Course 1

Structural analysis and rehabilitation
of concrete dams and spillways

HISTORIC CASES ON CONCRETE DAMS REHABILITATION

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STRUCTURAL ANALYSIS AND REHABILITATION OF CONCRETE DAMS AND SPILLWAYS- SEPTEMBER/17TH

PART	PERIOD	SUBJECT	AUTHOR
I	08:00- 10:00	MODELING OF THERMAL PROPERTIES IN DAMS STRUCTURES	*Eduardo de Moraes Rego Fairbairn*
II	10:15- 12:15	SIGNIFICANT PROBLEMS ON DAMS CONCRETE STRUCTURES	*Selmo Chapira Kuperman*
III	13:15- 15:15	HISTORIC CASES ON SPILLWAYS REHABILITATION	*Walton Pacelli de Andrade*
IV	15:30- 17:30	HISTORIC CASES ON CONCRETE DAMS REHABILITATION (*)	*Francisco Rodrigues Andriolo*

(*) The texts were developed independently, some overlap may occur. In the text of Part IV this author, only made reference about the Spillways, leaving the details to the author of Part III.

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6) EXAMPLES - CASES

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ANNEX

1. PRESENTATION

To discuss the rehabilitation of Concrete dams, as well as get to know about the properties of concrete, it is necessary to use the examples of nature action in dam concrete phenomena over time.

For both there were used the publications of the committees on dams of various countries (*Brazil, United States, United Kingdom, France, Switzerland, Germany, Austria, Portugal, Australia, South Africa, Japan, Italy, India*) and other publications available electronically (see item **7-REFERENCES**), and so this author thanks.

Many of the figures were obtained from available on electronic media.

The extension of the text and the details of each example took into account the presentation of other authors in this course.

2- MESSAGE

The reading of the documents consulted brought this author to observe two distinct scenarios:

- Documents reporting cases of rehabilitation with technical and managerial details and costs of the actions, and;
- Documents with superficial and inaccurate descriptions.

This induces the author to leave a message to young professionals who attend this course, and others who may have access to this text, as well as those from companies in administration of dams:

- ***"Be careful and consider the relevance of the information of damages and phenomena observed in the structures of a public infrastructure"*.**

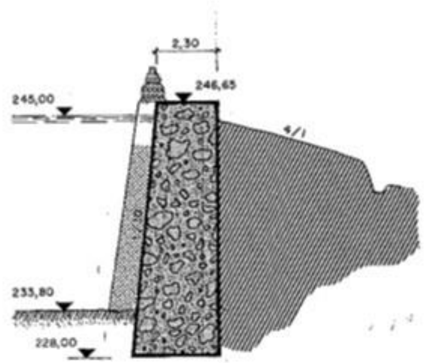
3-HISTORICAL INFORMATION

3.1- Proserpina Dam- Mérida- Spain

The **Proserpina Dam**[01; 02] is a Roman gravity dam, dating to the 1st - 2nd centuries, located about 10 km north of Merida, (Badajoz Province-Extremadura, Spain). Is 427 m long, 12 m high and is on top 2,3 m, crest and nine buttresses on the inner side of the dam. It was built as part of the infrastructure, which supplied the city of Emerita Augusta (Mérida) with water.

In the majority of the dams built in Spain by the Romans there is a basic characteristic construction element, almost systematically repeated: the retaining wall, used to achieve watertightness of the structure. Other elements, though not always, were added to ensure or complete the stability of the system. The Roman retaining wall is a very simple concept: a lime concrete core (*opus caementicium*), framed by two wall sections made of masonry (*opus incaertum*) or ashlar (*opus quadratum*).

Proserpina



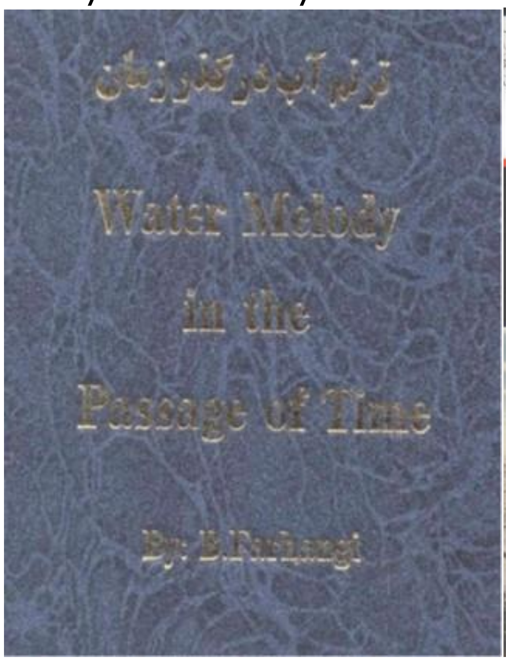
In 1991 the Confederación Hidrográfica del Guadiana (Water Management Administration) started a series of activities for the refurbishment of the dam and the regeneration of the reservoir, whose waters had reached a high degree of utrophication and could not be drained, as the deepest outlets –the original Roman intakes– had lost their function due to the partial silting up of the reservoir. The removal of these materials revealed nearly 7m of masonry whose morphology contrasts to some degree with that of the upper part of the structure, the one known up to that date. This activity and the data obtained from several drillings and other investigations carried out, enabled a good evaluation of the structure.

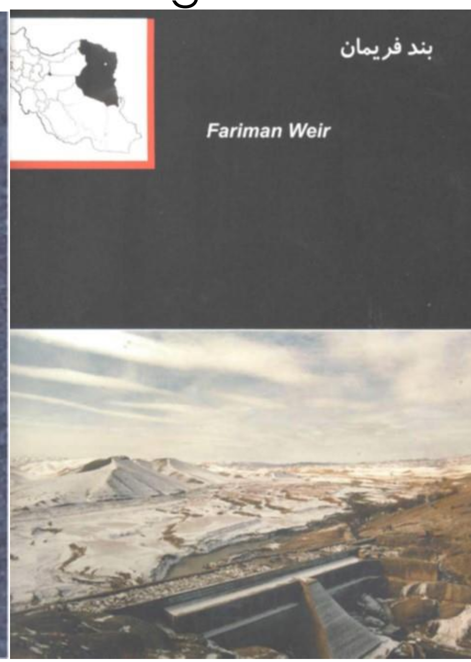
The dam of Proserpina is formed by a masonry wall (the retaining wall) to which an earth embankment is attached downstream.

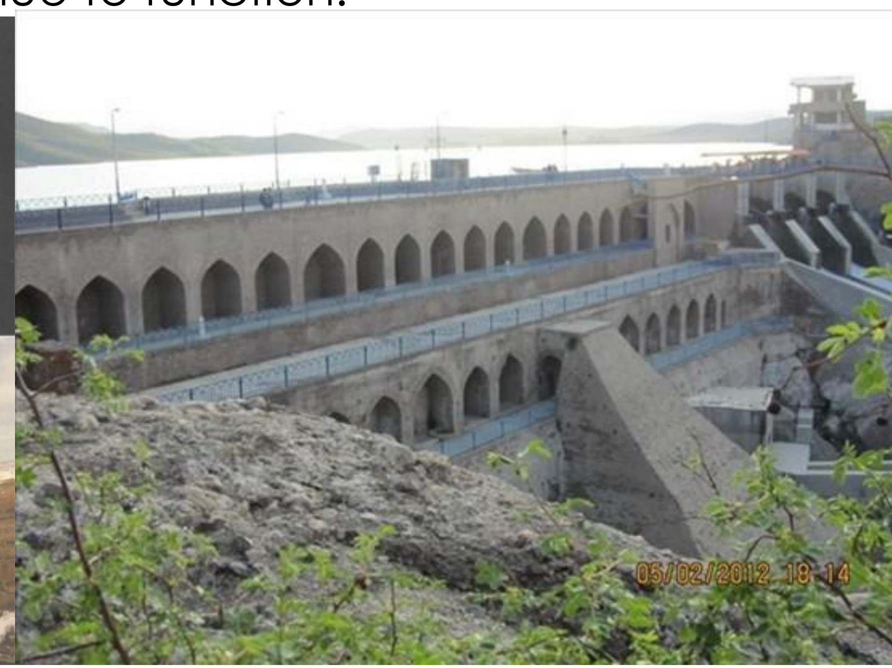
The retaining wall is formed by two granite masonry wall sections –*ashlar*, banded stone or masonry, depending on the areas with a core of lime concrete between them. The maximum height of this wall is of 21,60 m of which the lower 6,60 m belong to the recently discovered masonry. In layout the dam follows three straight alignments with a total crest length of 427,80 m. On the left edge there is also an auxiliary wall of about 100 m length used to enclose some areas where the ground remains below the crest of the dam.

3.2- Fariman Dam- Raazvi Khorasan- Iran

Large reservoir dams of the Timurid era (1350 to 1490 A.D.) [03; 04] in Khorasan province can best display the ability of Iranian engineers and architects in constructing large water structures. In the first half of the period, two gravity dams of Golestan and Fariman were also built in a similar style and now after 600 years they still stand strong and continue to function.







The effort that Iranians have put into exploiting water resources is dividable into two main periods. The first period from 1000 B.C. to the end of the Sassanid dynasty in 600 A.D. In this period, Iranians started to build diversion weirs in to control surface water. Among these structures one can mention weirs such as Daryoush, Bahman, Shahpur, Mizan and Amir that date back to 2000 to 2500 years ago in south west of Iran. All of these structures are weir bridges and are built with the purpose of bridging and diverting water. There are channels inside these weirs which carry the water to the mills. The second period of dam building in Iran started from 1100 to 1620 A.D. In this period, designing and building dams underwent a significant transformation. In a way that for the first time engineers and architects started to build large dams for the purpose of reservoir water

4- CONCEPTUAL ASPECTS AND UNDERSTANDING

What is a dam?

- Simply stated, a dam is a man made barrier constructed for the purpose of storing water;
- The two most common types of dams constructed around the world are embankment dams and concrete dams;
- A dam consists of a variety of different components, each having its own unique potential problem area and inspection requirement. The main components that make up a dam include: earth or concrete barrier, abutments, foundation, outlet, spillway and gates.

Dams are special infrastructure which provide significant benefits to communities in many ways including providing water supply, flood mitigation, power generation or irrigation. These structures may require upgrades or remedial works because of a need for increased storage or as a result of deterioration due to age, changes in design standards or inadequate original design.

The number of dams have increased markedly over the past six decades, today reaching more than 40.000 (*there are other figures reported*)[05] large dams – defined as those higher than 15m – in operation worldwide.

Concrete dams (as known as today) started to be built in the first half of last century, and are now more than 50 years old. Old concrete structures worldwide are now facing deterioration problems related to their ageing. To extend their lifetime and to maximize the benefits of existing dams, safety and serviceability requirements must be fulfilled.

Height (m)	Earth and/or Rock fill	Concrete or Masonry	Total
60- 300	800	1.200	2.000
30-60	5.000	2.500	7.500
15-30	27.000	3.500	30.500
TOTAL	32.800	7.200	40.000

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 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.

Why should a dam owner have a dam Safety Program?

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 materials 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 precipitation 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.

Why should a dam owner have a dam Safety Program?

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 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;

Why should a dam owner have a dam Safety Program?

- 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.

In some countries in Europe, with the race on to meet renewable energy targets, increasing the capacity of hydropower projects is proving to be an attractive alternative to new systems, particularly in some countries where the potential or new projects is limited.

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 given 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, the monitoring, the 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 considered as a risk.

Dams must not be thought of as part of the natural landscape, but as man-made structures, which must be designed, inspected, operated, and 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 not normally necessary if the dam was designed in accordance with good engineering practice, was built using good construction standards, and is operated and maintained properly.

Concrete dam Maintenance

Generally speaking, concrete is a reasonably durable material. However, because of the environment in which it is used, concrete does deteriorate over the years, and this process is accelerated by exposure to extreme weather conditions.

The most common form of failure is the breakdown of the surface layers of concrete as evidenced by the scaling, surface cracking and pitting which becomes very noticeable.

A more serious form of failure is indicated by the appearance of structural cracking in the concrete.

Monitoring- Non Destructive Methods (NDM- NDE)

Conventional dams inspection, in general is rather time consuming and often cost expensive due to the need of special apparatus or other large lifting platforms.

Concrete surfaces should be examined in a regular basis to identify spalling and deterioration due to weathering, or extreme stresses, or other physical, or chemical damage mechanism. Visual inspections have been so far 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.

Monitoring- Non Destructive Methods (NDM- NDE)

The framework for dam monitoring network and integrate online real-time heterogeneous sensor data, database and archiving systems, computer vision information, 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 aiming at registering and codifying into an electronic environment, the main deficiencies typically surveyed during visual inspections.

There are a number of Non Destructive Evaluation (***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 impossible to find with only visual means.

The various non destructive 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.

Visual Inspection by Drones

Recent advancement in drone technology, have opened a new chapter in the visual inspection of concrete dams. Drones are used for visual inspection of concrete surface and identifying 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 Unmanned Aerial Vehicle (***UAV***) as an assisting tool in inspections is obviously. 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 of concrete, or condition of concrete (physical of chemical damages).

Historic cases on concrete dams rehabilitation

Impact-Echo (IE)

Impact-Echo 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 freeze and thaw defects in concrete surfaces.

Spectral Analysis of Surface Waves (SASW)

The Spectral Analysis of Surface Waves (***SASW***) method has many applications in material characterization of multilayer systems. This can be used for in-situ evaluation of concrete 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)**, and freezing and thawing which are common in older dam structures.

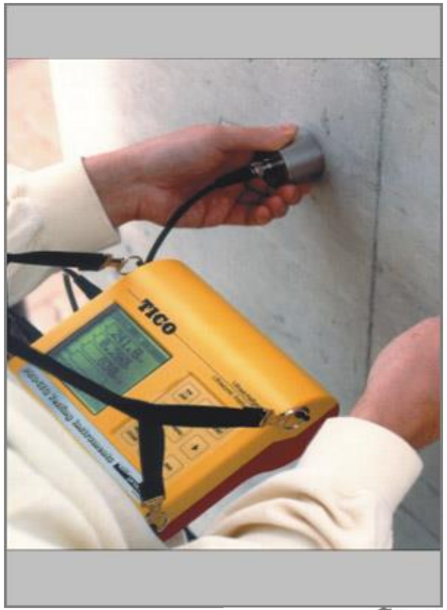
UPV Tomography / Seismic Tomography

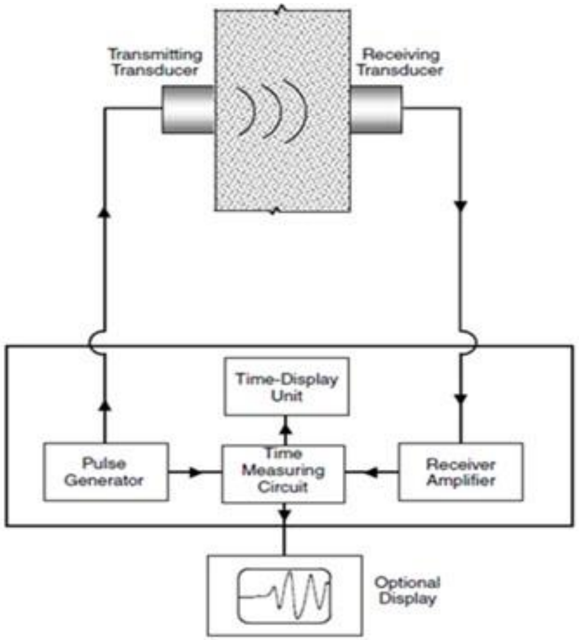
When there is no access problems (2 or more directions available), Ultrasonic Pulse Velocity (***UPV***) methods can be used for evaluation of concrete properties.

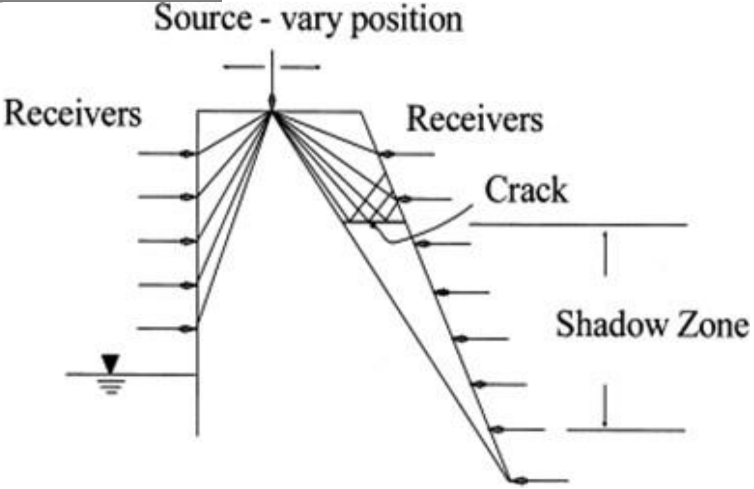
Ultrasonic Pulse Velocity (***UPV***) is an effective non-destructive testing (**NDT**) method for quality control of concrete materials, and detecting damages in structural components.

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.




Transmitting Transducer
Receiving Transducer
Time-Display Unit
Pulse Generator
Time Measuring Circuit
Receiver Amplifier
Optional Display


Source - vary position
Receivers
Receivers
Crack
Shadow Zone

Terrestrial Laser Scanners (TLS)

TLS can get the co-ordinates of millions of points in reflecting surfaces, 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 at mm to cm accuracy.

Remotely Operated Vehicles (ROVs)

The ***ROVs*** are dedicated to a number of inspection projects with severely restricted access requiring a more compact and portable system. The entire system is packaged in shock mount and padded cases, which are easily transported.

RGB cameras

RGB cameras (that delivers the three basic color components: red, green, and blue) 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:

Technical facilities and technological availabilities + **Knowledge of properties of materials and concrete in conjunction with practical experience** = **Are the basic conditions for the correct monitoring**

Is the Rehabilitation important?

There are more than **40 000** dams in the world. In 1950 there were about **20 000**. That means there are now at least **20 000** dams in the world more than **50 years** old. This is the challenge that faces in dealing with rehabilitation. Many of these dams were built under difficult circumstances with inadequate resources. [06]

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Management of Rehabilitation

What Is Dam Rehabilitation?

Just like any form of infrastructure (roads, bridges and water pipes) dams serve an important and sometimes critical function that requires periodic maintenance and rehabilitation.

The first step in rehabilitation is to develop an investigation program to define the extent of rehabilitation, and the methods to be used. Operating experience should be established through structured questioning of operating personnel and reference to published work.

The construction manager needs regular submissions of supporting data from the contractor and needs to generate significant records himself. Experience is needed to anticipate problems before they arise and to arrange for the necessary data to be collected in good time. Each position in the team carries well-defined responsibilities. The team must always be led by a person with sound technical skills and contracts administration experience.

Rehabilitation is needed to counter two major factors: ***Material factors*** on the one hand, and those associated with the ***evolution of technology***.

- ***Material factors contributing to ageing include***:
    - Decay through weathering and similar degradation;
    - Wear of equipment through misuse and age;
    - Loss of serviceability after prolonged operation;
    - Damage from natural events including floods, earthquake or landslides;
    - Damage from vandalism and war.

- The ***evolution of technology*** includes the following:
  - Overcoming construction deficiencies resulting from designs and construction of the former state of the art. An example is the clearer appreciation of uplift pressure and how it affects the stability of structures. This represents no criticism of our ancestors who were working at their state of the art;
  - Overcoming the effects of changes in operating conditions, for a reservoir for example;
  - Accounting for the improved understanding of the mechanics of weather changes, hence the better ability to predict the magnitude of floods and spillway capacity than was possible even a few decades ago. In a similar vein, to account for a better understanding of earthquakes and their behavior;
  - Accounting for changes downstream of a dam where perhaps there is more development and people now than formerly.

The present understanding of the physics of dam behavior is now improved and rehabilitation is sometimes necessary to meet legislative requirements.

Maintenance: the work required to keep the installation in working order. It includes repair;

Rehabilitation: is synonymous with remedial measures. It is the limited work needed to restore to the installation the reliable life expectancy it had when it was new. Rehabilitation work is not planned or designed to enhance performance except as a consequence of meeting the specific goal of the remedial measures and new construction or equipment is provided only to the extent necessary to meet this goal

Upgrading: is synonymous with uprating. It is the work considered necessary to maximize the benefit of the existing installation. New construction or equipment is installed where it can be justified economically.

Phenomena/ Observation/ Rehabilitation Plan

Concrete cracking was the deficiency most often reported. Other major problem areas were seepage and spalling. Materials and methods used at these projects include familiar and conventional approaches, as well as new, innovative applications.

Some of the repairs are simple and routine; others are highly complex and require trained personnel to perform. Some methods and materials can be used as described; others will serve as an impetus to the development of even more durable, cost-effective methods for preserving this vital part of the nation's infrastructure.

In some countries there are laws with regard to dam safety that are strictly enforced. In many countries, however, there is no such requirement and the engineer who is called upon to investigate the need for rehabilitation has to work with a more limited data base.

Phenomena/ Observation/ Rehabilitation Plan

Thus, good practice and government regulation typically requires that:

- sufficient monitoring equipment to allow a basic assessment of the behavior of the structure and its foundation;
- the monitoring equipment must be kept in good condition;
- measurement data should be routinely evaluated, comparing the readings with the long term behavior;
- a regular inspection of the dam, the reservoir and the area downstream should be made, and this should also include geological and hydrological aspects;
- where unusual behavior is noted, a call for an independent expert inspection be recommended.

Phenomena/ Observation/ Rehabilitation Plan

The following factors are important when carrying out the detailed design of rehabilitation work.

- Detailed consideration of construction techniques;
- The effect on the existing structure of the methods of rehabilitation;
- The effect on the structure of using materials that have different properties to those of the original materials;
- Monitoring the success in meeting the aims of the Rehabilitation Plan;
- Mitigation of environmental impact.

5- REHABILITATION

5.1 REHABILITATION OF THE FOUNDATION

5.1.1 Loss of Strength under Permanent or Repeated Actions

Phenomena

Alternating strain and stresses in the foundations

Examples

1; 2; 3; 4; 5; 6; 7; 8; A-001; A-002; A-003; A-004; A-005; A-006; A-007.

Aspect

- Movements of rock joints;
- Initiation and propagation of cracks;
- Seepage

Detection/ Monitoring

- Uplift pressure,
- Displacements;
- Drain blockage;
- Seepage

Rehabilitation/Repair Action

- Strengthening by grouting;
- Strengthening by anchors or tendons;
- Drainage;
- Impervious face;
- New dam

5.1- REHABILITATION OF THE FOUNDATION

5.1.2- Erosion and Solution

Phenomena	Examples
Dissolution and piping in fault and rock joint fillings, soluble rocks, and in consolidation grouting	3; A-004

Aspect

- The flow of water in erodible or fractured rock can increase leakage from the reservoir;
- More dangerous are solution processes within the dam foundation

Detection/ Monitoring

Changes in the piezometer head;

Rehabilitation/Repair Action

- Grouting of the cavities, as far as they are accessible;
- Grouting curtain

5.1- REHABILITATION OF THE FOUNDATION

5.1.3 Grout Curtains and Drains

Phenomena

Deterioration usually leads to increased seepage, higher uplift or erosion

Examples

2; 3;
A-005;
A-006;
A-007

Aspect

- Inadequate design, use of unsuitable pipe and filter materials;
- Poor quality of construction;
- Climatic conditions;
- Clogging of drain holes, pipes and wells

Detection/ Monitoring

Monitoring the amount and turbidity of seepage water

Rehabilitation/Repair Action

- Grouting of the cavities, as far as they are accessible;
- Grouting curtain;
- Reconstruction

5.2- REHABILITATION WORK CONCERNING THE DAM BODY

5.2.1 Chemical Reaction Resulting in Swelling

Phenomena

Water is an important role in this scenario which has two main origins:

- alkali-aggregate reaction and;
- the action of sulfates on concrete and mortar

Aspect

- Alkali-aggregate reaction;
- Sulphate action also can result from the oxidation of iron sulfide (pyrite) contained in some aggregates

Examples

12; 13; 14; A-008;
A-009;
A-010;
A-011;
A-012;
A-013;
A-014;
A-015

Rehabilitation/Repair Action

Mitigation of the effects of swelling has been tried by several methods as:

- cutting slots to relieve the stress caused by the expansive reaction;
- reinforcement or post-stressing in an attempt to reduce the deformation;
- additional weight has been used to reduce the stress in the concrete so as to allow it to operate at a lower stress level;
- waterproofing the upstream face of the dam to deprive the action of water;
- confine the concrete in critical zones to isolate the effect;
- break out the damaged materials and replacing them by sound mortar/concrete

5.2- REHABILITATION WORK CONCERNING THE DAM BODY

5.2.2- Shrinkage and Creep Leading to Contraction

Phenomena	Example
Cracks and/or displacements	17

Aspect

Shrinkage: Deformation of concrete associated with the chemical processes of setting:

Creep: Deformation behavior of concrete under load.

Detection/ Monitoring

Long term monitoring of displacements. Visual inspection is also valuable in describing cracks

Rehabilitation/ Repair Action

Structural strengthening

5.2- REHABILITATION WORK CONCERNING THE DAM BODY

5.2.3- Degradation at Dam Faces

Phenomena	Examples
May be caused by chemical reaction between the materials and external agents from the environment, including reservoir and underground water, air and temperature changes. Degradation is more serious for structures of low quality built in severe climates, structures containing thin elements and those exposed to the action of aggressive waters	15; 33; A-011; A-012; A-013; A-014; A-015; A-016; A-017

Aspect
The permeability of the dam body; • these pore fluids may react aggressively with concrete and mortar constituents; • temperature variations cause both cracking and the opening of joints, thereby influencing the overall permeability of the structure; • the growth of plants especially in the joints of masonry.

Detection/ Monitoring

- Visual inspections,
- Measurement of in-situ density and in-situ some velocity, trough non destructive inspection;
- water flow measurements, and;
- cores for laboratory tests.

Rehabilitation/Repair Action

Prevention of water from entering the dam body. Reducing the effects of extreme temperature variations.

Replacement and repair of the upstream face.

- barrier coatings to the upstream face of a variety of materials including bitumen, mastic asphalt, resins, chemical impregnation, concrete, metal or PVC membranes
- grouting the upstream part of the dam body
- repair of the facing.

5.2- REHABILITATION WORK CONCERNING THE DAM BODY

5.2.4- Loss of Strength Due to Permanent or Repeated Actions

Aspect

The development of cracks sometimes begins during construction and develops over time, its influence on the dam behavior only becoming significant after some years.

Detection/ Monitoring

- Visual inspections;
- Non destructive inspection,

Examples

6; 8; 9; 10; 11; 17; 19; A-018; A-020; A-021; A-022; A-034; A-035

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Rehabilitation/Repair Action

Reduce or remove the causes of cracking by strengthening the structure or by the physical protection of exposed faces.

