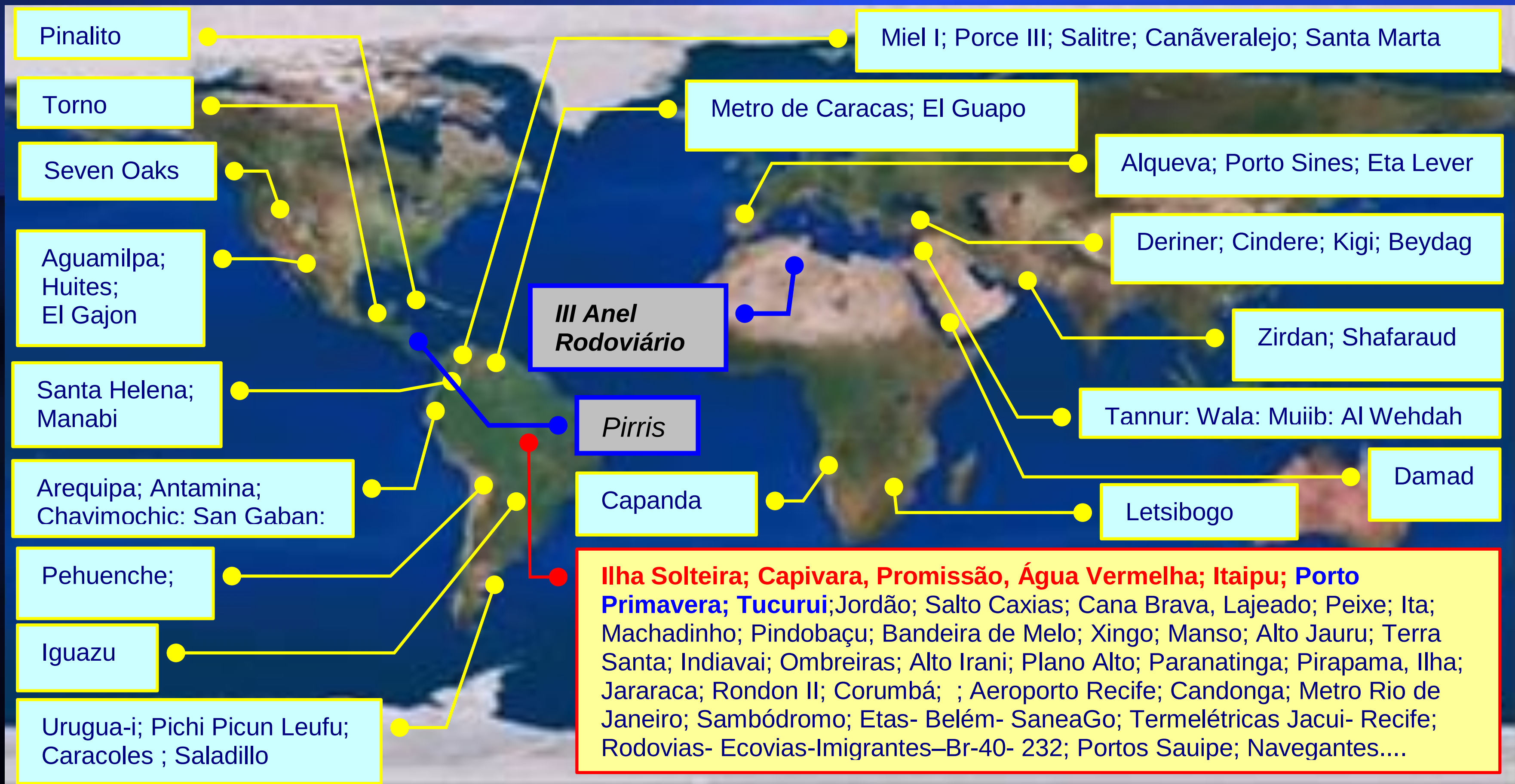
Workshop on Roller Compacted Concrete for Dams

Tehran- Iran- May/ 2011

RCC : Updating the Information

Eng. ***ANDRIOLO***, Francisco Rodrigues



- Cooperation in more than 100 Concrete Works;
- Participating in more than 58.000.000m^3 concrete, in
- 25 Countries
- 147 Technical Papers (Congresses & Magazines)
- 7 Technical Books
- 1 Technical Award and Nominated Concrete Laboratory –CESP-IS

Part I- General Information concerning the RCC Dams

I.a) Statistics about RCC Dams in the World

I.b) Main RCC Dams

I.c) Advantages and Disadvantages about RCC Dams

I.d) Comparison and Cost

Part II- RCC Dam Construction- Methodologies

II.a) Materials Availability and Processing – Timely Material Production

II.b) Production, Handling, Pouring, Compaction

II.c) Upstream and Downstream Faces

II.d) RCC Arch Dams

Part I- General Information concerning the RCC Dams

I.a) Statistics about RCC Dams in the World

Development Worldwide

The idea of Technical Construction of the RCC, was initially mentioned at conferences in Asilomar, California, as can be conveniently remembered:

- ✓ in March 1970 – Rapid Construction of Concrete Dams – “The optimum Gravity Dam” – ***Prof Jerome Raphael*** and ;
- ✓ in May 1972 - Economical Construction of Concrete Dams and their discussions, should be remembered:

[01] *"....The very lean concrete dam such as Professor Raphael apparently has in mind, would require that the upstream face have an impervious membrane which could be cemented.. provide to prevent deterioration from weathering..."*

[02] *"... it should suffice to say that the construction procedure is feasible, and that concrete compacted by this procedure is in every respect equal to or higher in strength than conventional concrete with equal cement content...* (This publication should be read by all who use the technique!)

[03] *"...It is concluded that the techniques are here to take the next step to building the economical soil-cement dam...."*

The Industry for Construction of Dams, almost immediately after World War II, developed two main lines of construction methods

- The Concrete Face Rock Fill Dams (CFRD), and
- The Roller Compacted Concrete (RCC) Dams

Both of these disputing for room and technical advantages, of time and costs, in the Worldwide scenario.

The series of RCC dams in the world reached at the end of 2010 over 420, and currently it could be more than 450, because several entities of several countries avoid sending information in order to reduce the harassment by professionals on the Project decisions. The CFRD, started earlier, total to around 320.

Each one shows advantages and characteristics in different places in various hydrological systems and a single reason cannot be declared for the preferences, which make up the appropriate and correct discretion.

RCC Development in the World

Dimensions (m)	All Methodologies	RCC	CFRD
Average	53	64	88
Highest	300	196	234
Lowest	15	15	26

China contribute with 42% of the CFRD and the others Countries (Large Builders) as Australia, Brazil, Chile, Colombia, USA participate with just 6% from the Total

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Anais do 50º Congresso Brasileiro do Concreto
CBC2008 - RCC Symposium
Setembro / 2008
ISBN
@ 2008 - IBRACON
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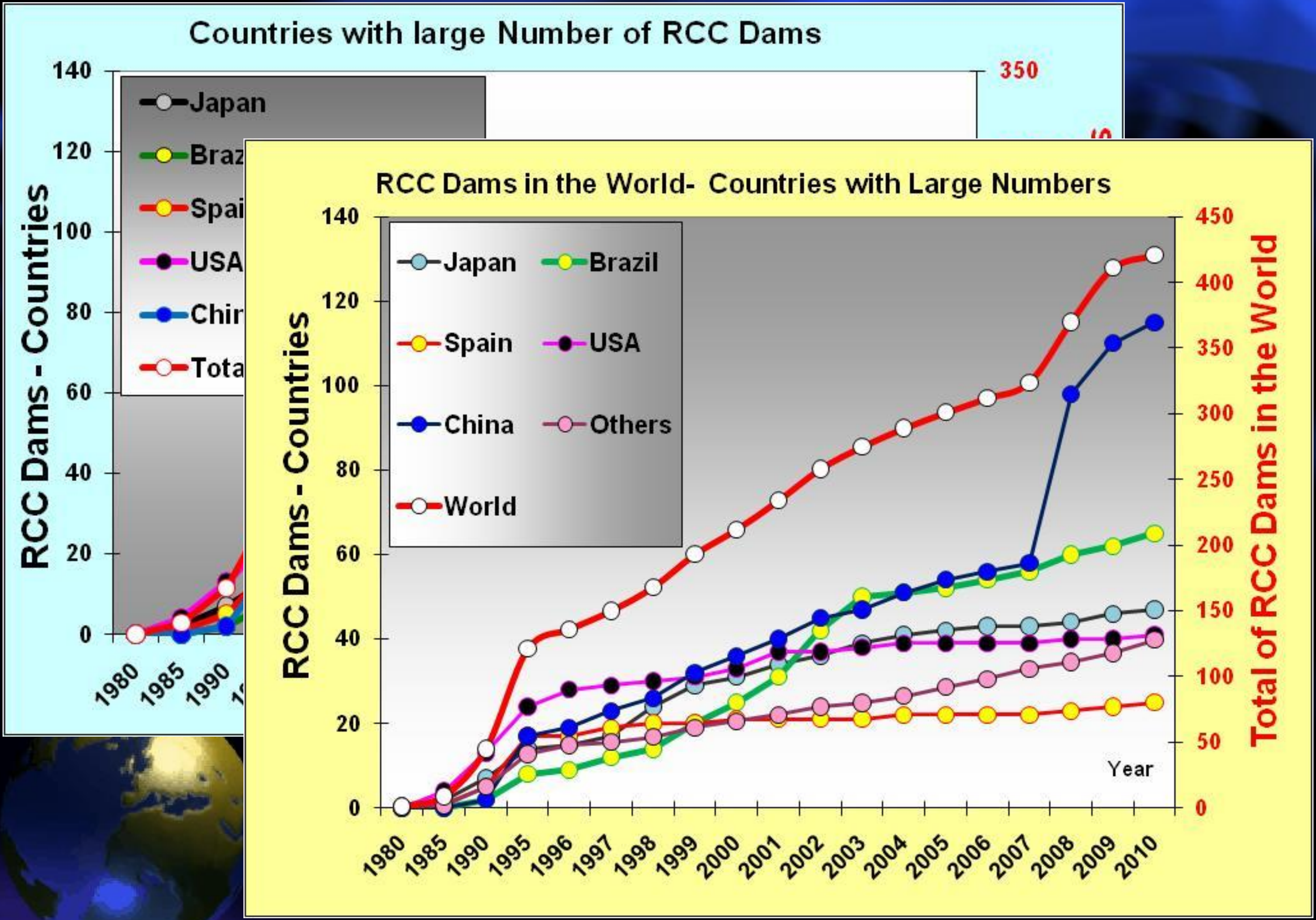
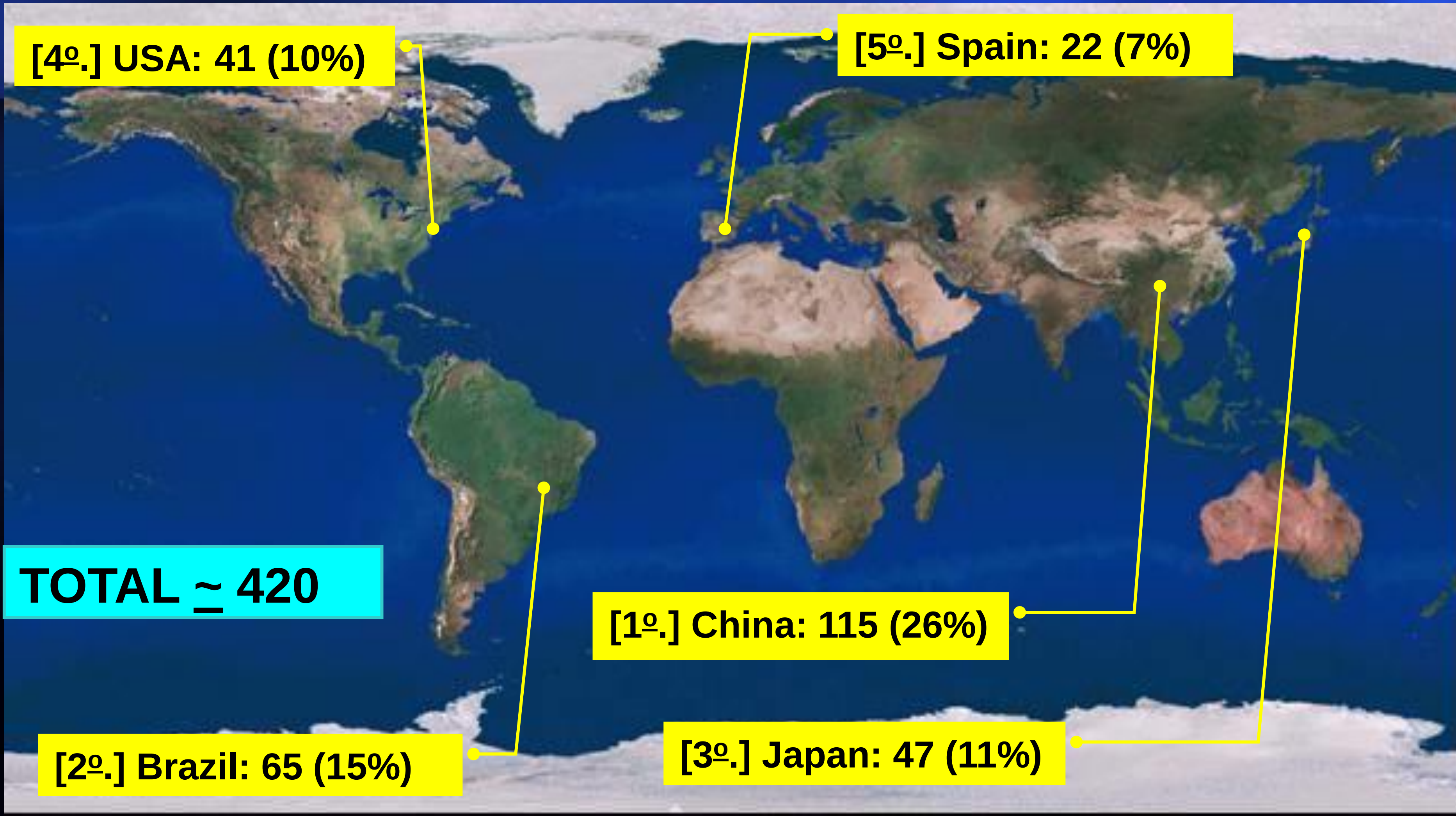

Countries with large Number of RCC Dams
RCC Dams - Countries
Japan
Braz
Spai
USA
Chir
Tota
RCC Dams in the World- Countries with Large Numbers
RCC Dams - Countries
Total of RCC Dams in the World
Japan
Brazil
Spain
USA
China
Others
World
Year
1980
1985
1990
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

By the end of 2010 there were more than 420 dams in the World.



