows with grease, replace the cover, and seal it.

The two threaded stems and the stem nuts must be free from dirt and always properly lubricated. For this purpose, lubricants approved for use with foodstuff and/or drinking water should be applied.

9.4.3 Instruments

Instruments designed for monitoring the potential deficiencies at existing dams must take into account the threat to life and property that the dam presents. Thus, the extent and nature of the instrumentation depends not only on the complexity of the dam and size of the reservoir, but also on the potential for loss of life and property downstream.

Instruments in poor and satisfactory conditions (pictures from Andriolo's archives)

An instrumentation program should involve instruments and evaluation methods that are as simple and straightforward as the project allows. Beyond that, the dam owner should make a definite commitment to an ongoing monitoring program or the installation of instruments probably will be wasted.

The instruments have functions of interest to the dam life, and they function reliably and systematically; and thus should be kept in good conditions and be maintained.

✓ ***Reservoir Staff Gauge***

If the reservoir staff gauge is not firmly fixed, tighten the bolts or use other methods to firmly fix it. If necessary, remove and reinstall the gauge making sure that the correct elevation is maintained. If the reservoir staff gauge is damaged, so as not to be accurate or readable, it should be replaced.

✓ ***Piezometers***

If the dam has piezometers for measuring internal water pressures, maintenance instructions can normally be obtained from the instrument manufacturer.

✓ ***Weirs at Drain Outfalls***

Keep the surfaces of the weir plate clean and the edge of the V-notch true. Damaged weir plates should be replaced. Remove vegetation from the upstream and downstream sides of the V-notch.

✓ ***Survey Monuments***

The brass cap survey monuments should be protected from damage and should not be covered or moved. Damaged survey markers should be replaced with the assistance of an experienced surveyor.

Typical National Park Service (NPS) Survey Monuments (From IBGE-Brazil). Figures from Ref. [09-03]

✓ ***Embedded Instruments***

Most manufacturers of embedded instruments usually highlight their benefits, but rarely point out their deficiencies and/or troubleshooting. For instance, transducers are sealed and cannot be opened for inspection and/or maintenance, but it is important to periodically check their cable connections and terminals.

⇒ Check if the same problem occurs with other instruments. If so, compare cable routes or check the readout unit:

- o Is the shield drain wire correctly connected to the readout unit?
- o Isolate the readout unit from the ground by placing it on a piece of wood or similar non-conductive material.

⇒ Check the battery of the readout unit.

⇒ Check for nearby sources of electrical noise such as motors, generators, electrical cables, or antennas. If there are noise sources nearby, shield the cable or move it.

⇒ If a data logger is used to take the readings, are the frequency-swept excitation settings well adjusted?
  - The sensor may have gone outside its range;
  - See previous records;
  - The sensor body may be short-circuited to the shield ;

⇒ Check the resistance between the shield drain and the sensor housing;

⇒ Check the cable integrity;

⇒ The sensor may have been damaged by shocks.

The instrument cannot be read:

⇒ Check the battery of the readout unit.

⇒ Check if the same problem occurs with other instruments. If so, the readout unit may be compromised, and the manufacturer should be consulted.

⇒ If a data logger is used to take the readings, are the frequency-swept excitation settings well adjusted?

⇒ The sensor may have gone outside its range. See previous records;

⇒ Check the coil resistance;

⇒ If the resistance is high or infinite, there may be a cut cable;

⇒ If the resistance is low or near zero, there may have been a short-circuit;

⇒ If resistances are within the nominal range and no reading is obtained, the transducer may be compromised, and the manufacturer should be consulted;

⇒ If cuts or short-circuits are located, the cable should be spliced according to the recommended procedures;

- The sensor may have been damaged by shocks or water may have penetrated inside its body. **There is no remedial action.**

⇒ If problems occur when reading the temperature, it is likely that a cable is cut or short-circuited because of the technology used (simple thermistor).

- Check the cable and splice it according to the recommended procedures.
- If even so no reading can be taken, water may have penetrated inside the sensor body. **There is no remedial action.**

9.4.4 Vegetation Control

Vegetation control is often a major ongoing effort for embankment dams. Keep the entire dam clear of unwanted vegetation such as underbrush and trees. Growth of underbrush and trees on an embankment will cause several problems:

⇒ It will obscure the surface of an embankment and prevent a thorough inspection of the dam;

⇒ Large trees can be uprooted by high wind or erosion and leave large holes that can lead to dam breaching;

⇒ Some root systems can decay and rot, creating passageways for water, causing erosion or piping of embankment material;

⇒ Growing root systems can lift concrete slabs or structures;

⇒ Trees, underbrush, and weeds can prevent the growth of desirable grasses;

⇒ Rodent burrows can develop as underbrush hides them and provides protection.

Underbrush should be removed to allow a clear view of the embankment.

After removal of underbrush or large trees, also remove their leftover root systems, if possible, and properly fill and compact the resulting holes. In cases where they cannot be removed, treat root systems with herbicide (properly selected and applied) to retard further growth.

If properly maintained, grass is not only an effective means of controlling erosion, but also enhances the appearance of a dam and provides a surface that can be easily inspected. Grass roots and stems tend to trap fine sand and soil particles, forming an erosion-resistant layer once the plants are well established. Grass is less effective in areas of concentrated runoff or subjected to wave action.

Periodic mowing is essential to maintain a good ground cover. Mow the grass areas regularly to control weeds, remove excessive vegetation, and prevent the growth of underbrush, saplings, woody vegetation, or trees on:

- ⇒ upstream slope,
- ⇒ downstream slope,
- ⇒ spillway(s),
- ⇒ diversion structure(s),
- ⇒ regular or adopted distance from the downstream toe of the dam.

Trees growing on the upstream slope that are less than 5 cm in diameter should be cut down. Trees growing on the downstream slope that are greater than 5 cm in diameter should be removed.

Areas adjacent to spillway structures, vegetated channels, and other areas associated with a dam require continuous maintenance of their vegetation cover. Removal of improper vegetation is necessary for the proper maintenance of a dam, dike, or levee. Reasons for proper maintenance of the vegetation cover include unobstructed viewing during inspection, maintenance of a non-erodible surface, discouragement of rodent burrow, and esthetics. Chemical spraying to kill small trees and underbrush is acceptable if precautions are taken to protect the local environment. Some chemical spraying may require proper training prior to application.

Figures showing unacceptable vegetation control on a dam. Downstream slope with trees growing and waist-high grass making visual inspection nearly impossible. Upstream slope is mowed, but trees and tall grass growing along the toe of dam above normal pool reservoir. Most of downstream slope is mowed, but trees and tall grass remain on slope and at the toe of dam. Mature trees growing on slopes and knee-high grass, hindering visual inspection (Pictures from Andriolo's archives)

Figures showing unacceptable vegetation control on a dam. Downstream slope with trees growing and waist-high grass making visual inspection nearly impossible. Upstream slope is mowed, but trees and tall grass growing along the toe of dam above normal pool reservoir. Most of downstream slope is mowed, but trees and tall grass remain on slope and at the toe of dam. Mature trees growing on slopes and knee-high grass, hindering visual inspection (Pictures from Andriolo's archives)

Figures showing an Acceptable Vegetation Control (From Refs. [09-04] to [09-08])

Tall grasses can make a visual inspection nearly impossible and can hide serious problems such as rodent activity, embankment slides, and cracking; all of which can lead to dam failure. It is important to ensure that the entire area surroundings the dam has been mowed. It should be free of all woody growth and be clear of other obstructions, so that a truck could drive around the dam if needed.

If the dam is mowed at regular intervals, the growth of saplings, trees, and underbrush will not become a problem; however, if that does occur, the resulting vegetation growth will hinder the proper maintenance and inspection of the project. Remove all of the roots when removing vegetation. The remaining holes should be backfilled and compacted.

Remove any vegetation growing in riprap areas. All trees and underbrush must be cleared and discarded away from the dam. Disposal of material on the upstream side of the dam or in areas where flood waters can carry it downstream is prohibited.

In riprap protected areas, ditches, or other areas of the project where power mowing is not possible, unwanted vegetation should be controlled through spraying of an approved herbicide or should be cut and/or removed using manual tools. Trees growing on the downstream slope that are greater than 5 cm in diameter should be removed. Trees growing on the crest, downstream slope, and beyond the toe (limited zone) of dam should be cut and removed. The voids resulting from tree or vegetation removal should be filled with impervious material, firmly compacted, and reseeded.

In places where there is a significant amount of floating material, such as vegetation or debris, should be established procedures should be established.

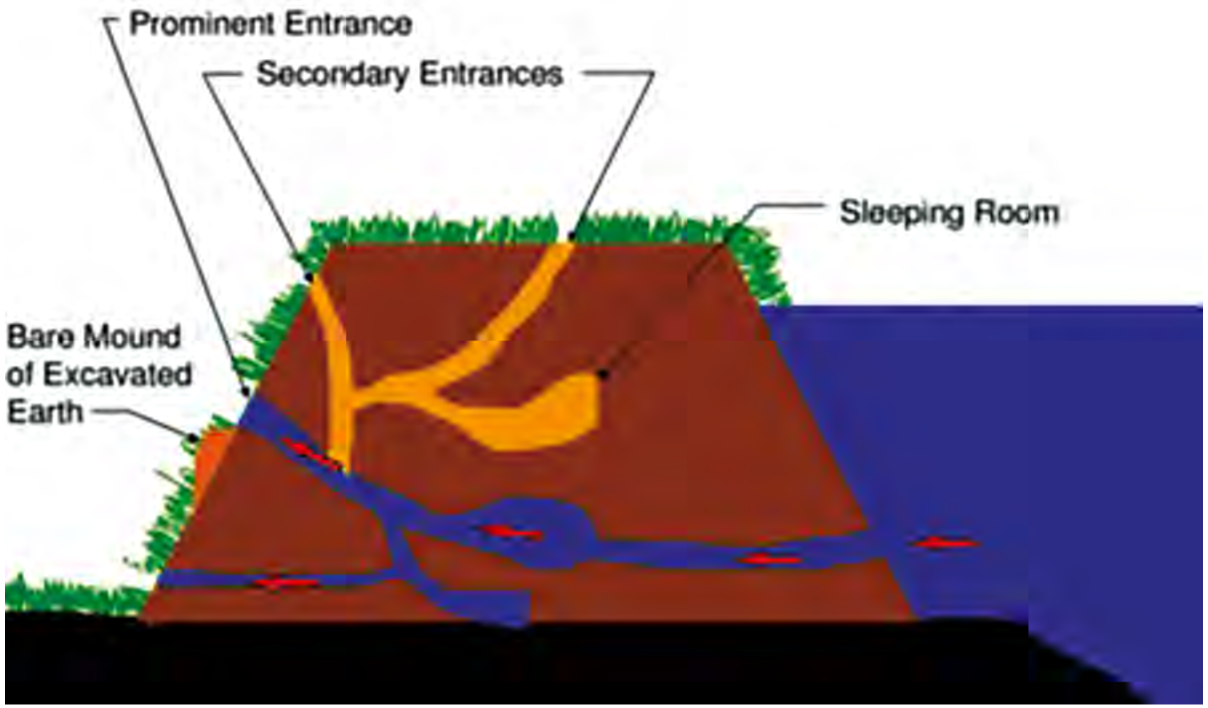
Pictures showing the removal of vegetation from a reservoir (from Ref. [09-09]).

9.4.5 Control of Burrowing Animals

Burrowing animals are naturally attracted to the habitats created by dams and reservoirs, and can endanger the structural integrity and proper performance of embankments and spillways. The burrows and tunnels dug by these animals generally weaken embankments and serve as pathways for seepage from the reservoir.

Beavers, armadillos, and other similar animals usually construct their tunnels and dens in the banks surrounding the reservoir or dam. The tunnel systems become very extensive as the colony grows, and embankment material located above these systems will eventually settle or collapse. Tunnels occasionally extend through a dam where pools of water are allowed to collect along its toe, and provide pathways for water to pass through the embankment.

Common signs of the presence of these animals include gnawed or cut vegetation around the waterline, burrows or sunken or collapsed areas on the crest or slopes of the embankment, and obstructions across spillways and inlets that produce unusual changes in the water level of the reservoir.



Schematic representation of animal burrows in an embankment illustrating the potential for developing a piping failure (From Ref. [09-07])

Barriers such as properly constructed riprap and filter layers offer the most practical protection against these animals. When an animal tries to dig a burrow, the sand and gravel of a filter layer will cave in and discourage den building. Filter layers and riprap should extend at least three feet below the waterline. Heavy wire fencing laid flat against a slope and extending above and below the waterline can also be effective. Eliminating or reducing aquatic vegetation along a shoreline will also discourage animal habitation.

Methods of repairing rodent damage depend on the nature of the damage but, in any case, extermination of the rodent population, if possible, is the most effective method. If the damage consists mostly of shallow holes scattered across an embankment, repair may be necessary to maintain the dam appearance, keep runoff waters from infiltrating the dam, or discourage rodents from subsequently returning to the embankment. In these cases, tamping of earth into the rodent hole should be sufficient repair. Soil should be placed as deeply as possible and compacted with a pole or shovel handle.

Large burrows on an embankment should be filled by mud packing. This simple, inexpensive method involves placing one or two lengths of metal stove or vent pipe vertically over the entrance of the den with a tight seal between the pipe and den. A mud-pack mixture is then poured into the pipe until the burrow and pipe are filled with the earth-water mixture. The pipe is removed and more dry earth is tamped into the hole. Plug all entrances with well-compacted earth and reestablish vegetation.

Different repair measures are needed if a dam has been damaged by extensive small rodent tunneling or beaver or armadillo activity. In these cases, it may be necessary to excavate the damaged area down to competent soil and repair. Small rodent activity can be discouraged by flattening the embankment slopes. Embankment with slopes flatter than 7H:1V make tunneling difficult, as they collapse easily because of the relatively shallow canopy of overhead earth material.

Occasionally, rodents will dig passages all the way through the embankment that could result in leakage of reservoir water, piping and, ultimately, failure. In those cases, do not plug the downstream end of the tunnel, since that will add to the saturation of the dam. Tunnels of rodents or ground squirrels will normally be above the phreatic surface with primary entrance on the downstream side of the dam, while those of beaver, nutria, and muskrat normally exist below or at the water surface, with entrance on the upstream slope. If a rodent hole extends through the dam, first locate its upstream end, excavate the area around the entrance, and then backfill it with impervious material, plugging the passage entrance so that reservoir water is prevented from saturating the dam. This should be considered a temporary repair. Excavation and backfilling of the entire tunnel or filling of the tunnel with cement grout are possible long-term solutions, but pressure cement grouting is an expensive and sometimes dangerous procedure. Pressure exerted during grouting can cause further damage to the embankment via hydraulic fracturing. Thus, grouting should be performed only under the supervision of an engineer.

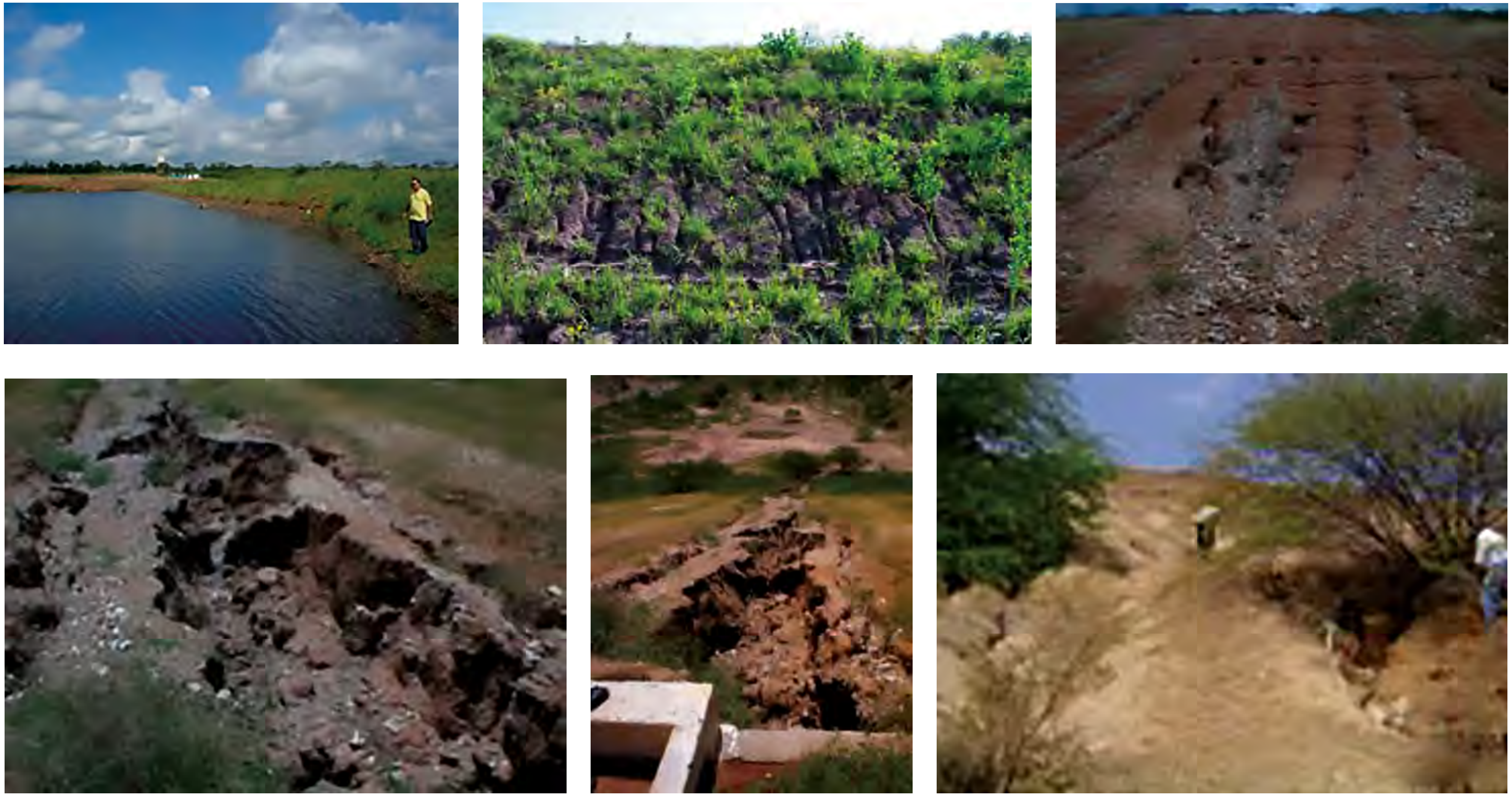
Any animal burrows observed on the dam embankment should be repaired. The burrow should first be assessed to eliminate the possibility of any seepage or piping through or near it. If any seepage or piping is observed, immediately inform the park superintendent. Burrow locations should be recorded and the hole should be completely backfilled and compacted.

9.4.6 Erosion

Erosion is one of the most common problems in embankment structures. Periodic and timely maintenance is essential to prevent continuous deterioration and possible failure.

Sturdy grass, free from weeds and underbrush, is an effective means of preventing erosion. Embankment slopes are normally designed and constructed so that surface drainage will be spread out in thin layers on the grassy cover. When embankment grass is in poor condition or flows are concentrated at any location, the resulting erosion will leave rills and gullies in the embankment slope. Look for such areas and be aware of the problems that may develop. Eroded areas must be promptly repaired to prevent more serious damage to the embankment. Rills and gullies should be filled with suitable soil, compacted, and seeded.

Erosion in large gullies can be slowed by stacking bales of hay or straw across the gully until permanent repairs can be made.



Figures showing sparse vegetation and erosion downstream of an embankment slope (Pictures from Andriolo's archives)

Figures showing sparse vegetation and erosion downstream of an embankment slope (Pictures from Andriolo's archives)

Figures showing sparse vegetation and erosion downstream of an embankment slope (Pictures from Andriolo's archives)

Not only should eroded areas be repaired, but the cause of erosion should be found to prevent a continuing maintenance problem. Erosion might be caused or aggravated by improper drainage, settlement, pedestrian traffic, animal burrows, or other factors. The cause of the erosion will have a direct bearing on the type of repair needed.

Paths due to pedestrian, livestock, or vehicular traffic are a problem in many embankments. When a path is established, vegetation will not provide adequate protection, and more durable cover will be required unless traffic is eliminated. Small stones, asphalt, or concrete may be used effectively to cover footpaths. All vehicular traffic, except for maintenance or an authorized road, should be prohibited in the dam area.

Erosion is also common at the points where an embankment and the concrete walls of a spillway or other structure meet. Poor compaction adjacent to such a wall during construction and subsequent settlement can result in an area along the wall that is lower than the embankment grade. Therefore, runoff often concentrates along these structures, resulting in erosion. People also frequently walk along these walls, wearing down the vegetation cover. Possible solutions include re-grading the area so that it slopes away from the wall, adding more resistant surface protection, or constructing wooden steps.

Adequate protection against erosion is also needed along the contact between the downstream face of an embankment and the abutments. Runoff from rainfall can concentrate in gutters constructed in these areas and can reach erosive velocities because of relatively steep slopes. Berms on the downstream face that collect surface water and empty into these gutters add to runoff volume. Grass surfaced gutters may not adequately prevent erosion in these areas. Paved concrete gutters may not be desirable, because they do not slow the water and can be undermined by erosion. Also, small animals often construct burrows underneath these gutters, adding to erosion potential.

Riprap covered with a thin concrete slurry has also been successful in preventing erosion in larger dams, and should be used if large stones are not available. As it occurs with erosion around spillways, erosion adjacent to gutters results from improper construction or poor design, in which the finished gutter is too high in relation to the adjacent ground - preventing much of the runoff from entering the gutter. Instead, the flow concentrates along the side of the gutter, eroding and potentially undermining it.

Care should be taken when replacing failed drainage channels or designing new gutters to ensure that:

⇒ The channel has adequate capacity;

⇒ Adequate erosion protection and a satisfactory filter have been provided;

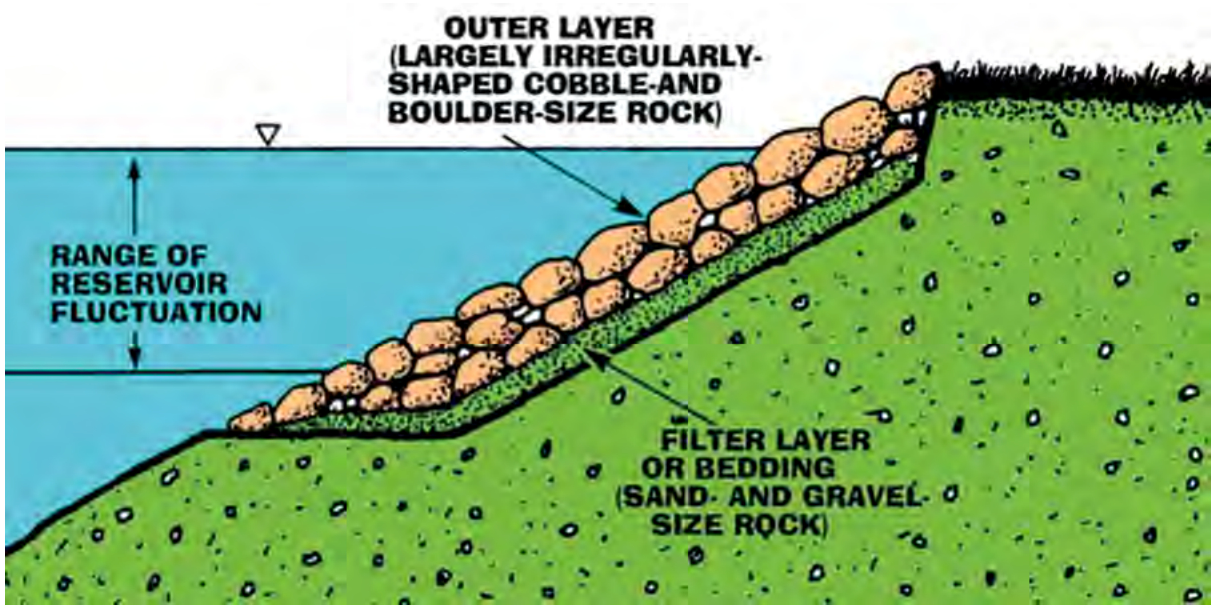
⇒ Surface runoff can easily enter the gutter;

⇒ The outlet is adequately protected against erosion.

A serious erosion problem, which can develop on the upstream slope, is "beaching". Waves caused by winds or high-speed powerboats can erode the exposed face of the embankment. Waves repeatedly strike the surface just above the pool elevation, rush up the slope, and then tumble downward into the pool. This action erodes material from the embankment face and displaces it farther down the slope, creating a "beach." Erosion of unprotected soil can occur rapidly and, during a severe storm, could lead to complete dam failure. The upstream face of a dam is commonly protected against wave erosion and resultant "beaching" by placing a layer of rock riprap over a layer of gravel bedding material. This provides an armored surface on which wave energy can dissipate.

"Beaching" can also occur in an existing riprap if a filter does not properly protect the embankment surface. Water running down the slope under the riprap can erode the embankment. Sections of riprap slumped downward are often signs of "beaching". Concrete facing used to protect slopes often fails because the wave action washes soil particles from beneath the slabs through joints and cracks. Detection, in this case, is difficult because the voids are hidden, and failure may be sudden and extensive. Effective slope protection should prevent soil particles from being removed from the embankment.

When erosion occurs and "beaching" develops on the upstream slope of a dam, repairs should be made as soon as possible. The pool level should be lowered and the dam surface prepared for replacing the slope protection. A small berm or "bench" should be made across the dam face to help hold the protective layer in place. The bench should be placed at the base of the new protection layer. The bench depth will depend on the thickness of the protective layer.



Detail of “beaching” protection for the upstream slope of an embankment dam (From Ref. [09-06])

Details of poor riprap protection for the downstream slope of an embankment dam (pictures from Andriolo’s archives)

If a rock riprap is used, it should consist of a heterogeneous mixture of irregularly shaped stones placed over a sand or geotextile and gravel filter. The maximum rock size and weight should be large enough to break up the energy of the maximum anticipated wave action and hold the smaller stones in place. Crushed or angular large rock is much less susceptible to erosion and sliding than round rock. The smaller stones help fill the spaces between the larger ones, forming a resistant mass. The gravel bedding prevents soil particles on the embankment surface from being washed out through the spaces (or voids) in the riprap. Erosion must be repaired to avoid the potential formation of sinkholes.

Figures showing sinkhole erosion (Pictures from Andriolo's archives)

Figures showing sinkhole erosion (Pictures from Andriolo's archives)

9.4.7 Other Maintenance Items

✓ ***Concrete***

Repair of deteriorated concrete should be discussed and repaired. Any vegetation observed growing from cracks in the concrete should be removed.

Over time, concrete surfaces weather, becoming rough to the touch, or hold moisture. When this occurs, consider applying a protective coating to the concrete surface to help prevent moisture from entering the structure. This will seal the cracks and greatly reduce the chances of freeze/thaw damage, increasing the lifespan of the structure. Prior to the application of a concrete sealer, the structure should be cleaned, existing cracks be sealed with a flexible sealant, and any spalling be repaired. Any sealer chosen for the concrete floodwall should be water- or solvent-based acrylic protective, either clear or colored, and may be textured.

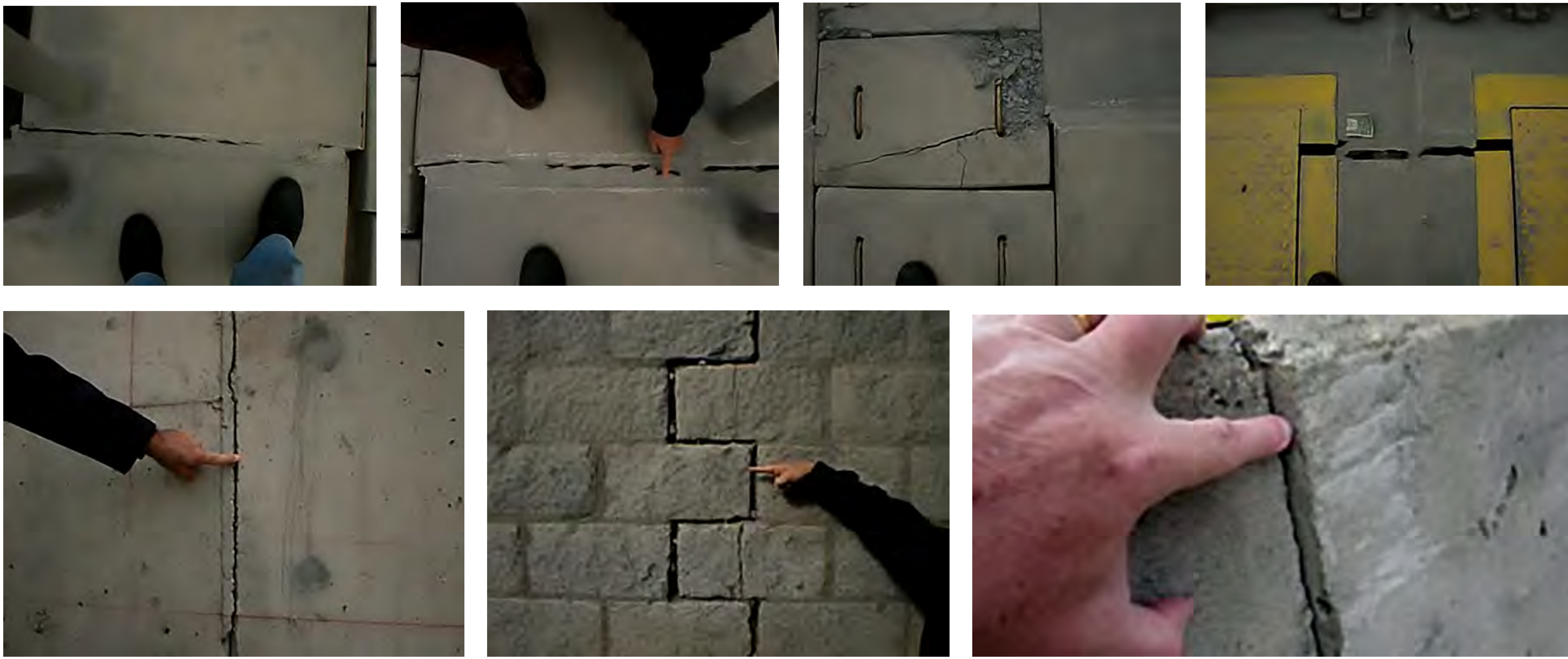
Periodic maintenance should be performed on all concrete surfaces to repair deteriorated areas. Repair deteriorated concrete as soon as observed; it is most easily repaired in its early stages of deterioration. Deterioration can accelerate and, if left unattended, result in serious problems. Consult an experienced engineer to determine both the extent of deterioration and the proper repair method. Seal joints and cracks in concrete structures to avoid damage beneath them.

Figures showing huge erosion in a concrete spillway structure (Pictures from Andriolo's archives)

More serious damage, such as spalling, should be repaired as soon as it is identified, especially if steel reinforcing has been exposed. All surfaces to be patched need to be structurally sound, clean, and free of loose debris, oils, vegetation, paints, sealants, and other contaminants. Surfaces should be sufficiently rough to ensure a good bond. Any existing reinforcing bars should be thoroughly cleaned. If required, existing concrete should be removed to fully expose the reinforcing bars. Sandblasting may be required to clean them thoroughly. All surfaces should be fully saturated and freestanding excess water should be removed before applying the repair material.

Visible cracking, scaling, or spalling are signs of concrete movement and stresses within the concrete. Cracks in concrete walls that are not repaired can be subject to freeze/thaw damage, which widens the gap and leads to additional spalling of the concrete. When examining any concrete structures, spalling, scaling, or cracking should be minimal.

Concrete plastic settlement cracks due to poor vibration during the pouring (Pictures from Andriolo's archives)



Structural cracks due to differential settlement of the foundation (Pictures from Andriolo's archives)

Concrete erosion on spillway surface due to poor concrete quality and lack of maintenance (Pictures from Andriolo's archives)

Concrete pop-out due to reinforcement corrosion resulting from poor covering (Pictures from Andriolo's archives)

Concrete cracks due to chemical reactions (Pictures from Andriolo's archives)

Some defects observed in concrete dams that require maintenance and repair result from errors or failures during construction, such as:

⇒ Deficiencies in the watertightness system – high permeability of concrete;

⇒ Inadequate compaction or vibration;

⇒ Deficiencies in the surface treatment of the concrete construction joint between layers.

Poor quality of roller-compacted concrete (RCC) concrete in a dam due to inadequate construction joint surface treatment and/or inadequate water tightness system (Pictures from Andriolo's archives)

Poor quality of RCC in a dam due to inadequate water tightness system (Pictures from Andriolo's archives)

Poor quality of RCC in a dam due to inadequate construction joint surface treatment and/or inadequate water tightness system (Pictures from Andriolo's archives)

Poor quality of RCC in a dam (Pictures from Andriolo's archives)

Some defects observed in concrete dams that require additional maintenance and repair result from errors or failures during previous repairs.

✓ ***Metal***

There may be two or more types of metal components. Galvanization and painting are common metal treatments. Metal components are galvanized to protect them against corrosion; however, if corrosion does occur, it should be completely removed using an appropriate method, and the area be re-coated with a galvanizing touch-up product.

Any corrosion that occur on painted metal components should be completely removed using an appropriate method, and the area be re-coated with paint. When areas are repainted, ensure that paint does not get on gate seats, wedges, and stems (where they pass through the stem guides), or on other friction surfaces, where it could cause binding. Use heavy grease on surfaces where binding can occur. Because rust is especially damaging to contact surfaces, remove existing rust before the periodic application of grease.

✓ ***Conduits***

Effective repair of conduit defects, such as cracks, open joints or corrosion, is difficult. It should be carefully planned and requires proper engineering supervision.

Corrosion is a common problem in spillway pipes and other conduits made of metal. Exposure to moisture, acid conditions, or salt will accelerate the corrosion process. In these areas, pipes made of non-corrosive materials, such as reinforced concrete or plastic, should be used.

Inadequate support for pipes (Pictures from Andriolo's archives)

Coated metal pipes that resist accelerated corrosion are available. Coatings can be of epoxy, aluminum, zinc (galvanized), or bituminous asphalt. Coatings applied to pipes in service are generally not very effective because of the difficulty in establishing a bond.

Adequate arrangement and protection of pipes (Pictures from Andriolo's archives)

Water leaks from some expansion joints (from Ref. [09-02])

The trace of water leak can cause damages to the protection paint (from Ref. [09-02])

Corroded part of a pipe outer surface (from Ref. [09-02])

Corrosion can also be controlled or stopped by installing cathodic protection. A metallic anode such as magnesium is buried in the soil and connected to the metal pipe by wire.

Erosion at conduit outlets is a common problem. Severe undermining of outlets can displace pipe sections and cause slides on the downstream slope of the dam as erosion progresses, and eventually lead to complete dam failure.

Eroded and undermined areas at spillway outlets can sometimes be repaired by filling them with large stone or riprap. Slush grouting riprap can be used to provide additional protection against erosion. In many cases, professional assistance should be sought for complete redesign and construction of the conduit outlet.

A satisfactory drainage system (Pictures from Andriolo's archives)

A satisfactory drainage system foundation (Pictures from Andriolo's archives)

Drains closed as a result of carbonation (Pictures from Andriolo's archives)

✓ ***Trash Racks***

A well-designed trash rack holds large debris that could plug the outlet pipe but allows unrestricted passage of water and smaller debris. Trash racks usually become plugged because the openings are too small, or the head loss at the rack causes material and sediment to settle and accumulate.

Small openings hold small debris, such as pine needles, twigs, and leaves, which in turn cause larger items to build up, eventually completely blocking the inlet. Trash racks should be routinely inspected and accumulated debris removed.

Maintenance should include periodically checking the rack for rusted and broken sections, and repairing as needed. Trash racks should be checked frequently during and after storm events to ensure proper functioning and remove accumulated debris.

✓ ***Embankment Earthwork***

Embankment dam surfaces can deteriorate for several reasons: wave action may cut into the upstream slope, vehicles may cause ruts on the crests or slopes, or runoff water may create erosion gullies on the downstream slope. Other problems, such as shrinkage cracks or rodent damage, may also occur. Damage of this nature should be repaired continually. The maintenance procedures described below are effective in repairing minor earthwork problems. Conditions such as embankment slides, structural cracking, and sinkholes threaten the immediate safety of a dam and require immediate repair under the supervision of a qualified engineer, and should not be performed without approval.

The material selected for embankment repair depends on the purpose of the earthwork. Generally, earth should be free from vegetation, organic materials, trash, and large rocks. Most of the earth should be fine-grained soils or earth clods that easily break down when worked with compaction equipment. The intent is to use a material that, when compacted, forms a firm, solid mass free from excessive voids.

If flow-resistant portions of an embankment are being repaired, materials that are high in clay or silt content should be used. If the area is highly permeable (riprap bedding, etc.), the repair material should have a higher percentage of sand and gravel. It is usually satisfactory to replace or repair damaged areas with soils similar to those originally in place.

An important soil property affecting compaction is moisture content. Soils that are too dry or too wet do not compact well. One may roughly test repair material by squeezing it tightly in the palm to form a ball. If the sample maintains its shape without cracking and falling apart (which means it is too dry), and without depositing excess water in the palm (which means it is too wet), the moisture content is probably near the proper level.

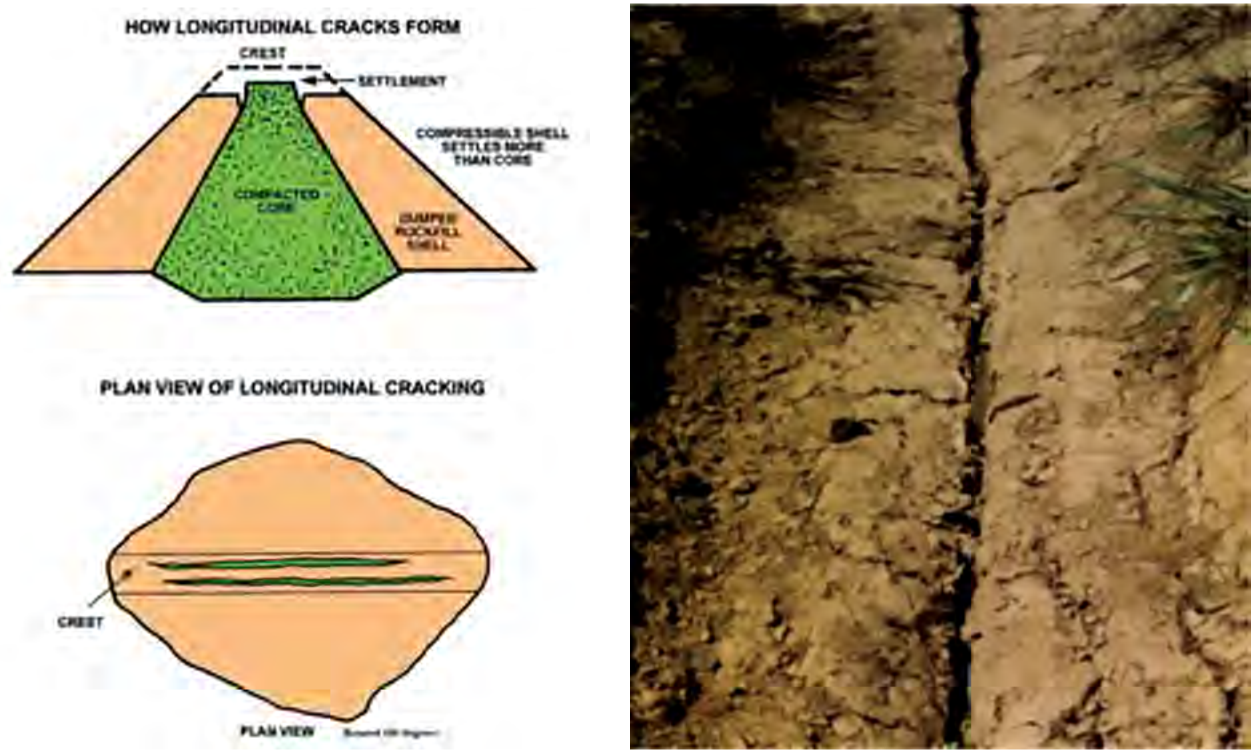
Before placing the earth, prepare the repair area by removing all inappropriate material. Clear vegetation such as underbrush, roots, and tree stumps, and remove any large rocks or trash. Also, unsuitable earth, such as organic or loose soils, should be removed, so that the work surface consists of exposed, firm, clean embankment material.

Following cleanup, shape and dress the affected area so that the new fill can be compacted and will properly tie into the existing fill. Trim slopes and roughen surfaces by scarifying or plowing to improve the bond between the new and existing fills and to provide a good base to compact against. Grade the slopes in a direction such that the soil ridges are parallel to the dam length—this will help minimize or reduce rill erosion. Roughening in the wrong direction may increase rill erosion.

Place soils in loose layers and compact them manually or mechanically to form a dense mass free from large stones or organic material. Maintain soil moisture within the proper range. The fill should be watered, mixed to the proper wetness, or scarified and allowed to dry if too wet.

During backfilling, ensure that the fill does not become too wet from rainstorm runoff. Direct runoff away from the work area and overfill repair areas so that the fill maintains a crown that will shed water. Occasionally minor cracks will form in an embankment dam because of surface drying. These are called desiccation (drying) cracks and should not be confused with structural or settlement cracks. Drying cracks are usually parallel to the main axis of the dam, typically near the upstream or downstream shoulders of the crest. These cracks often run intermittently along the dam length and may be up to four feet deep.

As a precaution, initially monitor suspected desiccation cracks with the same care used for other types of cracks. The problem area should be marked with survey stakes and monitoring pins should be installed on either side of the crack to allow recording of any changes in width or vertical offset. Once one is convinced that the cracking observed is a result of shrinkage or drying, monitoring can be discontinued.



Longitudinal cracking on an embankment crest (from Ref. [09-06])

Longitudinal cracking on an embankment crest (From Andriolo's archives)

These cracks should close as climatic or soil moisture conditions change. If they do not, it may be necessary to backfill them to prevent entrance of surface moisture, which could result in saturation of the dam. The cracks may be simply filled with earth that is tamped in place by hand or tools. It is also recommended that the crest of a dam be graded to direct runoff waters away from areas damaged by drying cracks. Repair ruts or settlement on any of the roads. In the event of any repairs, a description of the earthwork, estimated labor and cost, and sketches should be provided.

Some defects observed in embankment dams that require maintenance and repair result from errors or failures during construction, such as

⇒ Deficiencies in the water tightness system;

⇒ Inadequate system to control seepage;

⇒ Inadequate compaction.

Water seeping through an embankment dam (Pictures from Andriolo's archives)

Because of the potential for concentration of overtopping flows during major flood events, it is important that the crest be maintained leveled along the dam length. Low spots on the crest can create flow concentrations that could produce significant erosion and dam failure.

Crests should be graded to the upstream to prevent puddles from forming on the crest after rain/snow and limit the water that runs down the downstream face. If guardrails and railing become disaligned, there may be developing slumps, cracks, or slides. These problems should be identified and evaluated.

Embankment dams in initial pipping (from Refs. [09-06 to 09-08])

View of crests of different dams in satisfactory maintenance conditions (Pictures from Andriolo's archives)

Vehicles driving across an embankment dam can create ruts on the crest if it is not surfaced with roadway material. The ruts can then collect water and cause saturation and softening of the dam. Other ruts may be formed by vehicles driving up and down a dam face; these can collect runoff and cause severe erosion. Vehicles, except for those used in maintenance, should be banned from dam slopes and kept out by fences or barricades.

Maintenance vehicles should only travel on the soil and grass portions of the dam when the surface is dry, except in emergency situations. Any damage caused by traffic should be handled by park law enforcement authorities. The damage should be assessed, and the responsibility for its repair should be determined. Damage repair should be performed by the park.

✓ ***Riprap***

An erosion problem called "benching" can develop on the upstream slope of a dam. Waves caused by high winds can erode the exposed face of an embankment by repeatedly striking its surface just above the pool elevation, rushing up the slope, then tumbling back into the pool. This action erodes material from the face of the embankment and displaces it down the slope, creating a "bench". Erosion of unprotected soil can be rapid and, during a severe storm, could erode the dam.

The upstream face of a dam is commonly protected against wave erosion and resultant "benching" through armoring with a layer of riprap on bedding material. Materials such as bituminous or concrete facing, bricks, or concrete blocks have also been used to armor upstream slopes. Protective benches can also be built onto the upstream slope of small dams by placing a berm along the upstream face a short distance below the normal pool level, supplying a surface on which wave energy can dissipate.

Riprap erosion protection (upstream and downstream zones) on an embankment slope (Pictures from Andriolo's archives)

"Benching" can occur in existing riprap if the embankment surface is not properly protected by a filter. Water running down the slope under the riprap can erode the embankment. Sections of riprap that have slumped downward are often signs of this type of "benching".

Similarly, concrete facing used to protect slopes may fail because waves wash soil from beneath the slabs through joints and cracks. Detection is difficult because the voids are hidden, and failure may be sudden and extensive. Effective slope protection must prevent soil from being removed from the embankment.

When erosion occurs and “benching” develops on the upstream slope of a dam, repairs should be made as soon as possible. Lower the pool level and prepare the dam surface for repair. Have a small berm built across the dam face at the base of the new protection layer to help hold the layer in place. The size of the berm needed depends on the thickness of the protective layer. If rock riprap is used, it should consist of a heterogeneous mixture of irregularly shaped stones placed over gravel bedding.

Angular/crushed rock presents greater resistance to wave action and sliding than round rock. The bigger stones should be large and heavy enough to break up the energy of the maximum expected waves and hold the smaller stones in place. The smaller stones help fill the spaces between the larger stones and form a stable mass. The gravel bedding material prevents soil particles on the embankment surface from being washed out through the spaces between the rocks in the riprap. If the bedding material itself can be washed out through the voids in the riprap, graded layers of bedding material may be required, with the lower layer finer than the top layer.

Riprap should be monitored for deterioration resulting from weathering. Freezing and thawing, wetting and drying, abrasive wave action, and other natural processes can break down the riprap material. Maintain a uniform riprap surface. Reposition any displaced riprap. Replace any deteriorated or missing riprap. Remove all vegetation in riprap areas.

✓ ***Reservoir Sedimentation***

Erosion and sedimentation are natural processes in which soil particles are detached from the earth by rainfall or flowing water and carried away by streamflow. The velocity of the flowing stream carries the sediment load. When a flowing stream enters a reservoir, its velocity suddenly drops and the sediment load is deposited on the bottom of the reservoir.

Sedimentation rates vary widely, and depend on many factors of the watershed areas, including soil type, land cover, land slope, land use, stream slope, size of watershed, total annual precipitation, number and intensity of severe storm events, streambed material, and volume of the reservoir in relation to size of the drainage area. Sediment deposits first become apparent when deltas build up at the mouths of streams entering the reservoir. Severe sedimentation build-up in the reservoir can:

⇒ Reduce reservoir capacity and benefits;

⇒ Plug low level release inlets.

The best way to avoid problems caused by sedimentation is to reduce erosion and disturbances in the watershed area. Sediment removal from the reservoir basin is expensive because of the large equipment required and the *in-situ* wet conditions.

In reservoir, there are other deterioration scenarios associated with geological, geotechnical and hydraulic problems:

⇒ Slope stability, sedimentation and silting, falling large masses of rocks, induced seismicity and, in some cases, permeability;

⇒ Water quality.

✓ ***Debris Removal***

To obtain better hydraulic performance and minimize damage to the structure, it is important to remove floating logs and debris from the reservoir on an annual basis, or more often if possible.

✓ ***Mechanical equipment***

Mechanical equipment, in addition to those previously described, includes spillway gates, sluice gates or valves, stoplogs, sump pumps, flashboards, relief wells, emergency power sources, siphons, and other equipment associated with spillways and drain and water supply structures. Mechanical and associated electrical equipment should be checked for proper lubrication, smooth operation, vibration, unusual noises, and overheating.

Many dams have structures above and below ground that require some type of access. Water supply outlet works, reservoir drains, gate spillways, drop box spillways, and toe drain manhole interceptors are typical structures that require bridges, ladders, or walkways.



Poorly maintained mechanical and electrical equipment (Pictures from Andriolo's archives)

These means of access should be carefully designed, installed and maintained a view to user safety.

✓ ***Electrical equipment***

Electricity is typically used at a dam for lighting and to operate outlet gates, spillway gates, recording equipment, and other miscellaneous equipment. It is important that an electrical system be well maintained, including a thorough check of fuses and a test of the system to ensure that all parts are properly functioning. The system should be free from moisture and dirt, and wiring should be checked for corrosion and mineral deposits. Carry out any necessary repairs as soon as possible, and keep records of the work. Maintain generators used for auxiliary emergency power; change the oil, check the batteries and antifreeze, and make sure fuel is readily available.

Poorly maintained electrical equipment (Pictures from Andriolo's archives)

Adequacy and reliability of power supplies should also be checked during equipment operation. Auxiliary power sources and remote-control systems should be tested for adequate and reliable operation. All equipment should be examined for damaged, deteriorated, corroded, loose, worn or broken parts. There is no regularly scheduled maintenance of the electrical components at a dam. **Electrical repairs should be performed by a certified electrician.**

✓ ***Access Roads***

The safe operation of a dam depends on reliable and safe means of access. Usually, this involves maintaining a road to the dam. The road should be of an all-weather construction, suitable for the passage of automobiles and any required equipment for servicing the dam. Cut-and-fill slopes, both uphill and downhill from the road, should be stable under all conditions. The road surface should be located above the projected high-water elevations of any adjacent streams and the reservoir pool, so that access can be maintained at times of flooding.




Inadequate protection of different dam crest for use as a road (without guard rails) (Pictures from Andriolo's archives)

✓ ***Improper Use***

Improper use of regions near the reservoir is risk-intensive. Permitted or not, the construction of facilities immediately downstream of the dam or in regions that may be affected by the level of the reservoir, or that may induce the inadvertent presence of people is not be acceptable.

Improper use near the reservoir level

Improper use close to the downstream slope

Improper use of the spillway crest

Improper use of the reservoir water

Improper use of the reservoir (Pictures from Andriolo's archives)

✓ ***Vandalism***

Vandalism is a common problem faced by dam owners. Particularly susceptible to damage are the vegetated surfaces of the embankment, mechanical equipment, and riprap. Theft of manhole covers, gratings, signs, aluminum stoplogs, and other removable metal items is often a problem. Precautions should be taken to limit access to the dam to unauthorized persons and vehicles.

Dirt bikes (motorcycles) and four-wheel drive vehicles can severely damage the vegetation on embankments. Worn areas could lead to erosion and more serious problems. Constructing barriers such as fences, gates, and cables strung between poles is an effective way to limit the access of these vehicles. Boulders or a highway metal guardrail constructed immediately adjacent to the toe of the downstream slope is an excellent means for keeping vehicles off embankments. However, these features may interfere with the operation of mowing equipment.

Mechanical equipment and its associated control mechanisms should be protected. Buildings housing mechanical equipment should be sturdy, have protected windows and heavy-duty doors, and be secured with deadbolt locks or padlocks. Detachable controls such as handles and wheels should be removed when not in use and stored inside. Other controls should be secured with locks and heavy chains, where possible.

Rock used as riprap around dams is often thrown into the reservoir, spillways, stilling basins, pipe spillway risers, and elsewhere.

Riprap is often displaced by fishermen to form benches. The best way to prevent this abuse is to use rock that is too large and heavy to be moved easily, or to slush grout the riprap. Otherwise, the rock should be constantly replenished and other damages repaired.

Owners should be aware of their responsibility for public safety, including the safety of people not authorized to use the facility. "**No Trespassing"** signs should be posted and fences and warning signs should be put up around dangerous areas.

Vandalism against public good (Picture from Andriolo's archives)

9.5 Reports

Instructions for performing periodic maintenance should be given in detail, so that new personnel can understand the task and experienced personnel can verify if the work has been properly completed. All needed maintenance work should be identified and reported.

Maintenance records of structures and equipment include:

⇒ Rules for maintenance of structures and equipment;

⇒ Reports on the maintenance actions of the structures;

⇒ Brief reports on the modifications made in the scope of maintenance actions;

⇒ Reports on equipment behavior, including malfunctioning;

⇒ Reports on equipment changes and modernization;

⇒ Reports on equipment tests;

⇒ Procedures and maintenance requirements of the dam, spillways, operation circuits, power house, and other structures and conduits;

⇒ Equipment maintenance procedures, including instruments;

⇒ Reports on incidents of vandalism.

As previously suggested, operating a dam should include keeping accurate records of:

⇒ **Observations:** All observations should be recorded. Periodic observation of seepage is particularly important. Again, photographs are valuable for recording observations and documenting changes;

⇒ **Maintenance**: Written records of maintenance and major repairs are important to evaluate the safety of a dam;

⇒ **Rainfall and Water Levels**: A record of the date, time, and maximum elevation of extremely high water and associated rainfall or runoff is especially helpful in evaluating the performance of a dam and its spillway system. In particular, records should be kept for reservoirs that present widely fluctuating water levels.

⇒ **Drawdown:** A record of the amount, rate, and reason for pool level drawdown should be kept.

⇒ **Other Procedures**: A complete record of all operating procedures should be maintained.

Many project owners store and evaluate data using spreadsheet in desktop or laptop personal computers, ensuring permanent data assess.

9.6 Limits and Action Plan

When a dam develops a defect, it often takes very little time before it evolves into a full-scale failure mechanism that may result in complete breaching of the dam structure. However, if dam owners are knowledgeable about intervention strategies and take appropriate emergency action, a catastrophic breach can often be avoided. Therefore, severity of the situation and decisions about remedial action strategies should be evaluated thoroughly and immediately after learning about the potential failure. There are five essential steps involved in emergency reaction to a dam crisis:

⇒ Preparation;

⇒ Assessment;

⇒ Monitoring;

⇒ Response;

⇒ Post-Action Documentation and Follow-Up.

Hazard Classification Criteria are provided in Government legislation. Dams are classified as potentially hazardous. This classification is used to determine frequency of inspection and selection of the return period for hydrology studies. A weighted point system is used to divide the damage potential into four classifications: extreme, high, moderate, and low. Reservoir capacity, dam height, estimated evacuation, and potential damage are the factors used to classify damage potential. A similar point system is used to classify the condition of the dam as: poor, fair, good, and excellent. Age, general condition, geological and seismic setting are the factors evaluated to classify the condition of a dam. The hazard classification is reevaluated when development occurs downstream and when the dam condition changes, either by identifying deficiencies or when alteration/repair work is completed.

A Potential Failure emergency level indicates that conditions are developing at the dam that could lead to its failure. Examples are:

⇒ rising reservoir levels that are approaching the top of the non-overflow section of the dam;

⇒ transverse cracking of an embankment;

⇒ a verified bomb threat.

Potential Failure should convey that time is available for analyses, decisions, and actions before the dam could fail. A failure may occur, but predetermined response actions may moderate or alleviate it.

One of the most important actions to successfully intervene during the failure of a dam is to plan and prepare for various potential failure modes before warning signs are even observed. Time is usually essential during a dam failure emergency, and planning ahead is the best way to expedite dam repair procedures. Every dam owner should include detailed instructions on how to initiate such intervention processes.

It is also good practice to contact local contractors that may possess heavy machinery or necessary equipment beforehand and communicate which services may potentially be required from them in the event of failure. This will enable quick response and limit the number of miscommunications that might happen in the heat of the dam emergency moment. Stockpiling gravel, sand, and other remedial materials on site can be another important step to reduce the time between problem identification and beginning of solution work. This allows materials to be applied directly to the dam when needed and eliminates the possibility of not being able to obtain the needed resources in time to fix the problem.

Once a problem is identified at a dam site, it must be thoroughly assessed to determine exactly what type of crisis the dam owner is working with. The mode of failure, progression of the defect, and potential threats to public safety are all questions that must be answered quickly and accurately. An efficient chain-of-command should be established, and the appropriate parties and authorities should be notified of the situation. This includes informing those in areas of potential hazard downstream of the dam. It is also crucial to establish baseline conditions of the failure mode, as well as a way to measure their progression on a regular basis. Marking levels where sloughing occurs, installing weirs to measure seepage, and collecting readings from observation wells are examples of monitoring conditions for various failure modes.

A protocol for regularly monitoring conditions at the dam should subsequently be established and the results documented. Visual, in-person inspection is typically most effective, as it provides a mental picture for future reference, and one can have a “feel” for how serious the problem really is. Good descriptions, data recordings, and photos should be taken and kept for analysis. All people on site should be thoroughly briefed and updated on any changing conditions. Ideally, conditions will be observed to be steady or improving. If this is the case, repair-oriented actions should be taken to try to fix the problem before it develops.

Time is not as crucial of a resource in this instance. However, if conditions are noticed as becoming worse, emergency intervention options should be analyzed and implemented as soon as possible. Continuous, in-person monitoring should also be implemented in these situations. If the situation becomes too dangerous, the monitoring protocol should be altered to keep personnel in safe conditions. If efforts continue overnight, ensure there is adequate lighting at the dam structure to enable continued monitoring and keep workers safe.

Depending on the condition of the dam determined through monitoring, an appropriate response should be chosen and enacted. When considering how to respond to the emergency, public safety should be the number one concern, followed by downstream property and, lastly, the dam itself. Typically, the best action for each of these three concerns will be the same, but it is important to remember that protection of human life is always the number one concern. Sometimes damaging the dam structure will be the safest response, as in the case of a controlled breach.

Regulatory and resource agencies should be contacted and notified regarding the situation. If the condition of the dam is judged to be significantly deteriorating, emergency actions should be taken. This is when having various tools and materials set aside becomes very valuable. Actions such as using sandbags to increase freeboard and prevent overtopping, using riprap to prevent erosion to the dam structure, or applying a geotextile filter fabric to combat piping are all examples of emergency intervention techniques that can be used to try to save a dam from total failure.

In some instances, a dam incident will have progressed too far to realistically expect an emergency intervention to successfully prevent failure until it is noticed. Cases such as this warrant that actions be taken to delay a breach as long as possible, in order to provide as much time as possible for emergency procedures and evacuation to be enacted downstream. Being familiar with the various intervention techniques prior to a dam emergency facilitates an appropriate and timely response. It is also important to ensure that any intervention actions will "**do no harm**", as some actions could accelerate failure of the dam.

After the emergency situation has been resolved, documentation of this situation and actions taken should be developed as soon as possible. This should contain the conditions observed and any responses made throughout the entire emergency timeline. It should also be as descriptive as possible, and contain pictures, sketches, and any relevant measurements or data taken. The report should also recommend any further actions, if deemed necessary. These could include inspections or further repair of the dam structure.

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Recommended References

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https://www.youtube.com/watch?v=BNFQ1EJX4ho

10

MONITORING AND INSPECTION

10.1 General and a Preliminary Discussion

10.1.1 Learning about the Needs

There are no simple rules for determining the appropriate level of instrumentation and monitoring because it depends on dam design criteria and specification, degree of construction control, level of detail of what was built, the knowledge and responsibility of the owner, the knowledge and responsibility of the engineers and designers, size and hazard potential classification of the dam, the complexity of the dam and foundation, known problems and concerns, and the degree of conservatism in the design criteria. Therefore, evaluation of instrumentation and monitoring programs requires staff to apply engineering judgement and common sense.

As an example, it can be recalled that the authors lived through a time of construction of large dam projects in Brazil from the 1960s to 1970s, and at that time the lack of information on the performance of dam structures and the possibility of comparison with project data was great.

At that time, one could classify the objective of instrumenting the structures under two basic objectives:

⇒ **Control Concept**: to evaluate the characteristics in order to confirm or enable the taking of mitigating actions, and;

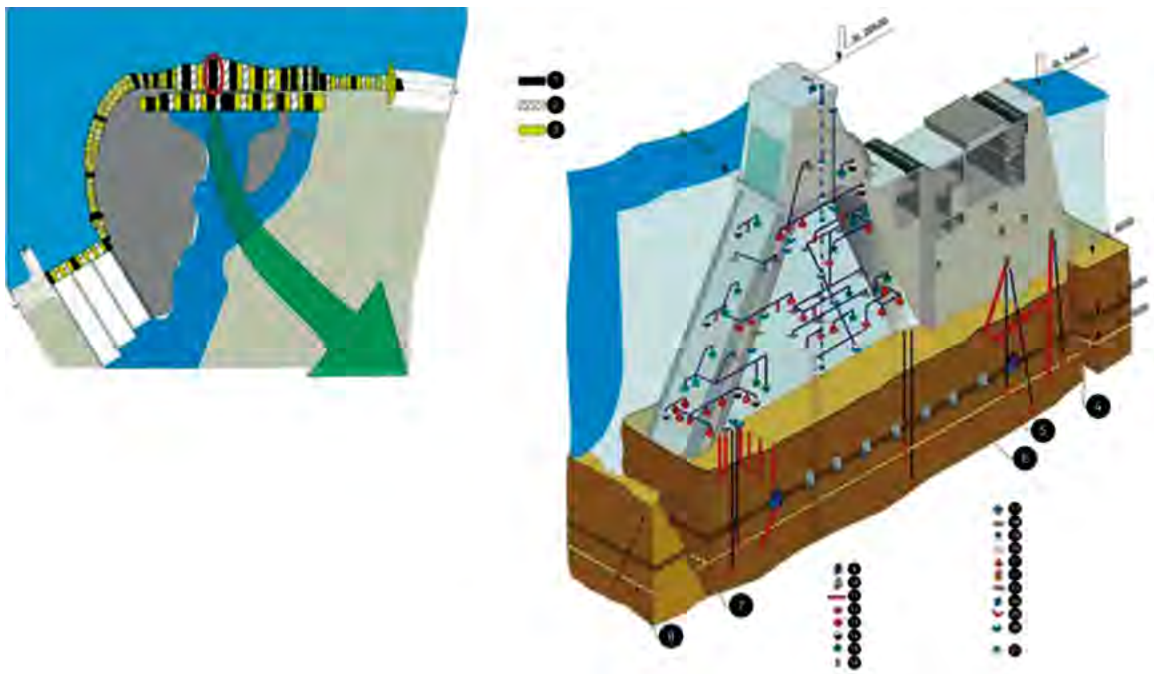
⇒ **Scientific Concept**: in order to acquire knowledge to be disseminated among Brazilian Designers and Engineers/Supervision Agents.

The **Scientific Concept** induced to have the dams with a huge set of instruments surpassing in many dams five hundred, of various types of apparatus. This enabled the learning and training of professionals for over two decades. After that, the application of instrumentation was adapted to the concepts of structural security as it is currently used. for Dam Safety!

One example of a large monitoring system for foundation, embankments, concrete structures, and behavior that was adopted for the Itaipu Project[10-01 & 10-02] (Parana River - in between Brazil/Paraguay border) and that are assisted by more than 2.200 (around 1,350 in the concrete structures, about 850 in the foundation and embankments, mostly procured, prepared, calibrated, installed, recorded and analyzed, during the construction period of 1976-1982) instruments of which more than 250 are automated.

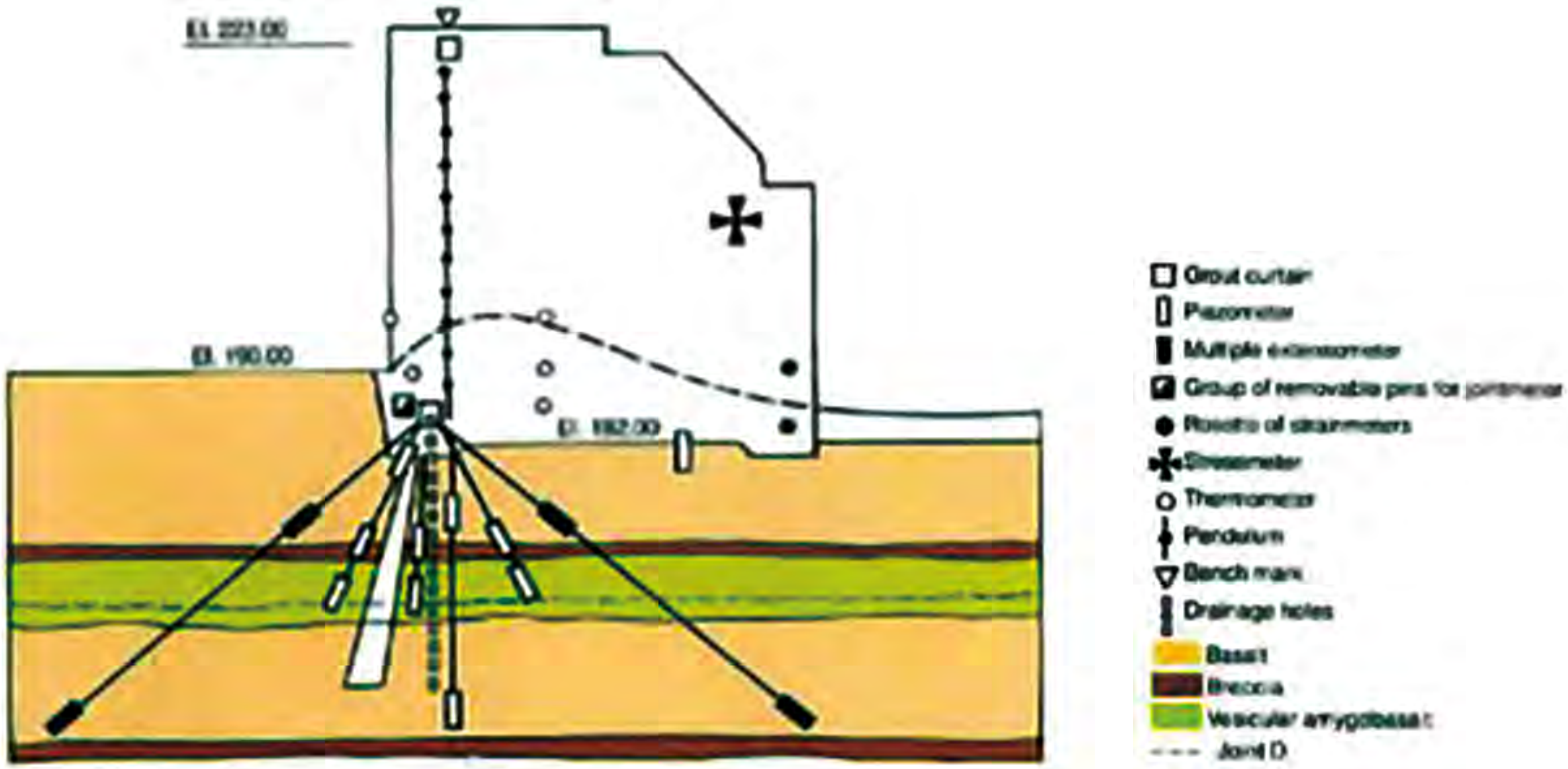
Most of this Monitoring Plan was discussed in between the Designers and the Itaipu Quality Control System and Professional Engineers, before its adoption.

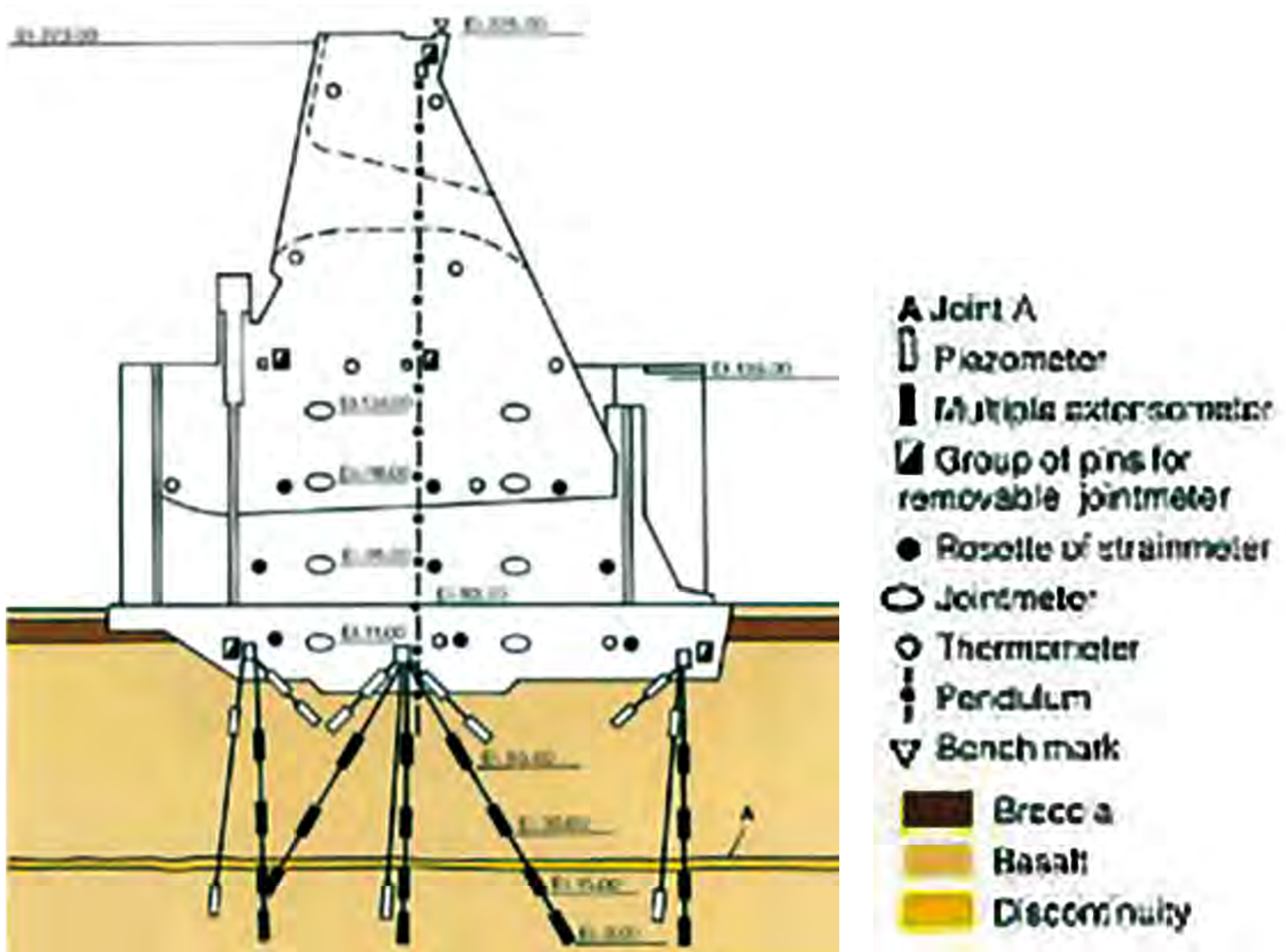
Furthermore, there are 5,239 drains (949 in concrete and 4,290 in foundations). The readings of these instruments occur at different frequencies (daily, weekly, fortnightly, and monthly) depending on the type and purpose of the instrument. Readings and data have been stored for more than 45 years.

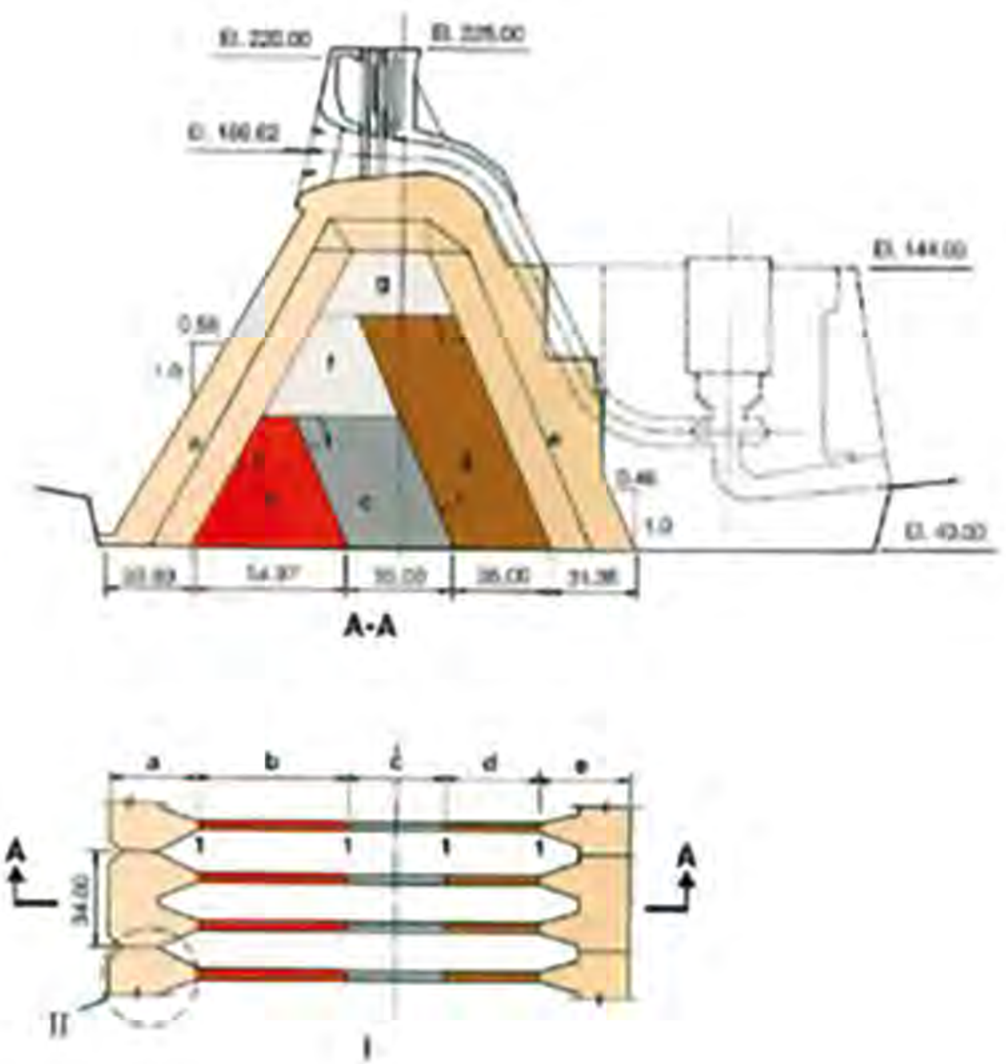


1	Key block	16	Simple stress meter
2	Little instrumented block	17	Group of strain meters
3	Block without instrumentation	18	Internal joint meter
4	Grout curtain	19	Direct pendulum
5	Lithological surface (shear zone)	20	Inverted pendulum
6	Geological characteristic (joint A)	21	Extensometer
7	Grout curtain	22	Piezometer
8	Mass of foundation (basalt)	23	topographic indicator
9	Drainage tunnel	24	Geodesic perspective
10	Concrete of keyways	25	Discharge weir
11	Grout curtain	26	Mark for removable joint meter on the floor
12	Terminal switchbox	27	Markers for removable joint meter on the wall
13	Concrete mass thermometer		
14	Surface thermometer		
15	Group of stress meters		

Layout of instruments and their installation locations in the structures - Diagram obtained at www.itaipu.gov.br


Grout curtain
Piezometer
Multiple extensometer
Group of removable pins for
Rosette of strainmeters
Stressmeter
Thermometer
Pendulum
Bench mark
Drainage holes
Basalt
Breccia
Joint D


Joint A
Piezometer
Multiple extensometer
Group of pins for removable jointmeter
Rosette of strainmeter
Jointmeter
Thermometer
Pendulum
Bench mark
Breccia
Basalt
Discontinuity


A-A
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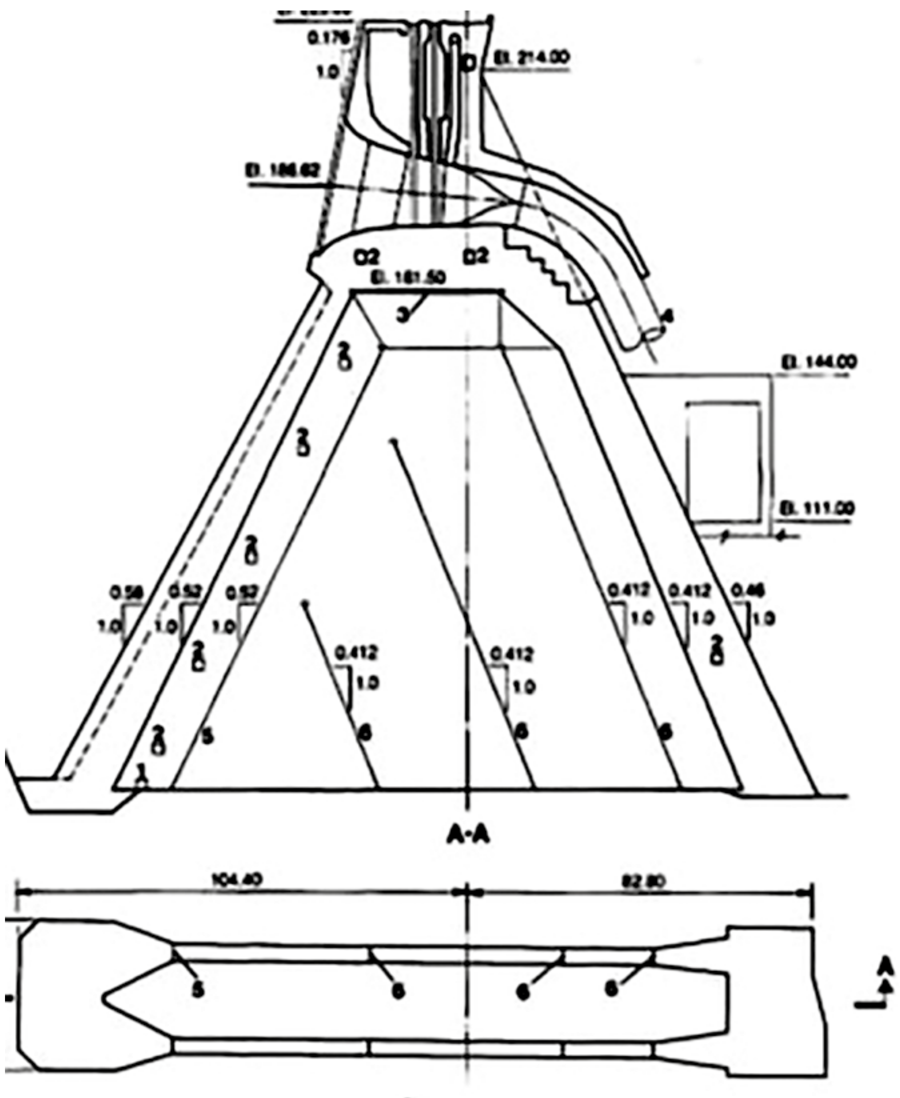
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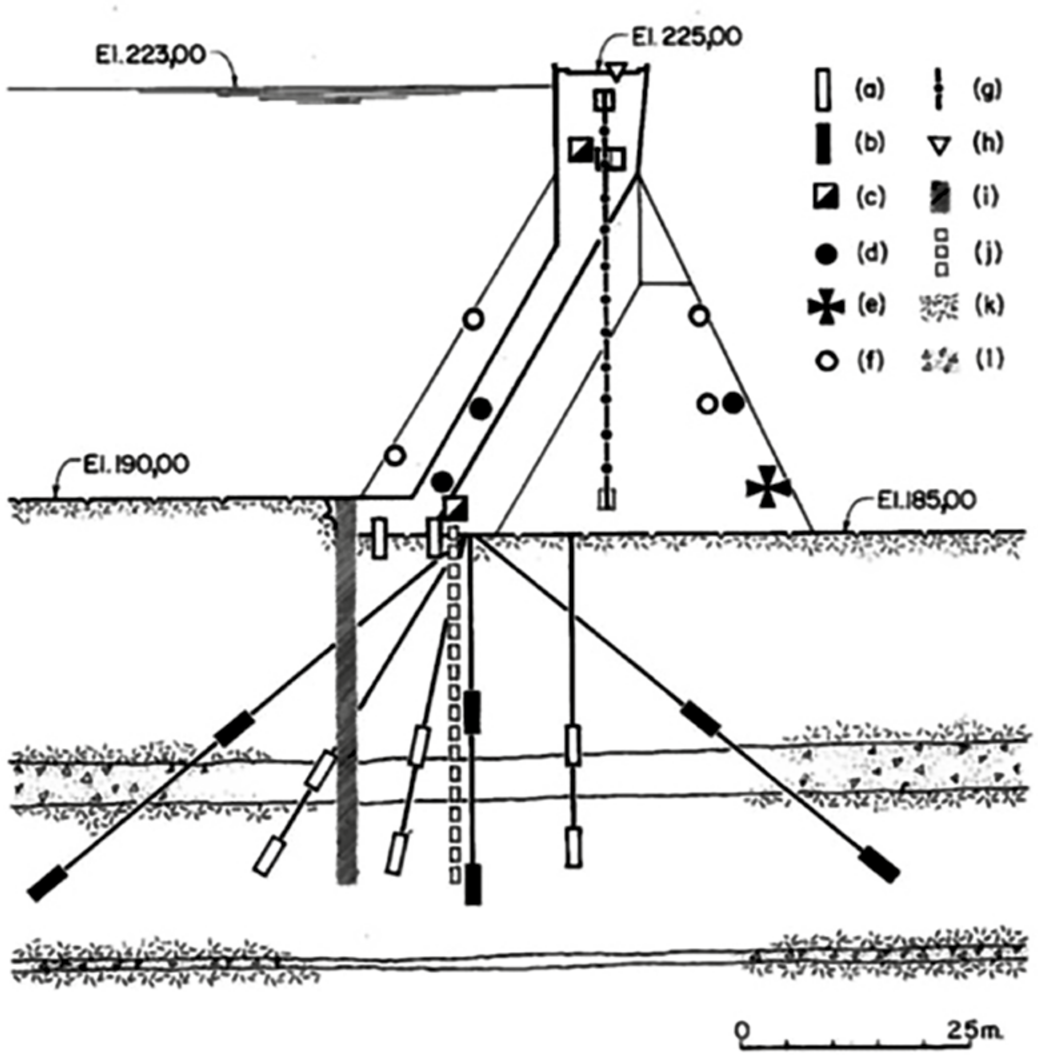
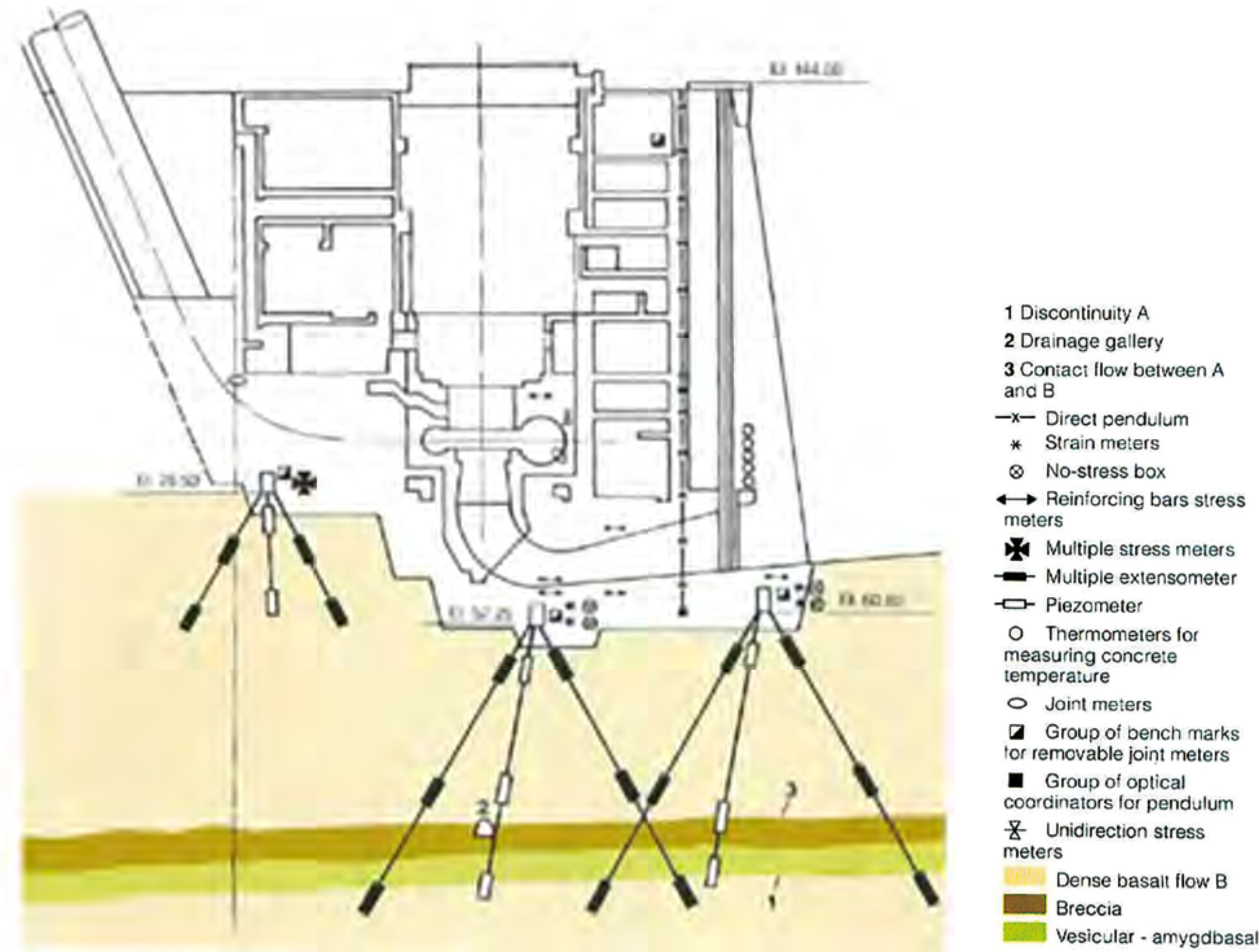
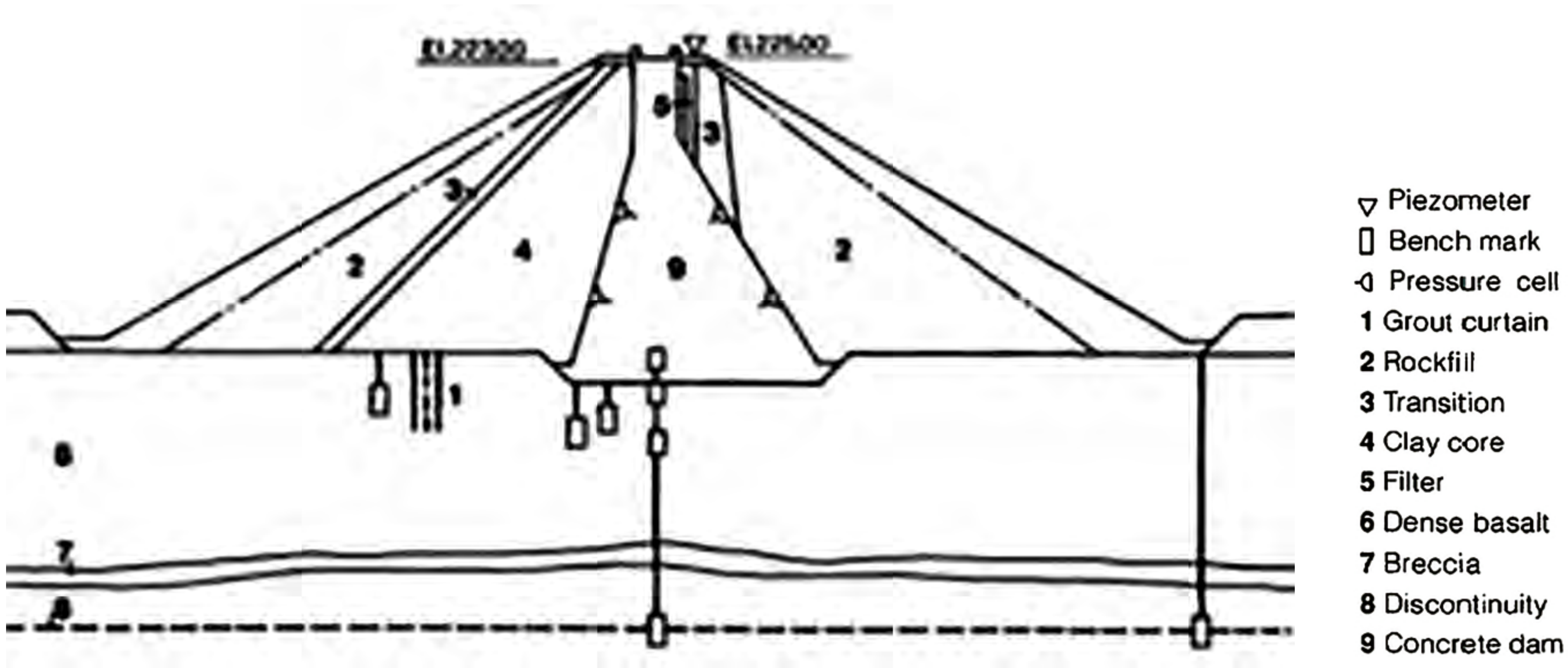


(a) – Piezometer
(b) – Multiple extensometer
(c) – Group of pins for removable jointmeter
(d) – Rosette of strainmeters
(e) – Stressmeter
(f) – Thermometer
(g) – Pendulum
(h) – Bench mark
(i) – Grout curtain
(j) – Drainage holes
(k) – Basalt
(l) – Breccia


1 Discontinuity A
2 Drainage gallery
3 Contact flow between A and B
Direct pendulum
Strain meters
No-stress box
Reinforcing bars stress meters
Multiple stress meters
Multiple extensometer
Piezometer
Thermometers for measuring concrete temperature
Joint meters
Group of bench marks for removable joint meters
Group of optical coordinators for pendulum
Unidirection stress meters
Dense basalt flow B
Breccia
Vesicular - amygdbasalt



Considering the development of information technology and robotics nowadays there are several equipment that enable the monitoring of structures and dams, as can be illustrated and taken into account for inspection and monitoring activities.

By employing commercially available digital cameras combined with efficient signal processing methods, it is possible to measure and compute the fundamental frequency of vibration of structural systems. The basic concept is that small changes in the intensity value of a monitored pixel with fixed coordinates caused by the vibration of structures can be captured by employing specifics techniques.

To discuss about the inspection, instrumentation, monitoring philosophy, and concept it is important to try to answer the following questions:

- ***How to monitor and measure?***
- ***What, Why, When, and Where to measure?***
- ***Why is it important to monitor a concrete structure?***

⇒ To get and understand the data in a real and accurate way;

⇒ To improve knowledge and understanding of a structure;

⇒ To allow mitigating actions to be taken in a safe way;

⇒ To ensure the structure safety;

⇒ To safely extend the lifetime of a deficient element or part;

⇒ To optimize operations and maintenance costs.

- ***What is involved in an Inspection?***

The inspection itself should include all of the components of the dam. This includes a close examination of all accessible moving parts. The inlet and outlet structures should be inspected with close attention to the internal condition of any conduit, pipes, or access wells. Anything unusual or anything that has changed since the last inspection should be noted (i.e., new or increased erosion, settlement, cracks, seepage, or wet areas).

- ***How important is the inspection, monitoring, and maintenance?***
- ***If designed and constructed properly, should not all dams be maintenance free?***

✓ ***The answer to these questions may seem obvious, but several dams can be considered as a risk.***

Dams should not be thought of as part of the natural landscape, but as man-made structures, which must be designed, inspected, operated, maintained, and, if necessary, repaired and/or rehabilitate accordingly. Maintenance is an ongoing process that not only involves such routine items, but also includes regularly inspecting the structure and properly operating its components. Major rehabilitation of a dam is normally not necessary if the dam was designed in accordance with good engineering practice, if it was built using good construction standards, and if it is operated and maintained properly.

10.1.2 Hazard as Source of Risk

The dam structure itself can be a source of risk due to possible construction flaws and weaknesses which develop because of aging. The site immediately surrounding the structure may also increase structural risk if the dam is not positioned or anchored properly or if excessive reservoir seepage erodes the foundation or abutments and is not considered to control measures in the design.

The physical hazards which can cause dam failure are translated into high risks when people or property are threatened, and when the high risks to which Americans are exposed are exacerbated by a number of important factors. For instance, in most states, people are allowed to settle below dams in potential inundation zones, thereby compounding risk.

Natural hazards such as floods, earthquakes and landslides are also important contributors to risk. These natural phenomena are considered “hazards” because development has placed people and property in their way, since most natural phenomena existed long before mankind established patterns of settlement. Failure to adjust to these events has been costly both to dam owners and the public in general.

Human behavior is another element of dam failure risk; simple mistakes, operational mismanagement, unnecessary oversights or destructive intent can interact with other hazards to compound the possibility of failure. Thus, there is a wide range of natural and human hazards which, taken separately or in combination, if not considered in the design and operating manual, increase the likelihood of dam failure and injury to people and property.

✓ ***Why should a dam owner have a Dam Safety Program?***

Dams, by their very nature, can induce risks. Although these risks may be minimal, they can increase substantially without proper inspection and maintenance. In most situations a *Dam Safety Program* that includes regular preventative maintenance, routine surveillance inspections, and the identification of problems in their early stages will ensure that the dam remains in good operating condition.

The number of dams which need rehabilitation is growing not only in countries that have a long tradition in dam building and operation, but also in those regions where the infrastructure is still in full development.

The availability of complete records on the dam's structural behavior and on meteorological, geological and hydrological data, as well as the knowledge of the material properties of the existing structure are important for the successful design of a rehabilitation project. While the criteria to be used in structural design should correspond to current standards, the definition of hydrological design criteria depends on considerations that vary widely from region to region or even from one country to another.

Regular inspection reveals defects and evolving shortcomings caused by ageing or material deterioration, in time to plan and carry out remedial action without hurl and excessive cost and before such defects can develop into serious danger.

A special inspection of affected components of a dam should be made immediately after extraordinarily large floods or any unusual event such as an earthquake, sabotage or terrorist action, or others.