- Strengthening the structure to reduce the level of stress in critical locations by :
  - grouting in joints and cracks;
  - construction of additional buttresses and backfilling, and filling of bays between buttresses and hollow chambers in buttress and multiple arch dams;
  - providing additional vertical loading through prestressed anchors or additional mass.
- Reducing the range of temperature variations by :
  - physical insulation and protection of the faces of gravity, arch and multiple arch dams;
  - closing the bays between buttresses to reduce the circulation of air ;
  - grouting works, to reduce leakage through open joints and cracks;
- improvement of drainage.

5.2- REHABILITATION WORK CONCERNING THE DAM BODY

5.2.5- Structural Joints

Phenomena	Examples
Deterioration of joints (Contraction -Construction) leads to loss of their mechanical and hydraulic properties	A-023;A-024; A-025;A-028; A-029;A-030; A-031;A-032; A-033
Aspect	
This scenario is worsened with the leakage through the joint and development of uplift forces.	

Detection/ Monitoring

- Visual inspection for detection of cracking and wet zones, as well as measurement of seepage and leakage;
- Leakage in galleries and at the downstream face of the dam;
- Lime efflorescence on the concrete face.

Rehabilitation/Repair Action

These works are usually carried out at the upstream face, or inside the dam body, either near the upstream face or at the surface of galleries.

- Breaking out and reconstruction of the joint, with a new waterstop;
- Grouting of joints and cracks to restore the joint watertightness;
- Holes crossing the joint or crack through which an appropriate sealant is grouted.

5.2- REHABILITATION WORK CONCERNING THE DAM BODY

5.2.6- Pre-Stressed Structures

Phenomena

Although the use of pre-stressing forces in structures is a current technique, it is not much used in dams, excepting for trunnion bearings of spillway gates.

Examples

A-020;
A-034

Aspect

- The need for an increase may be associated with the raising of the dam, the deterioration of the materials or because of changes in national regulations;
- to increase the thrust between the cantilever blocks or against the abutments in arch dams;
- to compensate for the tensile stresses developed next to the points of application of large concentrated forces, such as those near the trunnion bearings of large sector gates.

Detection/ Monitoring

Load cells and extra sleeves through the anchor blocks, to facilitate the future installation of additional tendons.

Rehabilitation/Repair Action

Installation of additional tendons.

5.3- REHABILITATION TO IMPROVE STATIC STABILITY

5.3.1- Pre-Stressed Structures

Aspect

The resistance to overturning or sliding of a dam on its foundation rock must be improved

Detection/ Monitoring

Until the 1930s the causes and effects of uplift under a gravity dam were not fully understood. It was not until the 1960s that the foundations of gravity dams were routinely and systematically drained at depth.

As a result the dams were found to be unsafe in terms of modem design standards. No drainage was provided.

Examples

6; 7; 8; 9; 10; 11; A-035; A- 036; A-037; A- 038; A-039; A-040;

Rehabilitation/Repair Action

Rehabilitation work is necessary to increase the stabilizing moment or sliding resistance of the cross section.

Rehabilitation may be necessary to achieve acceptable stability against seismic load.

- by enlarging the profile of the dam,
- by adding ballast, or
- by installing pre stressed anchors

5.4- REHABILITATION OF GATES AND OTHER DISCHARGE EQUIPMENT

Phenomena	Examples
The life of mechanical and electrical plant is usually no more than about 30 or 40 years.	16; 31; 34; 35;

Aspect

The problems experienced by hydraulic equipment that limit its life are caused by the combined effects of corrosion, erosion and poor maintenance, and technical ageing.

Detection/ Monitoring

Vibration of the equipment

Rehabilitation/Repair Action

Maintenance and good operating procedures, and repairs

5.5- SEDIMENTATION

Phenomena

Sedimentation [07] is a natural process that can have dramatic consequences for dams, most notably a reduction in storage capacity.

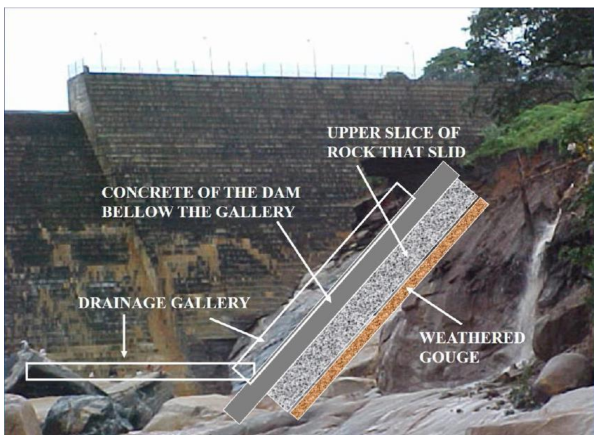
Even if the intensity of silting differs from one area to another, the classification of the risk should be considered a tool of forecast during planning and exploitation of dams.

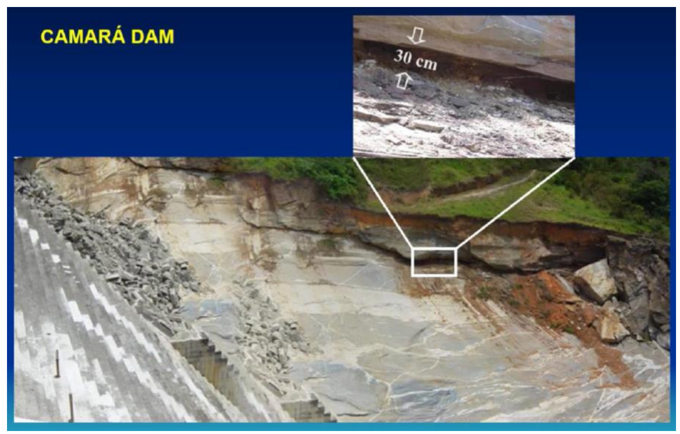
6-EXAMPLES- CASES

The author has prepared **140** examples of rehabilitation, with **35** major and comprehensive and the remaining **105** are described in annex.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
01	Camará Dam	Brasil	2002	2017	[08]
ASPECTS					
On the night of 17 June 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 dam was rebuilt by 2017.					

Course 1





rehabilitation
spillways

Historic cases on c
dams rehal

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
02	Oroville Dam	USA	1968	2017-2018	[09]- https://en.wikipedia.org

ASPECTS
In February 2017, Oroville Dam's main and emergency spillways were significantly damaged, prompting the evacuation of more than 180,000 people living downstream along the Feather River and the relocation of a fish hatchery. In the midst of widespread rainfall during the 2017 California floods, damage to the dam's main spillway appeared on February 7, resulting in its closure as management tried to assess the extent of damage and ways to mitigate further damage. As storms dumped significant precipitation on the area, the lake level rose until it flowed over a concrete weir at the top of the dam's emergency spillway, despite the reopening of the damaged main spillway.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
02	Oroville Dam	USA	1968	2017-2018	[09]- https://en.wikipedia.org

ASPECTS

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.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
03	Center Hill Dam	USA	1948	2008-2012	[10; 11]

ASPECTS

The construction of Center Hill Dam was completed in 1948. The dam is combination earth and concrete dam and provide valuable flood damage reduction, hydropower, water supply, recreation, and water quality benefits to the region.

The earth main 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 dam and 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 gained and a formal risk assessment completed which altered the recommendation.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
03	Center Hill Dam	USA	1948	2008-2012	[10; 11]

ASPECTS

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.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
03	Center Hill Dam	USA	1948	2008-2012	[10; 11]

ASPECTS

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.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
04	Kolnbrein Dam	Austria	1979	1989	[12]

ASPECTS

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 about 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.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
04	Kolnbrein Dam	Austria	1979	1989	[12]

ASPECTS

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.

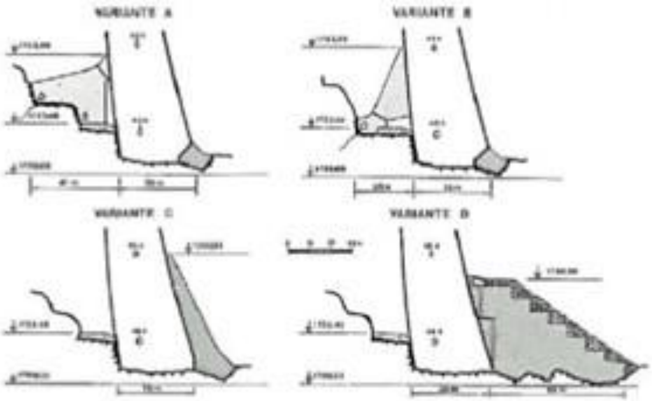
Although the desired reduction of uplift and seepage had been achieved, no satisfactory improvement of the dam behavior had been gained. A concept for the rehabilitation was developed comprising the following measures:

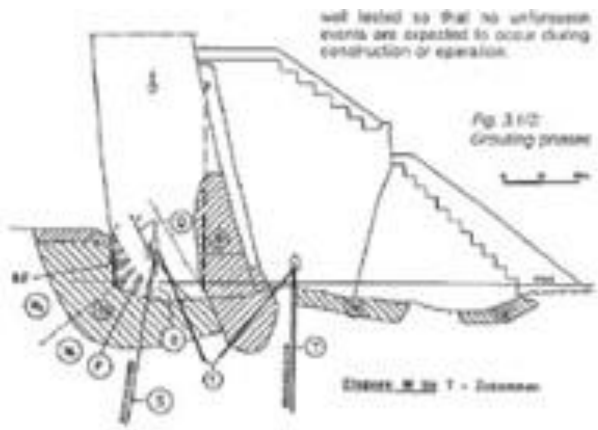
- As the high shear stresses in dam and abutment were considered responsible for the development of cracks, the lower parts of the dam were to be horizontally supported by a massive concrete block;
- Grouting with cement and with epoxy resin was planned to stabilize the cracked zones and to provide a watertight abutment;
- Grouting measures were necessary to improve the abutment below the upstream toe, especially for the empty reservoir condition.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
04	Kolnbrein Dam	Austria	1979	1989	[12]

ASPECTS

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.





CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
05	Upper Stillwater Dam	USA	1987	1988	[13; 14; 15]

ASPECTS
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 extend 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.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
05	Upper Stillwater Dam	USA	1987	1988	[13; 14; 15]

ASPECTS
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.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
06	Alum Creek Dam	USA	1974	1975	[16]

ASPECTS

On April 24 1975, during a periodic inspection of the completed dam, the US Army Corps of Engineers expressed concern about the safety of the spillway monoliths. The rock underlying the dam is highly fractured below the base of weathering. Within this shale are several light gray, silty to clayey shale seams up to 0.30 m thick. It may be possible that the spillway monolith and its underlying bedrock could slide, opening a gap between the monolith and the rolled earth dam leading to rapid and catastrophic erosion of the dam. To prevent the concrete monolith from sliding forward, it was decided to install seven cable anchors deep into the bedrock. Each anchor consisted of bundled, high strength steel cables that were concreted into the bottom of the holes. They were then hydraulically tensioned and the holes filled with grout. Anchors were installed at a 45 degree angle to a depth of 7.9 m below the foundation of the ogees.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
07	Pacoima Dam	USA	1929	1971-1976	[17; 18; 19]

ASPECTS

The dam was severely shaken by an earthquake of Richter magnitude 6,5. The left abutment proved to have inadequate seismic stability, and rock movement, cracking, and uplift pressures were observed. Interim rehabilitation measures included repair of sprayed concrete cover, stripping of loosened rock, installation of abutment relief drains, repair of left abutment grout curtain, consolidation grouting of upper left abutment, repair of spillway lining, and construction of an emergency outlet.

The permanent rehabilitation work included stabilization of the rock abutment with post-tensioned anchors. In addition, cracks and the open joint between the dam and thrust block were repaired by cement grouting.

The existing grout curtain in the foundation and abutment was repaired and extended. Further consolidation grouting of the foundation rock was carried out.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
Lessons Learned from Earthquake performance of Concrete Dams					[167]
ASPECTS					
An important paper was published in the April 1979 issue of International Water Power and Dam Construction entitled Response of Concrete Dams to Earthquakes. Authored by Kenneth D Hansen and Louis H. Roehm. The paper reported on the performance of 17 concrete dams in nine countries that had been subjected to ground shaking in excess of 0.10 g. From the recorded performance of these and the other dams, it was concluded, in general, concrete dams had performed extremely well when subjected to earthquake motions, even when shaken by forces far in excess of their design loading.					

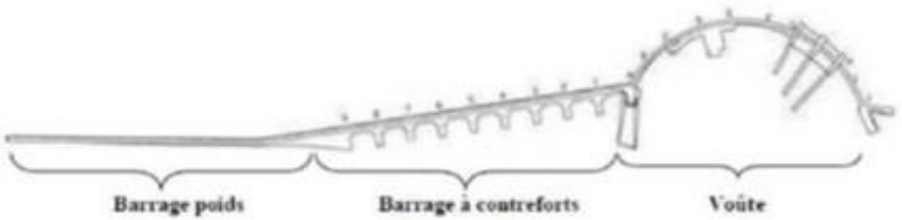
CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
08	Bluestone Dam	USA	1949	2011	[20]

ASPECTS
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	REHABILITATION/ REPAIR	REFERENCES
09	Rassisse Dam	France	1954	1992	[21; 22]

ASPECTS

Rassisse Dam is an arch dam with an artificial abutment on the right bank, which is reinforced with two tendons each of 12 000 kN. These tendons were designed to provide additional downforce equivalent to 80 % of the weight of the abutment. The safety conditions were under control, in spite of uncertainty over the condition of the tendons, because a model analysis showed that the required pre-stressing force is smaller than that initially assessed



CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
10	Morris Sheppard Dam	USA	1941	1987-1994	[23]

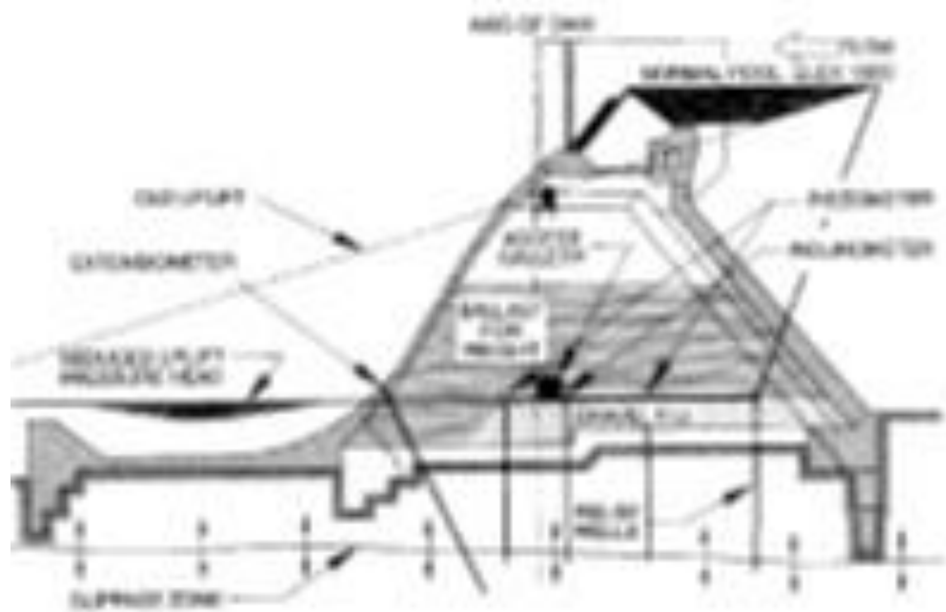
ASPECTS

The dam was successfully rehabilitated between 1987 and 1994, adopting:

- the lowering of the reservoir as an emergency response when the movement was discovered;
- the initial stabilization of the dam, by the addition of relief wells and grouting;

The maintenance personnel observed that cracks and spalls had developed in the heavily reinforced exterior walls of the powerhouse, also. Further investigation of the existing conditions revealed:

- That extensive corrosion of the embedded reinforcing steel was causing the thick concrete cover to shear off at the exterior face of the reinforcement;
- Delaminated concrete on the sloped top and vertical face of large encasement blocks that anchored the diameter penstock pipes that feed water from the lake to the generators' turbine wheels; and
- Spalling concrete beneath several of the large concrete struts located between the massive buttresses that support the dam's concrete slab.



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
11	Ennepe Dam	Germany	1904	1997	[24 ; 25]

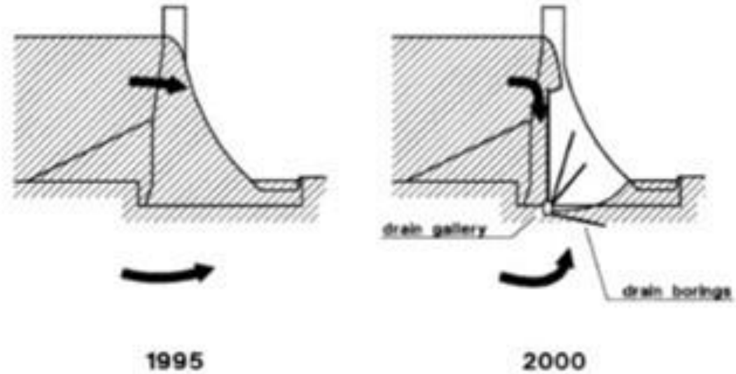
ASPECTS

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 has to 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.

Course 1



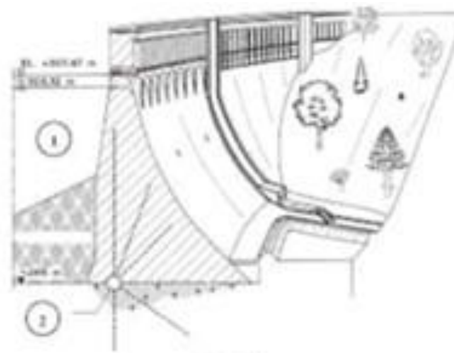


Fig. 3.4.13

Ennepe Dam. Drainage gallery as excavated

Structural analysis and rehabilitation of concrete dams and spillways

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
12	Illsee Dam	Switzerland	1924	1997	[26]

ASPECTS

Displacements were observed that were attributed to Alkali Silica Reaction and an impermeable layer was installed on the upstream face in an attempt to reduce the seepage of water into the dam, hence to slow and ultimately to stop the expansion process. The dam is faced with rough masonry and transition layers of geosynthetic materials were used instead of more traditional methods to make good local defects and to prepare the dam surface for the application of the PVC membrane.




Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
13	Friant Dam	USA	1942	1992/1997	[27]

ASPECTS

Alkali-aggregate reaction caused the expansion of the concrete at the outermost piers of the downstream face of the dam. The expansion caused binding of the drum gates, thus affecting operation of the dam. Following a 1992 study, the U.S. Bureau of Reclamation, decided to replace the outer drum gates with rubber dams and rehabilitate the inner drum gate. Further studies were implemented and BuRec decided to use the Pneumatic Spillway Gate System to replace the two outer drum gates. This system consists of high-strength steel gate panels connected to the spillway crest with a pivotal, reinforced elastomeric hinge. Inflatable actuators clamped along the hinge sections within an embedded keyway in the spillway concrete are used to operate the gates. This system provides a leakproof connection.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
13	Friant Dam	USA	1942	1992/1997	[27]

ASPECTS

The Obermeyer Spillway Gate system is a patented bottom hinged spillway gate with many unique attributes that include:

- Accurate automatic pond level control even under power failure conditions.
- Modular design that simplifies installation and maintenance.
- Unlike hydraulic spillway gates, Obermeyer gates are supported for their entire width by an inflatable air bladder, resulting in simple foundation requirements and a cost effective, efficient gate structure.
- Thin profile efficiently passes flood flows, ice and debris.
- No intermediate piers are required.
- Obermeyer Spillway gates are a great investment due to low installation cost, decreased maintenance, and increased revenue through optimized head.

These features are the result of combining rugged steel gate panels with a resilient pneumatic support system.

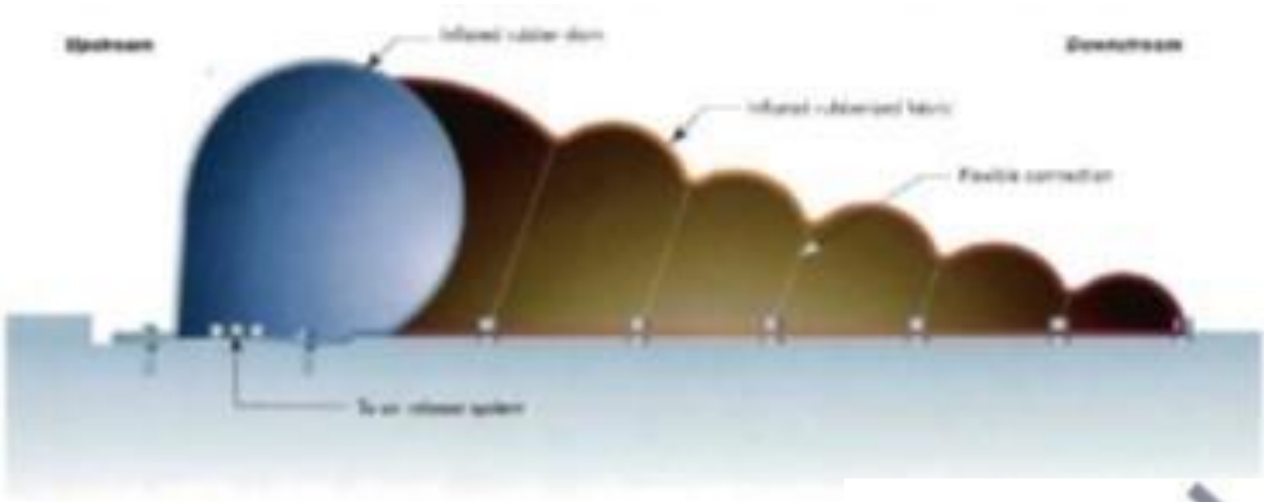
CASE		REFERENCES
Flexible Structures- Spilway Gates		[166]
ASPECTS		

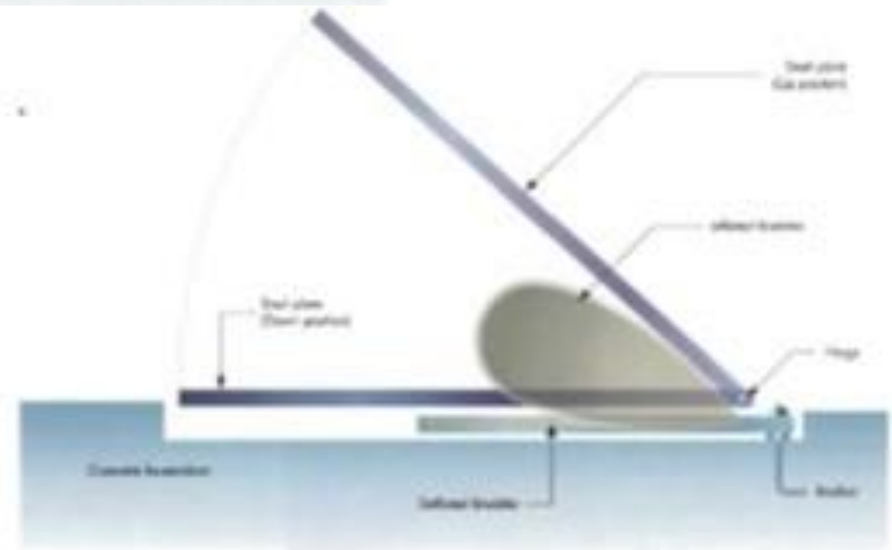
Rubber dams are flexible hydraulic structures. A rubber dam mainly consists of four parts:

(1) a rubberized fabric dam body;
(2) a concrete foundation;
(3) a control room housing mechanical and electrical equipment (e.g. air blower/water pump, inflation and deflation mechanisms); and
(4) an inlet/outlet piping system.

The dam body is fixed onto a concrete foundation and abutments by a single or double-line anchoring system. A typical foundation of the rubber dam has upstream and downstream cutoff walls to lengthen the groundwater seepage path and thus reduce the uplift force of ground water.

The first Fabridam was installed on the Los Angeles river, California, for groundwater recharge and flood mitigation.


Flexible connection



CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
14	Rio Descoberto Dam	Brazil	1974	2000	[28]

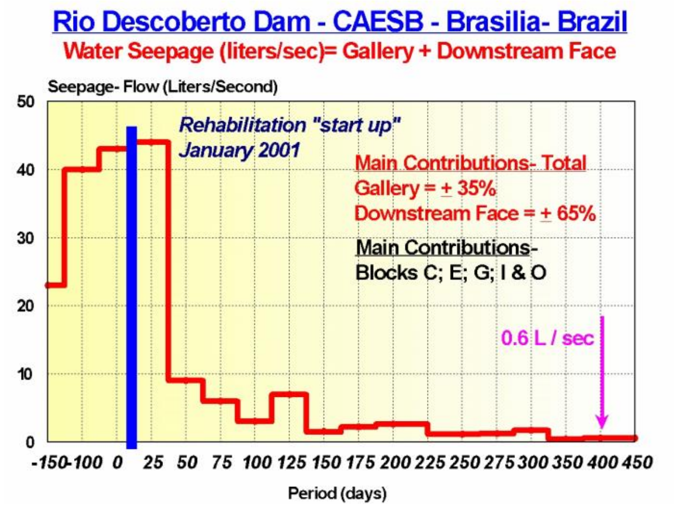
ASPECTS

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 Brasilia (1.5 million people) to be not 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 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.



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
15	Lost Creek Dam	USA	1924	1997	[22; 29]

ASPECTS

Lost Creek Dam is an arch 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.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
16	Möhne Dam	Germany	1913	1943- 1990	[30]

ASPECTS

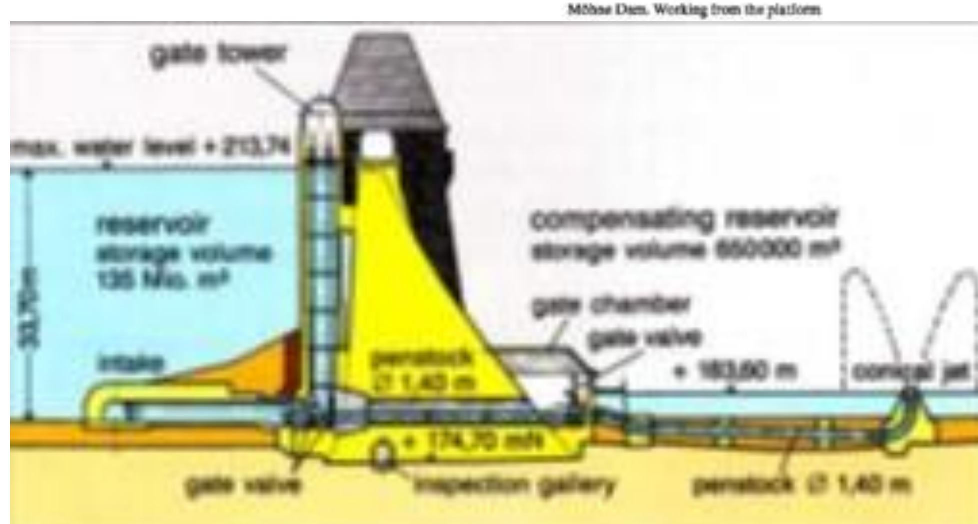
The dam was damaged by bombing in 1943 and repaired rapidly in the same year. The downstream face of the dam had not been investigated since the reconstruction in 1943. At the beginning of the nineties, a detailed inspection was made on the downstream face using specialized access platforms. It revealed that extended rehabilitation work was necessary. The masonry was repaired by replacing stones of the face 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 Möhne Dam in Germany the low level outlet gates were found by inspection to have suffered corrosion and to be leaking unacceptably.