Note: The 5 countries are responsible for about 70% of the RCC Dams in the World.

The practice of "Low Cementitious Content" was adopted at the outset of the first RCC Dams in the United States.

Almost simultaneously, Japan began to use the evaluations for using RCC in 1974, adopting the nomenclature RCD, with a cementitious content of 130 kg/m^3 with 91 kg/m^3 of cement and 39 kg/m^3 of Fly Ash.

China, another Country considered a great builder, began studies for the implementation of the RCC around 1980, with an cementitious content of 120 kg/m^3 to 152 kg/m^3, given that the Kengkou Dam effectively began a cycle of large RCC projects in China, with a content of 140 kg/m^3 of cementitious materials (60 kg/m^3 of cement and 80 kg/m^3 of Fly Ash)

RCC Main Characteristics

The average ratio of Tensile Strength (indirectly by diametrical compression- Brazilian Test) the Compression was around 11%, and Direct Tensile Strength / Compression between 6% to 7%.

Clearly, when a particular property is required, one should seek the mix proportion, with the materials available in order to meet such properties.

For example, a greater resistance to RCC of a Double Arch Curvature Dam, or Pavement.

But these concrete thus rationed, and applied by a Vibrator roller compaction are RCC, or better said-**CONCRETE**!

Part I- General Information concerning the RCC Dams

I.a) Statistics about RCC Dams in Brazil

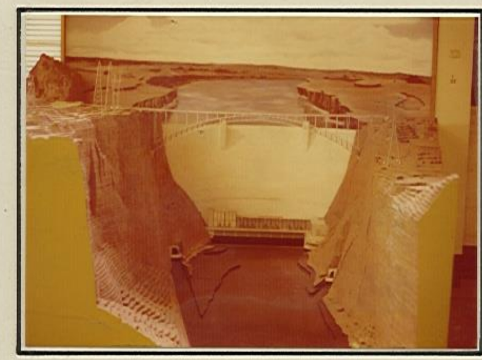
Brazil

CENTRAIS ELÉTRICAS DE SÃO PAULO S.A.
CESP

SETOR DE LABORATÓRIOS - ILHA SOLTEIRA

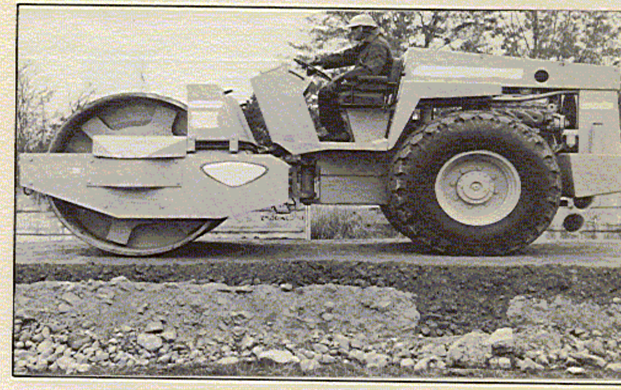
RELATÓRIO DE VIAGEM - ESTADOS UNIDOS

MAIO - 1.975

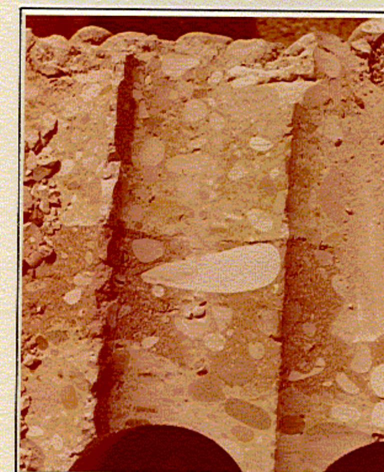


ENGº FRANCISCO RODRIGUES ANDRIOLO
CHEFE SETOR DE LABORATÓRIOS - I.S.

SETOR DE LABORATÓRIOS - ILHA SOLTEIRA.	DES.:	ESC.:
RELATÓRIO DE VIAGEM-ESTADOS UNIDOS-MAIO 1975	VER.:	FL. 64 de
	DES Nº	



F.109 - Rolo compactador usado para adensamento. Segundo informações do Prof. Raphael (Berkeley) e Dr. Borge (Corps - Portland) está se estudando a possibilidade de uso desse tipo de concreto, na construção de uma pequena barragem de regularização.



F.110 -


TESTEMUNHO DE CONCRETO ADENS DO
COM ROLO VIBRATÓRIO (NOV/7
APLICAÇÃO :
RAMPA DE ACESSO DA EL. 63,00 À EL. 85,00
A SANTE DA ESTRUTURA DE DESVIO
MÉDIOS OBTIDOS : (IDADE 110 dias 180 dias)
À COMPRESSÃO AXIAL ..(kg/cm2) 130 149
À COMPRESSÃO DIAMET. (kg/cm2) 13,4 15,0
DE ELASTICIDADE .... (kg/cm2)~300.000 ~300.000
PERMEABILIDADE ...(cm/seg) ~10-5
VOLUME TOTAL DE ROLLCRETE .....(m3) ~26.000
PICO DIÁRIO ....(21/05/78)(m3) 3.504

XIII SEMINÁRIO NACIONAL DE GRANDES BARRAGENS

RIO DE JANEIRO

ABRIL 1980

"CONCRETO ADENSADO COM ROLO VIBRATÓRIO"

TEMA: II

ENGº IDEVAL BETIOLI
Divisão de Controle de Qualidade de Campo

ENGº LUERCIO SCANDIUZZI
Divisão de Laboratório e Instrumentação do Concreto

ENGº FRANCISCO RODRIGUES ANDRIOLO
Assistência Construção de Concreto

ITAIPU BINACIONAL

General view of rollcrete placement at the Itaipu project.

Use of Roller Compacted Concrete in Brazil

by Francisco Rodrigues Andriolo, Gustavo Reis Lobo de Vasconcelos, and Humberto Rodrigues Gama

Roller compacted concrete (RCC) has been used in Brazil since 1976 and has been subjected to a number of studies. RCC allows continuous placement with the possibilities of time and cost economies in the construction of concrete gravity dams in that South American nation. This article also deals with laboratory studies, mix proportioning, placement procedures, and test methods.

Keywords: compacting; concrete dams; costs; **gravity dams; mix proportioning; placing; roller compacted concrete**; tests; vibration.

With the construction of large projects in Brazil, mainly hydroelectric power structures, technologists have continually searched for materials and new construction methods for greater concrete placement in shorter periods of time.

This research has been directed at materials such as cements with low heat of hydration, use of coarser aggregates, use of pozzolanic material, and concrete cooling methods to minimize or even totally avoid the cracking of concrete.

In recent years, attention has also been directed at new mix techniques for the construction of rock fills and embankments often necessary for mass concrete projects. The result of this attention has led to roller compacted concrete, commonly referred to as RCC or rollcrete.

RCC, in which a no slump concrete is used with a sandy aspect, permits the use of equipment in the construction of rock fills at a continuous placement. This leads

Rollcrete was applied to a permanent structure for the first time in Brazil at the Tucurui Dam navigational lock.

CIGB ICOLD CBGB

Comitê Brasileiro de Grandes Barragens

XVI SEMINÁRIO NACIONAL DE GRANDES BARRAGENS

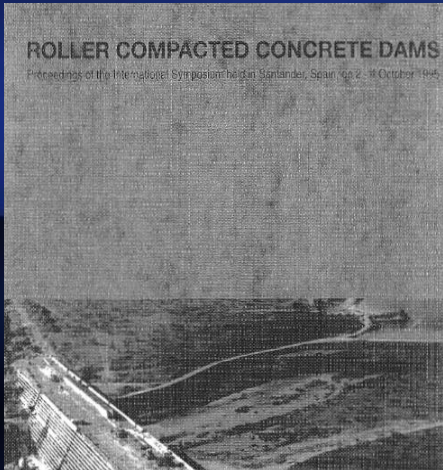
Comparações de Características e Propriedades de Concreto Rolado Aplicado no Brasil e em Outros Países

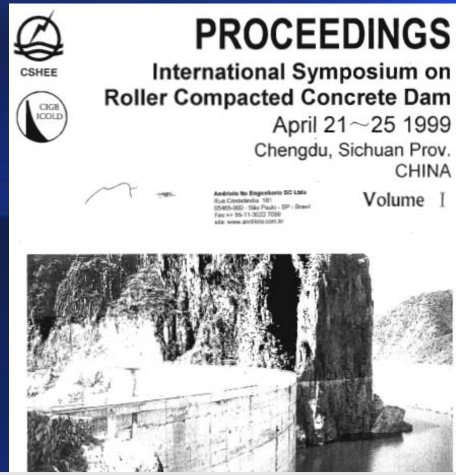
ANAIS

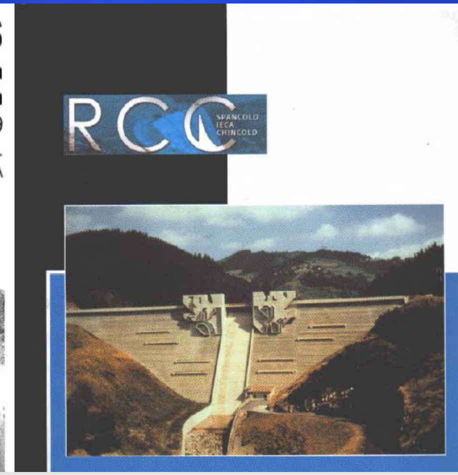
Belo Horizonte, novembro de 1985

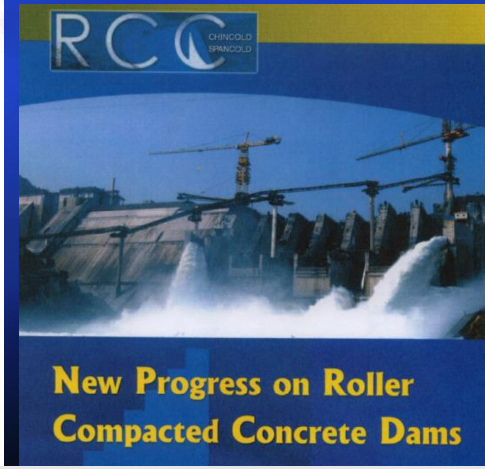
Part I- General Information concerning the RCC Dams

I.a) Statistics about RCC Congresses









Μεασυρεσ φορ τηε Τερμινατιον οφ τηε Ηιστορψ οφ ∀Νο Χονχρετε Δαμ ωιτηουτ Χραχκινγ∀

Ζηυ Βοφανγ

Χηινα Ινστιτυτε ο/Ωατερ Ρεσουρχεσ ανδ Ηψδροποωερ Ρεσεαρχη, Βειφινγ 100038, Χηινα

Αβστραχτ: Αλτηουγη α σεριεσ οφ μεασυρεσ ηαωε βεεν δεωελοπεδ το πρεωεντ χραχκινγ ιν χονχρετε δαμσ σινχε 1930,πραχτιχαλλψ τηερε ισ νο δαμ ωιτηουτ χραχκινγ. Αφτερ σψστεματιχ ινωεστιγατιον, τηε αυτηορ δισχοωερεδ τηατ τηε βασιχ ρεασον ισ τηε νεγλεχτ οφ συπερφιχιαλ τηερμαλ ινσυλατιον ιν τηε λατερ αγε οφ χονχρετε. Ιτ ισ ποσσιβλε το πρεωεντ χραχκινγ ιν χονχρετε δαμσ βψ περμανεντ συπερφιχιαλ τηερμαλ ινσυλατιον ιν αδδιτιον το χομπρεηενσιωε τεμπερατυρε χοντρολ ιν τηε χονστρυχτιον περιοδ. Τηερε αρε τηρεε χονχρετε δαμσ ωιτηουτ χραχκινγ αφτερ χομπλετιον ιν Χηινα. Τηε χοστ οφ περμανεντ συπερφιχιαλ τηερμαλ ινσυλατιον ισ ρατηερ λοω.