Summing up the lessons learned from successful rehabilitation projects, the following steps can be adopted:

⇒ Regular safety inspection is mandatory to detect shortcomings and problems, to avoid the development of danger and to make timely remediation possible;

- ⇒ Every rehabilitation project must be preceded by a review of all available design, construction and operation records, and a comprehensive overall site investigation;
- ⇒ Criteria for the design of structural rehabilitation should be in conformity with current standards and safety requirements;
- ⇒ Restoration of hydrological safety should be governed by the most demanding standards or regulations to be applied as required by law or the current state of the art;
- ⇒ An increase of spillway capacity requires a previous check of the downstream reach of the river to avoid possible harmful consequences of higher flood flows;
- ⇒ Rehabilitation projects can bear surprises. Removal of debris, partial demolition, and preparation of structural reinforcing must be done with care to avoid the loss of evidence, which could provide guidance to design and construction;
- ⇒ River diversion for rehabilitation can be much more complicated than for original construction and requires very careful studies and minute preparation;
- ⇒ Rehabilitation projects are often subject to serious time-related restrictions. In order not to affect the structural, operational, and environmental safety project, financing and timely availability of funds must be warranted throughout the job.

Dam structure itself can be a source of risk due to possible construction flaws and weaknesses which develop because of aging.

10.2 Inspection and/or Monitoring Types

10.2.1 Visual Observation

The "eyes" are the oldest, and up to now, usual instruments of a monitoring system, and that practically precedes the monitoring action when exercised by all other instruments[10-03].

"….Roman aqueducts required a comprehensive system of regular maintenance, to repair accidental breaches, to clear the conduits of gravel and other loose debris, and to remove channel-narrowing accretions of (calcium carbonate) in systems fed by (hard water) sources….

…Inspection and access points were provided at regular intervals on the standard, buried conduits. Syphons that used hard-water supplies would have presented particular maintenance problems, due to the narrow diameter of their pipes; but lead, ceramic and stone pipes were made in fairly short lengths whose damaged or blocked sections could be replaced or cleared…"

Visual observation of all structures should be made in conjunction with instrumentation monitoring to adequately assess the safety of a dam. Visual observation can readily detect indications of poor performance such as offsets, misalignment, bulges, depressions, seepage, leakage, and cracking. More importantly, visual observation can detect variations or spatial patterns of these features. Most visual observation provides qualitative, but important, rather than quantitative information, while instruments provide detailed quantitative information. Visual observation and instrumentation data are natural complements and when used together they provide the primary means for engineers to evaluate the safety of a dam.

Visual observations by the dam owner or the owner's representative may be the most important and effective means of monitoring the performance of a dam. The visual inspections should be made whenever the inspector visits the dam site and should consist in at least walking along the dam alignment and looking for any signs of distress or unusual conditions at the dam.

Clearly, a visual observation of the structures can be made dated and in conjunction with instrument monitoring. It typically consists of walking tours of the dam crest, toes, and abutments in order to identify any unusual or abnormal conditions that could jeopardize the safety of the dam. Photographs or videos are often useful to document existing conditions and to help evaluate whether or not there has been any change from the previous conditions.

10.2.2 Monitoring- Non Destructive Methods (NDM-NDE)

Conventional dams inspection is in general rather time consuming and is often expensive due to the need of special apparatus or other large lifting platforms. The surfaces should be examined in a regular basis to identify spalling and deterioration due to weathering, extreme stresses, other physical, or chemical damage mechanism. Visual inspections have so far been supported basically by human expertise and require specialized teams. Due to operational difficulties, the collected information is often inaccurate, from a positional point of view.

The use of such methodology requires a previous systematization and standardization of the main dam deteriorations identifiable by visual inspections.

Electronics and internet technologies are increasingly facilitating real-time monitoring. The advances in wireless communications are allowing practical deployment for large extended systems.

The framework for dam monitoring network, the integration of real-time online heterogeneous sensor data, database and archiving systems, computer vision information, and data analysis and interpretation improve usability of information technology applications and services.

The availability of combined terrestrial imaging systems has encouraged the development of a new methodology aimed at recording and coding into an electronic environment the main deficiencies typically surveyed during visual inspections.

There are a number of ***N***on ***D***estructive ***E***valuation (***NDE***) methods applicable to investigations. Some types of damage, such as voids under a spillway slab or cracking in the dam interior or on the upstream submerged face, are very difficult or even impossible to find with only visual means. The various nondestructive methods available use sound waves, radio waves, and other types of low level energy to penetrate through the concrete beyond what the eye can see.

10.2.3 Visual Inspection by Drones

Recent advancement in drone technology have opened a new chapter in the visual inspection of dams. Drones are used for visual inspection of surface and identification of surface cracks and defects. Drones equipped with **Infrared Thermography** sensor can also be used for detecting traces of moisture or sub-surface deficiencies for an enhance inspection.

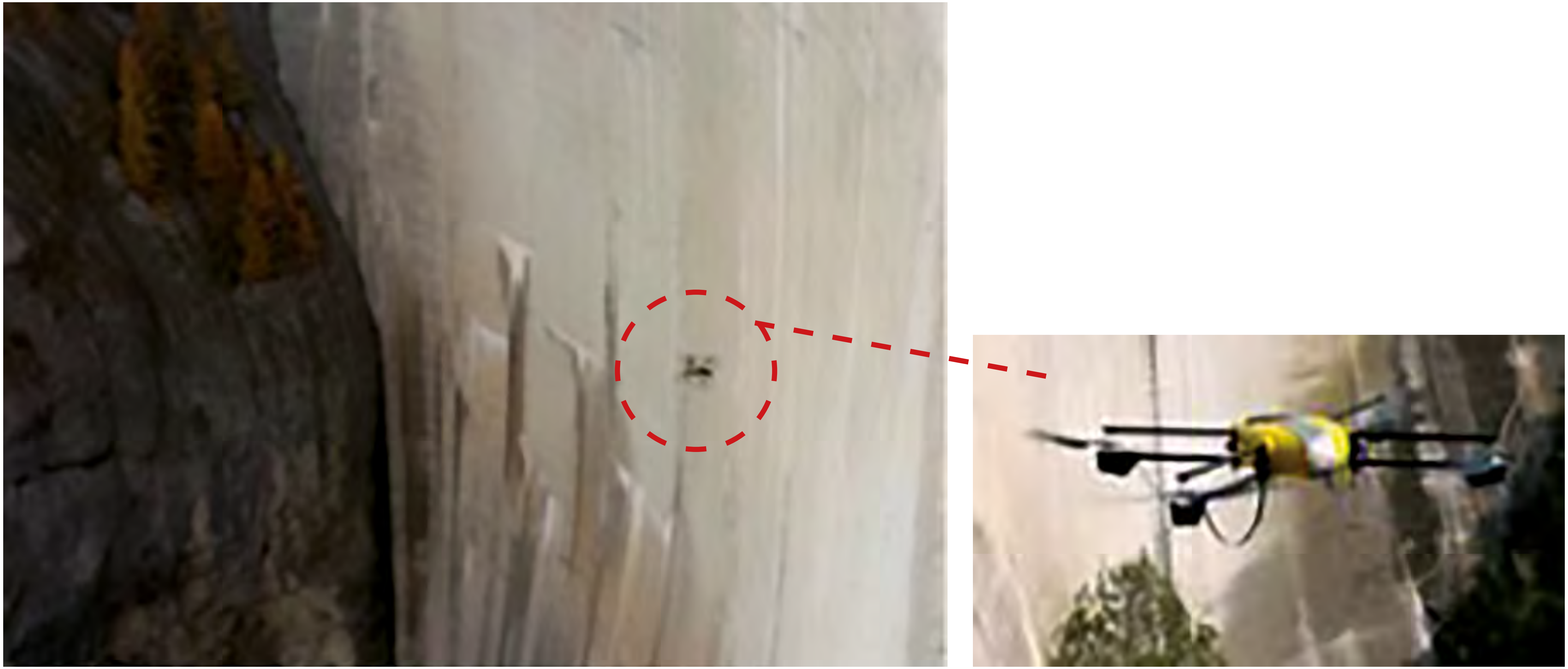
The utilization of an **U**nmanned **A**erial **V**ehicle (**UAV**) as an assisting tool in inspections is obvious. Furthermore, light-weight special sensors such as infrared and thermal cameras as well as laser scanner are available and predestined for usage on unmanned aircraft systems.

The main disadvantage of visual inspection (with or without drones) is that the method does not provide information about the properties or condition of concrete (physical of chemical damages).

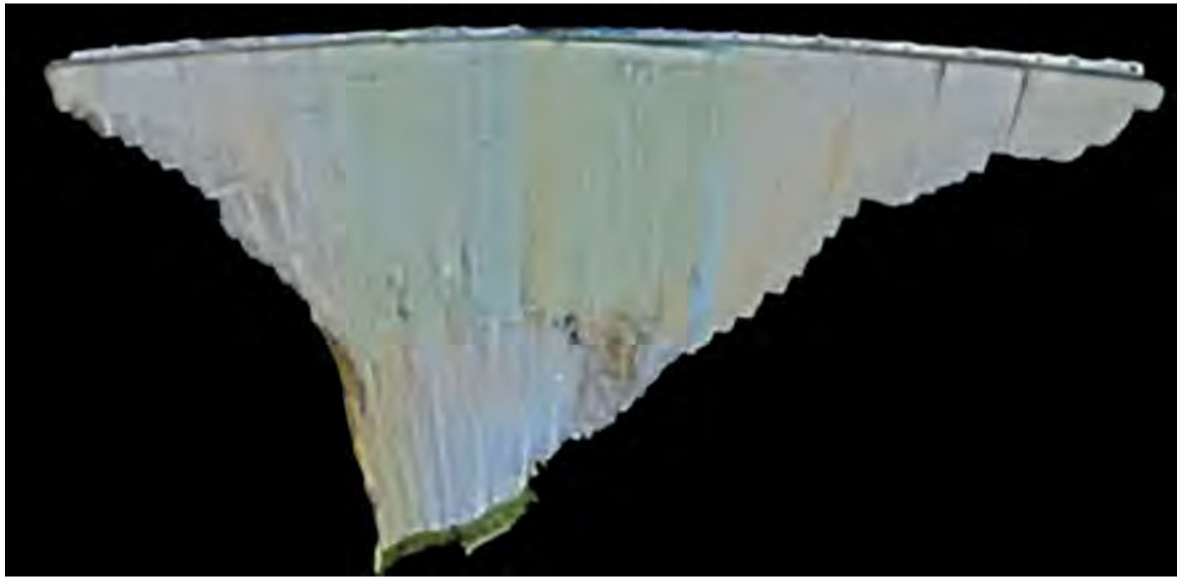
The Ridracoli Dam, is located in the village of Santa Sofia in the province of Forlı-Cesena, Emilia Romagna, Italy. The primary use of the reservoir is to supply drinking water through the regulation of the flow of the Bidente river during the year[from 10-04 to 10-06]

As another example the UAV with drones was used for Inspection of Tseuzier Dam.

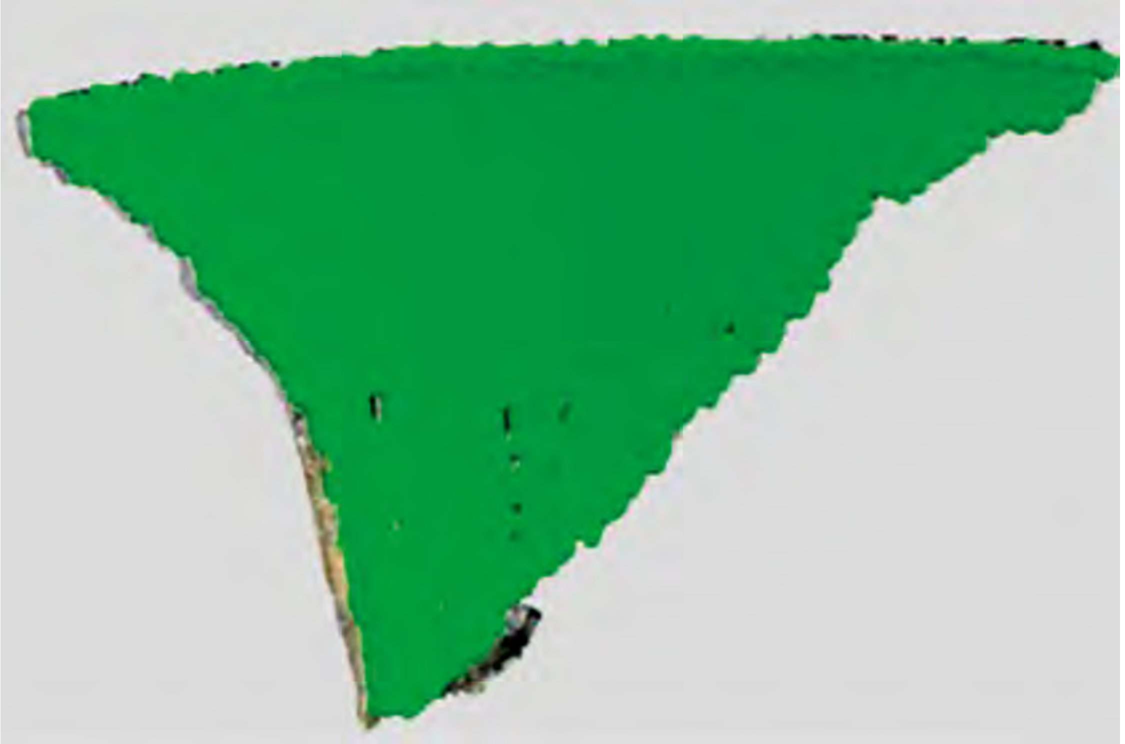
Tseuzier Dam, in Switzerland inspected by drones[10-07 & 10-08]

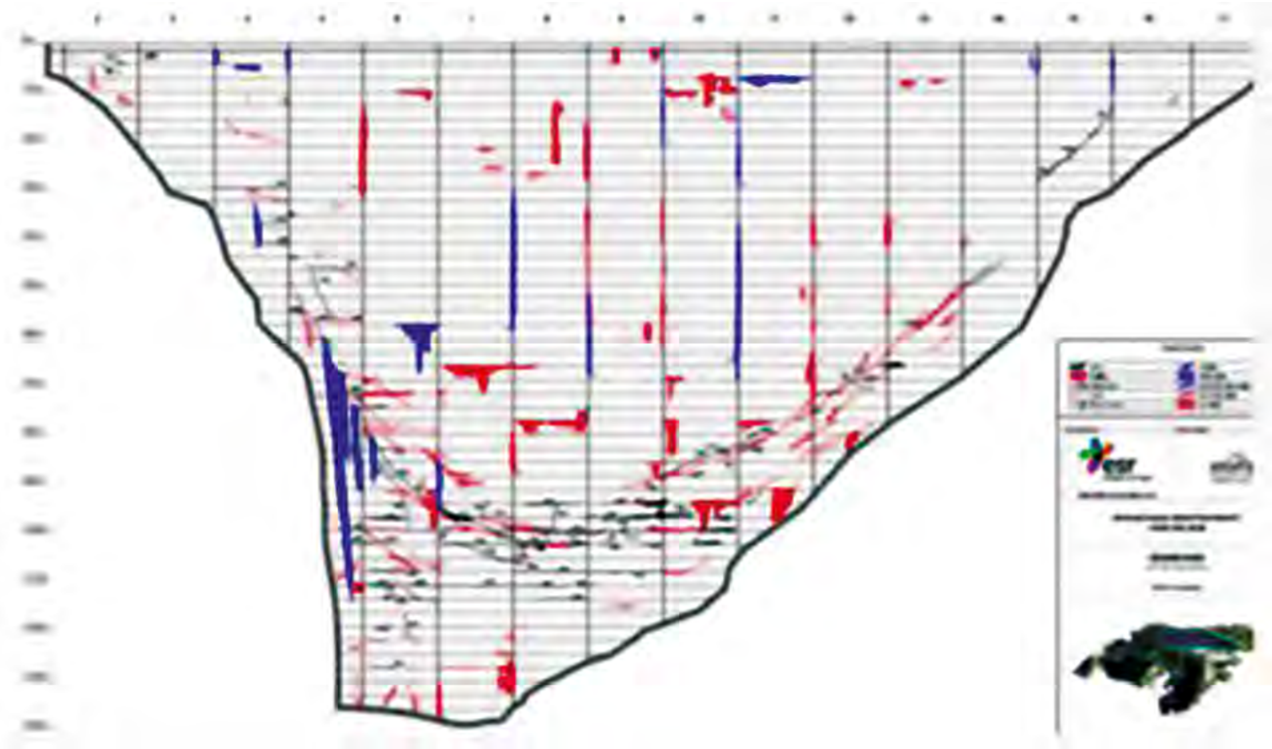


Tseuzier Dam, in Switzerland inspected by drones[10-07 & 10-08]



Tseuzier Dam, in Switzerland inspected by drones[10-07 & 10-08]





Tseuzier Dam, in Switzerland inspected by drones[10-07 & 10-08]

Released as part of a case study[10-07 & 10-08] of a project that the company undertook with Electricité de la Lienne and Energies Sion Région, the video documents the inspection and post inspection process of the downstream face of Tseuzier Dam, a more than 150 m high, arched structure on the Lienne River in Switzerland. The goal of the project was to produce a high-resolution photographic record that could be used as part of an inspection report submitted to the country's energy regulator every five years. It took about 50 flights to fully cover the approximately 18,000 m² of surface area.

10.2.4 Impact-Echo (IE)

Impact-***E***cho can be used to investigate the condition of concrete and extent of cracking in concrete. The pulse spreads into the test object and is reflected by cracks, flaws or interfaces, and boundaries. When stress waves travel within the concrete element, a part of emitted acoustic waves by the stress pulse on the surface is reflected over the boundary layers, where different the material stiffness changes.

The data received by the transducer is normally analyzed in the frequency domain to measure the wave speed and the thickness. Impact-Echo has the advantage of requiring access to only one side of the component. The method can be used to identify frost and thaw defects in concrete surfaces.

Impact Echo used for concrete inspection[10-03]

10.2.5 Spectral Analysis of Surface Waves (SASW)

The ***S***pectral ***A***nalysis of ***S***urface ***W***aves (***SASW***) method has many applications in material characterization of multilayer systems. This can be used for in-situ evaluation of massive and geological quality, thickness of layer and boundary condition in multilayer systems as well as estimating the modulus elasticity.

The ***SASW*** method is capable of providing the shear wave velocity versus depth profile of a structure, including measurements of the velocity of soils or rock behind the structure, with no coring or other damage to the structure required.

The methods can be used to evaluate damages due to alkali silica reaction (**ASR**), frosting and thawing and other expansive-breakable reaction (as from pyrite) which can be verified in structures.

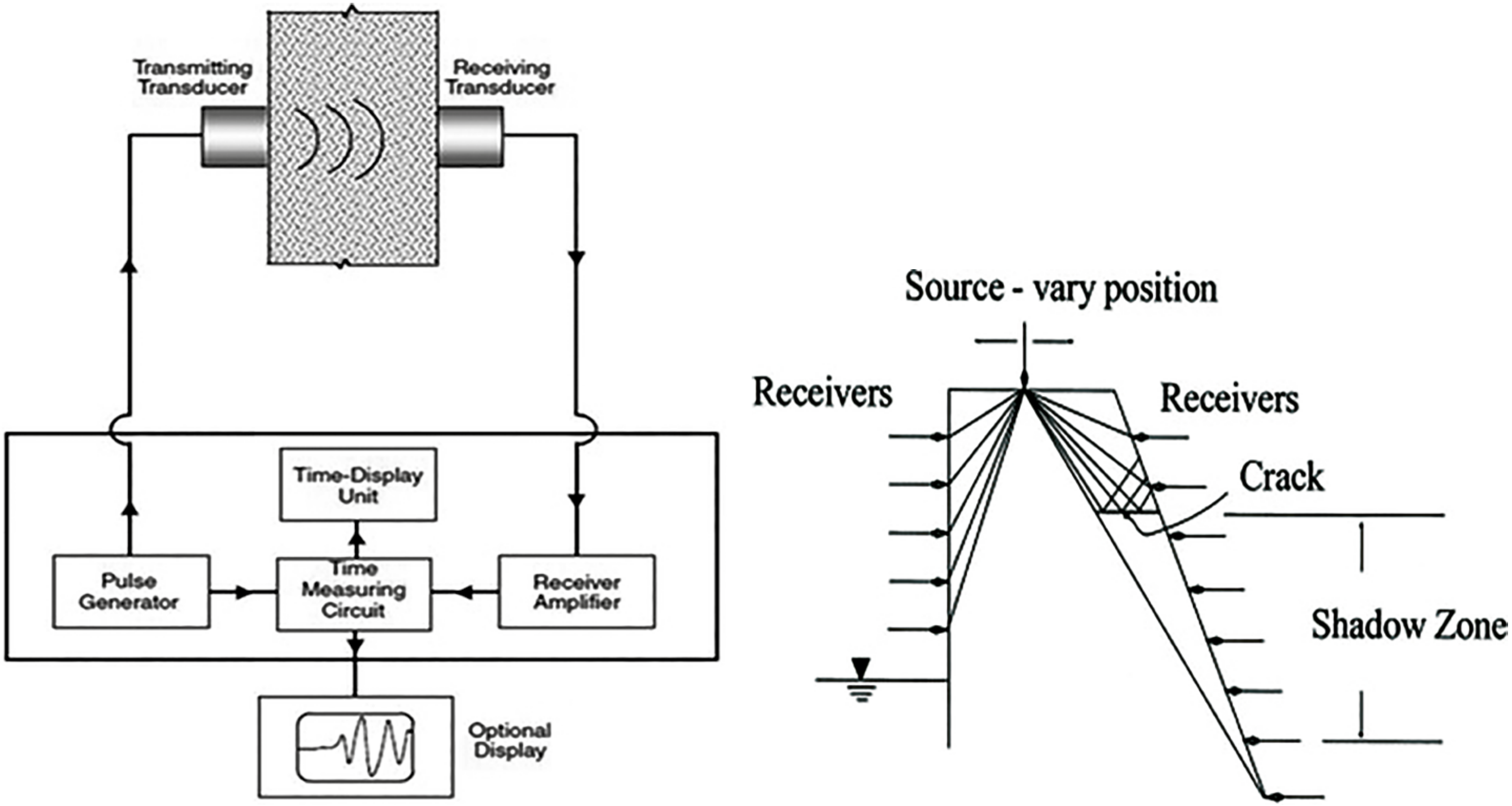
10.2.6 UPV Tomography/Seismic Tomography

When there is no access problems (2 or more directions available), ***U***ltrasonic ***P***ulse ***V***elocity (***UPV***) methods can be used for evaluation of concrete properties. Ultrasonic Pulse Velocity is an effective non-destructive testing (**NDT**) method for quality control of concrete materials, and detecting damages in structural components.

The most practical form of the ***UPV*** measurement in concrete structures is the seismic tomography. When access is possible, ***UPV*** tomography can be used to evaluate sub-surface deficiencies such as voids and cracks.

Ultrasonic is applicable for concrete inspection allowing imaging of the internal structure of objects from concrete, reinforced concrete and stone work. The operation applies pulse-echo technique at one-side access to the object.

***U**ltrasonic **P**ulse **V**elocity* (*UPV*) method being used for evaluation of concrete properties[10-03]



***Ultrasonic Pulse Velocity (UPV)* method being used for evaluation of concrete properties**[10-03]

10.2.7 Terrestrial Laser Scanners (TLS)

TLS can get the coordinates of millions of points in reflecting surfaces and provide new means for rapid and precise electronic geometric representation of objects.

It is possible to integrate laser scanner measurements with digital photo-imagery in a combined terrestrial imaging system (**CTIS**).

⇒ It is similar to Sonar and Radar but uses Light (Light Detection and Ranging);

⇒ Transmits a pulse of light and records the returned pulse of light – records time, divides by two, and multiplies by the speed of light for distance;

⇒ Able to record thousands of points a second recording target position (X,Y,Z), intensity, and color (**RBG**);

Capable of relative positioning with mm to cm accuracy.

TLS can get the coordinates of millions of points in reflecting surfaces[10-03]

10.2.8 Remotely Operated Vehicles (ROVs)

The **ROVs** are dedicated to a number of inspection projects with severely restricted access (as underwater inspection) requiring a more compact and portable system. The entire system is packaged in shock mount and padded cases, which are easily transported.

An underwater inspection requires a compact and portable system[10-03 & 10-09]

Amagase Dam- being inspected using ROV[10-09]

10.2-9 RGB Cameras

RGB cameras (that delivers the three basic color components: **r**ed, **g**reen, and **b**lue)[10-03] are mounted on **UAV**s, resulting on the image quality. An application for the combination of an **UAV** and a thermal camera can be used for the hard-to-access areas.

✓ ***But it is important to remember that:***

10.2.10 Instrumentation and Monitoring by Sensors Installed in the Dam

Instrumentation and monitoring must be carefully planned and executed to meet defined objectives. Every instrument in a dam should have a specific purpose. If it does not have a specific purpose, it should not be installed or it should be abandoned. Instrumentation for long-term monitoring should be rugged and easy to maintain and should be capable of being verified or calibrated.

Conversely, lack of normally expected natural phenomena may also indicate potential problems. For example, lack of seepage in a drainage system could indicate that seepage is occurring at a location where it was not expected or contemplated by the designer.

Instrumentation and monitoring, combined with vigilant visual observation, can provide early warning of many conditions that could contribute to dam failures and incidents. For example:

⇒ settlement of an embankment crest may increase the likelihood of overtopping;

⇒ increased seepage or turbidity could indicate piping (this requires a rapid action to create a defense);

⇒ settlement of an embankment crest, longitudinal cracks or bulging of embankment slopes could indicate sliding or deformation;

⇒ inelastic movement of concrete structures could indicate sliding or alkali-aggregate reaction or pyrite reaction.

Instrumentation typically provides data to:

⇒ characterize site conditions before and under construction (first loads);

⇒ verify design and analysis assumptions;

⇒ evaluate behavior during construction, first filling, and operation of the structure;

⇒ evaluate performance of specific design features;

⇒ observe performance of known geological and structural anomalies; and

⇒ evaluate performance with respect to potential site-specific failure modes.

✓ ***Installation of instruments or accumulation of instrument data by itself does not improve dam safety or protect the public;***

✓ ***Instruments must be carefully planned, selected, located, and installed.***

As stated above and in the need to establish instrumentation in a planned way, it is an activity that must be developed by trained and experienced professionals. A poorly planned program will produce unnecessary data where the dam owner will waste time and money collecting and interpreting, often resulting in disillusionment and abandonment of the program.

Data must be conscientiously collected, meticulously reduced, tabulated and plotted, and must be judiciously evaluated with respect to the safety of the dam in a timely manner.

Though only a small percentage of dams develop problems, it is impossible to predict those that will develop problems because of the highly indeterminate nature of the structures and the infinite number of possible variations in conditions that could affect the safety of a dam or appurtenant structures. Therefore, it is prudent that any dam that may affect the public safety has basic instrumentation to monitor vital signs. The minimum recommended instrumentation is limited to that which clearly provides useful information for evaluating dam safety and is also readily installed and monitored. Minimum instrumentation should be located where it will provide data that are representative of the entire structure.

10.3 Types of Instrumentation and Concepts

Common types of instruments can be noted considering an updated development for all types of instrumentation that are available in the literature and technical catalogs from many suppliers. For each type of measurement, basic engineering concepts and specific types of instruments must be discussed. It is interesting to have an overview of the aspects to be instrumented and monitored. Based on the objectives of monitoring with instruments, one can mention (from [10-10 to 10-13]):

Item	Monitoring	Conceptual Aspects – Advantages/Limitations
10.3.1	**Water Level and Pressure Water Level**  	Water level is commonly measured with staff gages, float-type water level gages, and ultrasonic sensors. Water pressure is commonly measured with bubblers, observation wells, and several types of piezometers, that are discussed below. For most dams, it is important to monitor the water level in the reservoir and the downstream pool regularly to determine the quantity of water in the reservoir and its level relative to the regular outlet works and the emergency spillway. The water level is also used to compute water pressure and pore pressure; the volume of seepage is usually directly related to the reservoir level. It is also important to establish the normal or typical flow through the outlet works for legal purposes. Seepage must be monitored on a regular basis to determine if it is increasing, decreasing, or remaining constant as the reservoir level fluctuates. A flow rate that changes relative to a reservoir water level can be an indication of a clogged drain, piping, or internal cracking of the embankment. Seepage may be measured using the following devices and methods: o Weirs (any shape such as V-notch, rectangular, trapezoidal, etc.) o Flumes (such as a Parshall flume) o Pipe methods o Timed-bucket methods o Flow meters Seepage comes into contact with various minerals in the soil and rock, in and around the dam. This can cause two problems: the chemical dissolution of a natural rock such as limestone, or the internal erosion of soil.

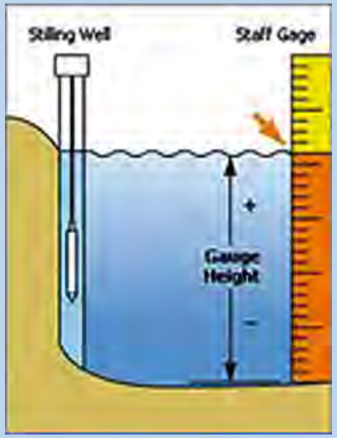
Item	Monitoring	Conceptual Aspects – Advantages/Limitations
10.3.1	**Water Level and Pressure Water Level** 	Dissolution of minerals can often be detected by comparing chemical analyses of reservoir water and seepage water. Such tests are site specific; for example, in a limestone area, one would look for calcium and carbonates, in a gypsum area, calcium and sulfates. Other tests, such as ph, can also sometimes provide useful information on chemical dissolution. Internal erosion can be detected by comparing turbidity of reservoir water with that of seepage water. A large increase in turbidity indicates erosion. Water levels may be measured by simple elevation gauges - either staff gauges or numbers painted on permanent, fixed structures in the reservoir - or by complex water level sensing devices . Flow quantities are often computed from a knowledge of the dimensions of the outlet works and the depth of flow in the outlet channel or pipe. A certain amount of water can seep through, under, and around the ends of all dams. The water moves through pores in the soil, rock, or concrete as well as through cracks, joints, etc. The pressure of the water as it moves acts uniformly in all planes and is termed pore pressure. The upward force (called uplift pressure) has the effect of reducing the effective weight of the downstream portion of a dam and can materially reduce dam stability. Pore pressure in an embankment dam, a dam foundation or abutment, reduces that component's shearing strength. In addition, excess water, if not effectively channeled by drains or filters, can result in progressive internal erosion (piping) and failure. Pore pressures can be monitored with the following equipment: o Piezometers: electrical, open well, pneumatic, hydraulic; porous tube; slotted pipe; o Pressure meters & gauges; o Load cells.

Item	Monitoring	Conceptual Aspects – Advantages/Limitations
10.3.1	**Water Level and Pressure Water Level** 	Many foundations and abutments have preferential paths of percolation. These percolation and leakages are, in general, not detected by instruments, but in field inspections. The primary factors influencing the distribution of water pressures in soil are the permeability of the soil, the ratio of horizontal to vertical permeability, and the variation of permeability within different zones and strata. The primary factors influencing the distribution of water pressures in rock are the joint permeability and the variation of the permeability due to the variation of the orientation, spacing, persistence, interconnection, and aperture of the joints. Where impervious strata exist in soil or rock, different pressures may occur in adjacent strata. Water pressure distribution is also affected by drains, abutment water tables, strata variations, and occasionally grout curtains. Rainfall and regional water levels may change local water levels, which in turn may affect water pressure distribution. All these aspects, with the control measures adopted in the design, must be properly understood and accounted for when selecting and locating piezometers. Water pressure within soils and within concrete is commonly referred to as pore pressure. Water pressure acting upward on the base of concrete dams is commonly known as uplift pressure. Water level and water pressure are directly related by the depth below the water surface or phreatic surface. Water pressure is a general term that includes pressure within a reservoir or other body of water, pore pressure, and uplift pressure. Thus, measurements or water pressure can be readily converted to water level and vice-versa.

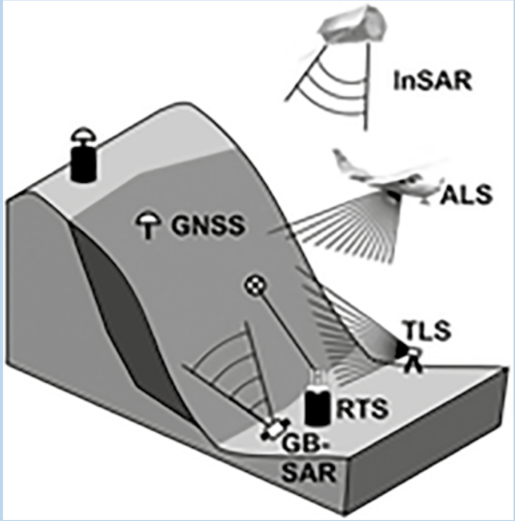
Item	Monitoring	Conceptual Aspects – Advantages/Limitations
10.3.1	**Water Level and Pressure Water Level**	Water pressure usually varies from headwater level on the upstream side of a dam to tailwater level, ground water level, or atmospheric pressure on the downstream side of a dam. The headwater, tailwater, and varying pressure across the dam produce forces on a dam that must be properly accounted for in stability analyses. Relatively high excess pore water pressures may develop in impervious zones and compressible foundation strata during construction of embankment dams as the height of the dam increases. The inability of the dam or foundation to maintain effective strength during construction may lead to deformation or, in extreme cases, slope or bearing capacity failures. Consolidation testing and analyses, and pore pressure measurements during construction provide guidance for regulating the rate of fill placement and/or moisture control in the fill during construction to prevent instability. These pressures change to steady-state seepage pressures with time, depending on the permeability and length of drainage paths of the system. The location of the phreatic surface for steady state seepage conditions in embankment dams is commonly established by theoretical analyses, and the variation of pressure beneath the phreatic surface is estimated by flow nets or is assumed to vary hydrostatically. Alternatively, pressures are estimated by finite element or finite difference models. Steady state seepage conditions may take years to develop. The correct design needs to take into consideration the defenses against the phreatic lines in the foundation and in the embankment. Uplift pressure beneath concrete structures is generally assumed to vary linearly from headwater to tailwater or downstream ground surface. If foundation drains exist and are adequately maintained, the uplift pressure is usually reduced at the line of drains in accordance with the effectiveness of the drainage system. The linear pressure distribution can be affected by the factors influencing the distribution of water pressures in soil and rock that are discussed above.

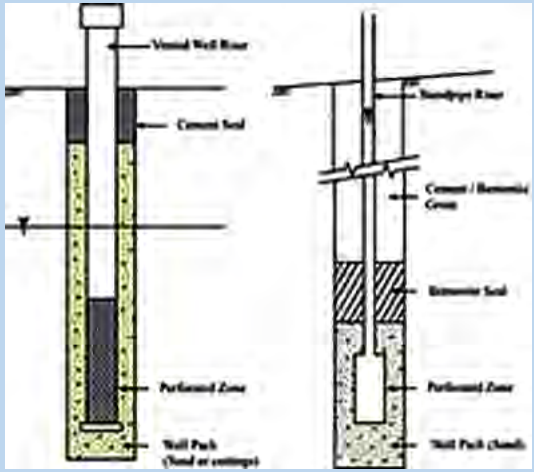
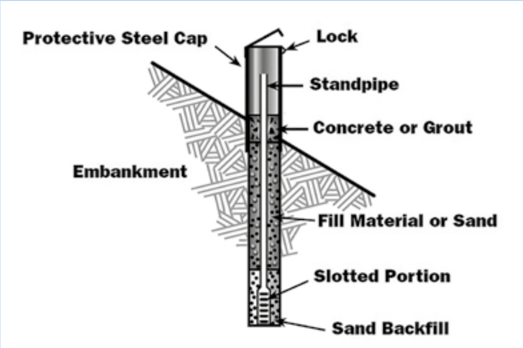
Item	Monitoring	Conceptual Aspects – Advantages/Limitations
10.3.1	Water Level and Pressure Water Level	Seasonal water pressure variations can occur as a result of seasonal reservoir level and temperature variations. Concrete dams and foundations deform slightly to adjust to these changing loads. In some cases, the deformations are sufficient to alter the aperture and permeability of foundation rock joints, which changes the pressure distribution. In a closed, perfectly rigid hydraulic system, changes in water pressure are transmitted, nearly instantaneously, by pressure waves. Piezometers are not perfectly rigid or closed. Therefore, some water must flow for a pressure change to be measured. The time required for the flow to occur is known as lag time. Lag time is influenced by the degree of saturation, the permeability of the materials surrounding the piezometer, the design of the instrument, and the magnitude of change in pressure. Open standpipe piezometers require a relatively large volume of water to fill the standpipe and, in low permeability soils, lag time can range up to several months. Pneumatic and diaphragm type piezometers installed in sealed and saturated zones require negligible flow, and lag time for these types of piezometers is generally short. If the sensor is not sealed in a saturated zone, the lag time is controlled by the filter pack or material surrounding the piezometer. Lag time is usually only significant for piezometers installed in impervious materials. Below the phreatic surface, soils are usually assumed to be saturated. Above the phreatic surface, soils contain both gas and water within the pore spaces. In partially saturated soils, piezometers measure pore air pressure rather than pore water pressure, unless high air entry porous tips are used. In cohesionless materials, the difference between pore air pressure and pore water pressure is minimal. In fine grained cohesive materials with high capillary pressure, pore air is always greater than pore water pressure. In some instances the difference can be significant with respect to evaluating the stability of a dam.

Item	Monitoring	Conceptual Aspects – Advantages/Limitations
10.3.1	**Water Level and Pressure Water Level**	Piezometer tubing and cables should be installed to avoid development of seepage paths along them, or through them as they deteriorate. Special attention must be paid to sealing tubing and cables where they cross zones of an embankment dam. Adequate filters must be used around tubing located outside of the core and where tubing exits from the dam to prevent piping along the tubing or through damaged or deteriorated tubing.
	Weather and precipitation	Monitoring the weather at a dam site can provide valuable information about both day-to-day performance and developing problems. A rain gauge, thermometer, humidity, and wind gauge can be easily purchased, installed, maintained and monitored at a dam site.

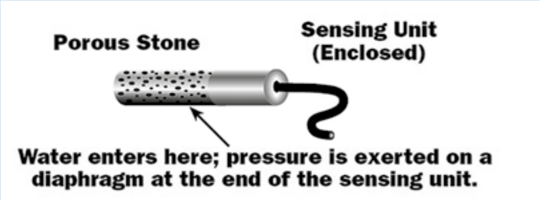
Type	Conceptual Aspects- Advantages/Limitations
Staff Gage 	Simple device, inexpensive, reliable.
Float-Type Water Level Gage- Practically as below	Simple device, inexpensive, reliable. Easily automated Requires readout device. Sensor must be in water. Must be protected from ice.

Type	Conceptual Aspects- Advantages/Limitations
Ultrasonic Water Level Sensor 	Simple device, inexpensive, reliable. Sensor does not touch water. Easily automated. Requires readout device. Must be corrected for air temperature. Debris, foam, and ice can cause false readings.
Bubbler 	Simple device, inexpensive, reliable. Easily automated. Requires readout device. Sensor must be submerged in water.

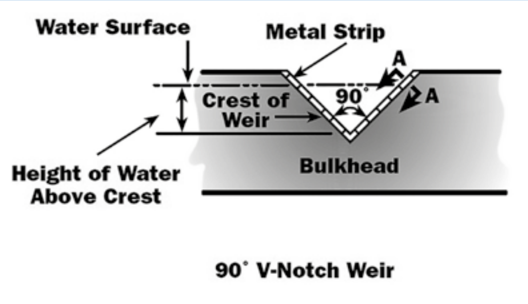
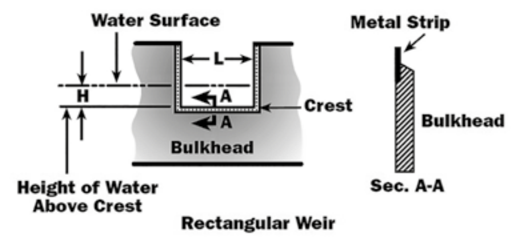
Type	Conceptual Aspects- Advantages/Limitations
Observation Well Sensor 	Simple device, inexpensive. Easily automated. Applicable only in uniform materials, not reliable for stratified materials. Long lag time in impervious soils.
Open Standpipe Piezometer – See bellow	Simple device, inexpensive, reliable. Simple to monitor and maintain. Standard against which all other piezometers are measured. Can be subjected to rising or falling head tests to confirm function. Easily automated. Long lag time in impervious soils. Potential freezing problems if water near surface. Porous tips can clog due to repeated inflow and outflow. Not appropriate for artesian conditions where phreatic surface extends significantly above top of pipe. Interferes with material placement and compaction during construction. Can be damaged by consolidation of soil around standpipe.

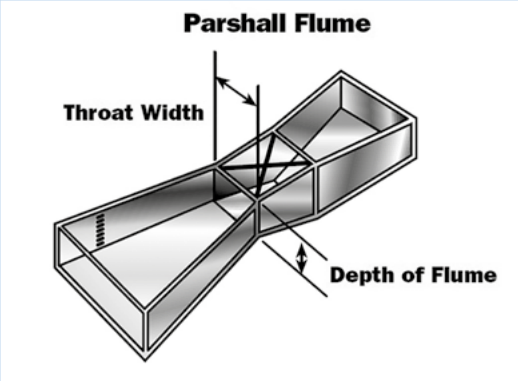
Type	Conceptual Aspects- Advantages/Limitations
Closed Standpipe Piezometer 	Same as for open standpipe piezometers. Same as open standpipe piezometer but appropriate for artesian conditions. Closed standpipe piezometers installed in concrete dams during construction usually have riser pipes that are not vertical, but rather routed to a gallery for ease of monitoring. Provisions for venting gas trapped inside of the riser pipe are often made, but are not required on most common sizes of riser pipes.
Twin-tube Hydraulic Piezometer 	Simple device, moderately expensive, reliable, long experience record. Short lag time. Minimal interference with construction operations. Cannot be installed in a borehole, therefore, generally not appropriate for retrofitting. Readout location must be protected from freezing. Moderately complex monitoring and maintenance. Periodic de-airing required. Elevation of tubing and of readout must be less than about 4 m above piezometric elevation. Can be automated, but moderately complex.

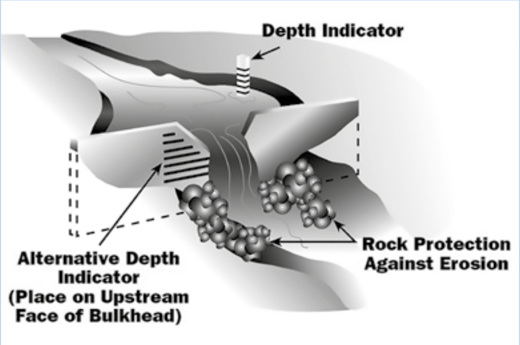
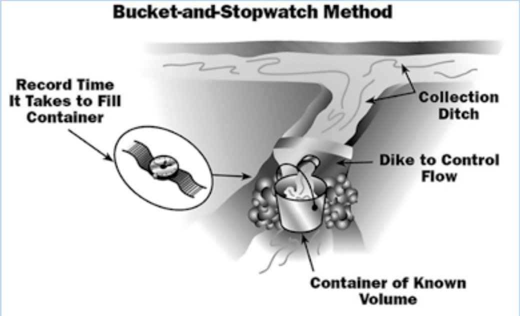
Type	Conceptual Aspects- Advantages/Limitations
Pneumatic Piezometer Available on Suppliers Catalogs	Moderately simple transducer, moderately expensive, reliable, fairly long experience record. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems. Moderately complex monitoring and maintenance. Dry air and readout device required. Can be automated, but not over long distances. Sensitive to barometric pressure. Automation is complex. Moderately expensive readout.
Vibrating Wire Piezometer Available on Suppliers Catalogs	Moderately complex transducer. Simple to monitor. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems. Frequency output signal permits transmission over long distances. Easily automated. Vibrating wire piezometers consist of a porous stone connected to a sealed metal chamber with a diaphragm adjacent to the stone. Inside the chamber, a wire is stretched between the diaphragm and a fixed point at the other end of the chamber. The chamber is connected to an electronic readout device. Water pressure deflects the diaphragm, which changes the tension and resonant frequency of the wire. Pressure is measured by electronically vibrating the wire, measuring the frequency of vibration, and relating frequency to water pressure using calibration data. Modern readouts perform the calibration automatically. Lightning protection required. Expensive transducer and readout. Sensitive to temperature and barometric pressure changes. Risk of zero drift, but some models available with in-situ calibration check.

Type	Conceptual Aspects- Advantages/Limitations
Bonded Resistance Strain Gage (Electronic) Piezometer 	Moderately complex device, expensive. Simple to monitor. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems. Easily automated. Bonded resistance strain gage piezometers (a.k.a. electronic piezometers) consist of a porous stone connected to a sealed metal chamber with a diaphragm adjacent to the stone, similar to vibrating wire piezometers. Inside the chamber, a strain gage is bonded to the diaphragm. Wires extend from the chamber to an electronic readout device. Water pressure deflects the diaphragm and the magnitude of the deflection is measured by the strain gage. Water pressure is determined by relating strain gage output to water pressure using calibration curves. These piezometers are subject to zero drift, and therefore are not appropriate for long-term monitoring. Lightning protection required. Subject to zero-drift, therefore, not recommended for long-term monitoring. Expensive transducer and readout. Voltage or current output signal sensitive to cable length, splices, moisture, etc.

Item	Monitoring	Conceptual Aspects- Advantages/Limitations
10.3.2	Seepage and Leakage – See ahead	*Seepage* is defined as interstitial movement of water through a dam, foundation, or abutments. It is differentiated from *leakage*, which is flow of water through holes or cracks. Seepage and leakage are commonly measured with weirs, Parshall flumes, and calibrated containers. Other types of flow measuring devices such as flow meters may be appropriate in special circumstances. Geophysical surveys can be used to determine flow direction. The difference in water levels between the upstream and downstream sides of a dam causes seepage and leakage, and can be supported by a filter and/or drain. The amount of seepage or leakage is directly proportional to permeability and pressure. It is possible to have large flow with high pressure, large flow with low pressure, low flow with high pressure, or low flow with low pressure. Most of the factors that influence the amount of seepage or leakage do not change during the life of a project. Usually the main variable is the reservoir level, and typically seepage and leakage volume are directly related to it. Any change in seepage or leakage volume not related to reservoir level must be evaluated immediately. Significant or rapid changes should also be investigated. An increase in seepage or leakage may be an indication of piping. A decrease in seepage or leakage may indicate clogged drains. A decrease in seepage may also indicate that seepage is increasing at a location other than that being measured, which could lead to piping. Cloudy or turbid seepage may indicate piping. New seeps or leaks may also be indications of developing problems. Another variable that affects the amount of seepage or leakage is the development of the steady-state phreatic surface in a newly constructed project. The steady-state phreatic surface can take years, during which, a gradual increase in seepage or leakage may occur. For dams on soluble rock foundations (e.g. gypsum or halite), seepage may increase with time due to dissolution of the rock. In these cases a slow steady increase in seepage may indicate developing problems. Water quality measurements can provide data to evaluate the dissolution of the foundation rock, the source of seepage, or piping. Common water quality measurements include field measurements of Ph, temperature, and conductivity, and laboratory measurements of total dissolved solids, total suspended solids, and a variety of minerals (e.g. sodium, potassium, carbonate, bicarbonate, sulfate, and chloride).

Type	Conceptual Aspects- Advantages/Limitations
Weirs   	Weirs are usually metal or plastic plates with a notch on the top edge. They are installed in a ditch, gutter, pipe, or in manholes in the relief well collection system. The quantity of water flowing through the notch is calculated by measuring the depth of water from the invert of the notch to the upstream water surface and using the measurement in the appropriate hydraulic equation. The notch can be triangular, rectangular, or trapezoidal. Triangular notches are appropriate for low flows (less than about 0.05 m^3/s). Rectangular or trapezoidal weirs are appropriate for larger flows. The crest of the weir should be thin enough that the nappe springs clear. Weirs are simple, reliable, inexpensive, and require little maintenance. Limitations are the severe restriction of the flow channel, relatively high head loss, and the need for sufficient elevation change to prevent the tailwater from submerging the weir.

Type	Conceptual Aspects- Advantages/Limitations
Parshall Flumes 	Parshall flumes are specially shaped open channel sections. They consist of a converging upstream section, a downward sloping throat, and an upward sloping and diverging downstream section. They are usually permanent installations made of reinforced concrete, metal, or prefabricated fiberglass and can be sized to measure a wide range of flows. Throat widths from 25 mm to 10 m are common. The quantity of water flowing through the throat is calculated by measuring the depth of water upstream and using the measurement in the appropriate hydraulic equation. Parshall flumes should be installed evenly and ideally at a site free of downstream submergence. Parshall flumes are simple, reliable, and require little maintenance. They cause minimal restriction to the flow channel and low head loss. The primary limitation is the relatively expensive installation.

Type	Conceptual Aspects- Advantages/Limitations
Calibrated Containers  	Containers of known volume can be used to measure low flows that are concentrated and free-falling. The flow rate is computed as the volume of the container divided by the time required to fill the container. Extremely low flow rates can be measured accurately. The maximum flow rate is limited by the size of the container that can be quickly maneuvered into and out of the flow or into which the flow can readily be diverted. Typically, calibrated containers are appropriate for flows less than about 0.003 m^3/s. Calibrated containers are reliable for low flows and are inexpensive. They have limited application because of the requirement for a free-falling flow, they are not accurate for large flows, and are labor intensive.

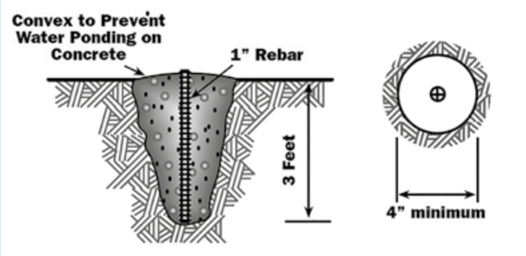
Item Basic	Monitoring	Conceptual Aspects- Advantages/Limitations
10.3.3	**Movement**	Movement can be divided into three types: ***surface movement, internal movement, and crack or joint movement***. Since it can occur in any direction, measurements in three mutually perpendicular directions are necessary to accurately determine vector movement. Measurements are typically made in vertical, transverse horizontal, and longitudinal horizontal directions. Movement in one or more of these directions is often judged to be negligible and is not measured. Movements occur in every dam. They are caused by stresses induced by reservoir water pressure, unstable slopes (low shearing strength), low foundation shearing strength, settlement (compressibility of foundation and dam materials), thrust due to arching action, expansion resulting from temperature change, and heave resulting from hydrostatic uplift pressures. They can be categorized by direction: ***Surface movement*** – is understood as horizontal or vertical movement of a point on the surface of a structure relative to a fixed point off of the structure. It is usually determined by some type of surveying. Modern surveying equipment has increased the number and type of surveys that are available. ***Horizontal Movement*** – Horizontal or translational movement commonly happens in an upstream–downstream direction in both embankment and concrete dams. It involves the movement of an entire dam mass relative to its abutments or foundation. In an embankment dam, instruments commonly used for monitoring such movement include: o Extensometers; o Multi-point extensometers; o Inclinometers; o Embankment measuring points;

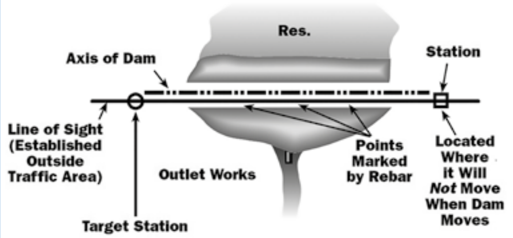
Item Basic	Monitoring	Conceptual Aspects- Advantages/Limitations
10.3.3	Movement	○ Shear strips; ○ Structural measuring points. For a concrete dam, instruments for monitoring horizontal movements may include: ○ Crack measuring devices; ○ Extensometers; ○ Multi-point extensometers; ○ Inclinometers; ○ Structural measuring points; ○ Tape gauges; ○ Strain meters. ***Vertical Movement*** – Vertical movement is commonly a result of consolidation of embankment or foundation materials resulting in settlement of the dam. Another cause is heave (particularly at the toe of a dam) caused by hydrostatic uplift pressures. In an embankment dam, vertical movements may be monitored by: ○ Settlement plates/sensors; ○ Extensometers; ○ Piezometers; ○ Vertical internal movement devices; ○ Embankment measuring points; ○ Structural measuring points; ○ Inclinometer casing measurements.

<table>
<tr><th>Item Basic</th><th>Monitoring</th><th>Conceptual Aspects- Advantages/Limitations</th></tr>
<tr><td>10.3.3</td><td>Movement</td><td>In a concrete dam, vertical movement monitoring devices may include:
o Settlement sensors;
o Extensometers;
o Piezometers;
o Structural measuring points;
o Foundation deformation gauges.
Rotational Movement – Rotational movement is commonly a result of high reservoir water pressure in combination with low shearing strength in an embankment or foundation and may occur in either component of a dam. This kind of movement may be measured in either embankment or concrete dams by instruments such as:
o Extensometers;
o Inclinometers;
o Tilt meters;
o Surface measurement points;
o Crack measurement devices;
o Piezometers;
o Foundation deformation gauges;
o Plumblines (concrete only).</td></tr>
</table>

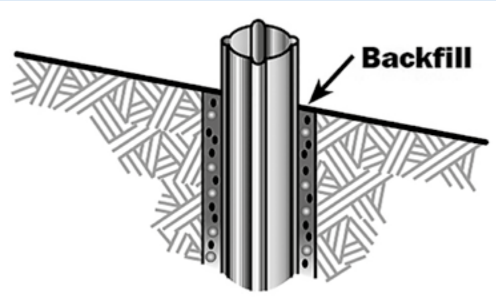
Item Basic	Monitoring	Conceptual Aspects- Advantages/Limitations
10.3.3	Movement	***Lateral Movement*** – Lateral movement (parallel with the crest of a dam) is common in concrete arch and gravity dams. The structure of an arch dam causes reservoir water pressure to be translated into a horizontal thrust against each abutment. Gravity dams also exhibit some lateral movement because of expansion and contraction due to temperature changes. These movements may be detected by: o Structural measurement points; o Tilt meters; o Extensometers; o Crack measurement devices; o Plumblines; o Strainmeters; o Stressmeters; o Inclinometers; o Jointmeters; o Thermometers; o Load cells. ***Internal movement*** – is understood as horizontal or vertical movement within the structure. It is usually determined relative to some point on the structure or in the foundation.

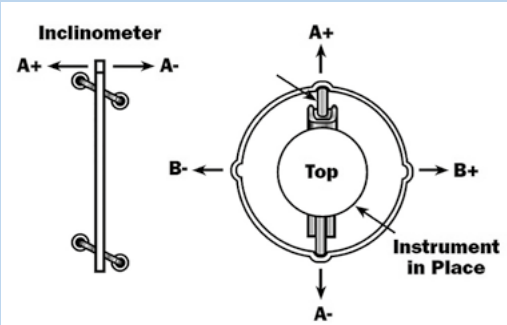
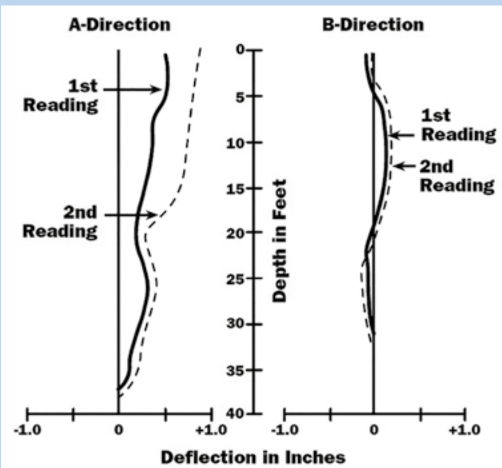
Item Basic	Monitoring	Conceptual Aspects- Advantages/Limitations
10.3.3	Movement	***Joint or crack movement*** – is understood as horizontal or vertical movement of one part of a structure relative to another part of a structure. It is usually measured across block joints or cracks in concrete structures or cracks in earth structures. Tubing or cables for movement measuring devices should be installed to avoid development of seepage paths along them, or through them, as they deteriorate. A special attention must be paid to sealing tubing and cables where they cross zones of an embankment dam. All structures move as the result of applied loads. Embankments settle and spread over time as the result of consolidation and secondary settlement of the dam and foundation from self-weight. Embankments also deform due to external loads produced by reservoir water, rapid drawdown, earthquakes, undermining, swelling clays, and piping. Concrete structures deform due to internal loads such as pore pressure, cooling, and alkali aggregate, and other expansive mineralogical element (as pyrite) reaction of concrete; and external loads caused by air and reservoir temperature, solar radiation, reservoir levels, uplift pressure, wind, earthquakes, undermining, ice, overflowing water, swelling clay, and foundation settlement. Movements in response to such loads are normal and acceptable, provided they are within tolerable ranges and do not cause structural distress. Embankments are less brittle than concrete structures and can undergo larger movements without distress. As a result, measurements of surface movements of embankment dams are typically less precise than those for concrete structures. Sudden or unexpected direction, magnitude, or trend of surface movement could indicate developing problems. Internal movement measurements of both concrete and embankment dams and their foundations should be detailed and precise. Measuring points for all movement surveys should be installed so that they are not subject to movement from freeze-thaw action or traffic.

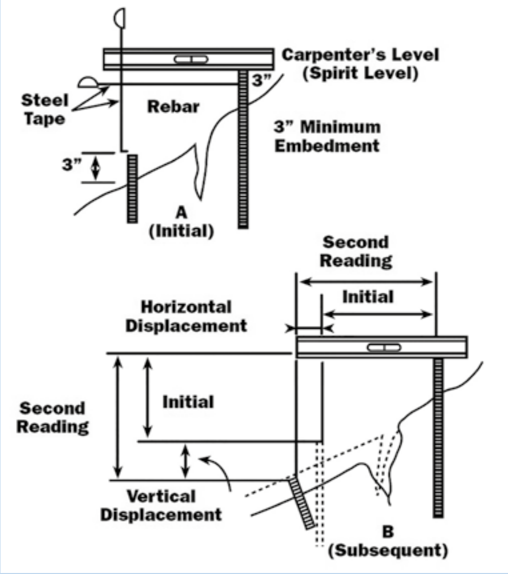
Type	Conceptual Aspects- Advantages/Limitations
Level Surveys 	Vertical surface movements are commonly measured by conventional differential leveling surveys. Measuring points are established on the crest or slopes of the dam. Embankment measuring points are usually steel bars embedded in concrete placed in the fill. Concrete dam measuring points are usually bronze markers set in the concrete or scratch marks. The change in elevation between the measuring points and survey control monuments off of the dam are measured using levels and rods. Typically, survey methods and equipment for measurements of embankments should be sufficiently accurate to discern movement on the order of 30 mm. A conventional level and rod are usually adequate for embankment dams. Typically, survey methods and equipment for measurement of concrete structures should be sufficiently accurate to discern movement on the order of 3 mm. Precision levels and rods equipped with micrometer targets are usually used for concrete structures. Level surveys are the simplest and most accurate method for determining vertical movement of a dam A limitation of level surveys is the labor cost, though modern surveying equipment has reduced the time required to perform a survey and reduce the data.

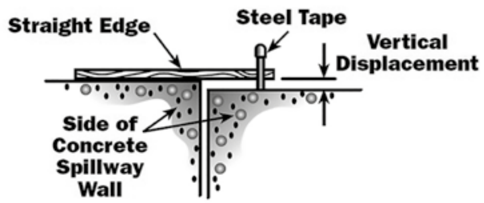
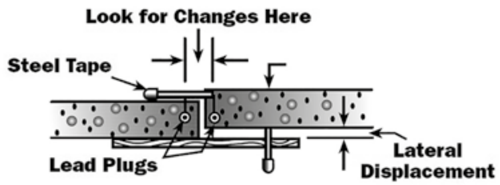
Type	Conceptual Aspects- Advantages/Limitations
Alignment Surveys  	Alignment surveys are the simplest and most accurate method for determining horizontal movement in straight dams. Horizontal surface movements are commonly measured as offsets from a baseline. The same measuring points used for the level surveys are normally used for alignment surveys. The method and equipment used depends on the type of dam and the desired accuracy. For embankment dams, one or more lines of measuring points are established along the crest and on the slopes parallel to the crest. Instrument and target monuments are established at the ends of the lines on the abutments beyond the dam. To measure movement, a theodolite is set up on the instrument monument on one abutment and sighted to the target monument on the opposite abutment. Offsets from the line-of-sight are then measured to each measuring point using a plumb bob and tape. Typically, survey methods and equipment should be sufficiently accurate to discern movement on the order of 30 mm. For concrete dams a similar procedure is employed, but with refinements to increase the accuracy of the measurements. These surveys are also known as collimation surveys. Measuring points are established along straight lines on the crest and, in some cases, along the face of the dam. The measuring points are markers set in the dam concrete. Instrument and target monuments are established outside the limits of the dam at the ends of the lines of measurement points. The monuments can usually be as those indicated on **Chapter 9**. The line-of-sight is established using a high precision theodolite set on the instrument monument and sighted to the target on the target monument. Offsets from the base line are measured with a micrometer attached to a moveable target leveled over each measuring point. Typically, survey methods and equipment should be sufficiently accurate to discern movement on the order of 3 mm. Their application is limited for curved dams, irregularly shaped dams, or where the line-of-sight is limited, because the number of measurement points along any one line is small. A limitation of alignment surveys is the labor cost, although modern surveying equipment has reduced the time required to perform a survey and reduce the data.

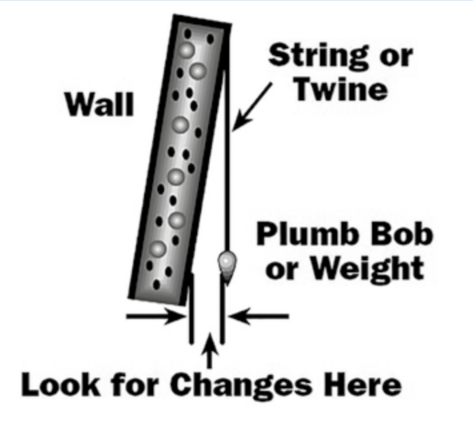
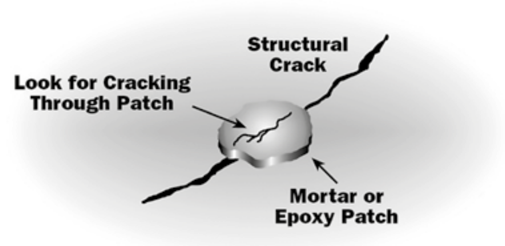
Type	Conceptual Aspects- Advantages/Limitations
Triangulation and Trilateration	Triangulation and trilateration use trigonometric principles of triangles to measure the location of points on a dam. In triangulation surveys, angles to a measuring point on the dam are determined from two locations on a baseline. Using the known distance between them, and the elevation of baseline monuments, the triangle between the three points is solved trigonometrically to determine the location (horizontal and vertical) of the measuring point. Angles are measured with precise theodolites. In trilateration surveys, the distances between a measuring point on the dam and two locations on a baseline are determined. Similar to the triangulation survey, the trilateration survey uses the known distance between them, and the elevation of monuments on the baseline, the triangle between the three points is solved trigonometrically to determine the location (horizontal and vertical) of the measuring point. Since distances can be measured more precisely than angles, trilateration surveys are more precise than triangulation surveys. Distances are measured with **e**lectronic **d**istance **m**easurement (***EDM***) equipment. EDMs determine distance by measuring the time it takes for light to travel from the source to a reflector and back, and then multiplying it by the speed of light. Extremely high accuracies can be obtained with this equipment. Measurements must be corrected for barometric pressure, temperature, and the curvature of the earth. Baseline monuments are similar to instrument monuments used for alignment surveys of concrete dams. Triangulation and trilateration are useful when measuring points do not lie along a straight line or when lines of sight are obstructed. Vertical movements can be measured with both surveys if the baseline has a significant vertical component. The disadvantages are the cost of the survey crew labor, the cost of establishing the baseline, the need for specialized equipment, and the relatively complex calculations. The surveys are highly accurate, but require an experienced crew.

Type	Conceptual Aspects- Advantages/Limitations
Internal Movement  	Internal settlement of an embankment or foundation can be measured with a variety of instruments including settlement plates, cross-arm devices, magnetic- or inductance-type probe extensometers, fluid leveling devices, pneumatic settlement sensors, vibrating-wire settlement sensors, and various other mechanical and electrical sounding devices. Internal horizontal and vertical movements are commonly measured with inclinometers and extensometers. Internal movements of concrete structures are commonly measured with plumblines, tiltmeters, inclinometers, and extensometers. Plumblines consist of a plumb bob suspended by a wire on a vertical shaft in a dam. Measurements of the location of the wire relative to the suspension point are taken at one or more elevations along the shaft. They are simple, inexpensive, accurate, and reliable. Tilt meters consist of a base plate, sensor, and readout device. They are commonly attached to a surface (internal or external) of a structure and measure vertical rotation of the surface. They are portable, accurate, and precise.

Type	Conceptual Aspects- Advantages/Limitations
Internal Movement   	Inclinometers consist of specially shaped casing, a probe, and readout device. They are commonly installed in vertical drill holes in dams, foundations and abutments, although they may be installed in a dam during construction. The inclination of the casing is measured at regular intervals and the lateral movement relative to the bottom of the casing is calculated. They are reliable and accurate. Extensometers consist of one or more rods anchored at different depths in a borehole and a reference head on the surface. They are commonly installed vertically to measure the vertical movement of the reference head relative to the anchor zone(s), although they may be installed in other orientations. They are accurate and can be used to measure small movements.

Type	Conceptual Aspects- Advantages/Limitations
Crack and Joint Measuring Devices  	Knowledge of the locations and widths of cracks and joints in concrete dams and in concrete spillways and other concrete appurtenances of embankment dams is important because of the potential for seepage through those openings. Even more, it is important to know if the width of such openings is increasing or decreasing. Various crack and joint measuring devices are available, and most allow very accurate measurement. Some use simple tape or dial gauges, while others use complex electronics to gain measurements. Movement of one side of a crack or joint in a concrete structure relative to the other side of the joint or crack is commonly measured with reference points or crack meters. Grout or plaster patches can be used to evaluate whether or not movement is occurring. Many variations are used.

Type	Conceptual Aspects- Advantages/Limitations
 (A) Straight Edge and Tape  (B) Straight Edge and Tape Plus Reference Points	Reference points can be scratch marks in the concrete, metal pins, or metal plates on opposite sides of a joint or crack. The distance between the scratch marks is measured with a micrometer or dial gage to determine movement. Sometimes three points are used in a triangle to measure both horizontal and vertical movement.

Type	Conceptual Aspects- Advantages/Limitations
 (C) Plumb Bob  (D) Mortar Marker	Crack meters are commercially available devices that allow movement in two directions to be measured. A common device consists of two plastic plates. One plate is opaque and contains a grid. The other plate is translucent and contains a set of cross hairs. One plate is fixed on each side of the crack or joint with the cross hairs set over the center of the grid. Movement is measured by noting the location of the cross hairs with respect to the grid. A variety of other crack meters including Carlson and vibrating-wire sensors, dial gages, and mechanics feeler gages may be used to measure movement of cracks. All these devices are simple to install and monitor. The accuracy and reliability varies depending on the details of the devices and measurements. Mineral deposits, iron staining, or efflorescence obscuring the instruments are a common problem if seepage or leakage flow is present.

Type	Conceptual Aspects- Advantages/Limitations
Stress and Strain – See ahead on 10.8	Measurements to determine stress and/or strain are common in concrete dams and, to a lesser extent, in embankment dams. The monitoring devices previously listed for measuring dam movements, crack and joint size, and temperature are also appropriate for measuring stress and strain. Monitoring for stress and strain permits very early detection of movement. Earth pressures within fill and against concrete structures are commonly measured with earth pressure cells. These are also known as total pressure cells. They consist of two flexible diaphragms sealed around the periphery, with a fluid in the annular space between the diaphragms. Pressure is determined by measuring the increase in fluid pressure behind the diaphragm with pneumatic or vibrating-wire sensors. Earth pressure cells should have similar stiffness as the surrounding soil to avoid inaccurate measurements of in-situ stress caused by arching. Soil pressures against structures can also be measured with a Carlson-type cell. It consists of a chamber with a diaphragm on the end. Deflection of the diaphragm is measured by a Carlson-type transducer and is converted to stress. Stress in concrete structures can be measured with total pressure cells or Carlson-type cells designed to have a stiffness similar to concrete. It can also be measured by over coring. A variety of mechanical and electrical strain gages are used to measure strain in concrete structures. Some of the instruments are designed to be embedded in the dam during construction and others are surface mounted following construction. Strain gages are often installed in groups (spiders), so that the three-dimensional state of strain can be evaluated. The modulus of elasticity, creep coefficient, and the Poisson's ratio for concrete can be determined from the laboratory testing of concrete field cylinders. These values are required for converting strain measurements to stress. Some tests can be seen ahead.

Type	Conceptual Aspects- Advantages/Limitations
Temperature – See ahead on 10.8	Temperature measurements of a dam, foundation, or instruments, are often required to reduce data from instruments, increase precision, or to interpret results. For example, movements of concrete dams and changes in leakage at concrete dams are commonly related to changes in temperature. Temperature is also commonly measured in concrete dams under construction to evaluate mix design, placement rates, and block and lift sizes; to time grouting of block joints; and to evaluate thermal loads. The internal temperature of concrete dams is commonly measured both during and after construction. During construction, the heat of hydration of freshly placed concrete can create high stresses which could result in later cracking. After construction is completed and a dam is in operation, it is not uncommon for very significant temperature differentials to exist depending on the season of the year. Temperatures can be measured with resistance thermometers or thermocouples. Temperature measurements of seepage and leakage may indicate the source of seepage. For example, during the winter, the upstream face of a dam remains relatively warm because of reservoir water temperature, while the downstream face of the dam is reduced to a cold ambient air temperature. The reverse is true in the summer. This needs be evaluated considering the climatic ambient of the zone. Temperature measurements are important both to determine causes of movement due to expansion or contraction and to compute actual movement. Temperature measurements can be made by using any of several different kinds of embedded thermometers or by making simultaneous temperature readings on devices such as stress and strain meters which provide means for indirectly measuring temperature of the mass.

Type	Conceptual Aspects- Advantages/Limitations
Seismic Loads  **Conceptual principle**  **Apparatus**	Seismic measuring devices record the intensity and duration of large-scale earth movements such as earthquakes. It may or may not be necessary for a private dam to contain any seismic devices depending upon whether it is in an area of significant seismic risk. Seismic instruments can also be used to monitor any blasting conducted near a dam site. Seismic strong motion instrumentation records acceleration from earthquake shaking. The data are used to evaluate the dynamic response of dams. Seismic acceleration and velocity are usually recorded with strong-motion accelerographs. These devices typically consist of three mutually-perpendicular accelerometers, a recording system, and triggering mechanism. To prevent accumulation of unwanted data, the instruments are usually set to be triggered at accelerations generated by nearby small earthquakes or more distant, larger earthquakes. They are expensive, especially considering that multiple instruments are necessary to record dynamic response at several locations on a structure, a foundation, or abutments. The devices must be properly maintained, so that they operate if an earthquake occurs.

Type	Conceptual Aspects- Advantages/Limitations
Loads in Post – Tensioned Anchors 	Post-tensioned anchors consist of single or multiple wires, strands, or bars installed in drilled holes. The bottom end is grouted in the dam or foundation and the top end is fitted with a head that allows the anchor to be post-tensioned. The section between the grouted end and the head is known as the stressing length. It may be free (ungrouted) or grouted. Post-tensioned anchors are commonly used to improve the stability of concrete dams, or in anchors for the trunnion of the spillway gates. There is no practical method of measuring loads in fully grouted anchors. Loads in post-tensioned anchors that have a free length can be evaluated by lift-off tests, load cells, extensometers, and fiber-optic cables. Load cells can be located beneath the anchor head to measure the load in the anchor. Hydraulic and vibrating-wire cells have been used successfully. Electrical resistance strain gage load cells have not had good performance records. Load cells can be permanently installed in new anchors and in some cases can be placed under the heads of existing anchors. Extensometers and fiber-optic cables can be installed integral with multiple strand or wire anchors to measure change in length. The length can be converted to load with elastic constants, assuming no slippage at the head. Water pressure, seepage, leakage, movement, stress, and strain data taken before and after installation of anchors may be useful in evaluating the response of the dam to anchor loads. In lift-off tests, a jack is attached to the head of an anchor and the pressure required to lift the head is measured by a pressure cell. This type of test requires the anchor head to be accessible and be capable of being connected to a jack.

The references[10-11 to 10-13] provide guidance on usable instruments in Concrete and Embankment dams. And the books[10-01 & 10-02], provide information on preparation procedures, calibrations, evaluations and analysis of monitoring instruments used in Itaipu, mainly during the construction phase.

10.4 Typical Set of Instruments to be Managed and Planned

A minimum instrumentation may not be recommended for all dams, but a typical set of instruments should be considered and discussed in between Owner and Designer, based on all scenarios to assist in having a ***Safe Dam***. This is considered to be generally applicable; however, since each dam is unique, the recommendations should be applied using engineering judgement and common sense. The instrumentation is separated into existing and proposed dams categories and further subdivided depending on hazard potential classification and the type of structure, as follows.

Extensive instrumentation on low-hazard potential dams is not required. Some low-hazard potential dams are a critical source of municipal water, may cause unacceptable environmental impacts if they fail (e.g., release of heavy metals in sediments), or are important to public safety for other reasons. Instrumentation at these dams should be reviewed on a case-by-case basis and increased as appropriate.

The instrumentation for significant and high-hazard potential dams includes that mentioned for low-hazard potential dams, plus additional instrumentation to monitor headwater and tailwater levels, significant seepage and leakage, pore pressure or uplift pressure, loads in post-tensioned anchors, and movement. Strong motion instrumentation should be considered on a case-by-case basis for dams in seismic zones.

TYPE OF MEASUREMENT FOR NEW DAMS	LOW HAZARD POTENTIAL DAMS — ALL TYPES	SIGNIFICANT AND HIGH-HAZARD POTENTIAL DAMS[10-14]					
		EMBANKMENT AND TAILING	CONCRETE GRAVITY	ARCH	BUTTRESS	SEPARATE SPILLWAY AND/ OR OUTLET	INTEGRAL POWERHOUSE
VISUAL OBSERVATION	X	X	X	X	X	X	X
RESERVOIR LEVEL	X	X	X	X	X	X	X
TAILWATER LEVEL	X	X	X	X	X	X	X
DRAIN FLOW, SEEPAGE, AND LEAKAGE		X	X	X	X	X	X
PORE/UPLIFT PRESSURE		X	X			X	X
SURFACE SETTLEMENT		X					
SURFACE ALIGNMENT		X	X	X	X	X	X
INTERNAL MOVEMENT		X					
JOINT/CRACK DISPLACEMENT			X	X	X	X	X
FOUNDATION MOVEMENT		X	X	X	X	X	X
SEISMIC LOADS		X	X	X	X	X	X
LOADS IN POSTTENSIONED ANCHORS			X	X	X	X	X

⇒ Additional instrumentation should be used to address specific concerns;

⇒ Visual observation consists of walking tours on the crest, toes, abutments, etc;

⇒ Using existing piezometers, observation wells, or foundation drains; or using new or existing piezometers, or dam observation wells with reduced uplift assumed in stability analysis, or that do not meet criteria using conservative estimate of the phreatic surface;

⇒ Only on structurally significant joints or cracks that have visible displacement;

⇒ Should be considered for dams on compressible or weak foundations;

⇒ Should be considered on a case-by-case basis for dams in seismic zones;

⇒ For anchors that are required to meet stability criteria, loads should be measured wherever it is possible to measure anchor loads, or anchors should be modified to measure loads.

Instrumentation for separate spillway and outlet structures that retain only minimal water should be evaluated on a case-by-case basis. In most cases, these types of structures will require little or no instrumentation.

Additional instrumentation than suggested should be used wherever it helps to resolve a dam safety issue. For example, a low dam on a pervious, weak, compressible, jointed, or similar problem foundation may require more instrumentation than a higher dam on a sound foundation. Instrumentation is often installed to help evaluate the causes of problems and concerns.

The instrumentation for existing dams may be less than for proposed dams, adjusted to the specific aspects, because instrumentation to monitor construction and first filling is not appropriate. Retrofitting instrumentation can be expensive, and the dam performance is known. Existing instruments should continue to be monitored if they still provide useful information. However, if existing instrumentation no longer provides useful or meaningful information, it should be abandoned.

PROBLEM/CONCERN	TYPICAL INSTRUMENTATION
Seepage or leakage	Visual observation, weirs, flowmeters, flumes, calibrated containers, observation wells, piezometers. An additional action needs to be performed.
Boils or piping	Visual observation, piezometers, weirs. An additional action needs to be performed.
Uplift pressure, pore pressure, or phreatic surface	Visual observation, observation wells, piezometers.
Drain function or adequacy	Visual observation, pressure and flow measurements, piezometers.
Erosion, scour, or sedimentation	Visual observation, sounding, underwater inspection photogrammetric survey.
Dissolution of foundation strata	Water quality tests.
Total or surface movement (translation, rotation)	Visual observation, precise position and level surveys, plumb measurements, tilt meters.
Internal movement or deformation in embankments	Settlement plates, cross-arm devices, fluid leveling devices, pneumatic settlement sensors, vibrating wire settlement sensor, mechanical and electrical sounding devices, inclinometers, extensometers, shear strips.
Internal movement or deformation in concrete structures	Plumblines, tilt meters, inclinometers, extensometers, joint meters, calibrated tapes.
Foundation or abutment movement	Visual observation, precise surveys, inclinometers, extensometers, piezometers.
Poor quality rock foundation or abutment	Visual observation, pressure and flow measurements, piezometers, precise surveys, extensometers, inclinometers.
Slope stability	Visual observation, precise surveys, inclinometers extensometers, observation wells, piezometers, shear strips.
Joint or crack movement	Crack meters, reference points, plaster or grout patches.
Stresses or strains	Earth pressure cells, stress meters, strain meters, over coring.

PROBLEM/CONCERN	TYPICAL INSTRUMENTATION
Seismic loading	Accelerographs.
Relaxation of post-tension anchors	Jacking tests, load cells, extensometers, fiber-optic cables.
Concrete deterioration	Visual observation, loss of section survey, laboratory and petrographic analyses.
Concrete growth	Visual observation, precise position and level surveys, plumb measurements, tiltmeters, plumblines, inclinometers, extensometers, joint meters, calibrated tapes, petrographic analyses.
Steel deterioration	Visual observation, sonic thickness measurements, test coupons.

Instrumentation, in addition to the suggested, should be required wherever there is a concern regarding a condition that may affect dam safety or other critical water retaining structures. Typical reasons to require additional instrumentation are to check design assumptions; to provide data to evaluate specific problems such as continuing movement, excessive cracking, or increased seepage; to provide data to support design of remedial modifications; and to provide data to evaluate effectiveness of remedial work.

Instrumentation and frequency of monitoring for specific problems and concerns should be selected based on the specific circumstances. Once the problem or concern has been resolved, the usefulness of the instrumentation should be re-evaluated. If it no longer provides useful information, it should be abandoned. Appropriate remedial measures should be taken for all problems and concerns.

As mentioned previously the types of measurements that are commonly monitored at a dam include headwater level, tailwater level, pore pressure, uplift pressure, seepage, leakage, surface movement, internal movement, crack or joint movement, stress, strain, temperature, and seismic loads. The magnitude and expected ranges of the parameters should be estimated to allow selection of the proper instruments. Levels that indicate the development of potentially hazardous conditions should be established during instrumentation system design.

10.5 Some Tips on Types of Instruments

Usually there are several commercially available instruments for each type of measurement required. When selecting instrumentation, the major consideration should be reliability and not cost. Reliability encompasses a variety of factors including simplicity, durability, longevity, precision, accuracy, and a length of satisfactory performance history. The relative importance of each of the factors depends on the purpose of the instrument. Instruments appropriate for use during construction may be different than those for long-term operation. This choice should be deeply analyzed by the Owner of the Dam Project, from the perspective of:

⇒ Human Resources and training, as well as the technical development of interest;

⇒ The availability of facilities for acquisition, maintenance, and assistance in the country.

The type of data acquisition — manual or automated — should be considered when choosing instruments. However, automated data acquisition systems should not be used to justify the use of inaccessible electrical transducers. Transducers that are accessible for calibration or replacement should be used wherever possible. For example, vibrating wire piezometers should not be used in preference to open standpipe piezometers just because the data will be acquired automatically. Open standpipe piezometers can be automated with accessible electrical transducers. For conditions for which access may be difficult (e.g., uplift pressures during floods), consideration should be given to the use of remote reading instruments.

The total cost should be considered when comparing alternative instruments or instrument systems. The total cost includes the instruments, installation, maintenance, longevity, monitoring, and data processing. Allocation of sufficient funds to cover the total cost of instrumentation during design phase can help avoid inadequate collection and evaluation of data due to lack of funds.

10.6 Procurement

Typically, once the type and quantity of instruments have been selected, a specification is prepared for their procurement and installation. Because many organizations are required by policy to select the lowest bid, it is important that the evaluation criteria are included in the technical specifications so that the best equipment can be obtained at the lowest cost.

Consideration should be given to instruments that have been field-proven in similar applications and have a record of reliability, ease of testing and maintenance, suitable response time, and ease of installation in the specific locations chosen. In some cases, delivery times, repair policies, and the number of vendors providing the type of instrument, can be important.

- ✓ ***Note: "Or equal" provisions in the specifications should be avoided since there is often a considerable difference between similar instruments made by different manufacturers. Proposed substitutions for specified instruments should be carefully evaluated and compared to the selection criteria".***

Installation specifications should include detailed step-by-step procedures for installing and testing instruments. The installation should include an installation log to document "as-built" conditions. Where appropriate, calibration measurement, performance testing, and initial readings should be obtained during installation. Consideration should be given to the contractor's level of experience in installing similar instruments under similar conditions that the contractor should have. A quality assurance program should be included in the specification.

Drilling to install instruments can potentially damage existing structures. Hydrofracturing of embankments can be caused by drilling and can lead to piping and loss of the reservoir. Drilling can intercept and destroy filter or transition zones in embankments, or damage drains, underground utilities, or other structures. Installation specifications should be carefully written and enforced to prevent damage to existing dams and appurtenances.

Instrumentation is often damaged by maintenance equipment or vandals. All instrumentation should be enclosed in lockable covers or should be otherwise protected.

10.7 Monitoring Program

A monitoring program that includes responsibility assignments and procedures for data collection, reduction, processing, analyses, recommendations, and presentation should be developed and documented. Responsibility for collecting, reducing, and evaluating the instrumentation data should be assigned to specific groups or individuals specialists. Specific step by step procedures for setting up equipment, taking measurements, recording data, and field screening data should be included.

The monitoring program should include steps for reporting the monitoring results through responsible management personnel and a system to ensure timely response to problems disclosed in the surveillance and evaluation of data. Personnel who perform visual observations and collect, reduce, and evaluate data, should be given basic dam safety training. The training should include as a minimum, common causes of dam failures and incidents, identification of signs of potential distress by visual observation, and actions to be taken when unusual conditions, signs of potential distress, or emergency conditions occur.

For manual data acquisition, data sheets should be developed for use in recording instrument data. All data sheets should be prepared considering the Owner Responsibility and Liability with all data required by Law and/or Codes. They should have places to record the date, time, operator, data, and comments. The sheets should also have places to record complementary data such as headwater and tailwater levels, weather, rainfall, snowfall, temperature, and any unusual conditions.

Threshold limits and the criteria used to develop them should be documented in the monitoring program, by the designers or consultants. Threshold limits should be established based on the specific circumstances. In some cases, they can be based on theoretical or analytical studies (e.g., uplift pressure readings above which stability guidelines are no longer met).

Sometimes they may be used to identify unusual readings, readings outside the limits of the instruments, or readings which, in the judgement of the responsible engineer, demand evaluation. Both magnitude and rate of change limits should be established.

In fact, with some usual software tables, there are some technical commands that can compare the readings and the limits for each type of action, which can be useful for preliminary visualization and eventual new readings or additional actions.

Threshold limits are intended to provide checks and balances in a monitoring program. Readings that exceed threshold limits do not necessarily mean that drastic action must be taken, only that some action must be taken. The monitoring program should include action to be taken if an instrument reaches its threshold limit. However, predetermined actions are no substitute for situation specific responses and should only be used as a guideline. Actions to be taken upon exceeding a threshold limit depend on the particular circumstances, but might include a combination of the following:

⇒ ***Never be complacent and/or tolerant of faults and/or errors***

⇒ Notify the responsible engineer;

⇒ Confirm the reading by retaking it, and where possible, confirm the instrument calibration by the use of redundant readings;

⇒ Inspect the dam;

⇒ Evaluate the situation and revise the threshold limit;

⇒ Increase the frequency of readings to monitor and provide data to further evaluate the situation;

⇒ Implement investigative measures such as the installation of additional instruments;

⇒ Implement remedial measures such as cleaning foundation drains, repairing damage, or modifying the dam;

⇒ Implement emergency measures such as drawing down the reservoir.

The monitoring program should include requirements for establishing initial or baseline measurements. Since most data are compared against these measurements, it is important that they are correct. The readings should meet expected values and accuracy. If they do not, the equipment should be checked and additional readings should be taken until readings meet expected values and accuracy, or the measured values can be justified.

Some instruments such as piezometers and some types of strain gages take a significant amount of time to stabilize after installation, due to drilling effects, lag time, or temperature. For these instruments, daily or more frequent readings should be taken until the readings have stabilized.

10.8 Preparation, Calibration and Installation of Instruments

As mentioned before, the references[10-11 to 10-13] provide guidance on usable instruments in Concrete and Embankment dams. And the books[10-01 & 10-02], provide information on preparation procedures, calibrations, evaluations and analysis of monitoring instruments used in Itaipu, mainly during the construction phase.

In addition, during the construction of the **Tucuruí Hydroelectric Project**[10-15], routines were established for instrumentation procedures (PROCOM - Technical Operation Instruction - Instrumentation - Miscellaneous Systems - 1984) – (in Portuguese) for the guidance of the teams. Some examples from the authors' publications[10-01 & 10-02] can be cited below.

Measurement Instrument	*Carlson transducer-strain meter (Andriolo's Archive)*
Movement Carlson Meters	
Carlson transducers utilize two different electromechanical principles, namely changes in wire tension, which cause changes in the length and temperature of the wire, consequently causing changes in the electrical resistance. The strain meter, joint meter, stress meter, pore pressure cell and reinforced concrete (R-C) meter utilize both principles to measure deformation and temperature changes. In the resistance thermometer, temperature changes are measured by means of the resistance changes of copper wire.	

Measurement Instrument

Movement Carlson Meters

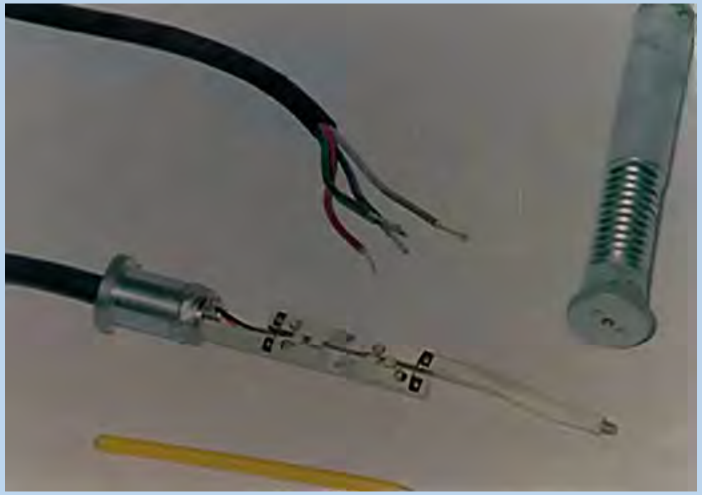
The standard Carlson strain meter can be embedded in concrete or attached to a surface with saddle mounts. This meter measures changes in length (strain) and temperature, with the help of a simple Wheatstone-bridge test set or the Carlson Test Set.

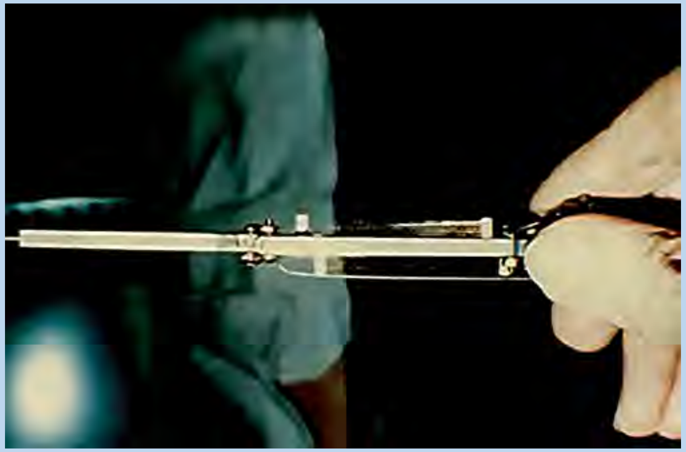
The meter contains two coils of highly elastic steel wire, one of which increases in length and electrical resistance when a strain occurs, while the other decreases.

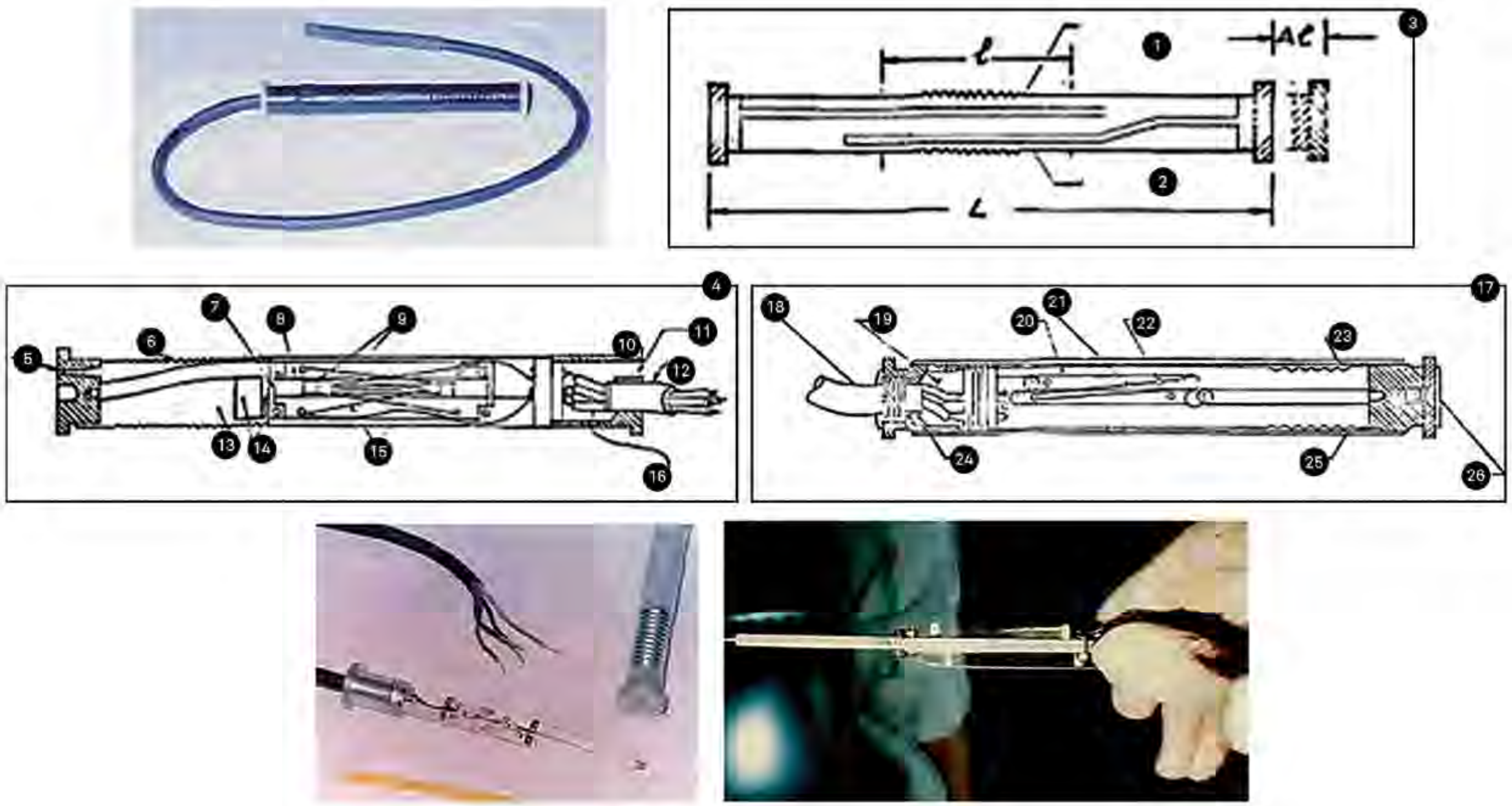
The ratio of the two resistances is independent of temperature (except for thermal expansion); therefore, the change in the resistance ratio is a measure of strain. The total resistance is independent of strain because one coil increases while the other decreases by the same amount, due to the change in the length of the meter. Therefore, the total resistance is a measure of temperature.