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.

Fig. 3.3.17

Möhne Dam. Working from the platform



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
17	Olef Dam	Germany	1955		[31]

ASPECTS

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.

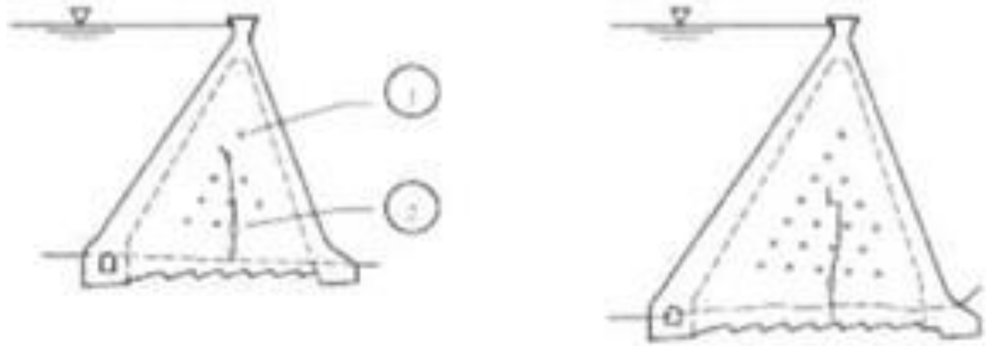


Fig. 3.3.4

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

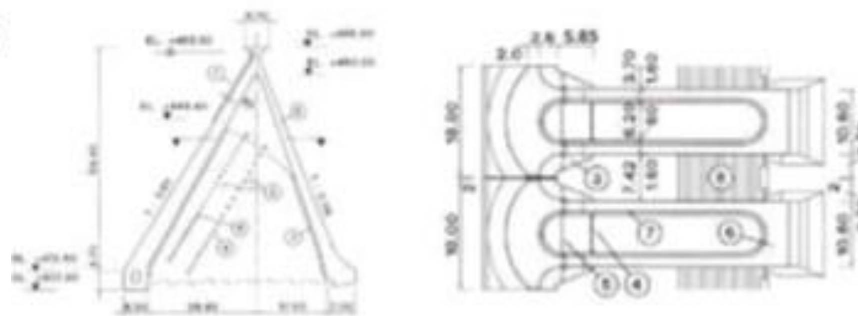


Fig. 3.3.8

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

Historic cases on concrete dams rehabilitation

Eng. Andriolo

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
18	Jupiá Dam	Brazil	1968	1963- 1965	[32; 33]

ASPECTS

Jupia Dam is an example of the actions were adopted due to the evolution of technology that includes:

- The use of Pozzolanic Material, and;
- The use of concrete pre-cooling

Pozzolanic Material: The gravels that were in abundance in the vicinity of the construction site of service contained mineralogical elements that react chemically with cement alkalis, and could lead to expansions in the hardened concrete, with the appearance of cracks and fractures that would compromise the safety and durability of the work. There was opted for the inclusion of Pozzolanic material in dosages. Therefore, from that concept and the fact there were deposits of kaolinitic clays suitable for the production of artificial pozzolana CELUSA decided to implement a pozzolan mill from the calcination of this clay in Três Lagoas, Mato Grosso do Sul, in the of the construction of the hydroelectric plant Jupiá.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
18	Jupia Dam	Brazil	1968	1963- 1965	[32; 33]

ASPECTS

Pre cooling: During the construction of the dam, at the beginning of the years 60, due to the means of production and release, increase in the dimensions of the blocks and cause the appearance of cracks in the concrete. The cracks were caused by volumetric variations arising from high temperature variations, with peaks of about 60° C.

Several studies have been developed and carried out tests to control the influence of the heat of hydration of cement, in the appearance of cracks. It was established the ideal temperature of the concrete to 7° C. To that end it was necessary the adoption of pre-cooling concrete measure.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
19	Delta Dam	USA	1910	1924	[34]

ASPECTS

Delta Dam is a cyclopean masonry with an uncontrolled spillway and four low-level outlet pipes discharging into the stilling basin downstream of the structure.

Problems at the site were evident in 1913, when the dam was completed. A high-water-content concrete had been used in construction to fill voids between the cyclopean stones. Leaching from the concrete left carbonate deposits on the outer surface of the dam and on the joints between adjacent monoliths. This leaching caused the concrete to deteriorate.

The subsequent inspection report carried recommendations for placing new masonry on the upstream and downstream faces of the dam, grouting to stop interior leakage, improving sliding stability of a portion of the spillway, installing a grout curtain in the foundation rock, and installing a drainage system to relieve uplift pressures.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
19	Delta Dam	USA	1910	1924	[34]

ASPECTS

Repairs since the inspection consisted of the following:

- partial grouting of the dam body was accomplished.
- a reinforced concrete lining was placed on the upstream face of the dam,
- the foundation area was grouted, and
- a concrete thrust block was placed over the western half of the downstream edge of the spillway apron.
- The concrete on a portion of the downstream face below the gate house was removed and replaced with gunite, and some portions of the dam were grouted.

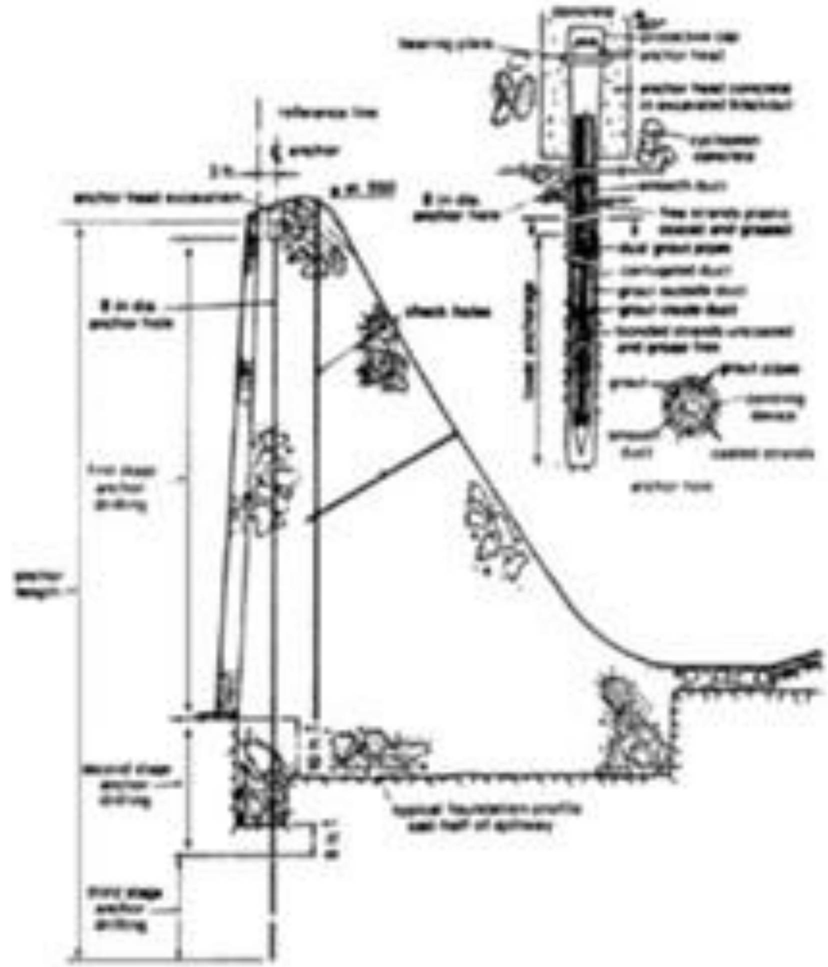
In 1958, the entire downstream face of the dam was resurfaced with gunite, and wrought iron nosing was installed on the gatehouse intake piers. Concrete deterioration continued despite these repair efforts.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
19	Delta Dam	USA	1910	1924	[34]

ASPECTS

In 1978, a detailed inspection of the dam and to make specific recommendations for rehabilitation of the structure. Engineers reviewed the hydrologic capacity and stability of the structure when placed under updated design criteria and evaluated the extent of concrete deterioration. Based on this study, they recommended that posttensioned anchors be installed to improve the stability of the dam, both the upstream and downstream faces of the dam be repaired, and portions of the dam be grouted.

The strands were installed with double corrosion protection consisting of a plastic duct and grouting. The grouting system included simultaneous tremie-placement of grout both between the strand and casing and the casing and anchor hole. Anchor embedment depth ensured resistance of the lower anchorage to applied upward pull. In the free length of the anchor, the smooth duct and a grease and plastic coating on the strands kept the strands from bonding to the grout.



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
20	Salt Springs Dam	USA	1931	2004	[35]

ASPECTS

The dam (CFRD) 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 consists 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.

As a result PG&E and its independent board of consultants decided that installation of a flexible membrane over the existing concrete face would more satisfactorily provide the desired leakage control and accommodate any future settlement.

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CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
21	Shih-Kang Dam	Taiwan	1977	To be rebuilt	[36; 37]

ASPECTS

On 21, September 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 for the damaged one.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
22	Gibson Dam	USA	1929	1982	[38; 39; 40; 41]

ASPECTS
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 will 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 project into the roadway, and the downstream edges are flush with the parapet walls. To prevent plucking erosion, rock bolts and concrete caps were installed on downstream rock abutments.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
23	FARIMAN DAM	Iran	~1400	1700;1930; 2001	[03; 04]

ASPECTS

The dam has been rehabilitated due to overtopping occurring almost every year during the flood season and leakage through the dam body. The height of the dam has been increased by about 5 m together with leakage prevention measures for its upstream face as well as strengthening the old structure in 200.

The purpose of its rehabilitation was to strengthen it due to leakage through the dam body and to increase its height by 5m due to overtopping occurring almost every year during the flood season.

Three alternatives for the prevention of leakage through the dam body and Reinforced Concrete was finally selected not only because of its least cost and lowest permeability but mainly because it strengthens the dam section and provides stability

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
24	Ute Dam	USA	1963	1984	[41]

ASPECTS

The original structure consisted of an embankment main 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 a labyrinth spillway in that the dam's approach flow is 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	REHABILITATION/ REPAIR	REFERENCES
25	El Guapo	Venezuela	1999	2009	[42]

ASPECTS

El Guapo dam reservoir was at his peak when he received the flood waters that could not contain due to its great magnitude and occurred a rupture. A new RCC concrete spillway was constructed and the embankment was repaired.

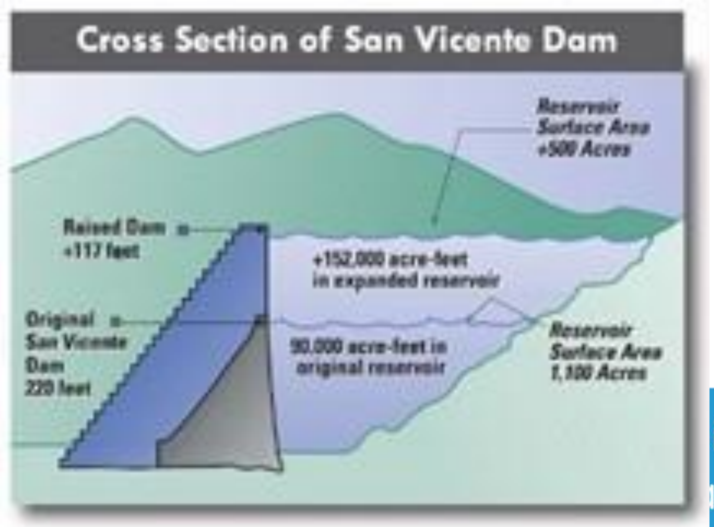






CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
26	San Vicente Dam	USA	1943	2014	[43]www.mwhglobal.com/project/san-vicente-dam-raise

ASPECTS
In June 2009, construction to raise the height of the dam by 36 m, in order to more than double its reservoir size, commenced. It is the largest dam raise in the United States and largest RCC dam raise in the world. The dam raise project was completed in early 2014



CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
27	Theodore Roosevelt Dam	USA	1911	1989-1996	[44; 45]

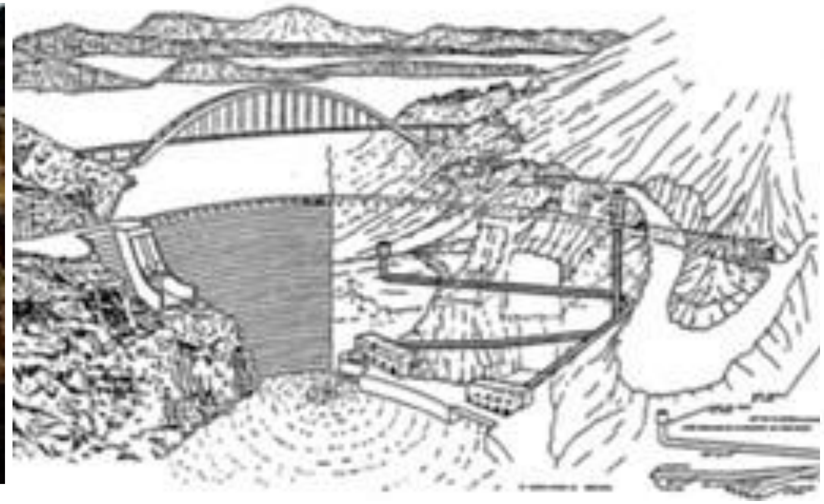
ASPECTS
When it was completed, it was the tallest cyclopean masonnry, gravity-arch dam in the world. Originally built between 1905 and 1911; the dam was renovated and expanded in 1989-1996. An important consideration was the bond and state of stress at the interface between the masonry dam and the new concrete. In determining the final design modification, several options were evaluated including double-and single-curvature arch alternatives. Theodore Roosevelt Dam was modified to provide additional conservation storage and flood protection for the Phoenix, Arizona, metropolitan area. The dam was resurfaced with concrete and its height was raised 23 m, which had the effect of increasing the storage capacity of Roosevelt Lake

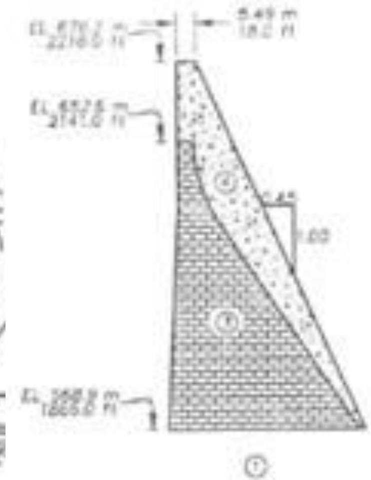
CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
27	Theodore Roosevelt Dam	USA	1911	1989-1996	[44; 45]

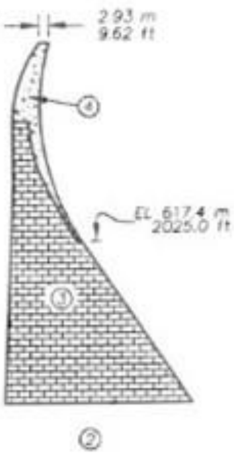
ASPECTS

In 1978, during investigations was identified as a high-hazard dam in need of modifications. According to revised PMF the dam would be overtopped, causing a loss of the spillways and the power plant and possibly causing failure of the three dams downstream.

Modifications included raising the height of the dam and increasing the length. A new river outlet works was added to provide for a more efficient emptying of the reservoir in case of an emergency.
The dam power plant was modified to enable its operation under higher reservoir heads and tailwater.
Before beginning concrete placement, workers cleaned the existing masonry surface by removing all loose, chipped material and then waterblasting the surface. The concrete blocks were then constructed on the downstream face of the dam.







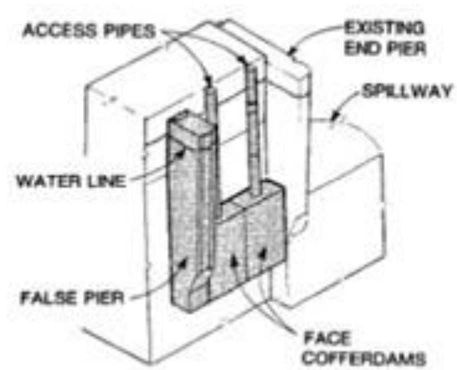
Historic cases on concrete dams rehabilitation

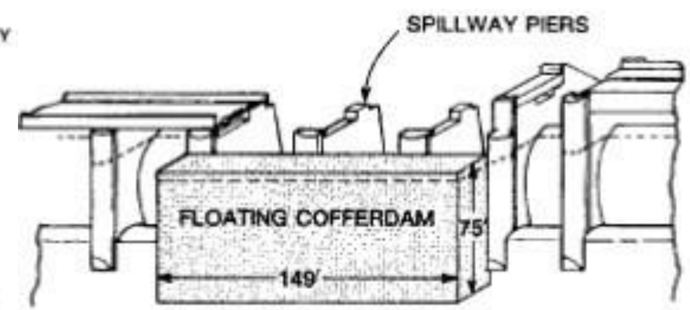
CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
28	Chief Joseph Dam	USA	1950	1981	[46; 47]

ASPECTS

The dam was modified to increase hydropower production. Modifications included raising the height of the dam by 3 m, and installing of 11 generating units in the powerhouse to bring the total to 27 as per the original plan.

This work had to be done without interruption of power production or the flow of the Columbia River. To solve this problem, engineers decided to use floating cofferdams that would allow several spillway bays to be dewatered at one time without the reservoir having to be lowered. Removal of the reinforced concrete required some experimentation. All repairs were performed underwater.



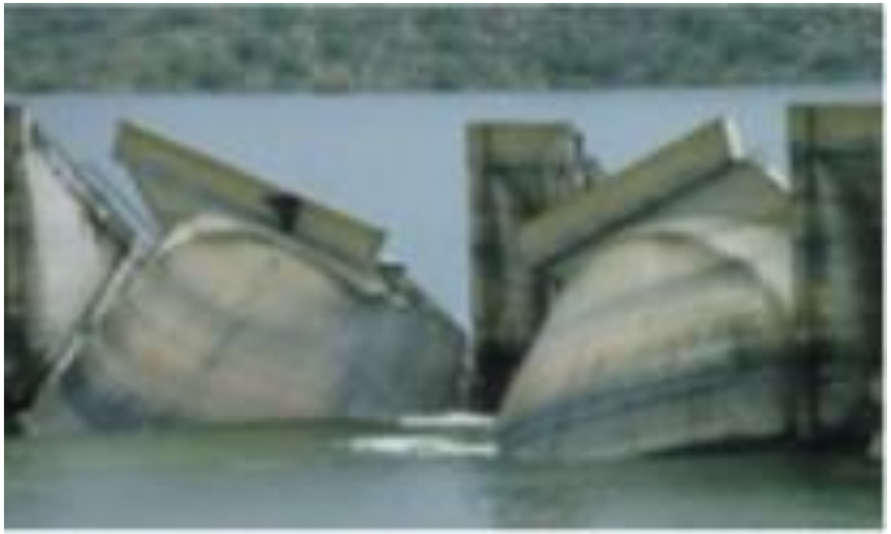


CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
29	Waddell Dam	USA	1926	1993	[48]

ASPECTS

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 104m high rockfill embankment dam, which is located about 0.8 km downstream of Waddell Dam, and which will inundate 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.



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
30	Cambambe Dam	Angola	1964	2017	[49]

ASPECTS

The Cambambe Dam rehabilitation and expansion project forms an integral part of a program that comprises three phases:

- Phase 1: Rehabilitation of the four existing turbine generators that was currently not operational;
- Phase 2: Construction of a second powerhouse with four additional turbine generators, with 700 MW in total, and;
- Phase 3: Heightening of the dam crest elevation by 30 m to the total height of 132 m and the construction of a lateral spillway.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
31	Chavimochic Dam	Peru	1993	2000	[50]

ASPECTS

During the rainy period of 1993/1994, which was characterised by being for long periods, flows of the order of 300 to 400 m³/s, besides the three floodgates remain open for long time, on the basis of works to be carried out within the water intake spillway.

As a consequence, there was an intense erosion on the pillar between the 2 gates I and 2, function of the impact of sediment in high speed and Increased the effect of the abrasion caused by the action of the vortices who graduated from your base, These efforts provoked a cesspool deep around the base of the pillar, which stretched to downstream in the greater inclination of the profile of the Spillways 1 and 2 causing wear and removal of protective coating
This protection was done with plates of 0.40 x 0, 40 x 0, 20 m high granite abrasion resistance.

Historic cases on concrete dams rehabilitation

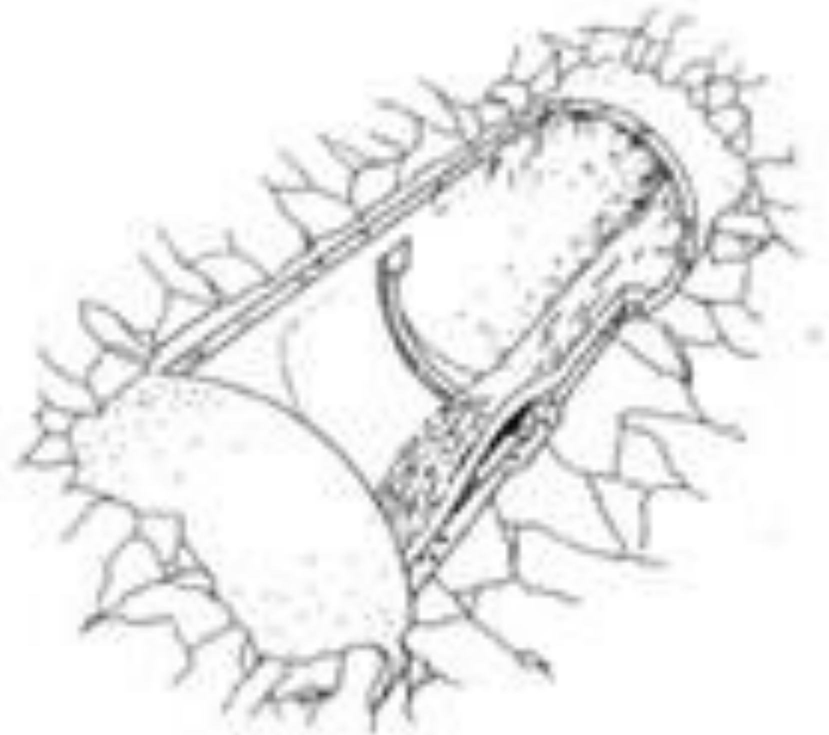
CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
32	Glen Canyon Dam	USA	1964	1980/1983	[51]

ASPECTS

An inspection of the tunnels following the test revealed minor cavitation damage to the liners. Vapor cavities occur in a 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, 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.



CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
33	Alpe Gera Dam	Italy	1964	1994	[22; 52]

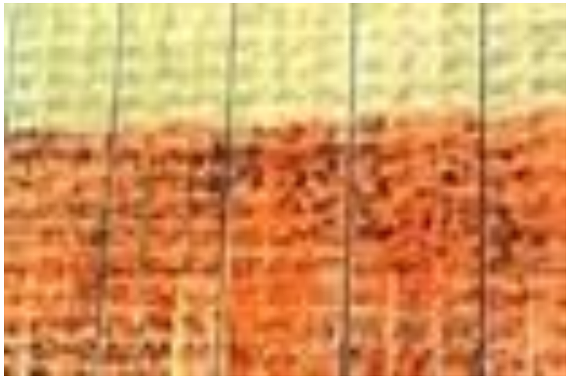
ASPECTS

Alpe Gera Dam is a concrete gravity dam, using a technique similar to modem RCC dams, and with steel facing as impervious upstream membrane. The top 96 meters were galvanized and coated with vinyl acrylic paint. Areas below this were not painted.

Most of the corrosion of the steel lining occurred in this lower area. Leakage increased to more than 50 l/s. A drained PVC geomembrane was adopted to protect the corroded steel facing. Steel patches were installed as anti-intrusion supports to the PVC geomembrane over the numerous holes formed in the steel.

The amount of water leaking from the area covered with PVC was reduced to practically zero.






Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
34	Sutton Dam	USA	1961	1980	[53; 54; 55]

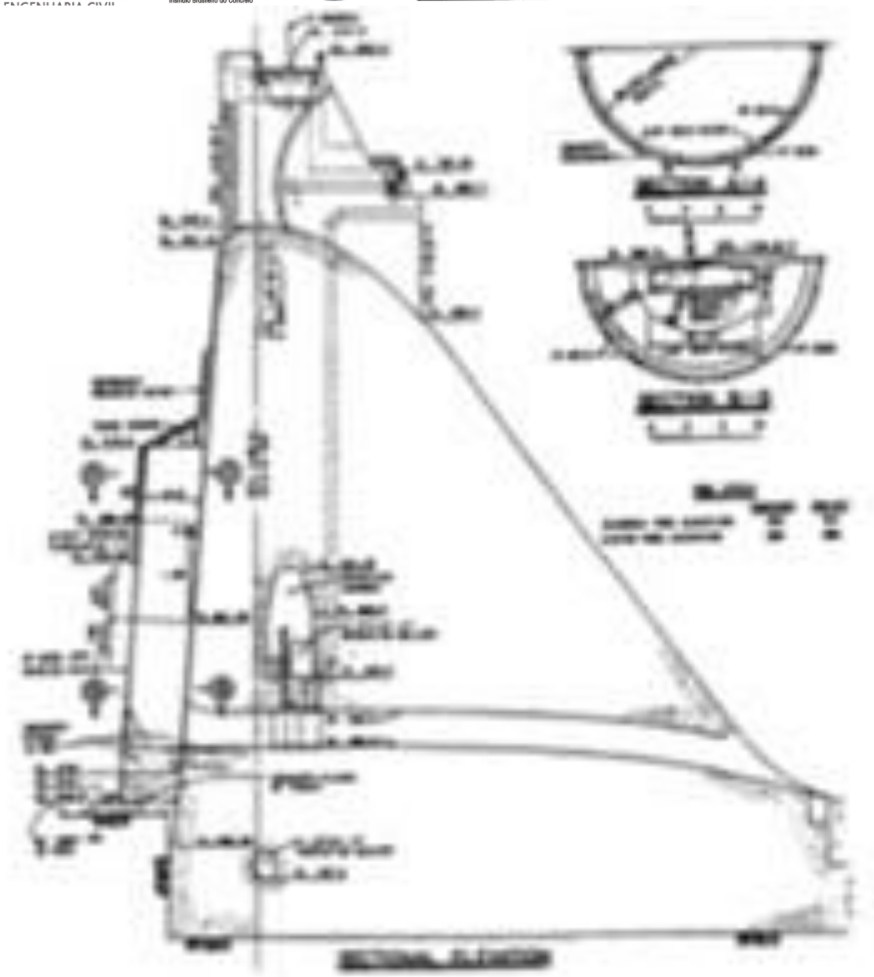
ASPECTS

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	REHABILITATION/ REPAIR	REFERENCES
35	Sayano Shushenskaya Dam	Russia	1979	2009	[56; 57; 58]

ASPECTS

On August 17th/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 main stream and the technical press. Over the ensuing months, theearly internet postings of photographs, videos and narratives from witnesses and technical experts in Russia were supplemented with studies, opinions and speculations about causes from writers both inside and outside of Russia. 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.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
35	Sayano Shushenskaya Dam	Russia	1979	2009	[56; 57; 58]

ASPECTS
This hypothesis is that the explosion was caused by water column separation in the draft tubes of the destroyed units. This condition can readily be caused by a too-rapid wicket gate closure during unit load rejection. This, combined with compromised stud connections due to poor maintenance, can explain the extreme violence of this accident. Complete and detailed technical data, such as drawings and data sheets, have not been available to support a full-scale technical paper on this subject. Therefore, the conclusions presented in this article are speculative. The importance of the safety issue to the profession and the hydroelectric industry.