Study on Seismic Safety of CSG Dam*

Xiong Kun, He Yunlong, Peng Yunfeng

State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China, E-mail: lynnxiong@163.com

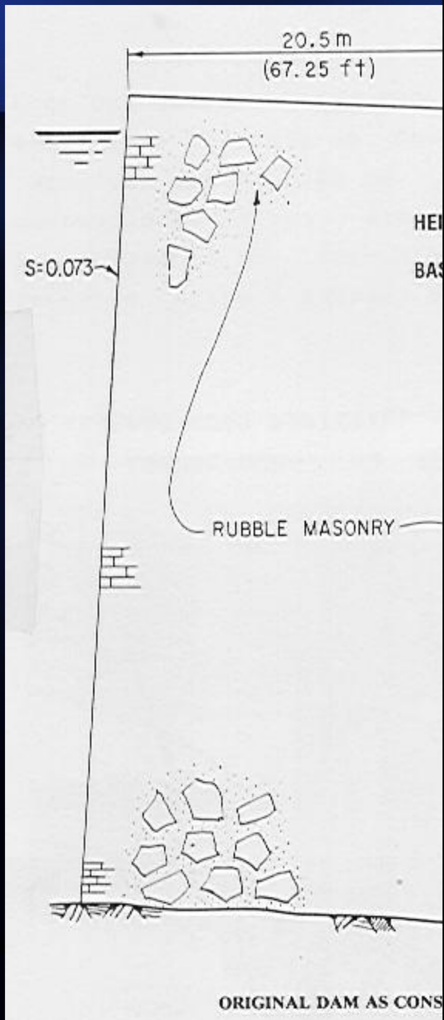
Abstract: Hardfill dam is a new type of dam (called CSG dam in Japan), which has a symmetrical trapezoid shaped cross section and a concrete impervious facing in the upstream. The hardfill dam is deemed to own a stronger earthquake-resistance. By means of the finite element method (FEM)…..

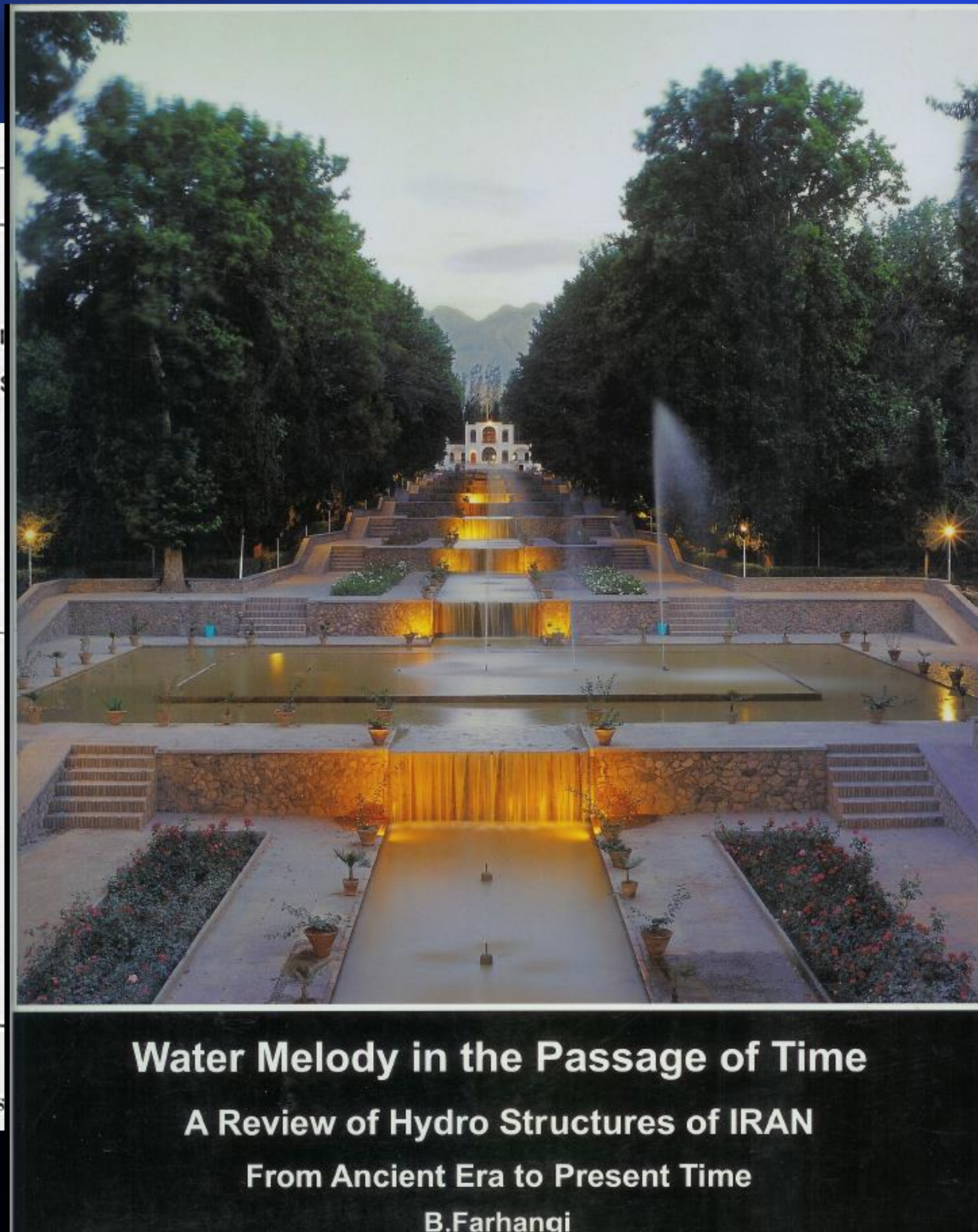
Study on the Structural Safety of CSG Dam*

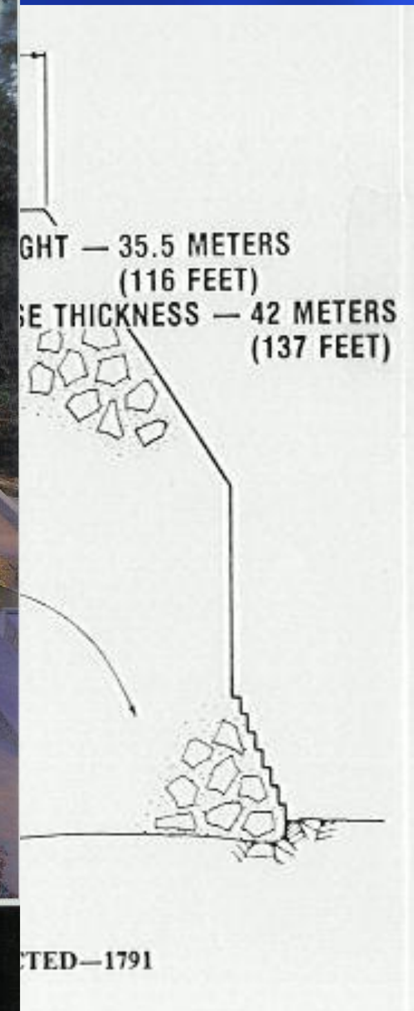
Peng Yunfeng, He Yunlong, Xiong Kun

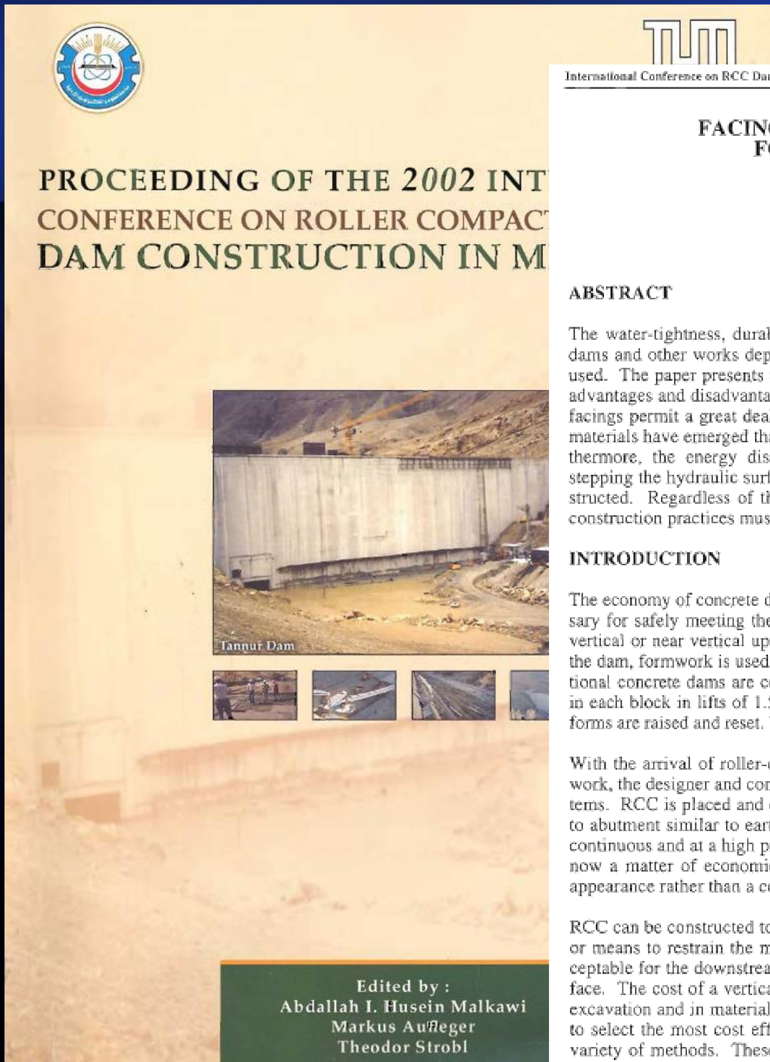
State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China, E-mail: whpyf@163.com

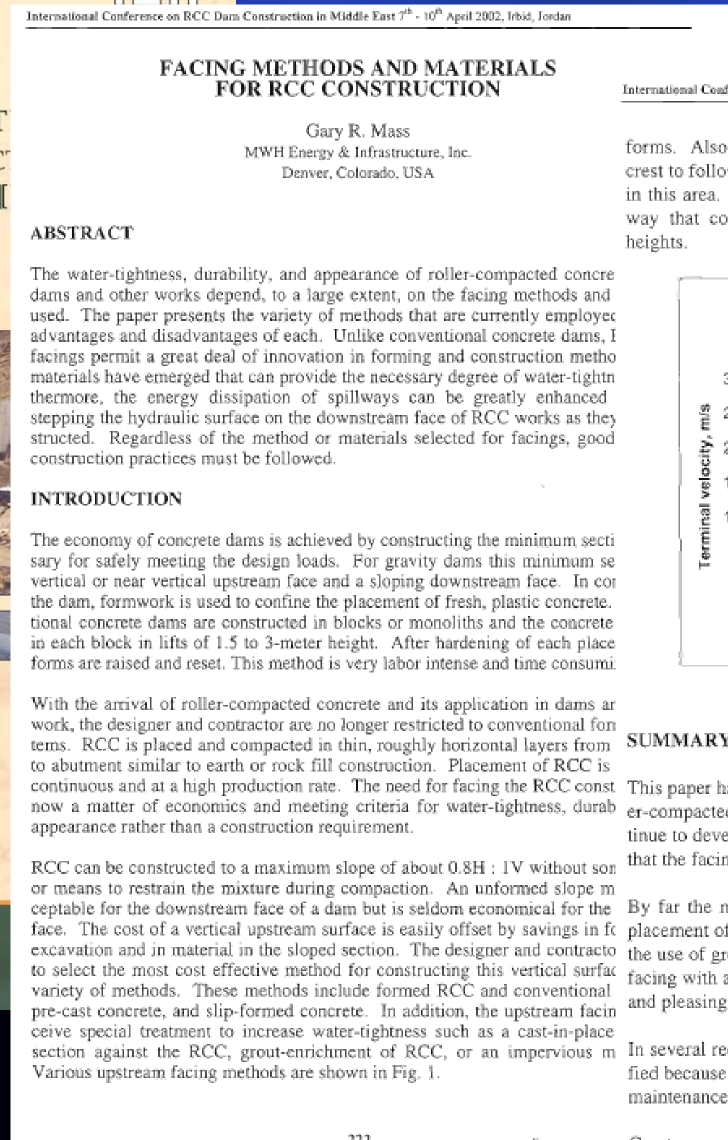
Abstract: Hardfill dam is a new type of dam, which is called CSG dam in Japan. It is a symmetrical trapezoid shaped dam with a concrete impervious face in the upstream. From the viewpoint of structural stability, the symmetrical trapezoid-shaped hardfill dam should have advantages of high safety. …… In this paper, the 3D finite element method (FEM) is used to analyze….


20.5 m
(67.25 ft)
S=0.073
RUBBLE MASONRY
ORIGINAL DAM AS CONS


Water Melody in the Passage of Time
A Review of Hydro Structures of IRAN
From Ancient Era to Present Time
B.Farhangi


GHT — 35.5 METERS
(116 FEET)
E THICKNESS — 42 METERS
(137 FEET)
TED—1791





International Conference on RCC Dam Construction in Middle East 7th - 10th April 2002, Irbid, Jordan

FACING METHODS AND MATERIALS
FOR RCC CONSTRUCTION

Gary R. Mass
MWH Energy & Infrastructure, Inc.
Denver, Colorado, USA

ABSTRACT

The water-tightness, durability, and appearance of roller-compacted concre dams and other works depend, to a large extent, on the facing methods and used. The paper presents the variety of methods that are currently employec advantages and disadvantages of each. Unlike conventional concrete dams, I facings permit a great deal of innovation in forming and construction metho materials have emerged that can provide the necessary degree of water-tightn thermore, the energy dissipation of spillways can be greatly enhanced stepping the hydraulic surface on the downstream face of RCC works as they structed. Regardless of the method or materials selected for facings, good construction practices must be followed.