Carlson transducer elements with two coils

(By Andriolo, 1975, during a visit to Carlson Instrument - California)

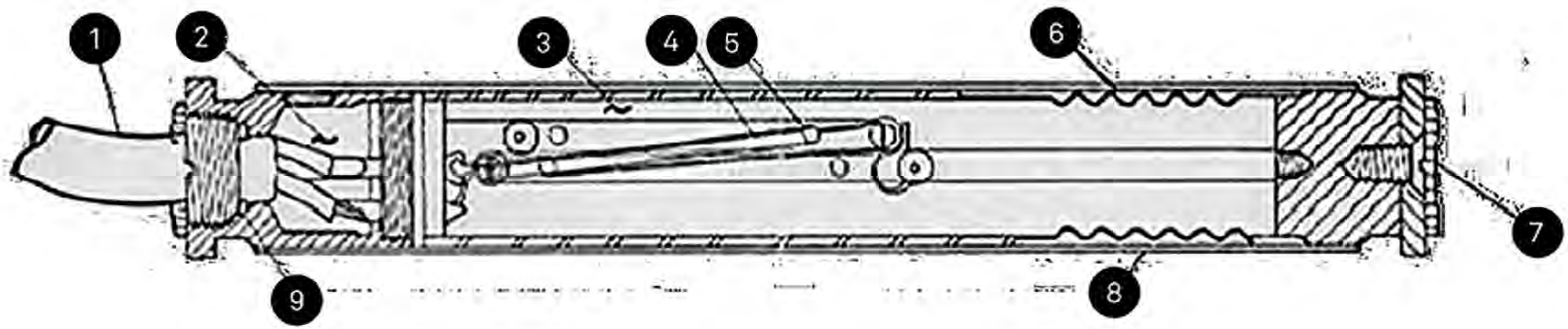




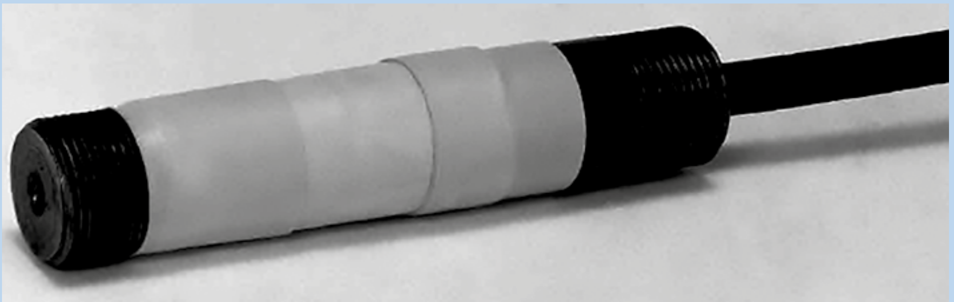


1 Resistance R2	14 Security lock
2 Resistance R1	15 Steel wire
3 Electrical strain meter (Carlson--Kyowa)	16 Seal chamber with insulating composite
4 Strain meter for concrete	17 Strain meter for concrete (Carlson)
5 Plug for oil	18 Conduit
6 Bellows	19 Seal component
7 Steel case	20 Oil
8 Steel bar	21 Elastic strand
9 Ceramic spool	22 Ceramic coil
10 Protection	23 Protection
11 Plug	24 Sealing and fixing ring
12 Conduit	25 PVC tube
13 Filling with oil against corrosion	26 Plastic

Internal aspects of the Carlson strain meter (Carlson Instruments) and a Carlson meter produced by Kyowa - Photo of the demonstration of strain meter done by Prof. Roy W. Carlson - 1975



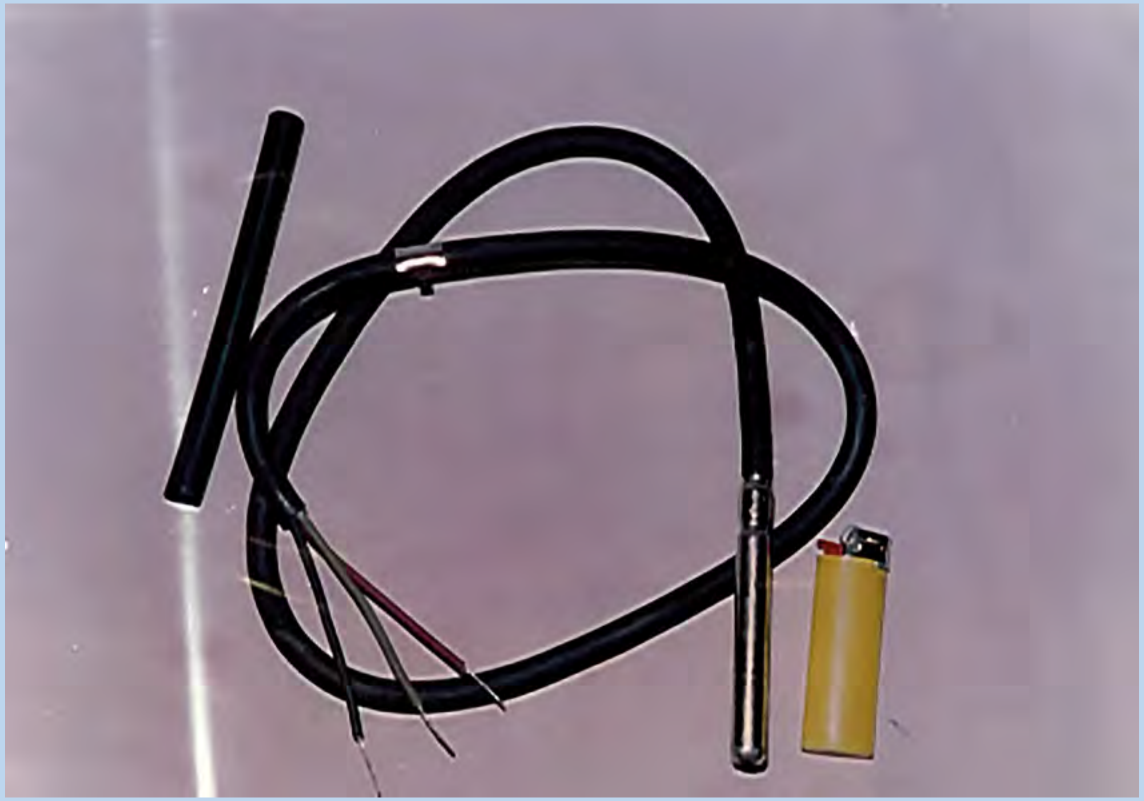
1 Conduit	4 Elastic strand	7 Plastic
2 Seal component	5 Ceramic coil	8 PVC tube
3 Oil	6 Protection	9 Sealing and fixing ring

Measurement Instrument	*Carlson Miniature Strain Meter*
Movement Carlson Miniature Meter	
The miniature meter is embedded in concrete in situations where small size and economy are essential. The principle of operation is essentially similar to the standard strain meter. One feature of the miniature meter is that the basic 100 mm meter can be extended to greater lengths by removing the end flange and adding an extender without disturbing the sensing element, thus increasing its sensitivity. The body of the meter is covered with PVC tubing to prevent bonding to the concrete.	

Measurement Instrument	*Carlson transducer-joint meter (from first instruments catalog)*
Movement Carlson Joint Meter	
The Carlson joint meter is similar to the strain meter except that it has a greater range. This range is accomplished by using a coil spring in series with each of two loops of elastic wire. The joint meter is used primarily to measure the opening of joints. Therefore, it utilizes most of its expansion range. This type of meter measures temperature and expansion or contraction in the same manner as the strain meter.	

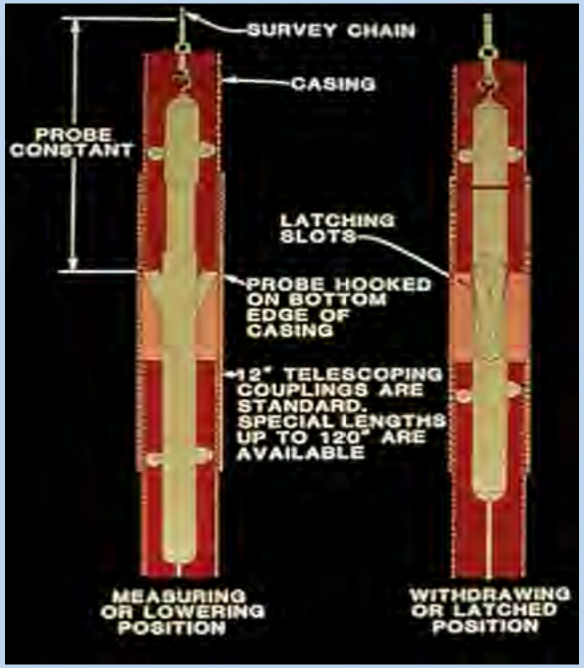
Measurement Instrument	*Carlson stress meters (From CESP By Andriolo, 1985)*
Movement Carlson Concrete Stress Meter	
The Carlson Concrete Stress Meter was designed to be embedded in concrete to measure compressive stress independent of shrinkage, expansion, creep, or changes in the elasticity modulus of the concrete. The Stress Meter was designed to simulate, as nearly as possible, a thin plate with a finite modulus of elasticity. The meter essentially consists of a plate with a strain-meter sensing element mounted on one face.	

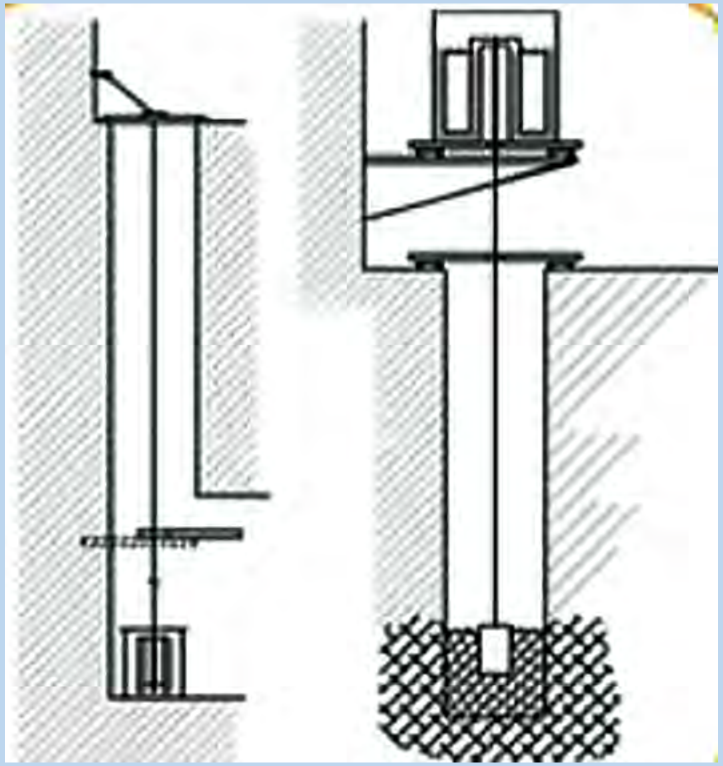
Measurement Instrument	***Carlson Reinforced Concrete Meter (From CESP By Andriolo, 1985)***
Movement Carlson Reinforced Meter	
The reinforced concrete meter (R-C meter) is a device for measuring the strain behavior of reinforced concrete. It consists of a miniature strain meter encased in a thick hollow steel bar. It is embedded in reinforced concrete and measures the average strain over the rod lengths. This gauge measures the average length change; this assessment is important for measuring stress as a function of the distance between threaded anchors at the end of a bar. Conventional strain meters of a shorter length would indicate a different result depending on whether a crack is within the gauge length or just beyond it. Consequently, a strain reading in the meter larger than the strain capacity of the concrete is an indication of a tensile crack in the concrete. Additionally, when the strain is below the tensile strain capacity, the meter indicates both tensile stress in the bar and strain in the concrete.	

Measurement Instrument	*Carlson thermometer (From Itaipu By Andriolo, 1977)*
Temperature Carlson Thermometer	
The Carlson resistance thermometer is especially designed and constructed to be embedded in concrete. The resistance thermometer is simply a non-inductively wound coil of enameled copper wire enclosed in a vinyl mastic cover. The wire is wound on an insulating spool in such a way that there will be no appreciable strain changes as the temperature changes.	

Measurement Instrument	Others With Carlson Transducer
 *Carlson pore pressure meter*	 *Carlson transducer*
 *Total pressure cell with Carlson transducer*	 *Load cells with Carlson transducer*

Carlson transducer meters (From CESP By Andriolo, 1985)

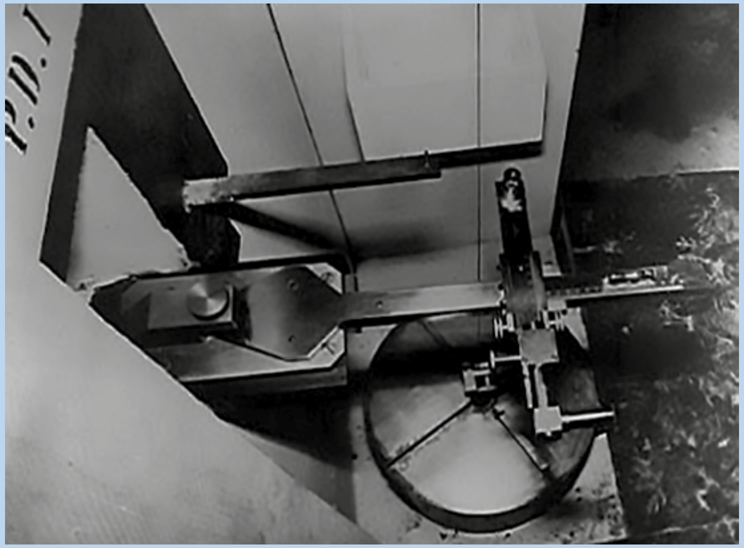
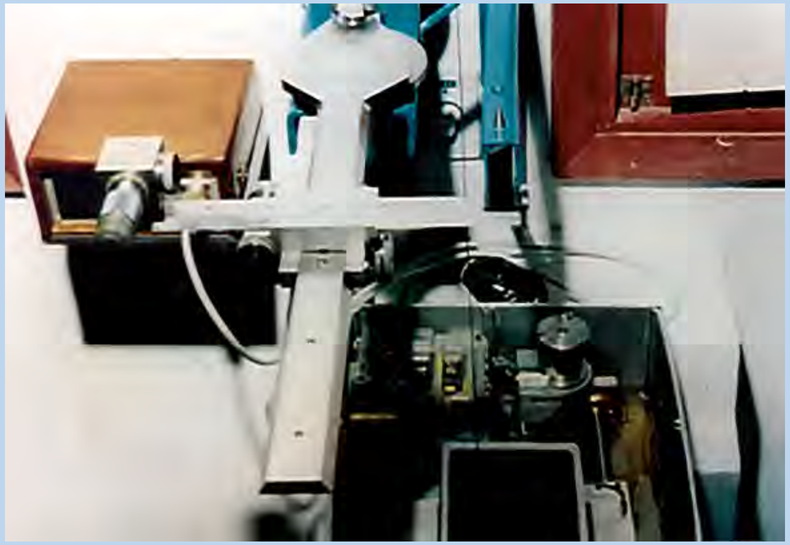
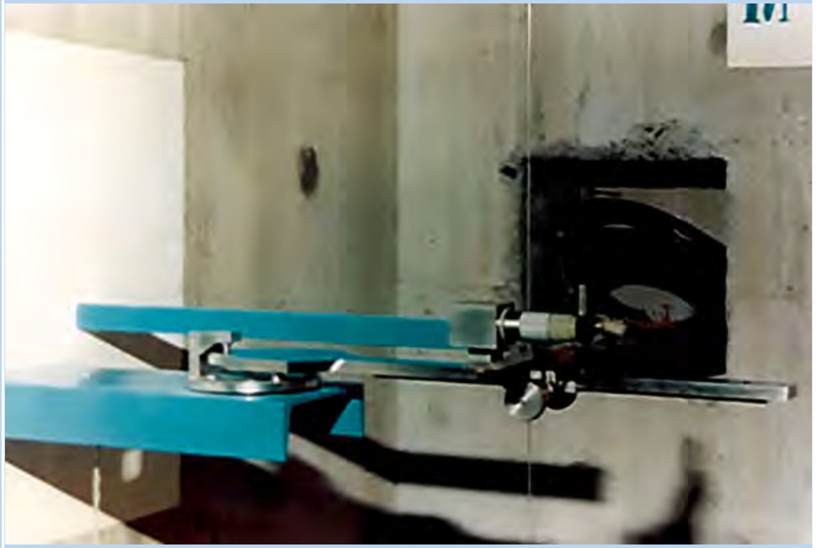
Measurement Instrument	Movement Inclinometers
Inclinometer casings can be used to measure the total or relative horizontal, vertical, or rotational movements or differential movements in any desired plane. Vertical movements, which indicate settlements of a foundation, are commonly the result of some change in foundation materials. The inclinometer settlement system uses the same type of casing that would be installed within drill hole installations.	  

Measurement Instrument	***Schematic of a plumb line use***
Movement Plumb Lines	
Plumb lines, inverted plumb lines, and optical plummets are designed to accurately measure bending, tilting, or deflection of concrete structures resulting from external loading to the structure, temperature changes within the structure, sliding of the structures, or deformation of the foundation. Through the measurement of structural deformations, these instruments furnish information about the general elastic behavior of the entire structure and foundation; provide means for determining the elastic shape of the deflected structure that permits separation of load deflection and thermal deflection components; and, with precise alignment data, allow the estimation of the amount of translation or sliding.	

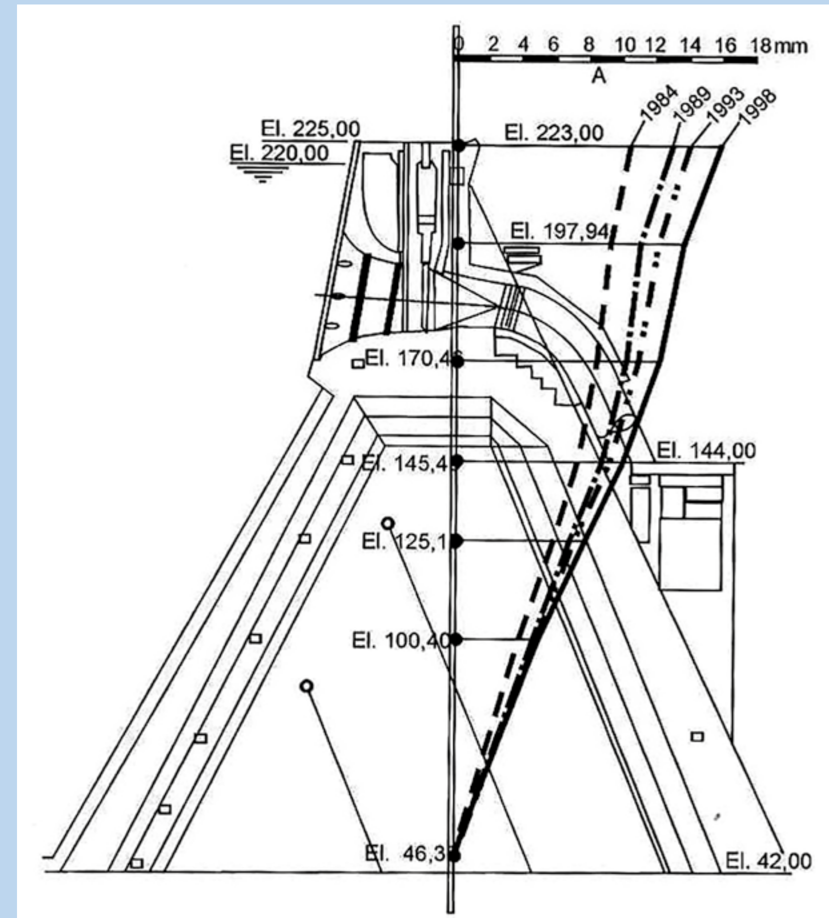
These instruments should be located in structures where unusual structural deflections are anticipated or where information on deflections is required. They should be located in the highest monoliths of the structure and at locations where reading stations are easily accessible.

The conventional type plumb-bob system should be installed in structures where provisions can be made for installing a plumb-bob line near the top of the structure, with a reading station in the lower part of the structure. Reading points should be provided in one or more of the galleries in the lower portion of the structure and at other elevations, if practical, where the position of the plumb line with respect to the structure is measured by a micrometer microscope.

Plumb-bob systems based on an inverted pendulum or deflectometer may be installed in structures where a reading station cannot be constructed near the base of the structure or where it is desired to extend the reference points into the foundation.

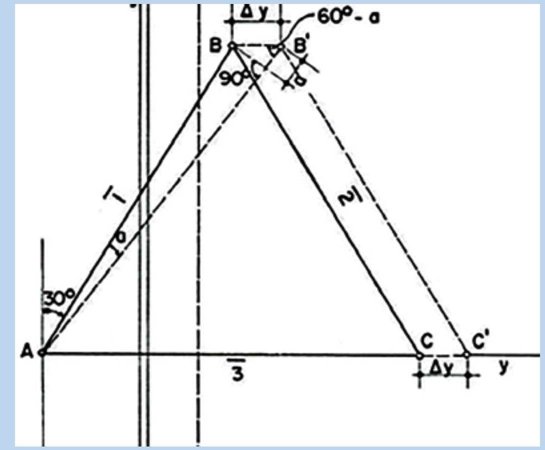
Measurement Instrument	**Movement Plumb Lines**	***Pictures of the Plumb Lines installed i n Itaipu Dam (by Andriolo, 1980)***
		

Measurement Instrument	Movement Plumb Lines	*Pictures of the Plumb Lines installed i n Itaipu Dam (by Andriolo, 1980)*
		

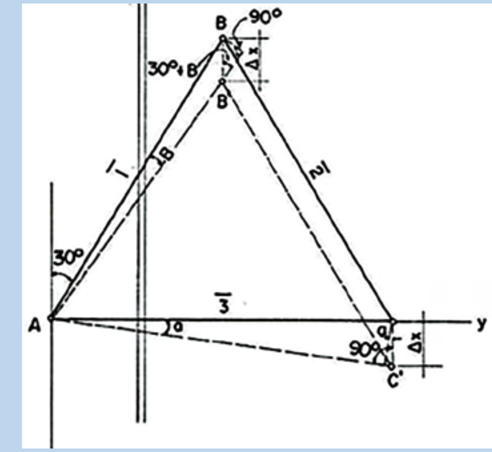
Measurement Instrument Movement Plumb Lines	*Pictures and data from Comparison Between Geodetic Technology Plumb Lines in Monitoring of Displacements of Itaipu Dam (From Firorini A.S and Alli, Lisbon, 2008)*
 	
	

Measurement Instrument

Movement 2D or 3D joint movement meter



Joint Opening

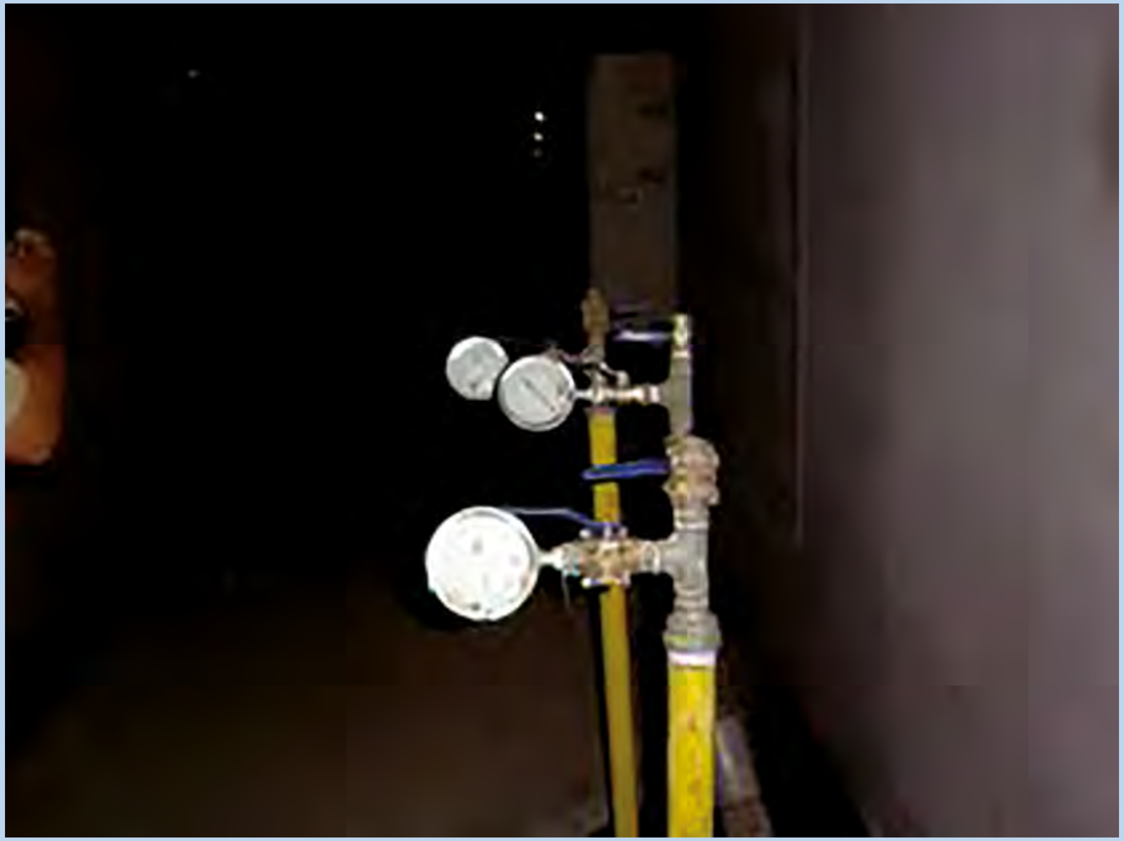


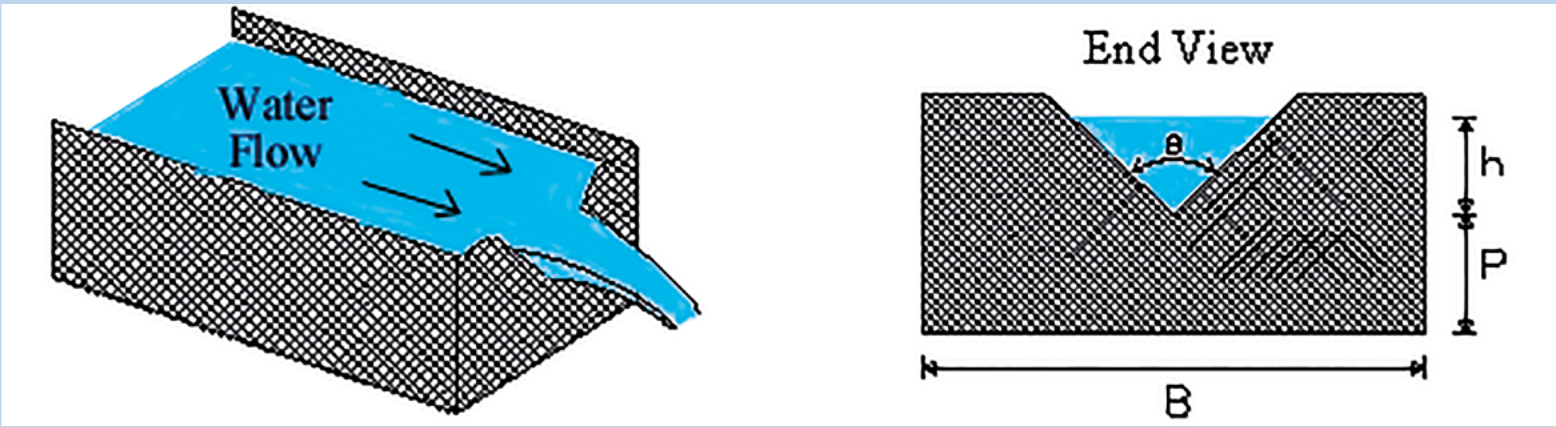
Differential Settlement

2D joint meter at Itaipu Dam (Andriolo's Archive)

Mechanical 3D joint meter (Andriolo's Archive)

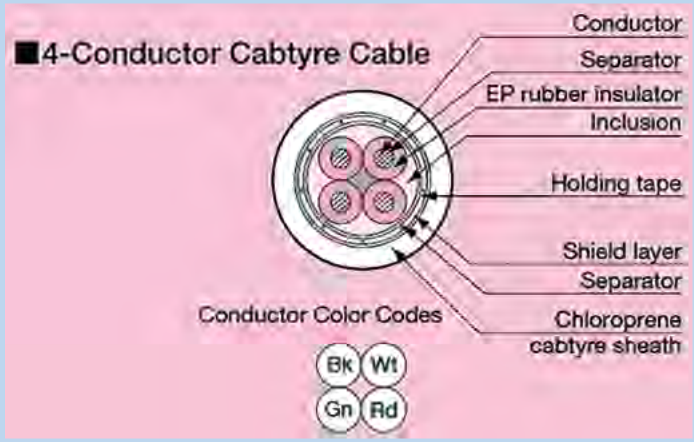
3D joint meter with vibrating wire measuring device

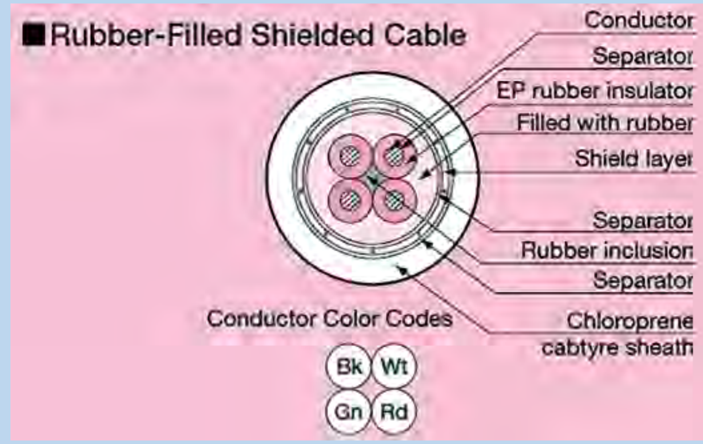
Measurement Instrument	*Piezometer with Bourdon Gauge in Capanda Dam Gallery (by Andriolo, 2012)*
Uplift and Pore Pressure Standpipe Cell	
The simplest and most commonly used type of uplift cell consists of a gravel-filled wooden box installed over a shallow drilled hole containing a pipe tee and two short lengths of perforated pipe. Plain pipe runs from the perforated pipe in the collection box to the reading station on a gallery wall, where the pipe is capped with a gauge adapter coupling and a stopcock. Pressure heads at the cell exceeding the elevation of the reading station are measured by Bourdon-type gauges. Pressure heads at the cell below the gauge elevation are determined by removing the gauge adapter and sounding to the water surface in the pipe or by reading the water level with an indicator.	

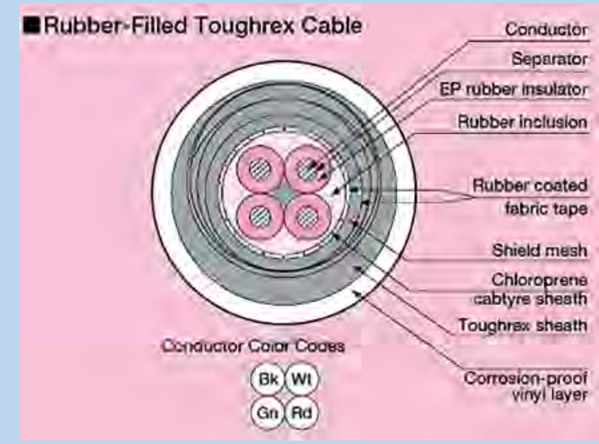
Measurement Instrument	Leakage Vee-notch Weir	*V-notch weir-Flow meter in Capanda Dam Gallery (by Andriolo, 2012)*
		

Weirs are typically installed in open channels (e.g., streams) to determine discharge (flow rate). The basic principle is that discharge is directly related to the water depth above the crotch (bottom) of the V; this distance is called the head (h). The V-notch design causes small changes in discharge to have a large change in depth, thus allowing more accurate head measurement than with a rectangular weir.

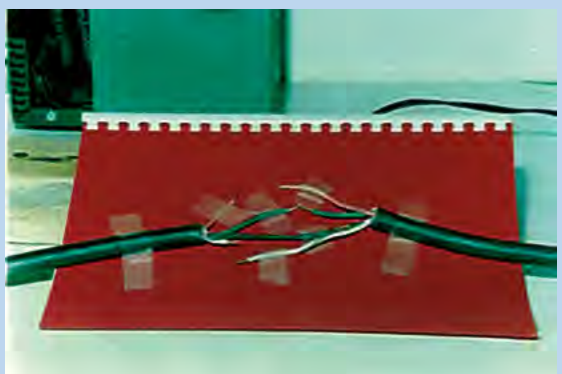
CABLES FOR MONITORING | ***Sequence of cable extensions for Carlson Meters used for Itaipu Dam (From Andriolo's Archive, 1977)***

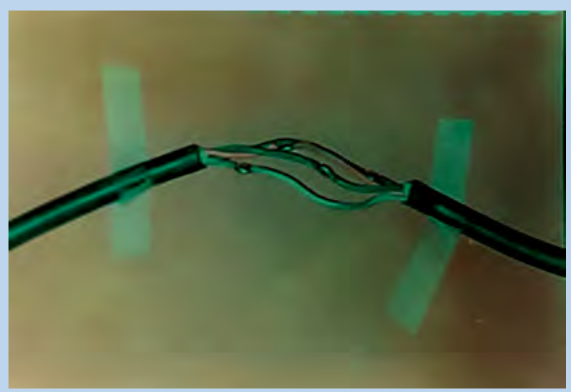


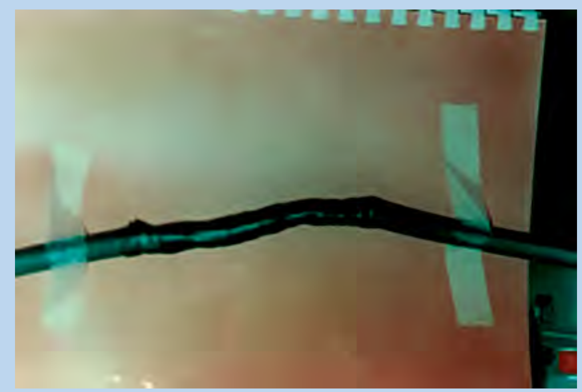




Recommended Cable System for Kyowa instruments



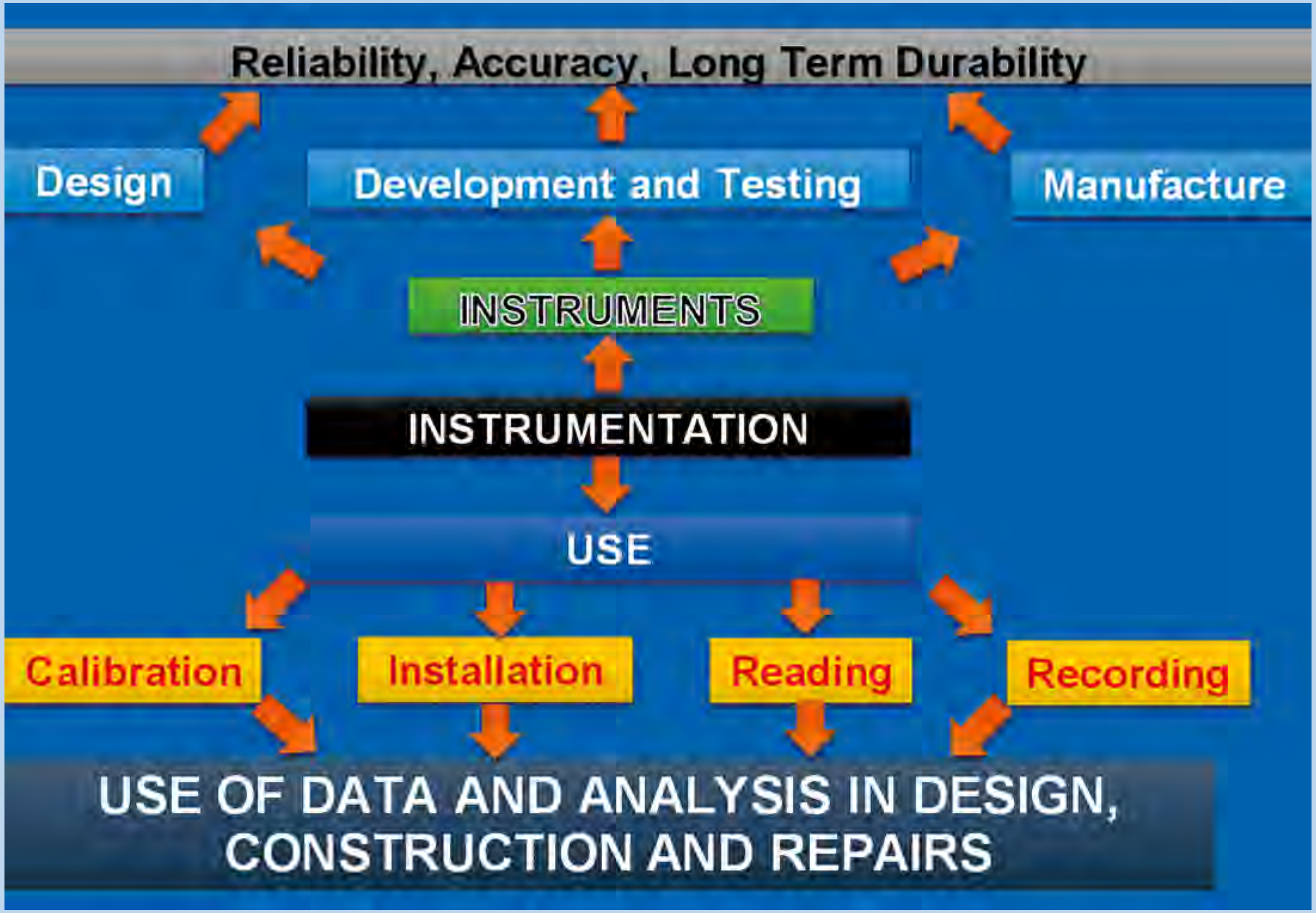




Sequence of cable extensions for Carlson Meters used for Itaipu Dam (From Andriolo's Archive, 1977)

CALIBRATION OF THE INSTRUMENTS

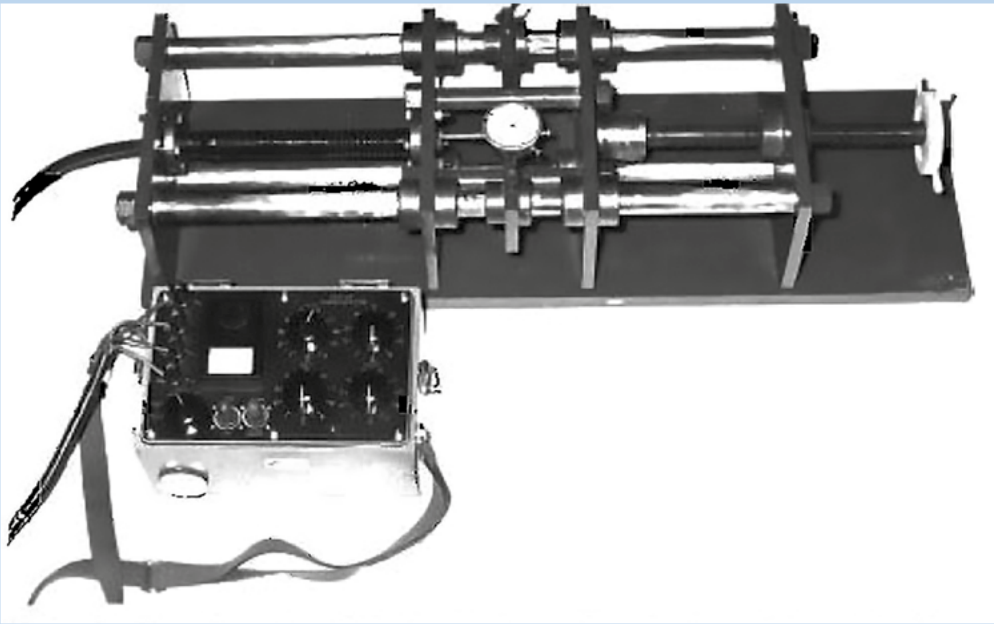
Instruments must be calibrated before installation. Measurement systems that are generally limited to errors of a fraction of a percentage of full-scale output under laboratory conditions do not need to provide this level of accuracy in field use. Total errors of a few percentage points can be tolerated in most cases. A schematic flow can be considered.



A routine of regular maintenance of instruments, readout devices, and field terminals should be established. For many instruments, manufacturers will suggest maintenance procedures and schedules that should be followed unless there is adequate justification to alter them. Periodic review of the calibration of all instruments is necessary to provide accurate data. Detailed measurements and careful evaluation of data has little value, and may be misleading, if the data is inaccurate. The nature and frequency of calibration depends on the specifics of the instrumentation and should be developed on a case-by-case basis.

CALIBRATION OF THE INSTRUMENTS

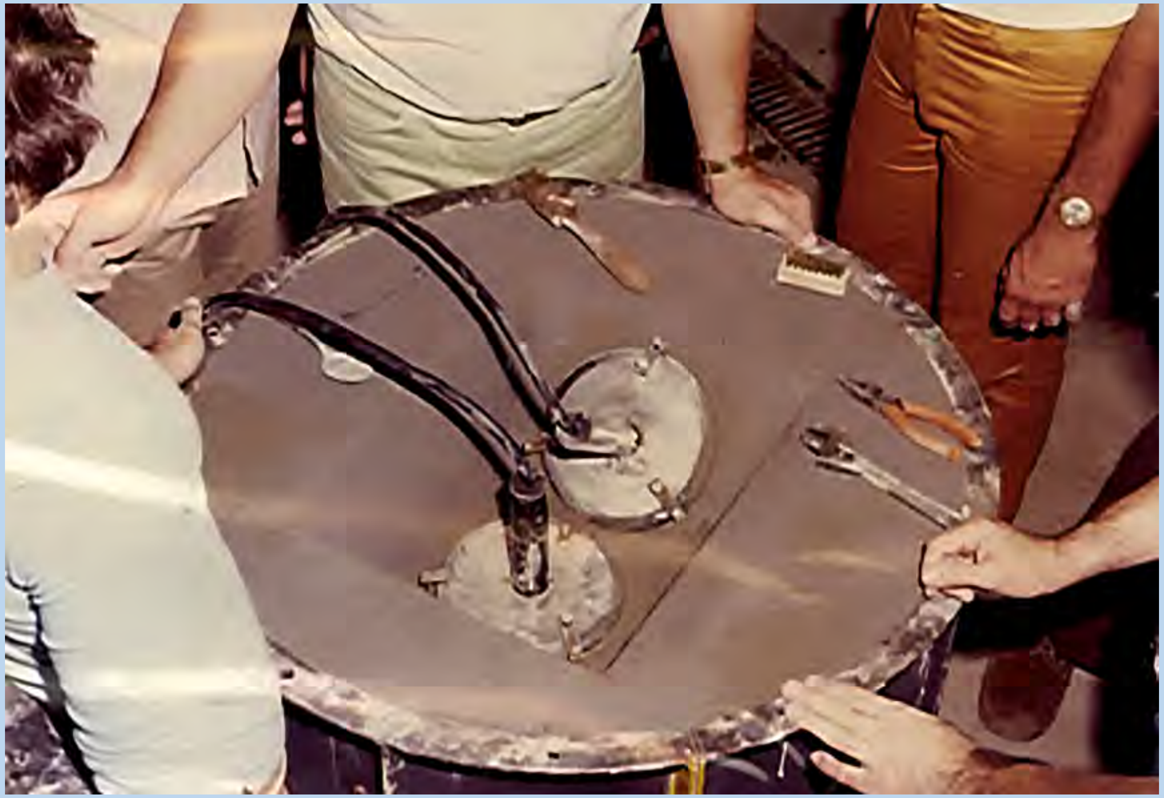
- ***Environmental sensitivity***. Most transducers are sensitive to temperature. At the extreme, there is a survival temperature range. In particular, a maximum survival temperature beyond which the transducer is likely to suffer permanent distortion or damage.



Device with a dial gauge to perform the calibration of the Carlson Strain Meter used at Ilha Solteira, Itaipu and Tucuruí Laboratories (From Andriolo's Archive)

Due to the large amount of instruments used in the Itaipu Project between 1977 and 1979, several studies were conducted on a body of large dimensions (450 * 900 mm and 900 * 2500 m) to assess various types of instruments, thus aiding in their calibrations.

CALIBRATION OF THE INSTRUMENTS



Fixing the strain meters in the mold and casting part of the specimen with a set of stress meters at Itaipu Laboratory (From Andriolo's Archive, 1978)

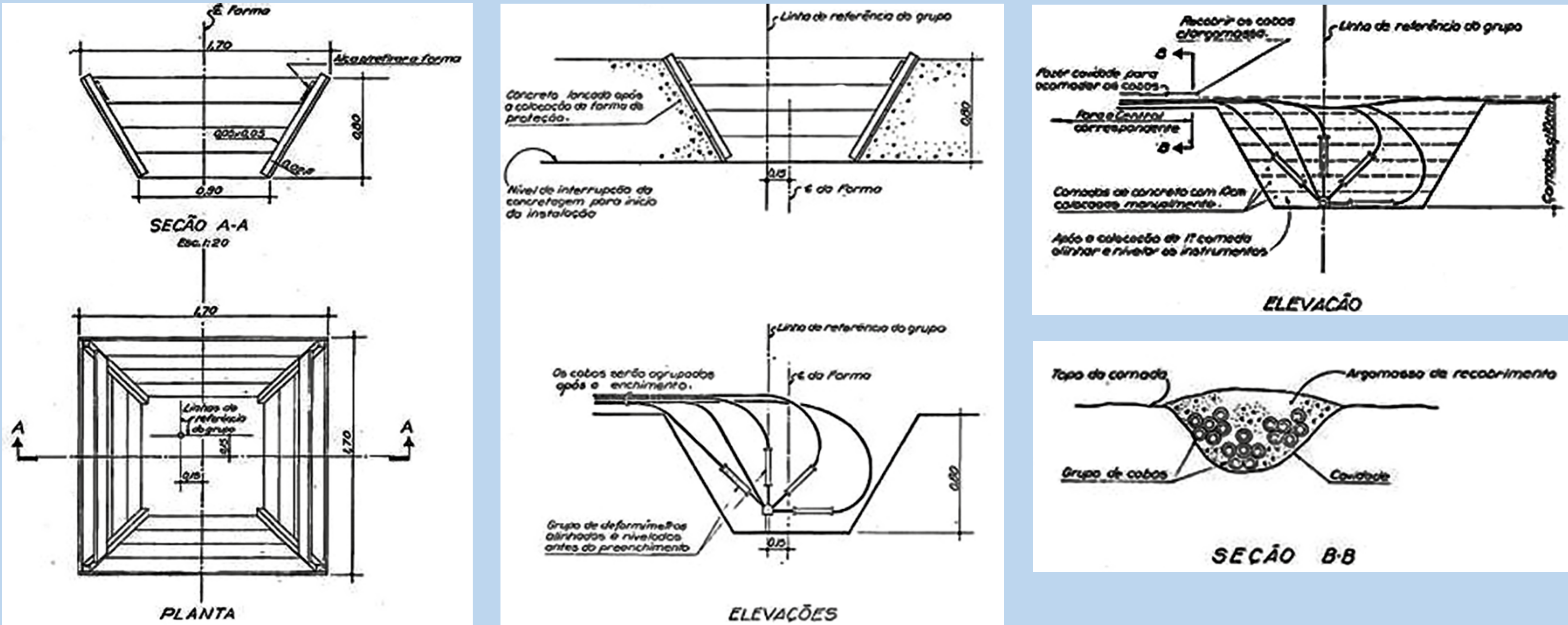
CALIBRATION OF THE INSTRUMENTS


Testing the large specimen with different the transducer meters at Itaipu Laboratory and a view after test (From Andriolo's Archive, 1978)

INSTALLING THE INSTRUMENTS

A model with a strain meter spider and autogenous box for training at Itaipu Laboratory (From Andriolo's Archive)

Illustration of the installation of a strain meter spider



INSTALLING THE INSTRUMENTS



Sequence of installation of a strain meter spider and autogenous box in the mass concrete at Itaipu Project (From Andriolo's Archive, 1978)

INSTALLING THE INSTRUMENTS

Installation of a strain meter spider and autogenous box in a confined zone at Tucurui Project (From Andriolo's Archive, 1982)

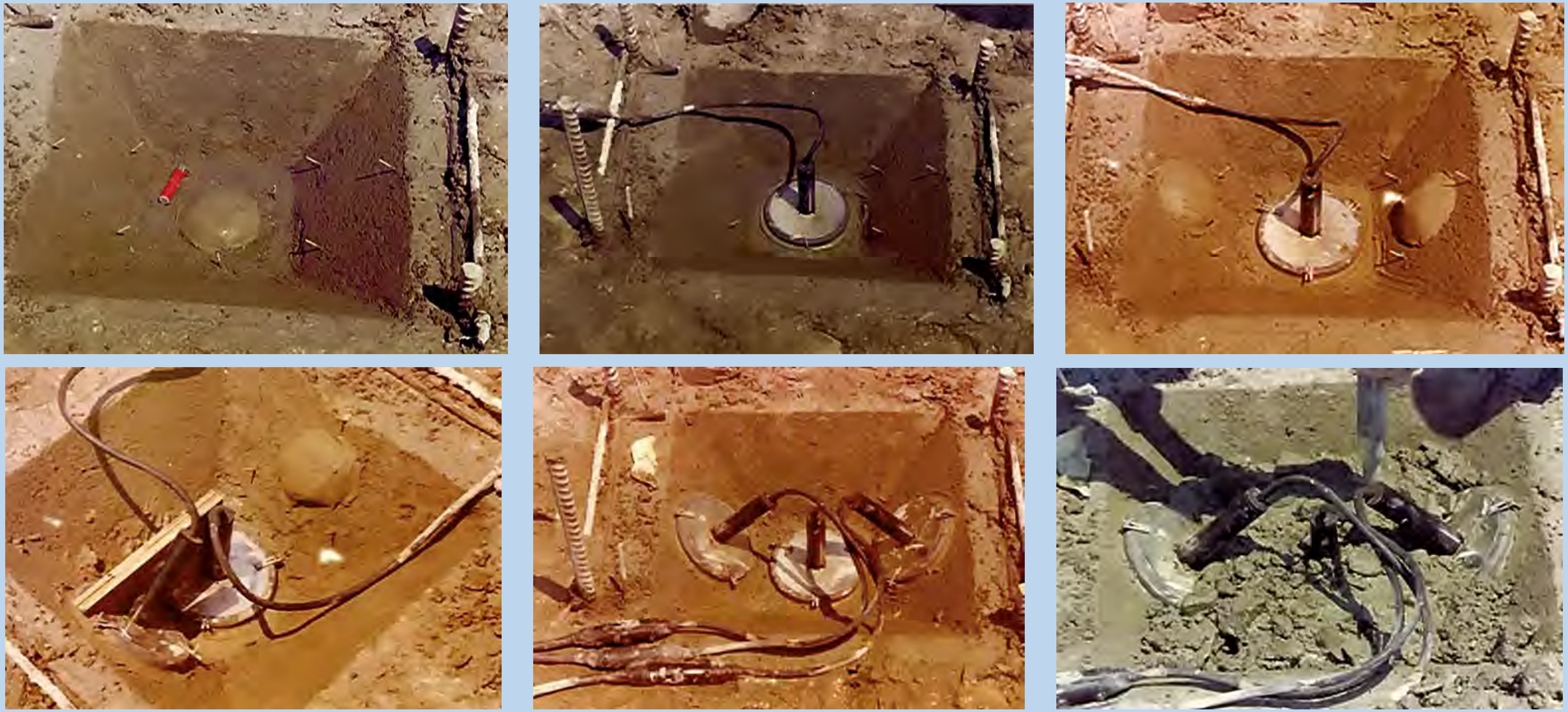
Installation specifications should include detailed step-by-step procedures for installing and testing instruments.

The installation should include an installation log to document "as-built" conditions. Where appropriate calibration measurements, performance testing, and initial readings should be obtained during installation.

Consideration should be given to the level of the contractor's experience with installing similar instruments in similar conditions.

A quality assurance program should be included in the specification. Drilling to install instruments can potentially damage existing structures.

INSTALLING THE INSTRUMENTS



Sequence of installation of a stress meter set in the mass concrete at Itaipu Project (From Andriolo's Archive, 1978)

INSTALLING THE INSTRUMENTS

Installation of a reinforced meter in a reinforced concrete at the Itaipu Power House (From Andriolo's Archive, 1980)

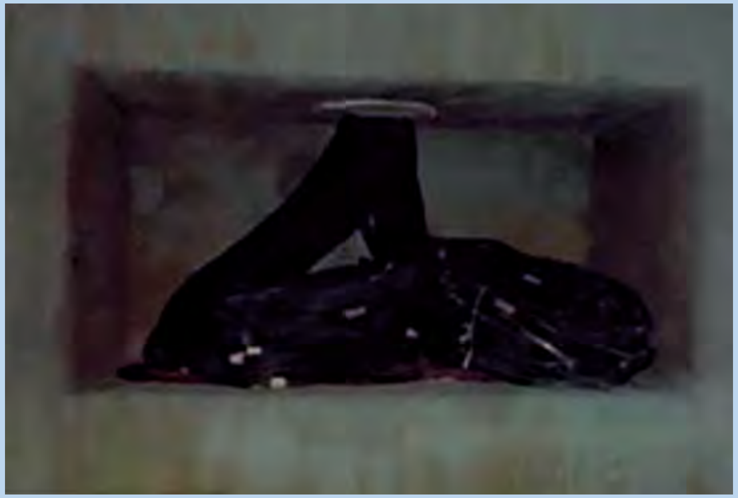
Automatic data acquisition is becoming more common. The steps required to process and evaluate data, whether collected manually or automatically, are the same. Each structure is instrumented with a data logger.

These last decades have seen many advances in sensor technology, data acquisition equipment, and data management that have made automated data acquisition more reliable, cost-effective, and readily available for broader applications in safety monitoring.

An automated data-acquisition system (ADAS) can range from a simple data logger temporarily connected to one or more instruments to a permanent system.

This provides the opportunity to measure in short intervals. In this manner, delayed effects of temperature and moisture fluctuation on expansion can be considered. Once a day, the data logger sends all measurements to a central database. Each data logger has sufficient backup capacity in case of disturbances in data communication.

DATA ACQUISITION AND READINGS- ***(From Andriolo's Archive, 1978)***

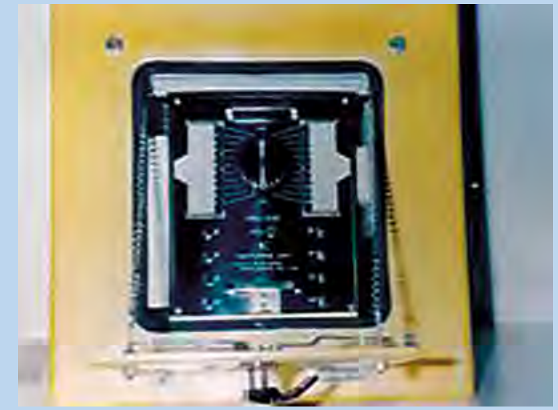


Visualization of the arrival of cables to the installation recess of the connection terminal

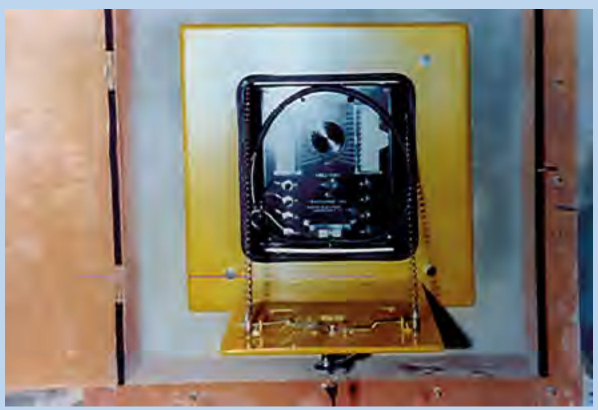
Visualization of the connection of cables to the connection terminal

DATA ACQUISITION AND READINGS- ***(From Andriolo's Archive, 1978)***

Insulation and sealing of connections in the terminal switchbox



Front view of the terminal switchbox for connection of the reading device



Additional cover case involving the terminal switchbox

Universal reading gage Apparatus

10.9 Visual Inspection and Relevant Aspects

10.9.1 Important Aspects to Note

Visual inspection performed on a regular basis is one of the most economical means a dam owner can use to observe the safety and long life of a dam and its immediate environment. Visual inspection is a straightforward procedure that can be used by any properly trained person to make a reasonably accurate assessment of a dam's condition. The inspection involves careful examination of the surface and all parts of the structure, including its adjacent environment. The equipment required is not expensive, and the inspection can usually be completed in less than one day. The aspects to be noted are described ahead[10-14].

REQUIRED INSPECTION AND ACTIONS [10-14]	ALIGNMENT	ANIMAL BURROWS	CRACKS	DEBRIS	DETERIORATION	EROSION AND WAVE	HUMAN ACTIVITY	LEAKAGE	MUDDY WATER	SEEPAGE	SETTLEMENT AND SLIDES	VEGETATION	WEATHERING
FEATURE													
EMBANKMENT DAM													
Upstream Slope	X	X	X			X	X				X	X	X
Downstream Slope	X	X	X			X	X	X	X	X	X	X	
Abutments		X	X					X	X	X	X	X	
Crest	X	X				X					X	X	
Seepage Areas								X	X	X		X	
Internal Drainage					X			X	X				
Relief Drains	X		X		X			X	X				

REQUIRED INSPECTION AND ACTIONS [10-14]	ALIGNMENT	ANIMAL BURROWS	CRACKS	DEBRIS	DETERIORATION	EROSION AND WAVE	HUMAN ACTIVITY	LEAKAGE	MUDDY WATER	SEEPAGE	SETTLEMENT AND SLIDES	VEGETATION	WEATHERING
FEATURE													
CONCRETE DAM													
Upstream Face			X		X						X		X
Downstream Face			X		X			X		X	X		X
Abutments			X		X			X		X	X	X	X
Crest	X		X		X						X		X
Internal drainage system					X								
Relief drains					X								
Galleries			X		X			X		X			
Sluiceways/controls					X								

REQUIRED INSPECTION AND ACTIONS [10-14]	ALIGNMENT	ANIMAL BURROWS	CRACKS	DEBRIS	DETERIORATION	EROSION AND WAVE	HUMAN ACTIVITY	LEAKAGE	MUDDY WATER	SEEPAGE	SETTLEMENT AND SLIDES	VEGETATION	WEATHERING
FEATURE													
SPILLWAYS													
Approach channel				X		X		X				X	
Inlet/outlet structure			X	X	X	X	X	X		X	X	X	X
Stilling basin						X							
Discharge conduit/channel				X	X						X	X	
Control features				X	X								
Erosion protection							X				X		
Side slopes			X			X		X			X	X	
INLETS, OUTLETS & DRAINS													
Inlet/outlet structure	X			X	X			X				X	
Stilling basin					X	X							
Discharge conduit/channel			X	X		X						X	
Trash Rack/Debris Control				X									
Emergency systems					X		X						

REQUIRED INSPECTION AND ACTIONS [10-14]	ALIGNMENT	ANIMAL BURROWS	CRACKS	DEBRIS	DETERIORATION	EROSION AND WAVE	HUMAN ACTIVITY	LEAKAGE	MUDDY WATER	SEEPAGE	SETTLEMENT AND SLIDES	VEGETATION	WEATHERING
FEATURE													
GENERAL AREAS													
Reservoir surface						X	X	X		X	X		
Mechanical /Electrical systems					X								
Shoreline											X	X	
Upstream watershed							X						
Downstream Flood Plains							X						

REQUIRED INSTRUMENTATION AND MONITORING [10-14]	VISUAL OBSERVATION	MOVEMENTS	UPLIFT PORE PRESSURE	WATER LEVELS & FLOW	SEEPAGE FLOWS	WATER QUALITY	TEMPERATURE MEASUREMENTS	CRACK AND JOINT MEASUREMENTS	SEISMIC MEASUREMENTS	STRESS-STRAIN MEASUREMENTS
EMBANKMENT & TAILING DAMS (no upstream incremental method)										
Upstream Slope	X	X		X					X	
Downstream Slope	X	X	X		X	X		X	X	
Abutments	X	X	X		X	X			X	
Crest	X	X						X	X	
Internal drainage system			X		X	X				
Relief drains	X		X		X					
Riprap & Slope protection	X									

REQUIRED INSTRUMENTATION AND MONITORING [10-14]	VISUAL OBSERVATION	MOVEMENTS	UPLIFT PORE PRESSURE	WATER LEVELS & FLOW	SEEPAGE FLOWS	WATER QUALITY	TEMPERATURE MEASUREMENTS	CRACK AND JOINT MEASUREMENTS	SEISMIC MEASUREMENTS	STRESS-STRAIN MEASUREMENTS
CONCRETE DAM										
Upstream Slope	X	X		X			X	X	X	X
Downstream Slope	X	X	X				X	X	X	X
Abutments	X	X	X		X	X			X	X
Crest	X	X	X				X	X	X	X
Internal drainage system			X		X			X		
Relief drains	X		X		X					
Galleries	X		X					X	X	X
Sluiceways/controls	X			X						

REQUIRED INSTRUMENTATION AND MONITORING [10-14]	VISUAL OBSERVATION	MOVEMENTS	UPLIFT PORE PRESSURE	WATER LEVELS & FLOW	SEEPAGE FLOWS	WATER QUALITY	TEMPERATURE MEASUREMENTS	CRACK AND JOINT MEASUREMENTS	SEISMIC MEASUREMENTS	STRESS-STRAIN MEASUREMENTS
SPILLWAYS										
Approach channel	X	X		X						
Inlet/outlet structure	X	X	X	X	X					
Stilling basin	X			X				X	X	
Discharge conduit/channel	X		X	X				X		
Control features	X									
Erosion protection	X									
Side slopes	X	X	X		X					

REQUIRED INSTRUMENTATION AND MONITORING [10-14]	VISUAL OBSERVATION	MOVEMENTS	UPLIFT PORE PRESSURE	WATER LEVELS & FLOW	SEEPAGE FLOWS	WATER QUALITY	TEMPERATURE MEASUREMENTS	CRACK AND JOINT MEASUREMENTS	SEISMIC MEASUREMENTS	STRESS-STRAIN MEASUREMENTS
OUTLETS & DRAINS										
Inlet/outlet structure	X	X	X	X				X	X	
Stilling basin	X									
Discharge conduit/channel	X	X	X	X				X		
Trash Rack/Debris Control	X									
Emergency systems	X									
GENERAL AREAS										
Reservoir surface	X					X				
Mechanical /Electrical systems	X			X						
Shoreline	X					X				
Upstream watershed	X					X				
Downstream Channel	X				X	X				

EMBANKMENT AND STRUCTURES	
Upstream slope	The first three conditions may indicate serious problems within the embankment. Severe erosion can noticeably weaken the structure. An upstream slope should receive a close inspection because riprap and high water levels can hide problems (when walking on riprap, caution should be used to avoid personal injury). When a reservoir is emptied, the exposed slope should be thoroughly inspected for settlement areas, rodent activity, sinkholes, or slides. Also, the reservoir basin (bottom of the reservoir) should be inspected for cave-ins or sinkholes and landslides. Again, most importantly, a crisscross path should be used when inspecting the slope, so that cracks and slides can be easily identified. In many instances, sighting along the waterline alignment will indicate a change in the uniformity of the slope. An inspector should stand at one end of the dam and sight along the waterline checking for straightness and uniformity. If a crack is seen, the crest and downstream slope in its immediate area should be carefully inspected. Cracks indicate possible foundation movement, embankment failure, or a surface slide. Locating them can be difficult. Cracks can be less than an inch in width, but still several feet deep. A line of recently dislodged riprap on an upstream slope could indicate a crack below the riprap. Slides can be almost as difficult to detect as cracks. When a dam is constructed, the slopes may not be uniformly graded. Familiarity with the slope configuration at the end of construction can help identifying subsequent slope movements. Moreover, the appearance of slides may be subtle. Dated photographs are particularly helpful in detecting such changes. Sinkholes or cave-ins result from internal erosion of the dam - a very serious condition for earthen embankments. The internal erosion, or piping, may be reflected by turbid seepage water on exit. Surface soil materials may be eroded by wave action, rain runoff, and burrow activities. If allowed to continue, the embankment thickness can be reduced, and the structure weakened.

EMBANKMENT AND STRUCTURES	
Downstream Slope	A downstream slope should be inspected carefully because it is the area where evidence of developing problems appears most frequently. To assure adequate inspection, this area should be kept free from obscuring weeds, brush, or trees. When cracks, slides or seepage are noted in the downstream slope, the designated dam safety authorities should be notified immediately. Cracks can indicate settlement, drying and shrinkage, or the development of a slide. Whatever the cause, cracks should be monitored and changes in length and width noted. Drying cracks may appear and disappear seasonally and normally will not show vertical displacement as will settlement cracks or slide cracks. Slides require immediate detailed evaluation.
SPILLWAYS	The main function of a spillway is to provide a safe exit for excess water in a reservoir. If a spillway is of inadequate size, a dam could be overtopped and fail. Similarly, defects in a spillway can cause failure by rapid erosion. A spillway should always be kept free of obstructions, have the ability to resist erosion, and be protected from deterioration. Because dams represent a substantial investment and spillways make up a major part dam safety and of dam costs, a conscientious annual maintenance program should be pursued not only to protect the public, but the structures itself. Inadequate capacity is determined by several factors, such as few hydrological data, inadequate hydrological studies, and design criteria used in the drainage area served, as well as the magnitude or intensity of storms in the watershed, storage and capacity of the reservoir, and the speed at which rainwater flows and fills the reservoir. An inadequate spillway can cause the water in a reservoir to overtop the dam. Obstructions of a spillway may result from excessive growth of grass and weeds, thick brush, trees, debris, or landslide deposits. An obstructed spillway can have a substantially reduced discharge capacity which can lead to overtopping of the dam. Grass is usually not considered an obstruction; however, tall weeds, brush, and young trees should be periodically cleared from spillways.

EMBANKMENT AND STRUCTURES	
SPILLWAYS	Similarly, any substantial amount of soil deposited in a spillway - whether from sloughing, landslide, or sediment transport - should be immediately removed. Timely removal of large rocks is especially important, since they can obstruct flow and encourage erosion. Erosion of a spillway may occur during a large storm when large amounts of water flow for many hours. Severe damage of a spillway or complete wash-out can result if the spillway cannot resist erosion. If a spillway is excavated out of a rock formation or lined with concrete, erosion is usually not a problem. However, if a spillway is excavated in soft materials, erosion protection is very important. Generally, resistance to erosion can be increased if a spillway channel has a mild slope, or if it is covered with a layer of grass or riprap with bedding material. A spillway cannot be expected to perform properly if it has deteriorated. Remedial action must be taken as soon as any sign of deterioration has been detected Drying cracks in an earth spillway channel are usually not regarded as a functional problem. However, missing rocks in a riprap lining can be considered a “crack” in the protective cover and must be repaired at once. Cracks in concrete lining of a spillway are commonly encountered. These cracks may be caused by uneven foundation settlement, shrinkage, slab displacement, or excessive earth or water pressure. Large cracks will allow water to wash out fine material below or behind the concrete slab, causing erosion, more cracks, and even severe displacement of the slab. The slab may even be dislodged and washed away by the flow. A severely cracked concrete spillway should be examined and repaired under the supervision of an engineer. Undermining of a spillway causes erosion at a spillway outlet, whether it be a pipe or overflow spillway, it is one of the most common spillway problems. Severe undermining of the outlet can displace sections of pipe, cause slides in the downstream embankment of the dam and eventually lead to complete failure of a dam. Water must be conveyed safely from the reservoir to a point downstream of the dam without endangering the spillway itself or the embankment. Often the spillway outlet is adequately protected for normal flow conditions, but not for extreme flows. It is easy to misestimate the energy and force of flowing water and the resistance of outlet material (earth, rock, concrete, etc.).

EMBANKMENT AND STRUCTURES	
SPILLWAYS	The required level of protection is difficult to establish by visual inspection but can usually be determined by hydraulic calculations performed by a professional engineer. The following four factors, often interrelated, contribute to erosion at the spillway outlet: 1. Flows that emerge from the outlet are above the stream channel. If outlet flows emerge at the correct elevation, tailwater in the stream channel can absorb a substantial amount of the high velocity, and the flow and the hydraulic energy will be reduced in the stilling basin; 2. Flows emerging from the spillway are generally free of sediment and therefore have substantial sediment carrying capacity. When obtaining sediment, moving water will scour soil material from the channel and leave eroded areas. Such erosion is difficult to design for and requires protection of the outlet for a safe distance downstream from the dam; 3. Flows leaving the outlet at high velocity can create negative pressure that can cause material to be loosened and removed from the floor and walls of the outlet channel. This action is called “cavitation” when it occurs on concrete or metal surfaces. Venting can sometimes be used to relieve negative pressures; 4. Water leaking through pipe joints and/or flowing along a pipe from the reservoir may weaken the soil structure around the pipe. Inadequate compaction adjacent to such structures during construction can compound this problem. Spillway inspection is an important part of a dam safety program. The basic objective of it is to detect any sign of obstruction, erosion, deterioration, misalignment, or cracking. When inspecting an earth spillway, one should determine whether side slopes have sloughed, whether there is excessive vegetation in the channel, and if there are signs of erosion and rodent activity. A probe also be used to determine the hardness and moisture content of the dam, which may run at an angle to the major axes of the dam and may exhibit abrupt changes in direction. These cracks can also have noticeable radial, transverse, or vertical displacement.

EMBANKMENT AND STRUCTURES	
SPILLWAYS	Concrete dams transfer a substantial load to the abutments and foundation. Although the concrete of a dam may endure, the natural abutments or foundation may crack, crumble, or move in a massive slide. If this occurs, support for the dam is lost, and it fails. Impending failure of the foundation or abutments may be difficult to detect because initial movements are often very small. Severe deterioration can result from a chemical reaction between alkali present in cements and certain forms of silica present in some aggregate. This chemical reaction produces byproducts of silica gels which cause expansion and loss of strength within concrete. Alkali reaction is characterized by certain observable conditions such as cracking (usually a random pattern on a fairly large scale), and by excessive internal and overall expansion. Additional indications include the presence of a gelatinous exudation or whitish amorphous deposits on the surface, and a chalky appearance of freshly fractured concrete. The alkali-aggregate reaction takes place in the presence of water. Surfaces exposed to the elements or dampened by seepage will deteriorate more rapidly. Once suspected, the condition can be confirmed by a series of tests performed on core samples drilled from a dam. Although the deterioration is gradual, alkali aggregate reaction cannot be economically corrected by any means now known. Continued deterioration may require total replacement of a structure. Inspection of a concrete dam is similar to that of an earth dam. However, the following additional items should be considered. o Access and safety; o Monitoring; o Outlet system; o Cracks at construction and expansion joints;

EMBANKMENT AND STRUCTURES	
SPILLWAYS	○ Shrinkage cracks; ○ Deterioration due to spalling; ○ Minor leakage. Access and safety are important because the faces of concrete dams are often nearly vertical, and the sites are commonly steep-walled rock canyons. Access to the downstream face, toe area, and abutments of such dams may be difficult and require special safety equipment such as safety ropes, or a boatswain's chair. Concrete dams pose a special problem for the dam owner because of the difficulty in gaining close access to the steep surfaces. Regular inspection with a pair of powerful binoculars can initially identify areas where change is occurring. When these changes are noted, a detailed close-up inspection should be conducted. Close inspection of the upstream face may also require a boatswain's chair or a boat. Monitoring helps detect structural problems in concrete dams such as cracks in the dam, abutments, or foundation. Cracks may develop slowly at first, making it difficult to determine if they are widening or otherwise changing overtime. If a structural crack is discovered, it should be monitored for changes in width, length, and offset, and a monitoring network of instruments should be installed and read on a regular basis. Outlet system deterioration is a problem for all dams, but the frequency of such damage may be higher in concrete dams because of their greater average hydraulic pressure. Thus, outlet system inspection should be emphasized for large concrete dams. Cracks at construction joints exist because concrete dams are built in segments, while expansion joints are built into dams to accommodate volumetric changes which occur in the structures after concrete placement. The latter are referred to as "designed" cracks. These joints are typically constructed so that no bond or reinforcing, except non-bonded waterstops and dowels, extend across the joints.

EMBANKMENT AND STRUCTURES	
SPILLWAYS	Shrinkage cracks often occur when, during original construction, irregularities or pockets in the abutment contact are filled with concrete and are not allowed to fully cure prior to placement of adjacent portions of the dam. Subsequent shrinkage of the concrete may lead to irregular cracking at or near the abutment. Shrinkage cracks are also caused by temperature variation. During winter months, the upper portion of a dam may become significantly colder than those portions which are in direct contact with reservoir water. This temperature differential can result in cracks which extend from the crest for some distance down each face of the dam. These cracks will probably occur at construction or expansion joints, if these are provided. Shrinkage cracks can be a sign that certain portions of the dam are not carrying the design load. In such cases, the total compression load must be carried by a smaller percentage of the structure. It may be necessary to restore load-carrying capability by grouting affected areas. This work requires the assistance of an engineer. Spalling is the process by which concrete chips and breaks away as a result of freezing and thawing. Almost every concrete dam in colder climates experiences continued minor deterioration due to spalling. Because it usually affects only the surface of a structure, it is not ordinarily considered dangerous. However, if allowed to continue, spalling can result in structural damage, particularly if a dam is of thin cross section. Also, repair is necessary when reinforcing steel becomes exposed. The method of repair of spalled areas depends upon the depth of the deterioration. Minor leakage through concrete dams, although unsightly, is not usually dangerous, unless accompanied by structural cracking. The effect may be to promote deterioration due to freezing and thawing. However, increases in seepage could indicate that, through chemical action, materials are being leached from the dam and carried away by the flowing water. Dam owners should note that decreases in seepage could also occur as mineral deposits are formed in portions of the seepage channel. In either case, the condition is not inherently dangerous and detailed study is required before it can be determined whether repair is necessary for reasons other than aesthetics.

EMBANKMENT AND STRUCTURES	
Crest	A dam's crest usually provides the primary access for inspection and maintenance. Because surface water will pond on a crest unless that surface is well maintained, this part of a dam usually requires periodic regrading. However, problems found on the crest should not be simply graded over or covered up. When a questionable condition is found, the state's dam safety engineers should be notified immediately. On the crest, some of the most threatening conditions that may be identified are: o Longitudinal cracking; o Transverse cracking; o Misalignment. Longitudinal cracking can indicate localized instability, differential settlement, and/or movement between adjacent sections of the embankment. Longitudinal cracking is typically characterized by a single crack or a close, parallel system of cracks along the crest in a direction more or less parallel to the axis of the dam. These cracks, which are usually continuous over their length and are usually greater than 1 foot deep, can be differentiated from drying cracks which are usually intermittent, erratic in pattern, shallow, very narrow, and numerous. Longitudinal cracking may precede vertical displacement as a dam attempts to adjust to a position of greater stability. Vertical displacements on the crest are usually accompanied by displacements on the upstream or downstream face of a dam. Transverse cracking can indicate differential settlement or movement between adjacent segments of a dam. Transverse cracking is usually a single crack or a close, parallel system of cracks which extend across the crest in a direction more or less perpendicular to the length of a dam. Transverse cracking poses a definite threat to the safety and integrity of a dam. If a crack should progress to a point below the reservoir water surface elevation, seepage could progress along the crack and through the embankment causing severe erosion and if not corrected, leading to failure of the dam. Misalignment can indicate relative movement between adjacent portions of a dam - generally in directions perpendicular to the axis of the dam. Excessive settlement of dam material and/or the foundation can also cause misalignment. Most problems are usually detectable during close inspection. Misalignment may, however, only be detectable by viewing a dam from either abutment. If on close inspection, the crest appears to be straight for the length of the structure, alignment can be further checked by standing away from the dam on either abutment and sighting along the upstream and downstream edges of the crest. On curved dams, alignment can be checked by standing at either end of a short segment of the dam and sighting along the crest's upstream and downstream edges, noting any curvature or misalignment in that section.

EMBANKMENT AND STRUCTURES	
Seepage areas	As previously discussed, although all dams have some seepage, seepage in any area on or near a dam can be dangerous, and all seepage should be treated as a potential problem. Wet areas downstream from dams are not usually natural springs, but seepage areas. Seepage must be controlled in both velocity and quantity. High velocity flows through a dam can cause progressive erosion and, ultimately, failure. Saturated areas of an embankment or abutment can move in massive slides and thus also lead to failure. Seepage can emerge anywhere on the downstream face of a dam, beyond the toe, or on the downstream abutments at elevations below normal reservoir levels. A potentially dangerous condition exists when seepage appears on the downstream face above the toe of a dam. Seepage on the downstream slope can cause a slide or failure of the dam by internal erosion (piping). Cattails, reeds, mosses, and other marsh vegetation often become established in seepage areas. Downstream abutment areas should always be inspected closely for signs of seepage, as should the area of contact between an embankment and a conduit spillway, drain, or other appurtenant structures and outlets. Slides in the embankment or an abutment may be the result of seepage causing soil saturation and high pore pressures. Since seepage can be present but not readily visible, an intensive search should be made of all downstream areas where seepage water might emerge. Even in short grass cover, seepage may not be visible and must be walked on to be found. Ideally, an inspection for seepage should be made when a reservoir is full.

General	
General	It is important that concrete dam owners are aware of the principal modes of failure of such dams and that they are able to discern between conditions which threaten the safety of the dam and those which merely indicate a need for maintenance. Should any of these conditions be discovered during inspection, an owner should obtain engineering assistance immediately. Structural cracks occur when portions of the dam are overstressed and are the result of inadequate design, poor construction, or faulty materials. Structural cracks are often irregular in the soil. Note the location of particularly wet or soft spots and see if the stilling basin or drop structure is properly protected with rocks or riprap. Since some erosion is unavoidable during stilling, an owner should also determine whether such erosion might endanger the embankment itself. If the spillway is installed with a sill, a dam owner should also determine if there are any cracks or misalignment in the sill and check for erosion beneath or downstream of the sill. Commonly encountered defects of concrete spillways and general inspection procedures for cracks, spalling, drains, joints, and misalignment are summarized ahead. Hairline cracks are usually harmless. Large cracks should be carefully inspected, and their location, width, length, and orientation noted. Deterioration should be determined, and exposure of reinforcing bars should be watched for. Spillway surfaces exposed to freeze-thaw cycles often suffer from surface spalling. Chemical action, contamination, and unsound aggregates can also cause spalling. If spalling is extensive, the spalled area should be sketched or photographed, showing the length, width, and depth of the area. The problem should be examined closely to see if the remaining concrete has deteriorated or if reinforcing bars are exposed. The concrete should be tapped with a “bonker” or rock hammer to determine if voids exist below the surface. Shallow spalling should be examined from time to time to determine if it is becoming worse. Deep spalling should be repaired as soon as possible by an experienced contractor. Walls of spillways are usually equipped with weep (or drain) holes. Occasionally spillway chute slabs are also equipped with weep holes. If all such holes are dry, the soil behind the wall or below the slab is probably dry. If some holes are draining while others are dry, the dry holes may be plugged by mud or mineral deposits. Plugged weep holes increase the chances for failure of retaining walls or chute slabs. The plugged holes should be probed to determine causes of blockage, and soil or deposits cleaned out to restore drainage. If this work is not successful, rehabilitation should be performed as soon as possible under the supervision of a professional engineer.

General	Spillway retaining walls and chute slabs are normally constructed in sections. Between adjoining sections, gaps or joints must be tightly sealed with flexible materials such as tar, epoxies, or other chemical compounds. Sometimes rubber or plastic diaphragm materials or copper foil are used to obtain watertightness. During inspection, one should note the location, length, and depth of any missing sealant, and probe open gaps to determine if soil behind the wall or below the slab has been undermined. Misalignment of spillway retaining walls or chute slabs may be caused by foundation settlement or earth or water pressure. The inspector should carefully look at the upstream or downstream end of a spillway near the wall to determine if it has been tipped inward or outward. Relative displacement or offset between neighboring sections can be readily identified at joints. Horizontal as well as vertical displacement should be measured. At the time of construction, the entire spillway chute should form a smooth surface. Thus, measurement of relative movement between neighboring chute slabs at joints will give a good indication of slab displacement. Misalignment or displacement of the walls or slab is often accompanied by cracks. A clear description of crack patterns should be recorded, or photos taken to help understanding the nature of the displacement.
Inlets, outlets, and Drains	The most common problems are misaligned, collapsed, or broken tile. Such problems may be indicated by wet spots on the field that used to drain properly. There also may be a blowout, or a place where water is bubbling up from the ground, or where soil has been pulled into the line. Tile can break down from old age and cumulative loading, especially older tile that was not designed for today's heavy equipment and axle loads. Improper installation can also lead to drainage failure. If tile is not installed below the frost line, freeze-thaw cycles can fracture tile. The original quality of the tile is important too. If the tile materials absorb too much water, the tile is more likely to disintegrate over time. There are other potential in-line tile problems, including in-line siltation. Occasionally, uniform soil particle size creates problems. Unstable soils (those with weak soil structure) erode into the tile line. If the cracks or slots in perforated tile are too wide, installing tile with a fabric or a filter sock on it may be the only way to prevent sediment entry into the line.

Reservoir pool levels	Reservoir pool levels are controlled by spillway gates, lake drain and release structures, or flashboards. Flashboards are sometimes used to permanently or temporarily raise the pool level of water supply reservoirs. Flashboards should not be installed or allowed unless there is sufficient freeboard remaining to safely accommodate a design flood. Very flat slopes or slopes with free-draining upstream soils can, however, withstand more rapid draw down rates, but not necessarily so. Conditions causing or requiring temporary or permanent adjustment of the pool level include: ○ Development of a problem which requires the pool to be lowered. Drawdown is a temporary solution until the problem is solved. Release of water downstream to supplement stream flow during dry conditions, if required. Fluctuations in the service areas demand water excess. ○ Repair of boat docks in the winter and growth of aquatic vegetation along the shoreline. ○ Requirements for recreation, hydropower, or waterfowl and fish management.
Lake drains	A lake drain should always be operable so that the pool level can be drawn down in case of an emergency or for necessary repair. Lake drain valves or gates that have not been operated for a long time can present a special problem for owners. If the valve cannot be closed after it is opened, the impoundment could be completely drained. An uncontrolled and rapid drawdown - if not considered in the design phase - could also cause more serious problems such as slides along the saturated upstream slope of the embankment or downstream flooding. Therefore, when a valve or gate is operated, it should be inspected and all appropriate parts lubricated and repaired. It is also prudent/obliged to warn downstream residents of large and/or prolonged discharges. To test a valve or gate without risking complete drainage, one must physically block the drain inlet upstream from the valve. Some drains have been designed with this capability and have dual valves or gates, or slots for stop logs (sometimes called bulkheads) upstream from the valve. Otherwise, divers can be hired to inspect the drain inlet and may be able to construct a temporary block at the inlet. Other problems may be encountered when operating a lake drain. Sediment can build up and block the drain inlet, or debris can enter the valve chamber, hindering its function. The likelihood of these problems is greatly decreased if the valve or gate is operated and maintained periodically.

Corrosion	Corrosion is a common problem of pipe spillways and other conduits made of metal. Exposure to moisture, acid conditions, or salt will accelerate corrosion. In particular, acid runoff from strip mine areas will cause rapid corrosion of steel pipes. In such areas, pipes made of noncorrosive materials such as concrete or plastic should be used. Metal pipes which have been coated to resist accelerated corrosion are also available. The coating can be of epoxy, aluminum, zinc (galvanization), asbestos or mortar. Coatings applied to pipes in service are generally not very effective because of the difficulty of establishing a bond. Similarly, bituminous coating cannot be expected to last more than one to two years on flowways. Of course, corrosion of metal parts of operating mechanisms can be effectively treated and prevented by keeping those parts greased and/or painted. Corrosion can also be controlled or arrested by installing cathodic protection. A metallic anode made from a material such as magnesium is buried in the soil and is connected to the metal pipe by wire. An electric potential is established which causes the magnesium to corrode and not the pipe.
Trash on pipe spillways	Many dams have pipe and riser spillways. As with concrete spillways, pipe inlets that become plugged with debris or trash reduce spillway capacity. As a result, the potential for overtopping is greatly increased, particularly if there is only one outlet. If a dam has an emergency spillway channel, a plugged principal spillway will cause more frequent and greater than normal flow in the emergency spillway. Because emergency spillways are generally designed for infrequent flows of short duration, serious damage may result. For these reasons trash collectors or racks should be installed at the inlets to pipe spillways and lake drains. A well-designed trash rack will stop large debris that could plug a pipe but allow unrestricted passage of water and smaller debris. Some of the most effective racks have submerged openings which allow water to pass beneath the trash into the riser inlet as the pool level rises. Openings that are too small will stop small debris such as twigs and leaves, which in turn will cause a progression of larger items to build up, eventually completely blocking the inlet. A trash rack should be properly attached to the riser inlet and strong enough to withstand the forces of fast-flowing debris, heavy debris, and ice. If the riser is readily accessible, vandals may throw riprap stone into it. The size of the trash rack openings should not be decreased to prevent this. Instead, a rock larger than the trash rack openings, or too large to handle should be used for riprap. Maintenance should include periodic checking of the rack for rusted and broken sections and repair as needed. The trash rack should be checked frequently during and after storms to ensure that it is functioning properly and to remove accumulated debris.

Cavitation	When water flows through an outlet system and passes restrictions (e.g., valves), a pressure drop may occur. If localized water pressures drop below the vapor pressure of water, a partial vacuum is created and the water actually boils, causing shockwaves which can damage the outlet pipes and control valves. This process can be a serious problem for large dams where discharge velocities are high.
Testing the outlet system	All valves should be fully opened and closed at least once a year. This not only limits corrosion buildup on control stems and gate guides, but also provides an opportunity to check for smooth operation of the system. Jerky or erratic operation could signal problems and indicate the need for more detailed inspection. The full range of gate settings should be checked. The person performing the inspection should slowly open the valve, checking for noise and vibration - certain valve settings may result in greater turbulence. He or she should also listen for noise which sounds like gravel being rapidly transported through the system. This sound indicates that the cavitation occurring and these gate settings should be avoided. The operation of all mechanical and electrical systems, backup electric motors, power generators, and power and lighting wiring associated with the outlet should also be checked.
Inspecting the outlet system	Accessible portions of the outlet, such as the outfall structure and control, can be easily and regularly inspected. However, severe problems are commonly associated with deterioration or failure of portions of the system which are either buried in the dam or normally under water. Outlet intake structures, wet wells, and outlet pipes with only downstream valves are the most difficult dam appurtenances to inspect because they are usually under water. These should be inspected whenever the reservoir is drawn down or at five-year intervals. If a definite problem is suspected, or if the reservoir remains full over extended periods, divers should be hired to perform an underwater inspection.

Other areas	Mechanical equipment includes spillway gates, sluice gates or valves for lake drains or water supply pipes, stoplogs, sump pumps, flashboards, relief wells, emergency power sources, siphons, and other devices. All mechanical and associated electrical equipment should be operated at least once a year and preferably more often. The test should cover the full operating range of the equipment under actual operating conditions. Each operating device should be permanently marked for easy identification, and all operating equipment should be kept accessible. All controls should be checked for proper security to prevent vandalism, and finally, all operating instructions should be checked for clarity and maintained in a secure, but readily accessible location. The reservoir surface and shoreline should be inspected to identify possible problems away from the actual structure. Whirlpools can indicate submerged outlets. Large landslides coming into the reservoir could cause waves overtopping the dam. Floods arise from the upstream watershed. Therefore, characteristics of the watershed, such as impervious areas (e.g., parking lots), relate directly to the magnitude of a flood. Urban development in a watershed can increase the size of flood peaks and the volume of runoff, thereby making a previously acceptable spillway inadequate. Awareness of upstream development and other factors which might influence reservoir inflows is important in order to anticipate possible problems and necessary or modifications in the dam. Development in downstream floodplains is also very important to the dam owner as the extent of development and flood preparedness relate directly to loss of life and damages should the dam fail.

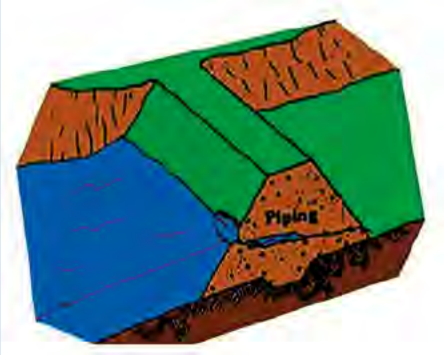
10.9.2 Tips to Consider in the Visual inspections

Some of the most common conditions that may be encountered during visual inspection include longitudinal and transverse cracking, desiccation cracking, depressions, settlement, slides, seepage, lack of protection from wave action, erosion, inappropriate vegetation, tree root penetration, poor maintenance, ponding water, animal burrows, and debris. Many of these concerns are interrelated and occur in conjunction or because of each other.

A dam inspector should visualize the worst-case conditions when looking for potential problem areas. For example, the maximum loads on roads and other structures, highest water levels in the reservoir, peak flow rates from the principal spillways, discharge through the auxiliary spillways, and winter icing conditions should be considered.

The dam's crest usually provides the primary access for visual inspection and maintenance. Because surface water will pond on the crest unless that surface is well maintained, this part of the dam may require re-grading periodically.

Sketches of conditions that may be found on a dam during a visual inspection are presented in the following pages. While most of the conditions shown in the drawings can be corrected by routine and periodic maintenance carried out by the dam owner, some of the problems noted are of a nature that threatens the safety and integrity of the dam. Therefore, they need the attention of qualified engineers and geologists to decide on remedial measures. Depending on the severity of a condition, the dam owner may need to take immediate action to prevent the problem from worsening.

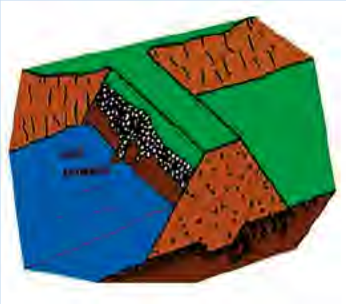
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SINKHOLE ON EMBANKMENT SLOPE 	Piping or internal erosion of embankment materials or foundation can cause a sinkhole. The cave-in of an eroded cavern can result in a sinkhole. A small hole in the wall of an outlet pipe can develop a sinkhole. Dirty water at the exit indicates erosion of the dam.	Piping can empty a reservoir through a small hole in the wall or can lead to failure of a dam as soil pipes erode through the foundation or a pervious part of the dam. Seepage with sediment at the seepage exit indicates potential internal erosion of the dam embankment or foundation. Internal erosion can lead to dam failure as soil pipes develop and erode through the dam embankment and/or foundation. Rapid outflow through the sinkhole can lead to a dam failure as soil pipes through the foundation or a permeable part of the dam.	Inspect other parts of the dam for seepage or more sinkholes. Identify exact cause of sinkholes. Check seepage and leakage outflows for dirty water. A qualified engineer should inspect the conditions and **immediately** recommend further actions to be taken. Check seepage and leakage outflows for muddy water. Inspect the dam and appurtenances for other anomalies, such as new seepage areas, depressions, cracks, etc. (*)

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SINKHOLE ON CREST AND ON SLOPE  	Rodent activity. Hole in outlet conduit is causing erosion of embankment material. Internal erosion or piping of embankment material by seepage. Breakdown of dispersive clays within embankment by seepage waters. Lack of adequate compaction; rodent hole below; piping through embankment or foundation.	Void spaces within the dam could cause localized caving, sloughing, instability, or reduced embankment cross section. Entrance point for surface water.	Carefully inspect and record location and physical characteristics (depth, width, length) of the sinkhole. A (*) should figure out the cause of the sinkhole and supervise all steps necessary to reduce the threat to the dam and to correct the condition. Excavate sinkhole, slope sides of the excavation, and backfill hole with competent material using proper construction techniques. (*)

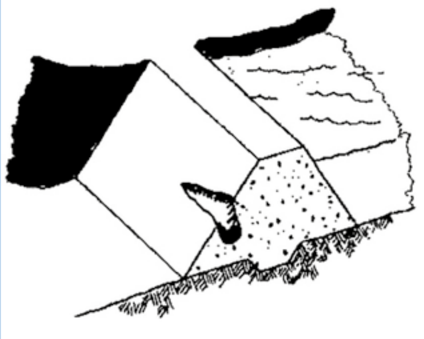
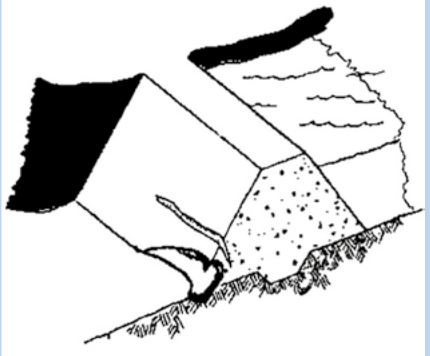
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
LARGE CRACKS AND SLUMP, LARGE HORIZONTAL CRACKS ON SLOPE, AND LONGITUDINAL CRACKS   	A portion of the embankment has moved because of loss of strength, or the foundation may have moved, causing embankment movement. Preceded by erosion undercutting a part of the slope. Can also be found on relatively steep slopes. Drying and shrinkage of surface material. Downstream movement or settlement of embankment.	Indicates onset of massive slide or settlement caused by foundation failure. Can expose impervious zone to erosion. Can promote internal erosion of the dam which might lead to a breach from piping. Can be an early warning of a potential slide. Shrinkage cracks allow water to enter the embankment and freezing will further crack the embankment. Settlement or slide indicating loss of strength in embankment can lead to failure.	Depending on the embankment involved, draw the reservoir level down. (*) Inspect area for seepage. Monitor for progressive failure. (*) If the cracks are caused by drying, dress area with well-compacted material to keep surface water out and natural moisture in. If cracks are extensive, (*).