Course 1

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7- REFERENCES

[01]- **Alcaraz, A.; Arenillas, M. y Martín**, J. –"*La estructura y la cimentación de la presa de Proserpina*"- IV Jornadas Españolas de Presas- Comité Nacional de Grandes Presas- Murcia- España-1993;

[02]- **F. Aranda Gutierrez & J.L. Sánchez Carcaboso**- "*Rehabilitación integral de la Presa y Embalse de Proserpina*"- Dam Maintenance and Rehabilitation II- Zaragoza, Spain- November 2010;

[03]- **Abbas Kangi, Jafar Rahnamarad, Mohammadali Alizade, Ahmad Ghandehary**-"*The ancient dams built by the Timurids (1350 to 1490 A.D.) in North East of Iran*";

[04]- **M.E Omran and H Abbas**- "*Strengthening, Heightening and Leakage Control Measures for an Ancient Fariman Dam in Iran*" - India Cold – New Delhi- November-1998;

[05]-**François Lemperie**- "*Risks and Hazards of Dam Failures: Low Cost Remedies*"- India Cold – New Delhi- November-1998;

[06]- **Geoffrey P Sims Brown & Root Services** "*The Rehabilitation of Dams and Reservoirs*" –UK;

[07]- **A. Remini; W. Hallouche**- "*Sedimentation in Algeria's Large Dams*"- International Water Power and Dam Construction-October-2007;

[08]- **Kanji, Milton Assis**- "*Dam Foundation Affected by Geological Aspects*"- Online Lecture- ISRM-December- 2017;

[09]- "*Independent Forensic Team Report- Oroville Dam Spillway Incident*" - January 2018; and Internet Information;

[10]- **US Army Corps of Engineers**- "*A history of Karst seepage - Center Hill Dam Rehabilitation*"**-** International Water Power and Dam Construction –June-2008**;**

[11]- **Hugenberg,Tom**-"*Alkali-carbonate rock reaction at Center Hill Dam, Tennessee*." SP-100-96, Concrete durability, Katharine and Bryant Mather international conference. John M. Scanon, ed., Vol 2, American Concrete Institute, Detroit, 1987- Repair and Rehabilitation of Dams: Case Studies- by **James E. McDonald, Nancy F. Curtis**- REMR- CS-83- September 1999;

[12]- **Obernhveber P**,- "*Remedial works for the Kolnbrein Dam: Design and Analysis*". 17th ICOLD Congress, Vienna, C7- 1991;

[13]- **Memorandum to Head, Dam Safety Inspection Section, Subject**: "*Examination Report for Upper Stillwater Dam - Safety Evaluation of Existing Dams (SEED) Program*", dated June 5, 1990- Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December 1998;

[14]- **Technical Memorandum No. US-8314-1**- "*Performance Monitoring Criteria- Upper Stillwater Dam, U.S. Bureau of Reclamation*", 1994- Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December 1998;

[15]- "*Crack repairs to Upper Stillwater Dam,*" Concrete International 1991- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September 1999;

[16]- **Barnes, W. D.** - "*Anchoring of spillway monoliths, Alum Creek Lake, Ohio,*" Concrete Structures Information Exchange Bulletin, C-82-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS-1982**-**Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR-CS-83- September 1999

[17]- **Fenves, Gregory L. and Soheil Mojtahedi**-"*Effects of Contraction Joint Opening on Pacoima Dam in the 1994 Northridge Earthquake*", Earthquake Engineering and Research Center, University of California, Berkeley, CA, September, 1995. Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December 1998;

[18]- **Fenves, Gregory L.**- "*Response of Pacoima Dam in the 1994 Northridge, California, Earthquake*", *EERC News,* No. 17, Issue 4, University of California, Berkeley, CA, October 1996. Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December 1998;

[19]- **Swanson, A. A. and R. P. Sharma.** -"*Effects of the 1971 San Fernando Earthquake on Pacoima Arch Dam*", Thirteenth Congress on Large Dams, Question No. 51, International Commission on Large Dams, Paris, France, 1979- Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December 1998;

[20]- **Amelia A Pridemore- "***The register Herald- Bluestone Dam***"** – The register Herald News Paper- February 2009;

[21]- **Alan BAIL; Paul ROYET** –'*Confortement du barrage de Rassisse* '- Symposium du CFBR du 26 janvier 2017 à Chambéry ;

[22] –-"*Waterproofing and Protection- Dry and Underwater Installations*" – Since 1963- Carpi Catalog;

[23]- **Rutledge, J.** -"*Increasing spillway capacity to allow passage of the PMF at Morris Sheppard Dam*" - Annual conference proceedings- Association of State Dam Safety Officials, Lexington, KY-1989- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September 1999;

[24]- **Ribler, P & Heitefuss, C.**- "*Adaptation of the Ennepe Dam Germany to the Established Technical Standards*" International Journal on Hydropower and Dams- Vol 6 issue 2-1999.

[25]- **V. Bettzieche & C. Heitefuss-** "*Monitoring as a basis of cost-effective rehabilitation of an old masonry dam*"- Ruhrverband (Ruhr-River-Association), Essen, Germany- 2001;

[26]- **Regamey, J. M. & Hammerscill.**-AG J G.- "*Barrage de l'Illsee – Assainissement*". SwissCOLD Conference Research and development in the field of dams, Crans Montana, Switzerland- 1995

[27]- **Hydropower and Dams.** -"*A review of hydropower and dam projects in North America: Spillway gates to be replaced at Friant Dam*" Issue 1997- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September 1999

[28]-**Sabino Freitas Corrêa; Nelson Luiz de Andrade Corrêa; Antônio Manoel Soares;Mércio Viana; Marianne Freitas Corrêa**- "*RIO DESCOBERTO DAM - In the Wet REHABILITATION TECHNIQUE PERMITS TO KEEP THE WATER SUPLLY IN BRASÍLIA – BRAZIL*"
US Cold – San Diego-2002;

[29]- **Harlan, R.C.; Onken S,; Scuero A M & Vaschetti G L.**- "*The underwater installation of a drained geomembrane system on Lost Creek Dam*"- Proceedings of CANCOLD Conference, Nova Scotia, Canada- 1998;

[30]**-** "*The Möhne Dam and Reservoir*"-Ruhrverband Information Department- Essen- Germany

[31]- **ICOLD Bullettin 119**- "*REHABILITATION OF DAMS AND APPURTENANT WORKS- State of the art and case histories*"- 2000;

[32]- **Andriolo, Francisco Rodrigues**- "*Utilização da Pozolana na Construção do Conjunto Hidroelétrico de Urubupungá*"- CESP- Abril-1975

[33]– **Andriolo, Francisco Rodrigues**; **Skwarczynski, Tadeusz**- "*Concreto Pré- refrigerado no Brasil: Uma Evolução com mais de 20 Anos*"- editora Graphos- Rio de Janeiro- Outubro-1988;

[34]- **Standig, K. F.** - "Rehabilitation of the Delta Dam" Water Power & Dam Construction- 1984- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[35]- **"***A permanent solution at Salt Springs dam*"- International Water Power and Dam Construction- 14 March 2006;

[36] **- Kung, Chen-Shan, Ni, Wei-Pin, and Chiang, Yun-Jen-** "*Seismic Fault-induced Failures*-*DAMAGE AND REHABILITATION WORK OF SHIH-KANG DAM***"-** January-2001;

[37]- **Kenneth D. Hansen; Larry K. Nuss-** *"Lessons Learned from Earthquake performance of Concrete Dams"*- International Water Power and Dam Construction- July-2011

[38]- **U.S.Bureau of Reclamation**- "*Geologic Report on the Modification of Gibson Dam*", Geology Branch, Frank Calcagno, Jr., Denver, May, 1982; Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December-1998;

[39]- **U.S.Bureau of Reclamation**, *"Final Report of Design and Construction",* Gibson Dam, Denver, 1930- Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December- 1998;

[40]- **U.S.Bureau of Reclamation**, *"Technical Report of Construction*", Gibson Dam Modification, Sun River Project, Montana, September 1982- Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December-1998;

[41]**- Neil Parrett-** *"New Approaches to Reabbing Old Dams***"-** Civil Engineering Database- ASCE- Vol 56- Issue 6- 1986;

[42]-*"El Guapo dam to be Rebuilt"*- International Water Power and Dam Construction- May-2006;

[43]-*"San Vicente Dam Raise"*- http://www.mwhglobal.com/project/san-vicente-dam-raise/- International Water Power and Dam Construction -July -2013;

[44]- **Anne Balogh** – *"Concrete Changes the Face of Theodore Roosevelt Dam*"- Concrete Construction- June 1996

[45]- **Hepler, T. E., Drake, D. M.** -"*Raising Roosevelt Dam: Protection against floods, earthquakes*" Hydro Review 1995- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September -1999;

[46]- **Sondergard, Kenneth B**.- "*Effective underwater joint sealing at Chief Joseph Dam*" -The REMR Bulletin 8(2), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 1991- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September -1999;

[47]- **Sondergard, Kenneth B**.- "*Remedial joint sealing at Chief Joseph Dam*" -Concrete International 1991- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[48]- **William R. Fiedler**- "*Breaching of Waddell Dam*"- Water Operation and Maintenance Bulletin- Bureau of Reclamation- 1992;

[49]- **CNO-** "*Cambambe Dam Project Phase 2 Environmental and Social Due Diligence*"- Report Number 452197/2;

[50]- **Giovene Pérez Campomanes**- "Bocatoma Chavimochic"-1999;

[51]- **Burgi, P. H., and Eckley, M. S**. - "*Repairs of Glenn Canyon Dam*"- Concrete International 1987- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[52]- **D. A. Cazzuffi ; S. Venesia**- "*Experimental Study an Adhesive-geomembrane System for a Dam*"- Metallic Facing Rehabilitation- 1990;

[53]- **Barnes, W. D.-** "*The high level intake at Sutton Dam, West Virginia*" Concrete structures: Repair and rehabilitation, C-82-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.- 1982 Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September -1999;

[54]- **Huntington, WV.** - "*Sutton Lake, Elk River, West Virginia, concrete dam*" Periodic inspection report no. 5, Huntington, WV. 1989- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September-1999;

[55]- **U.S. Army Engineer District, Huntington**- "*Sutton Lake, Elk River, West Virginia, concrete dam*" Periodic inspection report no. 4, -1984- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[56]- **F.A. Hamil**- "*Sayano Shushenskaya Accident- A Possible Direct Cause*"- International Water Power and Dam Construction- November-2010;

[57]- **N.I. Stefanenko; V.B. Zateev; L.S. Permiakoa; E.N. Reshetnikova; E.G. Gaziev**- "Behaviour Management"- International Water Power and Dam Construction-January-2010;

[58]- **A. Asarin**- "*Avaria en la central hidroeléctrica y la seguridad hidrológica de la central de la obra hidráulica de Sayano Shusheskaya*"- - Dam Maintenance and Rehabilitation II- Zaragoza, Spain, November -2010;

[59]- **SWISS NATIONAL COMMITIEE ON LARGE DAMS**- General Paper.14th ICOLD Congress, Rio de Janeiro, GP-RS8- 1982;

[60]- **Berchten, A R,.** *"Repairs of the Zeuzier arch-dam in Switzerland"*- 15th ICOLD Congress, Q 57 R 40 - 1985;

[61]- **Comite National Suisse des Grands Barrages**- *«Comportement anormal du barrage-voute de Zeuzier (Suisse)»*. Wasser, Energie, Lufi, edition speciale a l'occasion du XIVe Congres CIGB, Rio de Janeiro-1982;

[62]- **Pedro,J. 0.; Mascarenhas, A. T.; Sousa, L. R.; Rodrigues L. F.; Silva, H. S. & Castro, A T.-** "Rock Mass Foundation Deterioration of Portuguese Concrete Dams. Some Case Histories". Report to the European Research Office, USA Corps of Engineers. LNEC, Lisboa-1998;

[63]- **Ribler, P**,. -Germany **– ICOLD Bullettin 119- "REHABILITATION OF DAMS AND APPURTENANT WORKS-** ***State of the art and case histories"*** **- 2000**;

[64]- **Flogh, H. & Stauble, H,-** "*Experience with the Supplementary Installation of an Elastic Diaphragm in the Rock of Schlegeis Arch Dam*". 17th ICOLD Congress, Vienna, 066 R41- 1991

[65] **- YORKSHIRE WATER SERVICES Ltd**- *"Boothwood Reservoir, Reservoirs Act 1975: Certificate under Section 10 (6) as to the carrying out of Safety Recommendations"*- 1995;

[66]- **Taddei,B. & Poupart, M**,- *"Reinforcement of the Chambon Dam"*- SwedCOLD Symposium Repair and Upgrading of Dams- Stockholm- 1996;

[67]- **Bister, D, ; Bonnet, P, ; Denis. B, ; De Beauchamp. R, ; Dubois. P & Goguel. B**.- « Contribution au suivi des barrages en beton Français sujets a gonflement ou retrait - application a des ouvrages adultes (Chambon, Vouglans) et au betonjeune (cas du BCR) ».17th ICOLD Congress, Q65 R7. 1991 ;

[68]- **De Beauchamp. T.** – "Concrete swelling and reinforcement of measures at the Chambon Dam". International I on Hydropower & Dams. March-1994;

[69]- "*Anthology of Dam Modification Case Histories*", ISBN 1-884575- 09-9, USCOLD- April- 1996;

[70]**- Phillips, P. & Shannon, F. E.-** "*Recent Investigations at Wimbleball Dam, Somerset*"- Reservoir Safety and Environment, 8th British Dam Society Conference, Thomas Telford, London-1994;

[71]- **Feiner, A. & Zichner, G.-** "Sealing of the Agger Dam"- 9th ICOLD Congress, Istanbul, Q34 R11.- 1967;

[72]- **Silva Matos, D. & Liberal, 0**.- "*Pracana power plant refurbishment and uprating. An uncommon and challenging project*"- Uprating and refurbishment of hydro power plants - *IV*. Water Power & Dam Construction Conference, Florence- 1993;

[73]- **Tada, S. & Shibata, K.**- "*Kuromata dam- Leakage prevention work*" 17thICOLD Congress, Vienna, 065 R58- 1991

[74]– **Shibata, I. & Sano, T**.- "*Effects of ageing and subsequent repairs of dam concrete at Sasanagare Dam*"- 17th ICOLD Congress, 065 R21- 1991;

[75]- **Charvoz. B.**- « *Barrage de la Girotte - Etancheite voftte 11-12 par membrane CARPI* ».-EDF Dept. Sepr- 1995

[76]- **La Mar, B., Ivarson, W. R., and Tenke-White, K**.- "*Rehabilitation and replacement of slab and buttress dams at the Wissota Hydroelectric Project,*" Waterpower 1991- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[77]- Water Power & Dam Construction. "*Concrete repairs at Haweswater Dam, UK*," 1989- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September - 1999;

[78- **Lino, M. ; Salembier, M. ; Antoine, F. ; Rouags, G. ; Cledouet, D. & Saint-Marcel A.-**« Vieillissement de quelques barrages Français tres anciens. Pratique de leur rehabilitation»- 17th ICOLD Congress, Vienna, Q65 R1-1991;

[79]- **Lino, M.; Degoutte, G.; Goguel, B.; Chassard, G. ; Saint Marcel, A. ; Gouvenot, D. & Delmas, F.**-. "*Steps taken to improve the watertightness of dams and their foundation and to reduce the risk of internal erosion*"- 18th ICOLD Congress, Durban, Q68 R46-1994;

[80]- **Schberl, P**.-"*Crack sanitation at Zillergrundl arch dam*"- SwedCOLD Symposium. Repair and Upgrading of Dams, Stockholm-1996;

[81]- **Schoberl, P,; Duber, H & Dopper, H**.- "*Force-locking Crack Injection at Zillergründl Arch Dam*"- Grouting in Rock and Concrete- Balkema,Rotterdam- 1993;

[82]- Réévaluation et amelioration de la sécurité des barrages en maçonnerie et en béton- 18th ICOLD Congress, Durban Q 68 R 44- CFGB-1994;

[83]- Relatório AiE-COCA-Cando-04/2002- "Análise de Documentos e Visita Técnica às Obras da UHE Candonga- Outubro de 2002

[84]- Ageing of dams and appurtenant works. Review and recommendations-REHABILITATION OF DAMS AND APPURTENANT WORKS- *State of the art and case histories*. Bulletin 93- 1994;

[85]- **Diaz-Caneja Rodriguez J I**,- "Evaluation and increase of safety for dams in service in the basin of the Douro River.- Remedial works"- 19th ICOLD Congress, Durban, Q68 R30-1994;

[86]- "*Use of Geomembranes for Construction of New RCC /Fill Dams*"- Carpi- 2000;

[87]- "*Deterioration of dams and reservoirs. Report prepared by a team of Portuguese engineers of the Laboratorio de Engenharia Civil*". LNEC -Lisbon-ICOLD- 1983;

[88]- "*Some case studies of ageing scenarios control in Portuguese concrete dams*" Work Group of the Portuguese National Committee on Large Dams-ICOLD Congress, Vienna, 065 R57-1991;

[89]- "*Cracking and repair works at Cabril dam*"-Work Group of the Portuguese National Committee on Large Dams- ICOLD Congress, Lausanne, 057 R21- 1985;

[90]- **K. Silvano; F. Frongia, ; G. Lombardi; M. Foti, ; F. Ciciotti; F. Gallavresi**- "Rehabilitation of the Flumendosa arch dam by epoxy grouting"- Hydropower & Dams Issue Six, 1997;

[91]- **Eriksson, H.-** "*Investigation and rehabilitation of the Storfinnforsen dam*"- 18th ICOLD Congress, Durban, Q68 R19- 1994;

[92]- **Anders, Isander; Carl-Oscar, Nilsson; Richard, Malm-** "*Evaluation and Structural Rehabilitation of Storfinnforsen Concrete Buttress Dam*-1994;

[93]- **Brighton R, & Lamp A J**.- "*Ageing of B C Hydro's dams*" 17th ICOLD Congress, Vienna, Q65 R30-1991;

[94]- **W. Wittke; D. Schroder; H. Polczyk**- *"Upgrading The Stability of Three Masonry Dams In Different Ways"*- International Society for Rock Mechanics and Rock Engineering 10th ISRM Congress, 8-12 September, Sandton, South Africa – 2003;

[95]- "*Loyalhanna Dam," Fifth periodic inspection report*, Pittsburgh, PA. 1990- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[96]- "*Point Marion Lock and Dam, Monongahela River"-Fifth periodic inspection report*, Pittsburgh, PA. 1989- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[97]- "*Point Marion Lock and Dam, Monongahela River,' Seventh periodic inspection report*, Pittsburgh, PA1994- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[98]- **U.S. Army Engineer, District, Pittsburgh**. - "*Stonewall Jackson Dam, Second periodic inspection report*, Pittsburgh, PA. 1989- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[99]- "*Stonewall Jackson Dam," Fifth periodic inspection report*, Pittsburgh, PA. 1992- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[100]- "*Stonewall Jackson Dam," Seventh periodic inspection report*, Pittsburgh, PA. 1995- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[101]- **U.S. Army Engineer, District, Pittsburgh**. –“*Tygart Dam- Fourth periodic inspection report*”, Pittsburgh, PA. 1985- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[102]- "*Tygart Dam - Sixth periodic inspection report*”, Pittsburgh, PA. 1995- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[103]- **U.S. Army Engineer District, Wilmington**. - "*Philpot Lake Dam and Powerhouse, Roanoke River Basin, Virginia*" Periodic inspection report no. 1, Wilmington, NC. 1966- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September -1999;

[104]- "*Philpott Lake Dam and Powerhouse, Roanoke River Basin, Virginia*" Periodic inspection report no. 5, Wilmington, NC. 1988- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[105]- "*Philpott Lake Dam and Powerhouse, Roanoke River Basin, Virginia*" Periodic inspection report no. 6, Wilmington, NC. 1993- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September -1999;

[106]- **U.S. Army Engineer District, Little Rock** -"*Norfork Dam and Power Plant, Norfork River, Arkansas: Dam and Power Plant*" Periodic inspection report no. 8, Little Rock, AR. 1990- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[107]- **Bianchi, R. H., and Bruce, D. A.** –“*The use of post-tensioned anchorages on the arch portion of Stewart Mountain Dam, Arizona*" Geotechnical Practice in Dam Rehabilitation, No. 35, American Society of Civil Engineers, New York- 1993- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[108]- **Nuss, L. K., and Fielder, W. R.** -"*Proposed posttensioned anchors for Stewart Mountain Dam thin arch structure*" Corps of Engineers Structural Engineering Conference. Pittsburgh, PA. 1988- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[109]- **Hammer, J. J., and Buttrey, H. G.** -"*Chickamauga Dam and Lock*" Corps of Engineers structural engineering conference. Pittsburgh, PA.- 1984- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[110]- **Stowe, R. L., and Thornton, H. T., Jr.** -"*Condition survey repair and rehabilitation Lock and Dam No. 24, Mississippi River*" Miscellaneous Paper SL-81-21, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 1981- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[111]- **U.S. Army Engineer District, St. Louis** - "*Major Rehabilitation Report: Lock and Dam No. 24, Mississippi River*" Major rehabilitation project, St. Louis, MO. 1993- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[112]- "*Lock and Dam No. 24, Mississippi River, Clarksville, Missouri, Lock and Dam, Storage Yard and Overflow Dike*," Periodic inspection report no. 10, Rock Island, IL. 1997- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September-1999;

[113]- **TVA Today**. - "*Fixing the crack in Fontana*" 1976- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September-1999;

[114]- **Biefer, M.** -"*Taking a slice out of concrete growth,*" *Canadian Construction Record,* 18-21. 1989

[115]- **G. A. Thompson; R. R. Steele; and D. M. Coulson; Rousseau Sauv- "**Management of Concrete Growth at the Mactaquac Generating Station"- Second International Conference on Alkali-Aggregate Reactions in Hydroelectric Plants and Dams, held in Chattanooga, Tennessee- October 22-27-1995;

[116]- **Bruce, D. A**.- "*The repair of large concrete structures by epoxy resin bonding*" *The REMR Bulletin* 6(4), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS -1989;

[117]- **Bongard-Bazot et Fils** -«*Aménagement du barrage Pannecierre* **»** - Freyssinet- 2005

[118]- **Scuero A.M.; Vaschetti, G.L**.- "*Rehabilitation of a Masonry Dam with an Impermeable Flexible Membrane- The Camposecco Dam*"- Proceedings- International Conference on Dam Engineering – Kuala Lumpur- Malasya- August 1-2- 1995;

[119]- "*Taming a tenacious undertow with Fabricast bags*"- Tray Lock & Dam Intrusion-Prepakt, Inc.-1986- Spotlight, Cleveland, OH. Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September 1999

[120]- **Doak. S. S.** - "*Experimental concrete repairs*" Corps of Engineers structural engineering conference. St. Louis, MO. - Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[121]- **U.S. Army Engineer District, Rock Island**. - "*Illinois Waterway, Dresden Island Lock and Dam, Morris, Illinois, periodic inspection and continuing evaluation of completed Civil Works Structures*" Periodic inspection report no. 5, Rock Island, IL. 1990- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[122]-"*Illinois Waterway, Dresden Island Lock and Dam, Morris, Illinois, Periodic inspection and continuing evaluation of completed Civil Works Structures*" Periodic inspection report no. 6, Rock Island, IL. 1995- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[123]- **U.S. Army Engineer District, Rock Island** - "*Nine-foot channel project, Mississippi River, Canton, Missouri, Lock and Dam No. 20*" Periodic inspection report no. 6, Binder 1 of 2, Rock Island, IL. 1996- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September-1999;

[124]- "*Starved Rock Repair and Rehabilitation of Dams*"- Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September-1999;

[125]- "*Corps of Engineers- Illinois Waterway Locks & Dams Rock Island District*"- 2017;

[126]- "*Lock & Dam # 2 Repair and Rehabilitation of Dams: Case Studies*"- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[127]- "*Study of Waterproofing Revetments for the Upstream Face of Concrete Dams: Final Report*"- International Journal on Hydropower & Dams, Volume 4-1997- Commission Internationale des Grands Barrages- 1998;

[128]-"*Study of Waterproofing Revetments for the Upstream Face of Concrete Dams: Final Report*"- International Journal on Hydropower & Dams, Volume 4-1997- Commission Internationale des Grands Barrages- 1998;

[129]- **Cazzuffi D.; Monari, F.; Scuero, A.M.** – "*Geomembranes Waterprofing for rehabilitation of concrete and masonry dams- Lago Nero Dam- Italy*"- Proceedings, International Society for Soil Mechanins and Foundation Engineering- Geosynthetics Case Histories- March- 1993;

[130]- "Study of Waterproofing Revetments for the Upstream Face of Concrete Dams: Final Report" Commission Internationale des Grands Barrages, 1998

[131]- **Baldovin, G.; Baldovi, E.; Fiamberti, A**.- "*Rehabilitation and waterproofing of the upstream facing of Ceresole Reale dam*"- ICOLD- Congress, Durban, Q68 R87- 1994;

[132]- Sadagopan, A. A. - Kolappan, V. P.- "*Kadamparai dam to cure leakage*" -in International Journal on Hydropower and Dams - 12, 4; 79-81-2005

[133]- **A. Scuero, G. Vaschetti** – "*Geomembanes for Seepage Control in Dams: New Technologies in Rehabilitation and New Construction*"- CARPI TECH -V. Subramanian, CARPI INDIA Waterproofing Specialists- 1998;

[134] -**Jaya Prakash Chand**- "*Under Treatment of Cracks in Hirakud Dam*"- India Cold – New Delhi- November-1998;