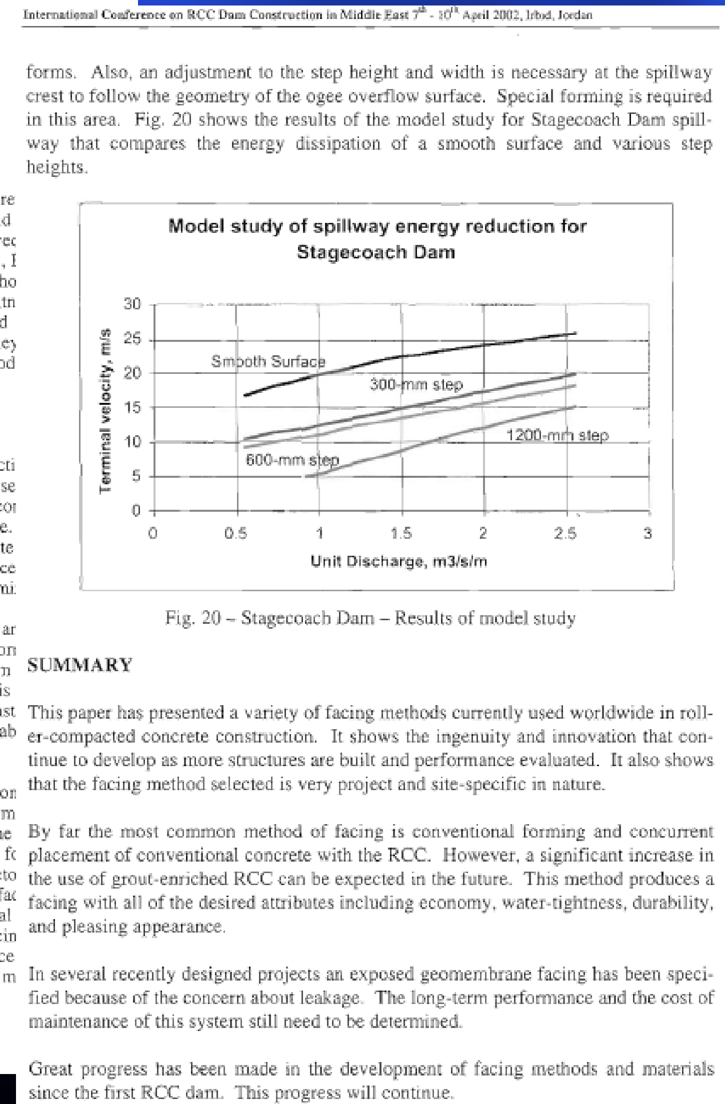
INTRODUCTION

The economy of concrete dams is achieved by constructing the minimum secti sary for safely meeting the design loads. For gravity dams this minimum se vertical or near vertical upstream face and a sloping downstream face. In cor the dam, formwork is used to confine the placement of fresh, plastic concrete. tional concrete dams are constructed in blocks or monoliths and the concrete in each block in lifts of 1.5 to 3-meter height. After hardening of each place forms are raised and reset. This method is very labor intense and time consumi

With the arrival of roller-compacted concrete and its application in dams ar work, the designer and contractor are no longer restricted to conventional for tems. RCC is placed and compacted in thin, roughly horizontal layers from to abutment similar to earth or rock fill construction. Placement of RCC is continuous and at a high production rate. The need for facing the RCC const now a matter of economics and meeting criteria for water-tightness, durab appearance rather than a construction requirement.

RCC can be constructed to a maximum slope of about 0.8H : 1V without son or means to restrain the mixture during compaction. An unformed slope m ceptable for the downstream face of a dam but is seldom economical for the face. The cost of a vertical upstream surface is easily offset by savings in fc excavation and in material in the sloped section. The designer and contracto to select the most cost effective method for constructing this vertical surfac variety of methods. These methods include formed RCC and conventional pre-cast concrete, and slip-formed concrete. In addition, the upstream facin ceive special treatment to increase water-tightness such as a cast-in-place section against the RCC, grout-enrichment of RCC, or an impervious m Various upstream facing methods are shown in Fig. 1.

- 222 -



International Conference on RCC Dam Construction in Middle East 7th - 10th April 2002, Irbid, Jordan

forms. Also, an adjustment to the step height and width is necessary at the spillway crest to follow the geometry of the ogee overflow surface. Special forming is required in this area. Fig. 20 shows the results of the model study for Stagecoach Dam spillway that compares the energy dissipation of a smooth surface and various step heights.

Fig. 20 – Stagecoach Dam – Results of model study

SUMMARY

This paper has presented a variety of facing methods currently used worldwide in roller-compacted concrete construction. It shows the ingenuity and innovation that continue to develop as more structures are built and performance evaluated. It also shows that the facing method selected is very project and site-specific in nature.

By far the most common method of facing is conventional forming and concurrent placement of conventional concrete with the RCC. However, a significant increase in the use of grout-enriched RCC can be expected in the future. This method produces a facing with all of the desired attributes including economy, water-tightness, durability, and pleasing appearance.

In several recently designed projects an exposed geomembrane facing has been specified because of the concern about leakage. The long-term performance and the cost of maintenance of this system still need to be determined.

Great progress has been made in the development of facing methods and materials since the first RCC dam. This progress will continue.

PRE-CAST CONCRETE

Pre-cast concrete facing has been used for both upstream and downstream faces.

It produces a very high-quality concrete since elements are manufactured under more controlled conditions.

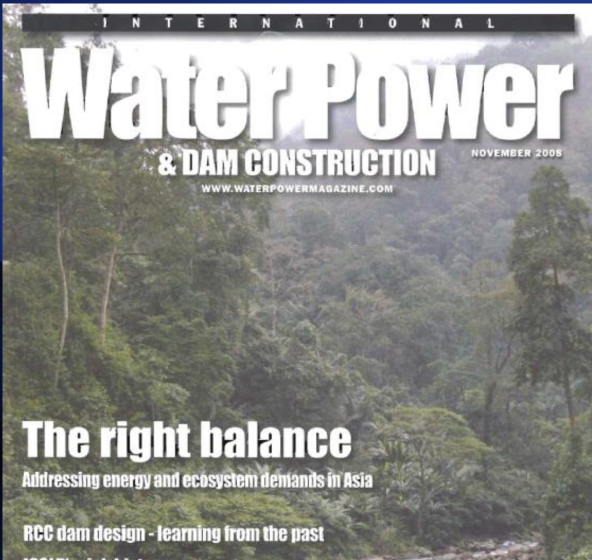
It is also a very rapid method of installation that has little inter-ference with RCC placement.

Furthermore, site pre-casting can be done during periods when weather or river water level prevent the placement of RCC.

MEMBRANES

A very positive method of ensuring water-tightness is the use of membranes. Two years after construction of Willow Creek Dam, Winchester Dam was constructed which also used the pre-cast panel system for the upstream face. However, at Winchester Dam the interior face of the panels was lined with a 6.S-mm thick, polyvinyl chloride (PVC) membrane for the impervious barrier. Joints in the membrane were thermally welded to produce a continuous watertight seal. Similar to Willow Creek Dam, the panels were anchored into the RCC body. Performance of this dam with respect to seepage has been excellent.

Galesville Dam was constructed about the same time as Winchester Dam but used a different technique. It incorporated an exposed elastomeric membrane coating that was sprayed on the upstream conventional concrete formed face in two 2.0-mm coats. Performance of the dam with respect to seepage has been much lower than expected. Maintenance on this structure has been high.



MIDDLE FORK DAM – COLORADO

This RCC dam was constructed in 1984 to provide a supplemental water supply and flood protection for a proposed, but never built, shale oil mine and processing plant. The dam has an upstream and stepped downstream facing of conventional concrete, but no transverse joints at its narrow canyon site.

As with many RCC dams, the concrete face effectively reduced seepage through the dam to acceptable limits. Calcification of the RCC mass further reduced seepage with time, with the seepage reduction being the most rapid during the first three months after complete reservoir filling in the fall of 1984.

Significant development of calcite (calcium carbonate) formed when calcium hydroxide from the cement hydration process is carried by seepage water to the gallery or dam drain holes. Here, the calcium hydroxide combines with carbon dioxide from the air to form this hard white precipitate. With time, this material can cause drain holes within the dam to clog. The drain holes at Middle Fork Dam were re-drilled in 2007 to reestablish their effectiveness for capturing seepage water and assuring reduction in uplift pressures.

GALESVILLE DAM – OREGON

Galesville Dam is another example of the rapid placement of RCC. The 161,000m³ of RCC was placed in about 1½ months in basically June and the first half of July in 1985. Placing all conduits through the dam in a concrete encasement on one abutment helped speed construction. The vertical upstream face is conventional concrete with no transverse contraction joints. Unformed RCC was used for the downstream slope with overbuild allowed by the contractor. The overbuild was allowed to ravel and served as a sacrificial layer of poorly compacted RCC.

For seepage control, two 20-mil thick layers of a coal-tar based elastomeric membrane was sprayed on the upstream face. A delay in the start of the RCC placement to warmer weather helped contribute to the initial formation of seven thermal related cracks that continued through the entire gravity structure. Following completion of the dam, unusually cold weather hit the site causing a reduction in volume and thus cracking. The sprayed on membrane did not have sufficient elasticity to bridge the cracks.

Repair methods used to reduce seepage through the cracks included: (1) dumping pelletized bentonite from a boat near the widest crack; and (2) divers caulking the cracks to a depth of 50 to 60 ft (15-18m) below the water surface. The dumped pellets worked reasonably well when there was sufficient velocity to draw the bentonite into the crack. Cracks lower in the structure remained uncaulked due to a limitation on the depth the divers could effectively work. The repair methods, together with some natural calcification and siltation, reduced seepage by about 70% over a two year period.

GRINDSTONE CANYON DAM – NEW MEXICO

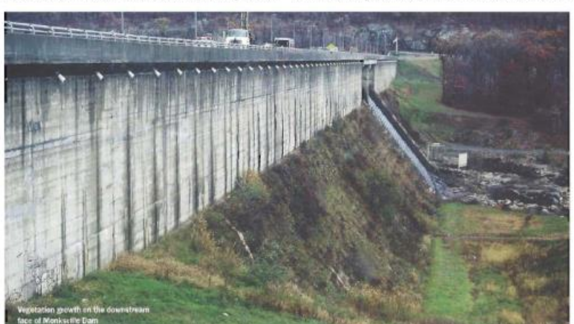
The seepage control system for this 432m long RCC dam consisted of a conventional concrete face and partially sealed face joints spaced 4.6m on center. No waterstopped transverse joints were included in the design. It was reported that the original joint sealant used in the vertical dummy joints was not of the type recommended by the manufacturer for underwater placement and was not applied to the depth specified in the formed V-notch joint.

Upon initial filling in 1988, nearly two years after completion of the dam, seepage exceeded the measuring capacity of the flume in the channel downstream of the dam. Calcification and siltation, together with repair of one hole at the right-end of the gallery, helped reduce total seepage. During cold weather the following winter, the RCC mass contracted and measured seepage increased. The reservoir was then lowered to allow for repair of the vertical joints and cracks. In addition to the seepage through cracks and joints, the author feels that additional seepage may be coming through horizontal lift lines in the conventional concrete face due to a delay in placing successive layers of facing concrete.

In 1995-1996, the New Mexico State Engineer's office reported it oversaw another rehabilitation project that reduced seepage by 70%.

MONKSVILLE DAM – NEW JERSEY

Monksville Dam became the first RCC dam constructed in the eastern US when completed in 1986. It had a conventional concrete face



Vegetation growth on the downstream face of Monksville Dam

Seepage visible on the downstream face of Willow Creek Dam

Lessons from the past

Kenneth D Hansen provides an insight into what today's engineers can learn from the first five years of RCC dam construction in the US

Kenneth D. Hansen

upstream and uncompacted RCC on a 0.78H:1.0 V downstream slope. It was the first dam in the US to utilise a thermal analysis for the purpose of determining among other things the spacing of water-stopped transverse joints. Because a delay in RCC construction due to warmer weather would produce higher placing and peak temperatures, the designers decided to decrease the spacing of water-stopped joints at higher elevations. The seepage control system, which included placement of bedding mortar on every other lift near the upstream face, worked reasonably well.

It was on the exposed RCC downstream face that things did not work out as well as expected. The original design called for a higher cement content (110kg/m³) RCC mix along the downstream face. This zone was not placed as intended. It was believed that the lean RCC mix (64 kg/m³ and no fly ash) would be sufficiently durable, and additionally there would be a cost savings in using this mix.

This lean, dry RCC mix did not prove to be durable in an area that is exposed to many cycles of freezing and thawing annually, as well as wetting and drying due to rain. The mix was also poorly compacted at the edge as the roller could not efficiently compact the RCC at this area due to lack of outer restraint, and the fear of operators working too close to this steep edge.

A coring and evaluation programme for the dam was undertaken in 1998. It determined, among other things, that the freeze thaw deterioration affected about 12 to 18 inches of RCC measured from the original downstream face. The loose RCC on the face was also determined to have a high degree of water absorption. This led to condition where bushes and other vegetation grew and covered the entire exposed downstream face (shown in the photograph on p22).

In 2007, a precast concrete face with loose drain gravel behind was installed to provide a durable, more attractive face and to limit any further deterioration of the RCC structure.

LOWER CHASE CREEK DAM – ARIZONA

This RCC dam was constructed in late 1986 on a generally dry creek to provide flood control for a copper mine. The creek drains into a watershed containing active and inactive open pit copper mines and mine waste dumps. Because water from these features is acidic, a Type V (high sulfate resistance) portland cement was used for the conventional concrete face for the RCC dam. No transverse joints were included in the design.

The 20m high dam is unique in that the gravity structure is built on a low modulus non-rock foundation. The site consists of a conglomerate overlaid by alluvium. In order to build a stable structure with less settlement and seepage potential, the design included placing the gravity structure atop an RCC foundation mat that extended through the alluvium and onto the conglomerate. The mat was up to 7.6m deep.