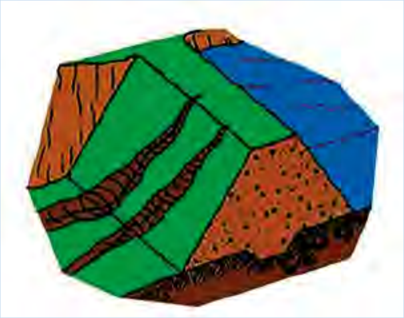
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SLIDE, SLUMP, OR SLIP   	Earth or rocks move down the slope along a slippage surface because of too steep a slope, or the foundation moves. Also, look for sliding motion in the reservoir basin. Loss of strength can be attributed to infiltration of water into the embankment or loss of support by the foundation. Earth or rocks move down the slope along a slippage surface because they were on too steep a slope. The foundation moves and a slide occurs. Lack of or loss of strength of embankment material. Loss of strength can be attributed to infiltration of water into the embankment or loss of support by the foundation.	(#) A series of slides can lead to obstruction of the outlet or failure of the dam. Foundation movement or a too steep slope can cause earth fill to move along a slip plane which can lead to a slump or slip of the embankment. Slide movements in the reservoir basin can lead to inlet obstruction or dam failure (through instability in the faces of the dam, or through wave action if the slide is along the perimeter of the reservoir). Can lead to failure of the dam. A series of slides can lead to obstruction of the outlet or failure of the dam. Shallow slides on the downstream slope may also be a sign of an overly steep slope, or poorly compacted soils, or a loss of strength in the embankment material; and a greater pore pressure than that should be considered in the design phase. Deep-seated slides are serious threats to the safety of the dam and may be recognized by the presence of a well-defined scarp or bulging on the slope or at the toe. Arc-shaped cracks on the slope are usually indications that a slide is beginning. This type of crack may develop into a large scarp at the top of the slide. Massive slide cuts through crest or upstream slope reducing freeboard and cross section. Structural collapse or overtopping can result.	Evaluate extent of the slide. Monitor the slide. Measure the extent and displacement of the slide. If continued movement is seen, begin lowering water level until movement stops. Inspect for new or changed seepage conditions downstream of the slide area, and for longitudinal and transverse cracks, scarps, etc. near the slide area. Draw the reservoir level down if the safety of the dam is threatened, (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SCARPS, BENCHES, OVER STEEP AREAS BROKEN DOWN MISSING RIPRAP 	Wave action, local settlement, or ice action cause soil and rock to erode and slide to the lower part of the slope forming a bench. Poor quality riprap has deteriorated. Wave action or ice action has displaced riprap. Round and similar-sized rocks have rolled downhill forming a bench.	Erosion lessens the width and possible height of the embankment and could lead to increased seepage or overtopping of the dam. Wave action against these unprotected areas decreases embankment width. The eroded area lessens the width and height of the embankment and could lead to increased seepage or the overtopping of the dam by flood flows.	Determine exact cause of scarps. Do necessary earthwork, restore embankment to original slope and provide adequate protection (bedding and riprap). Re-establish normal slope. Place bedding and competent riprap. Figure out the exact cause of the scarps. Carry out necessary earthwork, re-store embankment to the designed slope, install adequate protection (bedding and riprap).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
DISLODGE RIPRAP, EROSION BEHIND POORLY GRADED RIPRAP  	Inferior quality riprap has deteriorated because of freeze-thaw action and/or vandalism. Wave action or ice action has displaced the riprap. Round and similar sized rocks have rolled downhill. Similar-sized rocks allow waves to pass between them and erode small gravel particles and soil.	Wave action against these unprotected areas erodes the embankment, thereby decreasing its width. Damage near the crest is more severe because the embankment could be breached easier as a result. Soil is eroded away from behind the riprap. This allows riprap to settle, providing less protection and decreased embankment width.	Re-establish the original slope. Place bedding and competent riprap. Include proper filters below the protective riprap, either stone of the right size and gradation or a geotextile. Re-establish effective slope protection. Place bedding material, (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
TRANSVERSE CRACKING  	Drying and shrinkage of surface material are the most common causes. Differential settlement of the embankment also leads to transverse cracking (e.g., the center settles more than the abutments).	(#) Settlement or shrinkage cracks can lead to seepage of reservoir water through the dam. Shrinkage cracks allow water to enter the embankment. This promotes saturation and increases freeze-thaw action. Can give rise to an uncontrolled release of water through a breach. Differential settlement between adjacent segments of the embankment may cause transverse cracking. Deformation caused by differential settlement or slope instability may provide a path for seepage through the embankment cross section, which could initiate a breach of the embankment.	If necessary, first plug upstream end of crack to prevent flows from the reservoir. Inspect the crack and carefully record its location, length, depth, width, and other pertinent physical features. Stake out the crack limits. Under the direction of a qualified engineer, excavate the crest along the crack to a point below the bottom of the crack. Backfill the excavation using suitable material and correct construction techniques. This seals the cracks at the crest surface to prevent surface water infiltration. Visually monitor the crest routinely for evidence of future cracking, (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
CAVE-IN/COLLAPSE 	Lack of adequate compaction. Rodent hole below. Piping through embankment or foundation.	(#) Indicates possible wash out of embankment.	Inspect for and immediate repair of rodent holes. Control rodents to prevent future damage, (*).
SLUMP (LOCALIZED CONDITION) 	Preceded by erosion undercutting a portion of the slope. Can also be found on steep slopes.	Can expose impervious zone to erosion and lead to further slumps.	Inspect area for seepage. Monitor for progressive failure (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
GENERAL EROSION ON SLOPE OF A DAM  	Water from intense rainstorms or snowmelt carries surface material down the slope, resulting in continuous gutters. Surface Erosion can lead to severe deterioration of the downstream slope that can be expensive to repair.	(#) Can be hazardous if allowed to continue. Erosion can lead to eventual deterioration of the downstream slope and failure of the structure. Water from intense rainstorms or snowmelt carries surface materials down the slope and results in continuous gutters, rills, gullies, etc. It is preferable to catch the problem early, when resolving the issue is much less costly. Surface erosion can also occur upstream if the face is not protected with riprap.	The preferred method to protect eroded areas is rock or riprap. Re-establishing protective grasses can be adequate if the problem is detected early. If erosion is detected early, add protective grasses that may resolve the problem. Restore and protect eroded areas; add rock or riprap, where appropriate.

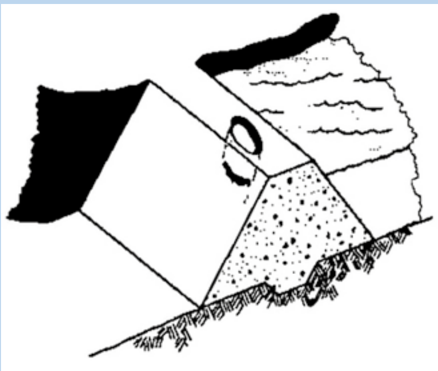
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
OBSCURING TREES AND BRUSH ON SLOPE 	Natural vegetation in the area. Natural vegetation other than short grass on the embankment slope and along the embankment toe.	Large tree roots can create seepage paths. Bushes can obscure visual inspection and harbor rodents.	Remove all large, deep-rooted trees and shrubs on or near the embankment. Properly backfill void. Control vegetation on the embankment that obscures visual inspection.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
RODENT ACTIVITY  **ANIMAL BURROWS ON SLOPE** 	Over-abundance of rodents. Holes, tunnels, and caverns are caused by animal burrows. Certain habitats like cattail type plants and trees close to the reservoir encourage these animals. Probably because of excessive vegetation on embankment slope and along embankment toe.	Can reduce length of seepage path, and lead to piping failure. If tunnel exists through most of the dam, it can lead to failure of the dam. Entrance point for surface runoff to enter dam. Could saturate adjacent portions of the dam. Especially dangerous if the hole penetrates dam below phreatic line. During periods of high storage, seepage path through the dam would be greatly reduced and a piping situation could develop. Cattail-filled areas and areas where trees are close to the reservoir provide ideal habitat and foraging areas for animals. An overabundance of rodents increases the chance of animal burrowing, which creates holes, tunnels, and caverns within an embankment dam.	Control rodents to prevent more damage. Backfill existing rodent holes. Remove rodents. Determine exact location of digging and extent of tunneling. Remove habitat and repair damages. Completely backfill the hole with competent, well-compacted material. Initiate a rodent control program to reduce the burrowing animal population and to prevent future damage to the dam. Start a rodent control program to reduce the population and prevent future damage to the dam.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
LIVESTOCK PATHS ON DAM FACES CAN LEAD EROSION  	Livestock paths and activities on the downstream dam face can damage slopes, especially when wet. Excessive travel by livestock; especially harmful to slope when wet.	Creates areas bare of erosion protection and causes erosion channels. Allows water to stand. Area susceptible to drying cracks.	Fence livestock outside embankment area. Repair eroded livestock trails with compacted soils and then revegetate. Repair erosion protection, i.e., riprap or grass.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
LONGITUDINAL CRACK  	Uneven settlement between adjacent sections or zones within the embankment. Foundation failure causing loss of embankment support. Initial stages of embankment slide.	(#) Creates local area of low strength within embankment. Could be the point of infiltration and future structural movement, deformation, or failure. Provides entrance point for surface run-off into embankment, allowing saturation of adjacent embankment area, and possible lubrication which could lead to localized failure. After an earthquake, longitudinal cracks could indicate liquefaction of the foundation and/or embankment materials might have occurred, which resulted in slope movements. Differential settlement between zones or within the embankment may cause longitudinal cracking. Cracks create a point for water to enter the embankment, which could result in slope instability.	Inspect crack and carefully record location, length, depth, width, alignment, and other pertinent physical features. Immediately stake out limits of cracking. Monitor frequently. Effectively seal the cracks at the crest's surface to prevent infiltration by surface water. Continue to routinely monitor crest for evidence of further cracking. An engineer should determine cause of cracking and supervise steps necessary to reduce danger to dam and correct condition (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
VERTICAL DISPLACEMENT 	Vertical movement between adjacent sections of the embankment. Structural deformation or failure caused by structural stress or instability, or by failure of the foundation.	(#) Provides local area of low strength within embankment which could cause future movement. Leads to structural instability or failure. Provides entrance point for surface water that could further lubricate failure plane. Creates a local area of low strength within embankment which could cause future movement. Leads to structural instability or failure. Creates an entry point for surface water that could further lubricate failure plane.	Carefully inspect and record location and physical characteristics (depth, width, length) of cave-in. Immediately stake out limits of cracking. An engineer should determine cause of displacement and cave-ins and supervise all steps necessary to reduce danger to dam and correct condition. Excavate area to the bottom of the displacement. Backfill excavation using competent material and correct construction techniques, all under supervision of engineer. Continue to monitor areas routinely for evidence of future cracking or movement (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
CAVE-IN ON CREST 	Rodent activity. Hole in outlet conduit is causing erosion of embankment material. Internal erosion or piping of embankment material by seepage. Breakdown of dispersive clays within embankment by seepage waters.	(#) The void within the dam could cause localized caving, sloughing, instability, or reduced embankment cross section.	Carefully inspect and record location and physical characteristics (depth, width, length) of cave in. Engineer should determine cause of cave in and supervise all steps necessary to reduce threat to dam and correct condition. Excavate cave in, slope sides of excavation, and backfill hole with competent material using proper construction techniques (*)

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
TRANSVERSE CRACKING 	Uneven movement between adjacent segments of the embankment. Deformation caused by structural stress or instability.	Can provide a path for seepage through the embankment cross section. Provides local area of low strength within embankment. Future structural movement, deformation or failure could begin. Provides entrance point for surface runoff to enter embankment.	Inspect and carefully record crack location, length, depth, width, and other pertinent physical features. Stake out limits of cracking. An engineer should determine cause of cracking and supervise all steps necessary to reduce danger to darn and correct condition. Excavate crest along crack to a point below the bottom of the crack. Then backfill excavation using competent material and correct construction techniques. This will seal the crack against seepage and surface runoff. Continue to monitor crest routinely for evidence of future cracking (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
CREST MISALIGNMENT, LOW AREA IN CREST OF DAM REDUCING THE FREEBOARD  	Movement between adjacent parts of the structure. Uneven deflection of dam under loading by reservoir. Structural deformation or failure near area of misalignment. Excessive settlement in the embankment or foundation directly beneath the low area in the crest. Internal erosion of embankment material. Foundation spreading to upstream and/or downstream direction. Prolonged wind erosion of crest area. Improper final grading following construction.	Area of misalignment is usually accompanied by low area in crest which reduces freeboard. Can produce local areas of low embankment strength which may lead to failure. Reduces freeboard available to pass flood flows safely through spillway. Foundation spreading upstream and/or downstream, prolonged wind erosion, or improper final grading following construction may cause a low area in the crest of a dam. Low area may have been intentionally included during original construction. Low areas can reduce the freeboard available and result in the embankment dam overtopping sooner.	Establish monuments across crest to determine exact amount, location, and extent of misalignment. An engineer should determine cause of misalignment and supervise all steps necessary to reduce threat to dam and correct condition. Monitor crest monuments on a scheduled basis following remedial action to detect possible future movement (*). Re-establish uniform crest elevation over crest length by placing fill-in the low area using proper construction techniques. Routinely survey established monuments along the dam crest to detect any unusual settlement along the crest of the dam. Re-establish monuments across the crest of dam and monitor monuments on a routine basis to detect probable future settlement (*). Note: Low areas may be desirable to direct flow over areas of dam less susceptible to damage or having lower consequences from downstream failure (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
OBSCURING VEGETATION  	Neglect of dam and lack of proper maintenance procedures. Natural vegetation (bushes) obscures visual inspection and harbors animals.	The vegetation obscures large parts of the dam, preventing adequate, accurate visual inspection of all parts of the dam. Problems that pose hazard the integrity of the dam can develop and remain undetected until they progress to a point that threatens the dam's safety. Associated root systems grow and penetrate into the dam's cross section. When the vegetation dies, the decaying root systems form paths for seepage. This reduces the effective seepage path through the embankment and could lead to possible piping situation. Prevents easy access to all parts of the dam for operation, maintenance, and inspection. Provides an attractive habitat for rodents. Large tree roots can create seepage paths. Large trees can blow over during a storm and damage the dam, which may cause a breach.	Remove all damaging growth from the dam. This would include removal of trees, bushes, brush, conifers, and growth other than grass. Grass should be encouraged on all segments of the dam to prevent erosion by surface runoff. Root systems should also be removed to the maximum practical extent. The void which results from removing the root system should be backfilled with well competent, well-compacted material. Control vegetation that obscures visual inspection of the embankment. Under the direction of a qualified engineer, remove all large, deep-rooted trees and shrubs on or near the embankment, with care, to minimize disturbance to the embankment. Backfill voids promptly. Monitor area after removal of trees, since deterioration of remaining roots from large trees may lead to voids in the embankment and potentially cause sinkholes and/or seepage paths. Future undesirable growth should be removed by cutting or spraying, as part of an annual maintenance program.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
WATER FLOWING FROM A SOURCE OF HIGH POINT ON SLOPE OR FROM RODENT HOLES OR ANIMAL BURROWS  	Rodents, frost action or poor construction have allowed water to create an open pathway or pipe through the embankment. Diggings by the rodent have shortened the flow path.	Continued flows can saturate portions of the embankment and lead to slides in the area. Continued flows can further erode embankment materials and result in failure of the dam.	Begin measuring outflow quantity. If the discharge is increasing, the water level in the reservoir needs to be lowered until the leak stops. Search for opening on the upstream side and plug it if possible, (*). Locate any entrance points on the upstream slope and plug them. Bring a halt to the rodent activity (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
GULLY ON CREST 	Poor grading and improper drainage of crest. Improper drainage causes surface runoff to collect and drain off the crest at low point in upstream or downstream shoulder. Can cause inadequate spillway capacity which has resulted in overtopping of the dam and erosion of the downstream embankment slope.	Can reduce available freeboard. Reduces cross-sectional area of dam. Inhibits access to all parts of the crest and dam. Can result in a hazardous condition if due to overtopping.	Restore freeboard to dam by adding fill material in low area, using proper construction techniques. Regrade crest to provide proper drainage of surface runoff. If the gully was caused by overtopping, provide adequate spillway that meets current design standards. Re-establish protective cover on the embankment (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
RUTS ALONG CREST 	Heavy vehicle traffic without adequate or proper maintenance or proper crest surfacing. Animal trails, particularly those made by cattle.	Inhibits easy access to all parts of crest. Allows continued development of rutting. Allows standing water to collect and saturate crest of dam. Operating and maintenance vehicles can get stuck.	Drain standing water from ruts. Regrade and re-compact crest to restore integrity and provide proper drainage to upstream slope. Provide gravel or road base material to accommodate traffic. Do periodic maintenance and regrading to prevent reformation of ruts.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
PUDDLING ON CREST; POOR DRAINAGE 	Poor grading and improper drainage of crest. Localized consolidation or settlement on crest allows puddles to develop.	Cause localized saturation of the crest. Inhibits access to all parts of the dam and crest. Becomes progressively worse if not corrected.	Drain standing water from puddles. Regrade and re-compact crest to restore integrity and provide proper drainage to upstream slope. Provide gravel or road base material to accommodate traffic. Do periodic maintenance and regrading to prevent reformation of low areas.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
DRYING–DESICCATION CRACKS 	Material on the crest of dam expands and contracts with alternate wetting and drying of weather cycles. Drying cracks are usually short, shallow, narrow, and large in number.	Provides point of entrance for surface runoff and surface moisture, causing saturation of adjacent embankment areas. This saturation, and later drying of the dam, could cause further cracking.	Seal surface of cracks with a tight, impervious material. Routinely grade crest to provide proper drainage and fill cracks, or cover crest with non-plastic (not clay) material to prevent large moisture content variations. Draw the reservoir down if the safety of the dam is threatened.
CRACKS DUE TO DRYING 	The soil loses its moisture and shrinks, causing cracks. ***NOTE***: Usually seen on crest and downstream slope mostly.	Heavy rains can fill cracks and cause small parts of embankment to move along internal slip surface.	Monitor cracks for increases in width, depth, or length. A specialist should inspect the condition and recommend further actions to be taken (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
EXCESSIVE QUANTITY OF CLEAR WATER AND/OR MUDDY WATER EXITING FROM A POINT WATER  	Has created an open pathway, channel, or pipe through the dam. The water is eroding and carrying embankment material. Large amounts of water have accumulated in the downstream slope. Water and embankment materials are exiting at one point. Surface agitation may be causing the muddy water. Water has created an open pathway or pipe through the dam.	(#) Continued flows can saturate parts of the embankment and lead to slides in the area. Water has created an open pathway, channel, or pipe through the dam. The water is eroding and carrying embankment material. Rodents, frost action, or poor construction may allow seepage water to create an open pathway or pipe through the embankment. Continued flows can further erode embankment materials and lead to failure of the dam.	Estimate or measure outflow quantity. Determine whether seepage flows are increasing with time, and whether material transport by the flow is continuing to occur. Have a qualified engineer inspect the condition and recommend further actions. Lower the water level in the reservoir. Search for an opening on the upstream side of the dam. Plug it if possible (*). If possible, place filter sand at the seepage exit location to prevent material from being transported along with the seepage. Gravel may need to be placed initially so that the flow velocity is slowed, so the sand is not washed away by fast-flowing water. Once the sand filter is in place, cover it with gravel so it does not get washed away by the seepage flow. Begin measuring outflow quantity and proving whether water is getting muddier, staying the same, or clearing up. If the amount of discharge is increasing, the water level in the reservoir should be lowered until the flow stabilizes or stops (*).

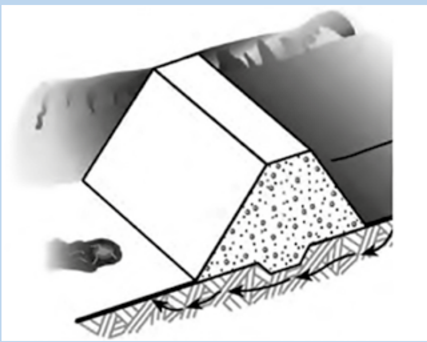
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
STREAM OF WATER EXITING THROUGH CRACKS NEAR THE CREST 	Severe drying has caused shrinkage of embankment material. Settlement in the embankment or foundation is causing the transverse cracks.	(#) Flows through the crack can cause failure of the dam.	Plug the upstream side of the crack to stop the flow. The water level in the reservoir should be lowered until it is below the level of the cracks (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SEEPAGE WATER EXITING AS A BOIL IN THE FOUNDATION SEEPAGE WATER FLOWING FROM BOIL IN THE FOUNDATION 	Some part of the foundation material is supplying a flow path. This could be caused by a sand or gravel layer in the foundation.	(#) Increased flows can lead to erosion of the foundation and failure of the dam.	Examine the boil for transportation of foundation materials. If soil particles are moving downstream, sandbags or earth should be used to create a dike around the boil. The pressure created by the water level within the dike may control flow velocities and temporarily prevent further erosion. A graded filter should be placed immediately in the boil to inhibit soil loss. If erosion is becoming greater, the reservoir level should be lowered (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SEEPAGE EXITING AT ABUTMENT CONTACT - LARGE AREA WET OR SEEPAGE FLOWING FROM SLOPE AND/OR TOE CONTACT 	Water flowing through pathways in the abutment. Water flowing through the embankment. A seepage path has developed through the abutment or embankment materials and failure of the dam can occur.	(#) Can lead to erosion of embankment materials and failure of the dam. Increased flows could lead to erosion of embankment material and failure of the dam. Saturation of the embankment can lead to local slides which could cause failure of the dam.	Study leakage area to determine quantity of flow and extent of saturation. Inspect daily for developing slides. Investigate leakage area to determine the quantity of flow and extent of saturation. The water level in the reservoir may need to be lowered to assure the safety of the embankment (*). Stake out the saturated area and monitor for growth or shrinking. Measure any outflows as accurately as possible. Reservoir level may need to be lowered if saturated areas increase in size at a fixed storage level or if flow increases (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
MARKED CHANGE IN VEGETATION ON SLOPE  **BULGE IN LARGE WET AREA ON SLOPE** 	Downstream embankment materials have begun to move. Runoff is being concentrated in shallow depressions which enable vegetation other than grass to thrive. Embankment materials are supplying flows paths. Natural seeding by wind. Change in seed type during early post-construction seeding.	(#) Failure of the embankment results from massive sliding that can follow these early movements. Can be a sign of a saturated area.	Use probe and shovel to establish if the materials in this area are wetter than surrounding areas. Compare embankment cross section to the end of construction condition to see if observed condition may reflect it or not. Stake out affected area and accurately measure outflow (*). If areas show wetness when surrounding areas do not, a qualified engineer should inspect the condition and recommend further actions to be taken (*).

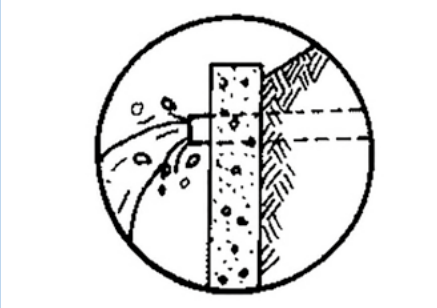
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
TRAMPOLINE EFFECT IN LARGE SOGGY AREA 	Water moving rapidly through the embankment or foundation is being controlled or contained by a well-established turf root system.	Condition shows excessive seepage in the area. If control layer of turf is destroyed, rapid erosion of foundation materials could result in failure of the dam.	Carefully inspect the area for outflow quantity and any transported material (*).

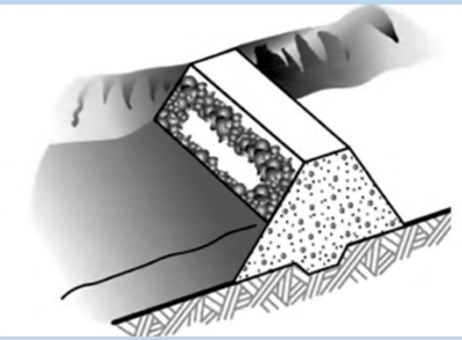
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SEEPAGE WATER EXISTING AS A BOIL DOWNSTREAM OF THE DAM  	Water Exiting as a Boil Downstream of the Dam.	Some part of the foundation material is supplying a path for reservoir seepage. This could be caused by a sand or gravel layer in the foundation. Increased flows can lead to high upward gradients and erosion of the foundation materials and dam failure.	Examine the boil to see if foundation materials are being transported (typically expressed as a ring of material around the exit point). Have a qualified engineer inspect the condition and recommend further actions. If soil particles are building up at exit points, use sandbags or earth to create a dike around the boil. The pressures created by the water level may halt the flow and prevent further erosion. If the situation cannot be controlled using sandbags, and soil materials are being carried by the flow, the reservoir level should be lowered.

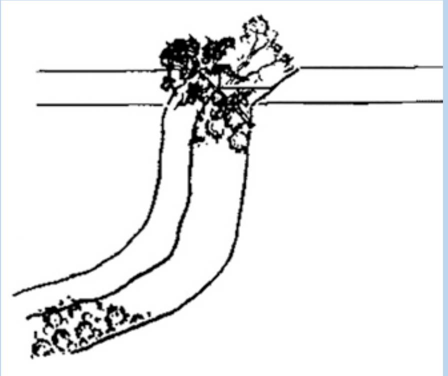
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
LEAKAGE FROM ABUTMENTS BEYOND THE DAM  	Seepage Water Exiting at the Abutment Contact. Water moving through cracks and fissures in the abutment materials.	Can lead to rapid erosion of abutment and evacuation of the reservoir. Can lead to massive slides near or downstream from the dam. Water flowing through pathways in the abutment or along embankment abutment contact can result in internal erosion. Seepage can lead to erosion of the embankment material and dam failure.	Begin measuring outflow quantity. Determine whether seepage flows are increasing with time, and whether material transport by the flow is continuing to occur. Have a qualified engineer inspect the condition and recommend further actions. Search for an opening on the upstream side of the dam. Plug it if possible. If possible, place filter sand at the seepage exit location to prevent material from being transported along with the seepage. Gravel may need to be placed initially so that the flow velocity is slowed, and subsequently the sand is not washed away by fast-flowing water. Once the sand filter is in place, cover it with gravel so it does not get washed away by the seepage flow. Lower the water level in the reservoir. Carefully inspect the area to determine quantity of flow and amount of transported material (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
WET AREA IN HORIZONTAL BAND  **LARGE AREA ON SLOPE SATURATED FROM BELLOW THE CREST** 	Frost layer or layer of sandy material in original construction. Water is flowing through the embankment. Snowdrifts are melting slowly during mild spring temperatures.	(#) Wetting of areas below the area of excessive seepage can lead to localized instability of the embankment. Excessive flows can lead to accelerated erosion of embankment materials and failure of the dam. Can lead to saturation of embankment materials and local or massive slides which could cause failure of the dam.	Determine as closely as possible the flow being produced. If flow increases, reservoir level should be reduced until flow stabilizes or stops. Stake out the exact area involved. Using hand tools, try to identify the material allowing the flow (*). Investigate saturated area to determine depth and extent of saturation. Inspect daily for developing slides. The water level in the reservoir may need to be lowered to assure the safety of the embankment (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
CONCRETE DETERIORATION, LEAKAGE, AND STAINING  **OPEN CONSTRUCTION JOINTS**  **CONCRETE DETERIORATION ON DOWNSTREAM FACE OF A DAM**  **DETERIORATION OF A CONCRETE PIER** 	Cracking, Opening/Closing or Offsets at Joints, or Apparent Deformations. Deterioration of Structural Materials.	Structural cracking (longer cracks, not pattern cracks), broken masonry, opening/closing or offsets at joints, and apparent deformation in structures can be indications of foundation problems. Foundation problems are the leading cause of concrete and masonry dam failures. Failures of concrete and masonry dams typically are sudden failures that can have catastrophic consequences due to their suddenness. Deteriorated concrete or masonry materials may have less strength, and therefore less ability to carry the reservoir loads imposed on the dam.	Have a qualified engineer assess the situation and supervise the steps necessary to reduce the danger to the dam. Draw down the reservoir to reduce the risks of dam failure, as warranted (*).

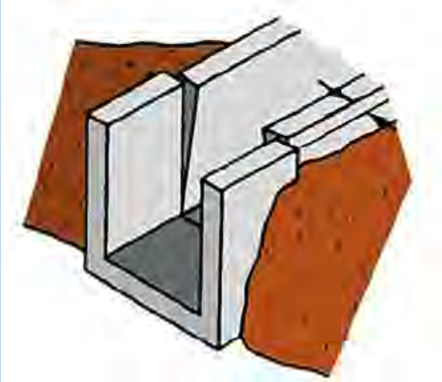
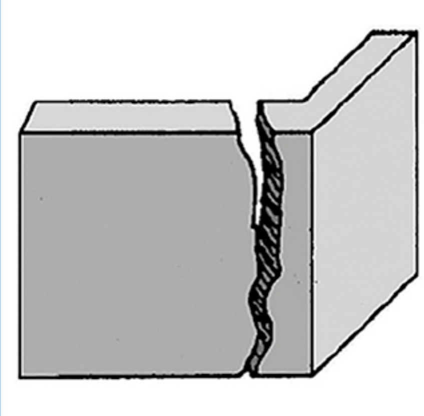
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
LARGE INCREASE IN FLOW OR SEDIMENT IN DRAIN OUTFALL 	A shortened seepage path or increased storage levels.	(#) Higher velocity flows can cause erosion of drain then embankment materials. Can lead to piping failure.	Accurately measure outflow quantity and determine amount of increase over previous flow. Collect samples to compare turbidity. If either quantity or turbidity has increased by 25%, a specialist should evaluate the condition and recommend further actions (*).
CRACKED DETERIORATED CONCRETE FACE 	Concrete deteriorated resulting from weathering. Joint filler deteriorated or displaced.	The soil is eroded behind the face and caverns could be formed. Unsupported sections of concrete crack. Ice action may displace the concrete.	Determine cause. Either patch with grout or contact engineer for permanent repair method. If damage is extensive, a qualified engineer should inspect the conditions and recommend further actions to be taken (*).

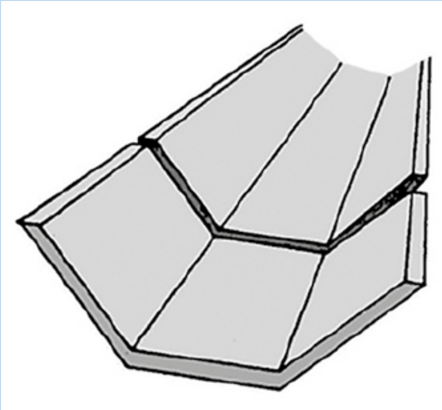
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
BROKEN DOWN OR MISSING RIPRAP  	Deteriorated or Missing Riprap.	Poor quality riprap deteriorates and does not protect the slope. Wave or ice action can displace riprap allowing erosion or oversteepening of the bank. Improperly sized riprap may displace and expose the slope. Wave action against these unprotected areas decreases the embankment width.	Reestablish the normal slope. Place bedding material and properly sized riprap to protect against wave action (*).

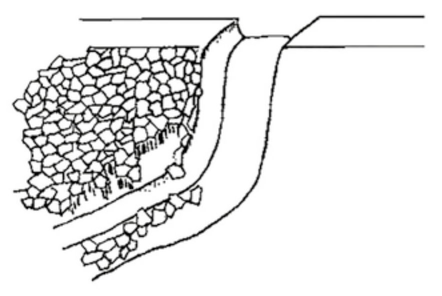
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
EXCESSIVE VEGETATION OR DEBRIS IN CHANNEL  	Excessive vegetation or debris in a spillway channel. A blocked spillway channel may cause overtopping of the dam due to the loss of the spillway discharge capability.	Reduced discharge capacity; overflow of spillway overtopping of dam. Prolonged overtopping can cause failure of the dam. An accumulation of slide materials, dead trees, debris, excessive vegetative growth, etc. in the spillway channel can reduce waterway capacity. Reduced discharge capacity may cause the dam to overtop. Prolonged overtopping can cause dam failure.	Clean out debris regularly as necessary to maintain an open waterway and control vegetative growth in the spillway channel. Install a log boom in front of the spillway entrance to intercept debris.

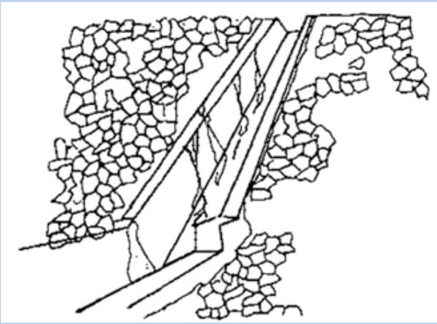
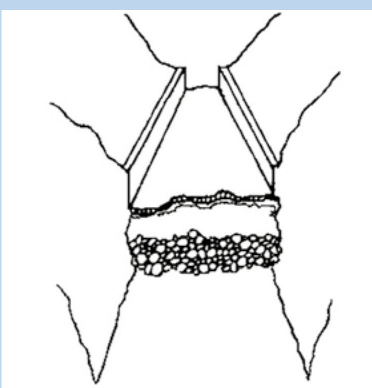
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
EROSION DOWNSTREAM CHANNELS  	Surface runoff from intense rainstorms or flow from spillway carries surface material down the slope, resulting in continuous troughs. Livestock traffic create gullies. Spillway channel erosion can lead to spillway sides falling or sliding, or large, uncontrolled and unintentional releases in the event that an erosive cut in the spillway channel breaks the spillway crest.	Unabated erosion can lead to slides, slumps or slips which can result in reduced spillway capacity. Surface runoff from intense rainstorms or flow through the spillway erodes spillway flow surfaces. Livestock traffic creates gullies where runoff flow can concentrate and cause erosion. Irregularities in concrete structure flow surfaces can lead to damage and loss of structure due to cavitation, stagnation pressures, etc. Unabated erosion can result in head cutting, erosional spillway failure, and unintended, uncontrolled, large releases at the spillway location. Spillway damage can result in reduced spillway capacity. Inadequate spillway capacity can lead to embankment overtopping and result in dam failure.	Photograph condition. Replace eroded material with compacted fill to repair damaged areas, if appropriate. Protect areas against future erosion by installing suitable rock riprap. Revegetate area if appropriate. Have a qualified engineer inspect the conditions and recommend remedial actions. Closely monitor spillway performance during flood events. Bring condition to the attention of the engineer during next inspection (*).

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
EXCESSIVE EROSION IN EARTH-SLIDE CAUSES CONCENTRATED FLOWS 	Discharge velocity too high; Bottom and slope material are loose or deteriorated; Channel and bank slopes are too steep; Bare soil is unprotected; Poor construction; Protective surface failed; Engaged too often.	Disturbed flow pattern, loss of material, increased sediment load downstream, collapse of banks, and failure of spillway can lead to the rapid evacuation of the reservoir through the severely eroded spillway.	Minimize flow velocity by proper design. Use sound material. Keep channel and bank slopes mild. Encourage growth of grass on soil surface. Construct smooth and well-compacted surfaces. Protect surface with riprap, asphalt, or concrete. Repair eroded part using sound construction practices.
UNDERCUT DOWNSTREAM END OF SPILLWAY CHUTE 	Poor configuration of stilling basin area. Highly erodible materials. Absence of cutoff wall at end of chute.	(#) Structural damage to spillway structure; collapse of slab can lead to a costly repair. Higher velocity flows can cause erosion of drain and consequently of embankment materials.	Dewater affected area; clean out eroded area and fill in properly. Improve stream channel below chute; provide properly sized riprap in stilling basin area. Install cutoff wall.

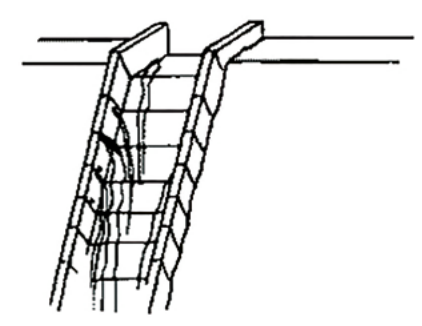
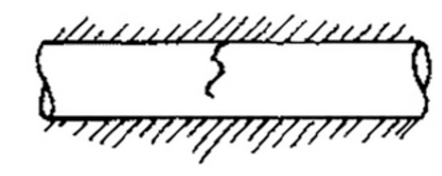
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
WALL DISPLACEMENT 	Poor workmanship; uneven settlement of foundation; excessive earth and water pressure; insufficient steel bar reinforcement of concrete.	Minor displacement will create eddies and turbulence in the flow, causing erosion of the soil behind the wall. Major displacement can cause severe cracks and eventual failure of the structure.	Reconstruction should be done according to sound engineering practices. Foundation should be carefully prepared. Adequate weep holes should be installed to relieve water pressure behind wall. Use enough reinforcement in the concrete. Anchor walls to prevent further displacement. Install struts between spillway walls if needed. Clean out and backflush drains to assure proper operations (*).
LARGE CRACKS 	Construction defect; local concentrated stress; local material deterioration; foundation failure, excessive backfill pressure.	(#) Disturbance in flow patterns; erosion of foundation and backfill; eventual collapse of structure.	Large cracks without large displacement should be repaired by patching. Surrounding areas should be cleaned or cut out before patching material is applied. Installation of weep holes or other actions may be needed. Replacement may be required in some cases.

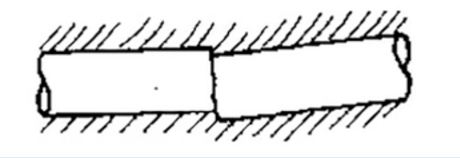
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
OPEN OR DISPLACED JOINTS 	Excessive and uneven settlement of foundation; sliding of concrete slab; construction joint too wide and left unsealed. Sealant deteriorated and washed away.	(#) Erosion of foundation material may weaken support and cause further cracks; pressure induced by water flowing over displaced joints may wash away wall or slab, or cause extensive undermining.	Construction joint should not be wider than 12 mm. Clean the joint, replace eroded materials, and seal the joint. All joints should be sealed with asphalt or other flexible materials. Waterstops should be used where feasible. Foundations should be properly drained and prepared. Underside of chute slabs should have ribs of enough depth to prevent sliding. Avoid steep chute slope (*).

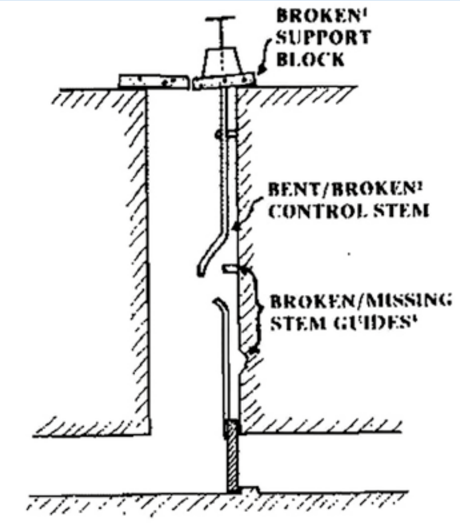
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
BREAKDOWN AND LOSS OF RIPRAP - MATERIAL DETERIORATION - SPALLING AND DISINTEGRATION OF RIPRAP AND CONCRETE 	Slope too steep; material poorly graded; failure of subgrade; flow velocity too high; improper placement of material; bedding material or foundation washed away. Use of unsound or defective materials; structures subject to freeze-thaw cycles; improper maintenance practices; harmful chemicals.	(#) Erosion of channel bottom and banks; failure of spillway. Structure life will be shortened; premature failure.	Design a stable slope for channel bottom and banks as well as a stable riprap. Riprap material should be well graded (the material should contain small, medium, and large particles). Sub-grade should be properly prepared before placement of riprap. Install filter fabric if necessary. Do not use shale or weathered sandstone for riprap. Add air-entraining agent when mixing concrete. Use only clean good quality aggregates in the concrete. Steel bars should have at least 1 inch of concrete cover. Concrete should be kept wet and protected from freezing during curing. Timber should be treated before using. Control flow velocity in the spillway by proper design. Riprap should be placed according to specification (*).

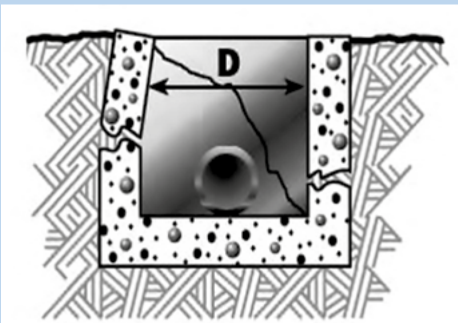
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
POOR SURFACE DRAINAGE 	No weep holes; no drainage facility; plugged drains.	Wet foundation has lower supporting capacity; uplift pressure resulting from seepage water may cause damage to spillway chute; accumulation of water may also increase total pressure on spillway walls and cause damage.	Install weep holes on spillway walls. Inner end of hole should be surrounded and packed with graded filtering material. Install drain system under spillway near downstream end. Clean out existing weep holes. Backflush and rehabilitate drain system under the supervision of an engineer (*).
CONCRETE EROSION, ABRASION, AND FRACTURING 	Flow velocity is too high (usually occurs at lower end of chute in high dams); rolling of gravel and rocks down the chute; cavity behind or below concrete slab.	Pockmarks and spalling of concrete surface may progressively become worse; small hole may cause undermining of foundation, leading to failure of structure.	Remove rocks and gravels from spillway chute before flood season. Raise water level in stilling basin. Use good quality concrete. Assure concrete surface is smooth (*).

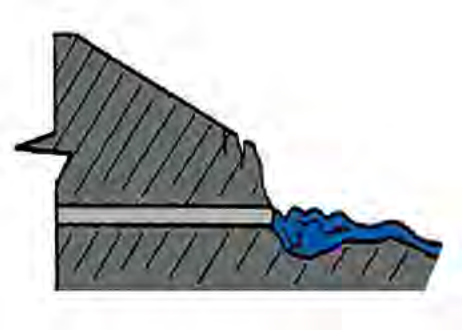
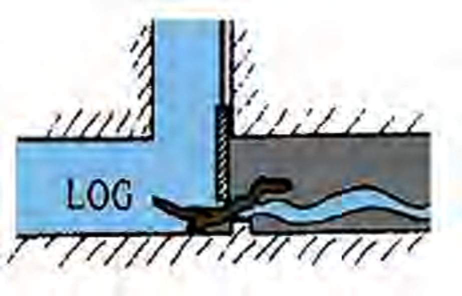
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
LEAKAGE IN OR AROUND SPILLWAY OR ABUTMENT SPILLWAY	Cracks and joints in geologic formation at spillway are permitting seepage. Gravel or sand layers at spillway are permitting seepage.	(#) Could lead to excessive loss of stored water. Could lead to a progressive failure if velocities are high enough to cause erosion of natural materials.	Examine exit area to see if type of material can explain leakage. Measure flow quantity and check for erosion of natural materials. If flow rate or amount of eroded materials increase rapidly, reservoir level should be lowered until flow stabilizes or stops (*).
EXCESSIVE LEAKAGE FROM SPILLWAY UNDER DRAINS 	Drain or cutoff may have failed.	(#) Excessive flows under the spillway could lead to erosion of foundation material and collapse of parts of the spillway. Uncontrolled flows could lead to loss of stored water.	Immediately measure flow quantity and check flows for transported drain material. If flows are accelerating at a fixed storage level, the reservoir level should be lowered until the flow stabilizes or stops (*).

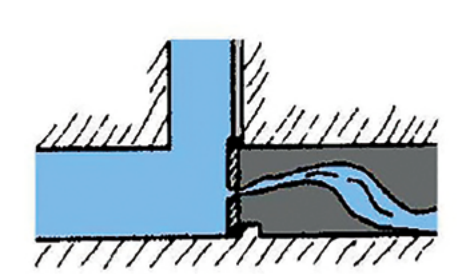
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SEEPAGE FROM A CONSTRUCTION JOINT OR CRACK IN CONCRETE STRUCTURE 	Water from the reservoir is collecting behind or under structure because of insufficient drainage or clogged weep holes. Lack of cutoff wall.	Can cause walls to topple and fall. Flows through concrete can lead to rapid deterioration from weathering. If the spillway is located within the embankment, rapid erosion can lead to failure of the dam.	Check area behind wall for puddling of surface water. Check and clean drain outfalls, hush lines , and weep holes as needed (*).
OUTLET PIPE DAMAGE - CRACK 	Settlement; impact.	(#) Creates a passageway for water to exit or enter the pipe. Excessive seepage, possible internal erosion.	Check for evidence of water either entering or exiting pipe at crack/hole/ etc.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
OUTLET PIPE DAMAGE - HOLE 	Rust (steel pipe); Erosion (concrete pipe); Cavitation.	(#) Excessive seepage, possible internal erosion.	Tap pipe in vicinity of damaged area, listening for hollow sound which shows that a void has formed along the outside of the conduit (*).
OUTLET PIPE DAMAGE - JOINT OFFSET 	Settlement or poor construction practice.	(#) Provides passageway for water to exit or enter pipe, resulting in erosion of internal materials of the dam.	Tap pipe near the damaged area and listen for a hollow sound which shows that a void has formed along the outside of the conduit (*).

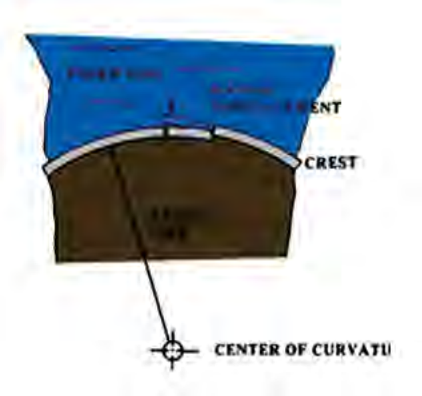
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
CONTROL WORKS 	Broken Support Block. Concrete deterioration. Excessive force exerted on control stem by trying to open gate when it was jammed. Bent/Broken Controls Stem- Rust. Excessive force used to open or close gate. Inadequate or broken stem guides. Broken/missing Stem Guides Rust. Inadequate lubrication. Excessive force used to open or close gate when it was jammed.	(#) Causes control support block to tilt: control stem may bind. Control headworks may settle. Gate may not open all the way. Support block may fail completely, leaving outlet inoperable. Outlet is inoperable. Loss of support for control stem. Stem may buckle and break even under normal use, as the picture shows.	Any of these conditions can mean the control is either inoperable or at best partly operable. Use of the system should be minimized or discontinued. If the outlet system has a second control valve, consider using it to regulate releases until repairs can be made, (*).

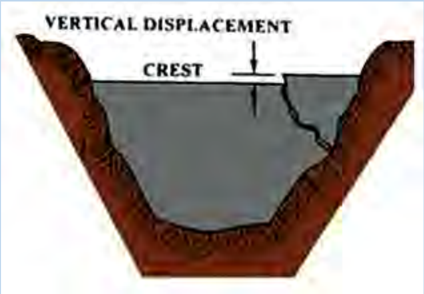
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
FAILURE OF CONCRETE OUTFALL STRUCTURE  **A SCOUR HOLE AT AN OUTLET RESULTING IN EROSION OF THE TOE OF THE SLOPE** 	Failure of Concrete or Rock Outfall Structures (Energy Dissipation). Excessive side pressures on non-reinforced concrete structure. Poor concrete quality.	(#) Excessive side pressures on a non-reinforced concrete structure or poor concrete quality can cause failure of the outfall structure. The embankment may be exposed to erosion by outlet releases because of loss of an outfall structure. Too steep of a slope can cause rocks to roll down the hill and partially block the outlet, which reduces the flows that can occur through the pipe.	Check for progressive failure by monitoring typical dimension, such as "D" shown in figure. Repair by patching cracks and supplying drainage around concrete structure. Total replacement of outfall structure may be needed. Have a qualified engineer inspect the situation and recommend corrective actions. The corrective actions may involve improving drainage and water pressure relief at the structure, as well as structure repair or replacement. Repair the slopes and place riprap to stabilize them, where applicable. Keep outlet free of blockages.

OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
OUTLET RELEASES ERODING TOE OF DAM 	Outlet pipe too short. Outlet releases eroding the toe of the dam.	(#) Erosion of the toe of the dam makes the downstream slope too steep and may cause progressive sloughing.The outlet pipe may be too short and result in scour at discharge end. No energy-dissipating pool or structure at the downstream end of the conduit can result in scour damage.	Protect embankment with riprap over suitable bedding. Extend the outlet pipe beyond the toe (use the same size of pipe and material). Form a watertight connection to the existing conduit. Stabilize the slope. Use riprap over suitable bedding to protect the embankment. Construct a stilling basin or energy-dissipating pool. (*)
VALVE LEAKAGE DEBRIS STUCK UNDER GATE 	The trash rack is missing or damaged.	Gate will not close. Gate or stem may be damaged in an effort to close the gate.	Raise and lower gate slowly until debris are loosened and float past valve. When the reservoir is lowered, repair or replace the trash rack.

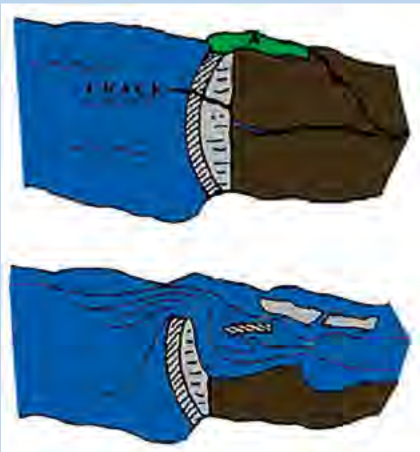
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
CRACKED GATE LEAF 	Ice action; Rust; Impact; Vibration. Stress resulting from forcing gate closed when it is jammed.	Gate-leaf may fail completely, evacuating reservoir.	Use valve only in fully open or closed position. Minimize the use of the valve until the leaf gate can be repaired or replaced.
DAMAGE GATE SEAT OR GUIDES 	Rust; Erosion; Vibration; Wear.	Leakage and loss of support for gate leaf. The gate may bind in guides and become inoperable.	Minimize use of valve until guides/seats can be repaired. If cavitation is the cause, check if air vent pipe exists, and if it is unobstructed.

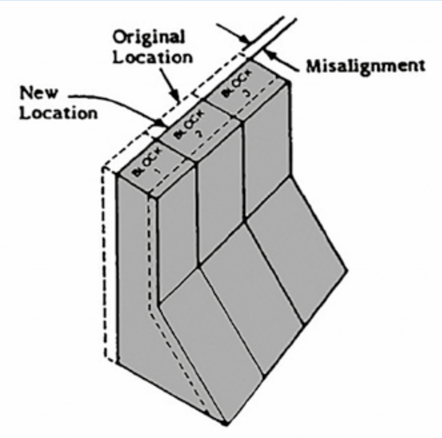
OBSERVATION-PROBLEM (FROM 10-10; 10-14; 10-16; 10-17;10-18]	PROBABLE CAUSE	POSSIBLE CONSEQUENCES (# HAZARDOUS)	RECOMMENDED ACTION (* A Specialist is Required Immediately)
SEEPAGE WATER EXITING FROM A POINT ADJACENT TO THE OUTLET  	A break in the outlet pipe. A path for flow from the reservoir has developed along the outside of the outlet pipe. Seepage water exiting from a point adjacent to the outlet pipe.	(#) Continued flows can lead to rapid erosion of embankment materials and failure of the dam. A break or hole in the outlet pipe or poor compaction around the pipe allows water to flow and creates a pathway along the outside of the outlet pipe.	Thoroughly investigate the area by probing and/or shoveling to see if the cause can be determined. Determine if seepage or leaking water are carrying soil particles (muddy water). Measure the discharge, determine quantity of flow, and if flow is increasing with time. Have a qualified engineer inspect the condition and recommend further actions. If flow increases or is carrying material, the reservoir level should be lowered until seepage flow stops. Investigate embankment along alignment of pipe to see if there are any signs of settlement or sinkholes (*).

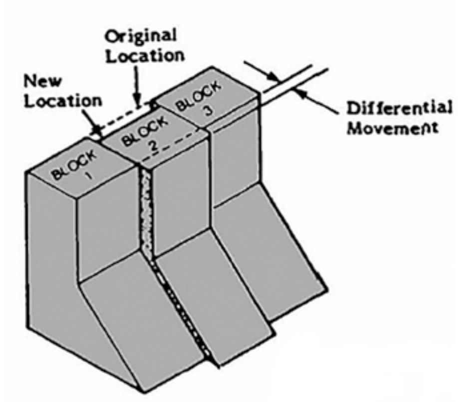
Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
CREST CAMBER 	The results of construction. Proportionally more fill is placed on the crest in higher segments of the embankment during construction to compensate for expected settlement within the dam and foundation.	None.	None.
Sketches of problems that are found at concrete and masonry dams, the hazards created, and remedial measures			
RADIAL DISPLACEMENT AND CRACKING OF ARCH DAM 	Sliding of a section of the dam because of excessive hydrostatic forces. Failure at an abutment resulting in downstream movement of a part of the arch.	If the crack and movement of the dam are significant, catastrophic failure is possible. Lowering of the reservoir level reduces hydropower production and availability of irrigation and municipal water supply.	Measure crack growth closely and decide on the severity of the problem. Check carefully for leakage through cracks to help decide on the seriousness of the problem. Immediate lowering of the reservoir level to reduce hydrostatic forces. Notify disaster management authorities if the failure of the dam is possible (*).

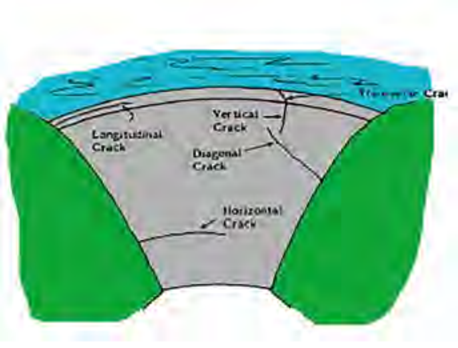
Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
VERTICAL DISPLACEMENT AND CRACKING 	Foundation settlement or piping may lead to structural cracking with vertical displacement.	Cracking in concrete may be a visible sign of stress or movement, which the concrete cannot tolerate. The underlying cause of cracking may pose an immediate threat to the dam, therefore, every effort to figure out the cause of the problem is important.	Grouting can stop or reduce seepage and piping, which should end settlement, and fill voids in the foundation. Cracks need to be repaired and monitored with crack meters to measure growth. Seepage needs to be carefully measured (*).
TRANSVERSE DISPLACEMENT 	Structural crack with transverse displacement and significant seepage.	Leakage through cracks in concrete dams, although unsightly, is not usually dangerous, unless accompanied by structural cracking. The worst effect may be to promote minor deterioration due to the elements through freeze-thaw action.	Repair cracks by filling with proper material that depends on the type, size, and extent of cracking. Install crack meters to check for continued development of cracking.

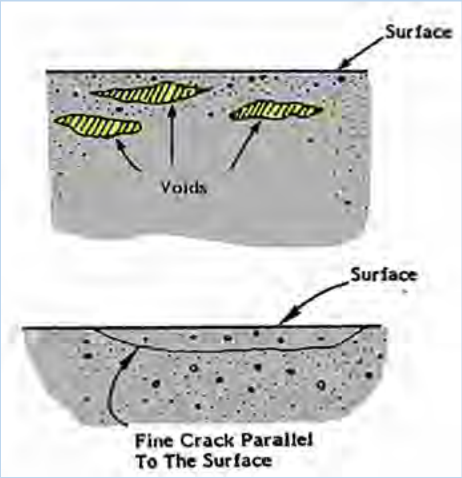
Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
CRACKS IN ABUTMENT AND FOUNDATION 	Cracks in the abutments and foundation of a dam may be a sign of a weak soil or rocky zone and settlement, piping of soils or soluble rock around or beneath the dam, or an overstressing caused by seismic activity or the loading of the dam and reservoir.	Continued internal erosion from seepage or leakage increase. In the worst case scenario, the dam may collapse and allow an uncontrolled released of impounded water.	Reduce seepage/leakage through abutments or foundation by grouting or slurry cutoff walls. Monitor seepage/ leakage carefully to see if flow rates are increasing or after re-medial measures have been taken, if flow rates have been reduced.
DOWNSTREAM MOVEMENT OR TILTING OF DAM 	Weak toe foundation may result in dam movement and seepage. Foundation failure may allow the dam to start to move because of the force of the water behind the structure.	In the worst case scenario, the dam may collapse and allow an uncontrolled released of impounded water.	If a significant movement has taken place and seepage is great, the reservoir level should be lowered at once. Buttresses, piling, and other structural reinforcement may be needed to support the dam.

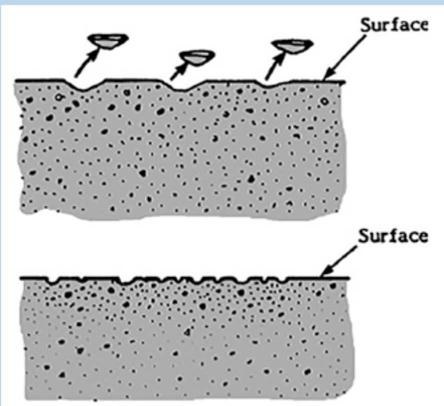
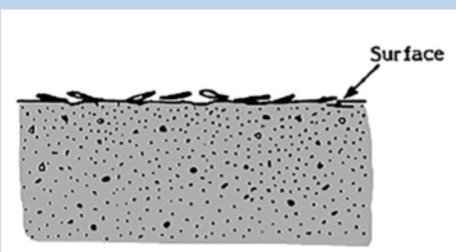
Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
WEAKNESS IN ABUTMENT 	A weak area in the left abutment is subjected to large stresses from this arch dam. Fault planes or weaknesses in the abutment may deteriorate with time, resulting in movement of the natural material in the abutment. Structural cracks in the concrete will be induced because of the movement in the abutment.	Structural cracks in the concrete will be induced because of the movement in the abutment. This situation creates the potential for failure of all or a part of the concrete structure resulting in breaching of the dam. Although the concrete of the dam may endure, the natural terrain may crack, crumble, or move in a massive slide. If this occurs, support for the dam will be lost, and the dam will fail.	If continued abutment movement is detected the reservoir level must be lowered at once to prevent further displacement. Geotechnical/structural measures need to be investigated to reinforce abutments.

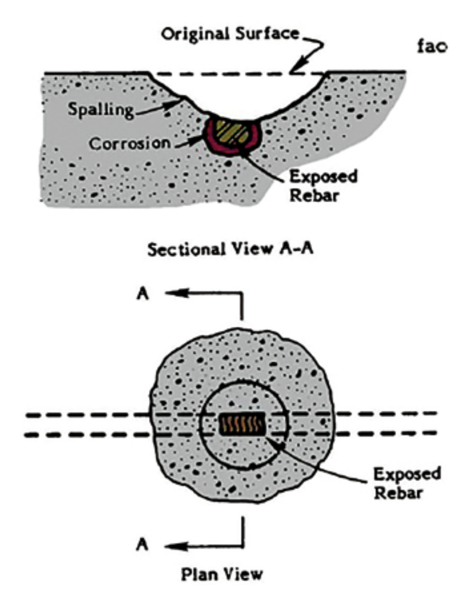
Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
MISALIGNMENT OF BLOCKS 	Inadequate foundation support. Misalignment is any variation from the original structural configuration and will be detected by sighting techniques at the crest of the dam.	Misalignment by itself is not a hazard. Small misalignments are of little concern and will not have an adverse impact on the stability of the dam. Misalignment becomes a hazard when it has an adverse effect on the entire structure or on one or more of its parts.	Movements need to be monitored closely. Excessive movement can be controlled by construction of buttresses or added mass on the downstream side of the dam.

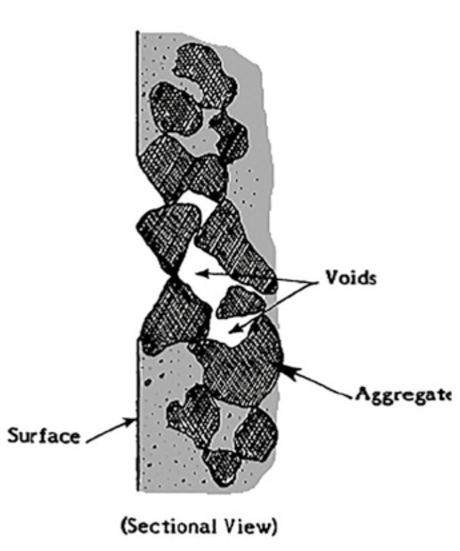
Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
DIFFERENTIAL MOVEMENT OF BLOCKS 	Differential movement of blocks can be caused by: a) abutment or foundation settlement or displacement, b) chemical reactions in the concrete, c) applied loadings of exceptional size (e.g., uplift pressures, earthquake, extreme temperature variations). The differential movement will be detected by sighting techniques at the crest of the dam. Differential movement most often appears as deflection at joints between adjacent blocks.	**(#)** Movement by itself is not a hazard. Small movements are of little concern and usually are considered in the design of the dam. Movement becomes a hazard when it has an adverse effect on the entire structure or on one or more of its parts.	Movements need to be monitored closely. Excessive movement can be controlled by construction of buttresses or added mass on the downstream side of the dam (*).

Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
CONCRETE CRACKING 	Cracking in a concrete dam occurs when tensile stresses develop that exceed the tensile strength of the concrete. These stresses may occur because of imposed loads on the structure or because of volumetric changes in the concrete. Volumetric change in mass concrete can be caused by changes in temperature or by a chemical reaction within the concrete.	Cracks typically caused by drying shrinkage, thermal movement, or other causes are usually minor and result in few problems. However, in some cases, a crack will enlarge over time and result in water seepage or the loss of structural integrity. Many cracks will be found during the course of an inspection, but not all cracks are serious. However, cracking should be watched closely because cracks can create openings in the concrete that allow other types of deficiencies to develop.	Trend is extremely important in monitoring cracking. The trend of a crack is its history of change. Studying prior reports before an inspection begins will enable an inspector to focus on how cracks have changed -that is, whether they have become longer, wider, deeper, changed direction, or are unchanged. Documenting changes will enable future inspectors to do the same thing. Measuring devices, or reference points, are sometimes permanently placed across a crack to measure the change in width over time.

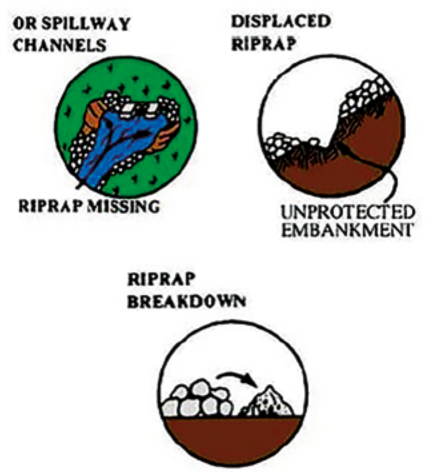
Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
DRUMMY CONCRETE 	Concrete has a void, separation, or other weakness – usually a thin surface layer separated from the mass. Caused when finishing operations occur too early.	The delamination problem caused by drummy concrete can be quite widespread and affect large zones of a surface. The presence of voids and fine cracks can worsen effects of the freeze-thaw action.	Drummy-sounding areas are easily detectable by hammer or chain dragging. Depending on their severity and surface use (such as exposure to wheel loads and heavy traffic), these zones are likely to detach sooner than from a sound surface. To achieve a high-quality surface, remove the defective concrete to a depth where only sound concrete remains. Proper removal of unsound concrete by suitable methods such as shot blasting, grinding, or hydrodemolition, is essential if repairs are to be successful.

Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
CONCRETE POPOUTS  	A popout is a hole in a concrete surface left after an aggregate particle has expanded and worked itself loose because of a) a physical reaction, or b) a chemical reaction. The physical expansion popout occurs when a lightweight, porous rock freezes, expands, and then fractures. The alkali-aggregate popout (chemical popout) occurs when the alkalies in the portland cement react chemically with the silica in some fine sands, causing an expansion of the silica particle. Freezing causes the water in the capillaries of the concrete to expand, creating pressure. Repetitive freeze-thaw cycles cause stresses which can break off the surface concrete. Improper concrete finishing can contribute to the premature spalling of concrete surface.	Popouts do not in any way decrease the life of a concrete surface. Popouts will not affect the structural serviceability of the surface. Usually, popouts are tolerated or overlooked, especially if their size and frequency are not excessive. However, surfaces with many popouts will be aesthetically unpleasing. Concrete spalling does not only look terrible, but it is potentially dangerous too. Over time, and with increased exposure to the elements, untreated pieces of concrete may fall from the structure. The hazard is caused by the piece of concrete falling and damaging property, or even worse, hitting a person walking below.	Surfaces with popouts can be repaired. A small patch can be made by cleaning out the spalled particle and filling the void with dry-pack mortar, epoxy mortar, or another patch material. If the popouts are too impractical to patch individually, a thin bonded overlay may be used. Repairing concrete surfaces affected by spalling require covering the entire area with a polymer-modified cementitious overlay that is colored to match the existing surface. Once the overlay cures, a water-proofing sealer should be applied to prevent the problem from reoccurring.

Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
CONCRETE DETERIORATION REINFORCING STEEL CORROSION 	Embedded reinforcing steel is normally protected by the concrete. When the concrete deteriorates, however, water can reach the steel and cause it to corrode. The oxide produced during corrosion results in an increase in volume, which causes the overlying concrete to crack and spall. The most well-known form of corrosion is rust.	Corrosion of steel reinforcing bars can weaken the concrete structure and cause it to fail. Corrosion of reinforcing bars has tendency to spalling and cracking.	Damage can be repaired by removing and replacing the deteriorated concrete and the badly corroded steel reinforcing bars.

Sketches of problems that are found at embankment dams, the hazards created, and remedial measures			
HONEYCOMBING 	Honeycombs are voids left on the concrete surface when the mortar does not fill spaces between the coarse aggregate particles. This is a construction defect caused by poor work practices such as inadequate concrete mixing, segregation because of improper placement, or insufficient vibration after placement of concrete in the forms.	The resulting defect is either simply accepted by the dam owner, or the contractor is required to remove the flawed concrete and rebuild that portion of the structure.	These defects, if minor, can be repaired by removing the flawed concrete and replacing it with dry pack, epoxy-bonded replacement concrete, or replacement concrete. Some minor defects resulting from movement or failure can be repaired with surface grinding.

Sketches of problems that are found at the spillway or outlet of a dam, the hazards created, and remedial measures			
DEBRIS OR OTHER OBSTRUCTION IN THE SPILLWAY 	Accumulation of slide materials. Dead trees. Excessive vegetative growth in spillway channel.	Reduced discharge capacity. Overtopping of the spillway sidewalls. Overtopping of the dam. Prolonged overtopping can cause failure of the dam.	Clean up debris periodically. Control vegetative growth in spillway channel. Install log boom in front of spillway entrance to intercept debris.

BREAKDOWN OR LOSS OF RIPRAP  	Slope too steep; material poorly graded; failure of sub-grade; flow velocity too high; improper placement of material; bedding material or foundation washed away. Use of unsound or defective materials; structure subjected to freeze-thaw cycles; improper maintenance practices; harmful chemicals.	The erosion of channel bottom and banks; the failure of the spillway. The life of the protected structure will be shortened.	Design a stable slope for channel bottom and banks. Riprap material should be well graded (the material should include small, medium, and large particles) and placed according to specification. Sub-grade should be properly prepared before placement of riprap. Install filter fabric if necessary. Control flow velocity in the spillway by proper design. Services of an engineer are recommended. Avoid using shale or sandstone for riprap. Add air-entraining agent when mixing concrete. Use only clean, excellent quality aggregates in the concrete. Steel bars should have at least 25 mm of concrete cover. Concrete should be kept wet and protected from freezing during curing. Timber should be treated before use.

10.10 Monitoring Schedules

Specific monitoring schedules should be developed on a case by case basis. During construction, the dam and foundation are adjusting to such factors as self-weight, thermal loads, and any unusual conditions. Measurements should be taken frequently to allow construction operations to be adjusted to changing conditions. Less frequent measurements may be appropriate during construction shutdowns.

During the first filling, the dam and foundation are adjusting to the reservoir load and seepage. Monitoring frequencies should depend, in part, on the rate of filling. In the first few years of operation following the first filling, most dams have not reached equilibrium with respect to self-weight, concrete thermal load, reservoir load, seepage forces, and pore pressure/uplift. Measurements should be taken frequently because most dam failures and incidents occur during these periods.

Even though existing dams have generally reached equilibrium with imposed loads, baseline data must be obtained to compare with subsequent measurements. Therefore, the frequency of measurements shown for first, second, and third years apply to new instrumentation installed at existing dams.

After a dam has substantially adjusted to the loads, the frequency of readings can be reduced but the new frequency may be justified in some cases.

More frequent measurements than those shown in the table should be made whenever an unusual situation develops or whenever they help to resolve a dam safety concern.

As mentioned in **CHAPTER 6- item 6.6,** during the construction of the Itaipu Project [10-02], the beginning of the filling was fully monitored, and the observations analyses can be cited as follows:

"...***9.6.3 Assessments after the Filling of the Reservoir until 2010***

The "General Report on the Behavior of the Itaipu Dams - 2006 – 2010" issued in October 2010, aimed to present a summary of the Itaipu Dam behavior to the Civil Consultants, highlighting the most important general scope aspects that occurred during this period.

Between 2006 and 2010, since the last meeting of the Civil Consultants, the following significant works were carried out in the Itaipu Power Plant:

a) *Installation of armored panels for the closing of the stalls of transformers in the gallery of transformers, El. 108.00 between axes A/B, aiming protection against explosions and fires.*

   The closure system of the stalls of transformers, located at elevation 108.00 between axes A and B, is intended to protect the area against accidents such as fire and explosions of transformers, in addition, there will also be a reduction in the noise level in the area.

b) *Cleaning of the foundation drains using water under pressure. Washing of foundation drains through water under pressure was held from November 2009 to June 2010. After the washing, some instruments indicated a small alteration.*

c) *Installation of new instruments in the overlap region between the concrete dam of stretch I and the rockfill dam. The instruments of the overlap region between the left connection dam (stretch I) and the rockfill dam (stretch K), after approximately 25 years of installation, had already reached the target range for their lifespan. With this scenario and given the importance of the instrumentation in the region, a re-instrumentation of this interface was conducted. The installation of piezometers in the overlap followed the Complementary Instrumentation Plan of the Dam Right and Left Overlaps, and attended the Board's recommendation of the 2006 meeting..."*

General Behavior of Concrete Structures - Instruments Comments

Pendula	*The crest displacements are measured by the pendulums between a point near the crest and the base of the block. They are influenced mainly by seasonal variations in temperature, reaching a maximum downstream in late winter and return to a minimum in late summer. Small oscillations of the reservoir levels are not actually perceived by the pendulums.* *The graphs show the evolution of crest displacements of the most important blocks, in the direction of the flow and normal to it, in recent years, and they also show the crest deformation with the maximum and minimum values along the dam in 2005 and 2009/10. Despite the 28-year time gap since the first filling of the reservoir, the pendulums are still registering a strain of the blocks and a crest displacement downstream.*
Joint Meters	*The maximum relative displacements measured between the blocks of the concrete dams from 2006 to 2010 were of millimeter magnitude, remaining within the specified limits. However, it should be emphasized that some relative displacements have not reached stabilization yet.*

Inverted Pendula	*Overall, the specific displacements and strains in the heel of the dam are proportional to its height, except for block E6, where the strain greatly exceeds the proportionality defined by other blocks, probably due to the presence of discontinuities treated with keys in its foundation and to downstream unconfining by the excavation of the powerhouse and next to the river canal.* *It should be highlighted that while the gages of the head show seasonal temperature variation and sporadic increases, inverted pendulums present practically constant and stabilized readings.* *A comparison between the specific strains of 2009 and those of 2000, whose winter was particularly cold and therefore greatly affected the strain meters, indicates that, with few exceptions, the situation is stabilized.* *The figures represent blocks D57, E6, F5/6, F13/14, F19/20, and F35/36, which are considered among the most important of the dam, because of their height and position, or owing to peculiar behavior.* *We tried to represent, in a thorough way, the results of the most important instruments, that is, the block displacements measured by pendulums, the foundation strains resulting from the strain meters, and the sub-pressures in the concrete-rock contact of the head at the end of the 1998 and 2000 winters.* *This way, the dam behavior can be more clearly observed, comparing the various types of instruments located in different parts of the block.* *The pendulums, the strain meters inclined upstream, and the piezometers are indicated with their winter peak value, considering that the crest, the head, and the upstream end of the blocks are influenced by temperature oscillations. While the inverted pendulums and the strain meters located in foundation in the middle of the block are not affected by temperature variations.*

Seepage Flow	*The several stretches of concrete dam indicate that there is a slight decrease or stabilization, and that only normal seasonal oscillations occur. Except for the buttress dam Stretch I, which shows increased seepage flows through the foundation and the concrete. However, in terms of specific yield, the value is below the mean value of the entire dam.* *Following is a figure that illustrates the seepage flow in the various stretches of the dam in September 2009. Comparison of flow measures in 2006 with those of 2009 and 2010 indicates that there was a small increase in seepage, with greater intensity in the foundation.* *The diversion structure has the highest seepage flow value probably due to the extensive system of drainage galleries in its foundation and abutments.* *A comparison with the values of 1984/85, of 75 l/s total and 2.6 l/min/m, indicates a large reduction in seepage flows through the foundations of the concrete dams since the beginning of the operation. However, compared with September 2006, the 2009 values are higher.* *The diversion structure also has the highest specific yield through concrete, twice as that of the main dam.*

Seepage Flow

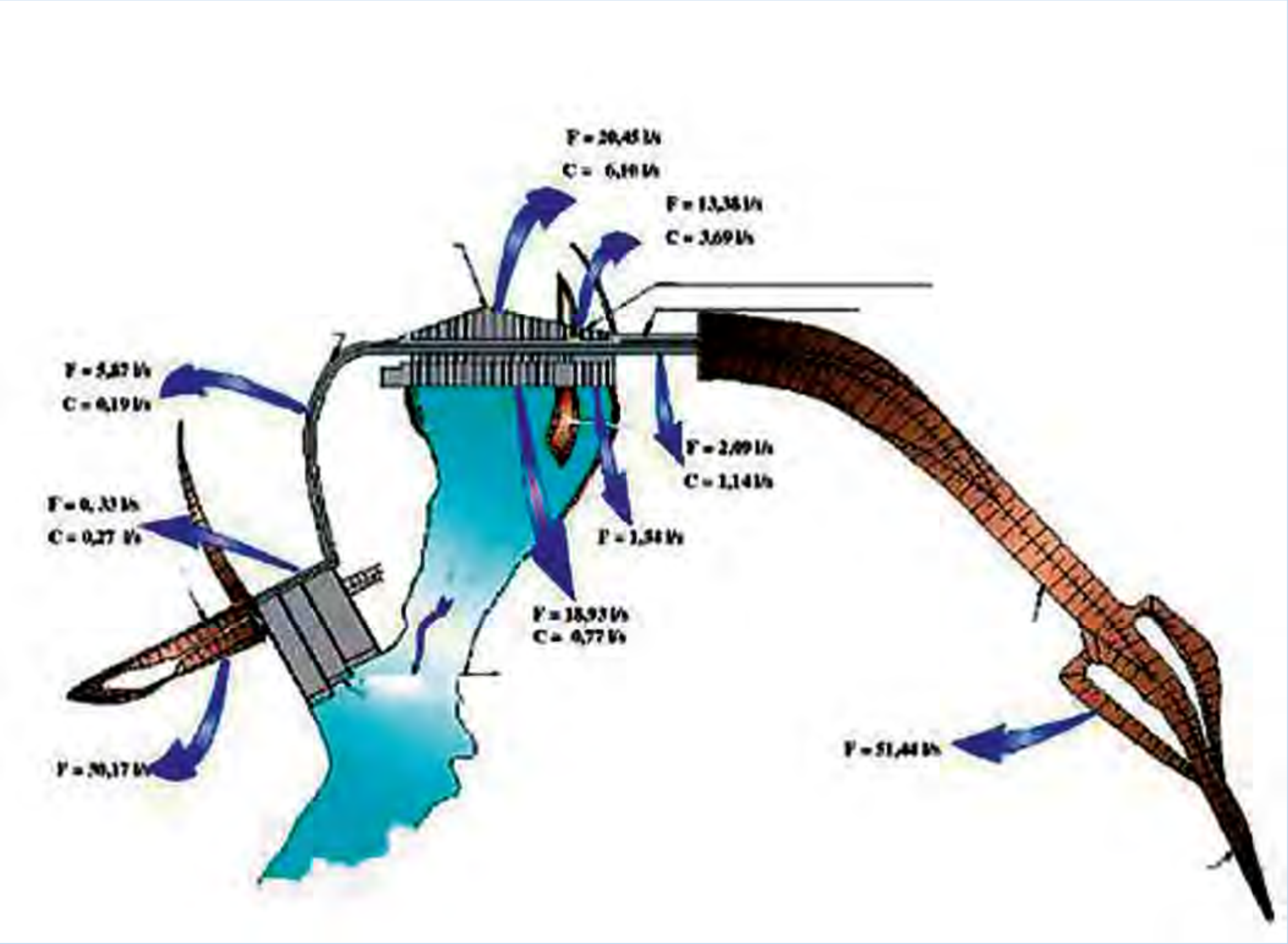
Seepages through the concrete dams

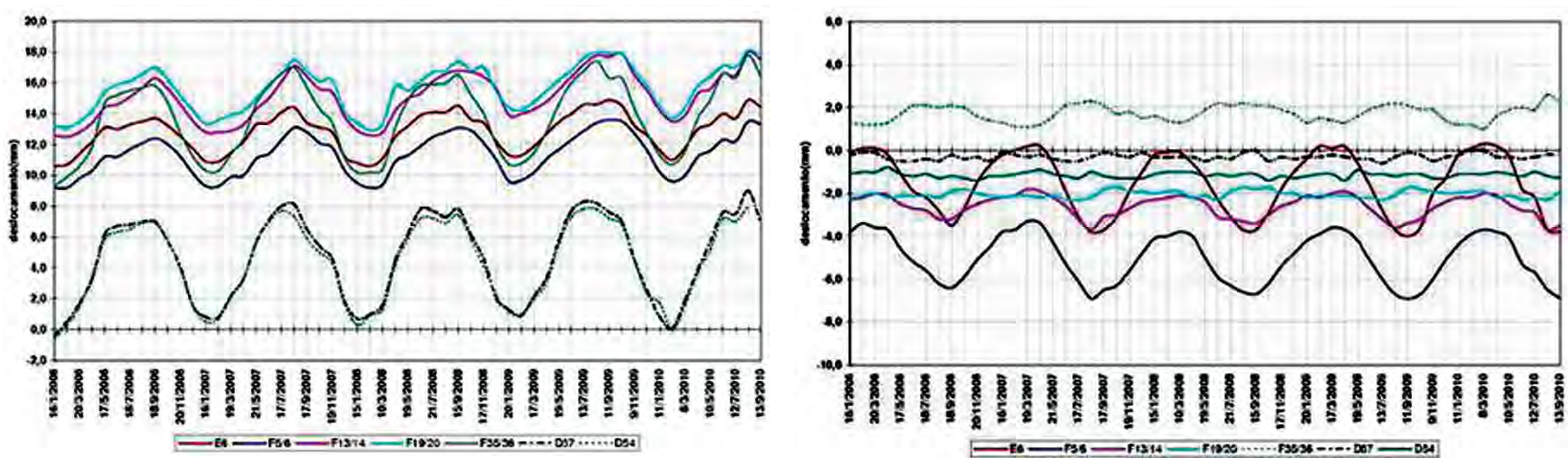
Flows- liter/second- All Concrete Dam				
September/year	2006	2007	2008	2009
Location				
Foundations	39,62	43,32	41,01	42,12
Concrete Structures	9,62	12,39	9,36	11,39
Powerhouse	11,24	10,25	10,72	20,47

Specific yields through concrete – Concrete dams (September 2009)

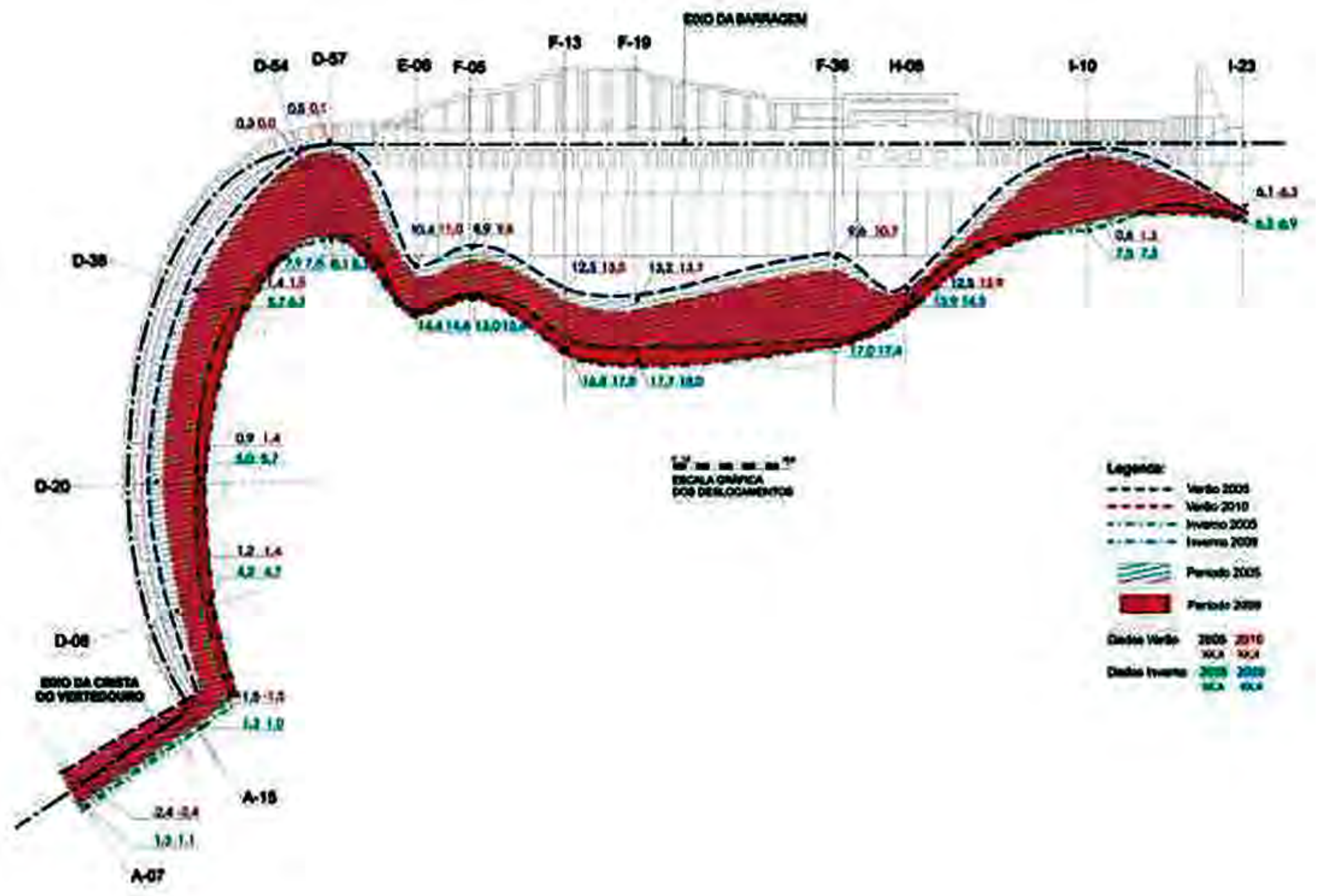
Flows- liter/second- All Concrete Dam				
Concrete Dams	Length (m)	Flow (l/s)	Flow (l/min)	Specific Flow (l/(min/m)
D-E	1088	0,19	11,4	0,01
F	612	6,10	366,0	0,60
H	170	3,69	221,4	1,30
I	459	1,14	68,4	0,15
Total	2329	11,2	667,2	0,29

1 – Hollow gravity dam
2 – Buttress dam
3 – Earthfill dam
4 – Spillway
5 – Paraná River
6 – Powerhouse
7 – Gravity dam
8 – Buttress dam
9 – Rockfill dam
10 – Earthfill dam
F – Foundation
C – Concrete
Total flow through foundation=144.20 L/sec.
Total flow through concrete =12.16 L/sec
Total flow in September 2009=156.36 L/sec
Flow predicted in project=458,60 L/sec

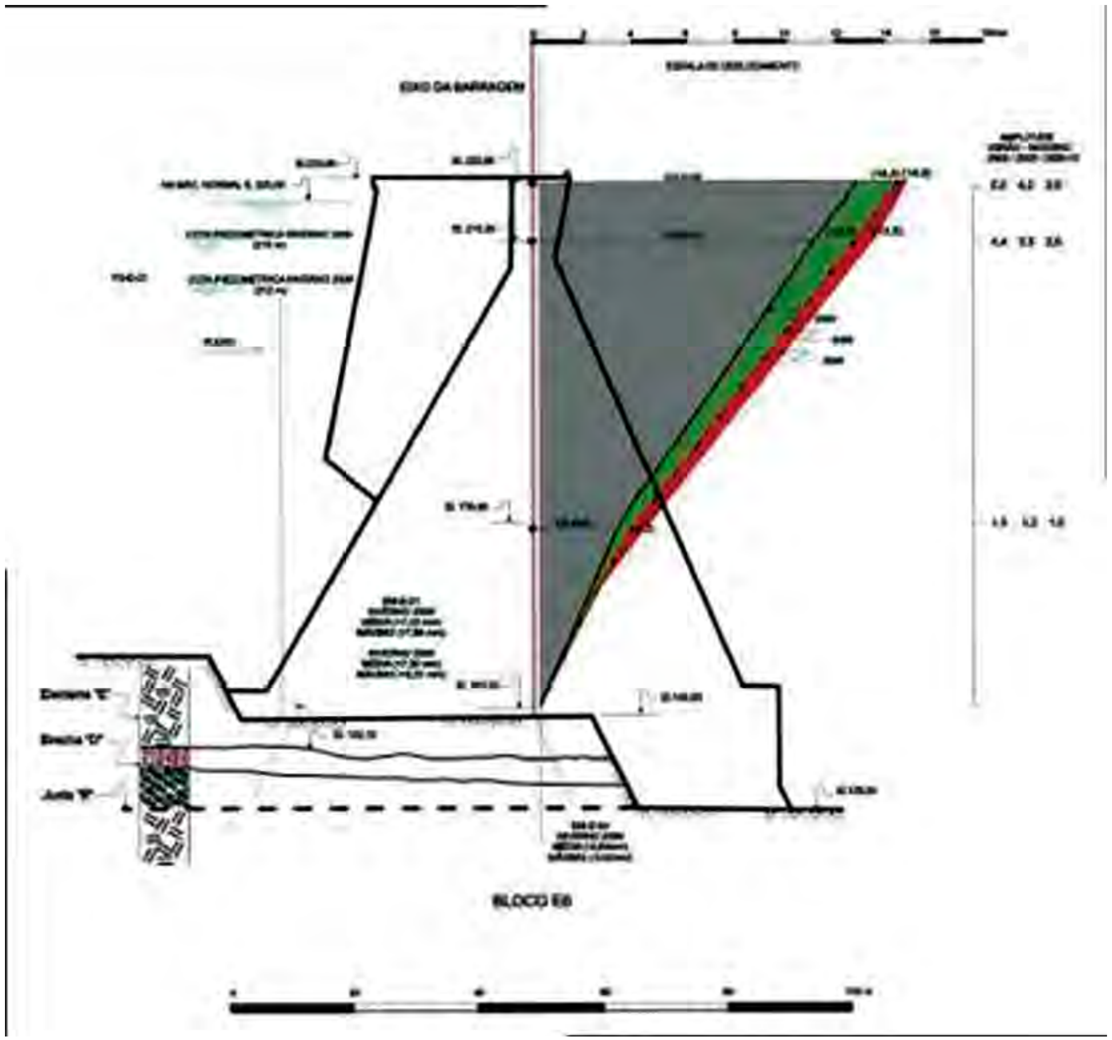




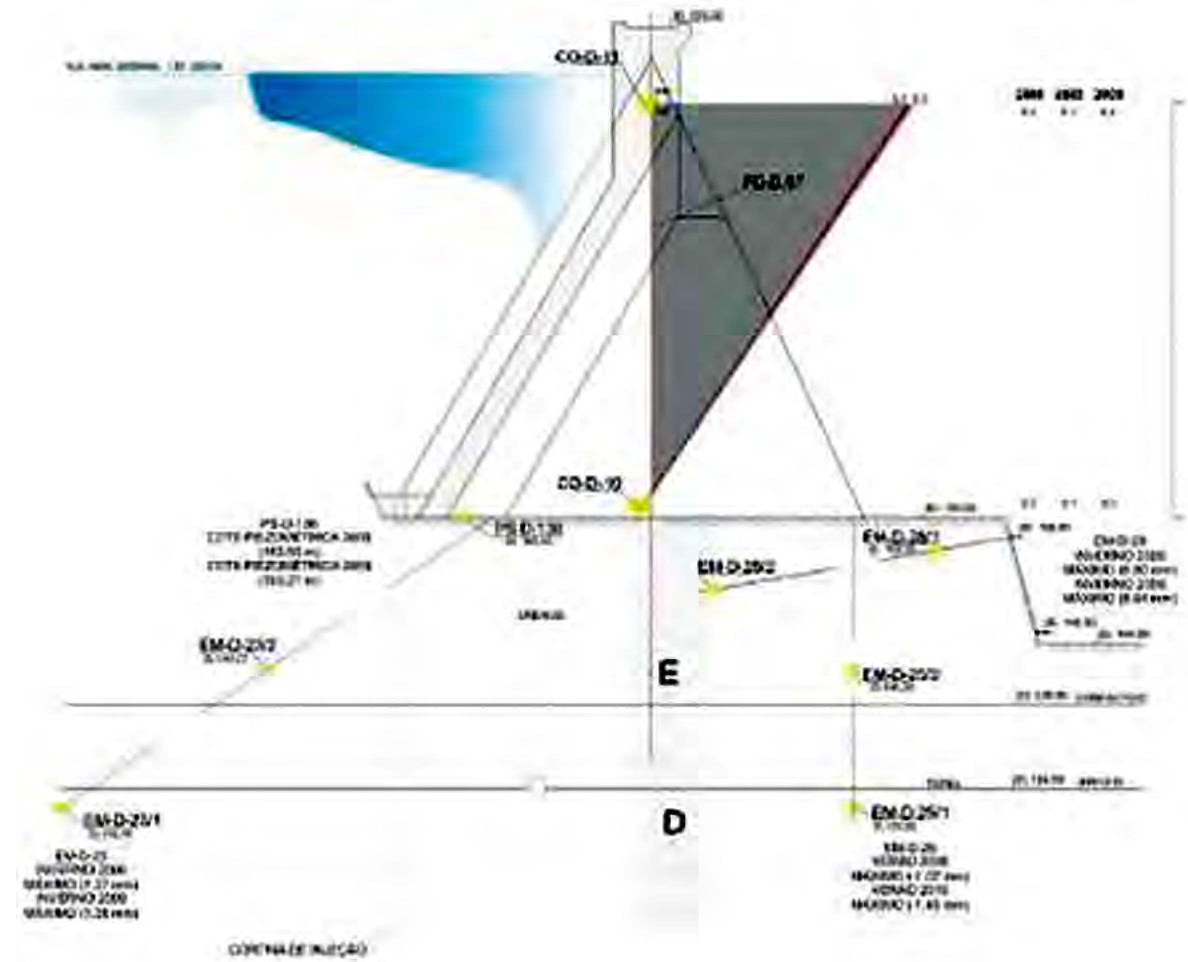
Displacement of the dam crest downstream in relation to the base of the blocks - measured by the pendula in 2005 and 2009/10



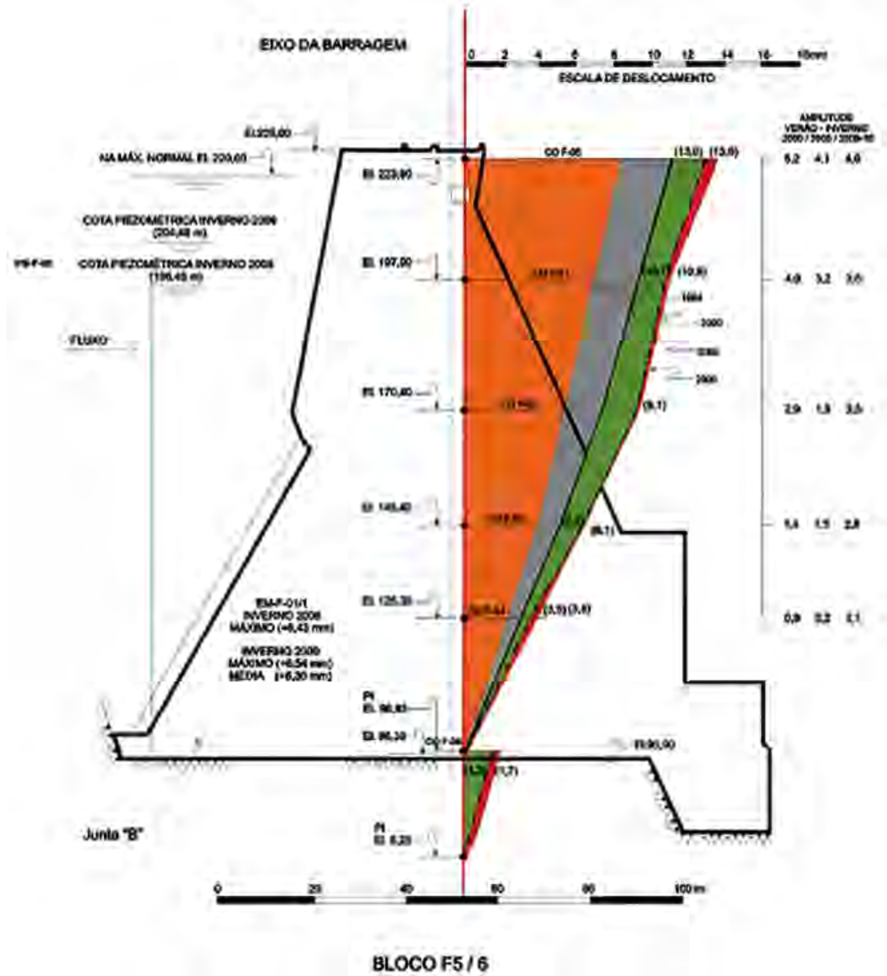
Displacement of the dam crest downstream in relation to the base of the blocks - measured by the pendula in 2005 and 2009/10

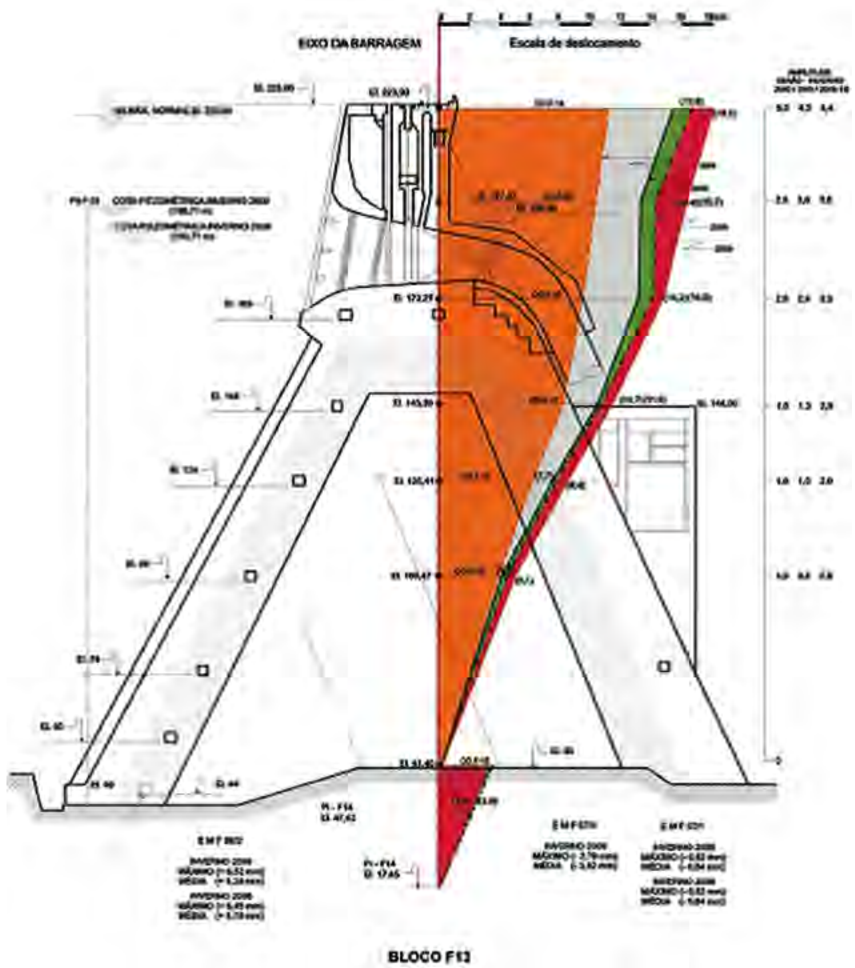


Maximum horizontal displacements downstream- Block E6



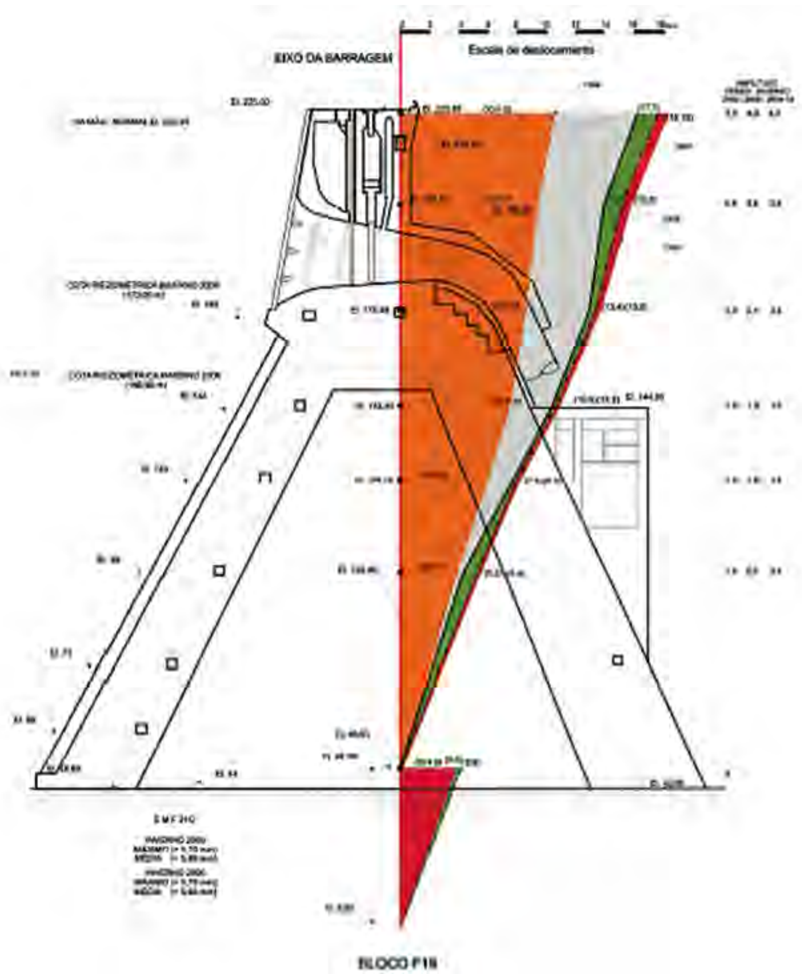
Maximum horizontal displacements downstream (during winter)- Block D



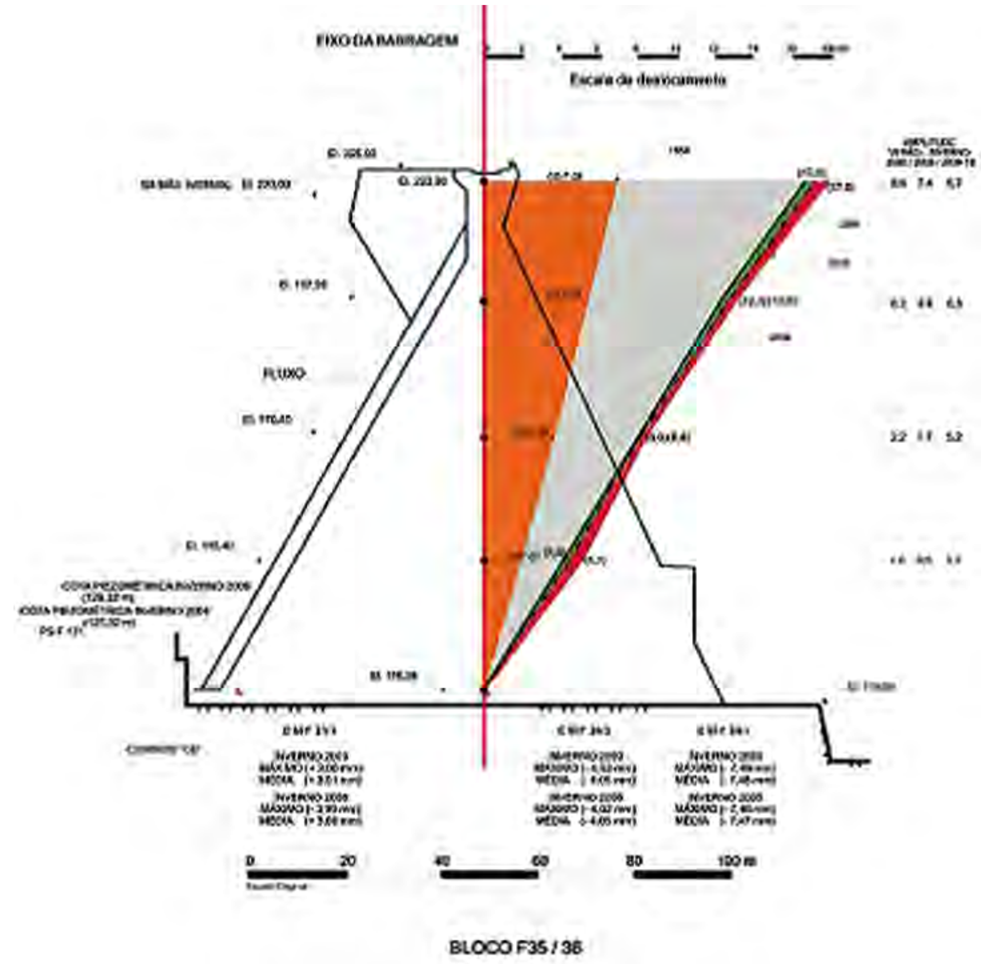


Maximum horizontal displacements downstream (during winter)- Block F 5/6

Maximum horizontal displacements downstream (during winter)- Block F 13



Maximum horizontal displacements downstream (during winter)- Block F 19



Maximum horizontal displacements downstream (during winter)- Block F 35/36

In addition to the experience of the authors, it is convenient to record the frequency of Monitoring for Dams with high hazard potential.