[135]- **Malholtra, R. K, Agarwal, M. L., and Bhat, A. P**.- "*Spillway repairs at Bhakra Dam,*" Water Power & Dam Construction- 1987- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[136] -**Ellett, Troy** - "*Water-activated foam used to seal leaks at Texas Dam*"- Hydro Review 10(1), 98-99. - Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September-1999;

[137] - **Carter, P. -** "*The upgrading of dams in New South Wales*," Water Power and Dam Construction 42(5), 19-22. Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[138]- "*Daniel Johnson Repair and Rehabilitation of Dams: Case Studies*"- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[139]- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[140]- **Bruce, D. A., and Clark, J. H.** - "*The stabilization of Shepaug Dam, CT, using high prestressed rock anchors*"- Annual conference proceedings- Association of State Dam Safety Officials, Lexington, KY, 1989- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September -1999;

[141]- **Beckman, T. R., and Hulick, R. M.** (). "*Diamond wire sawing accelerates dam rehabilitation scheme*" *Water Power and Dam Construction* 43(7), 25-28.-1991;

[142]-**Papadopoulos D.** – "*Seepage evolution and underwater repairs at Platanovryssi*"- The International Journal on Hydropower & Dams – Volume Nine- Issue Six-2002;

[143]- **Chakrabarti, P., and A.K. Chopra-** "*Analysis of the Earthquake Performance of Koyna Dam*", Bulletin of the Indian Society of Earthquake Technology, Volume 9, No. 2, Paper No. 121, June 1972 Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December- 1998;

[144]- **Chakrabarti, P., and A.K. Chopra-** "*The Koyna Earthquake of December 11, 1967 and the Performance of Koyna Dam*", Earthquake Engineering and Research Center Report No. EERC 71-1, University of California, Berkeley, CA, April 1971- Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December- 1998;

[145]- **Hall, J.F.**- "*The dynamic and earthquake behaviour of concrete dams: review of experimental behavior and observational evidence*"- Soil Dynamics and Earthquake Engineering- Volume 7, Concrete Dams- Case Histories of Failures and Nonfailures with Back Calculations- DSO-98-05- Bureau of Reclamation- December-1998;

[146]- **M. D. Pendse, S.N. Huddar and S.Y Kulkanrni**- "*Rehabilitation of Koyna Dam- A Case Study*"-India Cold – New Delhi- November-1998;

[147]- **C. Oosthuizen; L. Hattingh; I. Segers; J. Beukes; W. van der Westhuizen; & L. Moloi** – "*Rehabilitation of dams in South Africa ... 40 years on*" - Dam Maintenance and Rehabilitation II- Zaragoza, Spain, November- 2010;

[148]- **F. Rio Iglesias & R. Fernandes Cuevas**- "*Presa de Susqueda. Reinyeccion de juntas*" - Dam Maintenance and Rehabilitation II- Zaragoza, Spain, November- 2010;

[149]- **F.J. Riquelme; J. Garcia Orna; F.J. Herrero & F. Rio Iglesias**- "*Rehabilitación de los desagues de fondo de la Presa de Susqueda*"- Dam Maintenance and Rehabilitation II- Zaragoza, Spain, November- 2010;

[150]- **S. Garcia- Wolfrum; M. Humbsch; R. Männel & A. Robinson**- "*Refurbishment of Klingenberg Dam*"- Dam Maintenance and Rehabilitation II- Zaragoza, Spain, November- 2010;

[151]- **Chen Guanfu; Zhou Jianping; Zhao Quansheng**- "*Crack Treatment in Linhenkou RCC Arch Dam*"- International Water Power and Dam Construction-March-2006;

[152]- **Hasan T. Kocahan; Russel Wyckoff; Martin Wosnik**- "*Spillway inadequacy remediation in the US*"- International Water Power and Dam Construction-November-2009;

[153]- "*Canton Dam (USA): The tallest Fusegate New World Record*"- HYDROPLUS & YOU- 2007;

[154]- "*Catagunya Dam Restoration- Tasmania-Australia*"- International Water Power and Dam Construction-August/-2010:

[155] "*CADASTRO BRASILEIRO DE REABILITAÇÃO DE BARRAGENS*"- Comitê Brasileiro de Grandes Barragens -1990

[156] – "*Reparos no Vertedouro de Superfície de Ilha Solteira*"- Diretoria de Construção- CESP- Abril-1975

[157] **Andrzejewski, R.H**. - "*Proteção da Casa de Força da Usina Hidrelétrica Salto Santiago*"-Simpósio sobre casos históricos de deterioração de barragens e reservatórios, Sao Paulo, Agosto- 1986;

[158]- **Nicole Pagan Hasparyk; Alberto Jorge C. Tavares Cavalcanti; Walton Pacelli de Andrade** – "*Reação álcali-agregado em barragens*"- Revista Concret- IBRACON- Volume 42- 2006;

[159]- **Ávila, L.P. et ai** - "*Reparos no Concreto do Vertedouro da UHE de Marimbondo*". XV S9GB. Volume 1, Rio de Janeiro- 1993

[160]-**Massad, F.**- "*Ocorrência de Reação Expansiva nos Concretos da Usina Apolônio Sales, com Repercussão no Comportamento das Máquinas*"-Simpósio sobre casos históricos de deterioração de barragens e reservatórios, - São Paulo - 1972.

[161]-**Degaspare. J.C. e Cavalcanti. A.J.C.T.** –"Problemas Decorrentes da Reatividade Álcali Agregados na Usina Hidroelétrica Apolônio Sales (Moxotó)"- Tema 11. XVI S.N.G.B -Belo Horizonte- 1985;

[162]- **Cavalcanti. A.J.C.T.**, Silveira, J. F.A. & **Degaspare. J.C. – "***Alkali sílica reaction and remedial measures at Moxoto powerplant*"- 17th ICOLD Congress, Vienna, Q65 R8- 1991

[163]- **Andriolo, Francisco Rodrigues**- "*Concrete: Use in a Sustainable Way*"- Editora Cubo- São Carlos- São Paulo- Brasil- ISBN 978-85- 600064-43-4 Pages 11-1920 to 1922- 2014;

[164]-**Andriolo, Francisco Rodrigues**- "*Obras de Concreto de Itaipu: Desenvolvimento, Controle, Qualidade, Durabilidade... 40 Anos Depois*"- Editora Cubo- São Carlos- São Paulo- Brasil -ISBN 978-85-600064-61-8 Pages 9.903 to 9.905- 2015;

[165]- **Denson, R. H.** -"*Repair of cavitation/erosion damage at Dworshak Dam*"-Annual conference proceedings- Association of State Dam Safety Officials, 1989- Repair and Rehabilitation of Dams: Case Studies- by James E. McDonald, Nancy F. Curtis- REMR- CS-83- September- 1999;

[166]- **Xueqing Zhang**- "*Flexible Structures*"- International Water Power and Dam Construction-February-2007;

[167]- **Kenneth D Hansen & Louis H. Roehm**- "*Lessons learned from the earthquake performance of concrete dams*"- International Water Power and Dam Construction-September-2011.

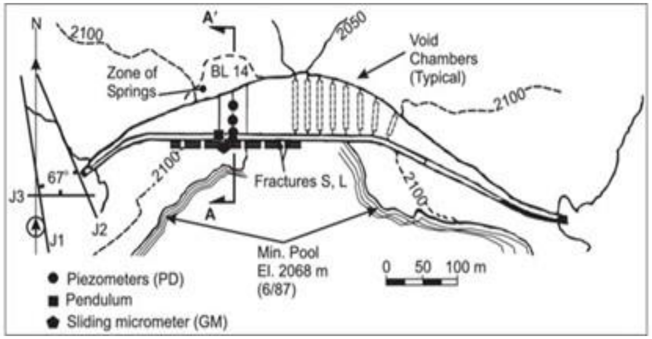
ANNEX

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-001	Albigna Dam	Switzerland	1959	1977	[59]

ASPECTS

During an investigations an open joint was detected along the upstream heel of the dam, extended over a length of 300 m with a width locally up to 8 mm. It became clear that the crack completely crossed the grout curtain. As a first measure in 1977 the water level was lowered immediately.

To repair the dam it was necessary to reduce the water pressure in the fracture opening. Grouting would not have been effective since, as previously mentioned, the rock valley deforms at every change of the reservoir water level.



CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-002	Zeuzier Dam	Switzerland	1957	1979	[60; 61]

ASPECTS

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.

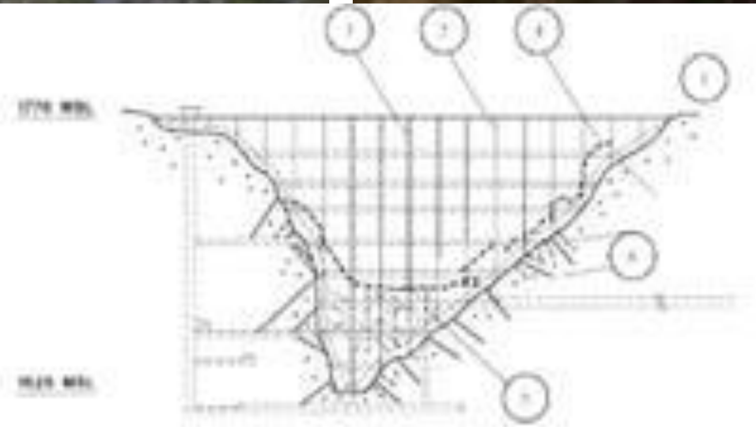


Fig. 3.2.2

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	REHABILITATION/ REPAIR	REFERENCES
A-003	Venda Nova Dam	Portugal	1951	1984	[62]

ASPECTS
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	REHABILITATION/ REPAIR	REFERENCES
A-004	Lister Dam	Germany	1911	1965	[63]

ASPECTS

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 has been allowed to fill, preventing further erosion.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-005	Schlegeis Dam	Austria	1973	1983	[64]

ASPECTS

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 5m deep cut off wall.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-006	Baitings Dam	United Kingdon	1958	1980-1990	[65]

ASPECTS

It was required that choked pressure relief holes should be cleared and if this could not be achieved, they should be replaced. A shrinkage crack should stay under regular observation. Nine new vertical pressure relief holes were drilled from the lowest gallery into the foundation rock

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-007	Booth Wood Dam	United Kingdon	1971	????	[65]

ASPECTS

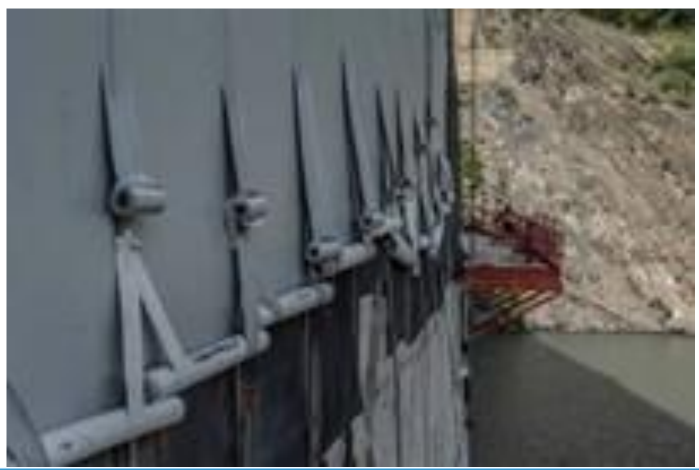
A shrinkage crack should stay under regular observation. Pressure relief holes were drilled from the lowest gallery into the foundation rock

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-008	Chambon Dam	France	1934	1992- 1997	[22; 66; 67; 68]

ASPECTS

The dam is affected by ASR swelling which has lead to progressive cracking and irreversible strains. The swelling had the effect of producing a 120 mm deformation upstream and an increase in height of 70 mm over 25 years.

After a program of grouting and the application of an upstream impermeable membrane to reduce the volume of water feeding the reaction. It was sawed 11 mm wide slots through the dam to relieve the compression within the upper 20 m of the dam and to relieve the left abutment of the heavy thrust of the swelling concrete. After sawing and before refilling the reservoir, the upstream watertight membrane was restored.



CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-009	Hiwassee Dam	USA	1940	1992-1995	[69]

ASPECTS

Expansion of the concrete was caused by AAR- alkali aggregate reaction resulting in high stresses and deflections in the dam. The nonoverflow sections were post-tensioned using high-strength multi-strand tendons. Two 12 mm slots 15 m deep were cut. Other modifications that are required to correct the AAR growth problems include recutting of closing slots, instrumentation for monitoring the slot behavior, and permanent monitoring.

Over the years various types of remedial action have been undertaken, including the cutting of slots and the installation of post tensioned anchors on the spillway piers.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-010	Wimbleball Dam	United Kingdon	1977	2003	[70]

ASPECTS

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 coloured stain below.
Thus 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	REHABILITATION/ REPAIR	REFERENCES
A-011	Agger Dam	Germany	1928	1967	[71]

ASPECTS

The upstream face of the dam was attacked severely by the water for a period of 40 years and considerable water losses due to seepage and finally required rehabilitation measures. This consisted of a complete renewal of the crest and sealing of the upstream face. The latter comprise a 120 mm asphaltic concrete seal behind a 280 mm reinforced, nearly vertical concrete protection wall fixed by anchors to the dam body.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-012	Pracana Dam	Portugal	1951	1985	[22; 72]

ASPECTS

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.

Historic cases on concrete dams rehabilitation

Eng. Andriolo

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-013	Kuromata Dam	Japan	1927	1981	[73]

ASPECTS

The dam had served for more than 50 years with a progressive deterioration, resulting in considerable leakage from the downstream surface of the dam. Therefore, grouting was applied to the dam body and its foundation rock to reduce their permeability to water.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-014	Mesce Dam	France	1917	1970	[31]

ASPECTS

This masonry dam, built without any drainage devices, did not meet the current standards. Among others the seepage at the whole downstream face contributed to this judgement. To minimize seepage, a drainage gallery had been excavated in the foundation of the dam and a system of vertical drains installed from the crest to the gallery. Epoxy resin grouting has been performed over the lower third of the height and near the upstream face, and a grout curtain carried out from the upstream toe into the bedrock.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-015	Sasanagare Dam	Japan	1923	1984	[74]

ASPECTS

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 ageing 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	REHABILITATION/ REPAIR	REFERENCES
A-016	La Girotte Dam	France	1949	19931994/1998	[22; 75]

ASPECTS

La Girotte Dam is a concrete multiple arch dam that comprises 18 vaults each about 2 m thick. Two main problems arose:

• In winter the reservoir water level is usually at the bottom of the arches and the effects on the concrete of freezing and thawing are at their maximum. Many cracks have been observed and these are attributed to thermal effects on the thin concrete elements.

• The quality of concrete is not suitable to combat the acid waters coming from the glaciers.

Due to the deterioration and leakage of the face of the dam it was repaired using PVC geomembrane.

The best results were obtained by applying a resin facing on the concrete surface that had been cleaned by sandblasting. One coat of epoxy resin was applied and this was covered with two or three coats of polyurethane-resin, applied at a rate of about 1.5 kg/m^2. This technique has been used for 25 years, since 1970. It was found to last for 12 to 15 years with some local repairs. After this it was necessary to replace the facing. The major disadvantage was the time it took to complete the sandblasting to take off the old facing.

This was considered to be too costly and alternatives were sought. Since 1994 the owner has experimented with a new PVC geomembrane facing. Five vaults have been covered and it is anticipated that the results concerning the behavior against ageing will be better than those with resin.






CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-017	Wissota Dam	USA	1918	1990	[76]

ASPECTS

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	REHABILITATION/ REPAIR	REFERENCES
A-018	Cedar Falls Hydro Dam	USA	1912	1986	[69]

ASPECTS

The concrete buttresses and corbels were significantly deteriorated due to seepage coupled with freeze-thaw cycles to the extent that the structure was judged to be a high hazard. The repair program consisted of innovative corbel post-tensioning, as well as the more traditional repair using buttressing.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-019	Haweswater Dam	United Kingdon	1942	1987	[77]

ASPECTS

The buttresses forming the dam are dumbbell shaped in plan, giving a continuous face downstream as well as upstream. The surface of the concrete showed spalling over 30 % of the downstream face, mainly in the lower two thirds of the face, with penetrations up to 100 mm. The problem appeared to be caused by high levels of condensation on the internal faces of the buttresses and of freezing and thawing of saturated concrete.

The whole of the downstream face was repaired using a system as:

- The concrete was prepared by mechanical cleaning and grit blasting.
- A surface sealer incorporating saline primer and acrylic top-coat. The purpose of the saline is to penetrate the concrete surface and by chemical reaction to form a hydrophobic block.
- A fairing coat or render which smooth the surface, fills minor blemishes and helps to prevent weak spots through which the cementitious mortar can be attacked.
- A cementitious mortar applied to the damaged area with an acrylic bonding agent.

It appears that the repairs have been successful in the main. After some years there is some cracking of the repair mortar.

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Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-020	La Bourne/ Auberives Dam	France	1878	1984	[78]

ASPECTS

This is an example of a dam rehabilitated through the addition of prestressed anchors. Auberives (La Bourne) was rehabilitated by adding tendons of 500 kN capacity, at 2 m centers along the dam crest. The anchor heads were incorporated within a reinforced concrete beam, shaped as a spillway crest, which also improved the discharge of the flow over the dam.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-021	Ternay Dam	France	1867	1990	[79]

ASPECTS

Stability problems and cracks were repaired by strengthening and by shape correction. An earth and rockfill embankment was placed downstream

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-022	Zillergründl Dam	Austria	1985	1988	[80; 81]

ASPECTS

During first impoundment, at a water depth of 175 m, suddenly a 1 mm wide flat crack developed in a block allowing the release of some 1601/s of seepage water. Rehabilitation measures consisted of force-locking injection of the crack with synthetic resin carried out in two stages.

As a result of the level of the injection pressure of the grout secondary joints appeared and also had to be sealed. Among the lessons learnt was the need to design the level of grout pressure to ensure that local tensile stresses do not exceed the tensile strength of the rock or concrete.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-023	Eguzon Dam	France	1926	1984	[82]
ASPECTS					
The joints and waterstops were rehabilitated by demolition of the squared stone masonry of the upstream face and the cyclopean concrete of the dam body, near the joint comers, and reconstruction with concrete, after inserting a new waterstop					

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-024	Candonga Dam	Brazil	2004	2002	[83]

ASPECTS
The joints and waterstops were rehabilitated by demolition of the concrete in the design line and reconstruction with concrete, after inserting a new waterstop

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-025	Saint-Sernin Dam	France	1922	1984	[84]

ASPECTS

The Saint-Sernin Dam was treated by means of polyurethane resin and by application of pre-stressing forces respectively

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-026	Arlanzon Dam	Spain	1933	1996	[85]

ASPECTS

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.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-027	Les Olivettes Dam	France	1987	1991	[86]

ASPECTS

The Olivettes RCC dam, with a crest length of 254 m, was constructed without contraction joints with concrete containing 130 kg of cement per cubic meter. Three vertical cracks developed, the treatment of which included the application of an elastic sealant in strips a few millimeters deep and 50 mm to 100 mm wide at the upstream face; and grouting the joint near the downstream face

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-028	Cabril Dam	Portugal	1954	1981	[87; 88; 89]

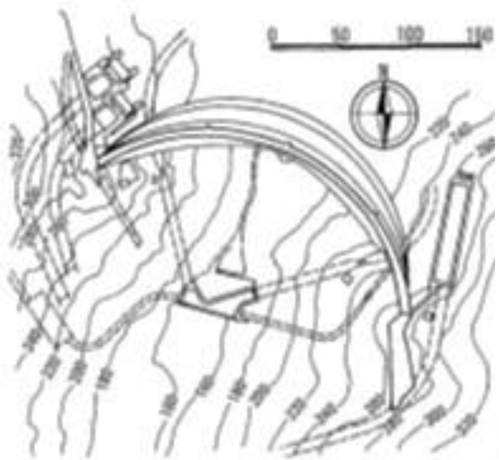
ASPECTS

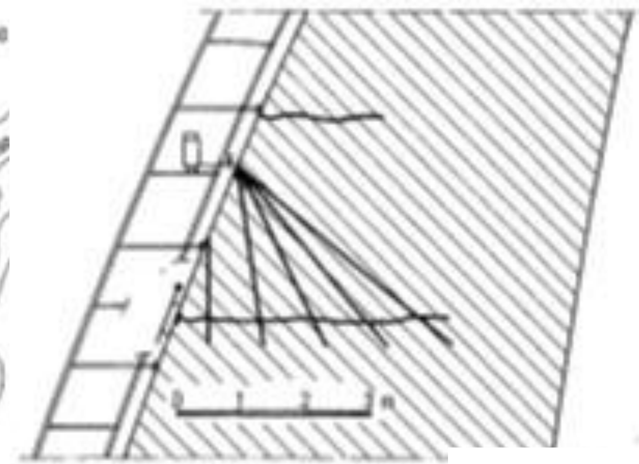
Cabril Dam showed cracking at the downstream face, concentrated in a narrow band about 10 m below the crest and following a construction lift joints. The transverse contraction joints opened, particularly at the downstream face, and when the reservoir operating level was low. The rehabilitation works included grouting of the cracks and transverse joints with epoxy resin

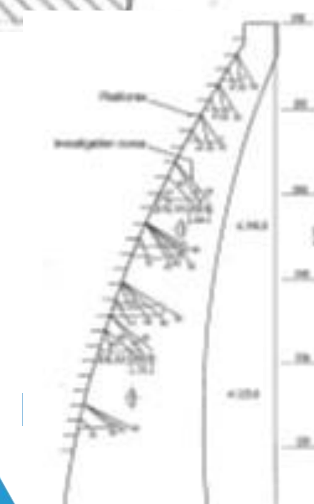
CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-029	Flumendosa Dam	Italy	1957	1995	[90]

ASPECTS

At Flumendosa Dam the cracks developed along construction lift joints, at the higher elevations of the upstream face. These were grouted with epoxy resin.







CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-030	Monceaux la Virole Dam	France	1945	???	[84]

ASPECTS

At Monceaux la Virole Dam the cracks developed along construction lift joints, at the higher elevations of the upstream face. These were grouted with epoxy resin. The contraction joints, which were constructed without a waterproofing system, were treated first with a bituminous mastic and some years later with silicone

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-031	Les Toules Dam	Switzerland	1963	???	[84]

ASPECTS

Les Toules Dam was constructed in phases, the interface between the old and the new concrete being in general a critical zone. This double curvature arch dam was initially constructed to 26 m high only, and the prepack joint between the old and new concrete had to be re-grouted after a few years of operation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-032	El Atazar Dam	Spain	1972	1979/1983	[85]

ASPECTS

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 neighbouring 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.

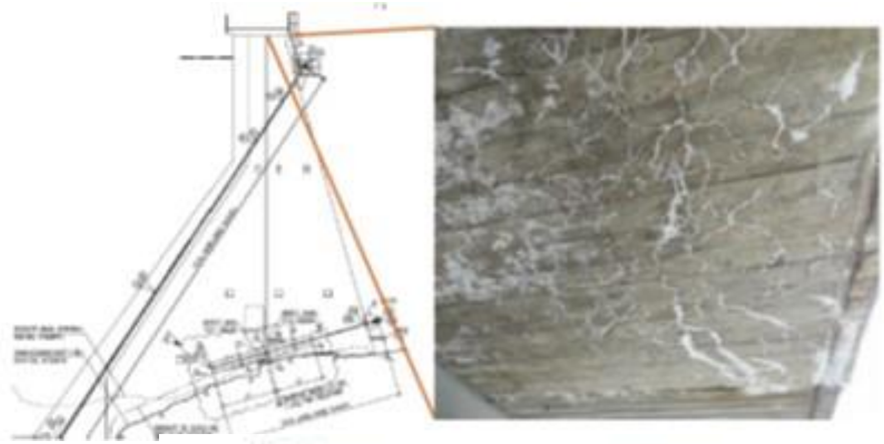
CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-033	Storfinnforsen Dam	Sweden	1954	1992-1994	[91; 92]

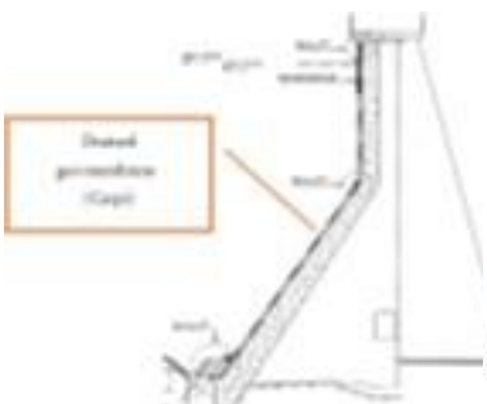
ASPECTS

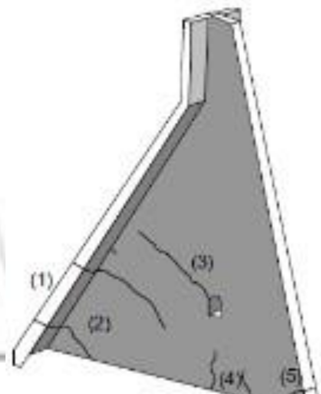
A few years after completion, horizontal cracks were found in the lower parts of the front-plates and freeze-thaw damage was detected on the upstream side of the front-plates. This resulted in a structural rehabilitation program where cracks were grouted and an insulating wall was installed to reduce 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.

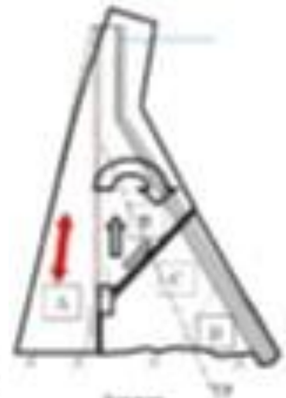
Post-tensioned anchors was the practical and cost-effective method of strengthening the dam. They was used to stabilize the concrete and to combat the effects of alkaline and aggregate reaction. The post-tensioning technique requires minimum demolition, has only a minor impact on the dam, and was relatively inexpensive using a small number of anchors.

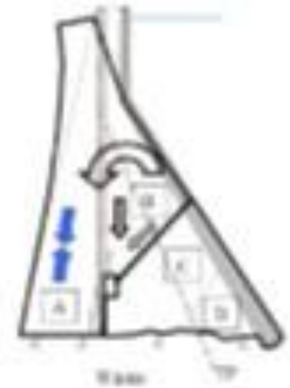
Course 1

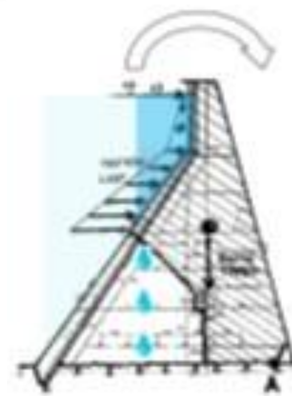












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CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-034	Stave Falls Dam	Canada	1911	1985	[93]

ASPECTS

At Stave Falls dam, load cells were installed in some anchor heads and arrangements were made to facilitate the inspection and the re-tensioning of the tendons, should this become necessary.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-035	Eder Dam	Germany	1914	1943; 1963; 1980	[94]

ASPECTS

It was damaged in 1943 during World War II, but was rebuilt in the same year. A drainage gallery was installed during the repairs at the base of the dam. Drainage and grouting work was undertaken at the upstream face and around the gap made by the bombs. The dam and the rock abutment were grouted in 1962 and 1963.