The deformation modulus of the conglomerate foundation was determined to be only 125 MPa. Seepage was not a problem through the usually dry dam.

A major crack occurred in the non-overflow sections at each end of the spillway, which extended across the deepest portion of the valley. In the author's opinion, the cracks were caused by differential settlement of the structure rather than being thermal related. In the central portion of the dam, greater dead load was applied to the conglomerate than by the reduced section adjacent to each abutment.

The design proved an RCC dam of this height could be placed on a low-modulus foundation. However, cracks caused by differential settlements need to be considered, especially for structures that will retain water most of the time.

UPPER STILLWATER DAM – UTAH

The design for Upper Stillwater Dam departed from all previous RCC dams in the US with respect to the RCC mixture proportions and design concept. Whereas the mixes for all seven previous RCC dams might be categorized as lean RCC mixes, Upper Stillwater used a high paste mix. Its predominate RCC mix contained 79kg/m³ of cement and 172kg of Class F fly ash, or a total of 251kg of cementitious materials. Upper Stillwater also had a wetter consistency as evidenced by a Vebe consistency (ASTM C1170) time in the 15-20 second range. The RCC mix with two-inch maximum size aggregate might be termed an 'excess paste' mix. This RCC mixture surpassed the minimum design direct tensile (180 psi) and direct shear (300 psi) properties at the lift lines at one year.

A minimum compressive strength of 3000 psi was desired at one year. After ten years, cores indicated the main interior dam mix had exceeded 6700 psi due mainly to latter age effects of the 70% pozzolan (fly ash) content.

This design concept called for the RCC mass to act as the water barrier with the air-entrained slip-formed facing serving as a form, and also providing durability at this cold site in the Utah mountains where the mean average temperature is 1.7° C. Seepage performance through the high strength RCC mass has been excellent.

The problem has been leakage through cracks through the RCC section. Three cracks contributed to most of the leakage through the dam, the main one is shown in the photograph on the left.

No transverse contraction joints were included in the design. Installation of initially proposed waterstopped joints at 15ft

Water escaping a major crack through Upper Stillwater Dam

Table 1: Early RCC Dams in the US (50ft [15m] minimum height)

Dam (construction period), location	Owner	Max. Dimension Height (m)	Length (m)	RCC Volume (m³)	C+FA (kg/m³)
1. Willow Creek (1982-83), Heppner, Oregon	US Army Corps of Engineers; Walla Walla District	52	543	331,000	52 + 25 Average
2. Winchester (1984) (Now C.E. Ecton), Winchester, Kentucky	Winchester Public Utilities	23	363	24,500	104 + 0
3. Middle Fork (1984), Parachute, Colorado	Exxon Co. US	38	125	42,200	66 + 0
4. Galesville (1985), Azalea, Oregon	Douglas County	50	290	161,000	55 + 51
5. Grindstone Canyon (1986), Ruidoso, New Mexico	Village of Ruidoso	42	432	87,900	80 + 0 Average
6. Monksville (1986), Ringwood, New Jersey	NJ District Water Comm. & Hackensack Water Co.	48	671	219,000	64+ 0
7. Lower Chase Creek (1987), Morenci, Arizona	Phelps Dodge Morenci, Inc. & Sumitomo Metal Mining	20	122	13,800	62 +42
8. Upper Stillwater (1985-87), Duchesne, Utah	US Bureau of Reclamation	90	815	1,125,000	79 + 172

Stillwater Dam is a high-cementitious (or high paste) RCC dam as it contained more than 160 kg C+FA per m³. The lean RCC dams were also constructed using a drier consistency RCC mixture.

Discussion of the relevant features and lessons learned from each dam follows.

WILLOW CREEK DAM – OREGON

RCC for a new dam in the US began in 1982 with construction of this flood control dam just upstream of the Town of Heppner, Oregon.

The 'all RCC dam' containing 331,000m³ was placed in just five months, at an average in place cost of about $25.00 per m³. This proved that an RCC dam could be built faster and at considerably less cost than a comparable concrete gravity or earthfill dam.

Although no transverse joints were included in the long dam, no problems with cracking were reported. However, seepage through the dam raised concerns with the US Army Corps of Engineers (USACE).

Soon after the reservoir was filled in the spring of 1983, seepage in the drainage gallery and at the downstream face was noticeable (see main photograph, left). As with nearly all RCC dams, measured seepage reduced with time. This reduction is seepage is attributed to additional calcification of the RCC mass, silting, and other materi-

using chemical grouting from the dam's upstream face did not produce sufficient reduced seepage. Subsequently, a cement grouting programme reportedly reduced seepage significantly. Further reduction of seepage was measured during the next two years. Still, 15 years after construction, a line of seepage continues to be visible on the downstream face with bushes growing out of the wet loose RCC.

With the joints between the upstream precast concrete panels unsealed, the RCC mass was considered to be the primary water barrier. The initial seepage through the dam was attributed to voids at the lift lines caused by segregation of the three-inch maximum size coarse aggregate of the lean-dry RCC mix during construction.

The main lesson learned from Willow Creek was that a more impermeable upstream face was needed for seepage reduction, and secondly that a reduction in the maximum size aggregate would help reduce segregation of the lean, dry RCC mixture during placement.

WINCHESTER DAM – KENTUCKY (NOW NAMED CARROLL E. ECTON DAM)

The design for this small municipal water supply dam was similar

(4.6m) centers in the slip-formed concrete upstream face was expected to complicate the placing operation and thus increase cost. With slip-formed concrete facing elements, producing a weakened plane is no problem. It is the sealing of the joint that has proved to be expensive.

A finite element thermal analysis predicted cracking, but the analysis determined the cracks would not penetrate the RCC mass by more than 20ft (6m). Then, because the reservoir would be lowered annually, it was thought the cracks could be repaired from the upstream face, if needed. It has been theorized that the major cracks may have been initiated by a horizontal downstream movement in the foundation of 10mm after the reservoir load was applied to the entire structure.

Crack repairs have been accomplished on several occasions by the US Bureau of Reclamation with varying results.

In 2004, a major grouting and crack leakage repair program was initiated. Seven cracks in the dam were chemically grouted with drains installed. In this case, hydrophobic polyurethane grout proved to be more successful than the previously used hydrophillic polyurethane chemical grout. An additional seven cracks only had drains installed to relieve water pressures in the dam.

Three of the wider cracks in the dam received a more positive cutoff. Fourteen foot (4.3m) wide slots with a minimum width of 4½ inches were drilled in the RCC across each major crack. Then a stainless steel 'corrugated' membrane was installed in 20ft (6m) sections from the dam crest that were welded together to provide a continuous water barrier. The area in the slot on either side of the steel membrane was the filled with an asphalt/cement mix. All indications are that this repair programme will provide the long term fix to the cracking problem at Upper Stillwater Dam.

CONCLUSION

The development of the RCC dam in the US in the early 1980s was met with a great deal of optimism and promise. Design engineers and owners became enthused with this new method of building a concrete dam more rapidly and at less cost by using construction techniques previously applied to building embankment dams. Still, the inherent safety of a concrete dam was maintained.

During the first five years of RCC dam development in the US, eight dams greater than 50ft (15m) in height were designed and built. Time and time again, more rapid construction and significantly less cost than a conventional concrete gravity dam were proven. Many features in the design of these dams were positive.

However, in all but one case (Winchester Dam), certain features of the design did not perform as anticipated. The perceived problems included excessive seepage through the RCC mass, leakage through transverse cracks, cracks due to differential settlement, deterioration at the downstream face due to freeze-thaw and wet-dry cycles, and the leaching of calcium hydroxide to form calcium carbonate deposits where it meets the air. In no case did the problem encountered jeopardize the safety of the dam.

Many of these problems required maintenance following completion of the dams. The performance of this first generation of RCC dams in the US was usually well publicized. The designers of future RCC dams owe a great deal of gratitude to the pioneering efforts of these early RCC dam designers. Lessons were learned that would be applied to more recent RCC dam designs.

Because of the noteworthy efforts of these pioneers, designers of RCC dams nowadays can develop a concrete dam that will perform well with little anticipated future maintenance. The cost has, however, risen somewhat for these improved designs.

Lessons learned

The main lessons learned from the design and subsequent performances of these eight first generation RCC dams in the US are:

- RCC dams should have sufficiently watertight upstream faces.
- RCC dams should have induced transverse waterstopped joints, to accommodate thermal induced contraction.
- The maximum size aggregate for lean, dry RCC mixtures should be reduced from 75mm to 38-50mm to help reduce segregation.
- Bedding mortars or excess paste RCC mixtures are needed near the upstream face to: a) Reduce seepage; and b) Increase shear and tensile properties at lift lines.
- Lean, poorly compacted RCC mixtures should not be left exposed in freeze-thaw areas.
- Low and variable foundation conditions need to be properly addressed in the design.

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  - *b) Increase shear and tensile properties at lift lines;*
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- *Low and variable foundation conditions need to be properly addressed in the design*

Part I- General Information concerning the RCC Dams

I.b) Main RCC Dams

The Khlong Tha Dan Dam (Thailand) was completed in 2005.

It is 93m high, 2720m long and 5.500.000 m^3 of concrete.

It is also the largest and longest RCC Dam in the World.

The Longtan Dam (China) was completed in 2009.

It is (192)216,5m high, 741m long and 4.480.000 m^3 of RCC.

.

The Miel – I Dam (Colombia) was completed in 2002.

It is 188m high, 345m long and 1.750.000 m^3 of RCC.

The Miyagase Dam (Japan) was completed in 2001.

It is 155m high, 400m long and 1.600.000 m^3 of RCC.

The Urayama Dam (Japan) was completed in 1999.

It is 156m high, 372m long and 1.600.000 m^3 of RCC

International Milestone RCC Projects

There are number of RCC dams constructed in last three decades around the globe. Eight RCC projects are recognized as International Milestone RCC Projects at the symposium based on the engineering design accomplishment and innovative instrumentation. There names are as follow:

Dam	Country	Aspect
Longtan	China	216,5m; 6.300MW
Miel I	Colombia	188m; 375 MW
Miyagase	Japan	156m
Olivenhain	USA	97,1m
Ralco	Chile	155m; 690 Mw
Rialp	Spain	101m
Salto Caxias	Brazil	67m; 1240 Mw
Wolwedans	South Africa	70m

Some Additional Highlights

Statistical Aspect	Dam and Detail	Country
	Miel I Dam- 190m	Colombia
Largest Volume-	Tha Dan Dam – 4.900.000 m^3	Thailand
Simplest Dam	Beydag Dam-3.000.000 m^3-Just one aggregate	Turkey


23 9:13

Part I- General Information concerning the RCC Dams

I.c) Advantages and Disadvantages about RCC Dams

Conceptual Aspects

Gravity dams built using the RCC construction method, afford economies over conventional concrete through rapid placement techniques.

Construction procedures associated with RCC require particular attention be given in the layout and design to watertightness and seepage control, horizontal and transverse joints, facing elements, and appurtenant structures.

The designer should take advantage of the latitude afforded by RCC construction and use engineering judgment to balance cost reductions and technical requirements related to safety, durability, and long-term performance.

The advantages of RCC in dam construction as compared with traditional-concrete dams include:

• more rapid construction (2,5 to 3 m vertical progress per week can be achieved in large dams - greater rates have been achieved in smaller dams);
• effective use of conventional equipment (trucks, dozers, vibratory rollers, etc.);
• a reduced cost of construction as a consequence of the above;
• thinner layers which lead to increased safety during construction by reducing the differences in levels between placement (a similar concept can be applied to traditional concrete dams using the ELCM (extended layer construction method) that has been used in Japan for smaller dams using similar methods to the RCD dam but using immersion vibrators rather than vibratory rollers – similar methods can be used for the top section of large dams);
• safety is also enhanced by the reduced dependence on formwork;
• reduced impact on the environment as there needs to be no excavation of the abutments for cableways, etc..

Advantages as compared with fill dams include:

• reduced time of construction by placing material at a comparable rate with a very much reduced volume;
• incorporation of the spillway over the dam;
• shorter river diversions (both in terms of length and time) during construction and reduced cofferdam requirements. As the flood risk is decreased, the size of the diversion can be reduced;
• shorter penstocks and conduits and the construction of any intake tower is possible against the dam face rather than being free-standing and is thus less sensitive to earthquake loading;
• as a consequence of the above a comparable cost of construction;
• reduced impact on the environment as less material is required, which in turn leads to a reduction in traffic and a reduction of dust, etc.;
• the dam is capable of passing floods during construction by over-topping without damage;
• the RCC construction season can be longer than that for a fill dam.

Design Focus

✓ Problems related to impermeability have arisen in several dams. Some engineers are in favour of building RCC dams to profit from their advantages but warranting their impermeability with a watertightness system in the upstream face.

✓ Which are the current trends with regard to the specific impermeabilization of the face?

✓ Which systems are the most used to have a minimum influence on costs and construction timing?

✓ Cementitious content used in RCC dams have low cement content. In theory, this must reduce the risk of chemical expansions and/or thermal aspects?

Design Focus

✓ Is it true that these dams present less risks with regard to expansions. On the other hand, the type of addition can trigger possible expansions?

✓ Have expansion phenomena been observed in RCC dams?

✓ Advisability of using “wet” RCC mixtures instead of dry ones for dam construction

✓ Advantages or inconvenient of the use of bedding mixes with high-paste content RCC mixtures

Crack and Temperature control

If the RCC was developed to simplify the concrete constructions:

☛ Which are the reasons to apply a temperature control, eventhought for layer of thin thickness?