TYPE OF MEASUREMENT	FREQUENCY OF MEASUREMENTS				
	CONSTRUCTION	FIRST FILLING	FIRST YEAR AFTER FILLING	SECOND AND THIRD YEARS	LONG-TERM OPERATION
VISUAL OBSERVATION	Daily	Daily	Weekly	Monthly	Monthly
RESERVOIR LEVEL		Daily	Daily to Weekly	Daily to Weekly	Daily to Weekly
TAILWATER LEVEL		Daily	Daily to Weekly	Daily to Weekly	Daily to Weekly
DRAIN FLOW		Daily to Weekly	Weekly to monthly	Monthly	Monthly to quarterly
SEEPAGE/ LEAKAGE FLOW	Monthly	Daily	Daily to Weekly	Monthly if control measure were applied	Monthly if control measure were applied
PORE PRESSURE/ UPLIFT	Daily to Weekly	Daily to weekly	Monthly	Monthly	Monthly
SURFACE SETTLEMENT		Monthly	Quarterly	Semi-annually to annually	Semi-annually to annually
SURFACE ALIGNMENT		Daily to monthly	Quarterly	Semi-annually to annually	Semi-annually to annually

TYPE OF MEASUREMENT	FREQUENCY OF MEASUREMENTS				
	CONSTRUCTION	FIRST FILLING	FIRST YEAR AFTER FILLING	SECOND AND THIRD YEARS	LONG-TERM OPERATION
INTERNAL MOVEMENT		Weekly to Monthly	Monthly to quarterly	Monthly to semi-annually	Monthly to annually
JOINT/CRACK DISPLACEMENT		Weekly to Monthly	Monthly to quarterly	Monthly to semi-annually	Monthly to annually
FOUNDATION MOVEMENT	Weekly	Weekly to Monthly	Monthly	Semi-annually	Semi-annually
TEMPERATURE	Hourly to weekly	Weekly	Semi-monthly	Monthly	Typically not required
LOADS IN POSTTENSIONED ANCHORS	Typically not required	Typically not required	Annually	Typically not required	Quinquennially

10.11 Documentation

An instrumentation document should be developed that includes a discussion of the purpose of each instrument, expected ranges of data, threshold limits, manufacturers' literature, procurement and installation specifications, installation logs, calibration data and initial readings. Plan and section drawings showing the number, location, and details of each instrument should be included in the document.

Appropriate subsurface stratigraphy should be shown on the drawings. Details of subsurface conditions and construction should be documented for all proposed dams and remedial work at existing dams.

10.12 Data Processing and Evaluation

Instrument data should be processed and evaluated according to the procedures established by the monitoring program. Accumulation of instrument data by itself does not improve dam safety or protect the public. Data must be conscientiously collected, meticulously reduced, graphically summarized, and interpreted in a timely manner. Data must be evaluated with respect to the safety of the dam. A poorly organized and planned program will produce unnecessary data that the dam owner will waste time and money collecting and interpreting, often resulting in disillusionment and abandonment of the program.

Data collected manually should be recorded on the data sheets prepared as part of the monitoring program. Complementary data, such as air temperature, reservoir level, reservoir temperature, recent precipitation, and other information or observations that may be important in evaluating the instrumentation data should be noted on the data sheets. Data should be compared against previous measurements and threshold limits in the field to identify erroneous measurements. Measurements that are outside of normal scatter or threshold limits should be immediately retaken.

Personnel collecting data should be trained in the operation of the instruments, the importance of the data and the need for proper documentation. They should be trained to identify improperly functioning instruments based on measured data or visual observations. They should be aware of the procedures to follow, should unusual or threshold measurements occur.

Personnel collecting data should visually observe the dam for indications of poor performance such as offsets, misalignment, bulges, depressions, seepage, leakage, change in color of seepage or leakage, and cracking.

All monuments and measuring points should be inspected during data collection for evidence of damage or movement from external sources such as frost heave, impact from maintenance equipment, or vandalism. The assumption is made during data reduction and interpretation that the survey control monuments have not moved and that any movements of the measuring points represent movement of the structure.

10.13 Data Analysis and Interpretation

The data analysis starts an optimization or reduction of the available data to be summarized in tabular form showing the date, time, measurements, and comments.

Plots facilitate screening of data and comparison with expected data. Plots are also useful to summarize data. All reduced data should be summarized in graphical form with different symbols or line types should be used to distinguish the data and a legend should be provided. All plots should include sufficient previous data to identify any long-term trends. Furthermore, the plots should be self-explanatory. They should show the project name, type of instrument, and what is being measured. Scales should be consistent to allow comparison of data between plots and they should be labeled. Threshold limits, scatter, and magnitude of significant changes should be considered when selecting scales. Plan and section drawings showing the number, location, and details of each instrument should be included with the plots.

Data should be reviewed for reasonableness, evidence of incorrectly functioning instruments, and transposed data. Several checks for reasonableness can be made on all data. The magnitude of data should be near the range of previous data. Data that are significantly different may be incorrect. Data should be within the limits of the instrument.

It is important to distinguish between accuracy and precision when dealing with measurements:

⇒ Accuracy is the nearness to the true value.

⇒ Precision is the degree of refinement of the measurement.

A measurement may be precise without being accurate and vice-versa. All data will have scatter from instrument error, human error, and from changes in natural phenomena such as temperature, wind, and humidity. The true accuracy of data will not be apparent until a significant number of readings have been taken under a variety of conditions.

All data will follow trends, such as decreasing with time or depth, increasing with time or depth, seasonal fluctuation, direct variation with reservoir or tailwater level, direct variation with temperature, or a combination of such trends. The trends are usually evident in the plotted data. Statistical analysis of data may be useful in evaluating trends that are obscured by scatter. ***However, such analyses are no substitute for judgment based on experience and common sense***. Data inconsistent with established trends should be investigated. Readings deviating from established trends should be verified by more frequent readings. Erroneous readings should be noted on the original data sheets and should be removed from summary tables and plots.

Constant measurements or widely varying measurements may indicate improperly performing equipment. Instruments that do not appear to be functioning properly should be further investigated. Accessible sensors or gages should be replaced to see if the error remains. Calibration of the instruments should be checked. Often, tests can be devised to evaluate proper functioning. Improperly functioning instruments should be abandoned or replaced if it is possible.

All data should be compared with expected behavior based on the basic engineering concepts that were adopted. Variations from expected behavior may suggest development of conditions that should be evaluated.

If no unusual behavior or evidence of problems is detected, the data should be filed for future reference. If data deviates from expected behavior or design assumptions, action should be taken. The action to be taken depends on the nature of the problem and should be determined on a case by case basis. Possible actions include:

⇒ performing detailed visual inspection;

⇒ repeating measurements to confirm behavior;

⇒ reevaluating stability using new data;

⇒ increasing frequency of measurements;

⇒ installing additional instrumentation;

⇒ designing and constructing remedial measures;

⇒ operating the reservoir at a lower level; and

⇒ emergency lowering of the reservoir.

10.14 Reports

10.14.1 General Procedure

Without proper documentation at the time of the inspection, it is extremely difficult to write a complete and accurate inspection report later. The most commonly used and accepted methods for recording information include:

⇒ Written or tape-recorded notes;

⇒ Visual records;

⇒ Photographs;

⇒ Videotapes;

⇒ Annotated drawings and sketches;

⇒ Description of the various techniques used to record information during a dam safety inspection;

⇒ Explanation of the importance of complete and accurate documentation of an inspection.

During an inspection of a dam, the professional needs be sure to take detailed notes, whether written or tape-recorded. These notes should contain information that can be used later to write your inspection report. The notes should be clear and specific, leaving absolutely nothing to memory. They should be organized in such a way that they document the present condition of each feature of the dam. In addition, any potential problem or defect that was identified during the records review should be noted and, during the inspection, its current condition should be recorded. The information typically recorded in written or tape-recorded notes includes:

⇒ Inspection team participants;

⇒ Climatic conditions, especially rainfall (amount if known), immediately prior to and at the time of the inspection;

⇒ Hydrology;

⇒ Geologic Features;

⇒ Operating conditions such as reservoir and tailwater elevation, spillway and outlet discharge, etc.;

⇒ Condition of all inspected features;

⇒ All location, elevation, and description information;

⇒ All quantitative measurements, including instrumentation readings and surveying results (if taken);

⇒ Any safety hazards that could pose a threat to the public or project personnel;

⇒ Description of changes in the upstream and downstream areas;

⇒ Notations on any verbal information gathered, prior to or during the inspection, from operating personnel and other individuals who are not members of the inspection team.

The three types of visual records generally used during a dam safety inspection are:

⇒ Photographs;

⇒ Videotapes;

⇒ Annotated drawings and sketches.

Each of these three types of records can be a very effective means of recording information and can be included as part of the report.

In some cases, records and data may be kept at the dam site. If so, you will need to get copies of any information that is pertinent to your inspection of the dam. These records may provide important information on instrumentation readings, maintenance, and operation. The information contained in the site records should be reviewed and documented during your inspection.

Some organizations require that an exit conference is conducted with the dam owner or operator at the conclusion of the onsite inspection. The exit conference may be either a formal or informal meeting with project personnel. Usually preliminary findings, conclusions, and anticipated recommendations are discussed at these meetings. The exit conference discussion may form the basis for your report. Further evaluation, data review, or just plain reflection about the conditions observed may lead you to different conclusions. Be open to this possibility and let everyone know that the conclusions and recommendations of this exit conference are tentative.

10.14.2 Types of Dam Safety Inspection

It is customary to have different types of inspection, which can be understood as follows:

Type of Inspection	Description
Initial or Formal Inspection	The initial or formal dam safety inspection includes an in-depth review and evaluation of all pertinent data available on the dam to be inspected. Design and construction data are evaluated against current criteria or state-of-the-art in order to identify: ○ Potential dam safety problems that may not be apparent from a visual inspection. ○ Areas of the dam that may require particular attention during the inspection. ○ After reviewing and evaluating the records, a thorough on-site inspection of all features is conducted. An attempt is made to operate all mechanical equipment through their full operating range, and as close to full design load (i.e., reservoir head) as possible.
Periodic or Intermediate Inspection	Periodic or intermediate dam safety inspections are inspections that are conducted between formal inspections. A periodic or intermediate dam safety inspection differs from a formal dam safety inspection because, although all available data are reviewed (in order to become thoroughly familiar with the dam and its features), they are not compared to the current state-of-the art. The data review focuses on the current status of the dam and its features. A comprehensive visual on-site inspection is conducted; however, all of the mechanical equipment may not be operated and tested by any person during inspection.
Routine Inspection	Periodic or intermediate dam safety inspections are inspections that are conducted between formal inspections. A periodic or intermediate dam safety inspection differs from a formal dam safety inspection because, although all available data are reviewed (in order to become thoroughly familiar with the dam and its features), they are not compared to the current state-of-the art. The data review focuses on the current status of the dam and its features. A comprehensive visual on-site inspection is conducted; however, all of the mechanical equipment may not be operated and tested by any person during inspection. The routine dam safety inspection is most typically conducted by field or operations personnel. The primary focus is on the current conditions of the dam and its features. Data may or may not be reviewed and evaluated prior to this type of inspection, depending on the inspector's familiarity with the dam and its features. Routine dam safety inspections may be structured or unstructured. Structured routine inspections are conducted on a set schedule. Unstructured routine inspections are performed in conjunction with other routine tasks.

Type of Inspection	Description
Special Inspection	A special inspection is conducted only when a particular feature is to be inspected. Often, a unique opportunity exists to inspect this feature which would not otherwise be easily inspected. For example, if an upstream slope is not watered, an inspection of that slope may be scheduled. Or, if scuba divers are to be employed to inspect features generally underwater, that part of the inspection may be conducted as a special inspection.
Emergency Inspection	An emergency inspection is performed when the immediate safety of the dam is of concern, or in the event of unusual or potentially adverse conditions at the dam (e.g., during a large flood or immediately following an earthquake).

10.14.3 Inspection Report

The final stage of the inspection process is to develop a written inspection report. The written inspection report pulls together all the information collected from the data review, onsite inspection, and any tests or analyses that may have been conducted. In addition, the report presents the conclusions and recommendations that resulted from your analysis of the information.

The report becomes a part of the Dam Safety File (normally requested by the Owner or the Governmental Agency) and provides a permanent record of the conditions of the dam and recommends follow-up actions at a point in time. To develop the report, reviewing the notes and other data should be done, including:

⇒ Selecting The Report Format;

⇒ Determining The Depth And Scope Of The Report;

⇒ Organizing The Report;

- ⇒ Writing The Report Introduction; Writing The Body of The Report;
- ⇒ Descriptions should be very precise. Avoid using general or vague statements.
- ⇒ Clearly state "***who***" said ***what*** or ***intends to do what and when***;
- ⇒ Descriptions should be complete enough to allow a reader who may be unfamiliar with the dam to understand the current conditions fully;
- ⇒ Descriptions should be written using consistent terminology;
- ⇒ Writing Conclusions;
- ⇒ Writing Recommendations;
- ⇒ Compiling Report Attachments;
- ⇒ Improving your report-writing skills;
- ⇒ Updating the Dam Safety File.

After completing this unit, you will be able to:

- ⇒ Explain the importance of reviewing and organizing information before beginning to write an inspection report;
- ⇒ Determine the appropriate depth and scope of an inspection report;
- ⇒ Select the format and organization to be used in presenting an inspection report;
- ⇒ Write an inspection report that includes findings, conclusions, and recommendations;
- ⇒ Explain the importance of maintaining and updating the Dam Safety File;
- ⇒ Review the inspection notes and correct it if necessary.

The depth and scope of an inspection report depends on the type of inspection that was performed. An initial or formal dam safety inspection report will be broader in scope since, by definition, it includes a comparison of design and construction data against current criteria.

The greatest differences among types of inspection reports are the depth to which project features are described and the extent to which design and construction data are analyzed. The depth of a report's conclusions and recommendations may also vary depending on the type of inspection performed and the extent to which data were reviewed during the inspection. A comprehensive data review will probably enable you to draw more thorough conclusions and make more extensive recommendations.

The conclusions presented in an inspection report are your assessment of the safety of the dam's features. Conclusions are developed based on the information collected from reviewing data and conducting the on-site inspection. Each conclusion must be supported by detailed information presented in the body of the report. Also, conclusions should make reference to conditions described in previous inspection reports.

Recommendations are developed for all conclusions that represent adverse, uncertain, or less than satisfactory findings. The conclusions provide the basis for the recommended follow up actions. Most reports list the conclusions in a separate section. Typically, the conclusions and recommendations are presented toward the beginning of the inspection reports. This allows senior officials and dam owners/operators the option of reading the front part of the report and referring to the body of the report, as needed, to gain more information.

A Dam Safety File is a complete historical record of all information pertaining to the safety of a dam. The Dam Safety File plays a critical role in the dam safety inspection process. A thorough assessment of dam safety cannot be made without ready access to all pertinent information. The last step of the inspection is making sure that the Dam Safety File is up to date. Typically, the Dam Safety File is prepared prior to the initial dam safety inspection.

10.14.4 Format Example

As an example, the following [as published in 10-19] **can be considered:**

Inspection Results—Dam Conditions

Dam Name:______________________ Inventory No:__________
Name of Inspector/s: ______________________
Name of Contact/s: ______________________
Date of Inspection: ________ Start Time: ________ End Time: ________ Weather: ______________

Crest level (at center) above water: ______________________
Service spillway level ❑ Above or ❑ Below water: ______________________
Emergency spillway level above water: ______________________
Ground Moisture Condition: ❑ Dry ❑ Damp ❑ Wet ❑ Snow ___ ❑ Other: ______________

Crest of Embankment General Condition: ❑ Good ❑ Fair ❑ Poor Width: ______________
Problems Noted: ❑ None ❑ Rutting ❑ Erosion ❑ Poor Drainage Height: ______________
❑ Trees ❑ Depressions ❑ Bulges ❑ Livestock Damage ❑ Cracks Length: ______________
❑ Misalignment of Crest ❑ Misalignment of Utility Poles ❑ Misalignment of Fences or Rails ❑ Sinkhole ❑ Burrows
❑ Breached ❑ Other: ______________________
Comments: ______________________

Upstream Embankment General Condition: ❑ Good ❑ Fair ❑ Poor Slope: ______________
Problems Noted: ❑ None ❑ Rip-Rap ❑ Erosion ❑ Too Steep ❑ Burrows ❑ Trees ❑ Cattails ❑ Depressions
❑ Bulges ❑ Livestock Damage ❑ Slides ❑ Concrete Decay ❑ Cracks ❑ Sinkhole ❑ Benching
❑ Misalignment of Rip-rap ❑ Open Joints in Concrete
Comments: ______________________

Downstream Embankment General Condition: ❑ Good ❑ Fair ❑ Poor Slope: ______________
Problems Noted: ❑ None ❑ Sloughing ❑ Erosion ❑ Too Steep ❑ Burrows ❑ Trees ❑ Cattails ❑ Depressions
❑ Bulges ❑ Livestock Damage ❑ Slides ❑ Concrete Decay ❑ Cracks ❑ Sinkhole ❑ Other:__________
Comments: ______________________

Seepage on Downstream Slope Amount: ❑ Major ❑ Moderate ❑ Minor ❑ None Found
Problems Noted: ❑ None ❑ Saturation Starts at __________ % up Embankment ❑ Presence of Sediment in Flow
❑ Cattails at Toe of Dam ❑ Surface Water at Toe of Dam ❑ Seepage Associated with Sloughing ❑ Continuous Flow
❑ Sporadic Flow
Comments: ______________________

Downstream Hazard Conditions ❑ Narrow Canyon ❑ Wide Canyon ❑ Lightly Sloping Prairie ❑ Pastureland
❑ Large Trees and Forest ❑ Brushy and Scrubby Forest ❑ No Homes ❑ Lightly Populated ❑ Moderately Populated
❑ Densely Populated ❑ Industrial ❑ Businesses Estimated number of homes: __________
Comments: ______________________

Service Inlet Structure General Condition: ❑ Good ❑ Fair ❑ Poor
Problems Noted: ❑ None ❑ Blockage ❑ Not Located ❑ Steel Corrosion ❑ Concrete Spalling ❑ Concrete Cracking
❑ Reinforcement Corrosion ❑ Missing Parts ❑ Timber Decay ❑ Leakage Below Water Level ❑ Inoperable Valve
❑ Other:
Comments: ______________________

Service Outlet Structure General Condition: ❑ Good ❑ Fair ❑ Poor
Problems Noted: ❑ None ❑ Blockage ❑ Not Located ❑ Corrosion of Conduit ❑ Presence of Sediment in Flow
❑ Inaccessible ❑ Concrete Cracking ❑ Concrete Spalling ❑ Reinforcement Corrosion ❑ Misalignment of Walls/Slabs
❑ Open Joints
Comments: ______________________

Service Spillway Condition: ❑ Good ❑ Fair ❑ Poor Depth: __________ Width: __________
Problems Noted: ❑ None ❑ Blockage ❑ Not Located ❑ Trees ❑ Burrows ❑ Back-Cutting Erosion ❑ Inaccessible
❑ Livestock Damage ❑ Concrete Cracking ❑ Concrete Spalling ❑ Reinforcement Corrosion ❑ Damaged Water-stops
❑ Open Joints ❑ Sinkholes ❑ Holes in Spillway Chute ❑ Seepage ❑ Misalignment of Walls/Slabs ❑ Damaged Gates
❑ Nonfunctional Gates ❑ Lubrication of Gates ❑ Testing of Gates
Comments: ______________________

Emergency Spillway Condition: ❑ Good ❑ Fair ❑ Poor Depth: __________ Width: __________
Problems Noted: ❑ None ❑ Blockage ❑ Not Located ❑ Trees ❑ Burrows ❑ Back-Cutting Erosion ❑ Inaccessible
❑ Livestock Damage ❑ Concrete Cracking ❑ Concrete Spalling ❑ Reinforcement Corrosion ❑ Damaged Water-stops
❑ Open Joints ❑ Sinkholes ❑ Holes in Spillway Chute ❑ Seepage ❑ Misalignment of Walls/Slabs ❑ Damaged Gates
❑ Nonfunctional Gates ❑ Lubrication of Gates ❑ Testing of Gates
Comments: ______________________

Other Items ❑ Major road along crest of dam ❑ Private road or driveway along crest of dam
❑ Vehicle bridge along crest of dam ❑ Culverts built into crest of dam
❑ Pipeline immediately downstream from dam - Type of pipeline: ______
❑ Water supply line in crest of dam ❑ Other: ______
Comments: ______

Repair Items Ranked by Priority
Item 1: ______
Item 2: ______
Item 3: ______
Item 4: ______

Security Issues ❑ Vehicle Accessible ❑ Vehicle Gates ❑ Vehicle Fences and Railing ❑ Pedestrian Accessible
❑ Pedestrian Gates and Fences ❑ Obscured from Surveillance ❑ Locks ❑ Breaches in Fence ❑ Evidence of Parties
❑ Graffiti ❑ Security System
Comments: ______

Operational Procedures ❑ SOP Available Location Kept: ______
❑ Logbook Location of Logbook: ______
❑ Major Events Noted ❑ Staff Training Topics of Training: ______
❑ Manual Gate Operations ❑ Powered Gate Operations ❑ Automated Gate Operations
Comments: ______

Communications ❑ Directory Available ❑ 24-Hour Coverage ❑ Telephone Available at Dam
❑ Cell Phone Coverage—Provider: ______
Comments: ______

Emergency Action Plan ❑ Available ❑ Filed with TCEQ ❑ Change in Downstream Hazard
Frequency of Update: ______ Date of Last Revision: ______
Date of Last Exercise: ______
Comments: ______

Instrumentation ❑ Present ❑ Adequately Maintained ❑ Inadequately Maintained ❑ Operational ❑ Data Collected
❑ Data Analyzed ❑ Adequately Protected
Comments: ______

Early Warning System ❑ Present ❑ Adequately Maintained ❑ Inadequately Maintained ❑ Operational
Frequency of Maintenance: ______ Date of Last Exercise: ______
Comments: ______

Reservoir Drawdown Capability Method of Drawdown: ______
Maximum Drawdown: ______ c.f.s. Frequency of Testing: ______
Comments: ______

Backup Power ❑ Present ❑ Adequately Maintained ❑ Inadequately Maintained ❑ Operational
Frequency of Maintenance: ______ Date of Last Exercise: ______
Comments: ______

10.15 Emergency Action Plan

10.15.1 General

The primary goal of the state's dam safety program is to reduce the risk to lives and property from the consequences of dam failure [10-19 to 10-26]. Although most dam owners have a high level of confidence in the structures they own and are certain their dams will not fail, history has shown that on occasion dams do fail and that often these failures cause extensive property damage—and sometimes death. A dam owner is responsible for keeping these threats to a minimum. A carefully conceived and implemented ***E***mergency ***A***ction ***P***lan (***EAP***) is one positive step you, the dam owner, can take to accomplish dam safety objectives and to protect your investment and reduce potential liability.

An **EAP** is not a substitute for proper maintenance or remedial construction, but it facilitates recognition of dam-safety problems as they develop and establishes nonstructural means to minimize risk of loss of life and reduce property damage.

A plan is essential for dams which have a high hazard potential and should also be prepared for significant hazard dams. The guidelines explained herein are for the purpose of defining the requirements of an acceptable emergency action plan and for facilitating its preparation, distribution, annual testing, and update. It is recommended that the plan is kept in a three-ring binder, for simplicity of updating, as it will allow the quick and easy replacement of revised pages and the removal of obsolete ones.

An ***EAP*** should contain:

⇒ title page;

⇒ table of contents;

⇒ statement of purpose;

⇒ description of project;

⇒ notification flowchart;

⇒ emergency detection, evaluation, and classification;

⇒ responsibilities;

⇒ preparedness;

⇒ inundation maps;

⇒ implementation.

The title page shall identify the document as an **EAP** and specify the dam for which it is developed. Include the owner's name and the inventory number for the dam. The table of contents should list all major items, including any appendixes for notification flowcharts, tables, and inundation maps.

The purpose of an **EAP** is to provide a systematic means to:

⇒ Identify emergency conditions threatening a dam.

⇒ Expedite effective responses to prevent failure.

⇒ Prevent or reduce loss of life and property damage should failure occur.

This purpose should be stated concisely in the **EAP**. A description of the project and its location shall include:

⇒ a project or vicinity map;

⇒ a drawing showing the project features;

⇒ any significant upstream or downstream dam;

⇒ downstream communities potentially affected by a dam failure or by flooding as a result of large operational releases.

A notification flowchart should identify who is to be notified, by whom, and in what order.

As owner, it is your responsibility to identify distress conditions at the dam and to notify all affected political jurisdictions and appropriate state and federal agencies of the condition and its possible consequences.

It is normally the responsibility of local governments, upon receiving such notification, to warn the public, make recommendations about evacuation, and offer shelter to area residents. There are instances, however, when the dam owner should more appropriately warn certain individuals instead of, or in addition to, relying on local government officials, particularly with small dams that may only affect a few people. Prompt emergency notification requires:

⇒ the identification of all affected jurisdictions;

⇒ the development and annual (or more frequent) updating of names, telephone flowchart, and calling the following parties to determine the appropriate contacts and phone numbers for key agencies that need to be notified in the event of an emergency.

In the event that an emergency condition is declared at a dam, you, the owner, or the operator will initiate emergency notification. Develop information on potential inundation areas. The notification element of an emergency action plan should be brief, simple, and easy to implement under any conditions.

The **EAP** should indicate procedures for timely and reliable detection, evaluation, and classification of an existing or potential emergency situation, listing the conditions, events, or measures for detection of an existing or potential emergency. Incorporate an assessment of the dam, including its vulnerability to all appropriate known emergency conditions such as severe thunderstorms with lightning and excessive rains, hurricanes, tornadoes, earthquakes, etc., as well as a listing and explanation of problem indicators.

The owner is responsible for regularly monitoring the condition of the dam and correcting any deficiencies. The plan must include a routine inspection schedule and name the person or position responsible for the inspection; it should emphasize indicators of the onset of problems that might cause failure of the dam:

⇒ slumping, sloughing, or slides on the dam or the abutment;

⇒ cloudy or dirty seepage or seepage with an increase in flow, boils, piping, or bogs

⇒ seepage around conduits;

⇒ cracks, settlement, misalignment, or sinkholes;

⇒ erosion or riprap displacement;

⇒ animal burrows, especially those associated with beavers or nutria;

⇒ growth of trees and brush;

⇒ failure of operating equipment;

⇒ abnormal instrumentation readings;

⇒ leakage of water into the intake tower;

⇒ undermining of spillways;

⇒ overtopping of the dam.

The plan must address what action to take and what resources will be used when one of these indicators is observed and how quickly you or your responsible agent is to report the problem. Keep records relating to any of the indicators listed above to determine if changes are occurring.

This will allow an intelligent assessment of the problems and the proper implementation of the emergency action plan. However, if you determine that failure is at all possible, report the situation immediately to the Public Dam Safety Program and immediately implement all applicable notification procedures and emergency actions.

10.15.2 Responsibilities

The **EAP** is to identify:

⇒ who is responsible for carrying out each of the emergency actions necessary to meet all requirements of the plan;

⇒ who is in charge of emergency response actions;

⇒ communication and coordination channels;

⇒ the location of the command post, control room, or emergency operating center; and

⇒ lines of succession and assumptions of responsibility necessary to ensure uninterrupted emergency-response actions under any conditions.

The **EAP** should identify ways of preparing for an emergency, increase response readiness in a uniform and coordinated manner, and help reduce the effects of a dam failure. The goal is maximum readiness to respond in a minimum amount of time.

Categorize potential emergencies into phases or conditions and identify specific actions to reduce the possibility of either underreacting or overreacting to a given situation. List anticipated failure situations and appropriate responses, such as:

⇒ **Emergency Water Release—** The release of water at the dam to lower reservoir levels is a normal procedure. An emergency release (i.e., more than normal) could flood certain downstream areas.

⇒ **Watch Condition—** A problem has been detected at the dam which requires constant monitoring or immediate action to repair or correct. At this time, the distress condition is manageable by dam personnel. A watch condition will continue until the problem is corrected or a possible dam failure warning is issued.

⇒ **Possible-Dam-Failure Warning—** A watch condition that is progressively getting worse. Efforts to correct the situation will continue but a possibility now exists that the dam could fail if these efforts are unsuccessful. There is no immediate danger; however, if conditions continue to deteriorate, the dam could fail.

⇒ **Imminent-Dam-Failure Warning—** The owner or the operator has determined that conditions will progress to failure of the dam and an uncontrollable release of the reservoir. The dam will most likely fail regardless of what immediate measures are taken.

⇒ **Dam Failure—** The dam has failed, and a flood wave is now moving downstream. Flooding will start immediately and will continue to move downstream until water levels at the reservoir are stabilized. Massive destruction can be expected from the flood wave and evacuation of downstream areas should continue in accordance with local plans.

The **EAP** should also identify:

⇒ support capabilities, such as personnel or organizations that can provide assistance and the procedures for contacting them;

⇒ the existence and location of supplies and equipment available for use in remedial actions;

⇒ procedures for emergency purchase or procurement of supplies and equipment needed for remedial actions; and

⇒ remedial construction and other activities to prevent failure of the dam.

Inundation maps showing potential areas of flooding from a dam failure are essential in local warning and evacuation planning. This must be included with the emergency action plan. The inundation maps shall delineate areas that would be flooded as a result of a dam failure and shall include the time to flood (the time from the breach to the time that critical structures are flooded) and the time to peak flow.

Aerial photographs, if available with reasonable clarity and scale, can also be used as a background for inundation maps.

It is important to consider, also, the Self-Rescue and Secondary Security Zones:

⇒ **Self-Rescue Zone:** a region downstream of the dam where it is considered that warning notices to the population are the responsibility of the entrepreneur, as there is not enough time for the competent authorities to intervene in emergency situations, and the greatest of the following distances must be adopted for its delimitation: the distance corresponding to the time of arrival of the flood wave and;

⇒ **Secondary Security Zone:** Zone considered in the Flood Map constant region, not defined as Self Rescue Zone.

10.15.3 Dam Break Aspect

The estimation of the breach location, size, and development time are crucial in order to make an accurate estimate of the outflow hydrographs and downstream inundation. However, these parameters are some of the most uncertain in the entire analysis.

A dam's potential breach characteristics can be estimated in several ways, including: comparative analysis (comparing your dam to historical failures of dams of similar size, materials, and water volume); regression equations (equations developed from historical dam failures in order to estimate peak outflow or breach size and development time); utilization of velocity (or shear stress) vs. erosion rates; and physically based computer models (software that attempts to model the physical breaching process by using sediment transport/erosion equations, soil mechanics, and principles of hydraulics).

Historically, all types of dams have experienced failures due to one or more type of event/loading. However, by far the majority of the failures were caused by earth dams, which caused some level of flooding.

The estimation of a dam breach location, dimensions, and development time are crucial in any assessment of a dam's potential risk. This is especially true in a risk assessment where dams are ranked based on the potential for loss of life and property damage. The breach parameters will directly affect the estimate of the peak flow coming out of the dam, as well as any possible warning time available to downstream locations.

Unfortunately, the breach location, size, and formation time are often the most uncertain pieces of information in a dam failure analysis.

When performing a dam breach analysis, one must first estimate the characteristics of the breach.

The breach dimensions and development time must be estimated for every failure scenario that will be evaluated. This requirement includes different failure modes as well as different hydrologic events. The breach parameters associated with a **PMF** (probable maximum flood) hydrologic event will be greatly different than the breach parameters for a sunny day failure at a normal pool elevation. Therefore, for each combination of pool elevation (hydrologic event) and failure scenario, a corresponding set of breach parameters must be developed.

In general, several methods should be used to predict a range of breach sizes and failure times for each failure mode/hydrologic event. A dam's potential breach characteristics can be estimated in several ways, including:

⇒ comparative analysis (comparing your dam to historical failures of dams of similar size, materials, and water volume);

⇒ regression equations (equations developed from historical dam failures in order to estimate peak outflow or breach size and development time);

⇒ utilization of velocity (or shear stress) vs. erosion rates, and;

⇒ physically based computer models (software that attempts to model the physical breaching process by using sediment transport/erosion equations, soil mechanics, and principles of hydraulics).

All of these methods are viable techniques for estimating breach characteristics. It is recommended that the modeler select several regression equations to estimate breach parameter values. Care must be taken when selecting regression equations, such that the equations are appropriate for the dam being investigated.

10.15.4 Implementation

After completing the plan, there are steps to be taken to implement it. Schedule briefings with local officials to facilitate the incorporation of planning information into local government emergency management plans.

Next, schedule training for the employees associated with the dam to familiarize them with the plan. Address:

⇒ How to use the plan;

⇒ How to identify problems and their severity;

⇒ How to use the notification procedures and the communications equipment

⇒ What resources are available;

⇒ The importance of employees' roles during emergencies;

⇒ The importance of updating downstream information.

Also, develop a drill that rehearses the plan in an exercise. Schedule exercises yearly to keep employees familiar with the plan and to eliminate any potential problems. Coordinate with state and local officials before any test of the plan.

Conduct a *tabletop exercise* at least once every five years in the form of a meeting between you, the owner, and state and local emergency-management officials in a conference room. Begin the exercise with a description of a simulated event and proceed to discussions among the participants to evaluate the **EAP** and response procedures. Also to resolve concerns about coordination and responsibilities.

An annual review and evaluation of the plan is recommended. At that time, update the notification procedures to include any changes in names and telephone numbers of staff, local officials, and downstream residents, and include any new problems. Submit plan revisions to the appropriate state and local government officials.

10.15.5 Notifications Messages

Communications should also be provided proactively for organizations and the public that will be, could be, or consider themselves impacted by a dam failure or by dam safety actions that will restrict or modify the operations at the dam. These communications should be initiated at the planning or investigation stage to prevent erroneous information and rumors from developing. Such presentations need to be appropriately technical, conveying the technical information in a manner that conveys the key issues and concerns at the dam, the potential impacts of a dam failure, the proposed actions to address the issues/concerns, and the impacts of these actions on organizations and the public. In addition, the presentation needs to convey the costs and schedule for the dam safety actions.

The **EAP** should also inform:

1) **EMERGENCY WATER RELEASE:** This is a message about a dam emergency. (owner's name) at (name of dam) Dam, Local, (has/have) declared a need for an emergency water release. There is no immediate danger of the dam failing. Releases to lower the lake level (began/will begin) at (time/date). (Minor) flooding is expected along the (stream name). (Briefly describe the problem/reason). For verification, call the phone numbers listed on page of the flood emergency plan for the (name of dam) Dam. Additional information will be provided as it becomes available.

2) **WATCH CONDITION:** This is a message about a dam emergency. (owner's name) at (name of dam) Dam, located at (approximate location), (has/have) declared a watch condition. (Briefly describe the problem/reason.) There is no immediate danger of the dam failing; however, the potential for failure does exist. Emergency water releases to lower the lake level (are / are not) planned. You are requested to initiate appropriate emergency management procedures. For verification, call the phone numbers listed on page of the flood-emergency plan for the (name of dam) Dam. Additional information will be provided as it becomes available.

3) **POSSIBLE DAM FAILURE WARNING:** This is a message about a dam emergency. (owner's name) at (name of dam) Dam, located at (approximate location), (has/have) declared a possible dam failure warning condition. (Briefly describe the problem/reason.) There is a possibility that the dam could fail. Attempts to save the dam are under way, but their success cannot be determined as yet. Emergency water releases to lower the lake level (are / are not) planned. You are requested to initiate emergency management procedures and prepare for evacuation of threatened areas. If (name of dam) Dam fails, flooding will occur along the (stream name). For verification, call the phone numbers listed on page of the flood-emergency plan for the (name of dam) Dam. Additional information will be provided as it becomes available.

4) **IMMINENT DAM FAILURE WARNING:** Urgent! This is a message about a dam emergency. The (name of dam) Dam, located at (approximate location), is in imminent danger of failing. Attempts to save the dam will continue, but their success is considered unlikely. You are requested to initiate emergency management procedures and begin evacuation of threatened areas. It is probable that the dam will fail in (number) hours. If (name of dam) Dam fails, a flood wave will move down the (stream name), through (cities), and on down the (stream name). For verification, call the phone numbers listed on page of the flood-emergency plan for the (name of dam) Dam.

5) **DAM FAILURE MESSAGE:** Emergency! This is an emergency message about a dam failure. This is (owner's name). (Name of dam) Dam, located at (approximate location), has failed. A flood wave is now moving down the (stream name) and the peak will reach (list prominent points and the time to reach them). Evacuate threatened areas immediately. For verification, call the phone numbers listed on page of the flood-emergency plan for the (name of dam) Dam.

6) **ANNOUNCEMENT FOR EMERGENCY WATER RELEASE:** (owner's name) at (name of dam) declared a need for emergency water releases to lower the lake level. (Briefly describe the problem/reason.) There is no immediate danger of the dam failing. Releases of (volume) cubic feet per second (began/will begin) at (time/date). (Minor) flooding is expected along the (stream names).

7) **ANNOUNCEMENT FOR SLOWLY DEVELOPING WATCH CONDITION:** (owner's name) declared a watch condition at (name of dam) Dam as of (time and date). (Describe the problem.) There is no immediate danger of the dam failing; however, the potential does exist. (Describe what actions are being taken to monitor/control the situation.) (State how much, if any, water releases are being made.)

8) **ANNOUNCEMENT FOR POSSIBLE DAM FAILURE WARNING CONDITION:** (owner's name) declared a possible dam failure warning condition at (name of dam) Dam as of (time and date). (Describe the problem.) There is a possibility that the dam could fail. Attempts to save the dam are under way, but their success cannot be determined as of yet. (Describe what actions are being taken to monitor/control the situation.) (State how much, if any, water is being released.) Additional news releases will follow as information is received.

9) **ANNOUNCEMENT FOR IMMINENT FAILURE WARNING CONDITION:** Urgent! (owner's name) announced at (time and date) that (name of dam) Dam is in imminent danger of failing. (Describe the problem.) Attempts to save the dam will continue, but their success is considered unlikely. (Describe what actions are being taken to monitor/control the situation.) It is probable that the dam will fail in (number) hours. Residents of (city) and other low areas along the (stream names) should prepare for immediate evacuation. Additional news releases will follow as information is received.

10) **ANNOUNCEMENT OF A DAM FAILURE:** Emergency! (Name of dam) Dam failed at (time and date). Residents who have not yet evacuated should immediately evacuate low areas along the (list prominent points and the time to reach them). Additional news releases will follow as information is received.

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11

DAM DECOMMISSIONING

11.1 Engineering Considerations

Dams continue to be an important part of the infrastructure worldwide. Many dams were built several centuries ago as ***Cornalbo (See Chapter 1), Almanacid de la Cuba, Tibi*** (Spain), ***Fariman*** (Iran) and ***Khaju Bridge-Dam*** (in Iran also), that continues being used by the society, and a few may have safety issues or reservoirs full of sediment.

Almanacid de la Cuba Aguas Viva – Height= 34 m; Length= 120 m – Ebro River – before the XIII Century[11-01 & 11-02]

The Tibi Dam, was constructed in between 1579 and 1594- with a Heigth of 46 m on Monegre River- Valencia-Spain[11-01]

For millennia, humans have built dams on river systems for navigation, irrigation, flood control, and power generation. Although new dams are still being built to meet the needs of society, particularly in developing countries, many dams are aging, have become hazardous, or are no longer fully serving the functions for which they were designed. Although dam failures are rare, they can be costly in terms of property damage and loss of life.

Khaju Bridge and Dam – Isfahan, Iran – Built around year 1650 (Andriolo's Archive – 2007)

Views of Fariman Dam constructed in between 1350 and 1490 A.D[11-03 to 11-05]

So ...

✓ ***Why Remove Dams?***

In many cases where a dam's negative impacts on a river and to a riverside community outweigh the dam's benefits, dam removal can be a reasonable approach to restore both. Dam owners have already chosen removal as the preferred alternative for of deteriorated, unsafe, or abandoned dams.

The decision to remove a dam should be based on a careful evaluation of a wide range of potential structural and non-structural alternatives, which will typically include dam rehabilitation or repair, dam replacement, dam removal, reservoir re-operation, and "No Action" alternatives. The primary factors in a decision to pursue a dam decommissioning project depend in part upon the type of dam ownership (whether public, private, or abandoned), but also may include:

⇒ Public Safety (implications of potential dam failure or recreational hazards);

⇒ Fish Passage and Aquatic Migration (for migration of protected species);

⇒ River Restoration (for improved water quality, aquatic habitat, and sediment transport);

⇒ Economics (due to dam obsolescence and high costs for operation and repair);

⇒ Project Funding (availability and source for project financing);

⇒ Public Benefits (for fisheries, recreation, navigation, and aesthetics);

⇒ Owner Benefits (for risk and liability reduction, and public relations);

⇒ Environmental Impacts (for environmental compliance and mitigation).

Dam owners must know regulatory agency requirements to ensure the safety of the public. The dam owner's liability associated with potential public safety hazards resulting from dam failure, including loss of life and damage to downstream property and the environment, may be eliminated or reduced by removing the dam, in lieu of extensive modifications or repairs to the dam. Engineering for dam decommissioning projects, which includes planning, design, and implementation, is an evolving science. The overall site restoration goals and project objectives should be well established when designing a dam decommissioning project.

In some cases, dam decommissioning projects may require the design and construction of various types of new features, including temporary structures for streamflow diversion during dam removal, and permanent protective works for remaining portions of the existing dam and appurtenant structures. Streamflow diversion may require the design of temporary cofferdams, bypass channels, flumes, culverts, and pipelines, which may involve the installation of dewatering wells and erosion protection.

There is the aspect of the occurrence of sedimentation, and it is observed in a more forceful way and can be mitigated in several ways.

Sediment Management Alternatives	Dam Decommissioning Alternatives[11- 06] to [11-08]		
	No Action	Partial Dam Removal	Full Dam Removal
No action	o Reservoir sedimentation continues at existing rates o Upstream sediment loads could possibly be reduced through watershed conservation practices o Reservoir operations could be modified to reduce reservoir sediment trap efficiency	o Only applicable if most of the dam is left in place. o Reservoir sediment trap efficiency would be reduced. o Some sediment may be eroded from the reservoir	o Not applicable.

Sediment Management Alternatives	Dam Decommissioning Alternatives[11-06] to [11-08]		
	No Action	Partial Dam Removal	Full Dam Removal
River erosion	o Drawdown the reservoir to flush sediment from the reservoir to the downstream river channel.	o Partial erosion of reservoir sediment, due to partial dam removal, to the downstream river channel o Additional erosion of reservoir sediment through reservoir drawdown.	o Erosion of reservoir sediment into the downstream river channel. Erosion rates depend on the rate of dam removal and reservoir inflow. The amount of erosion depends on the ratio of reservoir width to river channel width and sediment cohesion.
Mechanical removal	o Remove sediment from shallow depths by hydraulic or mechanical dredging or by conventional excavation after reservoir drawdown.	o Remove sediment from shallow depths before reservoir drawdown. o Remove sediment from deeper depths after reservoir drawdown	o Remove sediment from shallow depths before reservoir drawdown. o Remove sediment from deeper depths during or after reservoir drawdown
Stabilization	o Sediments are already stable, due to the presence of the dam and reservoir	o Retain the lower portion of the dam to prevent the release of coarse sediments, or retain most of the dam's length across the valley to help stabilize sediments along the reservoir margins. o Construct a river channel through or around the reservoir sediment.	o Construct a river channel through or around the existing reservoir sediments. o Relocate a portion of the sediment to areas within the reservoir area that will not be subject to high-velocity river flow.

11.2 Social, environmental and legal aspects

Dam owners must meet regulatory agency requirements to ensure the safety of the public. The dam owner's liability associated with potential public safety hazards resulting from dam failure, including loss of life and damage to downstream property and the environment, may be eliminated or reduced by removing the dam, in lieu of extensive modifications or repairs to the dam.

Removal of dams for dam safety reasons often results when the dams are not maintained and are abandoned, which is more often the case with small dams that no longer serve a useful purpose. Environmental justification for dam removal results from adverse impacts due to blockage of fish passage, changes in water quality, changes in the hydrologic regime, or downstream degradation due to changes in the sediment regime.

The decision to remove a dam should be based on a careful evaluation of a wide range of potential structural and non-structural alternatives, which will typically include dam rehabilitation or repair, dam replacement, dam removal, reservoir re-operation, and no other available alternatives.

Operation and maintenance programs generally provide funding for routine maintenance and repairs necessary to ensure the continued operation of the dam and appurtenant features but could possibly be used to remove a dam if justified on an economical basis.

Overall costs to the owner may be lower than modification alternatives, such as the construction and operation of fish ladders and screens for fish passage, or structural modifications to accommodate larger floods or earthquakes required by regulatory agencies. This may be especially true when considering the availability of public funding for dam removal compared to other project alternatives. Dam decommissioning projects can also result in public relations benefits to the owner by demonstrating a commitment to the public welfare and a concern for the environment.

The loss of reservoir storage may produce numerous impacts that need to be identified and evaluated as part of a dam decommissioning project. Obviously, the original benefits for which the dam was authorized and constructed may be permanently lost. The loss of project benefits resulting from the removal of a dam may adversely affect the local community, with associated socioeconomic impacts. These lost benefits could include water supply, flood control, power generation, and recreation.

Legal rights to water diversions may need to be addressed. In addition to the loss of water storage, lower groundwater levels may result, which in turn could impact local wells and springs.

Downstream water quality may be impacted by the passage of natural sediments (either as suspended solids or bed load) that had previously been contained within the reservoir. The coarser sediments may be deposited along the downstream channel, producing higher river stages and greater flooding potential. Downstream water intakes may also be adversely affected by sediment deposition.

The removal of a dam and loss of reservoir storage may also produce significant impacts to infrastructure within the reservoir area. The loss of channel depths may affect river navigation, and the removal of the dam may eliminate an important river crossing that will need to be replaced with a bridge.

Existing bridge piers, roadway and railroad embankments, levees, drainage culverts, and buried or submerged utilities (such as water and natural gas pipelines) within the reservoir area may become subjected to higher flow velocities, scour, and surface erosion and require protection or relocation. Previously inundated cultural and archeological sites may become exposed and subject to erosion or human disturbance. Older structures may represent a local historical resource that will be lost if removed.

A project also qualifies as a major governmental action if it involves approval of specific components, such as construction or management activities located in a defined geographic area or those that may affect protected wetlands, and actions approved by permit or by other regulatory decision, as well as federal and federally-assisted activities.

Local regulations will vary with location, and must be determined for the specific project area. Counties, cities, towns, and other local bodies may require a wide variety of permits covering areas such as zoning, administrative uses, road encroachment, wetlands impacts and mitigation, transportation, floodplain development, grading, hazardous materials, construction, operation, burning, fugitive emission controls, air pollution controls, demolition, waste disposal, recycling, and erosion and sediment control.

11.3 Sediment Management

Sedimentation of a reservoir created by a dam constructed on a natural watercourse can be inevitable. A dam on a river changes the hydraulic characteristics of flow and the sediment, indicating a change in the transport capacity. Reservoir sedimentation has become a significant problem with the aging of water storage facilities. Sediment deposition in reservoirs limits the active life of reservoirs by reducing the reservoir storage capacity for water supply or flood risk reduction. Sedimentation can impact dam outlets, reservoir water intakes, water quality, recreation, upstream flood stage, and downstream habitat.

Dam removal can also reestablish natural sediment transport and deposition mechanisms important to natural river geomorphology. If the impounded sediments are contaminated at levels above background levels for the river system, then those sediments would have to be removed or contained to prevent their release to the downstream channel.

Even if the reservoir sediments are not contaminated, the sudden release of fine and coarse sediments following dam removal will temporarily increase the suspended sediment concentration and turbidity of the flow, possibly creating lethal conditions for fish, and can result in sediment deposition along the downstream channel affecting spawning beds. If coarse sediment is deposited along a formerly degraded channel, then river water surface elevations may increase and affect flood stages.

Sediment management is often the most important and technically challenging environmental consideration for a dam decommissioning project, and it can represent a significant portion of the total project cost.

11.4 Erosion Aspect

Erosion protection measures may be required to preserve water quality until the new plants become established. A management program to control invasive plant species may also be required. This can involve a change in the spillway or discharges directions.

Spillways for large embankment dams typically feature an ogee structure and a section of concrete lined chute, but at some location discharge onto an unlined section. Erosion of this unlined section can require costly remediation and can potentially threaten the integrity of the dam. The unlined section of spillway is typically sited in fractured rock. The erosion of this highly heterogeneous substance does not conform to existing erosion assessment methods for sediment transport or rip-rap. Rather, the designer simply makes a judgement, based on comparison to erosion at other dam sites.

The El Guapo Dam spillway failed December 16 1999, as a result of spillway failure from chute wall overtopping and erosion. The Spillway was reconstructed with Roller Compacted Concrete[11-09]

The El Guapo Dam spillway failed December 16 1999, as a result of spillway failure from chute wall overtopping and erosion. The Spillway was reconstructed with Roller Compacted Concrete[11-09]

11.5 Methods for Removal or Dismantle

Lowering the normal maximum reservoir level may also be accomplished by non-structural methods, such as permanently opening (or removing) gates from the spillway and/or outlet works.

Full or partial removal of any type of dam requires the consideration of a wide variety of technical, environmental, social, political, and economic issues.

A preferred demolition method should be selected for project planning and cost estimating purposes, but the specifications should only define the removal limits and any pertinent constraints or restrictions, thereby allowing alternative demolition methods to be submitted by the contractor for approval. Individual work items should be well-defined but are generally paid as a lump sum to avoid the need for volume measurements in the field.

Dam Type	Removal or Demolition Methods – From [11-06] to [11-08]	
Concrete	Drilling and Blasting	For large dams, drilling and blasting is generally the most economical and effective method for concrete demolition, where permissible. Controlled blasting techniques may be required depending upon the site conditions, with limited load factors and the potential use of blasting mats as required to control fly rock and reduce the potential for damage beyond the structure removal limits. The maximum allowable peak particle velocity at a specific location may be specified to protect nearby structures or equipment as required. Blasting may not be permitted for some projects due to environmental concerns (such as noise, dust, and vibration), or may not be economically feasible for the demolition of slender reinforced concrete structures or small gravity weirs. Removal of concrete rubble following blasting is generally by front-end loaders, excavators, and dump trucks. Separation of the concrete and the reinforcing steel may be required for disposal. Controlled blasting may also be used to topple tall metal structures such as surge tanks for power plants.

Dam Type	Removal or Demolition Methods – From [11-06] to [11-08]	
Concrete	**Mechanical demolition**	These methods are very common for smaller dam removal projects. Impact equipment includes boom-mounted hydraulic impact hammers or "hoe-rams," crane-operated wrecking-balls, and jack-hammers. Hoe-rams are very effective for demolition of small structures constructed of masonry or low-strength concrete, with little or no reinforcement (Figure 6-5). Wrecking-balls may be used for taller structures. Jackhammers are smaller and more portable, for use in confined areas on low concrete structures or slabs. Hydraulic splitters or rock splitters are also small, hand-held pieces of equipment and are effective for controlled excavation in plain and reinforced concrete and in masonry, and hydraulic shears are effective for removal of reinforced concrete wall and roof slabs. Conventional line- or stitch-drilling uses diamond-bit rotary drilling to produce a series of closely-spaced or overlapping holes for excavation of larger openings in concrete. See examples ahead.
	Diamond-wire sawcutting	This method normally requires some drill holes and rollers to establish the wire loop. Common wire lengths used are between 15 and 20 m, with lengths up to 120 m possible. Smooth cuts can be produced without vibration through heavily reinforced concrete. Typical saw cutting rates average between 3 and 12 m2 per hour, depending upon the concrete strength and amount of reinforcing steel. The concrete can be removed in blocks by a crane and loaded onto a flatbed truck. This method is more expensive than blasting or mechanical demolition, but may be useful for special applications or conditions, such as the removal of a concrete gravity weir without impacting an adjoining abutment wall.
	Chemical expansive agents	The chemical agent is mixed with water in drilled holes may be used to produce cracks in concrete or rock without sound or vibration. Concrete fractures can occur within 10 minutes to 24 hours, depending upon the mixture and site conditions. The cracked concrete or rock can then be removed by mechanical methods.
	Other potential demolition	Other methods include hydro blasting, which uses high water pressures, typically for removal of weaker surface material on a concrete face; and flame cutting, which uses an oxygen thermal lance (reaching temperatures of 3000ºC or higher) for cutting high-strength, heavily reinforced concrete and steel pipes.

Dam Type	Removal or Demolition Methods – From [11-06] to [11-08]	
Embankments	**Common excavation**	Embankments (Earth and/or Rock Fills) may be removed using common excavation methods and earth-moving equipment, and can provide a source of clay, sand, gravel, cobbles, and rock for site restoration or for local commercial use. The removal sequence should generally be from the top down to avoid the formation of steep slopes. A controlled breach under the reservoir head may be considered for removal of a small, low hazard embankment dam, or for removal of the lower portion of a large embankment dam, provided the resulting outflow and erosion of earth materials would not harm the downstream channel or produce unacceptable consequences.

Following removal of all or parts of the dam and appurtenant structures, the remaining features may have to be modified to ensure public safety or to reduce long-term operation and maintenance requirements. The dam site and reservoir areas may require reshaping and revegetation. Stilling basins, plunge pools, power plant tailrace areas, building foundations, and canals may have to be backfilled to the original or otherwise designated ground surface. Stability berms or retaining walls may be required to stabilize potentially unstable slopes or landslide areas following reservoir drawdown.

Buried pipelines should generally be removed or stabilized to prevent future deterioration and collapse. Tall and slender structures, such as intake towers and surge tanks, may be susceptible to toppling during an earthquake and should be removed to avoid potential risks. Tunnel portals may need to be plugged or backfilled to prevent entry, with possible special provisions for future inspection and drainage.

Formerly inundated areas may have a restoration or planting plan and require some re-contouring. Depending upon site access, revegetation may be performed by hand, truck, barge, or helicopter.

In some cases, the original purpose of the dam is no longer needed or there may be significant environmental benefits achieved by removing a dam. Dam removal may be a viable management option when the lost benefits of a dam and a reservoir can be met through alternative means. Water storage and flood control benefits provided by many dams would be more difficult to replace if the dam were removed. Decommissioning of dams has primarily taken place in the US and Europe. The practice of decommissioning and decharacterization of dams is quite new in many countries.

From[11-10] it can be understood:

"...Aging infrastructure coupled with growing interest in river restoration has driven a dramatic increase in the practice of dam removal. With this increase, there has been a proliferation of studies that assess the physical and ecological responses of rivers to these removals. As more dams are considered for removal, scientific information from these dam-removal studies will increasingly be called upon to inform decisions about whether, and how best, to bring down dams.... The majority of studies focused on hydrologic and geomorphic responses to removal rather than biological and water-quality responses, and few studies were published on linkages between physical and ecological components. Our review illustrates the need for long-term, multidisciplinary case studies, with robust study designs, in order to anticipate the effects of dam removal and inform future decision making..."

Dam decommissioning, understood as anything from merely stopping the operation. From the above it can be understood that the conceptual aspect of a dam removal is quite new and the society need to improve the knowledge about, and a regulatory statement must emerge from this new cultural aspect.

The feasibility of any large dam decommissioning project consists of some elements:

⇒ environmental;

⇒ technical;

⇒ economic;

⇒ financial;

⇒ legal.

Dam removal, can range from partial removal of the dam alone to full removal of the dam and appurtenant facilities. For partial removal, the dam height and storage capacity should be reduced to the point that the structure no longer meets the statutory definition of a dam (which varies from state to state) or no longer presents a downstream hazard.

A dam decommissioning project would include all necessary activities associated with the full or partial removal of a dam and restoration of the river, from project planning through design and implementation. Retirement can be understood as the discontinued use of a dam and hydroelectric facilities, which would normally include their full or partial removal. A deactivated dam is a dam that has been removed, has failed, or is no longer in service.

The decision to remove a dam should be based on the careful evaluation of a wide range of alternatives to solve a specific problem at an existing facility, including ***dam safety*** concerns, high repair costs, high operation and maintenance costs, or significant impacts on aquatic resources and water quality. In some cases, the problem can be solved by partial removal of the dam rather than by full removal of the dam and project facilities. For example, a dam safety concern may be mitigated by partially removing the dam and lowering the normal maximum reservoir level in order to permanently reduce the loads on the dam, or to reduce potential downstream consequences in the event of dam failure.

Lowering the height of the dam and reducing the maximum storage capacity may also remove the dam from dam safety jurisdiction, or change its hazard classification. A controlled breach of an embankment dam by means of a notch requires engineering analysis to assure proper sizing, shaping, and armoring to prevent future overtopping failure.

The type of dam and the materials used in construction will, among other factors, influence the methods and equipment used to remove the dam. Of course, that this aspect need be considered as an engineer challenge with an adequate methodology and can have an impact in the cost for removal of the dam.

Common **dam safety** improvements to older dams include:

⇒ Increase in spillway discharge capacity for passage of new design floods;

⇒ Replacement of inlet and outlet structures, gates, and valves;

⇒ Modifications to increase static or seismic stability of concrete and masonry dams;

⇒ Modifications to control seepage and piping potential of embankment dams;

⇒ Erosion control improvements for embankment dams and unlined spillways;

⇒ Dam overtopping protection

Nowadays, the communities are considering the option of removing or modifying dams that have damaged local riverine ecosystems, outlived their usefulness, or become a safety hazard.

There are a range of ways to restore a dammed river, from fully removing the structure to modifying its operation. Dam removal can range from partial removal of the dam alone to full removal of the dam and appurtenant facilities. For partial removal, the dam height and storage capacity should be reduced to the point that the structure no longer meets the statutory definition of a dam or no longer presents a downstream hazard.

A dam decommissioning project would include all necessary activities associated with the full or partial removal of a dam and restoration of the river, from project planning through design and implementation.

The decision to remove a dam should be based on the careful evaluation of a wide range of alternatives to solve a specific problem at an existing facility, including dam safety concerns, high repair costs, high operation and maintenance costs, or significant impacts on aquatic resources and water quality.

⇒ **Dismantling:** The complete dismantling of all physical barriers to stream flow. Dam removal is usually staged to avoid sudden release of the sediments that have accumulated behind the dam wall. This is the costliest restoration option.

⇒ **Partial Decommissioning:** Some dam remains with this approach. Altering the dam structure will restore some flow and change the dam's original function.

⇒ **Modification:** Various options have little or no impact on dam function. For example, the addition of fishladders can be used to improve fish access to spawning habitat above the dam without altering the function of the dam itself. This approach

⇒ **Re-operation:** Improving the release of water from dams usually allows the dam to continue with its original functions. Re-operation can improve fish survival downstream by releasing more water from the reservoir during critical times such as spawning season. While more effective management of dams can help to mitigate environmental impacts, it should be noted that many dams around the world presently lack the mechanisms needed to control water discharge.

The costs for these improvements may require a significant expenditure of project funds, including potential costs for diversion and care of the streamflow during construction. Project benefits could also be adversely impacted during construction, such as the loss of hydroelectric power generation, representing an additional cost to the project.

11.6 Special Concerning – Tailings Dams

Tailings is a common by-product of the mineral recovery process. They usually take the form of a liquid slurry made of fine mineral particles – created when mined ore is crushed, ground and processed – and water.

The mining process produces slurry wastes known as tailings, which are stored in containment structures called tailings dams. Following mine closure, tailings dams are subject to natural forces as the dam transitions into a landform that is compatible with the natural landscape. This poses a significant technical and regulatory challenge, as tailings dams that are designed to be safe during the mine's active life also need to perform safely long after mine operations are finished. The underperformance of these structures can result in significant risks to public and environmental safety, as well as impacts to future land use and economic activities in the vicinity of such structures.

To prevent failure of these large structures after mining, their long-term behavior must be understood and incorporated into closure design, ideally from its conception and initial design. The challenges lies in the limited information available regarding how these structures age over time and forecasting loading and environmental scenarios over long time periods (weather events, seismicity, human activity, etc.). Ultimately, the goal of tailings dam closure is to reduce future risk of failure to the environment and public to a degree that is both practical and economical.

A number of significant tailings dam failures that have occurred in the beginning of this Century, induces the technical society and the population to take actions and governmental action regulations being adopted.

From [11-12] can be noted:

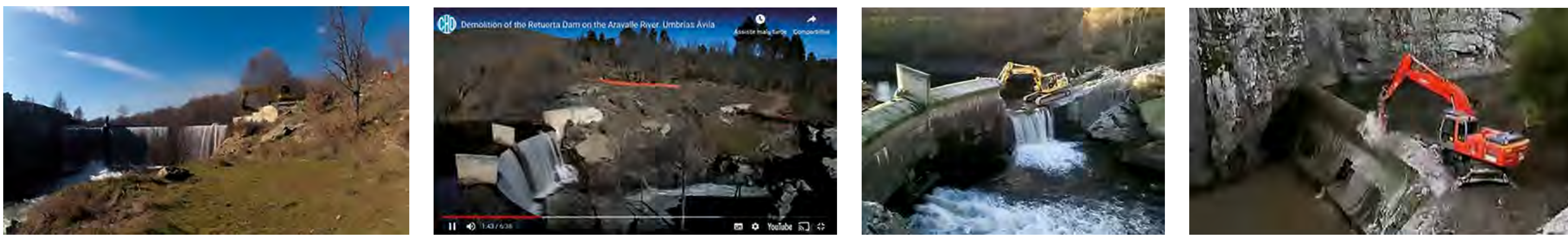
*"...Since the early 1990s the **United Nations Economic Commission for Europe** (ECE) has committed itself to the prevention of, preparedness for and response to industrial accidents, especially those with transboundary effects in its region. The 1992 ECE Convention on the Transboundary Effects of Industrial Accidents helps protect human beings and the environment against such accidents by preventing them as far as possible, by reducing their frequency and severity and by mitigating their effects. Issues related to the prevention of accidental water pollution are addressed in close cooperation with the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes. Industrial accidents at Tailings Management Facilities (TMFs) may indeed lead to accidental water pollution. TMFs store large amounts of mining waste which are generated as a by-product when extracting minerals. As such, they can pose serious threats to humans and the environment, especially in case of their improper design, handling or management. Thus, a failure may result in uncontrolled spills of tailings, dangerous flow-slides or the release of hazardous substances, leading to major environmental catastrophes.... .... The effective and safe disposal of mining wastes presents technical and environmental challenges...."*

Overtopping, slope instability, and earthquakes are considered the top three causes for active tailings dam incidents, with additional causes including foundation instability, seepage, structural inadequacies, erosion, mine subsidence, and unknown causes, up to now.

11.7 Examples – Decommissioning

Case	Identification	Country	Finished	Decommissioning	References
11.7-A	Retuerta	Spain	1970s	2013	11-13

Technical Information – The Retuerta dam was 14 m high and 55 m wide in Avilla zone – Spain. It was built in the 70s to supply water to a future urban development that never happened. In September 2012, the dam drainage suffered a sabotage that caused a serious fish mortality both at reservoir and downstream. From this fact and taking into account that the license had expired, Duero Basin Authority decided to demolish the dam in 2013.



Views of Retuerta dam before the removal and during the process of decommissioning[11-13]

Case	Identification	Country	Finished	Decommissioning	References
11.7-B	Condit	USA	1912	2011	11-14

Technical Information – Condit Dam was built in 1912 and 1913 but wasn't under license requirements until the 1960s. It was originally licensed by 1968, with a May 1, 1965 as the effective date. PacifiCorp began work to relicense the project in 1991. Several resource agencies and groups, including American Rivers, pushed for decommissioning and removal of the dam because it cut off salmon and steelhead from the upper White Salmon River.

Views of Condit dam before the removal and during the process of decommissioning[11-14]

Case	Identification	Country	Finished	Decommissioning	References
11.7-C	Arase	Japan	1954	2015	11-15

Technical Information- as follows:

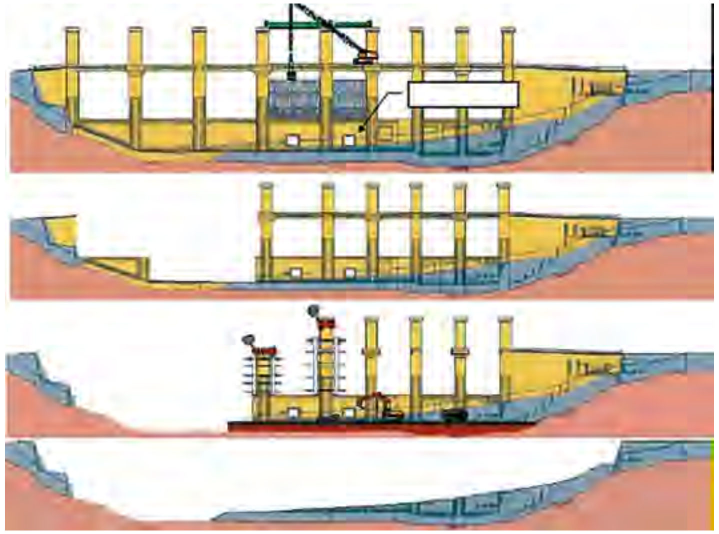
In the late 1940s, Kumamoto Prefecture suffered from power shortages because about 40 percent of the electricity generated within the prefecture was being sent to the Kitakyushu Industrial Zone in Fukuoka Prefecture. In response, Kumamoto Prefecture formulated the Kuma River Comprehensive Development Plan in 1951 to construct seven dams and 10 power plants along the Kuma River running through the southern part of the prefecture. This plan aimed to ensure a stable power supply by using the abundant water resources of the Kuma River, and as part of this plan the Arase Dam and Fujimoto Power Plant were built.

The Arase Dam was built exclusively for hydroelectric power generation. From the intake on the right bank of the dam, water flows through a 600 meter tunnel to the turbines at a maximum rate of 134 m^3/s to generate electricity, using an effective head of 15.96 meters. The power plant began operation in December 1954 with a maximum output of 18.2 Mw.

Before the water rights allocated to the prefecture expired in March 2003, Kumamoto Prefecture discussed their renewal, because the water rights were necessary for continued hydropower generation. Later, the prefecture decided to decommission and remove the Arase Dam because the local council had submitted an opinion brief that requested dam removal in response to local residents' complaints about adverse effects of the dam.

The Arase dam gate on the Kuma River was opened in April 2010. Surface and bottom sediments were compared using 10-cm-long cores (2011) and two grain size fractions. Surface sediment data from 2002, 2012, and 2013 from the Kuma River and Yatsushiro Bay were also compared. The sediments were analyzed using XRF for 23 elements, and the grain size analysis was done. The short core surface and bottom sediments do not show major chemical changes, and therefore, may not represent post-and pre-dam sediments. Results based on 2011 samples show that the removal of the Arase dam gates in 2010 has been environmentally beneficial due to the decrease of environmentally related trace elements Pb and Zn in 2013. However, a slight increase in the levels of Cr, Cu, Zr, and Nb in 2013 indicates that periodic flushing in winter leads to elevation in these elements due to an increase in the fine fraction. Metal enrichment factors (EF) in 2002 are higher and these have decreased by 2013. Some elements exceed environmental guidelines, but this is due to natural background values, and there is no anthropogenic contamination.

Thus, the environment of the river and bay has been significantly improved due to the dam opening. This result suggests that assessment and environmental monitoring studies are very important for dam management and future decision-making. The Kumamoto Prefecture finally decided to decommission and remove the Arase Dam in February 2010. In April 2010, it created an R&D committee for technologies to remove Arase Dam and started formulating a removal plan for the deconstruction work.



Arase Dam before removal, November 2005 – Photo by MK Products

Arase Dam as of January 1, 2014[11-15]

Case	Identification	Country	Finished	Decommissioning	References
11.7-D	Scott Falls	Canada	1912	1978	11-16

Technical Information – Scott Falls Dam was a dam constructed in 1912 in southeastern New Brunswick-Canada. The dam was decommissioned in the 1970s because of weak water flow.

Scott Falls dam during demolition[11-16]

Case	Identification	Country	Finished	Decommissioning	References
11.7-E	Benambra	Australia	1992	1996	[11-17 & 11-18]

Technical Information – From 1992 to 1996, the Benambra Mine operated as an underground base metal mine producing zinc and copper concentrate. In 1996, the Mine was placed into administration and mining operations ceased immediately without the undertaking of any environmental rehabilitation. The unplanned closure of the mine created an array of environmental problems and in 2005, the DPI engaged us to undertake design and documentation of a rehabilitation plan for the entire site, including the tailings dam. Our rehabilitation plan for the site covered a range of components, including:

- Re-engineering the Tailings Storage Facility (TSF) to satisfy long-term closure design criteria and minimization of contaminant production;
- Creation of an anaerobic wetland, downstream of the TSF;
- Disposal of remnant sulphidic waste into the TSF;
- Removal and disposal off site of all hydrocarbons, hydrocarbon contaminated soils, chemicals, plastics and steel waste;
- Crushing and co-disposal of all concrete; and
- landscaping and re-vegetation of the mine site and associated access roads.

Case	Identification	Country	Finished	Decommissioning	References
11.7-F	Boltby	UK	1880	2005	11-19

Technical Information – Boltby Dam, North Yorkshire, UK, was completed in 1880 as a means of water supply to the local area. In June 2005 a flood event with a return period in excess of 1 in 10 000 years caused significant damage to the masonry-lined spillway structure. The reservoir had not been used for supply since 2003, and it was subsequently decided to discontinue the reservoir under section 13 of the Reservoirs Act 1975. The discontinuance work consisted of the excavation of a notch in the dam approximately 70 m wide at crest level.

View of the damage after the 2005 flood, and the actions for the discontinuance of the dam[11-19]

View of the dam renovation[11-19]

Case	Identification	Country	Finished	Decommissioning	References
11.7-G	Marmot	USA	1989	2007	11-20

Technical Information – The 14.3 m high Marmot RCC dam diverted flow from the Sandy River, 30 miles from its mouth on the Columbia River The dam generated about 22 MW of electricity, enough to power about 16500 modern homes. In the late 1980s a concrete layer was added to the original earthen structure to strengthen the Marmot dam.

Faced with a requirement and its prohibition to harm listed species. Continued operation of the dam would require constructing and operating fish passage. Recognizing that dam removal would cost customers less in the long run, the owner engaged in 1999 to voluntarily removing Marmot and Little Sandy dams, and their associated infrastructure.

Engineers demolished the 14 m high Marmot Dam and the 4.9 m high Little Sandy Dam in 200t. The decommissioning restored the Little Sandy River to steelhead and salmon runs for the first time in nearly a century. In May 2009, a fish biologist reported that salmon and steelhead were spawning upstream of the former dam. Planning for the physical dam removal took several years. A coalition of agencies and conservation groups consulted with the utility on the terms and process would withdraw its hydropower license.

Deconstruction at Marmot began in summer 2007, with the river diverted by a temporary earthen coffer dam built behind the once permanent Marmot. In October 19, 2007, as calculated in dam removal plans, a seasonal storm rose with enough force to wash away the temporary dam. An excavator cut a small notch in the coffer dam, releasing first a trickle and then a roaring torrent. Approximately 19 hours later, the entire structure was washed away.

Marmot RCC Dam before the demolition by 2006

Marmot RCC Dam during the demolition 2007 [From 11-20]

Case	Identification	Country	Finished	Decommissioning	References
11.7-H	Lake Mokoan	Australia	1971	2004	11-21

Technical Information – Lake Mokoan Dam was an artificial lake in northern Victoria**,** Australia**,** roughly 7 km north-east of Benalla. It was created by diverting water from the Broken River and Hollands Creek into Winton and Green swamps. Construction began in the late 1960s and was completed in 1971. Planning for the decommissioning began in 2004,and work started in 2009.

Lake Mokoan Dam before (left) and under demolition (right) [From 11-21]

Case	Identification	Country	Finished	Decommissioning	References
11.7-I	Kernansquillec	France	1922	1996	11-22

Technical Information – This multi-vaulted concrete dam, roughly 15 m high, was built over the Léguer river in 1920 as a concession in order to supply energy to a paper plant. As the authorization procedure following the expiry of the license was being considered, the administrative authority informed the outgoing concessionaire of the conditions under which the new license would be granted: particularly, by increasing the capacity of the overflow works and removing the silt from the reservoir.
The outgoing concessionaire referred to give up his renewal request: the infrastructure was thus transferred back to the State by the end of the concession on December the 31st, 1993. The dam then supplied electricity to EDF, but when it was time to renew the license, the dam was in poor condition and there was limited economic interest. The former license-holder decided not to renew its application and the dam then became a public asset with associated responsibility for maintenance.
During the January 1995 flood, seven houses had to be evacuated downstream upon the experts' recommendations because of the insufficient capacity of the overflow works, as the water was about to overflow the dam. In addition, the dam prevented the passing of salmon and other migratory fishes. Considering its limited interest, its age and its potential dangers for public safety and the environment, it was decided to demolish the dam.

Kernansquillec Dam during the Demolition [From 11-22]

Case	Identification	Country	Finished	Decommissioning	References
11.7-J	Glines	USA	1927	2015	[11-06 to 11-08] & [11-23 & 11-24]

Technical Information – Glines Canyon Dam, also known as Upper Elwha Dam, built in 1927, was a 64 m high concrete arch dam built on the Elwha River within Olympic National Park**,** Clallam County, Washington. The dam was demolished in 2014 as part of the Elwha River ecosystem restoration project; as of 2015, it is the tallest dam ever to be intentionally breached. The Glines Canyon Dam was the largest dam removal ever.

Glines Canyon Dam and Lake Mills within Olympic National Park (photograph courtesy of National Park Service)

Glines Canyon Dam on the Elwha River near Port Angeles, Washington, prior to dam removal (photograph courtesy of Tim Randle, Bureau of Reclamation)

Initial demolition of Glines Canyon Dam by barge-mounted hoe ram whilereservoir releases were through the spillway (Photograph courtesy of Barnard Construction)

Mechanical excavation of the upper portion of Glines Canyon Dam in Washington, using a hydraulic excavator on a barge. (Photograph courtesy of National Park Service, January 14, 2012)

Drilling and blasting notches for excavation of the lower portion of Glines Canyon Dam in Washington (Photograph courtesy of National Park Service, July 1, 2012)

Hoe ram employed on a tracked vehicle floating on a barge immediately upstream from Glines Canyon Dam in Washington (photograph courtesy of Barnard Construction)

Demolition of Glines Canyon Dam by barge-mounted hoe ram that created a series of notches with which to drawdown the reservoir (Photograph courtesy of National Park Service)

Demolition of the Glines Canyon arch dam section by blasting notches. A portion of the gated spillway is visible in the top-right corner of the photograph (photograph courtesy of Barnard Construction)

Drilling and blasting activities at Glines Canyon Dam in Washington

At Glines Canyon Dam, the left-side spillway gates and the right abutment thrust block are retained for a public overlook within Olympic National Park in Washington (photograph courtesy of Tim Randle, Bureau of Reclamation)

A large ringer crane was employed at Glines Canyon Dam, WA (photograph courtesy of Tim Randle, Bureau of Reclamation)

At Glines Canyon Dam, Washington, the upstream tunnel barrier (left) was blocked using precast concrete panels while the downstream tunnel barrier (right) was blocked using metal panels (photograph courtesy of Tom Hepler, Bureau of Reclamation.)

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12

SUGGESTIONS AND RECOMMENDATIONS

12.1 General

A dam failure can result in a catastrophe (a break followed by a flood wave for example), often with considerable loss of life or property. Even if only the availability of the reservoir or the reliability of its operation is impaired.

All failures, therefore, have caused dam owners and engineers to give a great deal of care and attention to dam safety and to make safety a predominant factor.

Debates about safety in technical developments and construction methods in general are taking place recently in many countries. The reasons for this are:

⇒ ***firstly***, the increase in construction of structures which would cause great damage in case of failure; and

⇒ ***secondly***, accidents or disasters caused by failure of such structures.

As a result, it has become urgent that the safety of dams around the world be given the greatest possible concern, as well as a deep common understanding and definition of actions as precise as possible.

To be safe, therefore, a dam must be supplied with appropriate reserves, considering all reasonably imaginable scenarios of normal utilization and exceptional hazard which it may have to withstand during its life.

In dealing with safety problems during ***Design, Construction, Operation, Monitoring, Maintenance*** and ***Surveillance*** of dams, it is essential to carefully register, process, and study all available information on past incidents of unacceptable performance of damage, impairment of serviceability or outright failures.

In several cases of dam failure, particularly in some sizes and regions (but not only small dams), investigation has shown that these dams had not been designed by competent engineers or were not suitably supervised during construction, or experienced constructor.

Many failed dams did not have monitoring or warning systems or had systems that were out of order. In several cases, human error was involved during site investigation and design, as well as during construction and operation for instance some aspects can be mentioned (and as described in **Chapters 4 and 7**): inadequate foundation investigations, hydrology understanding. Incomplete data on available materials, poor design, negligent construction supervision, incompetent first impoundment, incorrect operation of flood gates, insufficient monitoring and data analysis, or lack of preventive measures or repair work.

The previous **Chapters**, had tried to induce to the concept of the ***KNOWLEDGE MANAGEMENT***, showing a list of points to pay attention, based on some important damages and a statistical list of failures that are available.

This concern leads on inevitably to the question of:

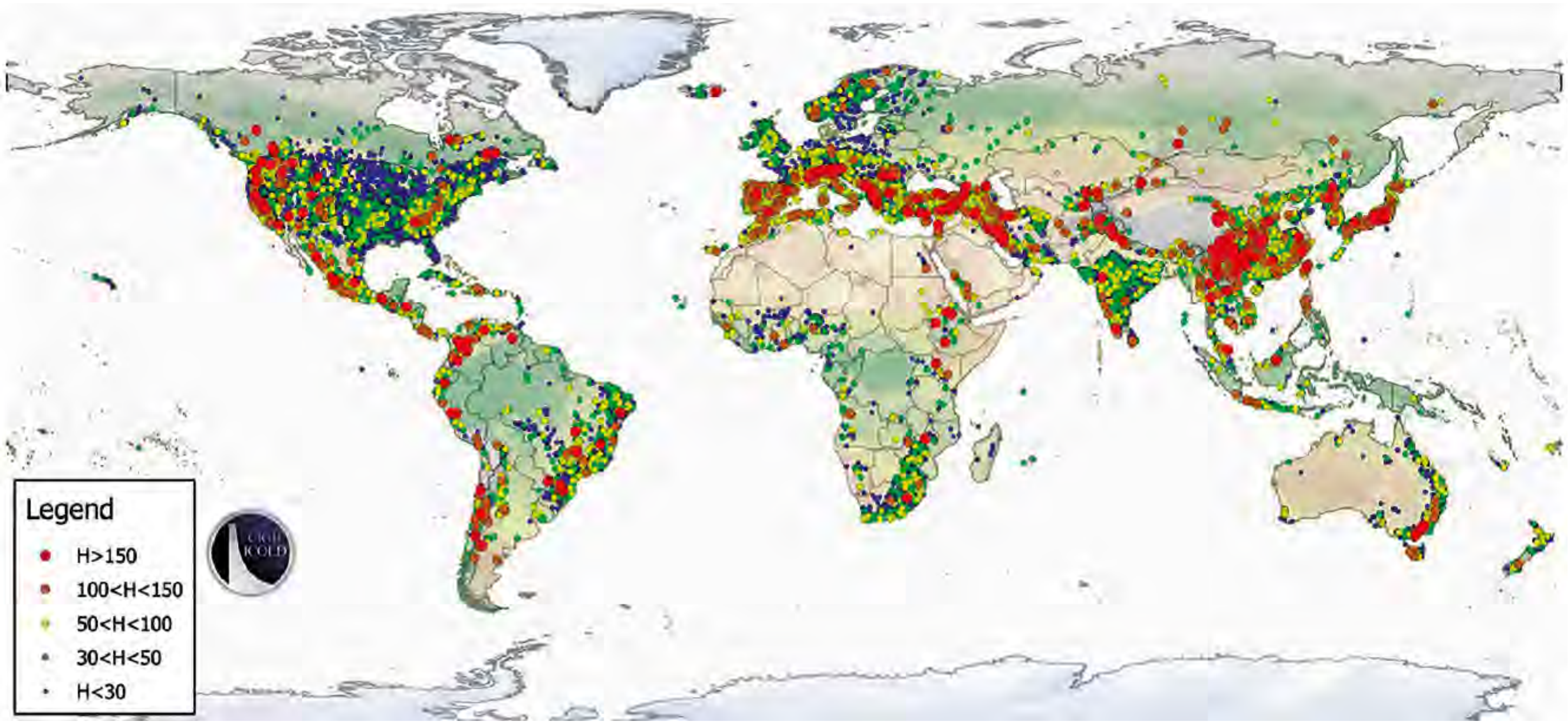
- ✓ ***How safe a dam should be?***

There are dams (as experienced by the authors - with some jobs constructed by the 70s at least, but there are even older ones) that have no technical data, no records, no stability analysis, no quality control data, etc. The Professional Team need, for example, to be as like as ***a taxidermist or archaeologist and opening a sarcophagus to do the Autopsy of the Mummy***, to look at the condition of the dam!

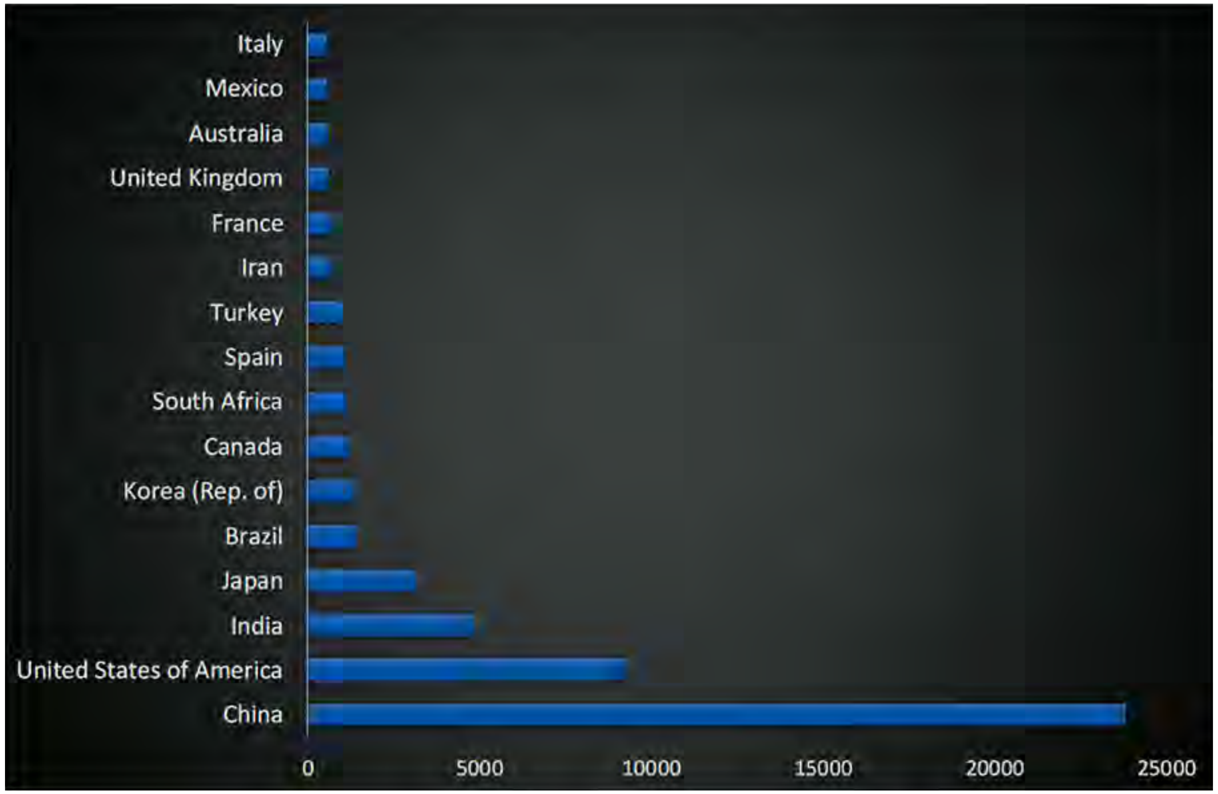
It is significant to note that the World has a huge number of dams and that many dams yet can be built. According to the ICOLD register[12-01], today more than 58,000 large dams are satisfying the worldwide vital needs for water, energy, food, and flood protection.

This is, above all, the highest importance for food production around the world, a good part of which depends on irrigation. The major problems of the world population in this century will be without doubt the safe supply of ecological and renewable energy, as well as the supply of water of good quality and enough to eliminate famine, poverty, and disease in the world. Still today, water supply and sanitation services leave much to be desired; 40% of the global population suffer from water scarcity, which is projected to rise, and almost 800 million people do not have access to clean water. Furthermore, an important part of the world population is still threatened with famine.

This risk could be considerably lessened by irrigation to produce food in arid areas, which are not cultivable today. Thus, in many countries, especially in Africa, there is still an urgent need for increased development of water and energy resources as the basis for the economic prosperity and cultural wealth of these societies.



Location of the 58,000 large dams according to the ICOLD register ranging from medium size dams (up to 50 m high, shown in yellow) to very high dams (above 150 m, shown in red)[12-01]



Distribution of the dams around the World, considering the main Countries Constructors[12-01]

Some of these influences, which vary in importance from one country to another, are the aging of dams, the limited opportunities for engineers to gain experience on dam design and construction. The demands for transparency and documented safety evaluations and deregulation and privatization introducing the profit motive.

The risks in these areas need to be analyzed and controlled with the same care as for the design of the dam structure. This need leads to the question of how the risk levels inherent in the traditional engineering standards relate to the tolerable risk criteria.

It is recognized that the traditional standards-based approach to dams engineering can be a very effective means of deciding whether risks are acceptable or not.

As a general rule, protection of persons and properties is a social responsibility for Government, who must legislate to enforce and control effective and efficient surveillance of dams. Dam surveillance must rely on a legal framework, which clarifies the duties and responsibilities of the different parties. It is generally accepted that the responsibility for dam surveillance and the assurance of safety belongs to the owner of the dam, or its operator.

But it is important to put some scenarios about what dam we are analyzing to present some suggestions or recommendations.

There can be considered 3 scenarios, as shown in the table ahead:

DAM SURVEILLANCE

EXISTING DAM- NO INFORMATION	EXISTING DAM- WITH INFORMATION	NEW DAM DESIGN
It is a situation that can be found in some Countries and Entities. In this case it is as if having to do the "*Autopsy of the Mummy*" i.e. the Expert Professionals will have to use all the experience to perform detailed inspections, obtain geometric data from the dams, obtain data of characteristics of the materials through drilled cores, surveys, hydrological data, climatological, seismicity. Based on the information establish memories of stability verification, flow, and recommend actions that establish the Safety of the Dam	In this situation, the scenario shows how it is expected and the procedures are analogous to the Usual Manuals for Inspection.	This is a situation that the Engineers need to pay attention and the Author's can suggest to adopt the routines pointed in the table

12.2 New Dams

It is essential to note that numerous dams yet can be built[12-02 & 12-03]. The hydraulic structures or water infrastructure designed for water utilization are often multipurpose projects providing water supply, irrigation, hydropower production and navigation. The structures designed for protection against water hazards include, besides flood control reservoirs, also sewage treatment facilities (hydraulic structures to eliminate pollution), drainage, flood protection and erosion protection measures. Today, large water infrastructure projects should be designed as multipurpose schemes to benefit from synergies between different objectives of use and protection and to gain wide acceptance from all stakeholders.