In the early eighties the stability of the Eder Dam was considered to be inadequate.

From six options considered it was selected: Prestressed anchors between crest and foundation rock. For this it was planned to build a new dam crest including a gallery for the anchor works. The cables were assembled at a workshop at the site and were transported without bending to the crest where they were taken by a steel frame designed to avoid strong bending.

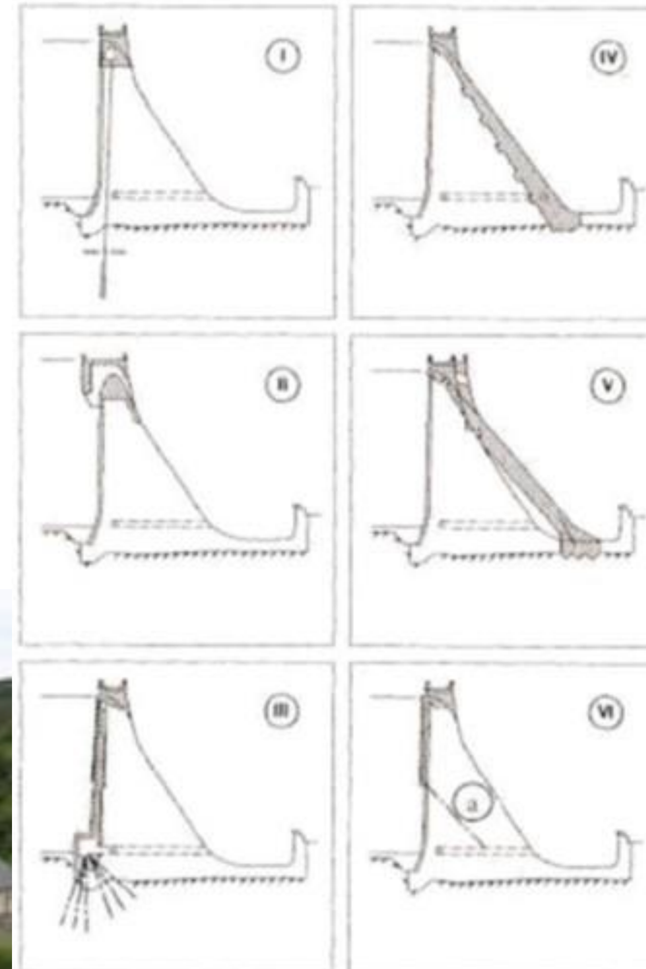

Fig. 3.4.3

Eder Dam. Six alternatives for rehabilitation

a. Drainage holes

Historic cases on concrete dams rehabilitation

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CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-036	Urft Dam	Germany	1904	1989	[94]

ASPECTS

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.

Course 1

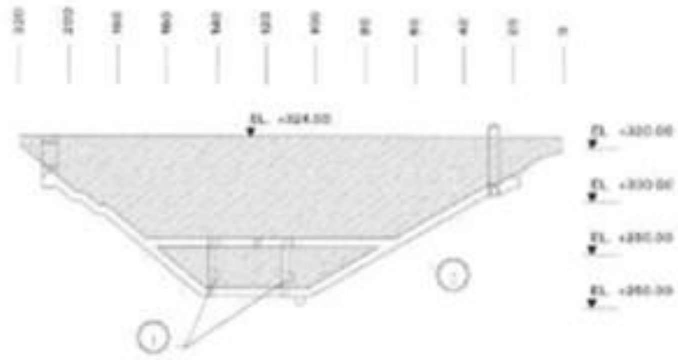

Fig. 3.4.6

Urft Dam. Longitudinal section

1. Bottom outlets
2. Right abutment

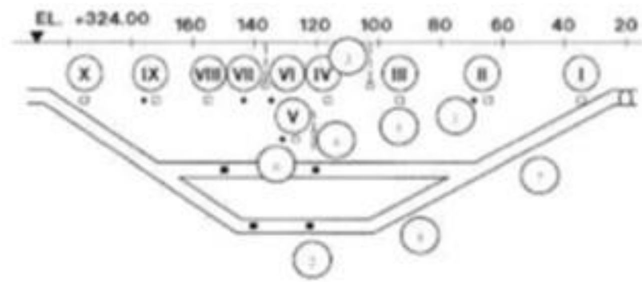

Fig. 3.4.7

Urft Dam. Instrumentation

1. Extensometer
2. Flat jack
3. Pendulum
4. Inverted pendulum
5. Piezometer
6. Thermometer
7. Upper gallery
8. Lower gallery

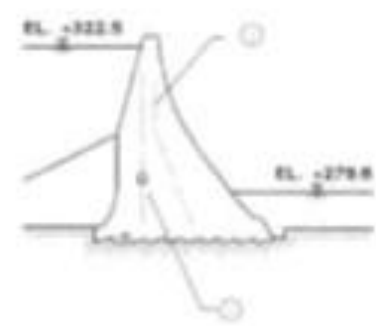

Fig. 3.4.5

Urft Dam. Cross section

1. Inspection gallery
2. Drain holes

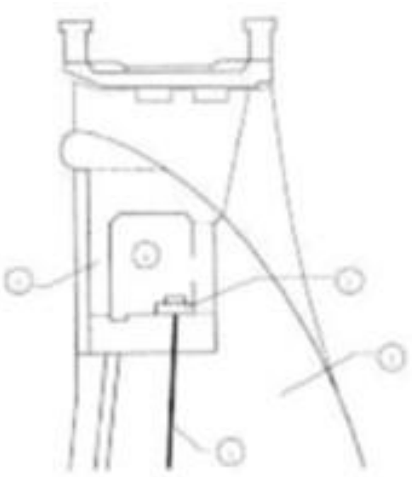

Fig. 3.4.4

Eder Dam. Final crest configuration

1. Anchor head
2. Masonry
3. Post tensioned anchor
4. Gallery
5. Concrete

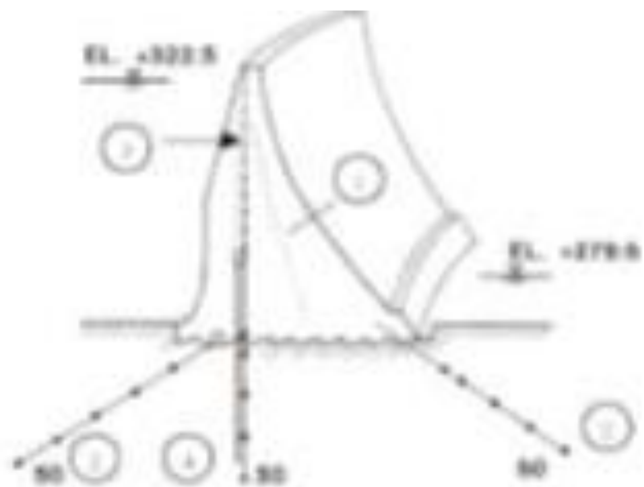

Fig. 3.4.8

Urft Dam. Instruments at cross sections V to VII

1. Drain holes
2. Extensometer
3. Pendulum
4. Inverted pendulum

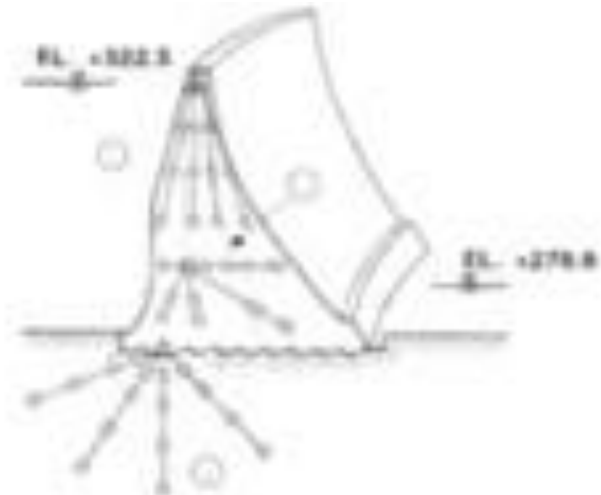

Fig. 3.4.9

Urft Dam. Instruments at cross section IV

1. Drain holes
2. Piezometers
3. Thermometers

of concrete dams and spillways

dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-037	Loyalhanna Dam	USA	1942	1946/1974	[95]

ASPECTS

Shortly after operation of the structure began in 1946, the steel service gates in the outlet works were replaced with CRD clad gates. The deterioration of the steel gates was attributed to acid water.

All four of the emergency gates in the outlet work have been renovated and the bottom section of the gates reconstructed. The dam top was marked with many areas of spalling, leaching, and cracking that varied in size and location.

Selective concrete repairs to the spillway crest were done in conjunction with repairs to the top of the dam.

Work included placement of an epoxy resin compound in all sluices at the concrete floor to deflector (tetrahedral) plate transition to alleviate any undercutting, placement of the same epoxy resin compound in miscellaneous other areas, and enlargement of the air vent gratings downstream of all service gates.

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CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-038	Point Marion Lock and Dam	USA	1926	1959/1988	[96; 97]

ASPECTS

The dam was reconstructed to provide a movable crest and to raise the upper pool by 1.2 m. This modification was done as part of a series of projects to provide a minimum of 2.7-m navigable depth in the upper Monongahela River.

The dam was rehabilitated in 1988 primarily to address stability concerns that the piers, dam sill, and abutment had potential for sliding.

Areas where original concrete remained exposed were in poor condition with cracks and spalling occurring frequently. Scouring in the area of the abutment and fixed weir appeared to be a recurring problem. Work accomplished during the dam rehabilitation included:

A. Anchoring the dam piers and dam gate sill monoliths. Two inclined rock anchors per pier were installed, one on each side. Four or five rock anchors per gate bay were installed. The anchors were designed to attain a minimum factor of safety against sliding of 2.0;
B. Refacing and anchoring the abutment. This refacing was heavily reinforced to distribute the load of the rock anchors required for stabilization;
C. Routing and caulking cracks;

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-038	Point Marion Lock and Dam	USA	1926	1959/1988	[96; 97]

ASPECTS

D. Repairing spillway faces;

E. Repainting the service bridge. The service bridge was sandblasted and painted with a urethane paint system instead of the original phenolic aluminum paint;

F. Brush-off sandblasting the emergency bulkhead and hoist and applying three to five coats of vinyl paint;

G. Performing selective lower spillway repairs in various areas. An attempt was made to use a fabricated caisson. Selective repairs of the spillway apron were then accomplished with an underwater placement of silica fume concrete; noted the following conditions of the rehabilitation work:

   I. The spillway face repairs showed uneven lips between the old concrete and the new shotcrete. No action was required; however, it was noted that this lip could cause accelerated deterioration.

   II. The concrete in the piers was generally in good condition except for the following items. New cracks of a relatively minor nature continued to propagate from the bridge seats. This cracking appeared to be slightly worse at the upstream seats, which are closer to the concrete edges.

   III. The new concrete refacing (done during the dam rehabilitation) on the upstream side, below the bridge seats exhibited signs of minor cracking.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-039	Stonewall Jackson Dam	USA	1988	1988	[98; 99; 100]

ASPECTS
During construction, problems with concrete mixture and placement caused entrapped air holes, or "bug holes," to develop in the faces of the dam and sluices. Several attempts to reduce or eliminate this problem were unsuccessful. It was not until the later stages of construction that a change in the vibrating procedure greatly reduced and in some cases eliminated the formation of the bug holes. A modification was issued to fill the deeper holes in the sluices and rub all the faces of the dam with a cement grout. The result is a more attractive surface, but one that may be subject to early weathering and damage from cycles of freezing and thawing. Several areas remain rough after treatment. Some seepage was identified as occurring through both horizontal lift joints and vertical monolith joints.The decision was to perform drilling and grouting.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-040	Tygart Dam	USA	1938	1985	[101; 102]

ASPECTS

Core samples of the concrete were sent for petrographic examination. Test results indicated the deterioration was caused by cycles of freezing and thawing, but there was no evidence of alkali-aggregate reaction. Deteriorated concrete was removed and replaced with latex modified concrete.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-041	Philpott Lake Dam	USA	1952	1968	[103; 104; 105]

ASPECTS

There was reported that a crack had widened and now extended completely across one monolith. Also, another horizontal crack had developed along a horizontal lift joint near the gutter at the upstream wall of the gallery. In some placed the crack dipped down into the bottom of the gutter.

A formal inspection of the gallery cracks was conducted. The conclusion of this inspection was that no imminent hazard existed; however, it was recommended that micrometer measurements across the cracks be taken, a stability analysis be performed on the portion of the spillway crest above the location of the cracks, exploratory drilling be done to determine the extent and width of the cracks, and repair plans be made. Crack measurements indicated upstream and downstream movement and opening and closing of the cracks.

The anchors were installed to arrest the growth of cracks in the spillway gallery and to improve the safety factor against sliding. From available data, there was no indication of any change in the cracks either during tensioning or immediately following installation of the anchors.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-042	Norfork Dam	USA	1944	1982	[106]

ASPECTS

The roadway on top of the non-overflow monoliths of the dam cracked near the center line in a longitudinal direction, raising concern about the integrity of the cantilever portion of the roadway section of the dam as some of the cracks extended into this area.

An examination of concrete cores taken from the roadway indicated that the cracks were more severe than surface cracks. A stability analysis, assuming a cracked section and neglecting concrete tension, indicated an unstable condition of the cantilevered portion of the roadway with the absence of reinforcement in the non-cantilevered roadway portion of the dam.

In 1983, the roadway cracks were sealed with a nonflexible epoxy. In the interval between the inspections, the roadway cantilever had been reinforced and the roadway cracks had been sealed with a nonflexible epoxy.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCE S
A-043	Stewart Mountain Dam	USA	1930	1988	[107; 108]

ASPECTS

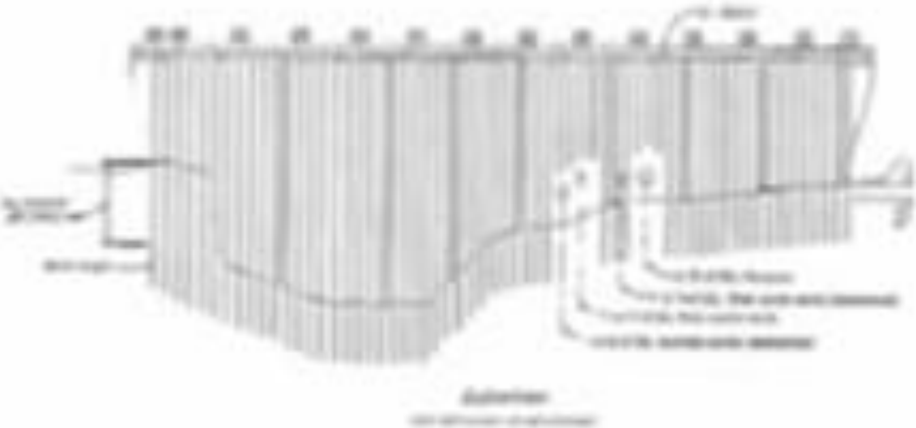
Structural stability investigations conducted by the BuRec in the late 1960s, indicated Stewart Mountain Dam was not stable enough to survive the revised maximum credible earthquake (MCE), Richter magnitude of 6.75 at 15 km. The stability of the dam was questioned because of poor bond of the horizontal construction joints, deterioration of surface concrete, a 152mm displacement of the arch crest, and revised PMF loads, which indicated the dam would be overtopped by 4.3 m.

Alkali-silica reacted concrete caused the surface deterioration and the displacement of the arch crest.

After further study, BuRec decided to construct an auxiliary spillway to alleviate the PMF loading and to stabilize the dam against possible seismic loadings with posttensioned rock anchors. Posttensioned anchors had been used to stabilize concrete gravity dams.

The installation of posttensioned cables was judged to be the least expensive, most viable solution for stabilizing the arch dam.

After drilling, every hole was water-pressure tested, pre-grouted, and re-drilled if necessary. The epoxy-coated strands for the tendons were delivered to the site on special uncoilers. Workers used extreme care to prevent abrasion of the epoxy coating when they installed the tendons in the holes. A special high-strength, plasticized grout was tremied into each hole to provide the exact bond length.



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-044	Chickamauga Lock and Dam	USA	1936	1964/1977/1984	[109]

ASPECTS

Shortly after construction was completed, pattern cracking was noted on the concrete surfaces of the dam; Later, structural problems developed as evidenced by misalignment in the powerhouse; the misalignment was attributed mainly to alkali-aggregate reactivity and its resulting expansion of the concrete. All the generating equipment and heavy crane runners have required realignment, but the most dramatic evidence of concrete growth has been in the navigation lock.

In 1964, a joint opening and vertical offset was discovered at the upstream joint of the upper approach wall of the lock. Divers inspected the six piers that support the wall and found cracks on the two upstream piers, which indicated the wall was expanding and moving the pier tops upstream. All contraction joints in the wall were very tight, and portions of the wall appeared to have increased inheight. To alleviate the adverse effect of the expanding (growing) wall and allow room for future expansion, three slots were cut in the wall. In addition, the two upstream piers which had cracked were posttensioned.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-044	Chickamauga Lock and Dam	USA	1936	1964/1977/1984	[109]

ASPECTS

In 1977 divers discovered similar cracking in the other four piers. During the same inspection, a large crack near the end of the lower river approach wall was discovered. This crack was grouted and posttensioned later that year. Subsequently, a slot was cut across the wall, upstream of the four cells, to provide space for future concrete growth. In 1983, a vertical crack and three horizontal cracks were discovered in the lower river wall gate block, and a horizontal crack was found in the adjoining downstream block. Repairs to the vertical crack completed in 1984 consisted of grouting the crack with a neat cement grout and posttensioning with high strength reinforcing bars. The horizontal cracks in the gate block and adjoining downstream block were grouted and postensioned with multi strand tendons

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-045	Lock and Dam No. 24	USA	1930	1993	[110; 111; 112]

ASPECTS

The investigation consisted of visual examination, ultrasonic pulse velocity movements, and testing of concrete cores. The investigation showed that 32 percent of the service bridge support columns were damaged, ranging from very light to severe.

A petrographic examination of the cores revealed that the concrete was nonair-entrained and that it contained sand and gravel of mixed composition with the maximum size aggregate being 38 mm. Coarse aggregate consisted of sandstone, quartz, chert, and particles of carbonate rock, igneous rock, and ironstone. Chalcedony in the chert particles was identified as the common reactive material. The types of cracking found were typical of that caused by cycles of freezing and thawing and alkali-silica reaction. The repair plan consisted of implementing modifications for keeping water from entering the concrete: sloping the tops of the columns and cross members so they would drain toward the interior opening between the columns, drilling drainage holes along the lift joint between the columns and column facings, and sealing the top surfaces of the columns and cross members. The crack sealer suggested for horizontal surfaces was a heavy- duty membrane of rubberized asphalt integrally bonded to polypropylene mesh with enough overlap that it could be installed with a mechanical band around the columns to secure it.

Repair methods considered for rehabilitating the concrete bridge supports included epoxy injection, encasement, and removing and replacing the deteriorated bridge support columns.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-046	Fontana Dam	USA	1945	1972/1983	[113]

ASPECTS

During a routine structural inspection, cracking was observed in the walls of the foundation drainage gallery in the curved portion of the dam near the left abutment. Further field investigations revealed the cracking to be excessive, so a comprehensive program of analysis and repair was initiated.

The conclusion reached was that a slow alkali-silica reaction plus an increase in temperature over a portion of the dam was producing an increase in volume.

A series of investigations and laboratory analyses on core samples led engineers to the conclusion that cutting the slot in the curved portion of the dam would have no adverse effect on the stability. In 1976, this slot was cut transverse to the dam adjacent to the curve at this location. A system of flexible primary and secondary seals was installed at the slot to prevent leakage during high reservoirs. Both seals consisted of industrial rubber conveyor belt stock 0.8 m wide. The primary seal on the upstream face was extended to the foundation.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-047	Mactaquac Dam	Canada	1967	1989	[114; 115]

ASPECTS

From the time the dam was constructed in the late 1960s, it had been slowly but steadily expanding. The expansion of the concrete was attributed to alkali-aggregate reaction.

A program for making two vertical cuts in the concrete cross section of the dam, was set.

Before the cutting could begin, the work area had to be dewatered. The saw has a drive unit with a large diameter drive wheel that is hydraulically powered, idler wheels, and a diamond-plated cutting wire.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-048	Shanteetlah Dam	USA	1928	1950/1967/1988	[116]

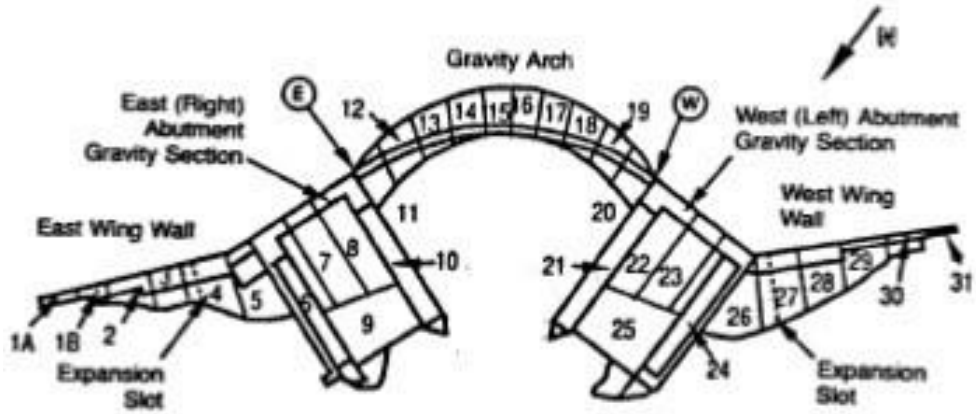
ASPECTS

The first modification was made to the dam in 1930 in an attempt to correct seepage problems. Massive amounts of concrete were placed on abutment blocks. Seepage recurred, and the same repair method was used for abutment blocks. A decision was made to use epoxy-resin grout to seal the joints and cracks. A long section in the most critical area was selected for treatment, which was conducted from within the lower gallery.

The concrete of the upstream gallery wall had begun to dry, and flows from secondary longitudinal roof fissures and from the downstream gallery wall were also stopped completely.

Santeetlah Dam has recorded history of continuous movements in the upstream and vertical direction which studies have shown to be a direct result of alkali-aggregate reactivity (AAR). This expansion has the potential of resulting in cracking, heaving, joint displacement, and spalling of concrete.

Repairs were also made in 1950 and 1967. A decision was made to use epoxy-resin grout to seal the joints and cracks. Expansion joints have been introduced using diamond wire saws in several existing concrete gravity dams to control deformations and release accumulated compressive stresses due to concrete swelling induced by alkali-aggregate reaction (AAR).



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-049	Panneciere Dam	France	1949	2005	[22; 117]

ASPECTS

The dam was suffering from:

- a loss of monolithism due to water circulating through a network of cracks resulting from post-war construction methods and concrete formulation;
- slight swelling due to alkali-aggregate reaction in the sealing mortar (gunite) on the upstream side;
- undesirable rotation and collapsing movements in the buttresses on the downstream side.

To rectify these various problems and set up the rehabilitation site, there were required several types of repair as well as strengthening against the risk of earthquakes.

In addition, on the downstream side, the structure's earthquake resistance was improved by the installation of braces, prefabricated on site, between each buttress. 26 braces, each14 meters long and weighing 20 tons, were installed in two rows inside the dam's arches, with the aim of both stabilizing and stiffening the structure in the event of an earthquake by preventing the buttresses from oscillating. A PVC membrane was applied.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-050	Campo Secco Dam	Italy	1930	1993	[22 ; 118]

ASPECTS

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	REHABILITATION/ REPAIR	REFERENCES
A-051	Troy Lock and Dam	USA	1915	1990	[119]

ASPECTS

The dam, which is founded on bedrock, was constructed with nonair-entrained concrete and river gravel aggregate. Cracked concrete on top of the piers was removed to sound concrete and replaced with air-entrained, reinforced concrete. Dowels were used to anchor the new concrete to the existing concrete.

Cracks in the dam access were sealed with a moisture-reactive, polyurethane chemical grout that helped control leakage. It was elected to use the polyurethane grout as it could be applied in wet conditions.

A follow-up inspection indicated repairs to the piers, the spalled areas, and cracks in the shafts and tunnels were performing as expected.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-052	Brandon Road Dam	USA	1933	1988	[120]

ASPECTS

Rehabilitation included repair and replacement of gates. On the upstream portions of the piers, deteriorated concrete was removed to a depth of approximately 203 mm. Replacement concrete was conventionally placed air-entrained reinforced concrete.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-053	Dresden Island Lock and Dam	USA	1933	1980	[121;122]

ASPECTS

A 1980 inspection of the 47-year-old dam revealed severe deterioration of the concrete as a result of years of being subjected to cycles of freezing and thawing and impact and abrasion. Deteriorated concrete in the roof of the head gate opening was removed, and grout was troweled on to provide a smooth surface. The surface was then painted with bituminous mastic. A waterstop was installed along the horizontal joint at the top of the closure panel.

Rehabilitation of the tainter gate section primarily consisted of removing and replacing 229 mm of concrete and installing new gate seal plates along the sides of the piers

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-054	Lock and Dam No. 20	USA	1935	1982/ 1989	[123; 124]

ASPECTS

Over time the structure experienced concrete deterioration, especially around the tainter gates and service bridge piers. Cause of the deterioration is attributed to the lack of entrained air in the concrete, which decreased its resistance to cycles of freezing and thawing, alkali-silica reactions. The repair method was to use high pressure to inject a low-viscosity epoxy grout into the crack.

Ultrasonic velocity measurements were made before and after the injection, and, where practical, tests were run on core samples. The major problem was that the epoxy sealant used to waterproof the pier tops did not completely seal them, and seepage still occurred through unfilled cracks.

The surface was then sealed with an epoxy gel. The epoxy injected into the pier was an ultra-low viscosity, two-component, 100 percent solids epoxy resin, insensitive to the presence of water.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-055	Starved Rock Lock and Dam	USA	1933	1980	[124]

ASPECTS

After almost 50 years of exposure to cycles of freezing and thawing and impact and abrasion from ice and debris, the nonair-entrained concrete in the structure showed signs of deterioration. An evaluation of the dam indicated that the rehabilitation should include construction of closure panels for the head gate section, conversion of the gated ice chute to an uncontrolled ogee crest, and resurfacing of the tainter gate piers.

Rehabilitation of the tainter gate section consisted of removing and replacing concrete on the surface of the piers, installing new gate seal plates and heating elements along the sides of the piers, and modifying concrete to accommodate new bridge bearing details.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-056	Lock and Dam No. 2	USA	1930	1987	[125; 126]

ASPECTS

Concrete on the piers directly beneath the existing bridge had deteriorated, and there was surface spalling of the concrete on the faces of the piers and in the trunnion recesses.