☛ Is it not better to request for a maximum temperature in the dam body?

☛ And so on, the Contractor develop its Construction Work Program on basis the layer thickness, placement interval (construction speed), ambient, placement and dam maximum temperatures, and cementitious content?

☛ Since the point of view that the watertightness of the upstream face is very important for the dam, which is best system to be used?

Application on Faced Symmetrical Hardfill Dams (FSHD)

😐 Under what foundation or materials availability conditions will a Hardfill Dam be more advantageous technically or economically than a typical RCC gravity dam?

😐 If the selection of the dam type is based on the rock foundation conditions, which are the geotechnical characteristics of the rock foundation that are required to build a FSHD?.

😐 How are the settlements at the concrete face considered?

😐 Do they always need a PVC membrane to prevent from leakage?

😐 If the selection of the dam type is based on the low cost of the materials, it is necessary to quantify the cost estimates that lead the designers to select the cemented gravel sand and/or hardfill materials instead of the traditional RCC mixes?

😐 Does it seem that the cost reduction of the CGS depends mainly on the availability of on site-generated materials?

😐 Otherwise, the costs of exploitation and processing the materials could be similar to that of aggregates for RCC?

Materials Focus

- Aggregate Gradings
- Application on cemented sand and gravel materials for dams (CGS)
- Cementitious Content - There seems to be a continuing debate on RCC mixes- low or high cementitious content (or lean * high paste mixes). What is a contractor's perspective in working with both types of mixes?
- Is there an optimum fly ash content for RCC mixes depending on the percent fines in the aggregate? also, an optimum content based on the relative cost of cement vs. fly ash?
- Also, I would to explore whether there is a different optimum aggregate gradation band depending on the consistency of the RCC (example low VeBe time vs. high or no VeBe time).
- Rock Flour
- CSG is defined as a material prepared by simple mixing of rock-based raw materials such as muck and riverbed gravel together with cement and water. CSG is being studied with an intention of making full use of site-generated materials. The CSG can be used as an alternative construction material to reduce construction costs. The quality of CSG is affected by various factors including grain size distribution, water content, cement mixing method, and compaction method.

Part I- General Information concerning the RCC Dams

I.d) Comparison and Cost

DAM TYPES AND STRUCTURES

Designated as:

- ☞ Behaviour (Rigid ou Flexible);
- ☞ Material (Earth- Soil; Rock; Concrete; Mortar);
- ☞ Geometry (Axis Linear; Curve-Arched)
- ☞ Construction Methodology (CVC, CCR; CFRD..)
- ☞ etc...

- ✓ Structural Concern
- ✓ “New Fashion” Dam
- ✓ Advantages e disavantages
- ✓ General Lay Out
- ✓ Details

General cost comparisons between RCC gravity structures and earthfill and rockfill structures will be volume dependent and can best be illustrated on a unit cost basis. Figure 4 is a semi-log plot of average dam height versus the volume ratio of an embankment dam to a gravity dam (developed for use in conjunction with Figure 2). This plot (on Figure 4) gives average dam height versus the ratio of earthfill or rockfill embankment dam volume to RCC gravity dam volume per unit length of dam. For example, based on values from Figure 2, at a dam height of 250 feet (76 m.), the required material volumes per unit length of dam for (1) an earthfill dam, (2) a rockfill dam, and (3) a gravity dam of RCC would be 6,643 cu. yd. (5,079 cu. m.), 4,097 cu. yd. (3,132 cu. m.), and 949 cu. yd. (725 cu. m.), respectively. The volume ratio of the earthfill and rockfill embankment dams to the RCC gravity dam would then be 7.0 and 4.3, respectively. This procedure was used to determine the dam height versus volume ratio relationship illustrated in Figure 4 for average dam heights ranging from 50 feet (15 m.) to 500 feet (122 m.).

Figure 4 takes on greater significance when utilized in conjunction with cost ratios developed from material and placement costs for the three major m...

mination of the unit cost
recently bid dam projects a
Figure 5. Because the ceme
tion of the dam design, it
unit costs. These costs re
only. Using Table 1 as a g
fill, and RCC of $3.80, $7.5
and $30.70 per cu. m.), res
result in cost ratios of
RCC to rockfill, respectivel

TYPICAL

MATERIAL

CORE MATERIAL
FILTER AND DRAI
MATERIAL
RIPRAP
RANDOM FILL
ROCKFILL
RCC
SLIP FORMED FAC

*To convert cost t

On the basis of these
determination of appropriat
can be made as to whether

COST COMPARISONS

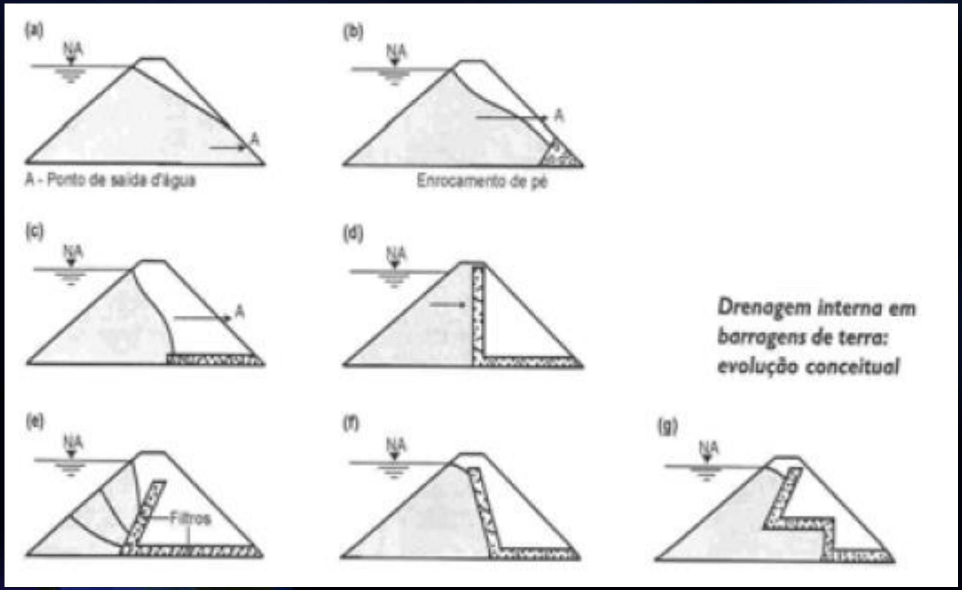
between RCC gravity dam structures and
ss concrete dams indicates the use of
ntional earthwork placement techniques
costs per unit of concrete. This is
h shows basic cost relationships from
ss concrete gravity dam projects (ex-
ly bid RCC gravity dam projects. Only
al are approached, does the economic
less significant. For placements of
yd. (1.5 million cu. m.) or less, a
dvantage of about 1:2 is realized with
nstructed mass concrete gravity dams.

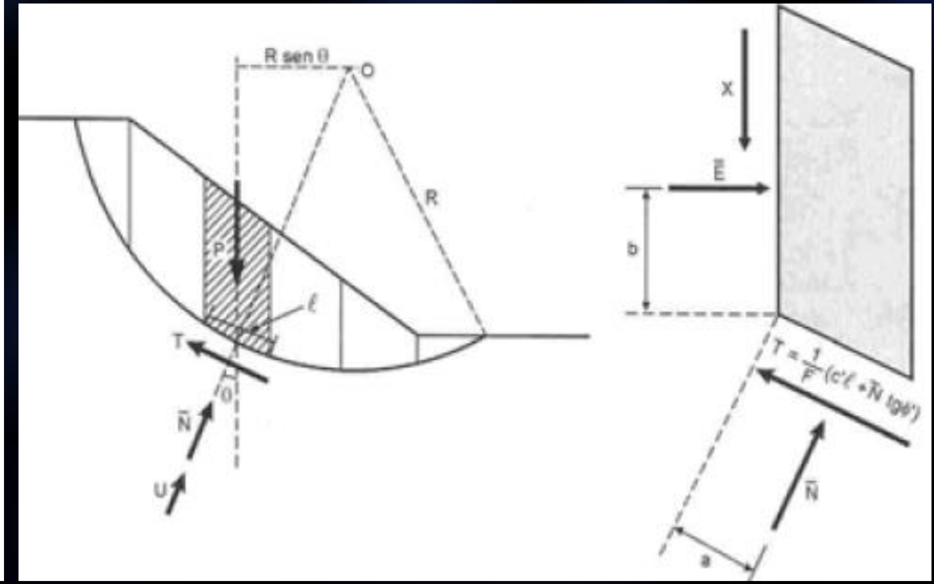
construction is available for a selected structure. It is assumed that in an economic assessment the point at which material and placement costs for an earthfill or rockfill dam equal those of an RCC gravity dam, the volume ratio of the embankment dam to the RCC gravity dam will be equal to the dams' cost ratio. Thus, the volume ratio to cost ratio will equal one. To apply this premise using the average unit costs previously cited for earthfill dams is entered from the left of Figure 4 at a cost ratio of 6.2 at which point a line is drawn horizontally to intersect the earthfill volume ratio curve of the earthfill dam. This intersection corresponds to a dam height of approximately 115 feet (35 m.) indicating that for the cited unit price costs of materials and placement, an RCC gravity dam could provide economic advantage over earthfill embankment alternatives in structures over 115 feet (35 m.) in height. Similarly, the height at which this would occur for a rockfill embankment structure would be approximately 30 feet (9 m.). It must be realized that this analysis relates only to dam construction costs (material and placement) based on average dam height and does not consider the foundation preparation costs or the important appurtenant structures such as spillway, outlet tower, etc. Even under such restrictions however, these relationships can be useful as preliminary evaluation tools. The possible economic advantages related to appurtenant structures for RCC gravity dams have been previously discussed in this paper.

Usual... in the practices

Earth Fill Dam

☞ It is the most traditional material
☞ Impermeability it is done by the compacted clay
☞ Transversal Section can be optimized based in percolation studies (slopes from 1V: 2,2 to 2,5H





Usual ...in practices

Earth Fill Dam

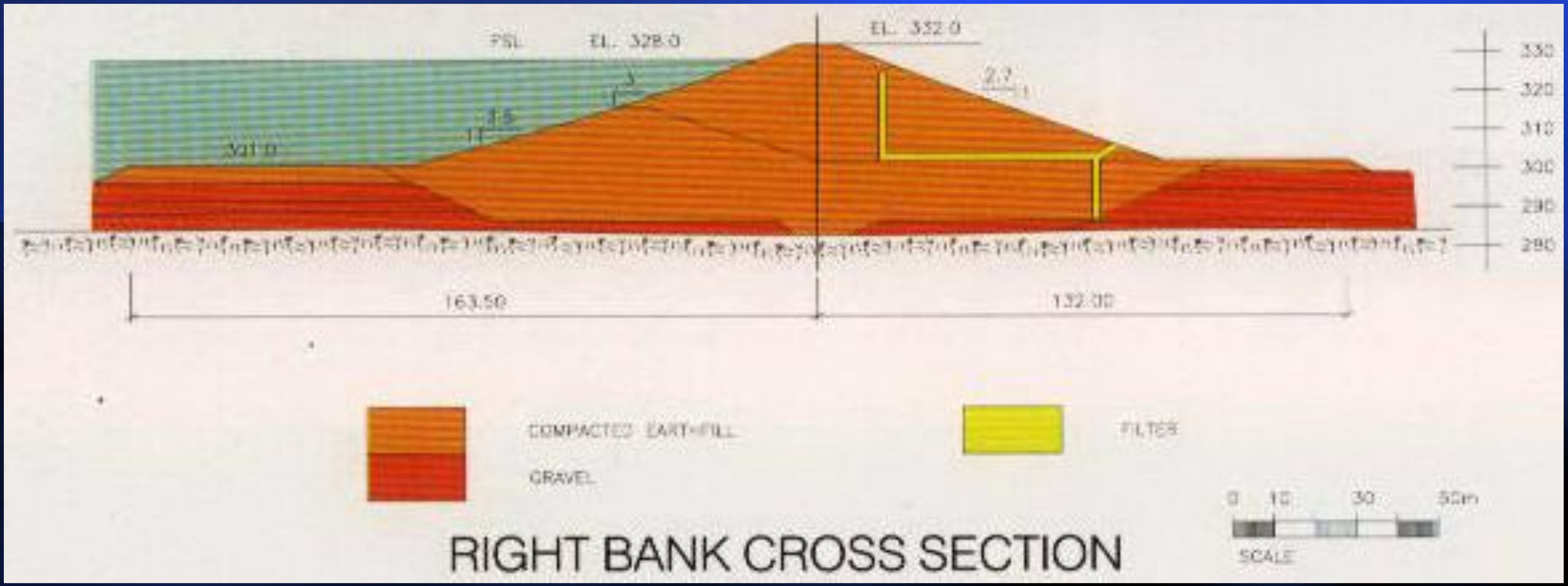
✓ There are build with fine and coarse grain soils and low permeability;

✓ There are constructed by compaction, and can be :

- ➢ Homogeneous (with claily soil less permeable)
- ➢ Zoned (with an impermeable core and 2 zones less imprmeables, with coarser material to avoid some sliding)

✓ Due to the large base area the body apply low loads to the foundation;