Thanks to these new water infrastructures, a security belt is formed around the world to ensure water, food, and energy. The zone of high density of new dams extends from Southern Europe over to the Middle East, to Central and East Asia. It covers the area of high-water stress in arid and semi-arid regions, as well as the Monsoon - exposed regions with extremely high population density.

The belt of new dams shown is less apparent across North America over the World's most productive crop growing region, where only a few dams have been built this century. This is because significant dam development took place in this region in the last century. It must also be noted that the regions along this belt are already affected perceptibly today by climate change, whose effects are expected to become even more dramatic in the future, according to model simulation predictions.

The belt of dams and reservoirs which covers these threatened and very vulnerable regions around the world will help provide food security, water, and energy. Therefore, it can be called a security belt. The trend for more new dam construction in the South compared with the North can be seen clearly in South America, as indicated by the arrow attached to the security belt mentioned earlier. Dams and reservoirs are a major part of the water infrastructure, which strengthens the security belt and its extensions.

New dams and reservoirs commissioned since 2000 creating a security belt around the world to ensure water, food and energy[12-02 & 12-03]

On basis the information that were presented in the previous **Chapters**, considering the design for a new dam, it can be summarized the points considering the ***Knowledge Management*** as described for each aspect and for each type of dams, as follows.

Some important tips for the defensive and safety aspects for a Dam Project

Actions on the Dams/Dam Types/ Other Structures				Nature				Materials								Properies				Actions During Operation						
Dam Face	Dam Body	Dam Type	Undefined	Geology	Hydrology Floods	Climatic	Earthquake	Rock	Soil	Asphalt	Geomembrane	Aggregates	Cement	Pozzolanic material	Reinfrcement	Mecanical properties	Elastic Properties	Thermical Behaviour	Construction	Stability	Overtopping	Seepage	Settlement	Cracks	Erosion	Human
DAM BODY								KMB- Knowledge of Basic Materials				QCR- Quality Control on Materials and Construction and Reports								M&M- Monitoring & Maintenance						
By Product	Tailings	Embankment	ASM	KM	KM	KM	KM	KMB	KMB							QCR				MKS	MKS	MKS	MKS	MKS	MKS	AD
Soil	Earth	Embankment	ASM	KM	KM	KM	KM		KMB							QCR				MKS	MKS	MKS	MKS	MKS	MKS	AD
Soil+Water	Hydraulic	Embankment	ASM	KM	KM	KM	KM		KMB							QCR				MKS	MKS	MKS	MKS	MKS	MKS	AD
Core	Rock-Clay	Embankment	ASM	KM	KM	KM	KM	KMB	KMB							QCR	QCR			MKS	MKS	MKS	MKS	MKS	MKS	AD
Rock	Rock-Asphalt Core	Embankment	ASM	KM	KM	KM	KM	KMB		KMB						QCR	QCR		KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Asphalt	Rock	Embankment	ASM	KM	KM	KM	KM	KMB		KMB						QCR	QCR		KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Concrete	Rock	Embankment	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Geomem-brane	Rock	Embankment	ASM	KM	KM	KM	KM	KMB			KMB					QCR	QCR		KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
	RCC-Gravity	RCC-Concrete	ASM	KM	KM	KM	KM	KMB			KMB	DMP	QCR	QCR		QCR	QCR		KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
CVC	RCC-Gravity	RCC-Concrete	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR		QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
GE-RCC	RCC-Gravity	RCC-Concrete	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR		QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
GE-RCC	RCC- Arch Gravity	RCC-Concrete	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR		QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
GE-RCC	RCC- Double Arch	RCC-Concrete	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR		QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
CVC	CVC -Mass	CVC Gravity	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR		QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
CVC	CVC	CVC Arch Gravity	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
CVC	CVC	CVC Double Arch	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
CVC	CVC	CVC Buttress	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
CVC	CVC	CVC Multiple Arch	ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
HYDRAULIC CIRCUITS								KMB- Knowledge of Basic Materials				QCR- Quality Control on Materials and Construction and Reports								M&M- Monitoring & Maintenance						
Diversion Circuits			ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Bottom Outlets			ASM		KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Spillway/ Discharge Conduits/ Bridges			ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Stilling Basis			ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Channels			ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Water Intakes			ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD
Power Houses/ Pump Houses			ASM	KM	KM	KM	KM	KMB				DMP	QCR	QCR	QCR	QCR	QCR	QCR	KCM	MKS	MKS	MKS	MKS	MKS	MKS	AD

LEGEND				
	AD- Adopt Defenses	KM- Knowledge management	ASM- Adopt Safety Margin	MKS- Management of the knowledge-Statistical data and margins of safety
M&M- Monitoring & Maintenance	KMB- Knowledge of Basic Materials	DMP-Domain of Materials Produced	QCR- Quality Control on Materials and Construction and Reports	KCM- Knowledge of Construction Methodologies

It means that **ALL THE ASPECTS** considering the Nature, Materials, Properties, Controls, and eventual Actions that the dam can suffer must be previously considered and evaluated in a scenario of Risks. The Design Defenses must be discussed and clearly understood by the Responsible.

12.3 Existing Dams

All the Guidelines and Dam Safety Monitoring and Inspections mentions that:

- ✓ ***Data collected during surveillance activities (inspections and monitoring) must be recorded, updated, and kept in a known, dedicated, and reliable archiving system.***

But, considering the real scenarios that can be faced, it could be possible to have as described in the Figure above:

12.3.1 Existing Dam without Information

This scenario can induce that the dam could be classified, on basis of some National Standards, as a Potential Risk.

For this condition, it can be recommended that:

- o It is a situation that can be found in some Countries and Entities, the Expert Professionals will have to use all the experience to perform detailed inspections, obtain geometric data from the dam, to obtain data of characteristics of the materials through drilled cores, surveys, hydrological data, climatological, seismicity. Based on the information, it is essential to establish memories of stability verification, flow, and recommend actions that confirm the Safety of the Dam.

After this, the results and the output from inspection, monitoring, behavior monitoring, and diagnosis activities must be recorded and kept throughout the rest of the life of the structure.

12.3.2 Existing Dam with Information

Data archiving procedures must allow for easy access for comparative analyses. It is also indispensable that the dam documentation be easily accessible and usable, with consolidated reference documents periodically updated.

The design of the dam and appurtenant structures should be reviewed to assess the actual performance compared to the intended performance of the structures. Engineering data and records originating during the construction period should be reviewed to determine if the structures were constructed as designed or that the necessary design revisions were made for any unusual or unanticipated conditions encountered. An onsite examination and review of available instrumentation records also should be made to assess the actual performance of the structures.

The original design and design data should be examined to determine if all appropriate loading conditions were considered. The design criteria should be reviewed to determine if changed conditions at the site have created any need for changes in the criteria such as ladings, flows, etc.

Any updated design data, such as newly developed floods, regional seismicity studies, changes in material properties, etc., should be studied to determine their influence on the structure. The data should be reviewed to determine if they are correct and if the latest information has been considered.

The design should be examined to determine if the structures will safely accomplish the tasks for which they were intended, both hydraulically and structurally. The methods and procedures used in the design should be determined and compared with the latest state-

Many times, weaknesses or deficiencies can be identified from changes in the behavior of the structure, foundation, abutments, or seepage. Knowledge of the behavior of the dam is an important tool for use in the evaluation. If surveys or instrumentation readings are lacking, they should be requested. Before the examination, the latest instrumentation results should be consulted. Historical plots of the behavior and seepage records should be available during the field examination for immediate comparison when a specific problem is suspected.

Notes should be organized in a manner covering each potential issue or defect identified during the records review and the examination, leaving nothing to memory. All data such as location, elevation, description, and quantity should be recorded. The use of a prescribed checklist for a given dam and its appurtenances can be helpful, but care must be taken to ensure that the scope of the examination is not restricted to only the listed items.

Any unusual behavior, regardless of how seemingly insignificant, should be identified and recorded because any unusual condition may be the forewarning of a newly developing unsafe condition.

An updated method of reviewing the condition of the dam is by studying earlier photographs. Photographs taken during the examination are a permanent record of conditions for future comparisons, as well as being an excellent method of note taking.

12.4 Education and Training

Dam owners are required to arrange for surveillance and inspection of dams in most countries [12-04]. This is usually done by contracting an independent experienced engineer, or in some cases a team of experts, in line with minimum competence standards, and subsequently reporting all information to the relevant enforcement authority. Some countries and entities (such as major hydropower utilities) give more serious consideration to maintaining the capacity of internal technical staff for dam safety surveillance, monitoring, and inspection along with training and mentoring programs. It is important to maintain such capacity for undertaking constant checking of dam safety conditions in connection with daily operational works. Enforcement authorities also periodically conduct their own formal audit inspections for a quick check of surveillance and inspection information in many cases. If resources for the regulator are limited, then random audits would be appropriate.

Ensuring that dams are adequately operated and maintained by dam owners is critical for dam safety assurance. It is therefore essential to ensure that sufficient funding is available to support O&M works. Education and training to ensure the competence of dam owners, operators, and the staff responsible for O&M, as well as the continuous training of regulatory staff, is an important part of dam safety assurance.

Specific qualifications and course requirements are stipulated for the owner's staff in Norway's dam safety regulations. Company managers are required to complete a course with emphasis on legal requirements, emergency action plans, and dam safety philosophy.

The content of a dam safety assurance regulatory scheme should spell out the specific mandates for regulators and owners. The scope and contents of the regulatory powers need to be defined within the context of the overall roles and responsibilities of the regulatory authority *vis-à-vis* the dam owners.

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UNITS & GLOSSARY

Note: This Chapter is supported by the references mentioned at the end of the text

UNITS

ACCELERATION		
Unit	(ft/s^2)	(m/s^2)
1 Foot per second squared (ft/s^2)	1	0,3048
1 Meter per second squared (m/s^2)	3,2808	1

AREA					
Unit	ft^2	m^2	ha	Acre	(mi^2)
1 Square foot (ft^2)	1	0.0929	$9{,}2903 \times 10^{-6}$	$2{,}2956 \times 10^{-5}$	$3{,}58 \times 10^{-8}$
1 Square meter (m^2)	10.7639	1	1×10^{-4}	$2{,}4711 \times 10^{-5}$	$3{,}8610 \times 10^{-7}$
1 Hectare (ha)	$1.0764 \times l0^{5}$	10,000	1	2.4711	3.8610×10^{-3}
1 Acre	43,560	4046.85	0.4047	1	$1.5625 \times l0^{-3}$
1 Square mile (mi^2)	$2.7878 \times l0^{7}$	2.5900×10^{6}	259	640	1

ENERGY						
Unit	**J**	**ft–Ib**	**Btu**	**kcal**	**hph**	**kWh**
1 Joule (J)	1	0.7376	9.481×10^{-4}	2.389×10^{-4}	3.725×10^{-7}	2.778×10^{-7}
1 Foot–pound (ft-Ib)	1.356	1	$1.285 \times l0^{-3}$	3.239×10^{-4}	5.051×10^{-7}	3.766×10^{-7}
1 British thermal unit (Btu)	1,055	777.9	1	0.252	3.929×10^{-4}	2.930×10^{-4}
1 Kilocalorie (kcal)	4,086	3,087	3.968	1	1.559×10^{-3}	$1.1\ 63 \times 10^{-3}$
1 Horsepower-hour (hph)	2.685×10^{6}	1.980×10^{6}	2,545	641.4	1	0.7457
1 Kilowatt-hour (kWh)	3.6×10^{6}	$2.655 \times l0^{6}$	3,413	860.1	1.341	1

FORCE					
Unit	**dyn**	**N**	**lbi**	**kgf**	**kip**
1 Dyne (dyn)	1	$1{,}0 \times 10^{-5}$	2.248×10^{-6}	1.020×10^{-6}	2.248×10^{-10}
1 Newton(N)	100,000	1	0.2248	0.1020	2.248×10^{-4}
1 Pound (Ibi)	444,800	4.448	1	0.04536	0.001
1 Kilogram (kgf)	980,700	9.807	2.205	1	2.205×10^{-3}
1 Kip	4.448 × 109	4,448	1,000	453.5	1

LENGTH					
Unit	in	ft	m	km	mil
1 Inch (in)	1	0.0833	0.0254	2.540×10^{-5}	1.5782×10^{-5}
1 Foot (ft)	12	1	0.3048	3.048×10^{-4}	1.8939×10^{-4}
1 Meter(m)	39.3710	3.2808	1	0.001	6.2136×10^{-4}
1 Kilometer (km)	39,370	3,280.84	1,000	1	0.6212
1 Mile (mi)	63,360	5,280	1,609.36	1,609.36	1

MASS						
Unit	lb	kg	Metric slug	Slug	Metric ton	Long ton
1 Pound (lb)	1	0.4536	0.0462	0.0311	4.536×10^{-4}	446.4×10^{-4}
1 Kilogram (kg)	2.205	1	0.1020	0.0685	0.001	9.842×10^{-4}
1 Metric slug	21.62	9.807	1	0.6721	0.0098	0.0096
1 Slug	32.17	14.59	1.490	1	0.0146	0.0144
1 Metric ton	2,205	1,000	102.0	68.52	1	0.9842
1 Long ton	2,240	1,016	103.7	69.63	1.016	1

POWER (Rate of Energy Flow)				
Unit	Btu/h	ft–lb/s	hp	kW
1 Btu/hour (Btulh)	1	0.2161	3.929×10^{-4}	2.920×10^{-4}
1 Foot-pound/second (ft-lb/s)	4.628	1	1.818×10^{-3}	1.356×10^{-4}
1 Horsepower (hp)	2,545	550	1	0.7457
1 Kilowatt (kW)	3,413	737.6	1.341	1
1 Watt = 1 *J/s*.				

1 kW is generated by 11.81 *ft3/s* of water falling 1 foot (at 100% efficiency) or by 0.102 m^3/s falling 1 meter (at 100% efficiency).

PRESSURE					
Unit	Pa	H_2O ft	Hg in	lb/in^2	atm
1 Pascal (Pa)	1	3.3456×10^{-4}	2.9533×10^{-4}	1.4504×10^{-4}	9.8692×10^{-6}
1 Foot of water@39.4 OF (H_2O ft)	2,989	1	0.88275	0.43352	0.0295
1 Inch of Mercury (Hg in)	3,386	1.13282	1	0.4911	0.03342
1 Pound per square inch (lb/in^2)	6,894.757	2.30671	2.03625	1	0.068046
1 Atmosphere (atm)	101,325	33.89945	29.92471	14.69595	1

1 Pa = 1 N/m^2 = 10 dyne/cm^2.

RATE OF FLOW				
Unit	**gal/min**	**ft³/s**	**Mgal/d**	**m³/s**
1 U.S. gallon per minute (gal/min)	1	0.00223	0.00144	6.31×10^{-5}
1 Cubic foot per second (ft^3/s)	448.8	1	0.6463	0.02832
1 Million U.S. gallons per day (Mgal/d)	694.4	1.547	1	0.0438
1 Cubic meter per second (m^3/s)	15,850	35.31	22.82	1

1 U.S. gallon per minute for 1 year = 1.614 acre-ft.

1 ft^3/s = 1.98 acre-ft/d = 724 acre-ft/yr.

TEMPERATURE				
Unit	**(°F)**	**(°C)**	**(K)**	**(R)**
x degrees Fahrenheit (°F)	1	(519)(X – 32)	(5/9)(x + 459.67)	x + 459.67
x degrees Celsius (°C)	(J/5)X + 32	1	x + 273.15	(J15)X + 491.67
x Kelvins (K)	(J/5)X – 459.67	x – 273.15	1	(J/5)X
x degrees Rankine (R)	x – 459.67	(519)(X – 491.67)	(519)X	1

VELOCITY					
Unit	ft/d	km/h	ft/s	mi/h	m/s
1 Foot per day (ft/d)	1	1.27×10^{-5}	1.157×10^{-5}	7.891×10^{-6}	3.528×10^{-6}
1 Kilometer per hour (km/h)	78.740	1	0.9113	0.6214	0.2778
1 Foot per second (ft/s)	86.400	1.097	1	0.6818	0.3048
1 Mile per hour (mi/h)	126.700	1.609	1.467	1	0.447
1 Meter per second *(m/s)*	283,500	3.600	3.281	2.237	1

VOLUME					
Unit	L	gal	ft^3	m^3	acre-ft
1 Liter(L)	1	0.264	0.035	0.001	8.11×10^{-7}
1 U.S. gallon (gal)	3.785	1	0.134	0.00379	3.07×10^{-6}
1 Cubic foot (ft^3)	28.317	7.48	1	0.02832	2.30×10^{-5}
1 Cubic meter (m^3)	1000	264	35.315	1	8.11×10^{-4}
1 Acre-ft (acre-ft)	1,233,500	325,851	43,560	1,233.48	1

1 U.S. gallon = 231 in^3 = 0.83 Imperial gallons.

1 L = 1,000 cm^3 = 1.05 quarts = 1,000 grams of water.

1 Barrel = 42 U.S. gallons.

1 ft^3 of water = 62.4 lb.

GLOSSARY

100 Year Floodplain – The area inundated during the passage of a flood with a peak discharge having a one percent chance of being equaled or exceeded in any given year at a specified location on a watercourse.

A

absorption — the process by which a liquid is drawn into and tends to fill permeable voids in a porous solid body; also, the increase in mass of a porous solid body resulting from the penetration of a liquid into its permeable voids,

abutment – That contact location at either end and beneath the flanks of a dam where the artificial barrier joins or faces against the natural earth or rock foundation material upon which the dam is constructed. The left and right abutments of dams are defined with the observer viewing the dam looking in the downstream direction.

acceleration — increase in velocity or in rate of change, especially the quickening of the natural progress of a process such as setting or strength development (hardening) of concrete.

acid and metalliferous drainage (AMD) – also known as acid mine drainage, or acid rock drainage (ARD), refers to the outflow of polluted water to the environment. Usually the water is acidic but not necessarily. AMD occurs naturally within some environments as part of the rock weathering process but is exacerbated by large-scale earth disturbances characteristic of mining and other large construction activities, usually within rocks containing an abundance of sulfide minerals.

acid etching — the removal of a cementitious surface through controlled dissolution to expose sand or aggregates, roughen a smooth cementitious surface in preparation for cementitious coating material application, or create art, design, or an architectural finish.

active storage: The volume of the reservoir that is available for some use such as power generation, irrigation, flood control, water supply, etc. The bottom elevation is the minimum operating level.

addition — a material that is interground or blended in limited amounts into a hydraulic cement during manufacture either as a processing addition to aid in manufacturing and handling the cement or as a functional addition to modify the use properties of the finished product.

additive — a substance added to another in relatively small amounts to impart or improve desirable properties or suppress undesirable properties.

adhesion — the state in which two surfaces are held together by interfacial effects that may consist of molecular forces, interlocking action, or both.

adhesives — the group of materials used to join or bond similar or dissimilar materials; for example, in concrete work, the epoxy resins.

adiabatic — a condition in which heat neither enters nor leaves a system.

admixture — a material other than water, aggregates, cementitious materials, and fiber reinforcement, used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing.

admixture, accelerating — an admixture that causes an increase in the rate of hydration of the hydraulic cement and thus shortens the time of setting, increases the rate of strength development, or both.

admixture, air-entraining — admixture, air-entraining—an admixture that causes the development of a system of microscopic air bubbles in concrete, mortar, or cement paste during mixing, usually to increase its workability and resistance to freezing and thawing.

admixture, anti-washout — a concrete admixture that reduces the loss of fine material from concrete when placed in water.

admixture, retarding — an admixture that causes a decrease in the rate of hydration of the hydraulic cement and lengthens the time of setting.

admixture, water-reducing — an admixture that either increases slump of freshly mixed mortar or concrete without increasing water content or maintains slump with a reduced amount of water, the effect being due to factors other than air entrainment.

admixture, water-reducing (high-range) — a water-reducing admixture capable of producing large water reduction or great flowability without causing undue set retardation or entrainment of air in mortar or concrete.

adsorption — development (at the surface of either a liquid or solid) of a higher concentration of a substance than exists in the bulk of the medium; especially formation of one or more layers of molecules of gases, of dissolved substances, or of liquids at the surface of a solid (such as cement, cement paste, or aggregates), or of air-entraining agents at the air-water interfaces; also the process by which a substance is adsorbed.

afwillite — a mineral with composition $3CaO{\cdot}2SiO_2{\cdot}3H_2O$ occurring naturally in South Africa, Northern Ireland, and California, and artificially in some hydrated portland cement mixtures.

agent — a general term for a material that may be used either as an addition to cement or an admixture in concrete, for example, an air-entraining agent. (**agent, bonding** — a substance applied to a suitable substrate to create a bond between it and a succeeding layer. **agent, curing** — a catalytic or reactive agent that induces cross-linking in a thermosetting resin. **agent, release** — material used to prevent bonding of concrete to a surface. **agent, surface-active** — a substance that affects markedly the interfacial or surface tension of solutions when present even in low concentrations. **agent, wetting** — a substance capable of lowering the surface tension of liquids, facilitating the wetting of solid surfaces, and permitting the penetration of liquid into the capillaries.

agglomeration — a gathering into a ball or mass.

aggregate — granular material, such as sand, gravel, crushed stone, crushed hydraulic-cement concrete, or iron blast-furnace slag, used with a hydraulic cementing medium to produce either concrete or mortar.

aggregate blending — the process of intermixing two or more aggregates to produce a different set of properties; generally, but not exclusively, to improve grading.

aggregate interlock — the effect of portions of aggregate particles from one side of a joint or crack in concrete protruding into recesses in the other side of the joint or crack so as to transfer load in shear and maintain alignment.

aggregate transparency — discoloration of a concrete surface consisting of darkened areas over coarse aggregate particles immediately below the concrete surface ((1) the process of providing motion in mixed concrete just sufficient to prevent segregation or loss of plasticity; and (2) the mixing and homogenization of slurries or finely ground powders by either mechanical means or injection of air).

aggregate, angular — aggregate particles that possess well defined edges formed at the intersection of roughly planar faces.

aggregate, coarse — aggregate predominantly retained on the 4.75 mm (No. 4) sieve or that portion retained on the 4.75 mm (No. 4) sieve.

aggregate, crusher-run — aggregate that has been mechanically broken and has not been subjected to subsequent screening.

aggregate, dense-graded — aggregates graded to produce low void content and maximum density when compacted.

aggregate, fine — aggregate passing the 9.5 mm (3/8 in.) sieve almost entirely passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 mm (No. 200) sieve; or that portion passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 mm (No. 200) sieve.

aggregate, gap-graded — aggregate graded so that certain intermediate sizes are substantially absent.

aggregate, heavyweight — aggregate of high density, such as barite, magnetite, hematite, limonite, ilmenite, iron, or steel, used in heavyweight concrete.

aggregate, lightweight — aggregate of low density, such as: 9(a) expanded or sintered clay, shale, slate, diatomaceous shale, perlite, vermiculite, or slag; (b) natural pumice, scoria, volcanic cinders, tuff, and diatomite; or (c) sintered fly ash or industrial cinders used in lightweight concrete).

aggregate, mineral — aggregate consisting essentially of inorganic nonmetallic rock materials, either natural or crushed and graded.

aggregate, normal weight — aggregate that is neither heavyweight nor lightweight.

aggregate, open-graded — aggregate in which the voids are relatively large when the aggregate is compacted.

aggregate, reactive — aggregate containing substances capable of reacting chemically with the products of solution or hydration of the portland cement in concrete or mortar under ordinary conditions of exposure, resulting in some cases in harmful expansion, cracking, or staining.

aggregate, refractory — aggregate having refractory properties that, when bound together into a conglomerate mass by a matrix, forms a refractory body.

aggregate, single-sized — aggregate in which a major portion of the particles is in a narrow size range.

aggregate, well-graded — aggregate having a particle-size distribution that produces maximum density, that is, minimum void space.

agitator — a device for maintaining plasticity and preventing segregation of mixed concrete by agitation.

aids, grinding — materials used to expedite the process of grinding by eliminating ball coating, dispersing the finely ground product, or both.

air blow pipe — air jet used in shotcrete gunning to remove rebound or other loose material from the work area.

air content — the volume of air voids in cement paste, mortar, or concrete, exclusive of pore space in aggregate particles, usually expressed as a percentage of total volume of the paste, mortar, or concrete.

air entraining — the capability of a material or process to develop a system of microscopic bubbles of air in cement paste, mortar, or concrete during mixing.

air entrainment — the incorporation of air in the form of microscopic bubbles (typically smaller than 1 mm) during the mixing of either concrete or mortar.

air lift — equipment whereby slurry or dry powder is lifted through pipes by means of compressed air.

air, entrained — microscopic air bubbles intentionally incorporated in mortar or concrete during mixing, usually by use of a surface-active agent; typically between 10 and 1000 μm (1 mm) in diameter and spherical or nearly so.

air, entrapped — air voids in concrete that are not purposely entrained and that are larger, mainly irregular in shape, and less useful than those of entrained air; and 1 mm or larger in size.

akermanite — a mineral of the melilite group, $Ca_2MgSi_2O_7$.

alabaster — a compact crystalline, weakly textured form of practically pure gypsum.

alignment wire — see **wire, ground** (preferred term).

alite — a name used to identify tricalcium silicate, including small amounts of MgO, Al2O3, Fe2O3, and other oxides; a principal constituent of portland-cement clinker.

alkali — salts of alkali metals, principally sodium and potassium; specifically sodium and potassium occurring in constituents of concrete and mortar, usually expressed in chemical analyses as the oxides Na_2O and K_2O.

alkyl aryl sulfonate — synthetic detergent used to entrain air in hydraulic-cement mixtures.

allowable bearing capacity — the maximum pressure to which a soil or other material should be subjected to guard against shear failure or excessive settlement.

also used in concrete construction as a bonding agent, surface sealer, or an integral concrete component.

alumina — aluminum oxide (Al_2O_3).

amount of mixing — the extent of mixer action employed in combining the ingredients for either concrete or mortar; in the case of stationary mixers, the mixing time; in the case of truck mixers, the number of revolutions of the drum at mixing speed after the intermingling of the cement with water and aggregates.

amplitude — the maximum displacement from the mean position in connection with vibration.

analysis, dynamic — analysis of stresses in framing as functions of displacement under transient loading.

analysis, mechanical — the process of determining particle-size distribution of an aggregate.

analysis, sieve — particle-size distribution; usually expressed as the mass percentage retained upon each of a series of standard sieves of decreasing size and the percentage passed by the sieve of finest size.

anchor — in prestressed concrete, to lock the stressed tendon in position so that it will retain its stressed condition; in precast concrete construction, to attach the precast units to the building frame; in slabs on grade or walls, to fasten to rock or adjacent structures to prevent movement of the slab or wall with respect to the foundation, adjacent structure, or rock.

anchor, form — device used to secure formwork to previously placed concrete of adequate strength; the device is normally embedded in the concrete during placement.

anchorage — in post-tensioning, a device used to anchor the tendon to the concrete member; in pre-tensioning, a device used to maintain the elongation of a tendon during the time interval between stressing and release; in precast-concrete construction, the devices for attaching precast units to the building frame; in slab or wall construction, the device used to anchor the slab or wall to the foundation, rock, or adjacent structure.

anchorage, dead-end — the anchorage at that end of a tendon that is opposite the jacking end- ((1) length of reinforcement, mechanical anchor, hook, or combination thereof, beyond the point of nominal zero stress in the reinforcement of cast-in-place concrete; and (2) mechanical device to transmit pre-stressing force to the concrete in a post-tensioned member).

anchorage, mechanical — any mechanical device capable of developing the strength of the reinforcement without damage to the concrete.

anchorage, threaded — an anchorage device that is provided with threads to facilitate attaching the jacking device and to effect the anchorage.

anchorage, wedge — a device for anchoring a tendon by wedging.

angle of repose — the angle between the horizontal and the natural slope of loose material below which the material will not slide.

anhydrite — a mineral, anhydrous calcium sulfate ($CaSO_4$); gypsum from which the water of crystallization has been removed, usually by heating above 325˚F (160˚C); natural anhydrite is less reactive than that obtained by calcination of gypsum.

annual exceedence probability (AEP) – the probability that a particular storm or event will be exceeded in any year eg. 1 in 1000 AEP Storm (or 1 in 100 AEP or 1 in 10,000 AEP) – a storm event which produces a rainfall that is statistically likely to occur once in a 1000 years (or 100, or 10,000 years) at the site under study.

appurtenant structures – Structures such as outlet works and associated gates and valves; water conveyance structures such as spillways channels, fish ladders, tunnels, pipelines or penstocks; powerhouse sections; and navigation locks, either in the dam or separate therefrom.

arc spectrography — spectrographic identification of elements in a sample of material heated to volatilization in an electric arc or spark.

architectural concrete — see **concrete, architectural**.

area of steel — the cross-sectional area of the steel reinforcement.

arenaceous — composed primarily of sand; sandy.

argillaceous — composed primarily of clay or shale; clayey.

arris — the sharp external corner edge that is formed at the junction of two planes or surfaces.

asbestos-cement products — products manufactured from rigid material composed essentially of asbestos fiber and portland cement.

aspect ratio, fiber — the ratio of length to diameter of a fiber in which the diameter may be an equivalent diameter.

asphalt — a dark brown to black cementitious material in which the predominating constituents are bitumens that occur in nature or are obtained in petroleum processing.

autoclave — a pressure vessel in which an environment of steam at high pressure may be produced; used in the curing of concrete products and in the testing of hydraulic cement.

axis of dam – The vertical plane or curved surface, chosen by a designer, appearing as a line, in plan or in cross-section, to which the horizontal dimensions of the dam are referenced.

axis, neutral — a line in the plane of a structural member subject to bending where the longitudinal stress is zero.

B

bacillus, cement — see **ettringite**

back plastering — plaster applied to one face of a lath system following application and subsequent hardening of plaster applied to the opposite face.

backshores — shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area without allowing the entire slab or member to deflect or support its own mass or existing construction loads.

baffle block – A block, usually of concrete, constructed in a channel or stilling basin to dissipate the energy of water flowing at high velocity.

bag (of cement; also sack) — a quantity of portland cement indicated on the bag – There are differences in some Countries!.

balanced moment — moment capacity at simultaneous crushing of concrete and yielding of tension steel.

balanced reinforcement — an amount and distribution of reinforcement in a flexural member such that in working-stress design the allowable tensile stress in the steel and the allowable compressive stress in the concrete are attained simultaneously; or such that in strength design, the tensile reinforcement reaches its specified yield strength simultaneously with the concrete in compression reaching its assumed ultimate strain of 0.003.

band iron — thin metal strap used as form tie, hanger, etc.

bar — an element, normally composed of steel, with a nominally uniform cross-sectional area used to reinforce concrete.

bar bender — a tradesman who cuts and bends steel reinforcement; or a machine for bending steel reinforcement.

bar schedule — a list of the reinforcement, showing the shape, number, size, and dimensions of every different element required for a structure or a portion of a structure.

bar spacing — the distance between parallel reinforcing bars, measured center to center of the bars perpendicular to their longitudinal axes.

bar support — hardware used to support or hold reinforcing bars in proper position to prevent displacement before and during concreting.

bar, coated — a bar on which a coating has been applied, usually to increase resistance to corrosion.

bar, deformed — a reinforcing bar with a manufactured pattern of surface ridges intended to reduce slip and increase pullout resistance of bars embedded in concrete.

bar, epoxy-coated —a reinforcing bar coated by an epoxy resin system, usually to increase resistance to corrosion.

bar, hooked — a reinforcing bar with the end bent into a hook to provide anchorage.

bar, plain — a reinforcing bar without surface deformations, or one having deformations that do not conform to the applicable requirements.

bar, standard hooked — a reinforcing bar with the end bent into a hook to provide anchorage.

bar, tie — bar at right angles to and tied to reinforcement to keep it in place.

bar-end check — a check of the ends of reinforcing bars to determine whether they fit the devices intended for connecting the bars.

barite — a mineral, barium sulfate ($BaSO_4$), used in either pure or impure form as concrete aggregate primarily for the construction of high-density radiation shielding concrete; designated "barytes" in United Kingdom.

barrier, moisture — a vapor barrier.

barrier, vapor — membranes located under concrete floor slabs that are placed on grade to retard transmission of water vapor from the subgrade.

bars, bundled — a group of not more than four parallel reinforcing bars in contact with each other, usually tied together.

bars, stem — bars used in the wall section of a cantilevered retaining wall or in the webs of a box; when a cantilevered retaining wall and its footing are considered as an integral unit,.

base — a subfloor slab or "working mat," either previously placed and hardened or freshly placed, on which floor topping is placed in a later operation; also the underlying stratum on which a concrete slab, such as a pavement, is placed.

base coat — any plaster coat or coats applied before application of the finish coat.

base course — a layer of specified select material of planned thickness constructed on the subgrade or subbase of a pavement to serve one or more functions, such as distributing loads, providing drainage, or minimizing frost action; also the lowest course of masonry in a wall or pier.

base for a column. For a tapered member, the least lateral dimension is the average of the top and bottom dimensions of the smaller side.

base plate — a plate of metal or other material formerly placed under pavement joints and the adjacent slab ends to prevent the infiltration of soil and moisture from the sides or bottom of the joint opening; also a steel plate used to distribute vertical loads, as for bridge beams, building columns, or machinery.

base screed — a preformed metal screed with perforated or expanded flanges to provide a guide for thickness and planeness of plaster and to provide a separation between plaster and other materials.

base thickness – Also referred to as base width. The maximum thickness or width of the dam measured horizontally between upstream and downstream faces and normal to the axis of the dam, but excluding projections for outlets, or other appurtenant structures.

bassanite — calcium sulfate hemi hydrate, $2CaSO_4{\cdot}H_2O$.

bat — a broken brick sometimes used to support reinforcement.

batch — (1. quantity of material mixed at one time or in one continuous process; or 2. to weigh or volumetrically measure and introduce into the mixer the ingredients for a quantity of material).

batch box — container of known volume used for measuring constituents of a batch of either concrete or mortar in proper proportions.

batch plant — an installation for batching or for batching and mixing concrete materials.

batch weights — the quantities of the various ingredients (cement, water, the several sizes of aggregate, and admixtures if used) that compose a batch of concrete.

batch, trial — a batch of concrete prepared to establish or check proportions of the constituents.

batched water — the mixing water added by a batcher to a cementitious mixture either before or during the initial stages of mixing (also called batch water).

batcher — a device for measuring ingredients for a batch of concrete- ((1) **manual batcher** — a batcher equipped with gates or valves that are operated manually, with or without supplementary power (pneumatic, hydraulic, or electrical), the accuracy of the weighing operation being dependent on the operator's observation of the scale; (2) **semiautomatic batcher** — a batcher equipped with gates or valves that are separately opened manually to allow the material to be weighed but that are closed automatically when the designated quantity of each material has been reached-(3) **automatic batcher** — a batcher equipped with gates or valves that, when actuated by a single starter switch, will open automatically at the start of the weighing operation of each material and close automatically when the designated quantity of each material has been reached, interlocked in such a manner that: 9a) the charging mechanism cannot be opened until the scale has returned to zero; (b) the charging mechanism cannot be opened if the discharge mechanism is open; (c) the discharge mechanism cannot be opened if the charging mechanism is open; (d) the discharge mechanism cannot be opened until the designated quantity has been reached within the allowable tolerance; and (e) if different kinds of aggregates or different kinds of cements are measured cumulatively in a single batcher, interlocked sequential controls are provided).

batching, cumulative — measuring more than one ingredient of a batch in the same container by bringing the batcher scale into balance at successive total weights as each ingredient is accumulated in the container.

batten (also batten strip) — a narrow strip of wood placed over the vertical joint of sheathing or paneling; also used to hold several boards together.

batter boards — pairs of horizontal boards nailed to wooden stakes adjoining an excavation; used as a guide to elevations and to outline the building.

bauxite — a rock composed principally of hydrous aluminum oxides; the principal ore of aluminum and a raw material for manufacture of calcium-aluminate cement.

bay — the space, in plan, between the centerlines of adjacent piers, mullions, or columns; a small, well-defined area of concrete placed at one time in the course of placing large areas, such as floors, pavements, or runways.

Beach Freeboard For upstream and center lift tailings dams without internal filters, it is crucial to control the phreatic surface level against the upstream face to minimize piping risks and maximize stability. This is achieved by placing tailings against the upstream face and maximizing the distance between the decant pond and the embankment. A minimum beach freeboard is specified for these dams, defined as the vertical distance between the top of the tailings, abutting the upstream face of the dam, and the tailings pond level after an appropriate extreme storm event.

beam — a structural member subjected to axial load and flexure but primarily to flexure; also the graduated horizontal bar of a weighing scale on which the balancing poises ride.

beam bottom — soffit or bottom form for a beam.

beam form — a retainer or mold so erected as to give the necessary shape, support, and finish to a concrete beam.

beam form-clamp — any of various types of tying or fastening units used to hold the sides of beam forms.

beam hanger — a wire, strap, or other hardware device that supports formwork from structural members.

beam pocket — opening left in a vertical member in which a beam is to rest; also an opening in the column or girder form where forms for an intersecting beam will be framed.

beam side — vertical or sloping side of a beam.

beam test — a method of measuring the flexural strength (modulus of rupture) of concrete by testing a standard unreinforced beam.

beam, double-tee — a precast-concrete member composed of two stems and a combined top flange, commonly used as a beam but also used vertically in exterior walls.

beam, drop-in — a precast element simply supported on adjacent cantilevered elements.

beam, edge — a stiffening beam at the edge of a slab.

beam, grade — a reinforced-concrete beam, usually at ground level, that strengthens or stiffens the foundation or supports overlying construction.

beam, simple — a beam without rotational restraint or continuity at its supports; also known as a simply supported beam.

beam, slender — a beam that, if loaded to failure without lateral bracing of the compression flange, would fail by buckling rather than in flexure.

beam, spandrel — a beam in the perimeter of a building, spanning between columns and usually supporting a floor or roof.

beam-and-slab floor (roof) — a reinforced-concrete system in which a slab is supported by and is often monolithic with reinforced-concrete beams.

beam-column — a structural member subjected to axial load and flexure forces but primarily axial load.

bearing stratum — the soil or rock stratum on which a concrete footing or mat bears or that carries the load transferred to it by a concrete pile, caisson, or similar deep foundation unit.

bedrock – The consolidated body of natural solid mineral matter which underlies the overburden soils.

belite — a name used to identify one form of the constituent of portland-cement clinker now known when pure as dicalcium silicate ($2CaO{\cdot}SiO_2$).

bending-moment diagram — a graphical representation of the variation of bending moment along the length of the member for a given stationary system of loads.

beneficiation — improvement of the chemical or physical properties of a raw material or intermediate product by the removal or modification of undesirable components or impurities.

bent bar — a reinforcing bar bent to a prescribed shape.

bent, pile — two or more piles driven in a row transverse to the long dimension of the structure and fastened together by capping and (sometimes) bracing.

bentonite — a clay composed principally of minerals of the montmorillonoid group, characterized by high adsorption and very large volume change with wetting or drying.

Berliner — a type of terrazzo topping using small and large pieces of marble paving, usually with a standard terrazzo matrix between pieces, also called Palladiana.

berm – A nearly horizontal step in the sloping profile of an embankment dam.

binder — material forming the matrix of concretes, mortars, and sanded grouts; or chemical treatment applied to fibers to give integrity to mats, roving, and fabric).

biological shielding — shielding provided to attenuate or absorb nuclear radiation, such as neutron, proton, alpha and beta particles, and gamma radiation; the shielding is provided mainly by the density of the concrete, except that in the case of neutrons the attenuation is achieved by compounds of some of the lighter elements (for example, hydrogen and boron).

Blaine apparatus — air-permeability apparatus for measuring the surface area of a finely ground cement, raw material, or other product.

Blaine fineness — the fineness of powdered materials such as cement and pozzolans, expressed as surface area per unit mass usually in square meters per kilogram, determined by the Blaine apparatus.

blanket, curing — a covering of sacks, matting, burlap, straw, waterproof paper, or other suitable material placed over freshly finished concrete.

blast-furnace slag — the nonmetallic product consisting essentially of silicates and aluminosilicates of calcium and other bases that develops in a molten condition simultaneously with iron in a blast furnace.

blast-furnace slag — the nonmetallic product consisting essentially of silicates and aluminosilicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. 1. air-cooled blast-furnace slag is the material resulting from solidification of molten blast-furnace slag under atmospheric conditions; subsequent cooling may be blast accelerated by application of water to the solidified surface; 2. expanded blast-furnace slag is the low density, cellular material obtained by controlled processing of molten blast-furnace slag with water, or water and other agents, such as steam, compressed air, or both; 3. granulated blast-furnace slag is the glassy, granular material formed when molten blast-furnace slag is rapidly chilled, as by immersion in water; and 4. ground granulated blast-furnace slag is granulated blast-furnace slag that has been finely ground and is a hydraulic cement.

bleeding — the autogenous flow of mixing water within, or its emergence from, a newly placed cementitious mixture caused by the settlement of solid materials within the mass.

bleeding capacity — the ratio of volume of water released by bleeding to the volume of paste or mortar.

bleeding rate — the rate at which water is released from a paste or mortar by bleeding.

blemish — any superficial defect that causes visible variation from a consistently smooth and uniformly colored surface of hardened concrete.

blinding — the application of a layer of lean concrete or other suitable material to reduce surface voids or to provide a clean, dry working surface; also the filling or plugging of the openings in a screen or sieve by the material being separated.

blistering — the irregular raising of a thin layer at the surface of a placed cementitious mixture during or soon after completion of the finishing operation, or, in the case of pipe, after spinning; also bulging of a finish coat as it separates and draws away from a base coat.

bloated — swollen, as in certain lightweight aggregates as a result of processing.

block beam — a flexural member composed of individual blocks that are joined together by prestressing.

block, concrete — a concrete masonry unit, usually containing hollow cores.

block, end — an enlarged end section of a member intended to reduce anchorage stresses to allowable values and provide space needed for post-tensioning anchorages.

block, wood — a solid piece of wood used in concrete formwork to fill space or prevent movement of the formwork.

blockout — a space within a concrete structure under construction in which fresh concrete is not to be placed, called core in United Kingdom.

blowpipe — a long pipe used to direct a compressed air stream that cleans a rock face or removes possible entrapped shotcrete rebound while placing shotcrete.

blowup — the raising of two concrete slabs off the subgrade where they meet as a result of greater expansion than the joint between them will accommodate; typically occurs only in unusually hot weather where joints have become filled with incompressible material; often results in cracks on both sides of the joint and parallel to it.

board butt joint — construction joint in shotcrete formed by sloping the sprayed surface to a 25 mm board laid flat.

bolster, slab — continuous wire bar support used to support bars in the bottom of slabs; top wire is corrugated at 25 mm centers to hold bars in position.

bolt sleeve — a tube surrounding a bolt in a concrete wall to prevent concrete from adhering to the bolt and acting as a spreader for the formwork.

bolt, anchor — a metal bolt or stud, headed or threaded, either cast in place, grouted in place, or drilled into finished concrete, used to hold various structural members or embedments in the concrete, and to resist shear, tension, and vibration loadings from various sources, such as wind and machine vibration; also known as a hold-down bolt or a foundation bolt.

bolt, hold-down — anchor bolt provided near the ends of shear walls for transferring boundary-member loads from the shear wall to the foundation.

bolt, she — a type of form tie and spreader bolt in which the end fastenings are threaded into the end of the bolt, thus eliminating cones and reducing the size of holes left in the concrete surface.

bond — [(1) adhesion of concrete or mortar to reinforcement or other surfaces against which it is placed, including friction due to shrinkage and longitudinal shear in the concrete engaged by the bar deformations; (2) adhesion of cement paste to aggregate; (3) adhesion or cohesion between plaster coats or between plaster and a substrate produced by adhesive or cohesive properties of plaster or supplemental materials; (4) patterns formed by the exposed faces of masonry units, for example, running bond or flemish bond 0].

bond area — the nominal area of interface between two elements across which adhesion develops or may develop, as between cement paste and aggregate.

bond breaker — a material used to prevent adhesion of newly placed concrete to the substrate.

bond plaster — a specially formulated gypsum plaster designed as first-coat application over monolithic concrete.

bond prevention — measures taken to prevent adhesion of concrete or mortar to surfaces against which it is placed.

bond stress, average — the force in a bar divided by the product of the perimeter and the development length of the bar.

bond, ceramic — the development of fired strength as a result of thermo-chemical reactions between materials exposed to temperatures approaching the fusion point of the mixture such as that which may occur, under these conditions, between calcium-aluminate cement and a refractory aggregate.

bond, chemical — bond between materials that is the result of cohesion and adhesion developed by chemical reaction.

bond, flexural stress — in structural-concrete members, the stress between the concrete and the reinforcing element that results from the application of external load.

bond, mechanical —physical interlock created when a plastic cementitious mixture is placed and hardens to conform with the surface texture of the existing solid material.

bond, transfer — in pre tensioning, the bond stress resulting from the transfer of stress from the tendon to the concrete.

bonded member — a prestressed-concrete member in which the tendons are bonded to the concrete either directly or through grouting.

bonder — a masonry unit that ties two or more wythes (leaves) of a wall together by overlapping.

boring — the removal by drilling of rock; a sample of soil or concrete for tests.

boron frits — clear, colorless, synthetic glass produced by fusion and quenching, containing boron.

borrow area – The area from which material for an embankment is excavated.

box out — to form an opening in concrete by a box-like form.

brace — a structural member used to provide lateral support for another member, generally for the purpose of ensuring stability or resisting lateral loads.

bracket — (1) an overhanging member projecting from a wall or other body to support weight acting outside the wall or a similar piece to strengthen an angle; and (2) formed shapes of channel or pencil rod used as structural reinforcement in erecting furred assemblies.

breach – An eroded opening through a dam which drains the reservoir. A controlled breach is a constructed opening. An uncontrolled breach is an unintentional opening which allows uncontrolled discharge from the reservoir.

bredigite — a mineral, alpha prime dicalcium silicate ($2CaO{\cdot}SiO_2$), occurring naturally at Scawt Hill, northern Ireland; and at the Isle of Muck, Scotland; also in slags and portland cement.

breeze — usually clinker; also fine divided material from coke production.

brick seat — ledge on wall or footing to support a course of masonry.

brick, calcium-silicate — a concrete product made principally from sand and lime that is hardened by autoclave curing.

brick, concrete — solid concrete masonry units of relatively small prescribed dimensions.

brick, rubbing — a silicon-carbide brick used to smooth and remove irregularities from surfaces of hardened concrete.

briquette (also briquet) — a molded specimen of mortar with enlarged extremities and reduced center having a cross section of definite area, used for measurement of tensile strength.

broadcast — to toss granular material, such as sand, over a horizontal surface so that a thin, uniform layer is obtained.

brown out — to complete application of base coat plaster.

brownmillerite — a ternary compound originally regarded as $4CaOAl_2OFe_2O_3$ (C_4AF) occurring in portland and calcium-aluminate cement; now used to refer to a series of solid solutions between $2CaOFe_2O_3$ (C_2F) and $2CaOAl_2O_3$ (C_2A).

brucite — a mineral having the composition magnesium hydroxide, Mg(OH)2, and a specific crystal structure.

buck — framing around an opening in a wall; a door buck encloses the opening in which a door is placed.

buckling — failure by lateral or torsional instability of a structural member, occurring with stresses below the yield or ultimate values.

buggy — a two-wheeled hand or motor-driven cart usually rubbertired, for transporting small quantities of concrete from hoppers or mixers to forms; sometimes called a concrete cart.

building official — the official charged with administration and enforcement of the applicable building code, the duly authorized representative of the official.

build-up — spraying of shotcrete in successive layers to form a thicker mass; also the accumulation of residual hardened concrete in a mixer.

bulk density – the overall density of a material being the mass of solids and water per unit volume of the solids plus liquids plus air voids. Also see "dry density", 'particle specific gravity".

bulk modulus, E = Young's modulus, and v = Poisson's ratio of the material under consideration.

bulkhead — [(1) a partition in formwork blocking fresh concrete from a section of the form, or a partition closing a section of the form, such as at a construction joint; or (2) a partition in a storage tank or bin, as for cement or aggregate].

bulking — increase in the volume occupied by a quantity of sand in a moist condition over the volume of the same quantity dry or completely inundated.

bulking curve — graph of change in volume of a quantity of sand due to change in moisture content.

burlap — a coarse fabric of jute, hemp, or less commonly flax, for use as a water-retaining covering in curing concrete surfaces; also called Hessian.

burnishing—((1) to hard trowel the surface of concrete or plaster up to final set; and (2) to otherwise produce a very smooth surface).

bush-hammer — a hammer having a serrated face, as rows of pyramidal points used to roughen or dress a surface; to finish a concrete surface by application of a bush-hammer.

butter — to spread mortar on a masonry unit with a trowel; also the process by which the interior of a concrete mixer, transportation unit, or other item coming in contact with fresh concrete is provided with a mortar coating so that fresh concrete coming in contact with it will not be depleted of mortar.

buttress — a projecting structure to support either a wall or a building.

butyl stearate — a colorless, oily, and practically odorless material ($C_{17}H_{35}COOC_4H_9$) used as an admixture for concrete to provide damp proofing.

C

C/S — the molar or mass ratio, whichever is specified, of calcium oxide (CaO) to silicon dioxide (SiO_2); usually of binder materials cured in an autoclave.

cabinet, moist — an upright and compartmented case having doors and shelves of moderate dimensions for storing and curing small test specimens of cement paste, mortar, and concrete in an atmosphere of about 23°C temperature and at least 95% relative humidity.

cage — a rigid assembly of reinforcement ready for placing in position.

caisson — part of a foundation, a watertight chamber used in construction underwater, or a hollow floating box used as a floodgate for a dock or basin.

calcareous — containing calcium carbonate or, less generally, containing the element calcium.

calcine — to alter composition or physical state by heating below the temperature of fusion.

calcite — a mineral having the composition calcium carbonate ($CaCO_3$) and a specific crystal structure; the principal constituent of limestone, chalk, and marble; a major constituent in the manufacture of portland cement.

calcium — a silver-white metallic element of the alkaline-earth group occurring naturally only in combination with other elements.

calcium chloride — a crystalline solid, $CaCl_2$; in various technical grades, used as a drying agent, as an accelerator of concrete, as a deicing chemical, and for other purposes.

calcium chloride solution — an aqueous solution of calcium chloride (usually at a specified concentration so that a given amount can be gauged to provide a specific concentration)

calcium chloride, anhydrous (CaCl2) — a solid, usually 94% calcium chloride, typically in pellet form.

calcium chloride, hydrous (CaCl2·2H2O) — a solid, usually77% calcium chloride, in flake form.

calcium stearate — $Ca(C_{18}H_{35}O_2)2$, commonly marketed in powder form, insoluble in water, used as a water repellent admixture in concrete.

caliche — gravel, sand, and desert debris cemented by calcium carbonate or other salts.

california bearing ratio (CBR) — the ratio of the force per unit area required to penetrate a soil mass with a 1940 mm² circular piston at the rate of 0.05 in. (1.3 mm) per min to the force required for corresponding penetration of a standard material; the ratio is usually determined at 2.5 mm penetration.

calorimeter — an instrument for measuring heat exchange during a chemical reaction, such as the quantity of heat liberated by the combustion of a fuel or hydration of a cement.

camber — a deflection that is intentionally built into a structural element or form to improve appearance or to nullify the deflection of the element under the effects of loads, shrinkage, and creep.

canister-type anchor bolt — anchorage assembly that includes a sleeve, a threaded rod, and means of removing the rod and adjusting rod location, projection, and tension.

cap — a smooth, plane surface of suitable material bonded to the bearing surfaces of test specimens to distribute the load during strength testing.

cap cables — short cables (tendons) introduced to pre stress the zone of negative moment only.

cap, pile — [(1) a structural member that is placed on top of a group of piles and used to transmit loads from the structure through the pile group into the soil; the piles may be connected to the cap with reinforcement to resist uplift or with reinforcement to resist moment so as to form a bent; also known as a rider cap or girder; also a masonry, timber, or concrete footing resting on a group of piles; and (2) a metal cap or helmet temporarily fitted over the head of a precast pile to protect it during driving; some form of shock absorbing material is often incorporated].

capacity — a measure of the rated volume of a particular concrete mixer or agitator, usually limited by specifications to a maximum percentage of total gross volume; also the output of concrete, aggregate, or other product per unit of time (as plant capacity or screen capacity); also load-carrying limit of a structure.

capillarity — the movement of a liquid in the interstices of concrete, soil, or other finely porous material due to surface tension.

carbon black — a finely divided form of carbon produced by the combustion or partial decomposition of hydrocarbon, used as an admixture to color concrete.

carbonation — reaction between carbon dioxide and a hydroxide or oxide to form a carbonate, especially in cement paste, mortar, or concrete; the reaction with calcium compounds to produce calcium carbonate.

cast-in-place — referring to a cementitious mixture that is deposited in the place where it is required to harden as part of the structure, as opposed to precast concrete.

catalyst, negative — a substance that slows a chemical reaction and which, itself, does not enter into the reaction; inhibitor.

catface — blemish or rough depression in the finish plaster coat caused by variations in the base coat thickness.

cathead — a notched wedge placed between two formwork members meeting at an oblique angle; a spindle on a hoist; the large, round retention nut used on she bolts.

cathodic protection — the form of corrosion protection wherein one metal is caused to corrode in preference to another, thereby protecting the latter from corrosion.

caulk — to place a material in a crack or joint with the intent of retarding entry of dirt or water.

celite — a name used to identify the calcium alumino-ferrite constituent of portland cement.

cement — any of a number of materials that are capable of binding aggregate particles together.

cement content — quantity of cement contained in a concrete, mortar, or grout preferably expressed as mass per unit volume of concrete, mortar, or grout.

cement paste — binder of concrete and mortar consisting essentially of cement, water, hydration products, and any admixtures together with very finely divided materials included in the aggregates.

cement paste (usually 10%) lies farther than that distance from the perimeter of the nearest air void .

cement paste to stiffen sufficiently to resist to an established degree, the penetration of a weighted test needle; also applicable to concrete or mortar with use of suitable test procedures.

cement paste, neat — a plastic mixture of hydraulic cement and water both before and after setting and hardening.

cement rock — natural impure limestone that contains the ingredients for production of portland cement in approximately the required proportions.

cement, air-entraining hydraulic — hydraulic cement containing sufficient amounts of air-entraining agent to produce a cementitious mixture containing entrained air within specified limits.

cement, asphalt — asphalt that is refined to meet specifications for use in the manufacture of bituminous pavements.

cement, bituminous — a black solid, semisolid, or liquid substance at natural air temperatures and appreciably soluble only in carbon disulfide or some volatile liquid hydrocarbon, being composed of mixed indeterminate hydrocarbons mined from natural deposits, produced as a residue in the distillation of petroleum, or obtained by the destructive distillation of coal or wood.

cement, blended — a hydraulic cement essentially consisting of portland cement, slag cement, or both, uniformly mixed with each other or a pozzolan through intergrinding or blending.

cement, bulk — cement that is transported and delivered in bulk (usually in specially constructed vehicles) instead of in bags.

cement, calcium-aluminate — the product obtained by pulverizing clinker consisting essentially of hydraulic calcium aluminates resulting from fusing or sintering a suitably proportioned mixture of aluminous and calcareous materials; called high-alumina cement in the United Kingdom.

cement, chemically prestressing — a type of expansive cement containing a higher percentage of expansive component than a shrinkage-compensating cement, when used in concretes with adequate internal or external restraint, that will expand sufficiently, due to chemical reactions within the matrix, to develop the stresses necessary for pre stressing the concrete.

cement, expansive — a cement that, when mixed with water, produces a paste that, after setting, increases in volume to a significantly greater degree than does portland-cement paste; used to compensate for volume decrease due to shrinkage or to induce tensile stress in reinforcement (posttensioning).(1. **cement, expansive, Type K** — a mixture of portland cement, anhydrous tetracalcium trialuminate sulfate (C_4A_3S), calcium sulfate ($CaSO_4$), and lime (CaO); the C_4A_3S is a constituent of a separately burned clinker that is interground with portland cement or alternately, it may be formed simultaneously with the portland-cement clinker compounds during the burning process; 2. **cement, expansive, Type M** — interground or blended mixtures of portland cement, calcium-aluminate cement, and calcium sulfate suitably proportioned; and 3. **cement, expansive, Type S** — a portland cement containing a high computed tricalcium aluminate (C3A) content and an amount of calcium sulfate above the usual amount found in portland cement).

cement, high-early-strength — portland cement characterized by attaining a given level of strength in mortar or concrete earlier than does normal portland cement; referred to in the United States as Type III.

cement, high-fineness — a hydraulic cement of substantially higher specific surface and substantially smaller mean particle diameter than typical for products of similar composition, produced by additional grinding or by separation by particle size.

cement, hot — newly manufactured cement that has not had an opportunity to cool after burning and grinding of the component materials.

cement, hydraulic — a binding material that sets and hardens by chemical reaction with water and is capable of doing so underwater. For example, portland cement and slag cement are hydraulic cements.

cement, hydrophobic — unhydrated cement treated so as to have reduced tendency to take up moisture.

cement, Keene's — a cement composed of finely ground, anhydrous, calcined gypsum, the set of which is accelerated by the addition of other materials.

cement, low-alkali — a portland cement that contains a relatively small amount of sodium or potassium or both; in the United States a portland cement containing not more than 0.60% Na_2O equivalent, that is, percent Na_2O + 0.658 x percent K_2O.

cement, low-heat — a portland cement for use when a low heat of hydration is desired, referred to in United States as Type IV.

cement, masonry — a hydraulic cement used for masonry and plastering construction, containing one or more of the following materials: portland cement, slag cement, portland-pozzolan cement, natural cement, slag cement, or hydraulic lime; and, in addition, usually containing one or more materials such as hydrated lime, limestone, chalk, calcareous shell, talc, slag, or clay as prepared for this purpose.

cement, moderate sulfate-resisting — a portland cement for use when either moderate sulfate resistance or moderate heat of hydration or both is desired, now referred to as Type

cement, modified — a portland cement for use when either moderate heat of hydration, moderate sulfate resistance, or both, is desired, now referred to as Type II (an obsolete term).

cement, natural — a hydraulic cement produced by calcining an argillaceous limestone at a temperature below the sintering point and then grinding to a fine powder.

cement, non staining — a masonry cement that contains not more than a stipulated amount of water-soluble alkali as measured by a stipulated test method.

cement, normal — general purpose portland cement, referred to in the United States as Type I.

cement, oil-well — hydraulic cement suitable for use under high pressure and temperature in sealing water and gas pockets and setting casing during the drilling and repair of wells;

cement, ordinary portland — the term used in the United Kingdom and elsewhere to designate the equivalent of American normal portland cement or Type I cement; commonly abbreviated OPC.

cement, plastic — a cement manufactured for plaster and stucco applications consisting of a blend of cement and lime that may include pozzolans, fillers, or additives to increase

cement, portland — a hydraulic cement produced by pulverizing clinker formed by heating a mixture, usually of limestone and clay, to 1400°C to 1600°C. Calcium sulfate is usually ground with the clinker to control set.

cement, portland blast-furnace slag — a hydraulic cement consisting of an intimately inter ground mixture of portland cement clinker and granulated blast-furnace slag or an intimate and uniform blend of portland cement and fine granulated blast-furnace slag in which the amount of the slag constituent is within specified limits.

cement, portland-pozzolan — a hydraulic cement consisting of an intimate and uniform blend of portland cement or portland blast-furnace slag cement and fine pozzolan produced by intergrinding portland-cement clinker and pozzolan, by blending portland cement or portland blastfurnace slag cement and finely divided pozzolan, or a combination of intergrinding and blending, in which the pozzolan constituent is within specified limits.

cement, regulated-set — a hydraulic cement containing fluorine-substituted calcium aluminate, capable of very rapid setting.

cement, Roman — a misnomer for a hydraulic cement made by calcining a natural mixture of calcium carbonate and clay, such as argillaceous limestone, to a temperature below that required to sinter the material but high enough to decompose the calcium carbonate, followed by grinding; so named because its brownish color resembles ancient Roman cements produced by use of lime-pozzolan mixtures.

cement, slag — granulated blast-furnace slag that has been finely ground and that is hydraulic cement.

cement, sticky — finished cement that develops low or zero flowability during or after storage in silos, or after transportation in bulk containers, hopper-bottom cars, etc.; may be caused by: ((a) interlocking of particles; (b) mechanical compaction; (c) electrostatic attraction between particles).

cement, sulfate-resistant — portland cement, low in tricalcium aluminate, that reduces susceptibility of concrete to attack by dissolved sulfates in water or soils, designated Type V in the U.S.

cement, supersulfated — a hydraulic cement made by intimately intergrinding a mixture of granulated blastfurnace slag, calcium sulfate, and a small amount of lime, portland cement, or portland cement clinker; so named because the equivalent content of sulfate exceeds that for portland blast-furnace slag cement.

cement, white — portland cement that hydrates to a white paste; made from raw materials of low iron content, the clinker for which is fired by a reducing flame.

cementation process — the process of injecting cement grout under pressure into certain types of ground (for example, gravel, fractured rock) to solidify it.

cementitious — having cementing properties.

cementitious mixture — a mixture (mortar, concrete, or grout) containing hydraulic cement.

centering — falsework used in the construction of arches, shells, space structures, or any continuous structure where the entire falsework is lowered (struck or decentered) as a unit.

chalk — a soft limestone composed chiefly of the calcareous remains of marine organisms.

chalking — formation of a loose powder resulting from the disintegration of the surface of concrete or of applied coating, such as cement paint.

chamfer — either a beveled edge or corner formed in concrete work by means of a chamfer strip.

channel – A general term for any natural or artificial facility for conveying water.

charge — to introduce, feed, or load materials into a concrete or mortar mixer, furnace, or other container or receptacle where they will be further treated or processed.

checking — development of shallow cracks at closely spaced but irregular intervals on the surface of plaster, cement paste, mortar, or concrete.

chert — a very fine-grained siliceous rock characterized by hardness and conchoidal fracture in dense varieties, the fracture becoming splintery and the hardness decreasing in porous varieties, and in a variety of colors; it is composed of silica in the form of chalcedony, cryptocrystalline or microcrystalline quartz, or opal, or combinations of any of these minerals.

chipping — treatment of a hardened concrete surface by chiseling.

chips — broken fragments of marble or other mineral aggregate screened to specified sizes.

chute — a sloping trough or tube for conducting concrete, cement, aggregate, or other free flowing materials from a higher to a lower point.

class (of concrete) — an arbitrary characterization of concrete of various qualities or usages, usually by compressive strength.

clay — natural mineral material having plastic properties and composed of very fine particles; the clay mineral fraction of a soil is usually considered to be the portion consisting of particles finer than 2 μm; clay minerals are essentially hydrous aluminum silicates or occasionally hydrous magnesium silicates.

clay content — mass fraction of clay of a heterogeneous material, such as a soil or a natural concrete aggregate or crushed stone.

clay, fire — an earthy or stony mineral aggregate that has as the essential constituent hydrous silicates of aluminum with or without free silica, plastic when sufficiently pulverized and wetted, rigid when subsequently dried, and of suitable refractoriness for use in commercial refractory products.

cleanout — an opening in the forms for removal of refuse, to be closed before the concrete is placed; a port in tanks, bins, or other receptacles for inspection and cleaning.

cleanup — treatment of horizontal construction joints to remove surface material and contamination down to a condition of soundness corresponding to that of a freshly broken surface of hardened concrete.

cleat — small board used to connect formwork members or used as a brace.

clinker — a partially fused product of a kiln, which is ground to make cement; also other vitrified or burnt material.

clinker, portland-cement — a partially fused ceramic material consisting primarily of hydraulic calcium silicates and calcium aluminates.

clip — wire or sheet-metal device used to attach various types of lath to supports or to secure adjacent lath sheets.

coat — a film or layer as of paint or plaster applied in a single operation.

coat, brown — the leveling coat of plaster, either the second coat of plaster in a three-coat application or the entire base coat of plaster in a two-coat application.

coat, dash-bond — a thick slurry of portland cement, sand, and water flicked on surfaces with a paddle or brush to provide a base for subsequent portland cement plaster coats;

coat, finish — [(1) final thin coat of shotcrete in preparation for hand finishing; and (2) final exposed coat of plaster or stucco].

coat, flash — a light coat of shotcrete used to cover minor blemishes on a concrete surface.

coat, scratch — the first coat of plaster or stucco applied to a surface in three-coat work; usually cross-raked or scratched to form a mechanical key with the brown coat.

coating — (a) (on concrete) — material applied to a surface by brushing, dipping, mopping, spraying, troweling, etc., to preserve,protect, decorate, seal, or smooth the substrate; (b) (on aggregate particles) — foreign or deleterious substances found adhering to the aggregate particles; or (c) (on architectural concrete) — material used to protect a concrete surface from atmospheric contaminants and those that penetrate slightly and leave a visible clear or pigmented film on the surface).

coating, form — a liquid applied to formwork surfaces for a specific purpose; to promote easy release from the concrete, to preserve the form material, or to retard setting of the nearsurface matrix for preparation of exposed-aggregate finishes.

coating, polysulfide — a protective-coating system prepared by polymerizing a chlorinated alkyl polyether with an inorganic polysulfide.

cobble — in geology, a rock fragment between 64 and 256 mm in diameter; as applied to coarse aggregate for concrete, the material in the nominal size range 75 to 150 mm.

cobblestone — a rock fragment, usually rounded or semi rounded, with an average dimension between 75 and 300 mm.

coefficient of subgrade friction — the coefficient of friction between a slab and its subgrade, commonly used in design of slabs-on-grade to estimate the force induced in the slab due to volume changes and elastic shortening if prestressed.

coefficient of subgrade reaction — ratio of: 9(1) load per unit area of horizontal surface of a mass of soil, to (2) corresponding settlement of the surface; determined as the slope of the secant, drawn between the point corresponding to zero settlement and the point of 1.3 mm settlement, of a load-settlement curve obtained from a plate load test on a soil using a 762 mm or greater diameter loading plate; used in the design of concrete pavements by the Westergaard method).

coefficient of thermal expansion — change in linear dimension per unit length or change in volume per unit volume per degree of temperature change.

coefficient of variation — the standard deviation divided by the mean value of a variable.

cold face — the surface of a refractory section not exposed to the source of heat; surface of concrete or masonry exposed to low ambient temperatures.

cold weather — a period when the average daily ambient temperature is below 40°F (5°C) for more than three successive days. Note: The average daily temperature is the average of the highest and lowest temperature during the period from midnight to midnight. When temperatures above 10°C occur during more than half of any 24-hour duration, the period

cold-joint lines — visible lines on the surfaces of formed concrete indicating the presence of discontinuities where one layer of concrete had hardened before subsequent concrete was placed.

colemanite — a mineral, hydrated calcium borate ($Ca_2B_6O_{11}\cdot 5H_2O$).

colloid — a substance that is in a state of division preventing passage through a semipermeable membrane, consisting of particles ranging from 0.1 to 0.001 µm in diameter.

colorimetric value — an indication of the amount of organic impurities present in fine aggregate.

column — member with a ratio of height-to-least lateral dimension exceeding 3 used primarily to support axial compressive load.

column capital — an enlargement of a column below a slab intended to increase the shearing resistance.

column clamp — any of various types of tying or fastening units to hold column form sides together.

column side — one of the vertical panel components of a column form.

column strip — the portion of a flat slab over the columns and consisting of the two adjacent quarter panels on each side of thecolumn center line.

column, composite — a concrete compression member reinforced longitudinally with structural steel shapes, pipe, or tubing with or without longitudinal reinforcing bars.

column, long — a column whose load capacity is limited by buckling rather than strength. **column, pipe** — column made of steel pipe; often filled with concrete.

column, short — a column whose load capacity is limited by strength rather than buckling; a column that is customarily so stocky and sufficiently restrained that at least 95% of the cross-sectional strength can be developed.

column, slender — a column whose load capacity is reduced by the increased eccentricity caused by secondary deflection moments.

column, spirally reinforced — a column in which the vertical bars are enveloped by spiral reinforcement, that is, closely spaced continuous hooping.

column, tied — a column laterally reinforced with ties.

come-along — [(1) a hoe-like tool with a blade approximately 100 mm highand 500 mm wide and curved from top to bottom, usedfor spreading concrete; or (2) a colloquial name for a device (load binder) used to tighten chains holding loads in place on a truck bed].

compacting factor — the ratio obtained by dividing the observed mass of concrete that fills a container of standard size and shape when allowed to fall into it under standard conditions of test, by the mass of fully compacted concrete which fills the same container.

compaction – mechanical action which increases the density by reducing the voids in a material.

component, expansive — the portion of an expansive cement that is responsible for the expansion, generally one of several anhydrous calcium aluminate or sulfo aluminate compounds and a source of sulfate, with or without free lime, (CaO); the expansive component may be produced separately and later ground or blended with a normal portland-cement clinker, in other instances, produced by firing in a kiln with the constituents of portland cement.

composite — engineering materials—for example, concrete or fiber reinforced polymer—made from two or more constituent materials that remain distinct, but combine to form materials with properties not possessed by any of the constituent materials individually; the constituent materials are generally characterized as matrix and reinforcement or matrix and aggregate.

composite concrete flexural members — concrete flexural members consisting of concrete elements constructed in separate placements but so interconnected that the elements

compound, curing — a liquid that can be applied as a coating to the surface of newly placed concrete to retard the loss of water and, in the case of pigmented compounds, to reflect heat so as to provide an opportunity for the concrete to develop its properties in a favorable temperature and moisture environment.

compound, joint-sealing — an impervious material used to fill joints in pavements or structures.

compound, waterproofing — material used to impart water repellency to a structure or a constructional unit.

compressive strength, average — the average compressive strength of a given class or strength level of concrete; defined as average compressive strength required to statistically meet a designated specific strength.

concrete — mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials.

concrete (mortar or grout), expansive-cement — a concrete (mortar or grout) made with expansive cement.

concrete (mortar or grout), self-stressing — expansive cement concrete (mortar or grout) in which expansion, if restrained, induces persistent compressive stresses in the concrete (mortar or grout); also known as chemically prestressed concrete.

concrete (mortar, grout), preshrunk — [(1) concrete that has been mixed for a short period in a stationary mixer before being transferred to a transit mixer, or (2) grout, mortar, or concrete that has been mixed one to three hours before placing to reduce shrinkage during hardening].

concrete breaker — a compressed-air tool specially designed and constructed to break up concrete.

concrete containment structure — a composite concrete and steel assembly that is designed as an integral part of a pressure retaining barrier, which in an emergency prevents the release of radioactive or hazardous effluents from nuclear power plant equipment enclosed therein.

concrete finishing machine — a machine mounted on flanged wheels that ride on the forms or on specially set tracks, used to finish surfaces such as those of pavements; or a portable power-driven machine for floating and finishing of floors and other slabs.

concrete reactor vessel — a composite concrete and steel assembly that functions as a component of the principal pressure-containing barrier for the nuclear fuel's primary heat.

concrete vibrating machine — a machine that consolidates a layer of freshly mixed concrete by vibration.

concrete, aluminate — concrete made with calcium-aluminate cement; used primarily where high-early-strength and refractory or acid-resistant concrete is required.

concrete, architectural — concrete that will be permanently exposed to view and therefore requires special care in selection of the concrete materials, forming, placing, and finishing to obtain the desired architectural appearance.

concrete, asphaltic — a mixture of asphalt cement and aggregate.

concrete, backfill — nonstructural concrete used to correct over-excavation, fill excavated pockets in rock, or prepare a surface to receive structural concrete.

concrete, boron-loaded — high density concrete including a boron-containing admixture or aggregate, such as the mineral colemanite, boron frits, or boron metal alloys, to act as a neutron attenuator.

concrete, cast-in-place — concrete that is deposited and allowed to harden in the place where it is required to be in the completed structure, as opposed to precast concrete.

concrete, cellular — a low-density product consisting of portland cement, cement-silica, cement-pozzolan, limepozzolan, or lime-silica pastes, or pastes containing blends of these ingredients and having a homogeneous void or cell structure, attained with gas-forming chemicals or foaming agents (for cellular concretes containing binder ingredients other than, or in addition to, portland cement, autoclave curing is usually employed).

concrete, central-mixed — concrete that is completely mixed in a stationary mixer from which it is transported to the delivery point.

concrete, centrifugally cast — concrete compacted by centrifugal action, for example, in the manufacture of pipe and poles.

concrete, chemically pre stressing — concrete made with expansive cement and reinforcement under conditions such that the expansion of the cement induces tensile stress in the reinforcement so as to produce prestressed concrete.

concrete, colloidal — concrete in which the aggregate is bound by colloidal grout.

concrete, confined — concrete containing closely spaced special transverse reinforcement that is provided to restrain the concrete in directions perpendicular to the applied stress.

concrete, cyclopean — mass concrete in which large stones, each of 50 kg or more, are placed and embedded in the concrete as it is deposited.

concrete, decorative — concrete that has received treatments to create aesthetic effects. These treatments may include coloring, polishing, texturing, embossing, molding, etching,

concrete, dense — concrete containing a minimum of voids.

concrete, dry-packed — concrete placed by dry packing.

concrete, epoxy — a mixture of epoxy resin and catalyst (binder), fine aggregate, and coarse aggregate.

concrete, exposed — concrete surfaces formed so as to yield an acceptable texture and finish for permanent exposure to view.

concrete, fair-face — a concrete surface that, on completion of the forming process, requires no further (concrete) treatment other than curing.

concrete, fiber-reinforced — concrete containing dispersed, randomly oriented fibers.

concrete, field — concrete delivered or mixed, placed, and cured on the job site.

concrete, flowing — a cohesive concrete mixture with a slump greater than 190 mm.

concrete, foamed — low-density concrete made by the addition of a prepared foam or by generation of gas within the unhardened mixture.

concrete, fresh — concrete that posses enough of its original workability so that it can be placed and consolidated by the intended methods.

concrete, gap-graded — concrete containing a gap-graded aggregate.

concrete, gas — lightweight concrete produced by developing voids with gas generated within the fresh mixture (usually from the action of cement alkalies on aluminum powder used as an admixture).

concrete, granolithic — concrete suitable for use as a wearing surface finish to floors, made with specially selected aggregate of suitable hardness, surface texture, and particle shape.

concrete, green — concrete that has set but not hardened appreciably.

concrete, gypsum — concrete in which the cementitious constituent is partially dehydrated calcium sulfate (plaster).

concrete, hardened — concrete that has developed sufficient strength to serve some purpose or resist breaking under stipulated loading.

concrete, heat-resistant — any concrete that will not disintegrate when exposed to constant or cyclic heating at any temperature below that at which a ceramic bond is formed.

concrete, high-density — concrete of substantially higher density than that made using normal-density aggregates, usually obtained by use of high-density aggregates and used especially for radiation shielding.

concrete, high-early-strength — concrete which, through the use of high-early-strength cement or admixtures, attains a given level of strength earlier than normal concrete does.

concrete, high-performance — concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional

concrete, high-strength — concrete that has a specified compressive strength for design of 55 MPa or greater.

concrete, insulating — concrete having low thermal conductivity; used as thermal insulation.

concrete, lean — concrete of low cementitious material content.

concrete, lightweight — concrete of substantially lower density than that made using aggregates of normal density.

concrete, low-density — concrete having an oven-dry density of less than 800 kg/m^3

concrete, mass — any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking.

concrete, monolithic — concrete cast with no joints other than construction joints.

concrete, negative-slump — concrete of a consistency such that it not only has zero slump but still has zero slump after adding additional water.

concrete, no-fines — a concrete mixture containing little or no fine aggregate.

concrete, nonair-entrained — concrete in which neither an air-entraining admixture nor air-entraining cement has been used.

concrete, nonslip — 1. a floor, pavement, or walkway of concrete the surface of which has been roughened, before final set, either by sprinkling fine particles of abrasive material thereon and then troweling or by swirling with either a coarse-bristled brush or a trowel; or 2. a concrete surfaced roughened after final set by acid etching, mechanically abrading, or grooving.

concrete, normalweight — concrete having a density of approximately 2400 kg/m3 made with normal density aggregates.

concrete, normalweight refractory — refractory concrete having a bulk density greater than 1600 kg/m^3.

concrete, no-slump — freshly mixed concrete exhibiting a slump of less than 6 mm.

concrete, pervious – concrete containing little, if any fine aggregate that results in a sufficient voids to allow air and water to easily pass from the surface to underlying layers.

concrete, plain — structural concrete with no reinforcement or with less reinforcement than the minimum amount specified in the applicable building code for reinforced concrete.

concrete, polymer — concrete in which an organic polymer serves as the binder.

concrete, polymer-cement — a mixture comprising hydraulic cement and aggregate combined at the time of mixing with organic monomers or polymers that are dispersed in water.

concrete, polymer-impregnated — a hydrated portland cement concrete that has been impregnated with a monomer that is subsequently polymerized.

concrete, popcorn — no-fines concrete containing insufficient cement paste to fill voids among the coarse aggregate so that the particles are bound only at points of contact.

concrete, precast — concrete cast elsewhere than its final position.

concrete, preplaced-aggregate — concrete produced by placing coarse aggregate in a form and later injecting a portland cement-sand grout, usually with admixtures, to fill the voids.

concrete, prestressed — Structural concrete in which internal stresses have been introduced to reduce potential tensile stresses in concrete resulting from loads.

concrete, pumped — concrete which is transported through hose or pipe by means of a pump.

concrete, ready mixed — concrete manufactured for delivery to a purchaser in a fresh state.

concrete, recycled — hardened concrete that has been processed for reuse, usually as aggregate.

concrete, refractory — hardened hydraulic-cement concrete that has refractory properties and that is suitable for use at temperatures between 315°C to 1315°C.

concrete, refractory-insulating — refractory concrete having low thermal conductivity.

concrete, reinforced — structural concrete reinforced with no less than the minimum amount of pre stressing steel or non prestressed reinforcement as specified in the applicable building code.

concrete, rich — concrete of high cement content.

concrete, roller-compacted — concrete compacted by roller compaction; concrete that, in its unhardened state, will support a roller while being compacted.

concrete, rubble — [(1) concrete similar to cyclopean concrete except that small stones (such as one person can handle) are used. (2) concrete made with rubble from demolished structures].

concrete, sand-lightweight — concrete made with a combination of expanded clay, shale, slag, or slate or sintered fly ash and natural sand; its density is generally between 1680 and 1920 kg/m^3.

concrete, sawdust — concrete in which the aggregate consists mainly of sawdust from wood.

concrete, self-consolidating — concrete, self-consolidating- is highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation.

concrete, shielding — concrete, employed as a biological shield to attenuate or absorb nuclear radiation, usually characterized by high density or high hydrogen (water) content or boron content, having specific radiation attenuation effects.

concrete, shrinkage-compensating — concrete containing expansive components usually based on formation of calcium sulfo aluminate (ettringite) in a mixture of calcium aluminate and gypsum.

concrete, shrink-mixed — ready mixed concrete mixed partially in a stationary mixer and then mixed in a truck mixer.

concrete, siliceous-aggregate — concrete made with normal density aggregates having constituents composed mainly of silica or silicates.

concrete, specified compressive strength of (**fc**') — compressive strength of concrete used in design.

concrete, structural — plain or reinforced concrete in a member that is part of a structural system required to transfer gravity and/or lateral loads along a load path to the ground.

concrete, structural lightweight — structural concrete made with low-density aggregate; having an air-dry density of not more than 1850 kg/m^3 and a 28-day compressive strength of more than 17.2 MPa.

concrete, terrazzo — marble-aggregate concrete that is castin- place or precast and ground smooth for decorative surfacing purposes on floors and walls.

concrete, transit-mixed — concrete, the mixing of which is wholly or principally accomplished in a truck mixer.

concrete, translucent — a combination of glass and concrete used together in precast and prestressed panels.

concrete, underwater — concrete placed underwater by tremie or other means.

concrete, vacuum — concrete from which excess water and entrapped air are extracted by a vacuum process before hardening occurs.

concrete, vermiculite — concrete in which the aggregate consists of exfoliated vermiculite.

concrete, vibrated — concrete consolidated by vibration during and after placing.

concrete, zero-slump — concrete of stiff or extremely dry consistency showing no measurable slump after removal of the slump cone.

conductance, thermal — time rate of heat flow through a unit area of body induced by a unit temperature difference between the body surfaces; the thermal conductance is the reciprocal of the thermal resistance.

conductivity, thermal — the property (of a homogeneous body) measured by the ratio of the steady-state heat flux (time-rate of heat flow per unit area) to the temperature.

conduit — A closed channel to convey water through, around, or under a dam.

cone bolt — a type of tie rod for wall forms with cones at each end inside the forms so that a bolt can act as a spreader as well as a tie.

cone, flow — a device for measurement of grout consistency in which a predetermined volume of grout is permitted to escape through a precisely sized orifice, the time of efflux (flow factor) being used as the indication of consistency; also the mold used to prepare a specimen for the flow test.

cone, pyrometric — a small, slender, three-sided oblique pyramid made of ceramic or refractory material for use in determining the time-temperature effect of heating and in obtaining the pyrometric cone equivalent (PCE) of refractory material.

cone, slump — a mold in the form of the lateral surface of the frustum of a cone with a base diameter of 203 mm top diameter 102 mm, and height 305 mm, used to fabricate a specimen of freshly mixed concrete for the slump test; a cone 152 mm high is used for tests of freshly mixed mortar and stucco.

confined region — region with transverse reinforcement within beam-column joints.

connection, scarf — a connection made by pre casting, beveling, halving, or notching two pieces to fit together; after overlapping, the pieces are secured by bolts or other means.

consistency — the degree to which a freshly mixed concrete, mortar, grout, or cement paste resists deformation.

consistency factor — a measure of grout fluidity, roughly analogous to viscosity, which describes the ease with which grout may be pumped into voids or fissures; usually a laboratory measurement in which consistency is reported in degrees of rotation of a torque viscosimeter in a specimen of grout.

consistency, flowable — the consistency at which a grout will form a nearly level surface when lightly rodded; the consistency of a grout with at least 125% at five drops on the ASTM C230 flow table and an efflux time through the ASTM C939 flow cone of more than 30 seconds.

consistency, fluid — the consistency at which a grout will form a nearly level surface without vibration or rodding; the consistency of a grout that has an efflux time of less than 30 s from the ASTM C 939 flow cone.

consistency, normal — [(1) the consistency exhibited when a mixture is considered acceptable for the purpose at hand; or (2) the consistency of cement paste satisfying appropriate limits defined in a standard test method (for example, ASTM C187)].

consistency, plastic — [(1) the consistency at which a mixture subjected to a constant stress undergoes increasing deformation without rupture; or (2) the consistency at which mixture properties satisfy appropriate limits defined in a standard test method].

consistency, wettest stable — the condition of maximum water content at which cement grout and mortar will adhere to a vertical surface without sloughing.

consistometer — an apparatus for measuring the consistency of cement pastes, mortars, grouts, or concretes.

consolidation — the process of inducing a closer arrangement of the solid particles in freshly mixed concrete or mortar during placement by the reduction of voids, usually by vibration, centrifugation, rodding, tamping, or some combination of these actions; also applicable to similar manipulation of other cementitious mixtures, soils, aggregates, or the like.

construction joint — The interface between two successive placings or pours of concrete where bond, and not permanent separation, is intended.

construction loads — the loads to which a permanent or temporary structure is subjected during construction.

construction, alternate-lane — a method of constructing soil supported concrete roads, runways, building floors, or other paved areas, in which alternate lanes are placed and allowed to harden before the remaining intermediate lanes are placed.

construction, cellular — a method of constructing concrete elements in which part of the interior concrete is replaced by voids.

construction, composite — a type of construction using members produced by combining different materials (for example, concrete and structural steel), members produced by combining cast-in-place and precast concrete, or cast-inplace concrete elements constructed in separate placements but so interconnected that the combined components act together as a single member and respond to loads as a unit.

construction, structural sandwich — a laminar construction comprising a combination of alternating dissimilar simple or composite materials assembled and intimately fixed in relation to each other so as to use the properties of each to attain specific structural and thermal advantages for the whole assembly.

contact ceiling — a ceiling that is secured in direct contact with the construction above without use of furring.

contact pressure — pressure acting at and perpendicular to the contact area between soil and a concrete element.

contingency storage allowance The additional freeboard allowed on top of the tailings, decant pond, wet season storage and extreme storm allowance to cater for wave run-up and uncertainty in the values adopted for the defined items.

continuous slab or beam — a slab or beam that extends as a unit over three or more supports in a given direction.

continuously reinforced pavement — a pavement with uninterrupted longitudinal steel reinforcement and no intermediate transverse expansion or contraction joints.

contraction — decrease in either length or volume.

contractor — the person, firm, or corporation with whom the owner enters into an agreement for construction of the work.

controlled low-strength material (CLSM) — self-consolidating cementitious mixture that is intended to result in a compressive strength of 8.3 MPa or less.

conveying hose — see **hose, delivery** (preferred term).

conveyor — a device for moving materials; usually a continuous belt, an articulated system of buckets, a confined screw, or a pipe through which material is moved by air or water.

coping — the material or units used to form a cap or finish on top of a wall, pier, pilaster, or chimney.

coquina — a type of limestone formed of sea shells in loose or weakly cemented condition, found along present or former shorelines; used as a calcareous raw material in cement manufacture and other industrial operations.

corbel — a projection from the face of a beam, girder, column, or wall used as a beam seat or a decoration.

core — A zone of low permeability material in an embankment dam. The core is sometimes referred to as central core, inclined core, puddle clay core, rolled clay core, or impervious zone.

cored beam — a beam whose cross section is partially hollow or a beam from which cored samples of concrete have been taken.

coring — the act of obtaining cores from hardened concrete or masonry structures, rock, or soil.

corner reinforcement — see **reinforcement, corner**.

corrosion — destruction of metal by chemical, electrochemical, or electrolytic reaction within its environment.

corrosion inhibitor — a chemical compound, either liquid or powder, usually intermixed in concrete and sometimes applied to concrete, and that effectively decreases corrosion of steel reinforcement.

corrosion, bacterial — destruction of a material by bacterial processes brought about by the activity of certain bacteria that consume the material and produce substances, such as hydrogen sulfide, ammonia, and sulfuric acid.

coupler — 1. a device for connecting reinforcing bars or prestressing tendons end to end; 2. a device for locking together the component parts of a tubular metal scaffold (also known as a clamp); or 3. internal threaded device for joining reinforcing bars with matching threaded ends for the purpose of providing transfer of either axial compression or axial tension or both from one bar to the other.

coupling agent — a substance used between the transducer and test surface to permit or improve transmission of ultrasonic energy.

coupling pin — an insert device used to connect lifts or tiers or formwork scaffolding vertically.

coupling sleeve — device fitting over the ends of two reinforcing bars for the eventual purpose of providing transfer of either axial compression or axial tension or both from one bar to the other.

course — in concrete construction, a horizontal layer of concrete, usually one of several making up a lift; in masonry construction, a horizontal layer of block or brick.

cover — the least distance between the surface of embedded reinforcement and the surface of the concrete.

crack — a complete or incomplete separation, of either concrete or masonry, into two or more parts produced by breaking or fracturing.

crack, diagonal — in a flexural member, an inclined crack caused by shear stress, usually at about 45 degrees to the axis; or a crack in a slab, not parallel to either the lateral or longitudinal directions.

crack, hairline — a concrete surface crack with a width so small as to be barely perceptible.

crack, longitudinal — a crack that develops parallel to the length of a member.

crack, plastic-shrinkage — surface crack that occurs in concrete prior to initial set.

crack, shrinkage — crack due to restraint of shrinkage.

crack, transverse — a crack that crosses the longer dimension of the member.

cracked section — a section designed or analyzed on the assumption that concrete has no resistance to tensile stress.

cracking — (**cracking, diagonal** — development of diagonal cracks.
cracking, map — (1) intersecting cracks that extend below the surface of hardened concrete; caused by shrinkage of the drying surface

concrete that is restrained by concrete at greater depths where either little or no shrinkage occurs; vary in width from fine and barely visible to open and well-defined; or (2) the chief symptom of chemical reaction between alkalies in cement and mineral constituents in aggregate within hardened concrete; due to differential rate of volume change in different portions of the concrete; cracking is usually random and on a fairly large scale, and in severe instances the cracks may reach a width of 12.7 mm).

cracking, shrinkage — cracking of a structure or member due to failure in tension caused by external or internal restraints as reduction in moisture content develops, carbonation occurs, or both.

cracking, stress-corrosion — a cracking process that requires the simultaneous action of a corrodent and sustained tensile stress. (This excludes corrosion-reduced sections that fail by fast fracture; also excludes intercrystalline or transcrystalline corrosion that can disintegrate an alloy without either applied or residual stress).

cracking, temperature — cracking due to tensile failure, caused by temperature drop in members subjected to external restraints or by temperature differential in members subjected to internal restraints.

cracks —cracks, craze — fine random cracks or fissures in a surface of plaster, cement paste, mortar, or concrete. **crazing** — the development of craze cracks; the pattern of craze cracks existing in a surface.

creep — time-dependent deformation due to sustained load.

creep, basic — creep that occurs without migration of moisture to or from the concrete.

creep, drying — creep caused by drying.

creep, nonrecoverable — the residual or nonreversible deformation remaining in hardened concrete after removal of sustained load.

crest length — The total horizontal distance measured along the axis of the dam, at the elevation of the top of the dam, between abutments or ends of the dam. Where applicable, this includes the spillway, powerhouse sections and navigation locks, where they form a continuous part of the impounding structure.

crest thickness (top width) — The thickness or width of a dam at the level of the top of dam (excluding corbels or parapets). In general, the term thickness is used for gravity and arch dams, and width is used for other dams.

critical project element — An element of a project whose failure could result in the uncontrolled release of the reservoir.

cross bracing — crossing members usually designed to act only in tension, often used in scaffolding systems.

cross section — An elevation view of a dam formed by passing a plane through the dam perpendicular to the axis.

cross-tee — a light-gage metal member resembling an upsidedown "tee" used to support the abutting ends of formboards in insulating concrete roof constructions.

crush plate — an expendable strip of wood attached to the edge of a form or intersection of fitted forms, to protect the form from damage during prying, pulling, or other stripping operations.

crusher — **crusher, primary,** a heavy crusher suitable for the first stage in a process of size reduction of rock, slag, or the like. **crusher, secondary,** a crusher used for the second stage in a process of size reduction of aggregate and the like

cubical piece (of aggregate) — one in which length, breadth, and thickness are approximately equal.

curb form — a retainer or mold used in conjunction with a curb tool to give the necessary shape and finish to a concrete curb.

curb tool — a tool used to give the desired finish and shape to the exposed surfaces of a concrete curb.

curing — action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and (if applicable) pozzolanic reactions to occur so that the potential properties of the mixture may develop.

curing, adiabatic — the maintenance of adiabatic conditions in concrete or mortar during the curing period.

curing, atmospheric-pressure steam — steam curing of concrete products or cement at atmospheric pressure, usually at maximum ambient temperature between 40°C to 95°C.

curing, autoclave — curing of concrete products in an autoclave at maximum ambient temperature generally between 170°C to 215°C).

curing, electrical — a system in which a favorable temperature is maintained in freshly placed concrete by supplying heat generated by electrical resistance.

curing, final — deliberate action taken between the final finishing and termination of curing to reduce the loss of water from the surface of the concrete and control the temperature of the concrete.

curing, fog — [(1) storage of concrete in a moist room in which the desired high humidity is achieved by the atomization of water ; and (2) application of atomized water to concrete, stucco, mortar, or plaster].

curing, initial — deliberate action taken between placement and final finishing of concrete to reduce the loss of water from the surface of the concrete.

curing, internal — supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation.

curing, mass — adiabatic curing in sealed containers.

curing, membrane — a process that involves either liquid sealing compound (for example bituminous and paraffinic emulsions, coal tar cut-backs, pigmented and non pigmented resin suspensions, or suspension of wax and drying oil) or nonliquid protective coating (for example, sheet plastics or "waterproof" paper), both of which types function as a film to restrict evaporation of mixing water from concrete surfaces.

curing, moist-air — curing in air of not less than 95% relative humidity at atmospheric pressure and normally at a temperature approximating 23°C.

curing, single-stage — autoclave curing process in which precast concrete products are put on metal pallets for autoclaving and remain there until stacked for delivery or yard storage.

curing, standard — exposure of test specimens to specified conditions of moisture and temperature.

curing, steam — curing of concrete, mortar, grout, or neat-cement paste in water vapor at atmospheric or higher pressures and at temperatures between about 40°C and 215°C.

curing, two-stage — a process in which concrete products are cured in low-pressure steam, stacked, and then autoclaved.

curling — out-of-plane deformation of the corners, edges, and surface of a pavement, slab, or wall panel from its original shape.

curvature friction — friction resulting from bends or curves in the specified prestressing cable profile.

curve, grading — a graphical representation of the proportions of different particle sizes in a granular material; obtained by plotting the cumulative or individual percentages of the material passing through sieves in which the aperture sizes form a given series.

cutoff trench — A foundation excavation later to be backfilled with material so as to limit seepage beneath a dam.

cycle, autoclave — the time interval between the start of the temperature-rise period and the end of the blowdown period; also, a schedule of the time and temperature-pressure conditions of periods which make up the cycle.

cylinders, field-cured — test cylinders that are left at the jobsite for curing as nearly as practicable in the same manner as the concrete in the structure to indicate when supporting forms may be removed, additional construction loads may be imposed, or the structure may be placed in service.