Repair of the piers and trunnion recesses consisted of removing the deteriorated concrete and replacing it with fiber-reinforced, acrylic-polymer modified concrete (FRAPMC) and eliminating leakage into the trunnion recesses. FRAPMC consists of mortar, coarse aggregate, and reinforcement fibers. It is mixed in a mortar mixer as a two-component system consisting of a liquid polymer emulsion of acrylic polymer and additives and a mixture of cements, aggregates, and admixtures. Polypropylene fibers and aggregate are mixed with the polymer emulsion mixture until the fibers are conditioned and dispersed, and then the cement mixture is added.

Typically, FRAPMC is mixed in batches that can be placed within 30 min or less. Cracks were injected with epoxy to seal them; joints were sealed with joint sealant. The epoxy was a two-component, 100 percent solids, low viscosity water insensitive material especially made for sealing concrete cracks.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-057	Scais	Italy	1939	1993	[22]

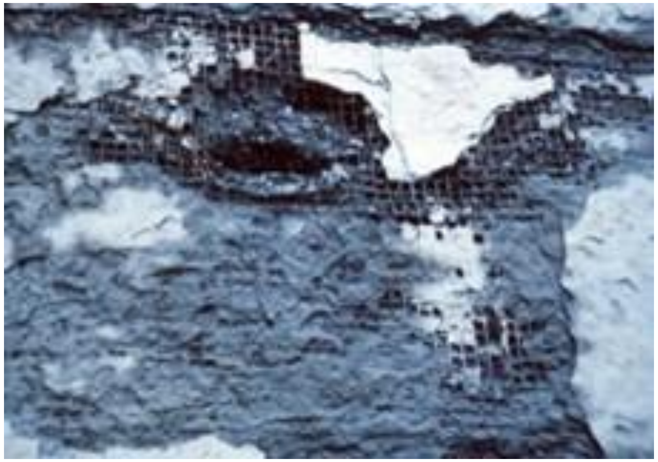
ASPECTS

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	REHABILITATION/ REPAIR	REFERENCES
A-058	Lago Nero Dam	Italy	1928	1981	[22; 128; 129]

ASPECTS

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	REHABILITATION/ REPAIR	REFERENCES
A-059	Cignana Dam	Italy	1928	1988	[22; 130]

ASPECTS

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	REHABILITATION/ REPAIR	REFERENCES
A-060	Ceresole Dam	Italy	1930	1992	[22; 131]

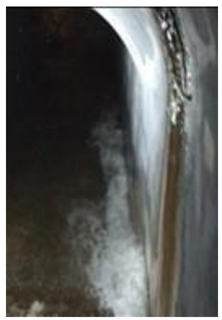
ASPECTS

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	REHABILITATION/ REPAIR	REFERENCES
A-061	Kadamparai Dam	India	1989	2006	[22; 132]

ASPECTS

Due to the deterioration and leakage of the face of the dam it was repaired using PVC geomembrane. Leakage before repairs was 38,000 liters per minute (633 l/s) After repair (2005) 30 l/m.




CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-062	Hirakud Dam	India	1957	1975	[22; 133; 134]

ASPECTS

Cracking in various locations of both the concrete spillway dams (due to ASR - Alkali Silica Reaction) have caused serious concern. The major distress and deficiencies observed in this project are:

a) Alkali Silica Reaction (ASR) in the concrete, resulting in cracks and other manifestations in both the concrete spillways;
b) Settlement of the crest of earth dam and dykes;
c) Inadequate spillway capacity;
d) Lack of efficient flood forecasting and flood modulation arrangement for effective flood control.

As the reservoir water level was operated normally, under water repairs to cracks in the upstream face of spillway was required.

The purpose of epoxy injection into the crack is to provide structural improvement of the concrete spillway by filling the internal cracks with an epoxy adhesive material under pressure and ensuring highest possible bonding.

The entire under water treatment procedure was scanned and monitored through TV which gives, much mor confidence and confirms the various treatment activities taken up under water. Further, the examination of extracted drill core from the under water treated surface and drilled-core test confirms satisfactory efficacy of the grouting and proper sealing of the cracks.

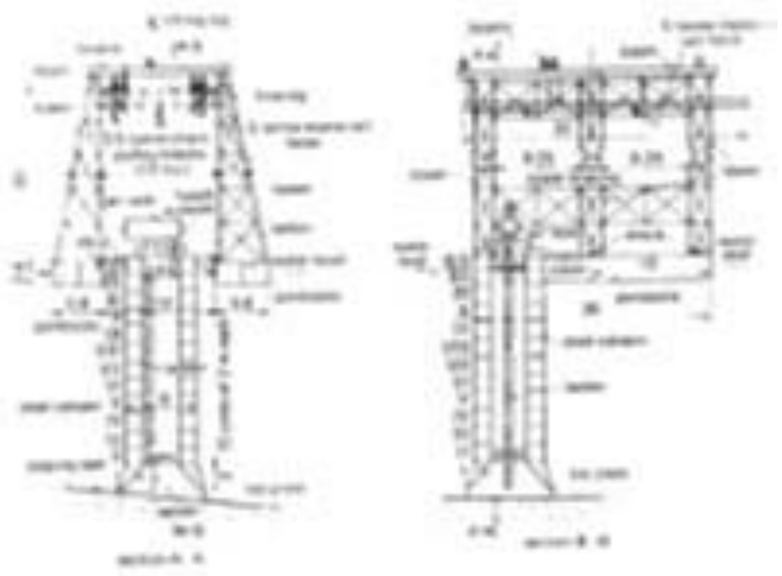
Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-063	Bhakra Dam	India	1963	1987	[135]

ASPECTS

When divers inspected the stilling basin, they found erosion damage, which was attributed to gravel and boulders in the stilling basin during flood discharge. The damage varied in depth from 50 to 700 mm. Because the two power plants had to remain in operation, the damage was initially repaired with conventional underwater concrete methods. A subsequent inspection revealed that the repair had failed because of inadequate bonding of the new and old concrete. Therefore, a new method of repair that would allow for the necessary bonding while keeping the power plants operating was needed.

Concrete repair consisted of cleaning the concrete surface with an air/water jet, removing deteriorated concrete manually or pneumatically, and repairing the eroded concrete. The repair method depended upon the depth of erosion. Deterioration less than 50 mm was replaced with epoxy concrete to designated height. Areas of deterioration in excess of 50 mm were coated with epoxy before the new concrete was placed. If the depth of erosion exceeded 200 mm, epoxy-grouted dowels were installed on 0.6-m centers to anchor the new concrete, and joints were treated with epoxy paint.



Historic cases on concrete dams rehabilitation

Eng. Andriolo

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-064	Lake Buchanan Dam	USA	1937	1985	[136]

ASPECTS

The dam is consisted of arches that are sloped such that the top of each arch is located downstream of its bottom. Each lift of an arch is keyed into the previous lift with the key occupying the middle third of the construction joint. Joints are perpendicular to the length of the arch and, thereby, inclined downstream from the horizontal.

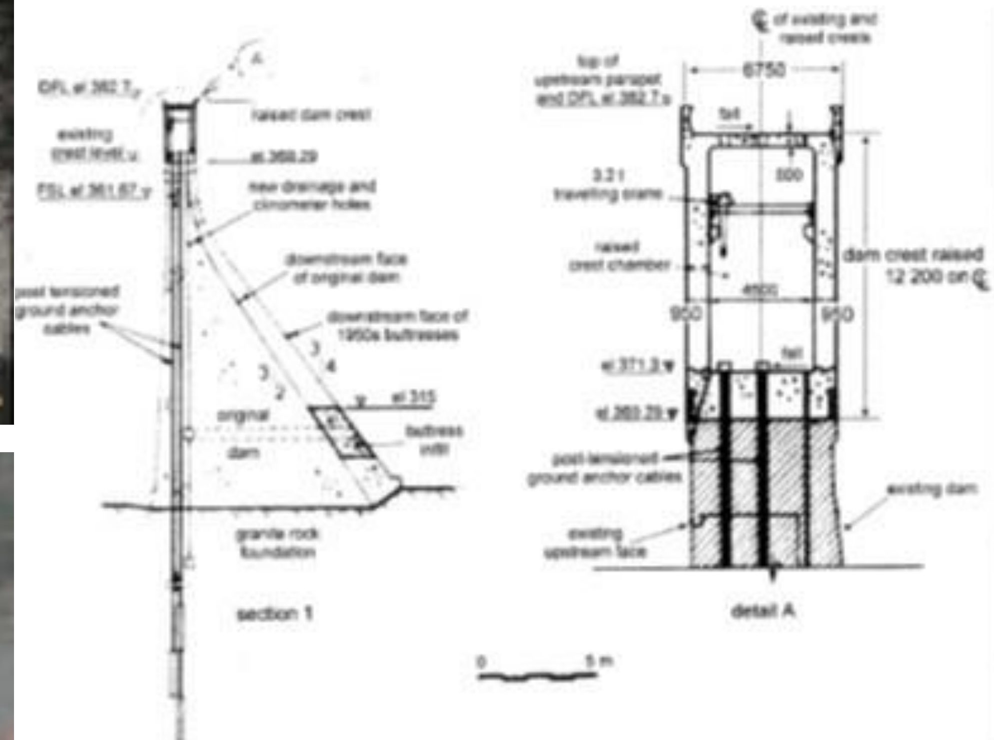
When the lake was impounded, the area between the original and later construction began leaking because of inadequate bond between the older and newer concrete, a result of the interruption in construction.

Although the dam was safe, there was required wanted to stop the leaks to conserve water and improve dam appearance. The repair method specified a water-activated foam, which would remain flexible and keep the voids filled as the dam expanded and contracted.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-065	Burrinjuck Dam	Australia	1930	1990	[137]

ASPECTS

In 1990, work began on a project to increase the height of the dam by 12,2m. An open reinforced-concrete chamber was constructed at the existing crest level of the dam, and the dam was stabilized with posttensioned ground anchor cables. During high flood levels, the chamber fills with water, thus providing additional stability. Two rows of posttensioned ground anchors provide a stabilizing force for the dam.
To provide corrosion protection, strands were encapsulated in grease-filled polyethylene tubes above the anchorage zone, and cables in the anchorage zone and the free length of cable were installed in a single-stage grouting operation. Cable load is monitored, and the anchors can be restressed if necessary.



Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-066	Daniel Johnson Dam	Canada	1970	1990	[138]

ASPECTS

During 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 was 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;

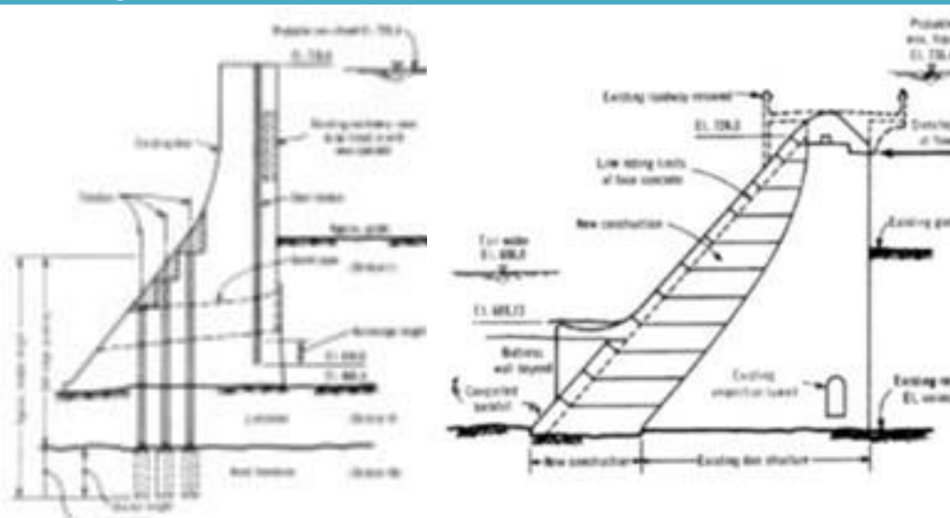
All flat profiles, nuts, washers, couplers, anchor bolts and other metal items used in the perimeter anchor seal are made of stainless steel.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCE S
A-067	Olmos Dam	USA	1975	1979	[139]

ASPECTS

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 nonoverflow 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	REHABILITATION/ REPAIR	REFERENCES
A-068	Shepaug Dam	USA	1955	1980	[140]

ASPECTS

A stability reassessment in the 1980s found that the dam would be overtopped by the PMF. Therefore, high-capacity prestressed rock anchors were designed and installed to safeguard the dam against overturning.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-069	Sherman Island Dam	USA	1910	1980	[141]

ASPECTS

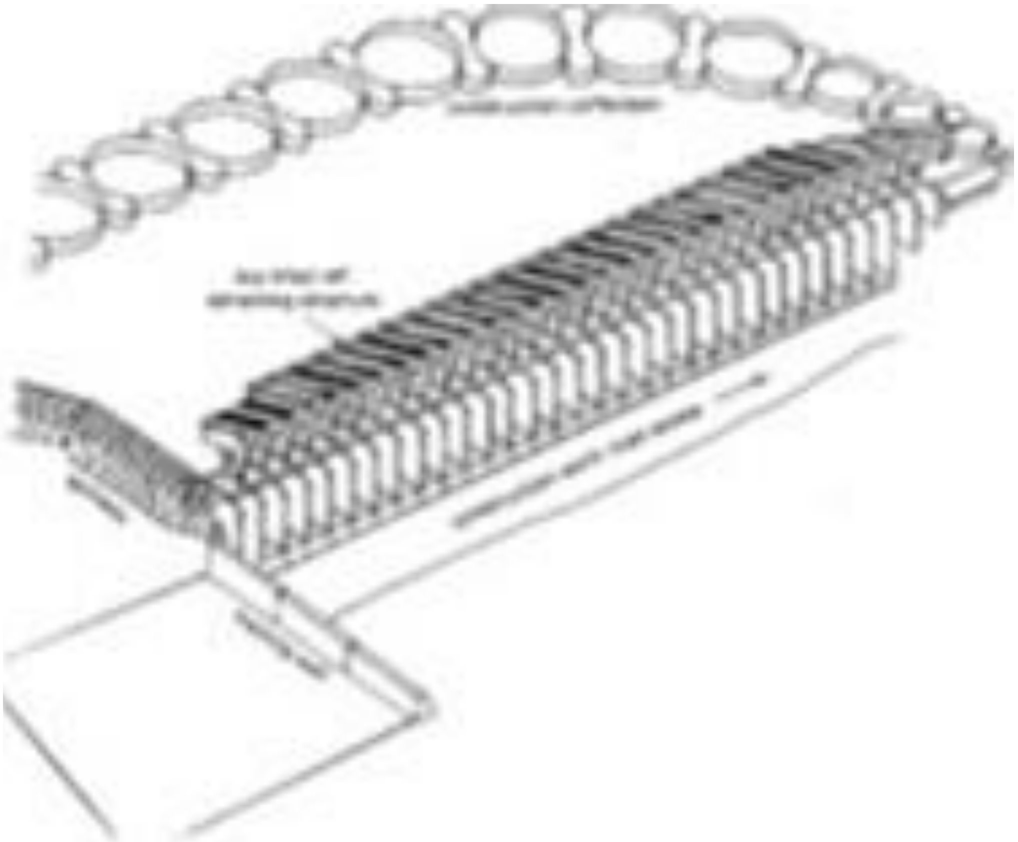
The dam was a hollow-arch concrete dam. Over time the dam, suffered concrete damage as a result of chemical reaction and cycles of freezing and thawing.

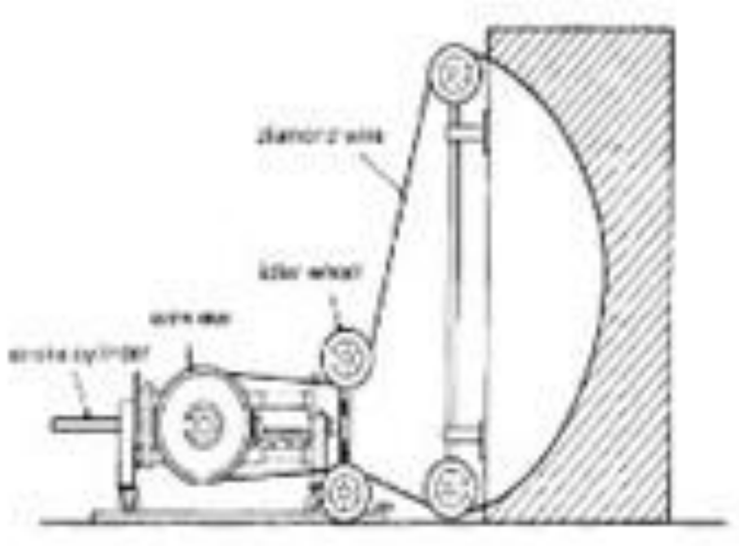
Despite extensive maintenance the deterioration continued to occur. By the mid- 1980s, severe cracking in the dam's arches and buttresses was allowing water to penetrate the structure and cause structural damage.

The first step in the rehabilitation was to dewater the area between a cellular cofferdam and the existing dam. Next came the demolition work on the dam. The foundation and lower buttress portions of the dam that had not been exposed to weathering were sound and usable; therefore, total concrete demolition was not required.

The entire reinforced concrete arch roof and selected areas of the buttresses would have to be removed. Partial removal of the concrete arches and severing reinforcing steel would affect the stability of the structure and increase the need to restrict heavy vibration.

Course 1





CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-070	Platanovrissi Dam	Greece	1994	1999	[22; 142]

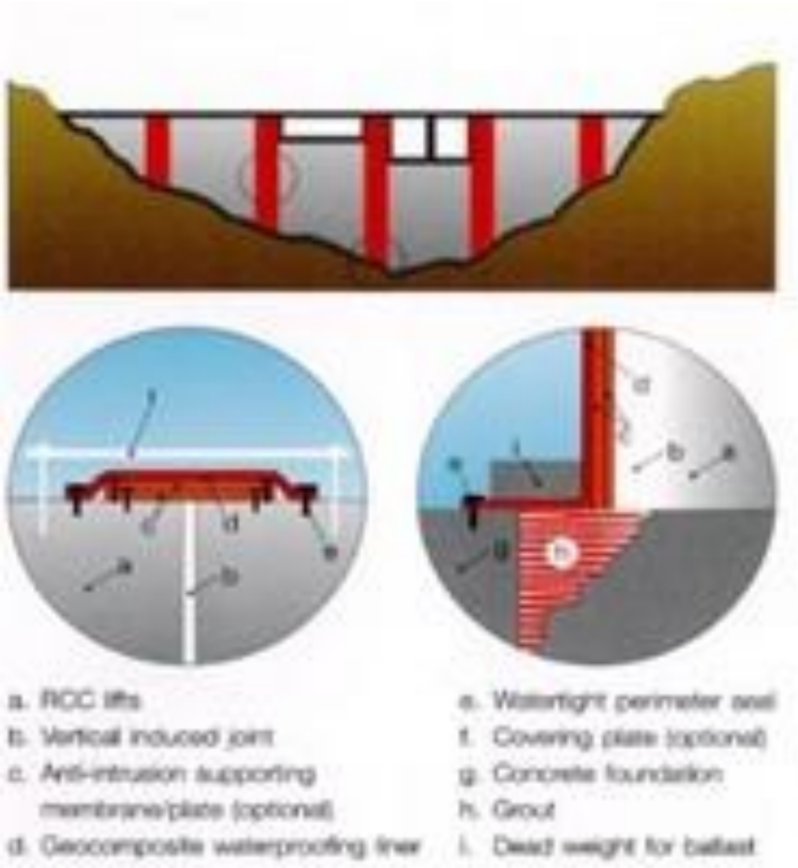
ASPECTS

The external waterstop system has been used for the underwater repair of Platanovryssi, a RCC dam in Greece. The dam, of the high cementitious content type, was designed to be impermeable in its whole RCC mass. The vertical contraction joints were waterproofed with 12 Carpi external waterstop system during construction.

On first filling, after mid-December 1999, seepage started increasing, and reached more than 21 l/s, dropped again and then increased to a maximum of 30,56 l/s on 10 October 2000. The cause of the leak was what appeared at first as a hairline crack in the gallery, then on the upstream and downstream face, with a maximum opening of 25 mm. The crack was approximately 20 m long.

Repair works were scheduled for Spring 2002. Due to an unusually dry season, the owner could not afford to lose the volume of the water to empty the reservoir in order to work in dry conditions. In addition to that restriction, when Platanovryssi is emptied the pumped storage scheme of Thissavros cannot operate, with serious implications to the production system.

Historic cases on concrete dams rehabilitation


a. RCC lifts
b. Vertical induced joint
c. Anti-intrusion supporting membrane/plate (optional)
d. Geocomposite waterproofing liner
e. Watertight perimeter seal
f. Covering plate (optional)
g. Concrete foundation
h. Grout
i. Dead weight for ballast

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-071	KOYNA DAM	India	1962	1990	[143; 144; 145; 146]

ASPECTS

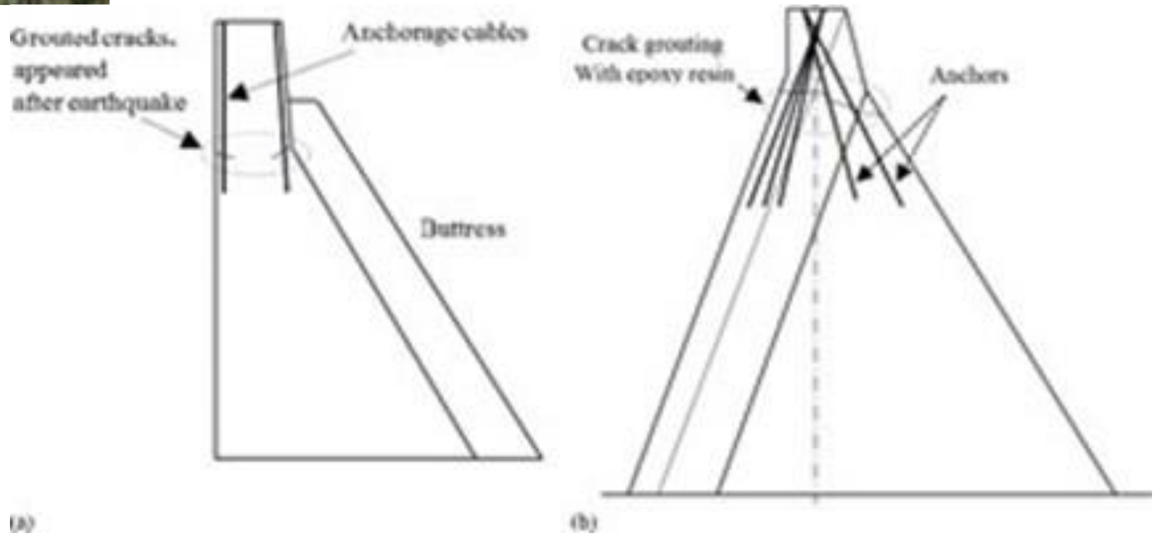
The dam has been designed for earthquake acceleration of 0.05g, constant over the entire height corresponding to maximum water level in the lake. The dam constructed in 1962 across river Koyna has experienced an earthquake of magnitude 6.5 in the Richter scale on December 11, 1967. By having measurements in the gallery located in the dam the leakage through the body of the dam and foundation was monitored. This showed 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:

a) Grouting of the cracks by epoxy resin, polyester grouting and sealing of crack on the upstream by grouting and guniting, thus reestablish the monolithicity of the dam as far as the epoxy grout can penetrate from the face and at the same time prevent the ingress of water into the body of the dam;
b) Strengthening of 7 high monoliths by pre-stressed cables was carried out because it was not possible to assert that:
   (i) the crack did not extend beyond the grouted face;
   (ii) the crack did not continue from upstream to downstream face;
   (iii) the resin grout has bonded the whole width of the dam.

It was therefore decided that cracked and deep monoliths should be stitched across crack by pre-stressed cables so that the bodies above and below the crack act together in unison under dynamic forces.

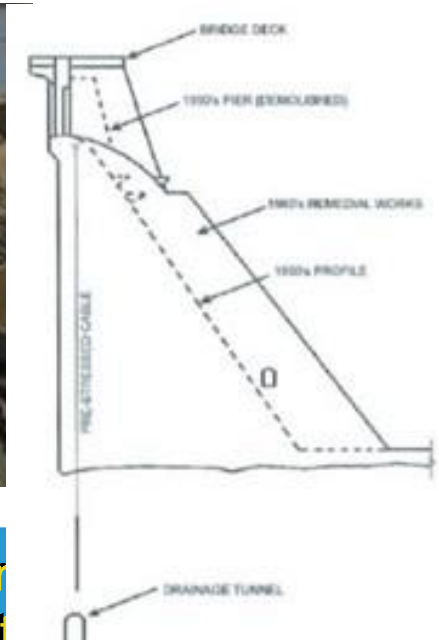
The end blocks did not require strengthening because they were shallow buried in the ground and were not cracked.


Grouted cracks, appeared after earthquake
Anchorage cables
Buttress
(a)
Crack grouting With epoxy resin
Anchors
(b)

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-072	Vaal Dam	South Africa	1938	1980	[147]

ASPECTS

In order to meet the increasing demand for water from the dam it was raised in the early 1950's. The concrete spillway section and the dam were raised with 3 m. Stability analyses conducted in 1975 however indicated that the structure did not comply with the dam safety standards of the time and the need for rehabilitation work was identified, specifically in so far the spillway capacity and the stability of the concrete gravity sections were concerned. The dam wall was stabilized using pre-stressed cables and by increasing the cross sectional area of the concrete sections of the wall.



CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-073	Calitzdorp Dam	South Africa	1918	1990	[147]

ASPECTS

During one of compulsory dam safety evaluations of the dams in the late 1980's, Ca1itzdorp dam was one of those that did not satisfy dam safety requirements (the drainage system of the concrete structure was not functional and the spillway capacity was not sufficient).

A decision was made to proceed with the remedial work based on the results of the prioritization methodology. The remedial work was done in the early 1990's and included improving the spillway capacity as well as the internal drainage system to decrease the influence of uplift.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-074	Susqueda Dam	Spain	1968	1993	[148; 149]

ASPECTS

The dam was provided with a comprehensive system of monitoring and has been the subject of frequent studies of its behavior. From these studies was found that was necessary to reinforce the structure reinjecting their vertical joints. The injection was performed with two component resins.

Renovation of the bottom outlets of the dam, in addition to having to overcome the difficulties imposed by its particular geometry was also planned in such a way that modernizes some outlets designed under criteria that today would not be entirely acceptable. Difficult access to the outlets, both upstream with almost a 90 m column of water, and downstream with a height of 30 m above the stilling basin, required special methods and structures to be used for sealing the conduit, for dismantling the existing hydro-mechanical systems and fo r the assembly the new ones.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-075	Klingenberg dam	Germany	1914	2008	[150]

ASPECTS

The main dam - a masonry gravity dam with massive cross section - was subject to an extensive rehabilitation measure. The entire intakes and associated structures, like sluice column and diversion tunnels, were completely rebuilt. Furthermore, the crest and the dam's upstream face received a new sealing. As a result of the enormous flood event in 2002, the spillway and the stilling basin were subject to design changes by means of partial alteration and reconstruction.