✓ Due to this can be constructed on quite poor foundation


FSL
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EL. 332.0
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3
3.5
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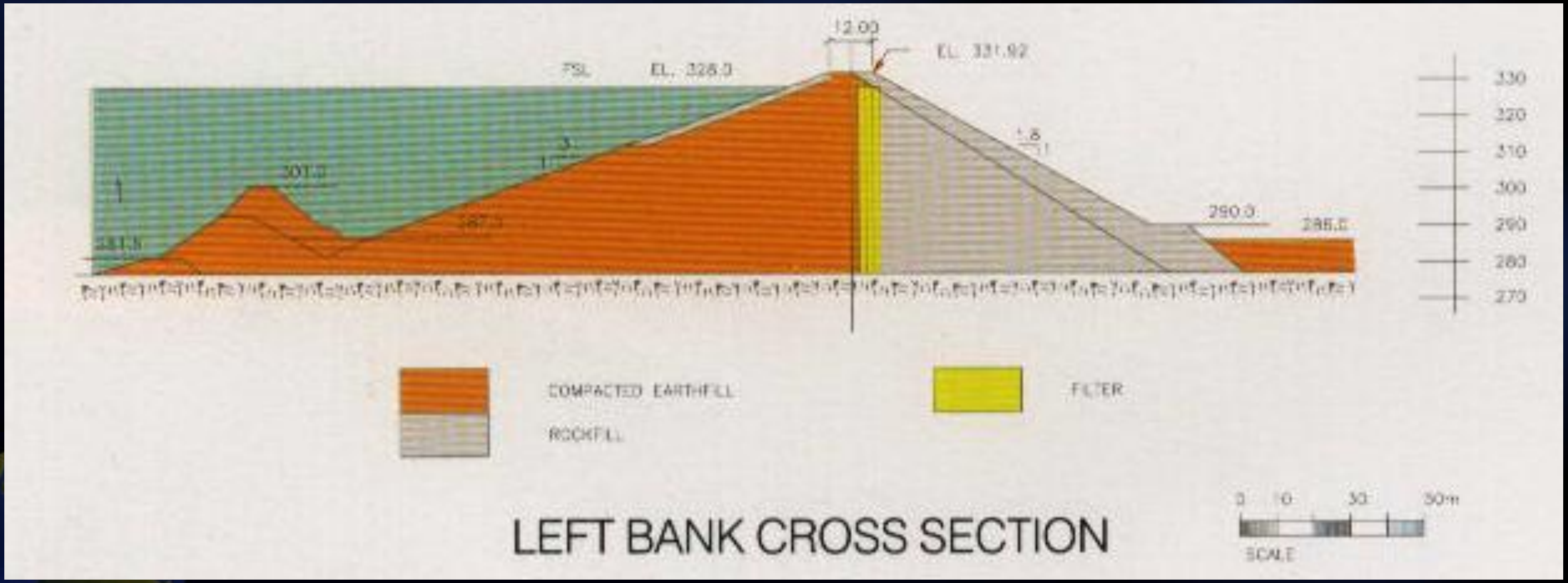
COMPACTED EARTHFILL
GRAVEL
FILTER
0 10 30 50m
SCALE
RIGHT BANK CROSS SECTION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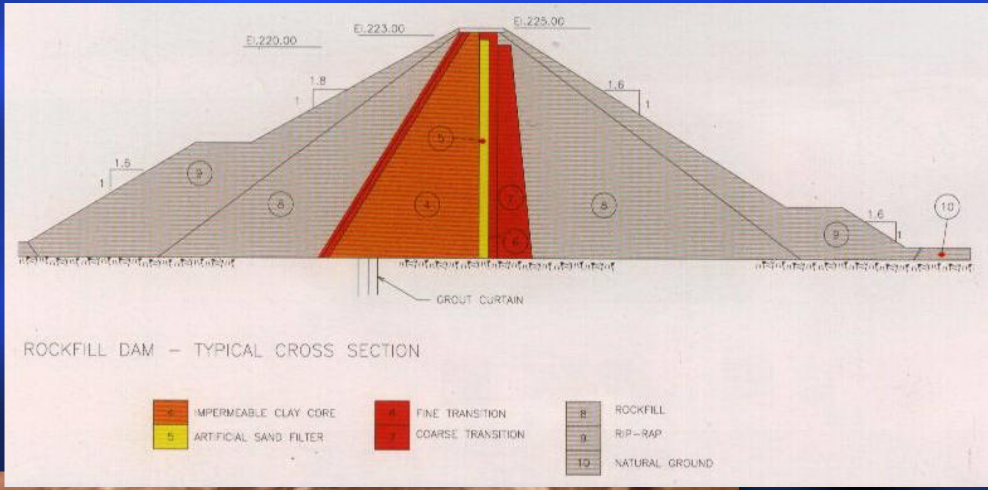
COMPACTED EARTHFILL
ROCKFILL
FILTER
0 10 30 50m
SCALE
LEFT BANK CROSS SECTION

Rock Fill Dams

- ✓ Are construted with rock blocks or gravel;
- ✓ Are costructed by compaction and with na impermeable element and a drainage system;
- ✓ There are less dependent of the rainy seasons than Earth Fill Dams;
- ✓ Due to the large base area the body apply low loads to the foundation;

- ✓ Impermeable System for the Dam Body:
  - ✓ Clay or
  - ✓ Betume
- ✓ Impermeable System for the Dam Face:
  - ✓ Concrete (EFC) ;
  - ✓ Asphalt Membrane ou
  - ✓ Sintetic Membrane (PVC)

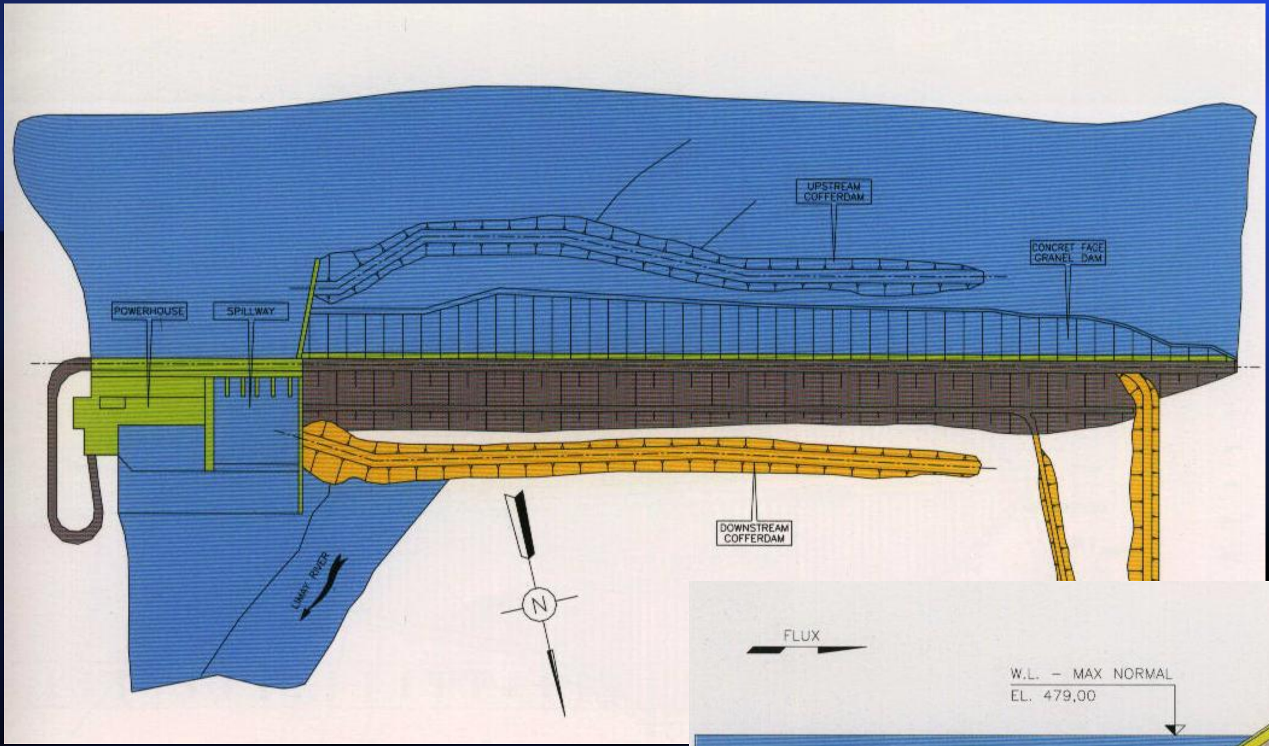


RCC : Up

Andriolo Ito Engenharia


DAEWOO

Xingo Hydro and Dam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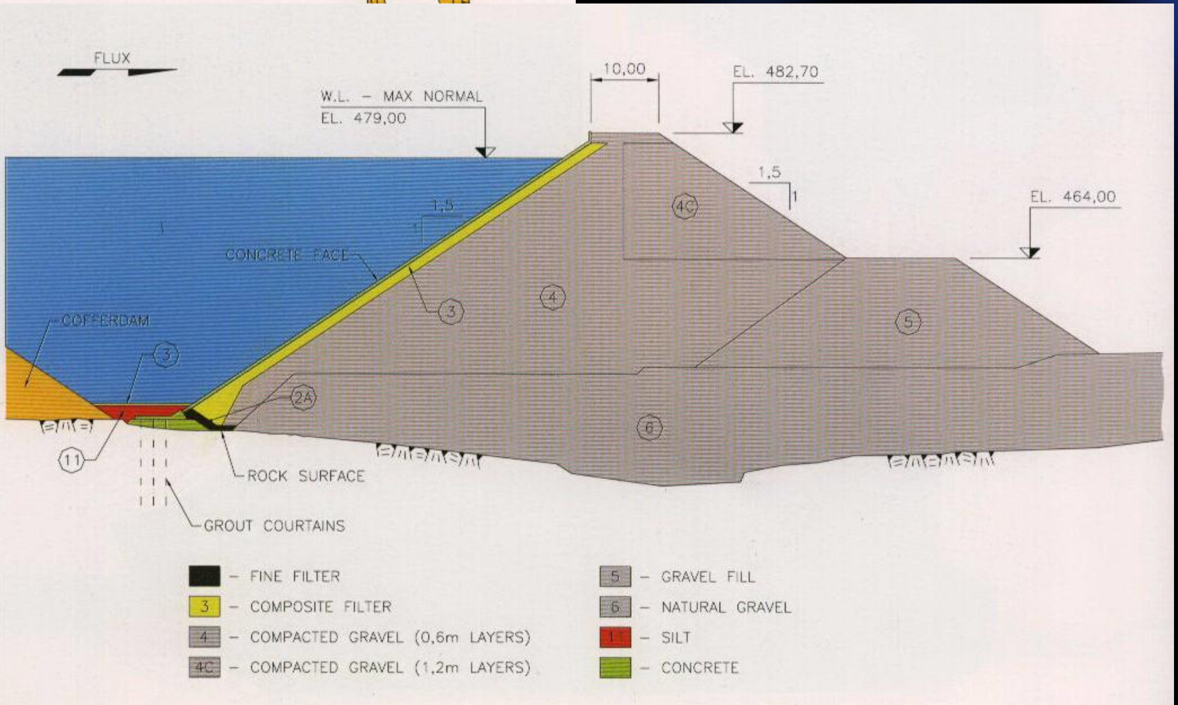
CONCRET FACE GRAVEL DAM
POWERHOUSE
SPILLWAY
DOWNSTREAM COFFERDAM
LIMAY RIVER
N


FLUX
10,00
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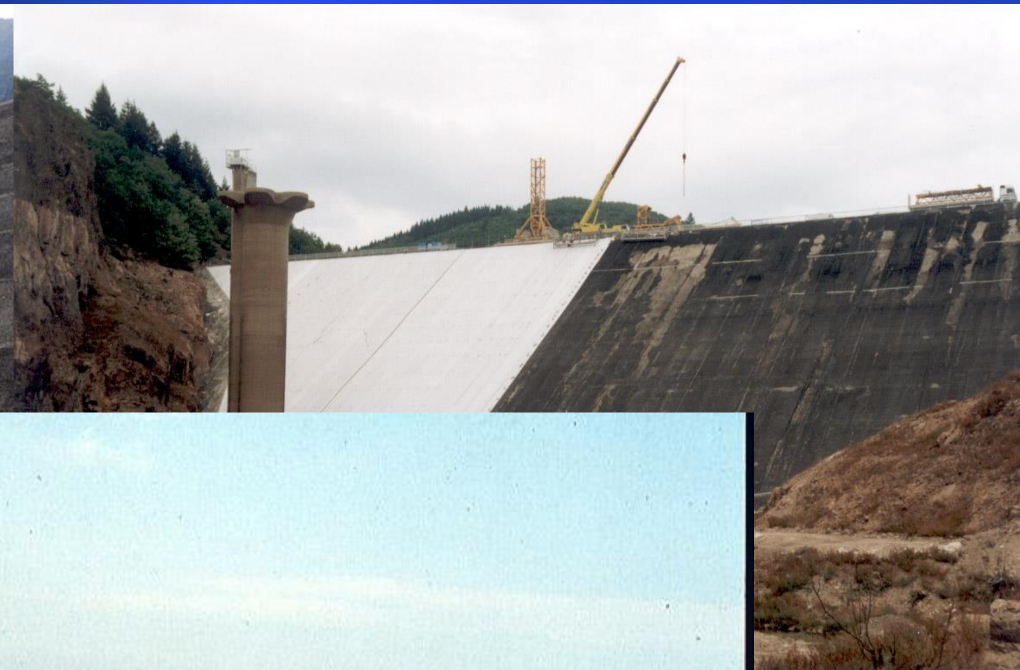
W.L. – MAX NORMAL
EL. 479,00
1,5
1
EL. 464,00
CONCRETE FACE
COFFERDAM
ROCK SURFACE
GROUT COURTAINS
– FINE FILTER
3 – COMPOSITE FILTER
4 – COMPACTED GRAVEL (0,6m LAYERS)
4C – COMPACTED GRAVEL (1,2m LAYERS)
5 – GRAVEL FILL
6 – NATURAL GRAVEL
11 – SILT
– CONCRETE