D

dam — Any artificial barrier and/or any controlling works, together with appurtenant works that can or does impound or divert water. **Arch dam**: A concrete or masonry dam which is curved upstream so as to transmit the major part of the water load to the abutments. **Cofferdam**: A temporary structure enclosing all or part of the construction area so that construction can proceed in the dry. A diversion cofferdam diverts a stream into a pipe, channel, tunnel, or other watercourse. C**rib dam**: A gravity dam built up of boxes, crossed timbers or gabions, filled with earth or rock. D**iversion dam**: A dam built to divert water from a waterway or stream into a different watercourse. E**arth dam**: An embankment dam in which more than 50% of the total volume is formed of compacted earth material generally smaller than 3-inch size. **Embankment dam**: Any dam constructed of excavated natural materials or of industrial waste materials. **Gravity dam**: A dam constructed of concrete and/or masonry which relies on its weight and internal strength for stability. **Hydraulic fill dam**: An earth dam constructed of materials, often dredged, which are conveyed and placed by suspension in flowing water. **Industrial waste dam**: An embankment dam, usually built in stages, to create storage for the disposal of waste products from an industrial process. The waste products are conveyed as fine material suspended in water to the reservoir impounded by the embankment. The embankment may be built of conventional materials but sometimes incorporates suitable waste products. **Masonry dam**: Any dam constructed mainly of stone, brick, or concrete blocks jointed with mortar. A dam having only a masonry facing should not be referred to as a masonry dam. **Mine tailings dam**: An industrial waste dam in which the waste materials come from mining operations or mineral processing. **Regulating dam**: A dam impounding a reservoir from which water is released to regulate the flow downstream.

dam failure — The uncontrolled release of impounded water. It is recognized that there are lesser degrees of failure and that any malfunction or abnormality outside the design assumptions and parameters which adversely affect a dam's primary function of impounding water is properly considered a failure. They are, however, normally amenable to corrective action.

dam height — The effective hydraulic height of a dam as measured by the vertical distance from the natural bed of the stream or watercourse at the downstream toe of the impounding barrier to the maximum storage elevation. If the dam is not across a stream or watercourse, the height is measured from the lowest elevation of the outside limit of the impounding barrier to the maximum storage elevation.

damage, abrasion — wearing away of a surface by rubbing and friction.

damage, cavitation — pitting of concrete caused by implosion, that is, the collapse of vapor bubbles in flowing water which form in areas of low pressure and collapse as they enter areas of higher pressure.

damp — either partial saturation or moderate covering of moisture; implies less wetness than that connoted by "wet" and slightly wetter than that connoted by "moist." **dampproofing** — treatment of concrete or mortar to retard the passage or absorption of water, or water vapor, either by application of a suitable coating to exposed surfaces, or by use of a suitable admixture or treated cement, or by use of a preformed film such as polyethylene sheets placed on grade before placing a slab.

dams engineer – An engineer experienced in investigation, planning, design, construction or management of dams and qualified to undertake work in the field of dams. Some aspects of tailings dam engineering may require specialist input. A Specialist would be a person with special skills such as geochemistry, hydrogeology, etc.

darby — a hand-manipulated straightedge, usually 1 to 2.5 m long, used in the early stage leveling operations of concrete or plaster, preceding supplemental floating and finishing.

davit — a device used to support and swing the access covers away from openings of vessels and tanks.

D-cracks — a series of cracks in concrete near and roughly parallel to joints, and edges.

dead end — in the stressing of a tendon from one end only, the end opposite that to which the load is applied.

dead storage: The storage that lies below the invert of the lowest outlet and that, therefore, cannot readily be withdrawn from the reservoir.

deadman — an anchor for a guy line, usually a beam, block, or other heavy item buried in the ground, to which a line is attached.

debonding — [(1) preventing bond of prestressing tendons to surrounding concrete; or (2) failure of cohesive or adhesive bond at the interface between a substrate and a strengthening or repair system].

decant pond – A pond within a tailings dam to allow collection and clarification of storm water and tailings water released on settling and consolidation of tailings.

decenter — to lower or remove centering or shoring.

deck — the form on which concrete for a slab is placed, also the floor or roof slab itself. **deck, bridge** — the structural concrete slab or other structure that is supported on the bridge superstructure and serves as the road way or other traveled surface.

decking — sheathing material for a deck or slab form.

deflection — movement of a point on a structure or structural element, usually measured as a linear displacement or as succession displacements transverse to a reference line or axis.

deflection, dowel — deflection caused by the transverse load imposed on a dowel.

deformation — a change in dimension or shape.

deformation, anchorage — the loss of elongation or stress in the tendons of prestressed concrete due to the deformation or seating of the anchorage when the prestressing force is transferred from the jack to the anchorage; known also as anchorage loss.

deformation, elastic — elastic deformation proportional to the applied stress.

deformation, inelastic — non-elastic deformation not proportional to the applied stress.

deformation, time-dependent — deformation resulting from effects such as autogenous volume change, thermal contraction or expansion, creep, shrinkage, and swelling, each of which is a function of time.

degree-hour — a measure of strength gain of concrete as a function of the product of temperature multiplied by time for a specific interval.

dehydration — removal of chemically bound, adsorbed, or absorbed water from a material.

deicer — a chemical, such as sodium or calcium chloride, used to melt ice or snow on slabs and pavements, such melting being due to depression of the freezing point.

delamination — a planar separation in a material that is roughly parallel to the surface of the material.

delayed ettringite formation — a form of sulfate attack by which mature hardened concrete is damaged by internal expansion during exposure to cyclic wetting and drying in service and caused by the late formation of ettringite; not because of excessive sulfate; not likely to occur unless the concrete has been exposed to temperatures during curing of 70°C or greater; and less likely to occur in concrete made with pozzolan or slag cement.

demold — to remove molds from concrete test specimens or precast products.

density — mass per unit volume (preferred over deprecated term **unit weight**.)

density control — control of density of concrete in field construction to ensure that specified values as determined by standard tests are obtained.

density, bulk — the mass of a material (including solid particles and any contained water) per unit volume including impermeable and permeable voids in the material.

density, dry — the mass per unit volume of a dry substance at a stated temperature. **density, dry-rodded** — mass per unit volume of dry aggregate compacted by rodding under standardized conditions; used in measuring density of aggregate.

density, fired — the density of refractory concrete, upon cooling, after having been exposed to a specified firing temperature for a specified time.

depth, effective — depth of a beam or slab section measured from the compression face to the centroid of the tensile reinforcement.

design step level — An integer value between one and ten used to designate increasingly stringent design loadings and conditions for design of critical project elements.

design storage allowance — This is the remaining safe storage capacity that needs to be provided in a non-release dam to accommodate tailings (solids and water), rainfall and wave action with a sufficient safety factor against overtopping and spillage of contaminated water. The design storage allowance must consider the post-wet season time that it may take to return the pond level to its normal operating level, or the time required (considering weather delays) to construct an incremental increase in storage capacity (new dam or raise of existing embankment).

design, elastic — a method of analysis in which the design of a member is based on a linear stress-strain relationship and corresponding limiting elastic properties of the material.

design, probabilistic — method of design of structures using the principles of statistics (probability) as a basis for evaluation of structural safety.

design, working-stress — a method of proportioning either structures or members for prescribed service loads at stresses well below the ultimate, and assuming linear distribution of flexural stresses and strains.

designer — Person with appropriate qualifications and experience responsible for the design of the tailings dam.

detail, emulative — a connection in which the structural performance is equivalent to that of a continuous member or a monolithic connection.

detail, jointed — a connection where the bending stiffness differs from that of the members and requires special design to collect, transfer, and redistribute forces from one member to another through the connection.

deterioration — [(1) physical manifestation of failure of a material (for example, cracking, delamination, flaking, pitting, scaling, spalling, staining) caused by environmental or internal autogenous influences on rock and hardened concrete as well as other materials; or (2) decomposition of material during either testing or exposure to service)].

device, extension — any device, other than an adjustment screw, used to obtain vertical adjustment of shoring towers.

diameter, equivalent fiber — diameter of a circle having an area equal to the average cross-sectional area of a fiber.

diatomaceous earth — a friable earthy material composed primarily of nearly pure hydrous amorphous silica (opal) in the form of frustules of the microscopic plants called diatoms.

dicalcium silicate — a compound having the composition $2CaO{\cdot}SiO_2$, abbreviated C_2S, an impure form of which (belite) occurs in portland-cement clinker.

differential thermal analysis (DTA) — indication of thermal reaction by differential thermocouple recording of temperature changes in a sample under investigation compared with those of a thermally passive control sample, that are heated uniformly and simultaneously.

diffusivity, thermal — thermal conductivity divided by the product of specific heat and density; an index of the facility with which a material undergoes temperature change.

dilation — an expansion of concrete during cooling or freezing generally calculated as the maximum deviation from the normal thermal contraction predicted from the length change temperature curve or length change-time curve established at temperatures before initial freezing.

diluent — a substance, liquid or solid, mixed with the active constituents of a formulation to increase the bulk or lower the concentration.

direct dumping — discharge of concrete directly into place from crane bucket or mixer.

discoloration — departure of color from that which is normal or desired.

disintegration — reduction into small fragments and subsequently into particles.

dispersant — a material that deflocculates or disperses finely ground materials by satisfying the surface energy requirements of the particles; used as a slurry thinner or grinding aid.

dispersant agent — an agent capable of increasing the fluidity of pastes, mortars, or concretes by reduction of inter-particle attraction.

distance from the neutral axis.

distress — physical manifestation of cracking and distortion in a concrete structure as the result of stress, chemical action, or both.

diversion channel, canal, or tunnel — A waterway used to divert water from its natural course. The term is generally applied to a temporary arrangement, e.g. to by-pass water around a dam site during construction. "Channel" is normally used instead of "canal" when the waterway is short.

documents, contract — a set of documents supplied by the owner to the contractor as the basis for construction. These documents contain contract forms, contract conditions, specifications, drawings, addenda, and contract changes.

dolomite — a mineral having a specific crystal structure and consisting of calcium carbonate and magnesium carbonate in equivalent chemical amounts which are 54.27 and 45.73% by mass, respectively; a rock containing dolomite as the principal constituent.

dolomite, hard-burned — the product of heating dolomitic rock at temperatures high enough to change the magnesium carbonate to magnesium oxide, a constituent that slowly expands on reaction with water.

dome — square prefabricated pan form used in two-way (waffle) concrete joist floor construction.

double-headed nail — a nail with two heads at, or near, one end to permit easy removal; widely used in concrete formwork.

double-up — a method of plastering characterized by application in successive operations with no setting or drying time between coats.

doughnut (donut) — a large washer of any shape to increase bearing area of bolts and ties; also a round concrete spacer with hole in the center to hold bars the desired distance from the forms.

dowel — ((1) a steel pin, commonly a plain or coated round steel bar that extends into adjoining portions of a concrete construction, as at an expansion or contraction joint in a pavement slab, so as to transfer shear loads; or (2) a deformed reinforcing bar intended to transmit tension, compression, or shear through a construction join).

downstream hazard classification — A rating to describe the potential for loss of human life and/or property damage if the dam were to fail and release the reservoir onto downstream areas. Downstream hazard classifications of 3, 2 and 1C, 1B, 1A correspond to low, significant and high downstream hazard classes respectively.

drain, blanket — A layer of pervious material placed to facilitate drainage of the foundation and/or embankment.

drain, chimney — A vertical or inclined layer of pervious material in an embankment to facilitate and control drainage of the embankment fill.

drain, toe — A system of pipe and/or pervious material along the downstream toe of a dam used to collect seepage from the foundation and embankment and convey it to a free outlet.

drainage area — The area which drains to a particular point on a river or stream.

drainage fill — [(1) base course of granular material placed between floor slab and sub-grade to impede capillary rise of moisture; or (2) also, lightweight concrete placed on floors or roofs to promote drainage].

drawdown — The difference between a water level and a lower water level in a reservoir within a particular time. Used as a verb, it is the lowering of the water surface.

drier — chemical that promotes oxidation or drying of a paint or adhesive.

drip — a transverse groove in the underside of a projecting piece of wood, stone, or concrete to prevent water from flowing back to a wall.

drop chute — a device used to confine or to direct the flow of a falling stream of fresh concrete. [(1) **drop chute, articulated** — a device consisting of a succession of tapered metal cylinders so designed that the lower end of each cylinder fits into the upper end of the one below; or (2) **drop chute, flexible** — a device consisting of a heavy rubberized canvas or plastic collapsible tube].

dry density — mass of solids per unit volume of the solids plus liquids plus air voids.

dry-shake — a dry mixture of hydraulic cement and fine aggregate (either natural or special metallic) that is distributed evenly over the surface of concrete flatwork and worked into the surface before time of final setting and then floated and troweled to desired finish; the mixture either may or may not contain pigment.

dry-volume measurement — measurement of the ingredients of grout, mortar, or concrete by their bulk volume.

duct — a hole formed in a concrete member to accommodate a tendon for post-tensioning; a pipe or runway for electric, telephone, or other utilities.

ductility — that property of a material by virtue of which it may undergo large permanent deformation without rupture.

dunagan analysis — a method of separating the ingredients of freshly mixed concrete or mortar to determine the proportions of the mixture.

durability — the ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.

dust of fracture (in aggregate) — rock dust created during production processing or handling.

dusting — the development of a powdered material at the surface of hardened concrete.

E

early age (of concrete) — the period after final setting, during which properties are changing rapidly. For a typical Type I portland cement concrete moist cured at room temperature, this period is approximately 7 days.

early-entry dry-cut saw — a tool designed to produce joints in concrete commencing 1 to 4 hours after finishing and without raveling the cut edges.

earth pigments — the class of pigments that are produced by physical processing of materials mined directly from the earth; also frequently termed natural or mineral pigments or colors.

earthquake — A sudden motion or trembling in the earth caused by the abrupt release of accumulated stress along a fault.

edge — **edge, feather**, a wood or metal tool having a beveled edge and used to straighten re-entrant angles in finish plaster coat; also the edge of a concrete or mortar patch or topping that is beveled at an acute angle. **edge, pressed**, edge of a footing along which the greatest soil pressure occurs under conditions of overturning.

edge, pressed — edge of a footing along which the greatest soil pressure occurs under conditions of overturning.

edger — a finishing tool used on the edges of fresh concrete to provide a rounded edge.

edging — the operation of tooling the edges of a fresh concrete slab to provide a rounded corner.

effective area of concrete — area of a concrete section assumed to resist shear or flexural stresses.

effective area of reinforcement — the area obtained by multiplying the right cross-sectional area of the metal reinforcement by the cosine of the angle between its centroidal axis and the direction for which its effectiveness is considered.

effective width of slab — that part of the width of a slab taken into account when designing T- or L-beams.

efflorescence — a generally white deposit formed when watersoluble compounds emerge in solution from concrete, masonry, or plaster substrates and precipitate by reaction such as carbonation or crystallize by evaporation.

elasticity — that property of a material by virtue of which it tends to recover its original size and shape after deformation.

electrolysis — production of chemical changes by the passage of current through an electrolyte.

electrolyte — a conducting medium in which the flow of current is accompanied by movement of matter; usually an aqueous solution.

elephant trunk — an articulated tube or chute used in concrete placement.

elongated piece (of aggregate) — particle of aggregate for which the ratio of the length to the width of its circumscribing rectangular prism is greater than a specified value.

elongation — increase in length.

embedment-length equivalent — the length of embedded reinforcement which can develop the same stress as that which can be developed by a hook or mechanical anchorage.

emergency action plan (EAP) — A plan of action to be taken to reduce the potential for property damage and loss of life in an area affected by a dam failure.

emergency condition — A situation where life and property are at imminent risk and actions are needed within minutes or hours to initiate corrective actions and/or warn the public.

emergency spillway — Any secondary spillway which is designed to be operated very infrequently and possibly in anticipation of some degree of structural damage or erosion to the spillway during operation.

emery — a rock consisting essentially of an intercrystalline mixture of corundum and either magnetite or hematite; also manufactured aggregate composed of emery used to produce a wear-and slip resistant concrete floor surface.

emulation — designing precast elements and their structural connections to perform as if the structure was a conventional cast-in-place concrete structure.

emulsion — a two-phase liquid system in which small droplets of one liquid (the internal phase) are immiscible in, and dispersed uniformly throughout, a second continuous liquid phase (the external phase).

encastré — the end fixing of a built-in beam.

end-bearing sleeve — device fitting over the abutting ends of two reinforcing bars for the purpose of assuring transfer of only axial compression from one bar to the other.

energy dissipator — A device constructed in a waterway to reduce the kinetic energy of fast flowing water.

epicenter — The point on the earth's surface located vertically above the point of origin of an earthquake.

epoxy — a thermosetting polymer that is the reaction product of epoxy resin and an amino hardener.

equivalent rectangular stress-distribution — an assumption of uniform stress on the compression side of the neutral axis in the strength method of design to determine flexural capacity.

erosion — progressive disintegration of a solid by abrasion or cavitation of gases, liquids, or solids in motion.

ettringite — a mineral, high-sulfate calcium sulfoaluminate (3 $CaO{\cdot}Al_2O_3 3CaSO_4{\cdot}30\text{-}32H_2O$), occurring in nature or formed by sulfate attack on mortar and concrete; the product of the principal expansion-producing reaction in expansive cements; designated as "cement bacillus" in older literature.

evaporation retardant — a material applied to the surface of concrete, before set, to reduce the evaporation rate of water without interfering with finishing operations.

exfoliation — disintegration occurring by peeling off in successive layers; swelling up and opening into leaves or plates like a partly opened book.

exigency condition — A situation where the impounding structure is significantly underdesigned according to generally accepted engineering standards or is in a deteriorated condition and life and property are clearly at risk. Although present conditions do not pose an imminent threat, if adverse conditions were to occur, the situation could quickly become an emergency.

expansion — increase in either length or volume.

exposure condition, moderate — an environment, normally in temperate climate regions, in which concrete will only occasionally be exposed to moisture and will not be saturated

exposure condition, severe — an environment, normally in cold climate regions, in which concrete may be saturated, or in almost continuous contact with moisture prior to freezing, and where deicing agents are used.

extender — a finely divided inert mineral added to provide economical bulk in paints, synthetic resins and adhesives, or other products.

extensibility — the maximum tensile strain that hardened cement paste, mortar, or concrete can sustain before cracking occurs.

extraction fluid (primary coolant).

extreme storm storage allowance The volume allowed for storage of an extreme storm event to prevent spill from the dam.

exudation — a liquid or viscous gel-like material discharged through a pore, crack, or opening in the surface of concrete.

F

fabric, welded-wire — a series of longitudinal and transverse wires arranged approximately at right angles to each other and welded together at all points of intersection.

fabric, woven-wire — a prefabricated steel reinforcement composed of cold-drawn steel wires mechanically twisted together to form hexagonally shaped openings.

face, pilaster — the form for the front surface of a pilaster parallel to the wall.

factor of safety — the ratio of load, moment, or shear of a structural member at the ultimate to that at the service level.

factor, bulking — ratio of the volume of moist sand to the volume of the sand when dry.

factor, coarse-aggregate — the ratio, expressed as a decimal, of the amount (mass or solid volume) of coarse aggregate in a unit volume of well-proportioned concrete to the amount of dry-rodded coarse aggregate compacted into the same volume (b/bo).

factor, durability — [(1) a measure of the change in a material property over a period of time as a response to exposure to a treatment that can cause deterioration, usually expressed as percentage of the value of the property before exposure; or (2) in ASTM C666, a measure of the effects of freezing and thawing action on concrete specimens, in which resonant frequency of vibration is used as the property measured].

factor, maturity — a factor that is a function of the age of the concrete (hours or days) multiplied by the difference between the mean temperature of the concrete (degrees) during curing and a datum temperature below which hydration stops.

factor, Philleo — a distance, used as an index of the extent to which hardened cement paste is protected from the effects of freezing, so selected that only a small portion of the cement paste (usually 10%) lies farther than that distance from the perimeter of the nearest air void.

factor, spacing — an index related to the maximum distance of any point in a cement paste or in the cement paste fraction of mortar or concrete from the periphery of an air void; also known as Powers' spacing factor.

factor, stiffness — a measure of the stiffness of a structural member; for a prismatic member, it is equal to the ratio of the product of the moment of inertia of the cross section and the modulus of elasticity for the material to the length of the member.

factor, strength reduction — capacity-reduction factor (in structural design); a number less than 1.0 (usually 0.65 to 0.90) by which the strength of a structural member or element (in terms of load, moment, shear, or stress) is required to be multiplied to determine design strength or capacity; the magnitude of the factor is stipulated in applicable codes and construction specifications for respective types of members and cross sections.

failure — the occurrence of an event outside the expectation of the design or facility license conditions, that could range from the uncontrolled release of water including seepage, to a major instability of an embankment leading to loss of tailings and/or water.

failure, fatigue — the phenomenon of rupture of a material, when subjected to repeated loadings, at a stress substantially less than the static strength.

falsework — the temporary structure erected to support work in the process of construction; composed of shoring or vertical posting, formwork for beams and slabs, and lateral bracing.

fascia — a flat member or band at the surface of a building or the edge beam of a bridge; also exposed eave of a building.

fastener — a device designed to attach, join, or hold two or more objects one to another in juxtaposition; commonly readily removed.

fatigue — the weakening of a material by repeated or alternating loads.

fault — A fracture or fracture zone in the earth crust along which there has been displacement of the two sides relative to one another.

fault, active — A fault which, because of its present tectonic setting, can undergo movement from time to time in the immediate geologic future.

fault, capable — An active fault that is judged capable of producing macro-earthquakes and exhibits one or more of the following characteristics: a. Movement at or near the ground surface at least once within the past 35,000 years. b. Macroseismicity (3.5 magnitude Richter or greater) instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault. c. A structural relationship to a capable fault such that movement on one fault could be reasonably expected to cause movement on the other. d. Established patterns of microseismicity which define a fault, with historic macroseismicity that can reasonably be associated with the fault).

faulting — differential displacement of a slab or wall along a joint or crack.

felite — a name used to identify one form of the constituent of portland-cement clinker now know when pure as dicalcium silicate ($2CaO{\cdot}SiO_2$).

ferrocement — a composite structural material comprising thin sections consisting of cement mortar reinforced by a number of very closely spaced layers of steel wire mesh.

fetch — The straight line distance across a body of water subject to wind forces. The fetch is one of the factors used in calculating wave heights in a reservoir.

fiber — a slender and greatly elongated solid material, generally with a length at least 100 times its diameter, that has properties making it desirable for use as reinforcement.

fiber count — the number of fibers in a unit volume of fiber reinforced concrete.

fiber, equivalent diameter — diameter of a circle having an area equal to the average cross-sectional area of a fiber.

fiber, extreme compression — farthest fiber from the neutral axis on the compression side of a member subjected to bending.

fiber, extreme tension — farthest fiber from the neutral axis on the tension side of a member subjected to bending.

fiber-reinforced polymer (FRP) — a general term for a composite material comprising a polymer matrix reinforced with fibers in the form of fabric, mat, strands, or any other fiber.

field bending — bending of reinforcing bars on the job rather than in a fabricating shop.

filler — ((1) a finely divided, relatively inert material, such as pulverized limestone, silica, or colloidal substances, added to portland cement, paint, resin, or other materials to reduce shrinkage, improve workability, reduce cost, or reduce density; or (2) material used to fill an opening in a form).

filler, joint — compressible material used to fill a joint to prevent the infiltration of debris and provide support for sealants applied to the exposed surface.

filter (filter zone) — One or more layers of granular material graded (either naturally or by selection) so as to allow seepage through or within the layers while preventing the migration of material from adjacent zones.

fin — a narrow linear projection on a formed concrete surface, resulting from mortar flowing into spaces in the formwork; also a type of blade in a concrete mixer drum.

finish — the texture of a surface after consolidating and finishing operations have been performed.

finish, broom — the surface texture obtained by stroking a broom over freshly placed concrete.

finish, bush-hammer — the finish on concrete surface obtained by means of a bush-hammer.

finish, exposed-aggregate — a decorative finish for concrete work achieved by removing, generally before the concrete has fully hardened, the outer skin of mortar and exposing the coarse aggregate.

finish, float — a rather rough, granular concrete surface texture obtained by finishing with a float.

finish, granolithic — a surface layer of granolithic concrete which may be laid on a base of either fresh or hardened concrete.

finish, gun — undisturbed final layer of shotcrete as applied from nozzle, without hand finishing.

finish, rubbed — a finish obtained by using an abrasive to remove surface irregularities from concrete.

finish, rustic or washed — a type of terrazzo topping in which the matrix is recessed by washing before setting so as to expose the chips without destroying the bond between chip and matrix; a retarder is sometimes applied to the surface to facilitate this operation. **finish, swirl** — a nonskid texture imparted to a concrete surface during final troweling by keeping the trowel flat and using a rotary motion.

finish, trowel — the smooth or textured finish of an unformed concrete surface obtained by troweling.

finishing — leveling, smoothing, consolidating, and otherwise treating surfaces of fresh or recently placed concrete or mortar to produce desired appearance and service.

finishing to obtain the desired architectural appearance.

fishtail — a wedge-shaped piece of wood used as part of the support form between tapered pans in concrete joist construction.

flange, compression — the widened portion of an I, T, or similar cross-section beam that is shortened or compressed by bending under normal loads, such as the horizontal portion of the cross section of a simple span T-beam.

flashboards — Structural members of timber, concrete, or steel placed in channels or on the crest of a spillway to raise the reservoir water level but that may be quickly removed in the event of a flood.

flashing — a thin impermeable sheet, narrow in comparison with its length, installed as a cover to exclude water from exposed joints, at roof valleys, hips, roof parapets, or intersections of roof and chimney.

flat piece (of aggregate) — one in which the ratio of the width to thickness of its circumscribing rectangular prism is greater than a specified value.

flatwork, concrete — a general term applicable to concrete floors and slabs that require finishing operations.

flip bucket — An energy dissipator located at the downstream end of a spillway and shaped so that water flowing at a high velocity is deflected upwards in a trajectory away from the foundation of the spillway.

float — (1) a circular shallow-pan attachment, often of 1.2 m diameter with a 19 mm high rim, for powered finishing equipment, typically used to impart a relatively smooth final finish to floors; (2) a shallow horizontal tray suspended behind paving equipment, dragged across the freshly placed concrete surface to improve closure, or smoothness, or both.

float, angle — a finishing tool having a surface bent to form a right angle; used to finish reentrant angles.

float, bull — a tool comprising a large, flat, rectangular piece of wood, aluminum, or magnesium usually 200 mm wide and 1 to 1.50 m long, and a handle 1 to 5 m in length used to smooth unformed surfaces of freshly placed concrete.

float, devils — a wooden float with two nails protruding from the toe, used to roughen the surface of a brown plaster coat.

float, rotary — a motor-driven revolving disc that smooths, flattens, and compacts the surface of concrete floors and floor toppings.

floating — the operation of finishing a fresh concrete or mortar surface by use of a float, preceding troweling when that is to be the final finish.

flood — A temporary rise in water levels resulting in inundation of areas not normally covered by water. May be expressed in terms of probability of exceedance per year such as one percent chance flood or expressed as a fraction of the probable maximum flood or other reference flood.

flood spill depth The depth of water flow over the spillway for the design flood event. This can be assessed by routing flows through the storage utilizing any Extreme Flood Storage and Contingency Storage Allowance.

f**lood surcharge**: The storage volume between the top of the active storage and the design water level.

floodplain — An area adjoining a body of water or natural stream that has been or may be covered by floodwater.

flow —((1) time-dependent irrecoverable deformation (see also **creep** and **rheology**); (2) a measure of the consistency of freshly mixed concrete, mortar, or cement paste expressed in terms of the increase in diameter of a molded truncated cone specimen after jigging a specified number of times; or (3) movement of uncured resin under gravity loads or differential pressure).

flow line — detectable line on a concrete wall or column usually departing somewhat from horizontal, that shows where the concrete in one placement has flowed horizontally before succeeding placement has been made.

flow, capillary — flow of moisture through a capillary pore system, such as in concrete.

flow, plastic — increase in the concrete strain of members subject to constant stress, and decrease in concrete stress of members subject to constant strain.

fluidifier — an admixture employed in grout to decrease the flow factor without changing water content.

fluosilicate — magnesium or zinc silico-fluoride used to prepare aqueous solutions sometimes applied to concrete as surface hardening agents.

fly ash — the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system.

foam, preformed — foam produced in a foam generator prior to introduction of the foam into a mixer with other ingredients to produce cellular concrete.

footing — a structural element of a foundation that transmits loads directly to the soil.

footing, combined — a structural unit or assembly of units supporting more than one column.

footing, continuous —a combined footing of prismatic or truncated shape, supporting two or more columns in a row.

footing, sloped — a footing having sloping top or side faces.

footing, stepped — a step-like support consisting of prisms of concrete of progressively diminishing lateral dimensions superimposed on each other to distribute the load of a column or wall to the subgrade.

force, jacking — in prestressed concrete, the temporary force exerted by the device which introduces tension into the tendons.

form — a temporary structure or mold for the support of concrete while it is setting and gaining sufficient strength to be self supporting.

form lining — materials used to line the concreting face of formwork either to impart a smooth or patterned finish to the concrete surface, to absorb moisture from the concrete, or to apply a set-retarding chemical to the formed surface.

form scabbing — inadvertent removal of the surface of concrete because of adhesion to the form.

form sealer — coating applied to the surface of a form to reduce or prevent absorption of water from the concrete.

form, climbing — a form which is raised vertically for succeeding lifts of concrete in a given structure.

form, drop-panel — a retainer or mold so erected as to give the necessary shape, support, and finish to a drop panel.

form, edge — formwork used to limit the horizontal spread of fresh concrete on flat surfaces such as pavements or floors.

form, permanent — any form that remains in place after the concrete has developed its design strength; it may or may not become an integral part of the structure.

form, top — form required on the upper or outer surface of a sloping slab or thin shell.

form, trench — the vertical sides and semicircular bottom of a trench excavated through compacted soil to provide the exterior form and base for a cast-in-place concrete pipe.

form, vented — a form so constructed as to retain the solid constituents of concrete and permit the escape of water and air.

form, wall — a retainer or mold so erected as to give the necessary shape, support, and finish to a concrete wall.

forms, flying — large prefabricated units of formwork incorporating support, and designed to be moved from place to place.

forms, ganged — prefabricated panels joined to make a much larger unit 9 by 15 m for convenience in erecting, stripping, and reusing; usually braced with wales, strongbacks, or special lifting hardware.

forms, moving — large prefabricated units of formwork incorporating supports, and designed to be moved horizontally on rollers or similar devices, with a minimum amount of dismantling between successive uses.

formwork — total system of support for freshly placed concrete including the mold or sheathing that contacts the concrete as well as supporting members, hardware, and necessary bracing; sometimes called shuttering in the United Kingdom.

foundation — the structural elements through which the load of a structure is transmitted to the earth. **foundation, grid** — a combined footing formed by intersecting continuous footings, loaded at the intersection foundation points, and covering much of the total area within the outer limits of the assembly. **foundation, mat** — a continuous footing supporting an array of columns in several rows in each direction, having a slab-like shape with or without depressions or openings, covering an area at least 75% of the total area within the outer limits of the assembly.

foundation, strip — a continuous foundation wherein the length considerably exceeds the breadth.

fracture — a crack or break, as of concrete or masonry; the configuration of a broken surface; also the action of cracking or breaking.

frame, rigid — a frame depending on moment in joints for stability.

free fall — descent of freshly mixed concrete into forms without drop chutes or other means of confinement; also the distance through which such descent occurs; also uncontrolled fall of aggregate.

Freeboard – Freeboard is a vertical distance between a water level within a dam and a critical design level. For tailings dams there are various freeboards provided for different purposes as follows:

freeboard — The vertical distance between the dam crest elevation and some reservoir level of interest.

fresno trowel — a thin steel trowel that is rectangular or rectangular with rounded corners, usually 100 to 250 mm wide and 420 to 900 mm long, having 1 to 5 m long handle, and used to smooth surfaces of nonbleeding concrete and shotcrete.

friction, wobble — in prestressed concrete, the friction caused by the unintended deviation of the prestressing sheath or duct from its specified profile.

frog — a depression in the bed surface of a masonry unit; sometimes called a panel.

from various sources, such as wind and machine vibration; known also as a hold-down bolt or a foundation bolt.

fugitive dye — a dye whose color fades in a few days to neutral on exposure, usually to ultraviolet rays in sunlight; used to temporarily color membrane-curing compounds so that

Fuller's curve — an empirical curve for gradation of aggregates; also known as the Fuller-Thompson ideal gradation curve; the curve is designed by fitting either a parabola or an ellipse to a tangent at the point where the aggregate fraction is one-tenth of the maximum size fraction.

furring — strips of wood or metal fastened to a wall or other surface to even it, to form an air space, to give appearance of greater thickness, or for the application of an interior finish such as plaster.

fuse plug spillway — A form of auxiliary spillway consisting of a low embankment designed to be overtopped and washed away during an exceptionally large flood.

G

ganister — a highly refractory siliceous sedimentary rock used for furnace linings.

gate — A movable, watertight barrier for the control of water in a waterway. (a. **Bascule gate**: See flap gate. **bulkhead gate**: A gate used either for temporary closure of a channel or conduit before dewatering it for inspection or maintenance or for closure against flowing water when the head difference is small, e.g., for diversion tunnel closure. c**rest gate (spillway gate)**: A gate on the crest of a spillway to control the discharge or reservoir water level. d. **drum gate**: A type of spillway gate consisting of a long hollow drum. The drum may be held in its raised position by the water pressure in a flotation chamber beneath the drum. e**mergency gate**: A standby or auxiliary gate used when the normal means of water control is not available. Sometimes referred to as guard gate. f**ixed wheel gate (fixed roller gate) (fixed axle gate)**: A gate having wheels or rollers mounted on the end posts of the gate. The wheels bear against rails fixed in side grooves or gate guides. f**lap gate**: A gate hinged along one edge, usually either the top or bottom edge. Examples of bottom-hinged flap gates are tilting gates and fish belly gates so called from their shape in cross section. f**lood gate**: A gate to control flood release from a reservoir. o**utlet gate**: A gate controlling the flow of water through a reservoir outlet. r**adial gate (Tainter gate)**: A gate with a curved upstream plate and radial arms hinged to piers or other supporting structure. r**egulating gate (regulating valve)**: A gate or valve that operates under full pressure flow conditions to regulate the rate of discharge. r**oller drum gate**: See drum gate. r**oller gate (stoney gate)**: A gate for large openings that bears on a train of rollers in each gate guide. s**kimmer gate**: A gate at the spillway crest whose prime purpose is to control the release of debris and logs with a limited amount of water. It is usually a bottom hinged flap or Basculegate. s**lide gate (sluice gate)**: A gate that can be opened or closed by sliding in supporting guides).

gate chamber (valve chamber) — A room from which a gate or valve can be operated, or sometimes in which the gate is located.

gehlenite — a mineral of the melilite group, $Ca_2Al(AlSi)O_7$.

gel — matter in a colloidal state that does not dissolve, but remains suspended in a solvent from which it fails to precipitate without the intervention of heat or of an electrolyte.

gel, cement — the colloidal material that makes up the major portion of the porous mass of which mature hydrated cement paste is composed.

gel, tobermorite — the binder of concrete cured moist or in

geotextiles — Any fabric or textile when used as an engineering material in conjunction with soil, foundations or rock. Geotextiles have the following uses: drainage, filtration, separation of materials, reinforcement, moisture barriers, and erosion protection.

girder — a large beam, usually horizontal, that serves as a main structural member.

girt — small beam spanning between columns, generally used in industrial buildings to support outside walls.

glass — an inorganic product of fusion that has cooled too a rigid condition without crystallizing, sometimes reactive with alkalies in concrete.

glass-fiber reinforced cement — a composite material consisting essentially of a matrix of hydraulic cement paste or mortar reinforced with glass fibers; typically precast into units less than 25 mm thick.

go-devil — a ball of rolled-up burlap or paper or a specially fabricated device put into the pump end of a pipeline and forced through the pipe by water pressure in order to clean the pipeline; also a device used with tremie concrete operations.

grade — the prepared surface on which a concrete slab is cast; the process of preparing a plane surface of granular material or soil on which to cast a concrete slab.

gradient — rate of change in a variable over a distance, as of temperature or moisture.

grading — the distribution of particles of granular material among various sizes; usually expressed in terms of cumulative percentages larger or smaller than each of a series of sizes (sieve openings) or the percentages between certain ranges of sizes (sieve openings).

grading, combined-aggregate — particle-size distribution of a mixture of fine and coarse aggregate.

grading, continuous — a particle size distribution in which intermediate size fractions are present, as opposed to gap grading.

granular material according to size.

gravel — [(1) granular material predominantly retained on the 4.75 mm (No. 4) sieve and resulting either from natural disintegration and abrasion of rock or processing of weakly bound conglomerate; and (2) that portion of an aggregate retained on the 4.75 mm (No. 4) sieve and resulting either from natural disintegration and abrasion of rock or processing of weakly bound conglomerate].

gravel, crushed — the product resulting from the artificial crushing of gravel with a specified minimum percentage of fragments having one or more faces resulting from fracture.

gravel, pea — screened gravel, most of the particles of which pass a 9.5 mm (3/8 in.) sieve and are retained on a 4.75 mm (No. 4) sieve.

grinding, finish — the final grinding of clinker into cement, with calcium sulfate in the form of gypsum or anhydrite generally being added; the final grinding operation required for a finished concrete surface, for example, bump cutting of pavement, fin removal from structural concrete, terrazzo floor grinding.

grizzly — a simple, stationary screen or series of equally spaced parallel bars set at an angle to remove oversize particles in processing aggregate or other material.

grog — burned refractory material; usually calcined clay or crushed brick bats.

groin — the area along the contact (or intersection) of the face of a dam with the abutments.

groover — a tool used to form grooves or weakened-plane joints in a concrete slab before hardening to control crack location or provide pattern.

gross volume (of concrete mixers) — in the case of a revolving drum mixer, the total interior volume of the revolving portion of the mixer drum; in the case of an open-top mixer, the total volume of the trough or pan calculated on the basis that no vertical dimension of the container exceeds twice the radius of the circular section below the axis of the central shaft.

grout — A fluidized material that is injected into soil, rock, concrete, or other construction material to seal openings and to lower the permeability and/or provide additional structural strength. There are four major types of grouting materials: chemical; cement; clay; and bitumen.

grout — a mixture of cementitious material and water, with or without aggregate, proportioned to produce a pourable consistency without segregation of the constituents; also a mixture of other composition but of similar consistency.

grout curtain — One or more zones, usually thin, in the foundation into which grout is injected to reduce seepage under or around a dam.

grout slope — the natural slope of fluid grout injected into preplaced-aggregate concrete.

grout, colloidal — grout in which a substantial proportion of the solid particles have the size range of a colloid.

grout, epoxy — a grout which is a mixture of ingredients consisting of an epoxy bonding system, aggregate or fillers, and possibly other materials.

grout, field-proportioned — a hydraulic-cement grout batched at the jobsite using water and predetermined portions of portland cement, aggregate, and other ingredients.

grout, hydraulic-cement — a grout which is a mixture of hydraulic cement, aggregate, water and possibly admixtures.

grout, machine-base — a grout which is used in the space between plates or machinery and the underlying foundation and which is expected to maintain essentially complete contact with the base and to maintain uniform support.

grout, masonry — a mixture hydraulic cement, aggregate, water and possibly other materials (ASTM C476), used for filling designated spaces in masonry construction.

grout, neat cement — a fluid mixture of hydraulic cement and water, with or without other ingredients; also the hardened equivalent of such mixture.

grout, preblended — a hydraulic-cement grout which is a commercially available mixture of hydraulic cement, aggregate, and other ingredients which requires only the addition of water and mixing at the jobsite; sometime termed premixed grout.

grout, sanded — grout in which fine aggregate is incorporated into the mixture.

grouting — the process of filling with grout.

grouting, advancing-slope — a method of grouting by which the front of a mass of grout is caused to move horizontally through preplaced aggregate by use of a suitable grout injection sequence.

grouting, closed-circuit — injection of grout into a hole intersecting fissures or voids which are to be filled at such volume and pressure that grout input to the hole is greater than the grout take of the surrounding formation, excess grout being returned to the pumping plant for recirculation.

grouting, contraction-joint — injection of grout into contraction joints.

grouting, curtain — injection of grout into a subsurface formation in such a way as to create a zone of grouted material transverse to the direction of anticipated water flow.

grouting, high-lift — a technique in masonry wall construction in which the grouting operation is delayed until the wall has been laid up to a full story height.

grouting, low-lift — a technique of masonry wall construction in which the wall sections are built to a height of not more than 5 ft (1.7 m) before the cells of the masonry units are filled with grout.

grouting, open-circuit — a grouting system with no provision for recirculation of grout to the pump.

grouting, perimeter — injection of grout, usually at relatively low pressure, around the periphery of an area that is subsequently to be grouted at greater pressure; intended to confine subsequent grout injection within the perimeter.

grouting, slush — distribution of a grout, with or without fine aggregate, as required over a rock or concrete surface that is subsequently to be covered with concrete, usually by brooming it into place to fill surface voids and fissures.

grouting, staged — sequential grouting of a hole in separate steps or stages in lieu of grouting the entire length at once.

gun — 1. shotcrete material delivery equipment, usually consisting of double chambers under pressure; equipment with a single pressure chamber is used to some extent; or 2. pressure cylinder used to propel freshly mixed concrete pneumatically. **gun, cement —** a machine for pneumatic placement of mortar or small aggregate concrete; in the "Dry Gun," water from a separate hose meets the dry material at the nozzle of the gun; with the "Wet Gun," the delivery hose conveys the premixed mortar or concrete.

Gunite — a proprietary term for shotcrete.

gunman — workman on shotcreting crew who operates delivery equipment.

gunning — the act of applying dry-mix shotcrete.

gunning pattern —((1) conical outline of material discharge stream in shotcrete operation; or (2) the sequence of gunning operations to ensure complete filling of the space, total encasement of reinforcing bars, easy removal of rebound, and thickness of shotcrete layers).

gypsum — a mineral having the composition calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$).

gypsum plaster — plaster made with plaster of paris.

H

hacking — the roughening of a surface by striking with a tool.

hairpin — the wedge used to tighten some types of form ties; a hairpin-shaped anchor set in place while concrete is unhardened; a light hairpin-shaped reinforcing bar used for shear reinforcement in beams, tie reinforcement in columns, or prefabricated column shear heads.

Hamm tip — flared shotcrete nozzle having a larger diameter at midpoint than at either inlet or outlet; also designated premixing tip.

hammer, rebound — an apparatus that provides a relative indication of the strength or hardness of concrete based on the rebound distance of a spring-driven mass after it impacts a rod in contact with the concrete surface.

hanger — a device used to suspend one object from another object.

hanger, form — device used to support formwork from a structural framework; the dead load of forms, mass of concrete, and construction and impact loads must be supported. [(1) a chemical (including certain fluor silicates or sodium silicate) applied to concrete floors to reduce wear and dusting; or (2) in a two-component adhesive or coating, the chemical component that causes the resin component to cure].

haunch — a deepened portion of a beam in the vicinity of a support.

haunching — [(1) concrete support to the sides of a drain or sewer pipe above the bedding; or (2) work done in strengthening or improving the outer strip of a roadway].

hawk — a tool used by plasterers to hold and carry plaster mortar; generally a flat piece of wood or metal 0.25 to 0.3 m square, with a wooden handle centered and fixed to the underside.

header — a masonry unit laid flat with its greatest dimension at a right angle to the face of the wall; when the unit is only the depth of the face withe it is known as a false header. [See also

healing, autogenous— a natural process of filling and sealing cracks in concrete or in mortar when kept damp.

heat of hydration — heat evolved by chemical reactions with water, such as that evolved during the setting and hardening of portland cement, or the difference between the heat of solution of dry cement and that of partially hydrated cement.

heat of solution — heat evolved or absorbed when a substance is dissolved in a solvent.

heating rate — the rate expressed in degrees per hour at which the temperature is raised to the desired maximum temperature.

hematite — a mineral, iron oxide (Fe_2O_3) used as aggregate in high density concrete and in finely divided form as a red pigment in colored concrete.

hemihydrate — a hydrate containing one-half molecule of water to one molecule of compound, the most commonly known hemihydrate is partially dehydrated gypsum (also known as plaster of paris), $CaSO_4 \cdot 1/2H_2O$.

hinge, Mesnager — a permanent semi articulation or flexible joint in a reinforced-concrete arch, wherein the angles of rotation at the hinge are very small; by crossing steel reinforcing bars within the opening between the concrete structural segments, the resultant articulation presents very small resistance to rotation, resists either axial thrust or shearing forces, and is permanently flexible; the center of rotation occurs at the intersection of the reinforcing bars.

hinge, plastic — region where ultimate moment capacity in a member may be developed and maintained with corresponding significant inelastic rotation as main tensile steel elongates beyond yield strain.

hod — a V-shaped trough or a tray, supported by a pole handle that is borne on the carrier's shoulder, for carrying small quantities of brick, tile, mortar, or similar load.

honeycomb — voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse-aggregate particles.

hook — a bend in the end of a reinforcing bar.

hose, delivery — hose through which shotcrete, grout, or pumped concrete or mortar passes; also known as conveying hose or material hose.

hot face — the surface of a refractory section exposed to the source of heat.

Hoyer effect — in pretensioned, prestressed concrete, frictional forces that result from the tendency of the tendons to regain the diameter which they had before they were stressed.

hydrate — a chemical combination of water with another compound or an element.

hydrate, calcium-silicate — any of the various reaction products of calcium silicate and water.

hydration — formation of a compound by combining water with some other substance. In cementitious materials, the chemical reaction between hydraulic cement and water.

hydraulic height — The vertical difference between the maximum design water level and the lowest point in the original streambed.

hydrochloric acid — a mineral acid sometimes used for cleaning or acid etching concrete or removing efflorescence; also known as muriatic acid, which is a 33% HCl solution.

hydrograph — A graphical representation of discharge, stage, or other hydraulic property with respect to time for a particular location on a watercourse.

hydrograph, breach or dam failure — A flood hydrograph resulting from a dam breach.

hydrograph, unit — A hydrograph with a volume of one inch of runoff resulting from a storm of a specified duration and areal distribution. Hydrographs from other storms of the same duration and distribution are assumed to have the same time base but with ordinates of flow in proportion to the runoff volumes.

hydromix nozzle — a shotcrete hose and nozzle configuration used in place of a pre dampening system to introduce pressurized water into the material stream via a water ring located approximately 3 m upstream of the nozzle tip. The nozzle man can control the amount of water introduced to the material stream via a control valve near the nozzle tip.

Hypocenter — the point or focus within the earth which is the center of an earthquake and the origin of its elastic waves.

I

ilmenite — a mineral, iron titanate ($FeTiO_3$), which in pure or impure form is commonly used as aggregate in high-density concrete.

impending slough — consistency of a shotcrete mixture containing the maximum amount of water such that the product will not flow or sag after placement.

impounding barrier — the structural element of the dam that has the primary purpose of impounding or diverting water. It may be constructed of natural and/or man-made materials.

inactive storage — the storage volume of a reservoir between the crest of the invert of the lowest outlet and the minimum operating level.

incident — the occurrence of any dam-related event where problems or conditions arise which may have posed a threat to the safety or integrity of the project or which may have posed a threat of loss of life or which resulted in loss of life.

increase its workability and resistance to freezing and thawing.

incrustation — a crust or coating, generally hard, formed on the surface of concrete or masonry construction or on aggregate particles.

index, plasticity (PI) — the range of water content in which a soil remains plastic, evaluated as the numerical difference between liquid limit and plastic limit, as calculated according to ASTM D4318. (Also referred to as plasticity.)

index, pozzolanic-activity — an index that measures pozzolanic activity based on the strength of cementitious mixtures containing hydraulic cement with and without the pozzolan; or containing the pozzolan with lime.

index, slag activity — the ratio of the compressive strength of a mortar cube made with equal amounts of slag and portland cement to the compressive strength of a mortar cube made with the same portland cement.

inflow design flood (IDF) — The reservoir inflow flood hydrograph used for sizing the spillways and for determining freeboard. It represents the largest flood that a given project is designed to safely accommodate.

insert — anything other than reinforcing steel that is rigidly positioned within a concrete form for permanent embedment in the hardened concrete.

insoluble residue — the portion of a cement or aggregate that is not soluble in dilute hydrochloric acid of stated concentration.

instrumentation — An arrangement of devices installed into or near dams (i.e., piezometers, inclinometer, strain gages, measurement points, etc.) which provide for measurements that can be used to evaluate the structural behavior and performance parameters of the structure.

insulation, form — insulating material applied to outside of forms between studs and over the top in sufficient thickness and air tightness to conserve heat of hydration to maintain concrete at required temperatures in cold weather.

insulation, roof — low-density concrete used for insulating purposes only and placed over a structural roof system.

intake — Any structure in a reservoir, dam or river through which water can be discharged.

inundation map — A map delineating the area that would be flooded by a particular flood event.

inverted L-beam — a beam having a cross section in the shape of an inverted L.

inverted T-beam — a beam having a cross section in the shape of an inverted T.

I-section — beam cross section consisting of top and bottom flanges connected by a vertical web.

J

jack — a mechanical device used for applying force to pre stressing tendons, for adjusting elevation of forms or form supports, and for raising objects small distances.

jack shore — telescoping, or otherwise adjustable, single-post metal shore.

jack, flat — a hydraulic jack consisting of light gage metal thatis folded and welded to a flat shape that expands under internal pressure.

jacking device — the device used to stress the tendons for prestressed concrete; also the device for raising a vertical slipform.

jaw crusher — a machine having two inclined jaws, one or both being actuated by a reciprocating motion so that the charge is repeatedly nipped between the jaws.

jet, air-water — a high-velocity jet of air and water mixed at the nozzle, used in clean-up of surfaces of rock or concrete, such as horizontal construction joints.

jitterbug — a grate tamper for pushing coarse aggregate slightly below the surface of a slab to facilitate finishing.

joint — [(1) a physical separation in a concrete system, whether precast or cast-in-place, including cracks if intentionally made to occur at specified locations; or (2) the region where structural members intersect].

joint, butt — a plain square joint between two members.

joint, cold — a joint or discontinuity resulting from a delay in placement of sufficient duration to preclude intermingling and bonding of the material, or where mortar or plaster rejoin or meet.

joint, construction — the surface where two successive placements of concrete meet, across which it may be desirable to achieve bond and through which reinforcement may be continuous.

joint, contraction — formed, sawed, or tooled groove in a concrete structure to create a weakened plane to regulate the location of cracking resulting from the dimensional change of different parts of the structure.

joint, cross — the joint at the end of individual form boards between sub purlins.

joint, expansion — [(1) a separation provided between adjoining parts of a structure to allow movement where expansion is likely to exceed contraction; or (2) a separation between pavement slabs on grade, filled with a compressible filler material; or (3) an isolation joint intended to allow independent movement between adjoining parts].

joint, hinge — any joint which permits rotation with no appreciable moment developed in the members at the joint.

joint, isolation — a separation between adjoining parts of a structure that allows relative movement in three directions. Isolation joints are usually vertical planes located to avoid formation of cracks in the structure.

joint, lift — surface at which two successive lifts meet.

joint, longitudinal — a joint parallel to the length of a structure or pavement.

joint, raked — a masonry-wall joint that was the mortar raked out to a specified depth while it is only slightly hardened.

joint, sawed — a joint cut in hardened concrete, generally not to the full depth of the member, by means of special equipment.

joint, semiflexible — a connection in which the reinforcement is arranged to permit some rotation of the joint.

joint, transverse — a joint normal to the longitudinal dimension of a structural element, assembly of elements, slab, or structure.

joint, warping — a joint with the sole function of permitting warping of pavement slabs when moisture and temperature differentials occur between the top and bottom of the slabs, that is, longitudinal or transverse joints with bonded steel or tie bars passing through them.

jointer (concrete) — a metal tool about 150 mm long and from 50 to 100 mm wide and having shallow, medium, or deep bits (cutting edges) ranging from 5 to 20 mm or deeper used to cut a joint partly through fresh concrete.

jointing — the process of producing joints in a concrete slab.

joist — a comparatively narrow beam, used in closely spaced arrangements to support floor or roof slabs (which require no reinforcement except that required for temperature and shrinkage stresses); also a horizontal structural member such as that which supports deck form sheathing.

jumbo — traveling support for forms, commonly used in tunnel work.

K

kaolinite — a common clay mineral having the general formula $Al_2(Si_2O_5)(OH_4)$, the primary constituent of kaolin.

Kelly ball — an apparatus used for indicating the consistency of fresh concrete, consisting of a cylindrical weight 150 mm in diameter, weighing 14 kg with a hemispherically shaped bottom, a handle consisting of a graduated rod, and a stirrup to guide the handle and serve as a reference for measuring depth of penetration.

kern area — the area within a geometric shape in which a compressive force may be applied without tensile stresses resulting in any of the extreme fibers of the section.

keyway — a recess or groove in one lift or placement of concrete that is filled with concrete of the next lift, giving shear strength to the joint.

kicker — a wood block or board attached to a formwork member in a building frame or formwork to make the structure more stable; in formwork it acts as a haunch.

kiln — a furnace or oven for drying, charring, hardening, baking, calcining, sintering, or burning various materials.

kiln, rotary — a long steel cylinder with a refractory lining, supported on rollers so that it can rotate about its own axis, and erected with a slight inclination from the horizontal so that prepared raw materials fed into the higher end move to the lower end where fuel is blown in by air blast.

L

lacing — horizontal bracing between shoring members.

lagging — heavy sheathing used as in underground work to withstand earth pressure. **laitance** — a layer of weak material derived from cementitious material and aggregate fines either: carried by bleeding to the surface or to internal cavities of freshly placed mixture; or separated from the mixture and deposited on the surface or internal cavities during placement of the mixture.

lap — the length by which one bar or sheet of fabric reinforcement overlaps another.

lapping (reinforcing steel) — the overlapping of reinforcing steel bars, welded-wire fabric, or expanded metal so that there may be continuity of stress in the reinforcing when the concrete member is subjected to loading.

larnite — a mineral; beta dicalcium silicate (Ca_2SiO_4); occurs naturally at Scawt Hill, Northern Ireland, and artificially in slags and as a major constituent of portland cement.

latex — a dispersion of organic polymer particles in water.

lath, diamond mesh or expanded-metal — a metal network, often used as reinforcement in construction, formed by suitably stamping or cutting sheet metal and stretching it to form open meshes, either of diamond-shaped or rhomboidal-shaped openings.

law, Abrams' — a rule stating that, with given concrete materials and conditions of test, the ratio of the amount of water to the amount of the cement in the mixture determines the strength of the concrete provided the mixture is of a workable consistency.

law, Hooke's — the law, which holds practically for strains within the elastic limit, that the strain is proportional to the stress producing it.

layer, bonding — a layer of mortar, usually 3 to 13 mm thick, which is spread on a moist and prepared, hardened concrete surface before placing fresh concrete.

L-beam — a beam having a cross section in the shape of an L; a beam having a ledge on one side only.

L-column — the portion of a precast-concrete frame, comprising the column, the haunch, and part of the girder.

ledger — any member with a protrusion or protrusions that support other structural members.

length — length, development — the embedment length required to develop the design strength of a reinforcement at a critical section; formerly called bond length. **length, embedment —** the length of embedded reinforcement provided beyond a critical section. **length, transfer —** the length from the end of the member where the tendon stress is zero, to the point along the tendon where the prestress is fully effective; also called transmission length. **length change —** increase or decrease in length. **length change, autogenous —** length change caused by autogenous volume change.

lever arm — in a structural member, the distance from the center of the tensile reinforcement to the center of action of the compression zone; also the perpendicular distance of a transverse force from a point about which moment is taken.

L-head — the top of a shore formed with a braced horizontal member projecting from one side, producing an inverted L shaped assembly.

licensed design professional — an engineer or architect who is licensed to practice structural design as defined by the statutory requirements of the professional licensing laws of a state or jurisdiction; or the architect or engineer, licensed as described, who is responsible for the structural design of a particular project (also historically referred to as the "engineer of record").

lift — the concrete placed between two consecutive horizontal construction joints, usually consisting of several layers or courses.

lift slab — a method of concrete construction in which floor and roof slabs are cast on or at ground level and hoisted into position by jacking; also a slab that is a component of such

lifts (or tiers) — the number of frames of scaffolding erected one above the other.

lime — specifically, calcium oxide (CaO); loosely, a general term for the various chemical and physical forms of quicklime, hydrated lime, and hydraulic hydrated lime.

lime, free — calcium oxide (CaO), as in clinker and cement, which has not combined with SiO_2, Al_2O_3, or Fe_2O_3 during the burning process usually because of underburning, insufficient grinding of the raw mixture, or the presence of traces of inhibitors.

lime, hard-burned — the product of heating limestone to temperatures sufficient to change the calcium carbonate to calcium oxide, which can undergo expansion when it slowly reacts with water.

lime, hydrated — calcium hydroxide, a dry powder obtained by treating quicklime with water.

lime, hydraulic hydrated — the hydrated dry cementitious product obtained by calcining a limestone containing silica and alumina to a temperature short of incipient fusion so as

lime, spray — a hydrated lime of such fineness that at least 95% of the particles pass a 45 µm (No. 325) sieve.

limestone — a sedimentary rock consisting primarily of calcium carbonate.

limit — limit, elastic — the limit of stress beyond which the strain is not wholly recoverable. **limit, liquid —** water content, expressed as a percentage of the dry weight of the soil at which the soil passes from the plastic to the liquid state under standard test conditions. **limit, plastic —** the water content at which a soil will just begin to crumble when rolled into a thread approximately 3 mm in diameter. **limit, proportional —** the greatest stress that a material is capable of developing without any deviation from proportionality of stress to strain. **limit, shrinkage** — the maximum water content at which a reduction in water content will not cause a decrease in volume of the soil mass. **limit, vibration —** the age at which fresh concrete has hardened sufficiently to prevent its becoming mobile when subjected to vibration.

limonite — an iron ore composed of a mixture of hydrated ferric oxides; occasionally used in heavyweight concrete because of its high density and combined-water content, which contribute to its effectiveness in radiation shielding; a mineral occurring commonly as a constituent of particles of natural aggregate.

linear prestressing — prestressing applied to linear members, such as beams and columns.

linear transformation — the method of altering the path of the prestressing tendon in any statically indeterminate prestressed structure by changing the location of the tendon at one or more interior supports without altering its position at the end supports and without changing the basic shape of the path between any supports; linear transformation does not change the location of the path of the pressure line.

linear-traverse method — determination of the volumetric composition of a solid by integrating the distance traversed across areas of each component along a line or along regularly spaced lines in one or more planes intersecting a sample of the solid; frequently employed to determine characteristics of the air-void system in hardened concrete by microscopical examination along a series of traverse lines on finely ground sections of the concrete; sometimes called the Rosiwal method.

lining — any sheet, plate, or layer of material attached directly to the inside face of formwork to improve or alter the surface texture and quality of the finished concrete.

lintel — a horizontal supporting member above an opening, such as a window or a door.

liquefaction — A condition whereby soil undergoes continued deformation at a constant low residual stress or with low residual resistance, due to the buildup and maintenance of high pore water pressures, which reduces the effective confining pressure to a very low value. Pore pressure buildup leading to liquefaction may be due either to static or cyclic stress applications and the possibility of its occurrence will depend on the void ratio or relative density of a cohesionless soil and the confining pressure.

liquid-volume measurement — measurement of grout on the basis of the total volume of solid and liquid constituents.

lithology — the study of rocks.

live storage: The sum of the active and the inactive storage.

load balancing — a technique used in the design of prestressed concrete members in which the amount and path of the prestressing is selected so that the forces imposed upon the member or structure by the prestressing counteract or balance a portion of the dead and live loads for which the member or structure must be designed.

load factor — a factor by which a service load is multiplied to determine a factored load used in the strength-design method.

load test, structural — procedure consisting of applying loads to verify the strength of a structure or structural member.

load, axle — the portion of the gross weight of a vehicle transmitted to a structure or a roadway through wheels supporting a given axle.

load, balanced — load capacity at simultaneous compressive failure of concrete and yielding of tension steel.

load, cracking — the load that causes tensile stress in a member to exceed the tensile strength of the concrete.

load, dead — [(1) the weights of the structural members, supported structure, and permanent attachments or accessories that are likely to be present on a structure in service; or (2) loads meeting specific criteria found in the governing building code (without load factors)].

load, design — obsolete term for factored load.

load, dynamic — a load that is variable, that is, not static, such as a moving live load, earthquake, or wind.

load, factored — load, multiplied by appropriate load factors, used to proportion members by the strength-design method.

load, live — [(1) load that is not permanently applied to a structure but is likely to occur during the service life of the structure (excluding environmental loads); or (2) loads meeting specific criteria found in the governing building code (without load factors)].

load, point — a load whose area of contact with the resisting body is negligible in comparison with the area of the resting body.

load, safe leg — the load that can safely be directly imposed on the frame leg of a scaffold.

load, service — all loads, static or transitory, imposed on a structure, or element thereof, during operation of a facility.

load, service dead — un factored loads, permanent or transient, imposed on a structure during operation.

load, service live — the live load specified by the general building code or other bridge specification, or the actual nonpermanent load applied in service.

load, shock — impact of material, such as aggregate or concrete, as it is released or dumped during placement.

load, snow — the force considered in the design of a flat or pitched surface, usually a roof, for the possible amount of snow, ice, or both, lying on it.

load, static — the mass of a single stationary body or the combined masses of stationary bodies in a structure (such as the load of a stationary vehicle on a roadway); or, during construction, the combined mass of forms, stringers, joists, reinforcing bars, and the actual concrete to be placed.

load, superimposed — the load, other than its own weight, that is resisted by a structural member or system.

load, ultimate — the maximum load that may be placed on a structure or structural element before its failure.

load, wheel — the portion of the gross mass of a loaded vehicle transferred to the supporting structure under a given wheel of the vehicle.

load, wind — pressure of suction due to wind on part or all of a surface of a structure.

load, working — forces normally imposed on a member in service (obsolete term).

loading hopper — a hopper in which concrete or other freeflowing material is deposited for discharge into buggies or other conveyances used for delivery to the forms or to other place of processing, use, or storage.

loading, bulk — loading of unbagged cement in containers, specially designed trucks, railroad cars, or ships.

loading, dynamic — loading from units (particularly machinery) that, by virtue of their movement or vibration, impose stresses in excess of those imposed by their dead load.

loading, ribbon — method of batching concrete in which the solid ingredients, and sometimes also the water, enter the mixer simultaneously.

load-transfer assembly — the unit (basket or plate) designed to support or link dowel bars during concreting operations so as to hold them in place while in the desired alignment.

locking device — a device used to secure a cross brace in scaffolding to the frame or panel.

logboom — A chain of logs, drums, or pontoons secured end to end and floating on the surface of a reservoir so as to divert floating debris, trash, and logs.

loss of prestress — the reduction in the prestressing force which results from the combined effects of slip at anchorage, relaxation of steel stress, frictional loss due to curvature in the tendons, and the effects of elastic shortening, creep, and shrinkage of the concrete.

loss on ignition — the percentage loss in mass of a sample ignited to constant weight at a specified temperature, usually 900 to 1000°C.

loss, elastic — in prestressed concrete, the reduction in prestressing load resulting from the elastic shortening of the member.

loss, friction — the stress loss in a prestressing tendon resulting from friction between the tendon and duct or other device during stressing.

loss, shrinkage — reduction of stress in prestressing steel resulting from shrinkage of concrete.

loss, slump — the amount by which the slump of freshly mixed concrete changes during a period of time after an initial slump test was made on a sample or samples thereof.

L-shore — a shore with an L-head.

lubricant, dowel — a material applied to part of the surface of a dowel to reduce bond with the concrete and permit axial movement.

M

macadam, cement-bound — a road consisting of crushed stone, crushed slag, or gravel and either a grout or mortar filler; formed by rolling a base of stone, slag, or gravel to a compacted mass having an even surface, and then rolling in the cementitious filler.

machine, finishing — a power-operated machine used to produce the desired surface texture on a concrete slab.

macrofiber — a fiber with an equivalent diameter greater than or equal to 0.012 in. (0.3 mm) for use in concrete.

macroscopic — visible to the naked eye (preferred term).

magnesium silicates that swell on wetting, shrink on drying, and are subject to ion exchange.

magnetite — a mineral, ferrous ferric oxide (FeO·Fe2O3); the principal constituent of magnetic black iron ore; density about 5.2 g/cc and Mohs hardness about 6; used as an aggregate in high-density concrete.

mainly by the density of the concrete, except that in the case of neutrons the attenuation is achieved by compounds of some of the lighter elements (for example, hydrogen and boron).

marble — a metamorphic rock composed essentially of recrystallized calcite, dolomite, or both.

marl — calcareous clay, usually containing from 35 to 65% calcium carbonate ($CaCO_3$), found in the bottoms of shallow lakes, swamps, or extinct fresh-water basins.

mason — an artisan who builds with concrete masonry units, bricks, stone, and tile; name sometimes given a concrete finisher.

mason's putty — a pasty substance, composed of water and hydrated lime mixed with portland cement and stone dust; used only for jointing ashlar masonry.

masonry — construction composed of shaped or molded units, usually small enough to be handled by one person and composed of stone, ceramic brick or tile, concrete, glass, adobe, or the like.

masonry filler unit — masonry unit used to fill in between joists or beams to provide a platform for a cast-in-place concrete slab.

masonry lift — the height to which masonry is laid between periods of grouting.

masonry unit, concrete — either a hollow or solid unit (block) composed of portland-cement concrete; often referred to by indicating the type of mineral aggregate incorporated (for example, lightweight or sand-gravel block).

masonry wall, solid — a wall built of blocks or solid masonry units, the mortar completely filling the joints between units.

masonry, ashlar — masonry composed of bonded blocks of concrete, either rectangular or square, always of two or more sizes; if the pattern is repeated, it is patterned ashlar; if the pattern is not repeated, it is random ashlar.

masonry, bonded hollow-wall — a cavity wall, built of masonry units, in which the inner and outer walls are tied together by bonders.

masonry, exposed — masonry constructed to have no surface finish other than paint.

masonry, grouted — unit masonry composed of either hollow units wherein the cells are filled with grout or multiple wythes where spaces between the wythes are filled with grout.

masonry, hollow-unit — masonry consisting either entirely or partially of hollow masonry units laid in mortar.

masonry, plain — (1) masonry without reinforcement; or (2) masonry reinforced only for shrinkage or thermal change).

masonry, reinforced — unit masonry in which reinforcement is embedded in such a manner that the two materials act together in resisting forces.

masonry, solid-unit — masonry consisting wholly of solid masonry units laid in mortar.

masonry, unit — a structural element consisting of concrete masonry units usually bonded by mortar, grout, or both.

mass — the physical property of matter that causes it to have weight in a gravitational field; the quantity of matter in a body.

mat — an assembly of steel reinforcement composed of two or more layers of bars placed at angles to each other and secured together either by welding or tying.

material, supplementary cementitious (SCM) — inorganic material such as fly ash, silica fume, metakaolin, or groundgranulated blast-furnace slag that reacts pozzolanically or hydraulically.

matrix — (1) the cement paste in which the fine aggregate particles in mortar are embedded; (2) the mortar in which the coarse aggregate particles in concrete are embedded; or (3) the resin or binders that hold the fibers in fiber-reinforced polymer together, transfer load to the fibers, and protect them against environmental attack and damage due to handling).

mats, cotton — cotton-filled quilts fabricated for use as a water retaining covering in curing concrete surfaces.

maximum credible earthquake (MCE) — The largest hypothetical earthquake that may be reasonably expected to occur along a given fault or other seismic source. It is a believable event which can be supported by all known geologic and seismologic data. A hypothetical earthquake is deterministic if its fault or source area is spatially definable and can be located a particular distance from the dam under consideration. A hypothetical earthquake is probabilistic if it is considered to be a random event, and its epicentral distance is determined mathematically by relationships of recurrence and magnitude for some given area. The MCE can be associated with specific surface geologic structures and can also be associated with random or floating earthquakes (movements that occur at depths that do not cause surface displacements).

maximum design earthquake (MDE) — The earthquake selected for design or evaluation of the structure. This earthquake would generate the most critical ground motions for evaluation of the seismic performance of the structure. The dam could be expected to be damaged by this earthquake but would retain its functionality.

maximum design water level — The maximum water elevation including the flood surcharge, that a dam is designed to withstand.

maximum flood control level — The highest elevation of the flood control storage.

maximum operating level — The maximum extent of a decant pond under normal operating conditions. This is the maximum level to which the water level can rise at which point the deposition of process tailings and water must cease, and the Dam Safety Emergency Plan will be activated.

maximum size (of aggregate) — in specifications for and in description of aggregate, the smallest sieve opening through which the entire amount of aggregate is required to pass.

maximum storage elevation — The maximum attainable water surface elevation of the reservoir pool that could occur during extreme operating conditions. This elevation normally corresponds to the crest elevation of the dam.

maximum-temperature period — a time interval throughout which the maximum temperature is held constant in an autoclave or steam-curing room.

mechanical analysis — the process of determining particle-size distribution of an aggregate.

mechanical connection — the complete assembly of an end bearing sleeve, a coupler, or a coupling sleeve, and possibly additional intervening material or other components to effect connection of reinforcing bars.

medium, grinding — a hard, free-moving charge in a ball or tube mill to reduce the particle size of introduced materials by attrition or impact.

melilite — a group of minerals ranging from the calcium magnesium silicate (akermanite) to the calcium aluminate silicate (gehlenite) that occur as crystals in blast-furnace slag.

melt — the molten portion of the raw material mass during the burning of cement clinker, firing of lightweight aggregates, or expanding of blast-furnace slags.

member, compression— any member in which the primary stress is longitudinal compression.

member, segmental — a structural member made up of individual elements prestressed together to act as a monolithic unit under service loads.

membrane theory — a theory of design for thin shells, based on the premise that a shell cannot resist bending because it deflects; the only stresses that exist, therefore, in any section are shear stress and direct compression or tension.

merwinite — one of the principal crystalline phases found in blast-furnace slags; chemical formula is $Ca_3Mg(SiO_4)2$, crystal system is monoclinic, and density is 3.15 g/cc.

mesh — the number of openings (including fractions thereof) per unit of length in either a screen or sieve in which the openings are 1/4 in. (6 mm) or less.

mesh roller — a finishing tool consisting of a rolling drum attached to a handle, of which the surface of the drum is made of mesh, sometimes used for rolling over the surface of fresh concrete to embed coarse aggregate.

mesh, diamond — a metallic fabric having rhomboidal openings in a geometric pattern.

meter, air — a device for measuring the air content of concrete and mortar.

method, advancing-slope — a method of placing concrete as in tunnel linings in which the face of the fresh concrete is not vertical and moves forward as concrete is placed.

microconcrete — a mixture of portland cement, water, and suitably graded sand for simulating concrete in small-scale structural models.

microcracks — small, numerous cracks that develop in hardened concrete.

microfiber — a fiber with an equivalent diameter less than 0.3 mm for use in concrete.

microsand — fine aggregate, passing the U.S. Standard 150 μm (No. 100) sieve, and essentially free of clay and shale.

microscope, polarizing — a microscope equipped with elements permitting observations and determinations to be made using polarized light.

microscope, scanning electron (SEM) — an electron microscope in which the image is formed by a beam operating in synchronism with an electron probe scanning the object; the intensity of the image-forming beam is proportional to the scattering or secondary emission of electrons by the specimen where the probe beam strikes it.

microscopic — discernible only with the aid of a microscope.

mill scale — the partially adherent layers of oxidation products (heavy oxides) developed on metallic surfaces during either hot fabrication or heat treatment of metals, as on hot-rolled steel reinforcing bars.

mill, ball — horizontal, cylindrical, rotating mill charged with large grinding media.

mill, rod — horizontal, cylindrical, rotating mill charged with steel rods for grinding.

mine closure – A process being undertaken between the time when the operating stage of a mine is ending or has ended and the final decommissioning or rehabilitation is completed. Closure may only be temporary or may lead to a period of care and maintenance.

mine completion – The goal of mine closure where mining lease ownership can be released and responsibility accepted by the next land user.

mineral filler — a finely divided mineral product at least 65% of which passes the U.S. Standard 75 μm (No. 200) sieve.

mineral processing to extract metals or compounds from ore;

minimum decant storage allowance The expected minimum volume of water to be held on a tailings dam to achieve the desired water quality for discharge conditions, either to the environment if appropriate or to return to the process plant for treatment and recycle.

minimum operating level — The lowest level to which the reservoir is drawn down under normal operating conditions.

mix (v.) — the act or process of mixing; also mixture of materials, such as mortar or concrete.

mix, dry — a concrete, mortar, or plaster mixture, commonly sold in bags, containing all components except water; also a concrete of near zero slump.

mixer — a machine used for blending the constituents of concrete, grout, mortar, cement paste, or other mixture.

mixer efficiency — the adequacy of a mixer in rendering a homogeneous product within a stated period; homogeneity is determinable by testing for relative differences in physical

mixer, batch — a machine that mixes batches of either concrete or mortar.

mixer, central — a stationary concrete mixer from which the freshly mixed concrete is transported to the work.

mixer, colloidal — a mixer designed to produce colloidal grout.

mixer, continuous — a mixer into which the ingredients of the mixture are fed without stopping, and from which the mixed product is discharged in a continuous stream.

mixer, horizontal-axis — a concrete mixer of the revolving drum type in which the drum rotates about a horizontal axis.

mixer, horizontal-shaft — a mixer having a stationary cylindrical mixing compartment, with the axis of the cylinder horizontal, and one or more rotating horizontal shafts to which mixing blades or paddle are attached; also called pugmill.

mixer, inclined-axis — a truck with a revolving drum that rotates about an axis inclined to the bed of the truck chassis.

mixer, non tilting — a horizontal rotating drum mixer that charges, mixes, and discharges without tilting.

mixer, open-top — a truck-mounted mixer consisting of a trough or a segment of a cylindrical mixing compartment within which paddles or blades rotate about the horizontal

mixer, tilting — a revolving-drum mixer that discharges by tilting the drum about a fixed or movable horizontal axis at right angles to the drum axis; the drum axis may be horizontal or inclined while charging and mixing.

mixer, truck — a concrete mixer suitable for mounting on a truck chassis and capable of mixing concrete in transit.

mixer, vertical-shaft — a cylindrical or annular mixing compartment having an essentially level floor and containing one or more vertical rotating shafts to which blades or paddles are attached; the mixing compartment may be stationary or rotate about a vertical axis.

mixer, volumetric — equipment that uses measurements based on the volumes of the ingredients to feed a container that continually agitates and combines those ingredients, for the production of concrete; also called volumetric-measuring and continuous-mixing concrete equipment (VMCM).

mixing cycle — the time taken for a complete cycle in a batch mixer, that is, the time elapsing between successive repetitions of the same operation (for example, successive discharges of the mixer).

mixing speed — rotation rate of a mixer drum or of the paddles in an open-top, pan, or trough mixer, when mixing a batch; expressed in revolutions per minute (rpm), or in peripheral feet per minute of a point on the circumference at maximum diameter.

mixing time — the period during which the constituents of a batch of concrete are mixed by a mixer; for a stationary mixer, time is given in minutes from the completion of mixer charging until the beginning of discharge; for a truck mixer, time is given in total minutes at a specified mixing speed or expressed in terms of total revolutions at a specified mixing speed.

mixing, continuous — producing concrete by continuously blending ingredients in fixed proportions. The discharge of the concrete mixture may be started or stopped as required.

mixing, dry — blending of the solid materials for mortar or concrete before adding the mixing water.

mixture — the assembled, blended, commingled ingredients of mortar, concrete, or the like; or the proportions for their assembly.

mixture proportion — the proportions of ingredients that make the most economical use of available materials to produce mortar or concrete of the required properties.

mixture, binary — concrete containing two cementitious materials.

mixture, harsh — a concrete mixture that lacks desired workability and consistency due to a deficiency of mortar or aggregate fines.

mixture, quad — concrete containing four cementitious materials.

mixture, ternary — concrete containing three cementitious materials.

mobile placer — a small belt conveyor mounted on wheels or truck-mounted that can be readily moved to the job site for conveying concrete from the ready mixed concrete truck to the forms or slab.

mobility — the ability of fresh concrete or mortar to flow.

modified cube — a portion of a rectangular beam of hardened concrete previously broken in flexure; used in determining the compressive strength of the concrete.

modified portland cement — a portland cement having moderate heat of hydration; this term was replaced by Type II cement beginning in 1960.

modular ratio — the ratio of modulus of elasticity of steel *Es* to that of concrete *Ec*; usually denoted by the symbol *n*.

modulus of compression — the ratio of compressive stress to cubical compression; always positive for physical substances; also known as bulk modulus; related to Young's modulus and Poisson's ratio.

modulus of deformation — 1. a concept of modulus of elasticity expressed as a function of two time variables; strain in loaded concrete as a function of the age at which the load is initially applied and of the length of time the load is sustained; and 2. the ratio of stress to strain for a material that does not deform in accordance with Hooke's law when subjected to applied load.

modulus of elasticity — the ratio of normal stress to corresponding strain for tensile or compressive stress below the proportional limit of the material; also referred to as elastic modulus, Young's modulus, and Young's modulus of elasticity;

modulus of elasticity, dynamic — the modulus of elasticity computed from the size, weight, shape, and fundamental frequency of vibration of a concrete test specimen, or from pulse velocity.

modulus of elasticity, static — the value of Young's modulus of elasticity obtained by arbitrary criteria from measured stress-strain relationships derived from other than dynamic loading.

modulus of elasticity, sustained — term including elastic and inelastic effects in one expression to aid in visualizing net effects of stress-strain up to any given time; computed by dividing the unit sustained stress by the sum of the elastic

modulus of rigidity — the ratio of unit shearing stress to the corresponding unit shearing strain; referred to as shear modulus and modulus of elasticity in shear, denoted by the symbol G.

modulus of rupture — the calculated apparent tensile stress in the extreme tension fiber of a plain concrete beam test specimen at the load that produces rupture when tested in accordance with ASTM C78 (third-point loading) or ASTM C293 (center-point

modulus of subgrade reaction — ratio of the load per unit area of soil to the corresponding settlement of the soil, typically evaluated in situ per ASTM D1196.

modulus, bulk — the ratio of the change in average stress to the change in unit volume.

modulus, fineness — a factor obtained by adding the total percentages of material in the sample that are coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 mm (3/8 in.), 19.0 mm (3/4 in.), 37.5 mm (1-1/2 in.), 75 mm (3 in.), 150 mm (6 in.).

modulus, section — a term pertaining to the cross section of a flexural member; the section modulus with respect to either principal axis is the moment of inertia with respect to that axis divided by the distance from that axis to the most remote point of the tension or compression area of the section, as required; the section modulus is used to determine the flexural stress in a beam.

modulus, Young's — see **modulus of elasticity** (preferred term).

Mohs scale — arbitrary quantitative units, ranging from 1 through 10, by means of which the scratch hardness of a mineral is determined; each unit of hardness is represented by a mineral that can scratch any other mineral having a lower-ranking number; the minerals are ranked from talc or 1 (the softest),upward through gypsum or 2, calcite or 3, fluorite or 4, apatite or 5, orthoclase or 6, quartz or 7, topaz or 8, corundum or 9, and diamond or 10 (the hardest).

moist — slightly damp but not quite dry to the touch; the terms "wet" implies visible free water, "damp" implies less wetness than "wet," and "moist" implies not quite dry.

moist room — a room in which the atmosphere is maintained at a selected temperature (usually 23.0 ± 2°C) and a relative humidity of at least 95%, for the purpose of curing and storing cementitious test specimens; the facilities must be sufficient to maintain free moisture continuously on the exteriors of test specimens; also known as a fog room.

moisture — (**moisture, absorbed** — moisture that has entered the permeable voids of a solid and has physical properties not substantially different from ordinary water at the same

moisture content — (geotechnical definition) mass of evaporable water as a percentage of the mass of solids. Also see "solids content", "water content".

moisture movement — (1) the movement of moisture through a porous medium; and (2) in the UK, the effects of such movement on efflorescence and volume change in hardened cement paste, mortar, concrete, or rock.

mold — (1) a device containing a cavity into which neat cement, mortar, or concrete test specimens are cast; and (2) a form used in the fabrication of precast mortar or concrete units (for example, masonry units).

mold, plaster — a mold or form made from gypsum plaster, usually to permit concrete to be formed or cast in intricate shapes or in conspicuous relief.

moment — the colloquial expression for the more descriptive term bending moment. **moment, bending** — the bending effect at any section of a structural element; it is equal to the algebraic sum of the moments of the vertical and horizontal forces, with respect to the centroidal axis of a member, acting on a free body of the member.

moment distribution — a method of structural analysis for continuous beams and rigid frames whereby successive converging corrections are made to an assumed set of moments until the desired precision is obtained; also known as the Hardy Cross method.

moment, negative — a condition of flexure in which top fibers of a horizontally placed member, or external fibers of a vertically placed exterior member, are subjected to tensile

moment, positive — a condition of flexure in which, for a horizontal simply supported member, the deflected shape is normally considered to be concave downward and the top fibers subjected to compression stresses; for other members and other conditions consider positive and negative as relative terms.

moment, secondary — in statically indeterminate structures, the additional moments caused by deformation of the structure due to the applied forces; in statically indeterminate prestressed-concrete structures, the additional moments caused by the use of a non concordant prestressing tendon.

monolithic terrazzo — the application of a 15 mm terrazzo topping directly to a specially prepared concrete substrate, eliminating an underbed.

monomolecular — composed of single molecules; specifically, films that are one molecule thick; denotes a thickness equal to one molecule, for example, certain chemical compounds develop a "monomolecular film" over bleeding water at the surface of freshly placed concrete or mortar as a means of reducing the rate

montmorillonite — a swelling clay mineral of the smectite group; main constituent of bentonite.

mortar — a mixture of cement paste and fine aggregate; in fresh concrete, the material occupying the interstices among particles of coarse aggregate; in masonry construction, joint mortar may contain masonry cement, or may contain hydraulic cement with lime (and possibly other admixtures) to afford greater plasticity and workability than are attainable with standard portland cement mortar.

mortar board — a platform or tray for holding freshly mixed mortar.

mortar, epoxy — a mixture of epoxy resin, catalyst, and fine aggregate.

mortar, lean — mortar that is harsh and difficult to spread because of either insufficient cement content or presence of coarse sand.

mortar, plastic —a mortar of plastic consistency.

mortar, stringing — the procedure of spreading enough mortar on the bed joint to ensure laying several masonry units.

mosaic — inlaid exposed surface designs of aggregates or other material.

mottling—uneven color shading or blotchiness across a surface.

mud balls — lumps of clay or silt ("mud").

mud sill — a timber or timber assembly bedded into the earth at grade to support framed construction.

mud slab — a 2 to 6 in. (50 to 150 mm) layer of concrete beneath a structural concrete floor or footing over soft, wet soil; also called mud mat.

multielement prestressing — prestressing accomplished by stressing an assembly of several individual structural elements as a means of producing one integrated structural member.

multistage stressing — prestressing performed in stages as the construction progresses.

multiwall-bag — a flexible container for transporting a cementitious material and usually consisting of four plies of kraft paper previously treated to ensure resistance to moisture.

mushroom system of flat-slab construction — a four-way reinforced-concrete girder less floor slab in which the column reinforcing bars are bent down into the slab around the column head in radial directions and additional reinforcing bars are bent into rings laid upon the radials, thus forming a spider web to provide additional reinforcement at the column head and to support the slab steel; mushroom designs of the true flat-slab type do not involve drop panels around the capitals of the columns.

N

nailer — a strip of wood or other fitting attached to or set in concrete, or attached to steel to facilitate making nailed connections.

natural air-drying — the process of drying cured concrete masonry units without any special equipment (for example, the drying that occurs in a covered storage area).

natural and artificial pozzolans.

neat line — a line defining the proposed or specified limits of an excavation or structure.

needle, Gillmore — a device used in determining time of setting of hydraulic cement.

needle, Vicat — a weighted needle for determining time of setting of hydraulic cements.

net cross-sectional area (of masonry) — the gross cross-sectional area of a section of masonry minus the area of cavities, cells, or cored spaces.

Nicol prism — a system of two optically clear crystals of calcite ("Iceland spar") used in producing plane-polarized light.

nip — the seizing of stone between either the jaws or the rolls of a crusher.

nominal maximum size (of aggregate) — in specifications for and in descriptions of aggregate, the smallest sieve opening through which the entire amount of the aggregate is permitted to pass.

nominal mixture — the proportions of the constituents of a proposed concrete mixture.

nonagitating unit — a truck-mounted container for transporting central-mixed concrete, not equipped to provide agitation (slow mixing) during delivery.

noncombustible — any material that neither ignites nor supports combustion in air when exposed to fire.

nonferrous — relating to metals other than iron; not containing or including iron.

nonvolatile content — the portion of a material that remains after volatile matter has been evaporated under specified ambient or accelerated conditions.

normal pool height — The vertical distance between the lowest point of the upstream toe of the impounding barrier and the normal storage elevation.

normal storage elevation — The normal maximum operating pool level in a reservoir. Where the principal spillway is ungated, the normal storage elevation is usually established by the level of the spillway crest.

nozzle — a metal or rubber tip attached to the discharge end of a heavy thick-walled rubber hose from which a continuous stream of shotcrete is ejected at high velocity.

nozzle liner — a replaceable rubber lining, fitted into the nozzle tip, to prevent abrasion of the interior surface of the nozzle.

nozzle operator — the technician who manipulates the nozzle of a placing machine and controls placement of the shotcrete.

nozzle velocity — the rate at which shotcrete is ejected from the nozzle, usually stated in feet per second or meter per second.

O

observation well — A hole used to observe the groundwater surface at atmospheric pressure within soil or rock.

obsidian — a natural volcanic glass of relatively low water content; usually of rhyolite composition.

offset — an abrupt change in alignment or dimension, either horizontally or vertically; a horizontal ledge occurring along a change in wall thickness of the wall above.

offset bend — an intentional distortion from the normal straightness of a steel reinforcing bar to move the center line of a segment of the bar to a position parallel to the original position of the center line; a mechanical operation commonly applied to vertical bars that reinforce concrete columns.

oil, form — oil applied to the interior surfaces of forms to promote easy release from the concrete when the forms are removed.

oil, mold — an oil that is applied to the interior surface of a clean mold, before casting concrete or mortar therein, to facilitate removal of the mold after the concrete or mortar has hardened.

opal — a mineral composed of amorphous hydrous silica ($SiO_2 \cdot nH_2O$).

opaline chert — chert composed entirely or mainly of opal.

open-circuit crushing — a crushing system in which material passes through the crusher without recycling of oversize particles.

operational basis earthquake (OBE) — That earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the dam site during the operating life of the dam; it is that earthquake which produces the vibratory ground motion for which those features of the dam necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

operational freeboard This is the vertical distance between the top of the tailings and the adjacent embankment crest. A minimum operational freeboard is normally specified to minimize the potential for backflow and overtopping as a result of tailings mounding at discharge points;

orthotropic — a contraction of the terms "orthogonal anisotropic" as in the phrase "orthogonal anisotropic plate"; a hypothetical plate consisting of beams and a slab acting together with different flexural rigidities in the longitudinal and transverse directions, as in a composite beam bridge.

outlet — A conduit and/or channel structure for the controlled release of the contents normally impounded by a dam and reservoir.

ovals — marble chips that have been tumbled until a smooth oval shape has resulted.

oven dry — the process of drying in an oven at a temperature usually between 105 and 115˚C until the mass of the test specimen becomes essentially constant.

oven-dry — the condition resulting from having been dried to essentially constant mass, in an oven, at a temperature that has been fixed, usually between 105 and 115°C.

overdesign — to require adherence to structural design requirements higher than service demands, as a means of compensating for statistical variation or for anticipated deficiencies or both.

overlay — a layer of concrete or mortar, seldom thinner than 25 mm, placed on and usually bonded onto the worn or cracked surface of a concrete slab to either restore or improve

oversanded — containing more sand than would be necessary to produce adequate workability and a satisfactory condition for finishing.

overstretching — stressing of tendons to a value higher than designed for the initial stress to:

overvibration — excessive use of vibrators during placement of freshly mixed concrete, causing segregation, stratification, and excessive bleeding.

owner — the corporation, association, partnerships, individual, or public body or authority with whom the contractor enters into an agreement and for whom the work is provided.

oxide, brown — a brown mineral pigment having an iron oxide content between 28 and 95%.