The destined works at the upstream side of the dam required draining the reservoir entirely. In order to secure continous water supply by nearby dams, an auxiliary raw water extraction system involving the upstream dam and ducts was implemented in advance.

After the 2002 event, intense rehabilitation and repair works have been conducted with a view to bringing the dam to the recommended standards. The main works at the dam have been:

- building of a new upper dam,
- construction of a 3,3 km long tunnel from above the pre-dam around the whole reservoir as an additional spillway and a facility to improve water quality and for securing adequate drinking water supply for the city of Dresden during the rehabilitation of the main dam (empty reservoir);
- increase of the spillway capacity to cope with the new design standard;
- construction of a new inspection gallery into the dam;
- refurbishment of the dam (sealing and monitoring instrumentation),
- construction of new hydraulic elements (outlets, intake system, stilling basin).

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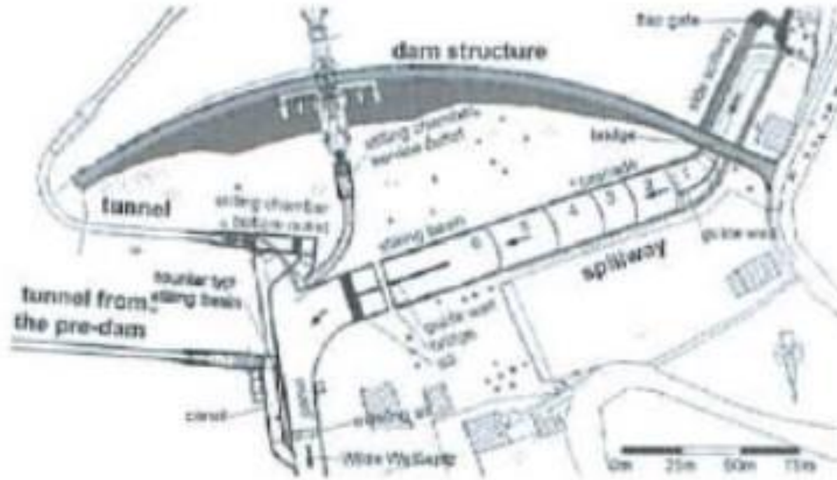
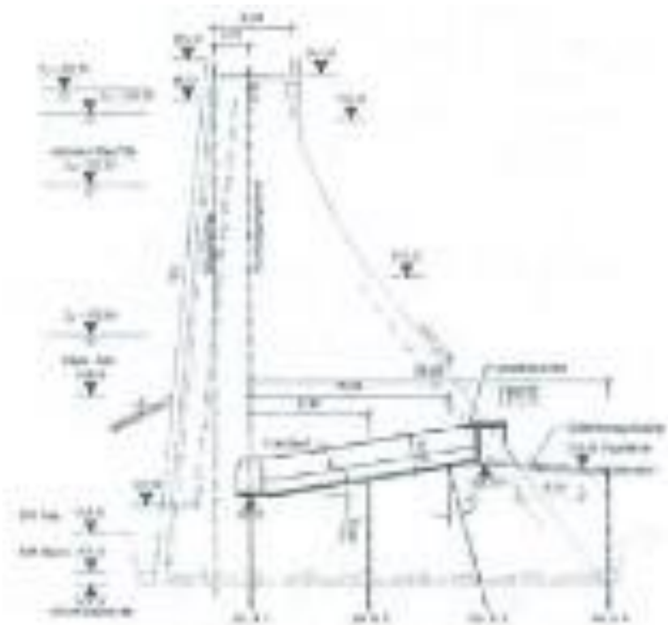
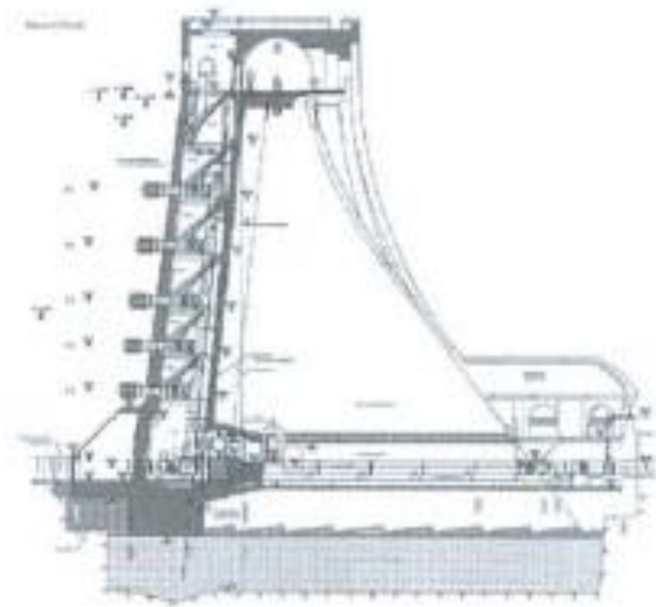






Structural analysis and rehabilitation of concrete dams and spillways

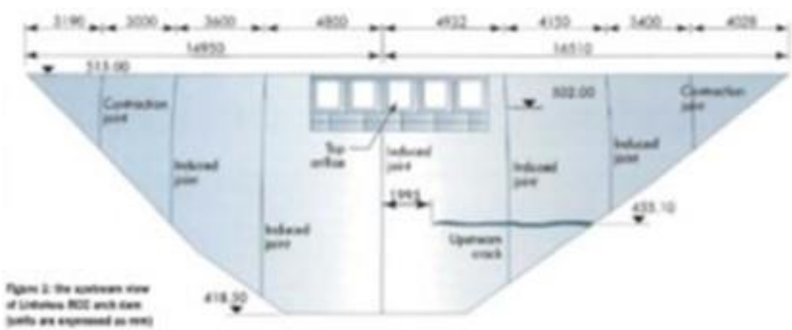
Historic cases on concrete dams rehabilitation

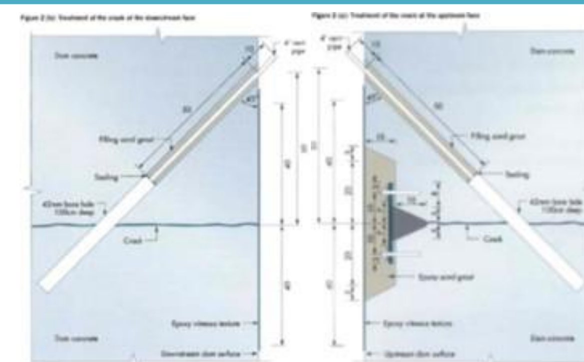
Eng. Andriolo

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-076	Linhekou dam	China	2003	2002	[151]

ASPECTS

On 8 August 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 the eighth and the ninth placing layer. The crack had developed from the dam upstream face to the downstream face, and had a total cracking area of nearly 1000m², with a width less than 0.3mm. 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.





CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-077	Canton Dam	USA		2002	[152; 153]

ASPECTS

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 consists 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.

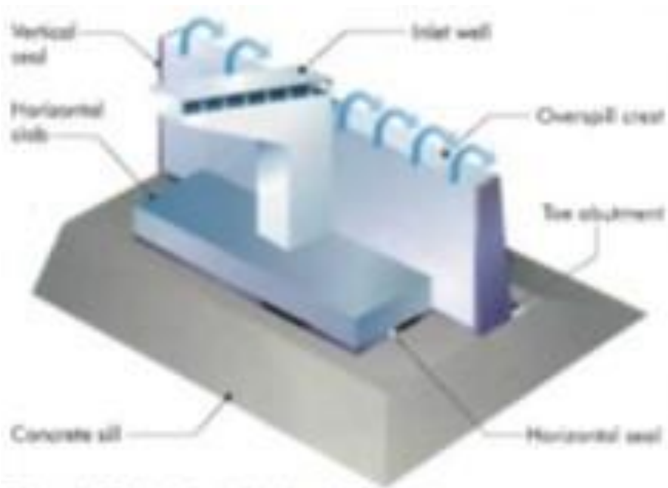
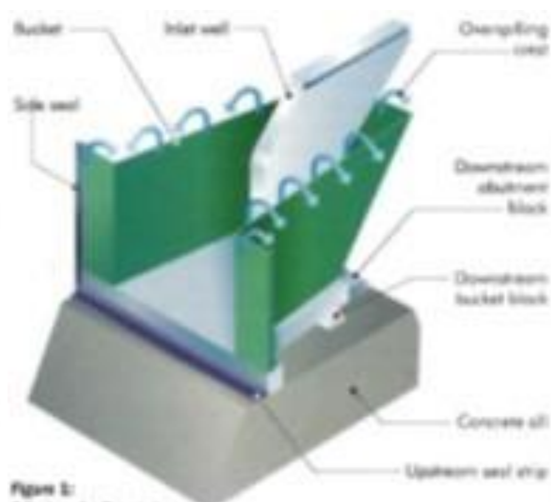


Figure 4: 3-D view of a straight crested Fusegate



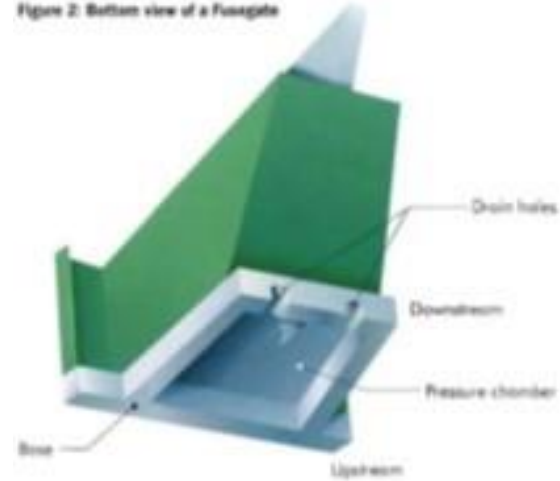


Figure 2: Bottom view of a Fusegate

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-078	Catagunya Dam	Australia	1962	2010	[154]

ASPECTS

Designed in the late 1950s and completed in 1962, Catagunya is a concrete gravity dam which relies on a large number of 200 ton capacity post-tensioned steel cables to provide the necessary structural stability against the stored water load. Its design was considered leading edge, being the highest post-tensioned dam in the world at the time of its construction, and the designers adopted a 50-year design life for the anchors. It was estimated that the use of post tensioning provided a saving in the order of 20% compared with a conventional gravity dam.

During construction of the dam in the early 1960s, 412 post-tensioned anchors were installed but the integrity of the original anchors can no longer be assured. The stability of the dam has been restored over the past two years using 92 modem, large diameter and corrosion protected, post-tensioned anchors that can be monitored for deterioration. These are the most highly stressed anchors applied to a dam at that time.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-078	Catagunya Dam	Australia	1962	2010	[154]

ASPECTS

A number of challenges were addressed during implementation, including:

- Installing more than half the anchors within an operating spillway, utilizing a limited construction window over the summer months;
- Providing access for drilling equipment and installation of the anchors well below the spillway crest on a 54° degree slope, 25m above the riverbed, and demobilizing these platforms sufficiently to allow floods to pass during the winter months;
- Replacing severed surface reinforcement with 9m long carbon fibre rods.

In order to gain access to the spillway of Catagunya dam for installation of the temporary access platform brackets on the spillway and the carbon fiber tensile reinforcing on the spillway face, a purpose designed and built travelling gantry was suspended from the spillway crest. This gantry had five working deck levels, with four of these providing access to the full length of the 9m long carbon fiber rods which were to be installed. Two 200m long temporary platforms were constructed to access the spillway. The upper platform was designed to provide access for the drilling, installation, and stressing equipment, as well as to provide safe and efficient egress in times of flood. The lower platform was used to give direct access to the anchor hole locations for installation of anchorage assemblies.

Historic cases on concrete dams rehabilitation

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-079	Bariri Dam	Brazil	1965	1980's	[155]

ASPECTS

The shielding of the sluiceway was damaged and there was erosion in concrete slab of spillway. A cofferdam was constructed and the shielding was repaired and the eroded concrete treated with special concrete resin-based.

Recently the equipment for the supervision and control of the power house and locks have been updated.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-080	Limoeiro Dam	Brazil	1958	1985	[155]

ASPECTS

Due to the abrasive action of loose rock blocks in the basin of spillway, occurred erosions in the basin slab, exposing the reinforcement bars. Adopting a small cofferdam the concrete slab surface was repaired. Recently the equipment for the supervision and control of the power house and locks have been updated.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-081	Barra Bonita Dam	BRAZIL	1962	1982/ 2006	[155]

ASPECTS

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.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-082	Caconde/ Graminha Dam	Brazil	1960	1979	[155]

ASPECTS

During an underwater inspections, were observed cracks in the wall that supports the rails of the trash rack. The concrete of the damaged areas was breakup and carried out the repairs with concrete.

Recently the equipment for the supervision and control of the power house and locks have been updated.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-083	Capivara Dam	Brazil	1976	1984	[155]

ASPECTS

There were observed erosions and cracks on the slabs of the of the spillway basin. The erosions were situated adjacent to the contraction joints as a result of the action of the flow at high speed. The repairs were carried out with epoxy mortar.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-084	Ilha Solteira Dam	Brazil	1974	1974	[155; 156]

ASPECTS

There was observed abrasion in the stilling basin due to the erosive action of rock blocks carried 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; repair of the eroded area with epoxy mortar and concrete.





CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-085	Promissão Dam	Brazil	1975	1980	[155]

ASPECTS

Erosion on the spillway basin due to rock blocks movement from the downstream cofferdam.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-086	Nova Avanhandava Dam	Brazil	1982	1984/2012	[155]

ASPECTS

Flood drainage galleries of the concrete structures due to the damage of fixing the seal rubbers at the base of the stop-logs of the draft tube, downstream of the powerhouse. Removal of stop-logs, replacement of the gasket, replacement of stop-logs.
Replacement of the supervision and control of the command of the power house.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-087	Chavantes Dam	Brazil	1970	1984	[155]

ASPECTS
Erosions on the slabs of spillway trough in the vicinity of the expansion joints. Repair eroded sites using mortar and concrete with epoxy resin.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-088	Paranoá Dam	Brazil	1960	????	[155]

ASPECTS
Concrete erosion exposing the reinforcement in some places. The repair was performed with epoxy mortar.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-089	Salto Santiago Dam- PR State	Brazil	1980	????	[155; 157]

ASPECTS
Leakage through some contraction joints between blocks due abnormalities in concrete, with the sealing devices. The infiltration observed flows were of the order of 50 l/min. Erosions in the second stage concrete pillar-and the creager surface due to the heterogeneity of mixture and inadequate pouring. Repairs performed by grouting and concrete placement.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-090	Salto Osório Dam	Brazil	1975	1973/2017	[155]

ASPECTS

Erosion by abrasion, during the diversion of the river, downstream of the structures, caused by material being washed from the foot of the rock fill dam. The spillway erosion were verified in the concrete trough at certain points, which induced the erosion.

The damaged concrete was repaired, with the appropriate concrete replacement to finish of hydraulic erosion were verified in the surfaces of the suction tube, downstream of the reinforcement in all units of the powerhouse. The damaged areas were treated with replacement of concrete eroded by conventional concrete and high strength mortar.

In October 2017 occurred a pullout of a gate of the Spillways, which was repaired after lowering the reservoir level

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-091	Passo Fundo Dam	Brazil	????	????	[155]

ASPECTS

Partial obstruction of the drainage holes in the rock mass of the foundation of the spillway. Periodic cleaning of the holes and the drainage gallery.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-092	Ilha dos Pombos Dam	Brazil	1924	1985	[155; 158]

ASPECTS

Since the early years of its operation, the concrete structures presented issues related to various causes that induced damage to the structures, causing a widespread cracking, mainly attributed to the expansion reactions in concrete, involving aggregates and alkalis (AAR).

On these findings, the measures for the recovery of the structures consisted of:

- Grout injections, with what would be reduced the leakage;
- recompose the segregated concrete, damaged and loose;
- implementation of a waterproof coating on the surfaces that will be in contact with water or moisture.

The waterproof coating was executed with reinforced concrete with thickness varying between 5 cm and 10 cm

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-093	Guarapiranga Dam	Brazil	1908	1976	[155]

ASPECTS

Heavy rains that occurred in January 1976 caused the water level to exceed the maximum reservoir level, due to the inability of the bottom spillway flow dischargers, whose peak, estimated at 870 m^3/s, was substantially higher than the designed. The increase in peak flood was a result of the urbanization experienced by marginal land to the reservoir, especially in the decade preceding the occurrence, leading to a reduction in time of flood concentration and increased impermeability of the basin.

The decrease in rainfall and immediate elevation of crest with sandbag avoided a more serious overtopping, and the structure of the dam remained full, avoiding damage downstream. Some studies include the preparation of a new flood hydrograph, which resulted in a flow of 1045m^3/s.

Later were maximized the largest storms observed to the maximum possible flood assessment, which resulted in a flow peak of 2000 m^3/s. With this value, the structure was heightened, resulting in a spillway with four spans of 6 m wide. At the same time, has been remodeled and rises the Earth Dam. The dam nowdays attempt the operational conditions.

Historic cases on concrete
dams rehabilitation

Eng. Andriolo

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-094	Jaguara Dam	Brazil	1970	????	[155]

ASPECTS

The dam was designed with a spillway (sky jump) without dissipation basin excavation with maximum capacity of 14100 m^3/s. The discharge operation of spillway had excavated a bigger basin than anticipated, coming close to the concrete wall that separates the anchored tailrace of the spillway. There was also damage to the earth-rock fill dam built in extension to the wall. Replacement of part of the earth-rock dam by reinforced concrete wall; controlled operation of the spillway gates to prevent the increase of erosion of the basin along the anchored wall.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-095	Peti	Brazil	1946	????	[155]

ASPECTS

The dam showed cracks (due to the reactivity of the aggregate/cement/water and to temperature changes) that allow percolation of water at various locations. The repairs were performed with the application of a special asphalt layer (components, epoxy) in the wall of upstream and on the platform of the crest. In the downstream wall was applied a layer (painting) of cement with waterproofing additive. The cracks were treated before application of protective layers. The fissures and cracks remain leakproof.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-096	Salto Grande Dam -MG State	Brazil	1956	????	[155]

ASPECTS
Due to the siltation of the Santo Antonio River reservoir, to the doorstep of the spillway, the spillway gates operation removes part of silted material. This fact made the surface strand suffered an abrasion process which culminated in the loss of some dissipators teeth (at 30 cm) and with the threat of loss of the geometry of the spillway. The repair was done overlaying the whole surface with high abrasion resistance concrete

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-097	Tres Marias Dam	Brazil	1961	1984	[155]

ASPECTS

Lateral overtopping of spillway chanel, before the formation of the jet, for discharges between 800 and 2,000 m³/s m3/s, causing erosions on the ground side walls due to external violent turbulence of the waters inside the gutter. Modifications of the spillway profile and concrete repair of the basin were performed. These modifications allow the flows up to 1.300 m³/s.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-098	Volta Grande Dam	Brazil	1974	????	[155]

ASPECTS
During the diversion through the sliceways, was carried into the spillway stilling basin part of the rocky material dissipation of the spillway channel. This cause a destructive process of erosion by abrasion and impact. The process has accelerated with the operation of the spillway. As a result, the concrete surface of the basin and dissipators teeth virtually disfigured with exposed reinforcements. The repair was performed with concrete.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-99	Xicão Dam	Brazil	1942	????	[155]

ASPECTS

The dam is a reinforced concrete structure with multiple vaults and buttresses, with a maximum height of 20 m and length of 115m. There were observed leaks by construction joints of concrete of the dam and the contact concrete/rock. The leaks were ferruginous spots in concrete, with evidence of corrosion of the reinforcement. Emptying the reservoir and treatment of construction joints. Performed the repair at the contact with the Foundation, reducing the leaks in the concrete dam and foundation contact.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-100	Marimbondo Dam	Brazil	1975	1982	[155; 159]

ASPECTS

In May 1975, after the river closure, erosion of the spillway chute and dissipation basin there were observed. 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 featured irregular due to erosion of the current return flows and the effect of the cracks of the rock. In 1980 and 1982 the stilling basin was dewatered for concrete repairs.

Foto 7 - Detalhe das ferragens arrancadas da bacia de dissipação

Historic cases on concrete dams rehabilitation

Eng. Andriolo

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-101	Porto Colombia Dam	Brazil	1974	????	[155]

ASPECTS

Erosion on surface of the blocks and slab of the spillway with the reinforcement exposed. The repair was performed with concrete and epoxy mortar.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-102	Moxotó Dam	Brazil	1975	1983-1990	[155; 160; 161; 162]

ASPECTS

In 1983, in order to minimize the effects of the AAR in the concrete involving the generating units, it was decided to realign all the equipment. With the evolution of the observed expansion through instrumentation data and simulation of mathematical model, it was shown that the opening together would provide the traction tension reduction on the elements of the turbine. The solution adopted was the opening of three expansion joints between the blocks using the technique of steel wires impregnated with abrasive, for a gap of 30 mm.

CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-103	Ype Dam	Brazil	2017	2017	www.emaisgoias.com.br
ASPECTS					
One of the spillway gates of the Rio Verde dam broke. The repair is undergoing					

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CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION / REPAIR	REFERENCES
A-104	Itaipu Dam	Brazil-Paraguay	1983	1980	[163; 164]

ASPECTS

During the construction of the Right Lateral Dam, some blocks, which are under the cableway cranes, were poured slowly, and at the other side of the cranes, they were poured in a faster sequence (5 or 6 layers per month). The blocks 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 in the foundation. The cracks if characterized from micro-cracks of small depth and extension, even some cracks were 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.









Historic cases on concrete dams rehabilitation

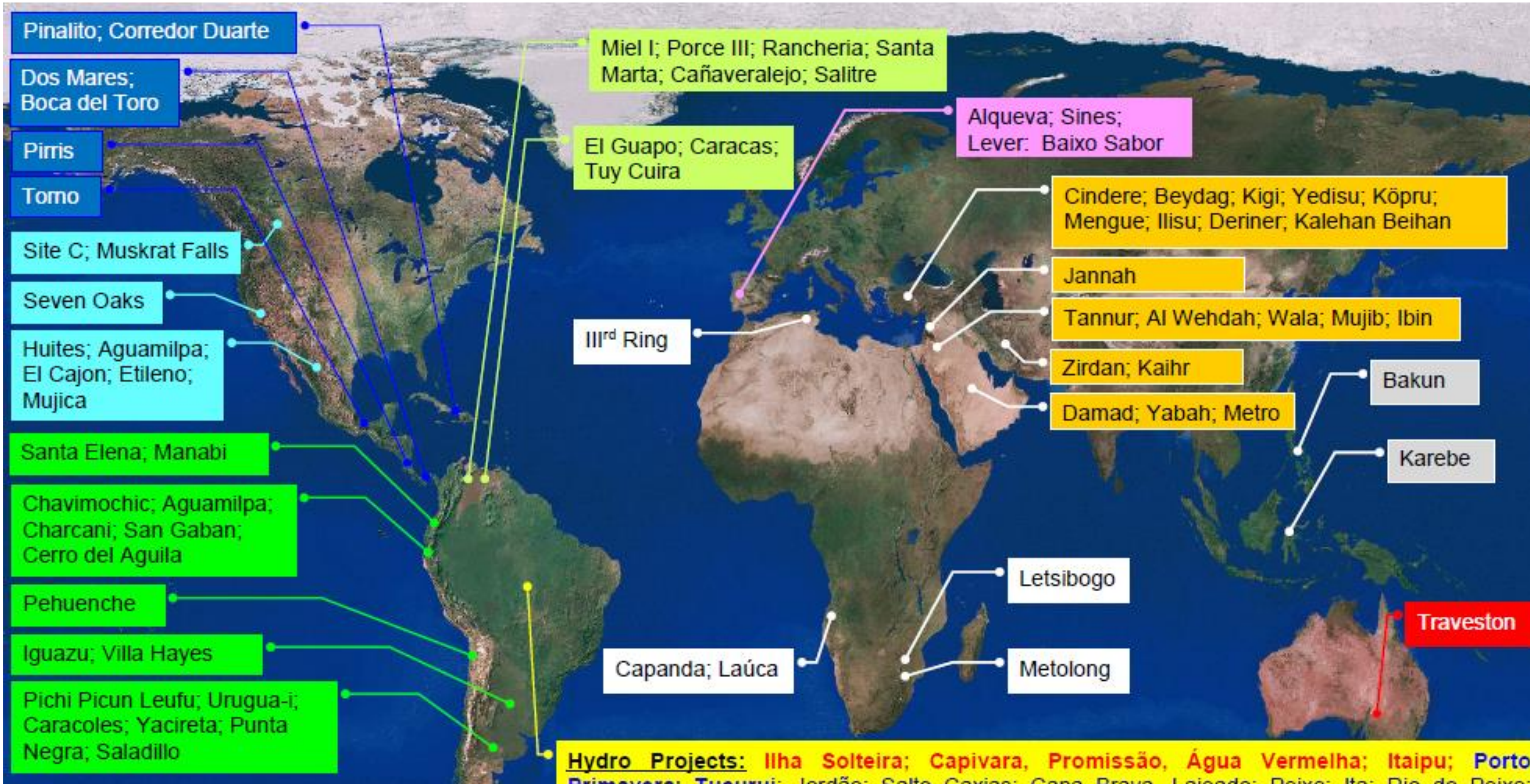
CASE	IDENTIFICATION	COUNTRY	FINISHED	REHABILITATION/ REPAIR	REFERENCES
A-105	Dworshak Dam	USA	1970	1971/1980	[165]

ASPECTS

Before the reservoir was filled, cracks on the upstream face of several monoliths were measured and mapped to pinpoint their exact location and length. At that time, the cracks were not regarded as being significant. After reservoir filling, eight of the cracks that were mapped penetrated the interior of the structure, causing an inflow of water into several galleries. These cracks were drilled to release hydrostatic pressure. After the drilling was completed, flows decreased, and over time most of the cracks healed as a result of calcification. The permanent solution selected was to seal the crack with an epoxy material designed to be placed underwater.

In the late 1980's, erosion resulting from the grinding action of riprap and trapped debris caused a loss of almost 1220 m^3 of concrete in the stilling basin, and the outlet conduit suffered cavitation damage when excessively high flows washed out large pieces of aggregate and matrix from the face of the outlet. Both the stilling basin and the outlet conduit were repaired with polymer-impregnated concrete in the first major field application of this repair material.

MANY THANKS
AND
GREAT SUCCESS !!



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- **More than 80.000.000 m³ concretes;**
- **More than 34 Countries;**
- **More than 165 Published Papers**
- **9 Books**
- **1 Technical Award and Nominated Concrete Laboratory –CESP-IS;**
- **Membro da Academia Nacional de Engenharia (2015)**

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