P

pack, dry — concrete or mortar mixtures deposited and consolidated by dry packing.

packaged concrete, mortar, grout — mixtures of dry ingredients in packages, requiring only the addition of water to produce concrete, mortar, or grout.

packer — a device inserted into a hole in which grout is to be injected which acts to prevent return of the grout around the injection pipe; usually an expandable device actuated mechanically, hydraulically, or pneumatically.

packing, dry — placing of zero-slump, or near zero-slump, concrete, mortar, or grout by ramming into a confined space.

paddle mixer — see **mixer, open-top** (preferred term).

paint, cement — a paint consisting generally of white portland cement and water, pigments, hydrated lime, water repellents, or hygroscopic salts.

paint, cold-water — a paint in which the binder or vehicle portion is composed of latex, casein, glue, or some similar material dissolved or dispersed in water.

pan — (1) a prefabricated form unit used in concrete joist floor construction; and (2) a container that receives particles passing the finest sieve during mechanical analysis of granular material.

panel — (1) a section of form sheathing that can be erected and stripped as a unit; (2) a concrete element that is relatively thin with respect to other dimensions and is bordered by joints or edges; and (3) a region of a suspended slab system bounded by column, beam, or wall centerline.

panel, drop — the thickened structural portion of a flat slab in the area surrounding column, column capital, or bracket, to reduce the intensity of stresses.

panel, exterior — in a flat slab, a panel having at least one edge that is not in common with another panel.

panel, ribbed — a panel composed of a thin slab reinforced by a system of ribs in one or two directions, usually orthogonal.

panel, sandwich — a prefabricated panel that is a layered composite, formed by attaching two thin facings to a thicker core, for example, a precast-concrete panel consisting of two layers of concrete separated by a nonstructural insulating core.

panel, solid — a solid slab, usually of constant thickness.

parallel-wire unit — a post-tensioning tendon composed of a number of wires or strands that are approximately parallel.

parapet — the part of a wall that extends above the roof level; a low wall along the top of a dam.

parapet wall — A solid wall built along the top of a dam (upstream or downstream edge) used for ornamentation, for safety of vehicles and pedestrians, or to prevent overtopping caused by wave run up.

parge — to coat with plaster, particularly foundation walls and rough masonry.

particle specific gravity (or Soil Particle Density) — mass per unit of solid volume of the solids particles in the tailings.

particle, colloidal — an electrically charged particle, generally smaller than 0.1 μm, dispersed in a second continuous medium.

pass — layer of shotcrete placed in one movement over the area of operation.

paste content — proportional volume of cement paste in concrete, mortar, or the like, expressed as volume percent of the entire mixture.

paste, cement — binder of concrete and mortar consisting essentially of cement, water, hydration products and any admixtures together with very finely divided materials included

pat — a specimen of neat cement paste, about 76 mm in diameter and 13 mm in thickness at the center and tapering to a thin edge, on a flat glass plate for indicating setting time.

path of prestressing force — the locus of points defining the resultant effective prestress force in a concrete member.

pavement (concrete) — a layer of concrete on such areas as roads, sidewalks, canals, playgrounds, and those used for storage or parking.

pavement, flexible — a pavement structure that maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability; cementing agents, where used, are generally bituminous materials as contrasted to hydraulic cement in the case of rigid pavement.

pavement, pervious—a pavement comprising material with sufficient continuous voids to allow water to pass from the surface to the underlying layers.

pavement, rigid — pavement that will provide high bending resistance and distribute loads to the foundation over a comparatively large area.

paver, concrete — (1) a concrete mixer, usually mounted on crawler tracks, that mixes and places concrete pavement on the subgrade. (2) Precast-concrete paving brick.

paving train — an assemblage of equipment designed to place and finish a concrete pavement.

peak load — the highest value for load in any test at which the form of the curve becomes nonlinear and substantially changes slope.

peak load strength — strength computed using the peak load.

pedestal — member with a ratio of height-to-least lateral dimension less than or equal to 3 used primarily to support axial compressive load, such as a short pier or plinth used as the

peeling — a process in which thin flakes of mortar are broken away from a concrete surface, such as by deterioration or by adherence of surface mortar to forms as forms are removed.

penetration — an opening through which pipe, conduit, or other item passes through a wall or floor.

penetration of a liquid into its permeable voids.

penstock — A pressurized pipeline or shaft between the reservoir and hydraulic machinery.

percent fines — the amount, expressed as a percentage, of material in aggregate finer than a given sieve, usually the 75 µm (No. 200); also the amount of fine aggregate in a concrete mixture expressed as a percent by absolute volume of the total amount of aggregate.

percentage of reinforcement — the ratio of cross-sectional area of reinforcing steel to the effective cross-sectional area of a member, expressed as a percentage.

periclase — a crystalline mineral, magnesia, MgO, the equivalent of which may be present in portland-cement clinker, portland cement, and other materials, such as open-hearth slags and certain basic refractories.

period, presteaming — in the manufacture of concrete products, the time between molding of a concrete product and start of the temperature-rise period.

period, soaking — in high-pressure and low-pressure steam curing, the time during which the live steam supply to the kiln or autoclave is shut off and the concrete products are exposed to the residual heat and moisture.

period, temperature-rise — the time interval during which the temperature of a concrete product rises at a controlled rate to the desired maximum in autoclave or atmospheric pressure steam curing.

periodic inspection — A detailed inspection of the dam and appurtenant works conducted on regular intervals and includes, as necessary, associated engineering analyses to confirm the continued safe operation of the project.

perlite — a volcanic glass having a perlitic structure, usually having a higher water content than obsidian; when expanded by heating, used as an insulating material and as a lightweight aggregate in concretes, mortars, and plasters.

perlitic structure — a structure produced in a homogeneous material by contraction during cooling, and consisting of a system of irregular convolute and spheroidal cracks; generally

permeability to water, coefficient of — the rate of discharge of water under laminar flow conditions through a unit cross sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions, usually 20°C.

petrography — the branch of petrology dealing with description and systematic classification of rocks aside from their geologic relations, mainly by laboratory methods, largely chemical and microscopical; also, loosely, petrology or lithology; also the techniques and knowledge of petrography applied to mortar, concrete, and the like.

petrology — the science of rocks, treating of their origin, structure, composition, etc., from aspects and in all relations.

photometer, flame —an instrument used to determine elements (especially sodium and potassium in portland cement) by the color intensity of their unique flame spectra resulting from introducing a solution of a compound of the element into a flame. (Also known as flame spectrophotometer.)

phreatic surface — The free surface of water seeping at atmospheric pressure through soil or rock.

pier — (1) a slender isolated foundation member of either plain or reinforced concrete that is cast on end in the ground; or (2) An isolated vertical masonry member whose horizontal dimension measured at right angles to its thickness is not less than three times its thickness nor greater than six times its thickness and whose height is less than five times its length.

pier cap — a concrete element that transfers load from a column or pedestal to the top of one or more supporting piers.

pier, belled — a drilled pier shaft with an expanded excavation at the bottom.

pier, drilled — a concrete pier with or without a casing, cast in place in a hole previously bored in soil or rock.

piezometer — An instrument used for measuring fluid pressure (air or water) within soil, rock, or concrete.

pigment — a coloring matter, usually in the form of an insoluble fine powder.

pilaster — column built with a wall, usually projecting beyond the wall.

pile — a slender structural element that is driven, jetted, or otherwise embedded on end in the ground to support a load or compact the soil.

pile cap — a concrete element that transfers load from a column or pedestal to the top of one or more supporting piles.

pile, batter — a pile installed at an angle to the vertical; a raking pile or raker pile.

pile, caisson — a cast-in-place pile made by driving a tube, excavating it, and filling the cavity with concrete.

pile, cast-in-place — a concrete pile concreted either with or without a casing in its permanent location, as distinguished from a precast pile.

pile, composite — a pile made up of different materials, usually concrete and wood, or steel fastened together end to end, to form a single pile.

pile, friction — a load-bearing pile that receives its principal vertical support from skin friction between the surface of the buried pile and the surrounding soil.

pile, pedestal — a cast-in-place concrete pile constructed so that concrete is forced out into a widened bulb or pedestal shape at the foot of the pipe which forms the pile.

pile, pipe — a steel cylinder, usually between 250 and 600 mm in diameter, generally driven with open ends to firm bearing and then excavated and filled with concrete.

pile, precast — a reinforced pile manufactured in a casting plant or at the site but not in its final position.

pile, sheet — a pile in the form of a plank driven in close contact or interlocking with others to provide a tight wall to resist the lateral pressure of water, adjacent earth, or other materials; may be tongued and grooved if made of timber or concrete and interlocking if made of metal.

pile, wing — a bearing pile, usually of concrete, widened in the upper portion to form part of a sheet pile wall.

pipe, vent —a small-diameter pipe used in concrete construction to permit escape of air in a structure being concreted or grouted.

piping — The progressive development of internal erosion within a soil mass by seepage.

pitting — development of relatively small cavities in a surface; in concrete, localized disintegration, such as a pop out; in steel, localized corrosion evident as minute cavities on the surface.

placement — the process of placing and consolidating concrete; a quantity of concrete placed and finished during a continuous operation; inappropriately referred to as pouring.

placing — the deposition, distribution, and consolidation of freshly mixed concrete in the place where it is to harden; inappropriately referred to as pouring.

plain pavement — unreinforced concrete pavement.

plane of weakness — the plane along which a body under stress will tend to fracture; may exist by design, by accident, or because of the nature of the structure and its loading.

plaster —((1) a mixture consisting essentially of a cementitious material or materials, fine aggregate, and water that forms a plastic mass. When applied to a surface, the mixture adheres to it and subsequently hardens; (2) the placed and hardened mixture; or (3) the act of placing such material).

plaster of paris — CaSO4·1/2H2O; gypsum, from which three quarters of the chemically bound water has been driven off by heating; when wetted it recombines with water and hardens quickly.

plaster, neat — plaster devoid of sand.

plastic — possessing plasticity, or possessing adequate plasticity.

plastic centroid — centroid of the resistance to load computed for the assumptions that the concrete is stressed uniformly to 85% of its design strength and the steel is stressed uniformly to its specified yield point.

plastic flow — obsolete term for creep and stress relation.

plastic or bond fire clay — a fire clay of sufficient natural plasticity to bond non plastic material; a fire clay used as a plasticizing agent in mortar.

plasticity — a complex property of a material involving a combination of qualities of mobility and magnitude of yield value; the property of freshly mixed cement paste, concrete, or mortar that determines its resistance to deformation or ease of molding.

plasticize — to produce plasticity or to render plastic.

plasticizer — a material that increases the plasticity of a fresh cement paste, mortar, or concrete.

plate — (1) in formwork for concrete: a flat, horizontal member either at the top or bottom, or both, of studs or posts; a mud sill if on the ground; and (2) in structural design: a member, the depth of which is substantially less than its length and width).

plate, deformed — a flat piece of metal, thicker than 6 mm, having horizontal deformations or corrugations; used in construction to form a vertical joint and provide a mechanical interlock between adjacent sections.

plate, flat — a flat slab without column capitals or drop panels.

plate, folded — (1) a framing assembly composed of sloping slabs in a hipped or gabled arrangement; and (2) prismatic shell with open polygonal section).

plum — a large random-shaped stone dropped into freshly placed mass concrete to economize on the amount of the other concrete ingredients.

plumb — vertical or to make vertical.

plunge pool — A natural or artificially created pool that dissipates the energy of free falling water.

point count method — method for determination of the volumetric composition of a solid by observation of the frequency with which areas of each component coincide with a regular system of points in one or more planes intersecting a sample of the solid.

point count method (modified) — the point count method supplemented by a determination of the frequency with which areas of each component of a solid are intersected by regularly spaced lines in one or more planes intersecting a sample of the solid.

point of inflection — the point on the length of a structural member subjected to flexure where the curvature changes from concave to convex or conversely and at which the bending moment is zero; also called "point of contra flexure."

polish or final grind — the final operation in which fine abrasives are used to hone a surface to its desired smoothness and appearance.

polyester — one of a large group of synthetic resins, mainly produced by reaction of dibasic acids with dihydroxy alcohols; commonly prepared for application by mixing with a vinyl-group monomer and free-radical catalysts at ambient temperatures and used as binders for resin mortars and concretes, fiber laminates (mainly glass), adhesives, and the like. **polyethylene** — a thermoplastic high-molecular-weight organic compound used in formulating protective coatings or, in sheet form, as a protective cover for concrete surfaces during the curing period, or to provide a temporary enclosure for construction operations.

polymer — the product of polymerization; more commonly a rubber or resin consisting of large molecules formed by polymerization.

polymerization — the reaction in which two or more molecules of the same substance combine to form a compound containing the same elements and in the same proportions but of higher molecular weight.

polyurethane — reaction product of an isocyanate with any of a wide variety of other compounds containing an active hydrogen group; used to formulate tough, abrasion-resistant coatings.

polyvinyl acetate — colorless, permanently thermoplastic resin; usually supplied as an emulsion or water-dispersible powder characterized by flexibility, stability towards light, transparency to ultraviolet rays, high dielectric strength, toughness, and hardness; the higher the degree of polymerization, the higher the softening temperature; may be used in paints for concrete.

polyvinyl chloride — a synthetic resin prepared by the polymerization of vinyl chloride, used in the manufacture of nonmetallic waterstops for concrete.

ponding — the creation and maintaining of a shallow pond of water on the surface of a concrete slab to assist curing; accidental or incidental occurrence of a shallow pond or ponds on a nominally flat surface of concrete; a condition in which a horizontal slab deforms downward between supports.

popout — the breaking away of small portions of a concrete, mortar, and plaster surface due to localized internal pressure that leaves a shallow, typically conical, depression.

population at risk — The number of people who may be present in areas downstream of a dam and could be at risk in the event of a dam failure.

porosity — the ratio, usually expressed as a percentage of the volume of voids in a material to the total volume of the material including the voids.

portlandite — a mineral; calcium hydroxide (Ca(OH)2); occurs naturally in Ireland; equivalent to a product of hydration of portland cement.

post — vertical formwork member used as a support; also known as shore, prop, or jack.

post-closure – The period after Mine Closure where the Tailings Dam is expected to perform safely into the long-term.

post-tensioning — method of prestressing in which prestressing steel is tensioned after concrete has hardened.

post-tensioning, bonded — post-tensioned construction in which the annular spaces around the tendons are grouted after stressing, thereby bonding the tendon to the concrete section.

pot life — time interval, after mixing of thermosetting resin and initiators, during which the mixture can be applied without degrading the final performance of the resulting polymer

pozzolan — a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties; there are both

pozzolan, artificial — materials such as fly ash and silica fume.

pozzolan, natural — a raw or calcined natural material that has pozzolanic properties (for example, volcanic tuffs or pumicites, opaline cherts and shales, clays, and diatomaceous earths).

pozzolanic — of or pertaining to a pozzolan.

precast — a concrete member that is cast and cured in other than its final position; the process of placing and finishing precast concrete. (See also **cast-in-place**.)

prefire — to raise the temperature of refractory concrete under controlled conditions before placing it in service.

pre-post-tensioning — a method of fabricating prestressed concrete in which some of the tendons are pretensioned and a portion of the tendons are post-tensioned.

preservation — the process of maintaining a structure in its present condition and arresting further deterioration.

pressure —

pressure, form — lateral pressure acting on vertical or inclined formed surfaces, resulting from the fluid-like behavior of the unhardened concrete confined by the forms.

prestress — to place a hardened-concrete member or an assembly of units in a state of compression before application of service loads; the stress developed by prestressing, such as by pretensioning or post-tensioning.

prestress, effective — the prestressing force at a specific location in a prestressed-concrete member under the effects of service dead load or total service load after losses of prestress have occurred.

prestress, initial — the prestressing stress (or force) applied to the concrete at the time of stressing.

prestress, transverse — prestress that is applied at right angles to the longitudinal axis of a member or slab.

prestressing, nonsimultaneous — the post-tensioning of tendons individually rather than simultaneously.

prestressing, partial — prestressing to a stress level such that, under design loads, tensile stresses exist in the precompressed tensile zone of the prestressed member.

pretensioning — a method of prestressing reinforced concrete in which the tendons are tensioned before the concrete has hardened.

pretensioning bed (or bench) — the casting bed on which pretensioned members are manufactured and which resists the pretensioning force prior to release.

primary nuclear vessel — interior container in a nuclear reactor designed for sustained loads and for working conditions.

principal spillway (or service spillway) — A spillway designed to provide continuous or frequent releases from a reservoir, without significant damage to either the dam or its appurtenant structures.

prior to freezing and where no deicing agents or other aggressive chemicals are used.

probability — The likelihood of an event occurring.

probable maximum flood (PMF) — the largest flood hydrograph resulting from PMP and, where applicable, snowmelt, coupled with the worst flood-producing catchment conditions that can be realistically expected in the prevailing meteorological conditions.

probable maximum Flood (PMF) — The most severe flood that is considered reasonable possible at a site as a result of meteorologic and hydrologic conditions.

Probable Maximum Precipitation (PMP) — the theoretical greatest depth of precipitation for a given duration that is physically possible over a particular catchment,

Probable Maximum precipitation (PMP) — Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location.

probe, penetration — a device for obtaining a measure of the resistance of concrete to penetration; customarily determined by the distance that a steel pin is driven into the concrete from a special gun by a precisely measured explosive charge.

process — (**process, centrifugal** — a process for producing concrete products, such as pipe, that uses an outer form that is rotated about a horizontal axis and into which concrete is fed by a conveyor, also called spinning process. **process, dry** — in the manufacture of cement, the process in which the raw materials are ground, conveyed, blended, and stored in a dry condition. **process, dry-cast** —a process for producing concrete products, such as pipe, using low-frequency high-amplitude vibration to consolidate dry-mix concrete in the form. **process, packerhead** — a process for producing concrete pipe that uses a rotating device that forms the interior surface of the pipe as concrete is fed into the form from above. **process, tamp** — a process for producing concrete products, such as pipe, that uses direct mechanical action to consolidate the concrete by the action of tampers that rise automatically as the form is rotated and filled with concrete from above.

process, wet — in the manufacture of cement, the process in which the raw materials are ground, blended, mixed, and pumped while mixed with water; the wet process is chosen where raw materials are extremely wet and sticky which would make drying before crushing and grinding difficult. **process, wet-cast** — a process for producing concrete items, such as pipe, that uses concrete having a measurable slump, generally placed from above, and consolidated by vibration).

promoter, flow — substance added to coating to enhance brush ability, flow, and leveling.

property — a particular physical or chemical or structural characteristic of a substance or material.

proportion — to select proportions of ingredients to make the most economical use of available materials to produce mortar or concrete of the required properties.

protected paste volume — the portion of hardened cement paste that is protected from the effects of freezing by proximity to an entrained air void.

protection period — the required time during which the concrete is maintained at or above a specific temperature to prevent freezing of the concrete or ensure the necessary strength of development.

psychrometer, sling — a psychrometer containing independently matched dry- and wet-bulb thermometers, suitably mounted for manually swinging through the ambient air, to simultaneously indicate dry- and wet-bulb temperatures.

pumice — a highly porous and vesicular lava usually of relatively high silica content composed largely of glass drawn into approximately parallel or loosely entwined fibers, which themselves contain sealed vesicles.

pumicite — naturally occurring finely divided pumice and glass shards.

pump, concrete — an apparatus that forces concrete to the placing position through a pipeline or hose.

pumping (of pavements) — the ejection of water, or water and solid materials, such as clay or silt, along transverse or longitudinal joints and cracks, and along pavement edges caused by downward slab movement activated by the passage of loads over the pavement after the accumulation of free water on or in the base course, subgrade, or subbase.

punching shear — failure of a base or slab when a heavily loaded column punches a hole through it.

punching shear stress — shear stress calculated by diving the load on the slab that is transferred to the column by the product of the perimeter and the thickness of the base or cap or by the product of the perimeter taken at 1/2 the slab thickness away from the column and the thickness of the base or cap.

punning — an obsolete term designating a light form of ramming.

purlin — in roofs, a horizontal member supporting the common rafters.

putty — a plaster composed of quicklime or hydrated lime and water with or without plaster of paris or sand.

pycnometer — a vessel for determination of specific gravity of liquids or solids.

pyrite — a mineral, iron disulfide (FeS2) that, if it occurs in aggregate used in concrete, can cause popouts and dark brown or orange-colored staining.

pyrometric-cone equivalent (PCE) — the number of that cone whose tip would touch the supporting plaque simultaneously with that of a cone of the refractory material being investigated when tested in accordance with a specified procedure such as ASTM C24.

Q

quality assurance — actions taken by an organization to provide and document assurance that what is being done and what is being provided are in accordance with the contract documents and standards of good practice for the work.

quality control — actions taken by an organization to provide control and documentation over what is being done and what is being provided so that the applicable standard of good practice and the contract documents for the work are followed.

quicklime — calcium oxide (CaO).

R

rake classifier — machine for separating coarse and fine particles of granular material temporarily suspended in water; the coarse particles settle to the bottom of a vessel and are scraped up an incline by a set of blades, the fine particles remaining in suspension to be carried over the edge of the classifier.

raker — a sloping brace for a shore head.

ramming — a form of heavy tamping of concrete, grout, or the like by means of a blunt tool forcibly applied.

ratio, A/F — the molar or mass ratio of aluminum oxide (Al_2O_3) to iron oxide (Fe_2O_3), as in portland cement.

ratio, aggregate-cement — the ratio of cement to total aggregate, either by mass or volume.

ratio, Poisson's — the absolute value of the ratio of transverse (lateral) strain to the corresponding axial (longitudinal) strain resulting from uniformly distributed axial stress below the proportional limit of the material; the value will average about 0.2 for concrete and 0.25 for most metals.

raveling — the wearing away of the concrete surfaced caused by the dislodging of aggregates particles.

raw mix — blend of raw materials, ground to desired fineness, correctly proportioned, and blended ready for burning; such as that used in the manufacture of cement clinker.

Rayleigh wave — an ultrasonic surface wave in which the particle motion is elliptical and effective penetration is approximately one wavelength.

reaction, alkali-aggregate — chemical reaction in either mortar or concrete between alkalies (sodium and potassium) from portland cement or other sources and certain constituents of some aggregates; under certain conditions, deleterious expansion of concrete or mortar may result.

reaction, alkali-carbonate rock — the reaction between the alkalies (sodium and potassium) in portland cement and certain carbonate rocks, particularly calcitic dolomite and dolomitic limestones, present in some aggregates; the products of the reaction may cause abnormal expansion and cracking of concrete in service.

reaction, alkali-silica — the reaction between the alkalies (sodium and potassium) in portland cement and certain siliceous rocks or minerals, such as opaline chert, strained quartz, and acidic volcanic glass, present in some aggregates; the products of the reaction may cause abnormal expansion and cracking of concrete in service.

reaction, endothermic — a chemical reaction that occurs with the absorption of heat.

reaction, exothermic —a chemical reaction that occurs with the evolution of heat.

reactive silica material — several types of materials that react at high temperatures with portland cement or lime during autoclaving, includes pulverized silica, natural pozzolan, and fly ash.

reactivity (of aggregate), alkali — susceptibility of aggregate to alkali-aggregate reaction.

rebar — colloquial term for reinforcing bar.

rebound — shotcrete materials, or wet shotcrete, that bounces away from the surface against which the shotcrete is being projected.

reference standards — standardized mandatory language documents of a technical society, organization, or association, including the building codes of local or state authorities, which are referenced in the contract documents.

refractories — materials, usually nonmetallic, used to withstand high temperatures.

refractoriness — in refractories, the property of being resistant to softening or deformation at high temperatures.

refractory — resistant to high temperatures.

refractory, castable — a packaged, dry mixture of hydraulic cement, generally calcium-aluminate cement, and specially selected and proportioned refractory aggregates that, when mixed with water, will produce refractory concrete or mortar.

refractory, neutral — a refractory that is resistant to chemical attack by either acidic or basic substances.

reglet — a groove in a wall to receive flashing.

rehabilitation — the process of repairing or modifying a structure to a desired useful condition.

reinforcement — bars, wires, strands, fibers, or other slender elements that are embedded in a matrix such that they act together to resist forces.

reinforcement displacement — movement of reinforcing steel from its specified position in the forms.

reinforcement ratio — ratio of the effective area of the reinforcement to the effective area of the concrete at any section of a structural member.

reinforcement, auxiliary — in a prestressed member, any reinforcement in addition to that participating in the prestressing function.

reinforcement, axle-steel — either plain or deformed reinforcing bars rolled from axle steel.

reinforcement, cold-drawn wire — steel wire made from rods that have been hot rolled from billets, cold-drawn through a die; for concrete reinforcement of diameter not less than

reinforcement, cold-worked steel — steel bars or wires that have been rolled, twisted, or drawn at normal ambient temperatures.

reinforcement, compression — reinforcement designed to carry compressive stresses.

reinforcement, corner — metal reinforcement for plaster at reentrant corners to provide continuity between two intersecting planes; or concrete reinforcement used at wall intersections or near corners of square or rectangular openings in walls, slabs, or beams.

reinforcement, crack-control — reinforcement in concrete construction designed to minimize opening of cracks, often effective in limiting them to uniformly distributed small cracks.

reinforcement, curtain — a mat of orthogonal reinforcing steel in a member such as a wall; known as a double curtain (of reinforcement) when a mat is at each face.

reinforcement, deformed — metal bars, wire, or fabric with a manufactured pattern of surface ridges that provide a locking anchorage with surrounding concrete.

reinforcement, distribution-bar — small diameter bars, usually at right angles to the main reinforcement, intended to spread a concentrated load on a slab and to prevent cracking.

reinforcement, edge-bar — tension steel sometimes used to strengthen otherwise inadequate edges in a slab without resorting to edge thickening.

reinforcement, four-way — a system of reinforcement in flat slab construction comprising bands of bars parallel to two adjacent edges and also to both diagonals of a rectangular slab.

reinforcement, heavy-edge — wire-fabric reinforcement for highway pavement slabs having one to four edge wires heavier than the other longitudinal wires.

reinforcement, helical — steel reinforcement of hot-rolled bar or cold-drawn wire fabricated into a helix (more commonly known as spiral reinforcement).

reinforcement, hoop — a one-piece closed tie or continuously wound tie not less than No. 3 in size, the ends of which have a standard 135 degree bend with a ten-bar diameter extension, which encloses the longitudinal reinforcement.

reinforcement, lateral — transverse reinforcement, usually applied to ties, hoops, and spirals in columns or column-like members.

reinforcement, longitudinal — reinforcement parallel to the length of a concrete member or pavement.

reinforcement, negative — steel reinforcement for negative moment.

reinforcement, nonprestressed — reinforcing steel, not subjected to either pretensioning or post-tensioning.

reinforcement, positive — reinforcement for positive moment.

reinforcement, rail-steel — reinforcing bars hot-rolled from standard T-section rails.

reinforcement, shear — reinforcement designed to resist shear or diagonal tension stresses.

reinforcement, shrinkage — reinforcement designed to resist shrinkage stresses in concrete.

reinforcement, spiral — continuously wound reinforcement in the form of a cylindrical helix.

reinforcement, temperature — reinforcement designed to carry stresses resulting from temperature changes; also the minimum reinforcement for areas of members that are not subjected to primary stresses or necessarily to temperature stresses.

reinforcement, tension — reinforcement designed to carry tensile stresses such as those in the bottom of a simple beam.

reinforcement, transverse — reinforcement at right angles to the longitudinal reinforcement.

reinforcement, twin-twisted bar — two bars of the same nominal diameter twisted together.

reinforcement, two-way — reinforcement arranged in bands of bars at right angles to each other.

reinforcement, web — reinforcement placed in a concrete member to resist shear and diagonal tension.

reinforcement, welded — reinforcement joined together by welding.

reinforcement, welded-wire fabric — welded-wire fabric in either sheets or rolls, used to reinforce concrete.

relative humidity — the ratio of the quantity of water vapor actually present to the amount present in a saturated

release, partial — release into a prestressed-concrete member of a portion of the total prestress initially held wholly in the prestressed reinforcement.

remoldability — the readiness with which freshly mixed concrete responds to a remolding effort such as jigging or vibration, causing it to reshape its mass around reinforcement and to conform to the shape of the form.

render — to apply a coat of mortar by a trowel or float.

repair — to replace or correct deteriorated, damaged, or faulty materials, components, or elements of a structure.

repair system — the combination of materials and techniques used in the repair of a structure.

repair, structural — increasing the load-carrying capacity of a structural component beyond its current capacity or restoring a damaged structural component to its original

repeatability — variability among replicate test results obtained on the same material within a single laboratory by one operator; a quantity that will be exceeded in only about 5% of the repetitions by the difference, taken in absolute value, of two randomly selected test results obtained in the same laboratory on a given material; in use of the term, variable factors should be specified.

reproducibility — variability among replicate test results obtained on the same material in different laboratories; a quantity that will be exceeded in only about 5% of the repetitions by the difference, taken in absolute value, of two single test results made on the same material in two different, randomly selected laboratories; in use of the term, variable factors should be specified.

reservoir — Any basin that contains or will contain the water impounded by a dam.

reservoir capacity: The sum of the dead and live storage of the reservoir.

reservoir Routing — The procedures used to determine the attenuating effect of reservoir storage on a flood as it passes through a reservoir.

reservoir surface area — The area covered by a reservoir when filled to a specified level.

resetting (of forms) — setting of forms separately for each successive lift of a wall to avoid offsets at construction joints.

reshore — a temporary support placed against the bottom of a slab or other structural member immediately after the forms and original shores have been removed.

residual strength, test specimen — strength in the post-peak load region of a static load-deflection curve.

resilience — the work done per unit volume of a material in producing strain.

resin — generally a thermosetting polymer used as the matrix and binder in FRP composites.

resin, acrylic — one of a group of thermoplastic resins formed by polymerizing the esters or amides of acrylic acid used to make polymer-modified concrete and polymer concretes;

resin, epoxy — a class of organic chemical bonding systems used in the preparation of special coatings or adhesives for concrete or as binders in epoxy-resin mortars, concretes, and fiber reinforced polymer composites.

resin, phenolic — a class of synthetic, oil-soluble resins (plastics) produced as condensation products of phenol, substituted phenols and formaldehyde, or some similar aldehyde that may be used in paints for concrete.

resin, polystyrene — synthetic resins, varying from colorless to yellow, formed by the polymerization of styrene on heating with or without catalysts, that may be used in paints for concrete, or for making sculptured molds, or as insulation.

resistance —

resistance, abrasion — ability of a surface to resist being worn away by rubbing and friction.

resistance, fire — the property of a material or assembly to withstand fire or give protection from it; as applied to elements of buildings, it is characterized by the ability to confine a fire or, when exposed to fire, to continue to perform a given structural function, or both.

resistance, penetration — the resistance, usually expressed in pounds per square inch (psi) or megapascals (MPa), of either mortar or cement paste to penetration by a plunger or needle under standard conditions, such as to determine time of setting.

resistance, skid — a measure of the frictional characteristics of a surface.

resistance, sulfate — ability of concrete or mortar to withstand sulfate attack. **resistance, thermal** — the reciprocal of thermal conductance expressed by the symbol ***R***.

responsible engineer — Person with appropriate qualifications and experience responsible for the supervision of construction, or subsequent raising of the tailings dam. Ideally this should be the Designer, or if not, a well-defined linkage between the design and supervision personnel should be developed to ensure that design requirements are met by the construction and operational phases.

restoration — the process of reestablishing the materials, form, and appearance of a structure to those of a particular era of the structure.

restraint (of concrete) — restriction of free movement of fresh or hardened concrete following completion of placing in formwork or molds or within an otherwise confined space; restraint can be internal or external and may act in one or more directions.

retardation — reduction in the rate of either hardening, setting, or both, that is, an increase in the time required to reach time of initial and final setting or to develop early strength of fresh concrete, mortar, or grout.

retarder — an admixture that delays the setting of cement paste, and of mixtures, such as mortar or concrete, containing cement.

retarder, surface — a retarder applied to the contact surface of a form or to the surface of newly placed concrete, to delay setting of the cement, to facilitate construction joint cleanup, or to facilitate production of exposed-aggregate finish.

retemper — to add water and remix a cementitious mixture to restore workability to a condition in which the mixture is placeable or usable.

reveal (n.) — the vertical surface forming the side of an opening in a wall, as for a window or door; depth of exposure of aggregate in an exposed aggregate finish.

revibration — one or more applications of vibration to fresh concrete after completion of placing and initial consolidation but preceding initial setting of the concrete.

rheology — the science dealing with flow of materials, including studies of deformation of hardened concrete, the handling and placing of freshly mixed concrete, and the behavior of slurries, pastes, and the like.

rib — one of a number of parallel structural members backing sheathing; the portion of a T-beam which projects below the slab; in deformed reinforcing bars, the deformations or the longitudinal parting ridge.

ribbon — a narrow strip of wood or other material used in formwork.

rich mixture — a concrete mixture containing a high proportion of cement.

rigidity, flexural — a measure of stiffness of a member, indicated by the product of modulus of elasticity and moment of inertia divided by the length of the member.

ring, air — perforated manifold in nozzle of wet-mix shotcrete equipment through which high pressure air is introduced into the material flow.

ring, proving — a device for calibrating load indicators of testing machines, consisting of a calibrated elastic ring and a mechanism or device for indicating the magnitude of deformation under load.

riprap — A layer of large uncoursed stone, precast blocks, bags of cement or other suitable material, generally placed on the upstream slopes of an embankment or along a watercourse as protection against wave action, erosion or scour. Riprap is usually placed by dumping or other mechanical methods and in some cases is hand placed. It consists of pieces of relatively large size as distinguished from a gravel blanket.

risk — The relationship between the consequences resulting from an adverse event and its probability of occurrence.

risk assessment — As applied to dam safety, the process of identifying the likelihood and consequences of dam failure to provide the basis for informed decisions on a course of action.

risk management process — systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk.

rock pocket — a porous, mortar-deficient portion of hardened concrete consisting primarily of coarse aggregate and open voids; caused by leakage of mortar from the form, separation (segregation) during placement, or insufficient consolidation.

rock; shear stress at the surface of a reinforcing bar, preventing relative movement between the bar and the surrounding concrete when the bar carries tensile force.

rockfill dam: An embankment dam in which more than 50% of the total volume is comprised of compacted or dumped cobbles, boulders, rock fragments, or quarried rock generally larger than 76mm size.

rod — (1) a tool that is used as a straightedge or screed to provide a uniform and even surface across a plaster coat usually by trimming to a ground or dot; (2) a tool used as a guide for a scoring (combed) finish or similar repeating pattern finish; or (3) a sharp-edged cutting screed used to trim shotcrete to forms or ground wires.

rod buster (colloquial) — one who installs reinforcement for concrete.

rod, pencil — plain metal rod of about 6 mm diameter.

rod, tamping — a straight steel rod of circular cross-section and having one or both ends rounded to a hemispherical tip.

rodability — the susceptibility of fresh concrete or mortar to consolidation by means of a tamping rod.

rodding — consolidation of concrete by means of a tamping rod.

rodding, dry — in measurement of the mass per unit volume of coarse aggregates, the process of consolidating dry material in a calibrated container by rodding under standardized conditions.

r**oller compacted concrete dam**: A concrete gravity dam constructed by the use of a dry mix concrete transported by conventional construction equipment and compacted by rolling, usually with vibratory rollers.

roller compaction — a process for compacting concrete using a roller, often a vibratory roller.

rolling — the use of heavy metal or stone rollers on terrazzo topping to extract excess matrix.

roof, barrel-vault — a thin concrete roof in the form of a part of a cylinder.

rough grind — the initial operation in which coarse abrasives are used to reduce the projecting stone chips in hardened terrazzo down to a level surface.

rout — to deepen and widen a crack to prepare it for patching or sealing.

rubble — rough stones of irregular shape and size, broken from larger masses by geological processes or by quarrying; concrete reduced to irregular fragments, as by demolition or natural catastrophe.

rule curve — The rules and procedures used to regulate reservoir levels and project operation for various reservoir inflows and for both normal and unusual seasonal conditions.

runway — decking over area of concrete placement, usually of movable panels and supports, on which buggies of concrete travel to points of placement.

rustication — a groove in a concrete surface.

S

sack rub — a finish for formed concrete surfaces, designed to produce even texture and fill pits and air holes; after dampening the surface, mortar is rubbed over the surface; then, before the surface dries, a mixture of dry cement and sand is rubbed over it with either a wad of burlap or a sponge-rubber float to remove surplus mortar and fill voids.

saddle dam (or dike): A subsidiary dam of any type constructed across a saddle or low point on the perimeter of a reservoir.

safety evaluation flood (SEF) — The largest flood for which the safety of a dam and appurtenant structure is to be evaluated.

sample — either a group of units, or portion of material, taken respectively from a larger collection of units or a larger quantity of material, that serves to provide information that can be used as a basis for action on the larger collection or quantity or on the production process; the term is also used in the sense of a sample of observations.

sample, composite — sample obtained by blending two or more individual samples of a material.

sampling plan — a procedure that specifies the number of units of product from a lot that is to be inspected to establish acceptability of the lot; and

sampling, continuous— sampling without interruptions throughout an operation or for a predetermined time.

sampling, intermittent — sampling successively for limited periods of time throughout an operation or for a predetermined period of time; the duration of sampling periods and the

sand — granular material passing the 9.5 mm sieve and almost entirely passing the 4.75 mm sieve and predominantly retained on the 75 µm (No. 200) sieve, and resulting either from natural disintegration and abrasion of rock or processing of completely friable sandstone; and that portion of an aggregate passing the 4.75 mm (No. 4) sieve and predominantly retained on the 75 µm (No. 200) sieve, and resulting either from natural disintegration and abrasion of rock or processing of completely friable sandstone. Note: the definitions are alternatives to be applied under differing circumstances.

sand box (or sand jack) — a tight box filled with clean, dry, sand on which rests a tight-fitting timber plunger that supports the bottom of posts used in centering; removal of a plug from a hole near the bottom of the box permits the sand to run out when it is necessary to lower the centering.

sand equivalent — a measure of the relative proportions of detrimental fine dust or claylike material or both in soils or fine aggregate.

sand plate — a flat steel plate or strip welded to the legs of bar supports for use on compacted soil.

sand pocket — a zone in concrete or mortar containing fine aggregate with little or no cement.

sand streak — a streak of exposed fine aggregate in the surface of formed concrete, caused by bleeding.

sand, natural — sand resulting from natural disintegration and abrasion of rock.

sand, sharp — coarse sand consisting of particles of angular shape.

sand, standard — (silica sand, composed almost entirely of naturally rounded grains of nearly pure quartz, used for preparing mortars in the testing of hydraulic cements. Note: standard sand is produced in two gradings. (a) 20-30 sand — standard sand, predominantly graded to pass a 850 µm (No. 20) sieve and be trained on a 600 µm (No. 30) sieve and the 150 µm No. 100) sieve. (b) graded sand — standard sand, predominantly graded between the 600 μm (No. 30) sieve and the 150 μm (No. 100) sieve).

sand, stone — fine aggregate resulting from the mechanical crushing and processing of rock.

sandblast — a system of cutting or abrading a surface such as concrete by a stream of sand ejected from a nozzle at high speed by compressed air; often used for cleanup of horizontal construction joints or for exposure of aggregate in architectural concrete.

sand-coarse aggregate ratio — ratio of fine to coarse aggregate ina batch of concrete, by mass or by volume.

sandstone — a cemented or otherwise indurated sedimentary rock composed predominantly of sand grains.

Santorin earth — a volcanic tuff originating on the Grecian island of Santorin and used as a pozzolan.

saponification — the alkaline hydrolysis of fats forming a soap, more generally the hydrolysis of an ester by an alkali with the formation of an alcohol and a salt of the acid portion.

saturated surface-dry — condition of an aggregate particle or other porous solid when the permeable voids are filled with water and no water is on the exposed surfaces.

saturated surface-dry (SSD) particle density — the mass of the saturated surface-dry aggregate divided by its displacement volume in water or in concrete.

saturation — (1) in general: the condition of coexistence in stable equilibrium of either a vapor and a liquid or a vapor and solid phase of the same substance at the same temperature; and (2) as applied to aggregate or concrete: the condition such that no more liquid can be held or placed within it.

saturation, critical — a condition describing the degree of filling by freezable water of a pore space in cement paste or aggregate that affects the response of the material to freezing; usually taken to be 91.7% because of the 9% increase in volume of water undergoing the change of state to ice.

saturation, vacuum — a process for increasing the amount of filling of the pores in a porous material, such as lightweight aggregate, with a fluid, such as water, by subjecting the porous material to reduced pressure while immersed in the fluid.

sawcut — a cut in hardened concrete made using abrasive blades or discs.

scab — a short piece of wood fastened to two formwork members to secure a butt joint.

scaffolding — a temporary structure for the support of deck forms, cartways, or workers, or a combination of these, such as an elevated platform for supporting workers, tools, and materials; adjustable metal scaffolding is frequently adapted for shoring in concrete work.

scale — the oxide formed on the surface of metal during heating.

scaling — local flaking or peeling away of the near-surface portion of hardened concrete or mortar; also of a layer from metal.

scalper — a sieve for removing oversize particles.

scalping — the removal of particles larger than a specified size by sieving.

schist — a finely layered metamorphic rock that splits easily and in which the grain is coarse enough to permit identification of the principal minerals.

scoria — vesicular volcanic ejecta of larger size, usually of basic composition and characterized by dark color; the material is relatively heavy and partly glassy, partly crystalline; the vesicles do not generally interconnect.

scour — erosion of a concrete surface, exposing the aggregate.

screed — 1. to strike off concrete lying beyond the desired plane or shape; and 2. a tool for striking off the concrete surface, sometimes referred to as a strikeoff.

screed, cutting — sharp-edged tool used to trim shotcrete to the finished outline. **screed guide** — firmly established grade strips or side forms for unformed concrete that guide the strike off in producing the desired plane or shape.

screeding — the operation of forming a surface using a screed.

screen — production equipment for separating granular material according to size, using woven-wire cloth or other similar device with regularly spaced apertures of uniform size.

screens, finish — vibrating screens (preferably horizontal) operated at a batching plant so that excessive amounts of significant undersize material are removed and delivered directly

screw, adjustment — a leveling device or jack composed of a threaded screw and an adjusting handle; used for the vertical adjustment of shoring and formwork.

sealant, joint — compressible material used to exclude water and solid foreign materials from joints.

sealer — a liquid that is applied to the surface of hardened concrete to either prevent or decrease the penetration of liquid or gaseous media, for example water, aggressive solutions, and carbon dioxide, during service exposer, that is absorbed by the concrete, is colorless, and leaves little or nothing visible on the surface.

secondary nuclear vessel — exterior container or safety container in a nuclear reactor subjected to design load only once in its lifetime, if at all.

section, transformed — a hypothetical section of one material arranged so as to have the same elastic properties as a section of two or more materials.

segregation — (1) nonuniform concentration of components in concrete or mortar; or (2) nonuniform distribution of size fractions in a mass of aggregate).

self-desiccation — the removal of free water by chemical reaction so as to leave insufficient water to cover the solid surfaces and cause a decrease in the relative humidity of the system; applied to an effect occurring in sealed concretes, mortars, and pastes.

self-furring — metal lath or welded-wire fabric formed in the manufacturing process to include means by which the material is held away from the supporting surface, thus creating a space for "keying" of the insulating concrete, plaster, or stucco.

self-furring nail — nails with flat heads and a washer or a spacer on the shank; for fastening reinforcing wire mesh and spacing it from the nailing member.

selvage — a finished edge of woven-wire screen cloth produced in the weaving process of the finer meshes.

sensor — a device designed to respond to a physical stimulus (as temperature, illumination, and motion) and transmit a resulting signal for interpretation, measurement, or for operating a control.

separation — (1) divergence from the mass and differential accumulation of coarse aggregate during movement of the concrete; (2) divergence from the mass and differential accumulation of large coarse aggregate from the bulk coarse aggregate as it is being moved; or (3) the gravitational settlement of solids from a liquid).

separation, heavy-media — a method in which a liquid or suspension of given specific gravity is used to separate particles into a portion lighter than (those that float) and a portion heavier than (those that sink) the medium.

separator, air — an apparatus that separates various size fractions of ground materials pneumatically; fine particles are discharged as product; oversize is returned to the mill as tailing.

sequence-stressing loss — in post-tensioning, the elastic loss in a stressed tendon resulting from the shortening of the member when additional tendons are stressed.

set (n.) — the condition reached by a cement paste, mortar, or concrete when it has lost plasticity to an arbitrary degree, usually measured in terms of resistance to penetration or deformation; initial set refers to first stiffening; final set refers to attainment of significant rigidity; also, strain remaining after removal of stress.

set, false — the rapid development of rigidity in a freshly mixed portland cement paste, mortar, or concrete without the evolution of much heat, which rigidity can be dispelled and plasticity regained by further mixing without addition of water; premature stiffening, hesitation set, early stiffening, and rubber set are terms referring to the same phenomenon, but false set is the preferred designation.

set, final — a degree of stiffening of a mixture of cement and water greater than initial set, generally stated as an empirical value indicating the time in hours and minutes required for a cement paste to stiffen sufficiently to resist, to an established degree, the penetration of a weighted test needle; also applicable to concrete and mortar mixtures with use of suitable test procedures.

set, flash — the rapid development of rigidity in a freshly mixed portland cement paste, mortar, or concrete, characteristically with the evolution of considerable heat, which rigidity cannot be dispelled nor can the plasticity be regained by further mixing without addition of water; also referred to as quick set or grab set.

set, initial — a degree of stiffening of a mixture of cement and water less than final set, generally stated as an empirical value indicating the time in hours and minutes required for

set, permanent — inelastic elongation or shortening.

set, warehouse — ((1) the partial hydration of cement stored for a time and exposed to atmospheric moisture; and (2) mechanical compaction occurring during storage).

set-control addition — material, composed essentially of calcium sulfate in any hydration state from $CaSO_4$ to $CaSO_4{\cdot}2H_2O$, interground with the clinker during manufacture of cement to modify the setting time of the cement.

setting time — the length of time required to set or harden resin or adhesive under heat or pressure.

setting time, final — the time required for a freshly mixed cement paste, mortar, or concrete to achieve final set.

setting time, initial — the time required for a freshly mixed cement paste, mortar, or concrete to achieve initial set.

settlement — sinking of solid particles in grout, mortar, or fresh concrete, after placement and before initial set.

settling — the lowering in elevation of sections of pavement or

shale — a laminated and fissile sedimentary rock, the constituent particles of which are principally in clay and silt sizes; the laminations are bedding planes of the rock.

shale, expanded (clay or slate) — lightweight vesicular aggregate obtained by firing suitable raw materials in a kiln or on a sintering grate under controlled conditions.

shear — an internal force tangential to the plane on which it acts.

shearhead — assembled unit in the top of the columns of flat slab or flat plate construction to transmit loads from slab to column.

shearwall — a wall portion of a structural frame intended to resist lateral forces, such as earthquake, wind, and blast, acting in the plane of the wall.

sheath — an enclosure in which post-tensioning tendons are encased to prevent bonding during concrete placement.

sheathing — the material forming the contact face of forms; also called lagging or sheeting.

shelf angles — structural angles with holes or slots in one leg for bolting to the structure to support brick work, stone, or terra cotta.

shim — a strip of metal, wood, or other material employed to set base plates or structural members at the proper level for placement of grout, or to maintain the elongation in some types of post-tensioning anchorages.

shiplap — a type of joint in lumber or precast concrete, made by using pieces having a portion of the width cut away on both edges, but on opposite sides, so as to make a flush joint with similar pieces.

shock, thermal — the subjection of newly hardened concrete to a rapid change in temperature that may be expected to have a potentially deleterious effect.

shoot wire — a wire running across the width of the sieve cloth, as woven; also known as fill, filler, weft, or woof wire.

shore — a temporary support for formwork and fresh concrete or for recently built structures that have not developed full design strength; also called prop, tom, post, strut.

shore head — wood or metal horizontal member placed on and fastened to vertical shoring member.

shore, post — individual vertical member used to support loads; also known as pole shore.((1) adjustable timber single-post shore — individual timber used with a fabricated clamp to obtain adjustment and not normally manufactured as a complete unit; (2) fabricated single-post shore — Type I: single all-metal post, with a fine-adjustment screw or device in combination with pin-and-hole adjustment or clamp; Type II: single or double wooden post members adjustable by a metal clamp or screw and usually manufactured as a complete unit; and (3) timber single-post shore — timber used as a structural member for shoring support).

shoring — props or posts of timber or other material in compression used for the temporary support of excavations, formwork, or unsafe structures; the process of erecting shores.

shoring layout — a drawing prepared before erection showing arrangements of equipment for shoring.

shoring, horizontal — metal or wood load-carrying strut, beam, or trussed section used to carry a shoring load from one bearing point, column, frame, post, or wall to another; may be adjustable.

shortening, elastic — in prestressed concrete, the shortening of a member that occurs immediately on the application of forces induced by prestressing.

shotcrete — concrete placed by a high velocity pneumatic projection from a nozzle.

shotcrete, dry-mix— shotcrete in which most of the mixing water is added at the nozzle.

shotcrete, wet-mix — shotcrete in which the ingredients, including water, are mixed before introduction into the delivery hose.

shoulder — an unintentional offset in a formed concrete surface usually caused by bulging or movement of formwork.

shrinkage — decrease in either length or volume.

shrinkage or displacement of the support.

shrinkage, carbonation — shrinkage resulting from carbonation.

shrinkage, drying — shrinkage resulting from loss of moisture.

shrinkage, initial drying —the difference between the length of a specimen (molded and cured under stated conditions) and its length when first dried to constant length, expressed as a percentage of the moist length.

shrinkage, plastic — shrinkage that takes place before cement paste, mortar, grout, or concrete sets.

shrinkage, settlement — a reduction in volume of concrete before the final set of cementitious mixtures, caused by settling of the solids and displacement of fluids.

shrinkage-compensating — a characteristic of grout, mortar, or concrete made using expansive cement in which volume increases after setting, and if properly elastically restrained, induces compressive stresses that are intended to approximately offset the tendency of drying shrinkage to induce tensile stresses.

shrink-mixed concrete — see **concrete, shrink-mixed**.

SI (Système International) — the modern metric system.

side, pilaster — the form for the side surface of a pilaster perpendicular to the wall.

sieve — a metallic plate or sheet, a woven-wire cloth, or other similar device, with regularly spaced apertures of uniform size, mounted in a suitable frame or holder for use in separating

sieve correction — correction of a sieve analysis to adjust for deviation of sieve performance from that of standard calibrated sieves.

sieve fraction — that portion of a sample that passes through a standard sieve of specified size and is retained by some finer sieve of specified size.

sieve number — a number used to designate the size of a sieve, usually the approximate number of openings per linear inch; applied to sieves with openings smaller than 6.3 mm

sieve size — nominal size of openings between cross wires of a testing sieve.

significant (statistically significant) — values of a test statistic that lie outside of predetermined limits of test precision and so taken to indicate a difference between populations.

silica — silicon dioxide (SiO_2).

silica flour — very finely divided silica, a siliceous binder component that reacts with lime under autoclave curing conditions; prepared by grinding silica, such as quartz, to a fine powder; also known as silica powder.

silica fume — very fine non crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon.

silicate — salt of a silicic acid.

silicon carbide — an artificial product (SiC), granules of which may be embedded in concrete surfaces to increase resistance to wear or as a means of reducing skidding or slipping on stair treads or pavements; also used as an abrasive in saws and drills for cutting concrete and masonry, and as abrasive grit in a range of particle sizes.

silicone — a resin, characterized by water-repellent properties, in which the main polymer chain consists of alternating silicon and oxygen atoms, with carbon-containing side groups; silicones may be used in caulking or coating compounds or as admixtures for concrete.

silt — a granular material resulting from the disintegration of rock, with grains largely passing a 75 µm (No. 200) sieve; alternatively, such particles in the range from 2 to 50 µm diameter.

sinter — a ceramic material or mixture fired to less than complete fusion, resulting in a coherent mass; also the process involved.

sintering — the formation of a porous mass of material by the agglomeration of fine particles during particle fusion.

sintering grate — a grate on which material is sintered.

skew back — sloping surface against which the end of an arch rests, such as a concrete thrust block supporting thrust of an arch bridge.

slab — a molded layer of plain or reinforced concrete, flat, horizontal (or nearly so), usually of uniform but sometimes of variable thickness, either on the ground or supported by beams, columns, walls, or other framework.

slab, flat — a concrete slab reinforced in two or more directions and having drop panels or column capitals or both.

slabjacking — the process of either raising concrete pavement slabs or filling voids under them, or both, by injecting a material (cementitious, non cementitious, or asphaltic) under pressure.

slab-on-ground — a slab cast directly on the ground. May be structural or non-structural. Structural slabs-on-ground are a required part of a load path which transmits vertical or lateral loads to the ground and must conform to applicable structural building codes. Non-structural slabs-on-ground serve only as an architectural wearing surface and are not subject to structural building code requirements.

slate — a fine-grained metamorphic rock possessing a well developed fissility (slaty cleavage), usually not parallel to the bedding planes of the rock.

sleeve — ((1) a pipe or tube passing through formwork for a wall or slab through which pipe, wires, or conduit can be passed after the forms have been stripped; and (2) a device used around an anchor to accommodate adjustment and preloading of the anchor after the concrete has hardened).

sleeve, expansion — a tubular metal covering for a dowel bar to allow its free longitudinal movement at a joint.

slenderness ratio — the effective unsupported length of a uniform column divided by the least radius of gyration of the cross sectional area.

slick line — end section of a pipe line used in placing concrete by pump which is immersed in the placed concrete and moved as the work progresses.

slimes — silt or clay size material, usually with a high water content.

slip — movement occurring between steel reinforcement and concrete in stressed reinforced concrete, indicating anchorage breakdown.

slipform — a form that is pulled or raised as concrete is placed; may move in a generally horizontal direction to lay concrete evenly for highway paving or on slopes and inverts of canals, tunnels, and siphons; or may move vertically to form walls, bins, or silos.

slope — Inclination from the horizontal. Sometimes referred to as batter when measured from vertical.

sloughing — subsidence of shotcrete, plaster, or the like, generally due to excessive water in the mixture; also called sagging.

slugging — pulsating and intermittent flow of shotcrete material due to improper use of delivery equipment and materials.

slump — a measure of consistency of freshly mixed concrete, mortar, or stucco equal to the subsidence measured to the nearest 5 mm of the molded specimen immediately after removal of the slump cone.

slurry — a mixture of water and any finely divided insoluble material, such as portland cement, slag, or clay in suspension.

slurry density (or Bulk Density or Pulp Density) — total mass of slurry per unit of total volume of the solids plus liquids.

smectite — a group of clay minerals, including montmorillonite, characterized by a sheet-like internal atomic structure; consisting of extremely finely-divided hydrous aluminum or

snap tie — a proprietary concrete wall-form tie, the end of which can be twisted or snapped off after the forms have been removed.

soffit — the underside of a part or member of a structure, such as a beam, stairway, or arch.

soft particle — an aggregate particle possessing less than an established degree of hardness or strength as determined by a specific testing procedure.

soil — a generic term for unconsolidated natural surface material above bedrock.

soil cement — a mixture of soil and measured amounts of portland cement and water, compacted to a high density.

soil stabilization — chemical or mechanical treatment designed to either increase or maintain the stability of a mass of soil or otherwise to improve its engineering properties.

soil, coarse-grained — soil in which the larger grain sizes, such as sand and gravel, predominate.

soil, fine-grained — soil in which the smaller grain sizes predominate, such as fine sand, silt, and clay.

soldier — a vertical wale used to strengthen or align formwork or excavations.

solid masonry unit — a unit whose net cross-sectional area in every plane parallel to the bearing surface is 75% or more of its gross cross-sectional area measured in the same plane.

solids content (or concentration) — mass of solids as a percentage of the combined mass of solids plus liquids in a slurry.

solubility — the amount of one material that will dissolve in another, generally expressed as mass percent, or as volume percent, or parts per 100 parts of solvent by mass or volume at a specified temperature.

solution — a liquid consisting of at least two substances, one of which is a liquid solvent in which the other or others, that may be either solid or liquid, are dissolved.

sounding well — a vertical conduit in the mass of coarse aggregate for preplaced-aggregate concrete, provided with continuous or closely spaced openings to permit entrance of grout; the grout level is determined by means of a float on a measured line.

soundness — the freedom of a solid from cracks, flaws, fissures, or variations from an accepted standard; in the case of a cement, freedom from excessive volume change after setting; in he case of aggregate, the ability to withstand the aggressive action to which concrete containing it might be exposed, particularly that due to weather.

space, capillary — void space in concrete resembling microscopic channels small enough to draw liquid water through them by the molecular attraction of the water adsorbed on their inner surfaces.

spacer — device that maintains reinforcement in proper position, also a device for keeping wall forms apart at a given distance before and during concreting.

spacer, slab — bar support and spacer for slab reinforcement; similar to slab bolster but without corrugations in top wire; no longer in general use.

spading — consolidation of mortar or concrete by repeated insertion and withdrawal of a flat, spade like tool.

spall — a fragment, usually in the shape of a flake, detached from a larger mass by a blow, the action of weather, pressure, or expansion within the larger mass.

spalling — the development of spalls.

span — distance between the support reactions of members carrying transverse loads.

span, effective — the lesser of the two following distances: a) the distance between supports; or b) the clear distance between supports plus the effective depth of the beam or slab.

span-depth ratio — the numerical ratio of total span to member depth.

spandrel — that part of a wall between the head of a window and the sill of the window above it.

Spatter dash — a rich mixture of portland cement and coarse sand; it is thrown onto a background by a trowel, scoop, or other appliance so as to form a thin, coarse-textured, continuous coating; as a preliminary treatment before rendering, it assists bond of the undercoat to the background, improves resistance to rain penetration, and evens out the suction of variable backgrounds.

specific gravity — (**specific gravity, absolute** — ratio of the mass (referred to a vacuum) of a given volume of a solid or liquid at a stated temperature to the mass (referred to a vacuum) of an equal volume of gas-free distilled water at a stated temperature; **specific gravity, apparent** — the ratio of the mass of a volume of the impermeable portion of a material at a stated temperature to the mass of an equal volume of distilled water at a stated temperature; **specific gravity, bulk** — the ratio of the mass of a volume of a material (including the permeable and impermeable voids in the material, but not including the voids between particles of the material) at a stated temperature to the mass of an equal

specific gravity factor — the ratio of the mass of aggregates (including moisture), as introduced into the mixer, to the effective volume displaced by the aggregates).

specific heat — the amount of heat required per unit mass to cause a unit rise of temperature, over a small range of temperature.

specification (in ASTM) — an explicit set of requirements to be satisfied by a material, product, system, or service.

specification, performance-based — a specification in which the requirements are stated in terms of required results with criteria for verifying compliance rather than specific composition, design, or procedure.

specimen — a piece or portion of a sample used to make a test.

spectrophotometer — instrument for measuring intensity of radiant energy of desired frequencies absorbed by atoms or molecules; substances are analyzed by converting the absorbed energy to electrical signals, proportional to the intensity of radiation.

spectroscopy, infrared — the use of a spectrophotometer for determination of infrared absorption spectra (2.5 to 18 μm wave lengths) of materials; used for detection, determination, and identification especially of organic materials.

speed, agitating — the rate of rotation of the drum of a truck mixer or agitator when used for agitating mixed concrete.

spillway — A channel structure and/or conduit for the safe release of surplus water or floodwater. s**pillway channel** — An open channel or closed conduit conveying water from the spillway inlet downstream. **spillway chute** — A steeply sloping spillway channel that conveys discharges at super-critical velocities. **spillway crest** — The lowest level at which water can flow over or through the spillway. **spillway, shaft** — A vertical or inclined shaft into which water spills and then is conveyed through, under, or around a dam by means of a conduit or tunnel. If the upper part of the shaft is splayed out and terminates in a circular horizontal weir, it is termed a bellmouth or morning glory spillway).

spinning — the essential factor of the process of producing spun concrete.

splice — connection of one reinforcing bar to another by lapping, welding, mechanical couplers, or other means; connection of welded-wire fabric by lapping; connection of piles by mechanical couplers.

splice, contact — a means of connecting reinforcing bars in which the bars are lapped and in direct contact.

splice, lap — a connection of reinforcing steel made by lapping the ends of bars.

splice, welded-butt — a reinforcing bar splice made by welding the butted ends.

split-batch charging — method of charging a mixer in which the solid ingredients do not enter the mixer together; cement, and sometimes different sizes of aggregate, may be added separately.

split-face block — a concrete masonry unit with one or more faces purposely fractured to provide architectural effects in masonry wall construction.

splitting tensile test (diametral compression test) — a test for tensile strength in which a cylindrical specimen is loaded to failure in diametral compression applied along the entire length.

spray drying — a method of evaporating the liquid from a solution or dispersion by spraying it into a heated gas.

sprayed mineral fiber — a blend of mineral fibers and inorganic binders, to which water is added during the spraying operation.

spread footing — a generally rectangular prism of concrete, larger in lateral dimensions than the column or wall it supports, to distribute the load of a column or wall to the subgrade.

spreader — (1) a piece of lumber, usually about 1 by 2 in. (25 by 50 mm), cut to the thickness of a wall or other formed element and inserted in the form to hold it temporarily at the correct dimension against tension of form ties; wires are usually attached to spreaders so they can be pulled up out of the forms as the pressure of concrete permits their removal; and (2) a device consisting of reciprocating paddles, a revolving screw, or other mechanism for distributing concrete to required uniform thickness in a paving slab.

spreader, concrete — a machine, usually carried on side forms or on rails parallel thereto, designed to spread concrete from heaps already dumped in front of it, or to receive and spread concrete in a uniform layer.

stabilizer — a substance that makes either a solution or suspension more stable, usually by keeping particles from precipitating.

stacking tube — a slender, free-standing tubular structure used to store granular materials; the material is loaded into the top of the tube and spills out of wall openings to make a conical pile surrounding the tube.

standard deviation — the root mean square deviation of individual values from their average.

standard fire test — the test prescribed by ASTM E119.

standard hook — a hook at the end of a reinforcing bar made in accordance with a standard.

standard matched — tongue-and-groove lumber with the tongue and groove offset rather than centered as in center matched lumber.

standard time-temperature curve — the graphic time table for application of temperature to a material or member for the ASTM E119 fire test.

stationary hopper — a container used to receive and temporarily store freshly mixed concrete.

steam box — enclosure for steam-curing concrete products.

steam-curing cycle — the time interval between the start of the temperature rise period and the end of the soaking period or the cooling-off period; also a schedule indicating the duration of and the temperature range of the periods that make up the cycle.

steam-curing room — a chamber for steam curing of concrete products at atmospheric pressure.

stearic acid — a white crystalline fatty acid, obtained by saponifying tallow or other hard fats containing stearin.

steel sheet — cold-formed sheet or strip steel shaped as a structural member for the purpose of carrying the live and dead loads in lightweight concrete roof construction.

steel, axle — steel from carbon-steel axles for railroad cars.

steel, billet — steel, either produced directly from ingots or continuously cast, made from properly identified heats of open-hearth, basic oxygen, or electric-furnace steel, or lots of acid Bessemer steel and conforming to specified limits on chemical composition.

steel, high-strength — steel with a high yield point; in the case of reinforcing bars 60,000 psi (414 MPa) and greater.

steel, prestressing — high-strength steel used to prestress concrete, commonly seven-wire strands, single wires, bars, rods, or groups of wires or strands.

stiffening, early — the early development of an abnormal reduction in the working characteristics of a hydraulic-cement paste, mortar, or concrete, which may be further described as false set, quick set, or flash set.

stiffness — resistance to deformation.

stilling basin — A basin constructed to dissipate the energy of rapidly flowing water, e.g., from a spillway or outlet, and to protect the riverbed from erosion.

stirrup — bar or wire reinforcement oriented normal to or at an acute angle to the longitudinal reinforcement in a flexural member and extending as close as practical to the extreme tension and compression fibers of the cross section.

stoichiometric — characterized by or being a proportion of substances or energy in a specific chemical reaction in which there is no excess of any reactant or product; and proportioning based on atomic or molecular weigh).

stone, cast — concrete or mortar cast into blocks or small slabs in special molds so as to resemble natural building stone.

stone, crushed — the product resulting from the artificial crushing of rocks, boulders, or large cobblestones, substantially all faces of that possess well-defined edges resulting from the crushing operation

stoplogs — Large logs, timbers, or steel beams placed on top of each other with their ends held in guides on each side of a channel or conduit so as to provide a cheaper or more easily handled means of temporary closure than a bulkhead gate.

storage — The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel. Definitions of specific types of storage in reservoirs are.

storage sapacity — The potential containment capacity of the facility, usually referred to in units of dry tonnes. This requires knowledge of the in-situ dry density of the tailings likely to be achieved in the storage.

straightedge —((1) a rigid, straight piece of either wood or metal used to strike off or screed a concrete surface to proper grade or to check the planeness of a finished grade; and (2) a highway tool for truing surfaces instead of a bull float).

straight-line theory — an assumption in reinforced-concrete analysis according to which the strains and stresses in a member under flexure are assumed to vary in proportion to the

strain — the change in length per unit of length, in a linear dimension of a body; a dimensionless quantity that may be measured conveniently in percent, in inches per inch, in millimeters per millimeters, but preferably in millionths.

strain, unit — deformation of a material expressed as the ratio of linear unit deformation to the distance within which that deformation occurs.

strand — a prestressing tendon composed of a number of wires twisted above the center wire or core.

strand grip — a device used to anchor strands.

strand wrapping — application of high tensile strand, wound under tension by machines, around circular concrete or shotcrete walls, domes, or other tension-resisting structural components.

strand, compacted — prestressing strand that is drawn through a circular die to deform the wires and produce a strand with a smaller circular shape.

strand, indented — strand having machine-made surface indentations intended to improve bond.

stratification — the separation of over wet or over vibrated concrete into horizontal layers with increasingly lighter material toward the top; water, laitance, mortar, and coarse aggregate tend to occupy successively lower positions in that order; a layered structure in concrete resulting from placing of successive batches that differ in appearance; occurrence in aggregate stockpiles of layers of differing grading or composition; a layered structure in a rock foundation.

Stratling's compound — dicalcium aluminate monosilicate-8-hydrate, a compound that has been found in reacted limepozzolan and cement-pozzolan mixtures.

strength — a generic term for the ability of a material to resist strain or rupture induced by external forces.

strength, bond — resistance to separation of mortar and concrete from reinforcing and other materials with which it is in contact; a collective expression for forces such as adhesion, friction due to shrinkage, and longitudinal shear in the concrete engaged by the bar deformations that resist separation.

strength, cold — the compressive or flexural strength of refractory concrete determined before drying or firing.

strength, concrete compressive — the measured maximum resistance of a concrete specimen to axial compressive loading; expressed as force per unit cross sectional area.

strength, cube — the load per unit area at which a standard cube fails when tested in a specified manner.

strength, design — nominal strength multiplied by a strength reduction factor φ.

strength, dried — the compressive or flexural strength of refractory concrete determined within three hours after first drying in an oven at 105 to 110°C for a specified time.

strength, early — strength of concrete or mortar usually as developed at various times during the first 72 hours after placement.

strength, fatigue — the greatest stress that can be sustained for a given number of stress cycles without failure.

strength, fired — the compressive or flexural strength of refractory concrete determined upon cooling after first firing to a specified temperature for a specified time.

strength, flexural — the property of a material or a structural member that indicates its ability to resist failure in bending; in concrete flexural members, the stress at which a section reaches its maximum usable bending capacity; for under-reinforced concrete flexural members, the stress at which the compressive strain in the concrete reaches 0.003;

for over-reinforced concrete flexural members, the stress at which the compressive stress reaches 85% of the cylinder strength of the concrete; for unreinforced concrete members, the stress at which the concrete tensile strength reaches the modulus of rupture.

strength, nominal — strength of a member or cross section calculated in accordance with provisions and assumptions of the strength design method before application of any strength-reduction (φ) factor.

strength, nominal flexural — the flexural strength of a member or cross section calculated in accordance with provisions and assumptions of the strength-design method before application of any strength-reduction (φ) factor.

strength, nominal shear — the shear strength of a member or cross section calculated in accordance with provisions and assumptions of the strength-design method before application of any strength-reduction (φ) factor.

strength, offset yield — the stress at which the strain exceeds, by a specified amount, an extension of the initially proportional part of the stress-strain curve; expressed either as percentage of the original gage length in conjunction with the strength value (yield strength at ... percent offset = ...psi) or as force per unit area (psi) or (MPa).

strength, required — strength of a member or cross section required to resist factored loads or related internal moments and forces in such combinations as are stipulated in the applicable code or specification.

strength, shear — the maximum shearing stress a flexural member can support at a specific location as controlled by the combined effects of shear forces and bending moment.

strength, specified compressive — compressive strength of concrete used in design.

strength, specified concrete compressive — the specified resistance of a concrete specimen to axial compressive loading used in design calculations and as a criterion for material proportioning and acceptance.

strength, specified concrete equivalent — in-place concrete compressive strength adjusted by correction factors that can be directly substituted into conventional strength equations with customary strength reduction factors.

strength, splitting tensile — tensile strength of concrete determined by a splitting tensile test.

strength, tensile — maximum unit stress that a material is capable of resisting under axial tensile loading; based on the cross-sectional area of the specimen before loading.

strength, transfer — the concrete strength required before stress is transferred from the stressing mechanism to the concrete.

strength, yield — the stress at which a material exhibits a specific limiting deviation from the proportionality of stress to strain.

strength-design method — a design method that requires service loads to be increased by specified load factors and computed nominal strengths to be reduced by the specified phi (φ) factors.

stress — force per unit area.

stress corrosion — corrosion of a metal either initiated or accelerated by stress.

stress relaxation — the time-dependent decrease in stress in a material held at constant strain.

stress, allowable — maximum permissible stress used in design of members of a structure and based on a factor of safety against rupture or yielding of any type.

stress, anchorage bond — the bar forces divided by the product of the bar perimeter or perimeters and the embedment length.

stress, bond — the force of adhesion per unit area of contact between two bonded surfaces, such as concrete and reinforcing steel, or any other material, such as foundation rock; shear stress at the surface of a reinforcing bar, preventing relative movement between the bar and the surrounding concrete when the bar carries tensile force.

stress, final — in prestressed concrete, the stress that exists after substantially all losses have occurred.

stress, jacking — the maximum stress occurring in a prestressed tendon during stressing.

stress, mean — the average of the maximum and minimum stress in one cycle of fluctuating loading (as in a fatigue test); tensile stress is considered positive and compressive stress, negative.

stress, normal — the stress component that is perpendicular to the plane on which the force is applied; designated tensile if the force is directed away from the plane and compressive if the force is directed toward the plane.

stress, principal — maximum and minimum stresses at any point acting at right angles to the mutually perpendicular planes of zero shearing stress, which are designated as the principal planes.

stress, proof — stress applied to materials sufficient to produce a specified permanent strain; a specific stress to which some types of tendons are subjected in the manufacturing process as a means of reducing the deformation of anchorage, reducing the relaxation of steel, or ensuring that the tendon is sufficiently strong.

stress, shear — the stress component acting tangentially to a plane.

stress, temperature — stress in a structure or a member due to changes or differentials in temperature in the structure or member.

stress, temporary — a stress that may be produced in a precast concrete member or in a component of a precast-concrete member during fabrication or erection, or in cast-in-place concrete structures due to construction or test loadings.

stress, torsional — the shear stress on a transverse cross section resulting from a twisting action.

stress, working — maximum permissible design stress using working-stress design methods.

stresses, initial — the stresses occurring in prestressed-concrete members before any losses occur.

stresses.

stressing end — in prestressed concrete, the end of the tendon at which the load is applied when tendons are stressed from one end only.

stress-strain diagram — a diagram in which corresponding values of stress and strain are plotted against each other; values of stress are usually plotted as ordinates (vertically) and values of strain as abscissas (horizontally).

stretcher — a masonry unit laid with its length horizontal and parallel with the face of a wall or other masonry member.

strikeoff — to remove concrete in excess of that which is required to fill the form evenly or bring the surface to grade; performed with a straight edged piece of wood or metal by means of a forward sawing movement or by a power operated tool appropriate for this purpose; also the name applied to the tool.

striking — the releasing or lowering of centering or other temporary support.

stringer — a secondary flexural member that is parallel to the longitudinal axis of a bridge or other structure.

strip — to remove formwork or a mold; also a long thin piece of wood, metal, or other material.

strip, chamfer — either a triangular or curved insert placed in an inside form corner to produce either a rounded or flat chamfer or to form a rustication, also called cant strip, fillet, dummy joint, and skew back.

strip, grade — usually a thin strip of wood tacked to the inside surface of forms at the elevation to which the top of the concrete lift is to rise, either at a construction joint or the top of the structure.

strip, middle — in flat-slab framing, the slab portion that occupies the middle half of the span between columns.

strip, panel — a strip extending across the length or width of a flat slab for structural design and construction or for architectural purposes.

strip, rustication — a strip of wood or other material attached to a form surface to produce a groove or rustication in the concrete.

strip, wrecking — small piece or panel fitted into a formwork assembly in such a way that it can be easily removed ahead of main panels or forms, making it easier to strip those major form components.

stripper — a liquid compound formulated to remove coatings by either chemical or solvent action, or both.

stripping — the removal of formwork or a mold.

strips, divider — in terrazzo work, nonferrous metal or plastic strips of different thicknesses, usually embedded from 10 to 40 mm, used to form panels in the topping.

strongback — a frame attached to the back of a form or precast structural member to stiffen or reinforce the form or member during concrete placing operations or handling operations.

structural adhesive — a bonding agent used for transferring required loads between adherents exposed to service environments typical for the structure involved.

structural end-point — the acceptance criterion of ASTM E119, which states that the specimen shall sustain the applied load without collapse.

structural height — The vertical distance between the lowest point of the excavated foundation to the top of the dam.

stucco — a portland cement-based plaster used for coating exterior walls and other exterior surfaces.

stud — member of appropriate size and spacing to support sheathing of concrete forms; and an headed steel device used to anchor steel plates or shapes to concrete members).

subbase — the layer in a pavement system between the subgrade and the base course, or between the subgrade and the pavement.

subgrade — the soil prepared and compacted to support a structure or a pavement system.

subpurlin — a light structural section used as a secondary structural member; in lightweight concrete roof construction, used to support the form boards over which the lightweight concrete is placed.

subsample — a sample taken from another sample.

subsieve fraction — particles all of which pass through a U.S. Standard 45 µm (No. 325) sieve.

substrate — any material on the surface of which another material is applied.

substructure — all of that part of a structure below grade.

sulfate attack — either a chemical or a physical reaction or both between sulfates usually in soil or ground water and concrete or mortar; the chemical reaction is primarily with calcium aluminate hydrates in the cement-paste matrix, often causing deterioration.

superstructure — all of that part of a structure above grade.

surface active — having the ability to modify surface energy and to facilitate wetting, penetrating, emulsifying, dispersing, solubilizing, foaming, frothing, etc., of other substances.

surface air voids — small regular or irregular cavities, usually not exceeding 15 mm in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation.

surface bonding (of masonry) — bonding of dry-laid masonry by parging with a thin layer of fiber-reinforced mortar.

surface tension — an internal molecular force that exists in the surface film of all liquids and tends to prevent the liquid from flowing.

surface texture — degree of roughness or irregularity of the exterior surfaces of aggregate particles and also of hardened concrete.

surface, brushed — a sandy texture obtained by brushing the surface of freshly placed or slightly hardened concrete with a stiff brush for architectural effect or, in pavements, to increase skid resistance.

surface, specific — the surface area of particles or of air voids contained in a unit mass or unit volume of a material; in the case of air voids in hardened concrete, the surface area of the air-void volume expressed as square inches per cubic inch or square millimeters per cubic millimeter.

surface-active agent — agent, surface-active.

surfactant — a shortened form of the term surface-active agent.

surficial inspection — A visual inspection conducted to identify obvious defects or changed conditions.

surkhi — a pozzolan consisting of burned clay powder principally produced in India.

sway brace — a diagonal brace used to resist wind or other lateral forces.

sweepout — The hydraulic condition in a hydraulic jump energy stilling basin where there is insufficient tailwater depth to offset the hydrodynamic forces of the incoming discharge. The hydraulic jump is "swept" out of the basin and the downstream receiving stream is subjected to the full erosional forces of the high velocity discharge.

swelling — increase in either length or volume.

swift — a reel or turntable on which prestressing tendons are placed to facilitate handling and placing.

syneresis — the contraction of a gel, usually evidenced by the separation from the gel of small amounts of liquid; a process possibly significant in bleeding and cracking of fresh hydraulic-cement mixtures.

syngenite — potassium calcium sulfate hydrate, a compound sometimes produced during hydration of portland cement, found in deteriorating portland-cement concrete and said to form in portland cement during storage by reaction of potassium sulfate and gypsum.

system —

system, one-way — the arrangement of steel reinforcement within a slab that presumably bends in only one direction.

system, two-way — a system of reinforcement; bars, rods, or wires placed at right angles to each other in a slab and intended to resist stresses due to bending of the slab in two directions.

T

table, flow — a flat, circular jigging device used in making flow tests for consistency of cement paste, mortar, or concrete.

tailings (or tailing or tails) — Tailings, or "tails" comprise the residue or waste that comes out of the "tail" end of a processing plant. The processes that produce tailings can be:

tailings dam — a structure or embankment that is built to retain tailings and/or to manage water associated with the storage of tailings, and includes the contents of the structure. This does not include separate water dams (e.g. seepage collection dams or clarification ponds) that may be part of the overall TSF.

tailings storage — a site where processing wastes are temporarily or permanently stored, not necessarily formed by a dam structure.

tailings storage allowance The volume of tailings allowed for at the design period of tailings dam operation stage, prior to closure or raising, calculated as the expected dry tonnage of tailings produced at the expected dry density to be achieved within the storage.

tailings storage facility (TSF) — includes the tailings storage, containment embankments and associated infrastructure.

talc — a mineral with a greasy or soapy feel, very soft, having the composition $Mg_3Si_4O_{10}(OH)_2$.

tamper — 1. an implement used to consolidate concrete or mortar in molds or forms; and 2. a hand-operated device for consolidating floor topping or other unformed concrete by impact from the dropped device in preparation for strikeoff and finishing contact surface often consists of a screen or a grid of bars to force coarse aggregates below the surface to prevent interference with floating or troweling

tamping — the operation of consolidating freshly placed concrete by repeated blows or penetrations with a tamper.

T-beam — a beam composed of a stem and a flange in the form of a T.

telltale — any device designed to indicate movement of formwork or of a point on the longitudinal surface of a pile under load.

temper — to add water to a cementitious mixture as necessary to initially bring the mixture to the desired workability.

temperature — temperature, glass-transition — the midpoint of the temperature range over which an amorphous material (such as glass or a high polymer) changes from (or to) a brittle, vitreous state to (or from) a plastic state. **temperature, heat-deflection —** the temperature at which a plastic material has an arbitrary deflection when subjected to an arbitrary load and test condition; this is an indication of the glass-transition temperature. **temperature rise —** the increase of temperature caused by either absorption of heat or internal generation of heat, for example, hydration of cement in concrete.

template — a thin plate or board frame used as a guide in positioning or spacing form parts, reinforcement, or anchors; also a full-size mold, pattern, or frame, shaped to serve as a guide in forming or testing contour or shape.

tendon — an assembly consisting of a tensioned element (such as a wire, bar, rod, strand, or a bundle of these elements) used to impart compressive stress in concrete, along with any associated components used to enclose and anchor the tensioned element.

tendon profile — the path or trajectory of the prestressing tendon.

tendon, bonded — a prestressing tendon that is bonded to the concrete either directly or through grouting.

tendon, concordant — a tendon with a profile that does not produce secondary moments and support reactions due to the prestressing force.

tendon, eccentric — a prestressing tendon that follows a trajectory not coincident with the gravity axis of the concrete member.

tendon, unbonded — a tendon that is permanently prevented from bonding to the concrete after stressing.

tendons, and the effects of elastic shortening, creep, and shrinkage of the concrete.

tendons, concentric — tendons following a line coincident with the gravity axis of the prestressed-concrete member.

tendons, deflected — tendons that have a trajectory that is curved or bent with respect to the gravity axis of the concrete member.

tensile strength, splitting — tensile strength of concrete determined by a splitting tensile test.

tension, diagonal — the principal tensile stress resulting from the combination of normal and shear stresses acting upon a structural element.

tesserae — small pieces of glass or marble tile used in mosaics.

test — a trial, examination, observation, or evaluation used as a means of measuring either a physical or a chemical characteristic of a material, or a physical characteristic of either a structural element or a structure.

testing machine — a device for applying test conditions and accurately measuring results.

tetracalcium aluminoferrite — a compound in the calcium aluminoferrite series, having the composition $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$, abbreviated C4AF, that is usually assumed to be the aluminoferrite present when compound calculations are made from the results of chemical analysis of portland cement.

texture — the pattern or configuration apparent in an exposed surface, as in concrete and mortar, including roughness, streaking, striation, or departure from flatness.

texturing — the process of producing a special texture on either unhardened or hardened concrete.

T-head — in precast framing, a segment of girder crossing the top of an interior column; also the top of a shore formed with a braced horizontal member projecting on two sides forming a T shaped assembly.

thermal contraction — contraction caused by decrease in temperature.

thermal expansion — expansion caused by increase in temperature.

thermal movement — change of dimension of concrete or masonry resulting from change of temperatures.

thermocouple — two conductors of different metals joined together at both ends, producing a loop in which an electric current will flow when there is a difference in temperature between the two junctions.

thermoplastic — becoming soft when heated and hard when cooled.

thermosetting — becoming rigid by chemical reaction and not remeltable.

thin-shell precast — precast concrete characterized by thin slabs and web sections.

thixotropy — a reversible, time-dependent decrease in viscosity when a fluid is subjected to increased shear stress or shear rate.

threaded anchorage — see **anchorage, threaded**.

thrust block — A massive block of concrete built to withstand a thrust or pull.

tie — 1. loop of reinforcing bars encircling the longitudinal steel in columns; and 2. a tensile unit adapted to holding concrete forms secure against the lateral pressure of unhardened concrete.

tieback — a rod fastened to a dead man, a rigid foundation, or either a rock or soil anchor to prevent lateral movement of formwork, sheet pile walls, retaining walls, bulkheads, etc.

tilt-up — a construction technique for casting concrete elements in a horizontal position at the jobsite and then tilting them to their final position in a structure.

time of haul — in production of ready mixed concrete, the period from first contact between mixing water and cement until completion of discharge of the freshly mixed concrete.

time of setting — (1) the time required for a freshly mixed cement paste, mortar, or concrete to achieve initial set or; (2) the time required for a freshly mixed cement paste, mortar, or concrete to achieve final set.

time, final setting — the time required for a freshly mixed cement paste, mortar, or concrete to achieve final set.

time, initial setting — the time required for a freshly mixed cement paste, mortar, of concrete to achieve initial set.

tobermorite — a mineral found in Northern Ireland and elsewhere, having the approximate formula $Ca_5(Si_6O_{16}(OH)_2 \cdot 4H_2O$ identified approximately with the artificial product tobermorite (G) of Brunauer, a hydrated calcium silicate having $CaO:SiO_2$ ratio in the range 1.39 to 1.75 and forming minute layered crystals that constitute the principal cementing medium in portland-cement concrete; a mineral with 5 mols of lime to 6 mols of silica, usually occurring in plate-like crystals, which is easily synthesized at steam pressures of about 100 psig and higher; the binder in several properly autoclaved products.

toe of dam — The junction of the face of a dam with the ground surface. For concrete dams, see heel.

tolerance — the permitted deviation from a specified dimension, location, or quantity.

tongue and groove — a joint in which a protruding rib on the edge of one side fits into a groove in the edge of the other side, abbreviated "T & G."

tool, arrissing — a tool similar to a float, but having a form suitable for rounding an edge of freshly placed concrete.

tool, gutter — a tool used to give the desired shape and finish to concrete gutters.

tooling — the act of compacting and contouring a material in a joint.

topping — (1) a layer of concrete or mortar placed to form a floor surface on a concrete base; (2) a structural, cast-in-place surface for precast floor and roof systems; and (3) the mixture of marble chips and matrix that, when properly processed, produces a terrazzo surface.

topping, monolithic —on flatwork: a higher quality, more serviceable topping course placed promptly after the base course has lost all slump and bleed water.

Total Freeboard. The vertical distance between the Maximum Operational Pond Level and the crest of the dam, and represents the capacity of the dam to pass an extreme storm by combination of extreme storm storage, spillway discharge depth, wave freeboard and contingency freeboards to prevent overtopping of the dam.

toughness — the property of matter that resists fracture by impact or shock.

transfer — to shift the tensioning force for a strand or strands from a jack or pretensioning bed to a concrete or masonry member.

traprock — any of various fine-grained, dense, dark colored igneous rocks, typically basalt or diabase; also called q"trap."

trashrack — A device located at an intake to prevent floating or submerged debris from entering the intake.

trass — a natural pozzolan of volcanic origin found in Germany, namely, trachytic tuffs that are intensely altered by geologic processes.

traveler — an inverted-U-shaped structure usually mounted on tracks that permit it to move from one location to another to facilitate the construction of an arch, bridge, or building.

travertine — dense to irregularly porous, commonly stratified or banded calcium carbonate, either aragonite or calcite, formed by deposition from hot spring waters.

tremie — a pipe or tube through which concrete is deposited under water, having at its upper end a hopper for filling and a bail for moving the assemblage.

tremie seal — the depth to which the discharge end of the tremie pipe is kept embedded in the fresh concrete that is being placed; a layer of tremie concrete placed in a cofferdam for the purpose of preventing the intrusion of water when the cofferdam is dewatered.

trench form (for cast-in-place concrete pipe) — the vertical sides and semicircular bottom of the trench shaped to provide full, firm, and uniform support for the lower 210 degrees of the pipe.

triaxial compression test — a test in which a specimen is subjected to a confining hydrostatic pressure and then loaded axially to failure.

triaxial test — a test in which a specimen is subjected simultaneously to lateral and axial loads.

tricalcium aluminate — a compound having the composition $3CaO{\cdot}Al_2O_3$, abbreviated C3A.

tricalcium silicate — a compound having the composition 3CaO·SiO2, abbreviated C3S, an impure form of which (alite) is a main constituent of portland cement.

trough, flow —a sloping trough used to convey concrete by gravity flow from either a truck mixer or a receiving hopper to the point of placement.

trowel — (1) a flat, broad-blade steel hand tool used in the final stages of finishing operations to impart a relatively smooth surface to concrete floors and other unformed concrete surfaces; (2) a flat, triangular-blade tool used for applying mortar; or (3) a flat, broad-blade steel hand tool used to place, spread, shape, finish, or otherwise apply materials.

troweling — smoothing and compacting the unformed surface of fresh concrete by strokes of a trowel.

troweling machine — a motor driven device that operates orbiting steel trowels on radial arms from a vertical shaft.

truck, agitating — a vehicle in which freshly mixed concrete can be conveyed from the site of mixing to the site of placement; while being agitated, the truck body can either be stationary and contain an agitator or it can be a drum rotated continuously so as to agitate the contents; designated "agitating lorry" in the United Kingdom.

T-shore — a shore with a T-head.

tube-and-coupler shoring — a load-carrying assembly of tubing or pipe which serves as posts, braces, ties, a base supporting the posts, and special couplers that connect the uprights and join the various members.

tunnel — A long underground excavation with two or more openings to the surface, usually having a uniform cross section used for access, conveying flows, etc.

tunnel lining — a structural system of concrete, steel, or other materials to provide support for a tunnel for exterior loads, to reduce water seepage, or to increase flow capacity.

turbidimeter — a device for measuring the particle-size distribution of a finely divided material by taking successive measurements of the turbidity of a suspension in a fluid.

turbidimeter fineness — the fineness of a material such as portland cement, usually expressed as total surface area in square centimeters per gram, as determined with a turbidimeter.

two-way reinforced footing — a footing having reinforcement in two directions generally perpendicular to each other.

U

ultimate-design resisting moment — the moment at which a reinforced-concrete section reaches its usable flexural strength, commonly accepted for under-reinforced concrete flexural members to be the bending moment at which the concrete compressive strain equals 0.003; an obsolete term..

ultrasonic — pertaining to mechanical vibrations having a frequency greater than approximately 20,000 Hz.

unbonded member — a prestressed-concrete member posttensioned with tendons that are not bonded to the concrete between the end anchorages after stressing.

unbonded post-tensioning — post-tensioning in which the tendons are not grouted after stressing.

unbraced length of column — distance between lateral supports.

underbed — the base mortar, usually horizontal, into which strips are embedded and on which terrazzo topping is applied.

undersanded — concrete containing an insufficient proportion of fine aggregate to produce optimum properties in the fresh mixture, especially workability and finishing characteristics.

undersize — particles of aggregate passing a designated sieve.

unit water content — the quantity of water per unit volume of freshly mixed concrete, often expressed as pounds or gallons per cubic yard; the quantity of water on which the water-cement ratio is based, not including water absorbed by the aggregate.

unit weight — or specific weight of any material is its weight per unit volume that means in a unit volume.

unsound — not firmly made, placed, or fixed; subject to deterioration or disintegration during service exposure.

U-value — overall coefficient of heat transmission; a standard measure of the rate at which heat will flow through a unit area of a material of known thickness.

V

valve — A device fitted to a pipeline or orifice in which the closure member is either rotated or moved transversely or longitudinally in the waterway so as to control or stop the flow.

valve bag — paper bag for cement or other material, either glued or sewn, made of four or five plies of kraft paper and completely closed except for a self-sealing paper valve through which the contents are introduced and released.

vapor pressure — the pressure exerted when a vapor is in equilibrium with its liquid or solid form at a given temperature.

vebe apparatus — an apparatus for measuring workability of very low-slump or no-slump concrete, including a vibrating table, a sample container, and other ancillary items, that permits measurement of the time (vebe time) required to be consolidated in a mold.

vehicle — liquid carrier or binder of solids.

velocity, pulse — the velocity at which compressional waves are propagated through a medium.

velocity, settling — the terminal rate of fall of a particle through a fluid as induced by gravity or other external force; the rate at which frictional drag balances the accelerating force (or the external force).

veneer — a masonry facing that is attached to the backup, but not so bonded as to act with it under load.

venetian — a type of terrazzo topping that incorporates large chips of stone.

vermiculite — a micaceous mineral, also a group name for certain platy minerals, hydrous silicates of aluminum, magnesium, and iron characterized by marked exfoliation on heating; also a constituent of clays.

vibration — energetic agitation of freshly mixed concrete during placement by mechanical devices, either pneumatic or electric, that create vibratory impulses of moderately high frequency to assist in consolidating the concrete in the form or mold. (1) external vibration employs vibrating devices attached at strategic positions on the forms and is particularly applicable to manufacture of precast items and for vibration of tunnel-lining forms; in manufacture of concrete products, external vibration or impact may be applied to a casting table; (2) internal vibration employs one or more vibrating elements that can be inserted into the fresh concrete at selected locations, and is more generally applicable to in-place construction; and (3) surface vibration employs a portable horizontal platform on which a vibrating element is mounted.

vibrator — an oscillating machine used to agitate fresh concrete so as to eliminate gross voids, including entrapped air but not entrained air, and to produce intimate contact with form surfaces and embedded materials.

vibrator, spud — a vibrator, having a vibrating casing or a vibrating head, used to consolidate freshly placed concrete by insertion into the mass.

vibrator, surface — a vibrator used for consolidating concrete by application to the surface of a mass of freshly mixed concrete; four principal types exist: vibrating screeds, pan vibrators, plate or grid vibratory tampers, and vibratory roller screeds.

Vicat apparatus — a penetration device used in the testing of hydraulic cements and similar materials.

viscometer — instrument for determining viscosity of slurries,mortars, or concretes.

viscometer, torque — an apparatus used for measuring the consistency of slurries in which the energy required to rotate a device suspended in a rotating cup is proportional to viscosity.

viscosity — a measure of the resistance of a fluid to deform under shear stress.

void —**void, air** — a space in cement paste, mortar, or concrete filled with air; an entrapped air void is characteristically 1 mm or more in size and irregular in shape; an entrained air void is typically between 10 µm and 1 mm in diameter and spherical or nearly so. **void, water** — void along the underside of an aggregate particle or reinforcing steel which formed during the bleeding period; initially filled with bleed water. **void-cement ratio** — volumetric ratio of air plus net mixing water to cement in a concrete or mortar mixture. **voids, surface** — cavities visible on the surface of a solid. **volatile material** — material that is subject to release as a gas or vapor; liquid that evaporates readily.

volume — **volume, absolute** — in the case of solids, the displacement volume of particles themselves, including their permeable and impermeable voids, but excluding space between particles; in the case of fluids, their volume. **volume, dry-rodded** — the bulk volume occupied by a dry aggregate compacted by rodding under standardized conditions; used in measuring density of aggregate. **volume batching** — measuring the constituents of mortar or concrete by volume. **volume change** — an increase or decrease in volume due to any cause. **volume change, autogenous** — change in volume produced by continued hydration of cement, exclusive of effects of applied load and change in either thermal condition or moisture content. **volume change, thermal** — the increase or decrease in volume caused by changes in temperature.

volume of distilled water at a stated temperature; and **specific gravity, bulk (saturated-surface-dry)** — the ratio of the mass of a volume of a material (including the mass of water within the voids, but not including the voids between particles) at a stated temperature to the mass of an equal volume of distilled water at a stated temperature.

volumetric measuring — dispensing an ingredient based on volume, either in discrete quantities or by continuous flow.

W

Wagner fineness — the fineness of portland cement, expressed as total surface area in square centimeters per gram, determined by the Wagner turbidimeter apparatus and procedure.

wale — a long formwork member (usually double) used to gather loads from several studs (or similar members) to allow wider spacing of the restraining ties; when used with prefabricated panel forms, this member is used to maintain alignment; also called waler or ranger.

wall — a vertical element used primarily to enclose or separate spaces.

wall, enclosure — a non-load-bearing wall intended only to enclose space.

wall, load-bearing — a wall designed and built to carry superimposed vertical or in-plane and shear loads, or both.

wall, nonbearing — a wall that supports no vertical load other than its own weight and no in-plane shear loads.

wall, stub — low wall, usually 100 to 200 mm high, placed monolithically with a concrete floor or other members to provide for control and attachment of wall forms; called kicker in the United Kingdom.

warping — out-of-plane deformation of the corners, edges, and surface of a pavement, slab, or wall panel from its original shape.

water — **water, adsorbed** — water held on surfaces of a material by electrochemical forces and having physical properties substantially different from those of absorbed water or chemically combined water at the same temperature and pressure. **water, evaporable** — water in set cement paste present in capillaries or held by surface forces; measured as that removable by drying under specified conditions. **water, mixing** — the water in freshly mixed sand-cement grout, mortar, or concrete, exclusive of any previously absorbed by the aggregate (for example, water considered in the computation of the net water-cement ratio). **water, nonevaporable** — the water that is chemically combined during cement hydration; not removable by specified drying. **water, wash (or flush)** — water carried on a truck mixer in a special tank for flushing the interior of the mixer after discharge of the concrete. **water blast** — a system of cutting or abrading a surface such as concrete by a stream of water ejected from a nozzle at high velocity).

water content — (process engineering definition) mass of water as a percentage of the combined mass of solids plus liquids. See also "moisture content".

water ring — a device in the nozzle body of dry-mix shotcrete equipment through which water is added to the materials.

water-cement ratio — the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of portland cement in concrete, mortar, or grout, stated as a decimal and abbreviated as w/c.

water-cementitious material ratio — the ratio of the mass of water, excluding that absorbed by the aggregate, to the mass of cementitious material in a mixture, stated as a decimal.

waterproof — impervious to water in either liquid or vapor state (Because nothing can be completely "impervious" to water under infinite pressure over infinite time, this term should not be used.)

water-repellent — property of a surface that resists wetting (by matter in either liquid or vapor state) but permits passage of water when hydrostatic pressure occurs.

watershed divide — The divide or boundary between catchment areas (or drainage areas).

waterstop — a thin sheet of metal, rubber, plastic, or other material inserted across a joint to obstruct the seepage of water through the joint.

watertight — impermeable to water except when under hydrostatic pressure sufficient to produce structural discontinuity by rupture.

wave Freeboard An allowance for wave run up over and above the maximum calculated flood level.

wave runup — The vertical height above the stillwater level to which water from a specific wave will run up the face of a structure or embankment.

wearing course — a topping or surface treatment to increase the resistance of a concrete pavement or slab to abrasion.

weathering — changes in color, texture, strength, chemical composition or other properties of a natural or artificial material due to the action of the weather.

wedge — a piece of wood or metal tapering to a thin edge; used to adjust elevation or tighten formwork.

weigh batching — measuring the constituent materials for mortar or concrete by mass.

weight, dry-batch — the mass of the materials, excluding water, used to make a batch of concrete.

weir — A notch of regular form through which water flows.

weir, broad-crested: An overflow structure on which the nappe is supported for an appreciable length in the direction of flow.

weir, measuring: A device for measuring the rate of flow of water. It generally consists of a rectangular, trapezoidal, triangular, or other shaped notch, located in a vertical, thin plate over which water flows. The height of water above the weir crest is used to determine the rate of flow.

weir, ogee: A reverse curve, shaped like an elongated letter "S." The downstream faces of overflow spillways are often made to this shape.

wet — covered with visible free moisture; not dry.

wet screening — screening to remove from fresh concrete aggregate particles larger than a certain size.

wet season storage allowance The volume allowed for wet season water storage which could conservatively be required to be held in a tailings dam by a combination of excess wet season rainfall run-off from the tailings dam catchment and decant water from process inputs that cannot be progressively be extracted from the dam.

wet sieving — use of water to facilitate sieving of a granular material on standard sieves.

wheel, feed — material distributor or regulator in certain types of shotcrete equipment.

width, effective flange — width of slab adjoining a beam stem where the slab is assumed to function as the flange element of a T-beam section.

wind setup — The vertical rise in the stillwater level at the face of a structure or embankment caused by wind stresses on the surface of the water.

wire — **wire, cold-drawn** — wire made from rods that are hot-rolled from billets and then cold-drawn through dies. **wire, crimped** — wire deformed into a curve that approximates a sine curve as a means of increasing the capacity of the wire to bond to concrete; also welded wire fabric crimped to provide an integral chair. **wire, ground** — small-gage high-strength steel wire used to establish line and grade as in shotcrete work; also called alignment wire and screed wire.

wire wrapping — application of high tensile wire, wound under tension by machines, around circular concrete or shotcrete walls, domes, or other tension-resisting structural components.

wire, indented — wire having machine-made surface indentations intended to improve bond; depending on type of wire, used for either concrete reinforcement or

wobble coefficient — a coefficient used in determining the friction loss occurring in post-tensioning, which is assumed to account for the secondary curvature of the tendons.

workability — that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition.

wythe (leaf) — each continuous vertical section of a wall that is one masonry unit or grouted space in thickness.

X

X-brace — paired set of crossing sway braces.

xonotlite — calcium silicate monohydrate ($Ca_6Si_6O_{17}(OH)_2$), a natural mineral that is readily synthesized at 150°C to 350°C under saturated steam pressure; a constituent of sandlime masonry units.

X-ray diffraction — the diffraction of X-rays by substances having a regular arrangement of atoms; a phenomenon used to identify substances having such structure.

X-ray fluorescence — characteristic secondary radiation emitted by an element as a result of excitation by X-rays, used to yield chemical analysis of a sample.

Y

yellowing — development of yellow color or cast in white or clear coatings as a consequence of aging.

yield — the volume of freshly mixed concrete produced from a known quantity of ingredients; the total mass of ingredients divided by the density mass of the freshly mixed concrete; also the number of units produced per bag of cement or per batch of

yield point — the first engineering stress in a test in which stresses and strains are determined for a material that exhibits the phenomenon of discontinuous yielding, of which an increase in strain occurs without an increase in stress.

yoke — a tie or clamping device around column forms or over the top of wall or footing forms to keep them from spreading because of the lateral pressure of fresh concrete; also part of a structural assembly for slip forming which keeps the forms from spreading and transfers form loads to the jacks.

Z

zone, anchorage — in post-tensioning, the region adjacent to the anchorage subjected to secondary stresses resulting from the distribution of the prestressing force; in pretensioning, the region in which the transfer bond stresses are developed.

zone, precompressed — the area of a flexural member that is compressed by the prestressing tendons.

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