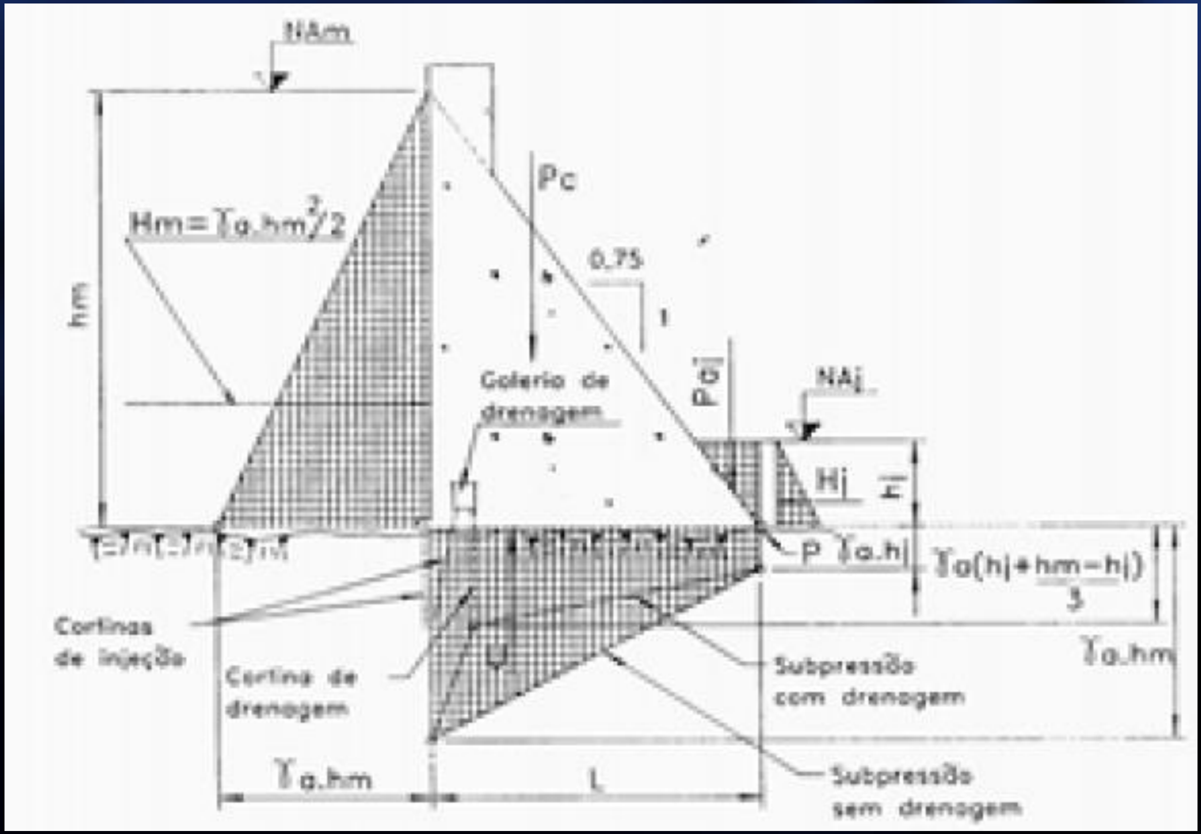
RCC

Andriolo Ito Engenharia

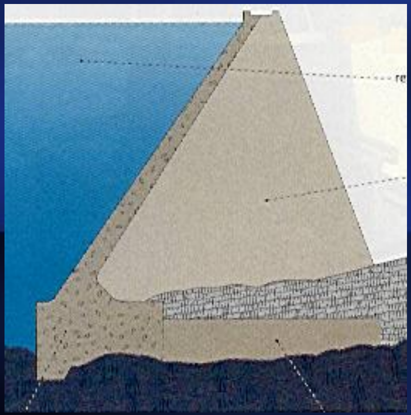
Concrete Dams

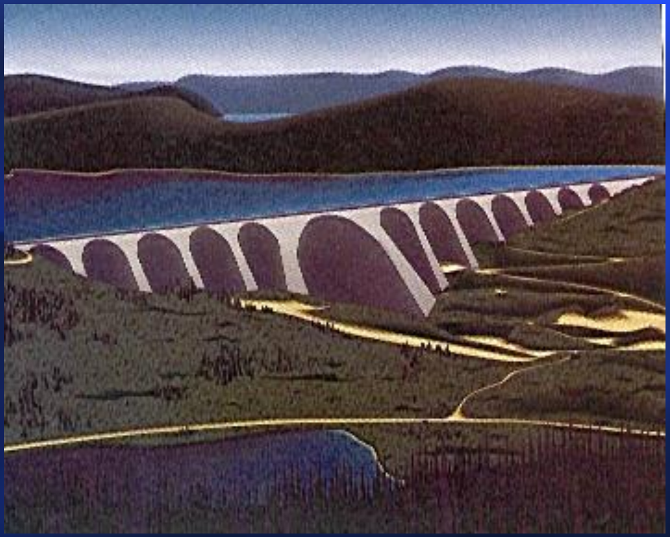
- Gravity Dam;
- Butress Dam;
- Hollow Gravity; and
- Arch (cylindical or Double)Dam

The Stability (Sliding and Turning) is provided by the Dead Load induced by the Adopted Section, for the Geomechanical condition of the available Foundation



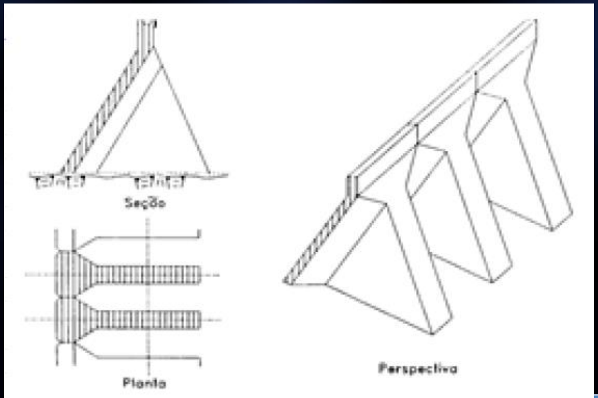
Contrete "Gravity" Dam





Concrete Butress Dam

- ✓ The under-pression it is reduced;
- ✓ The concrete volume is reduced;
- ✓ The load on the Foundation it is increased;
- ✓ Due to this the Foundation need be better



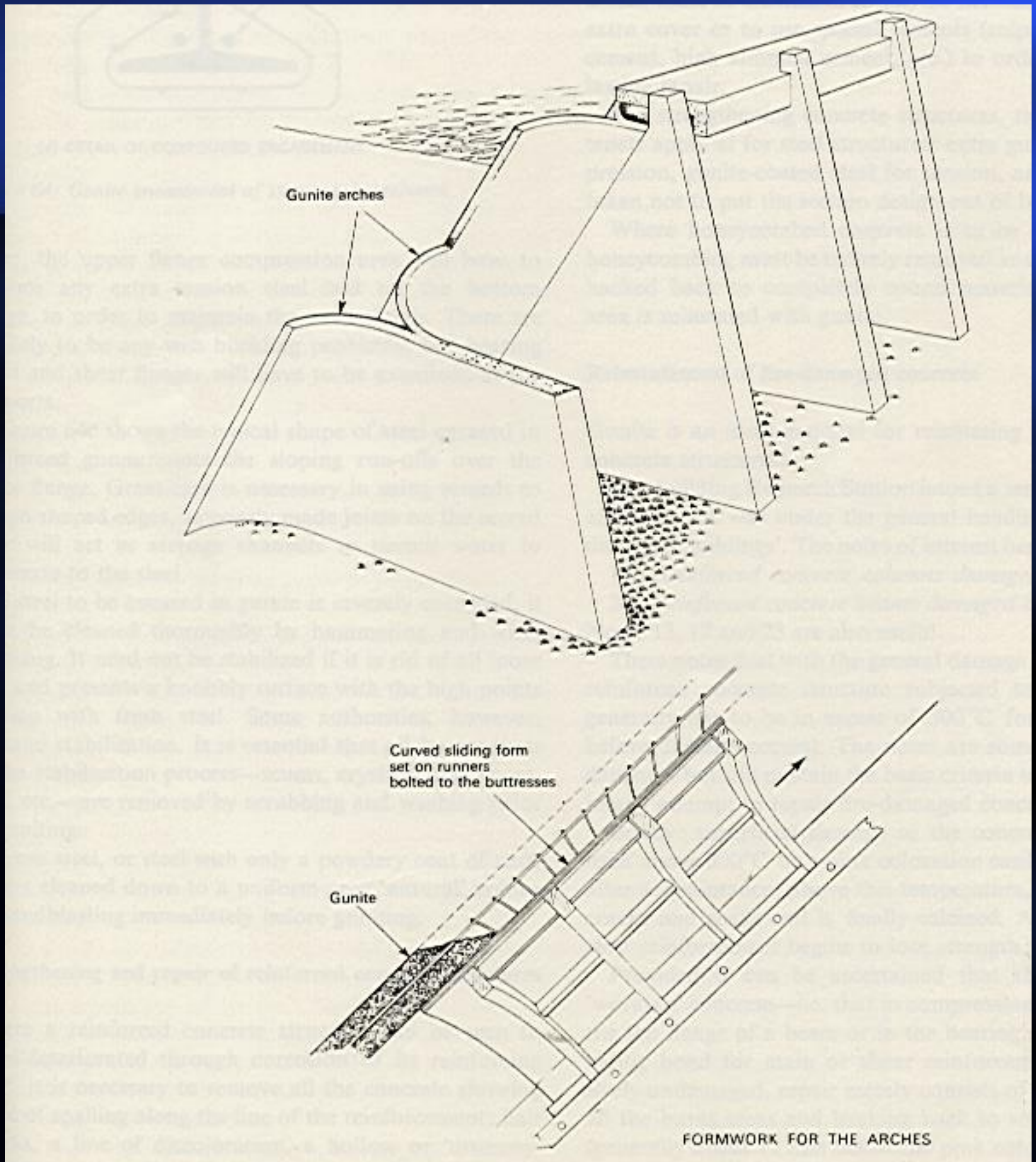


Figure 63: Rabodanges Dam, France. (See Figure 1.)

Hollow Gravity Dam

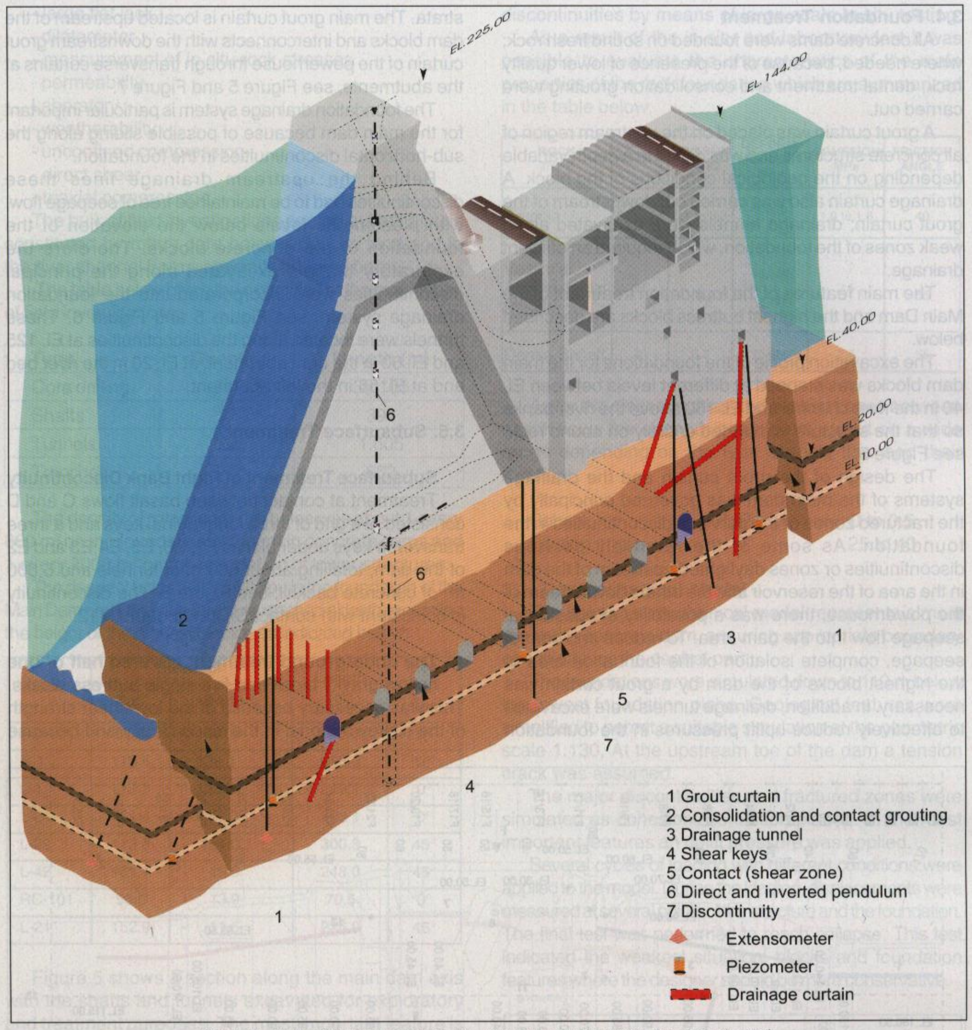


Figure 7 - Foundation treatment of main dam and powerhouse in the river channel

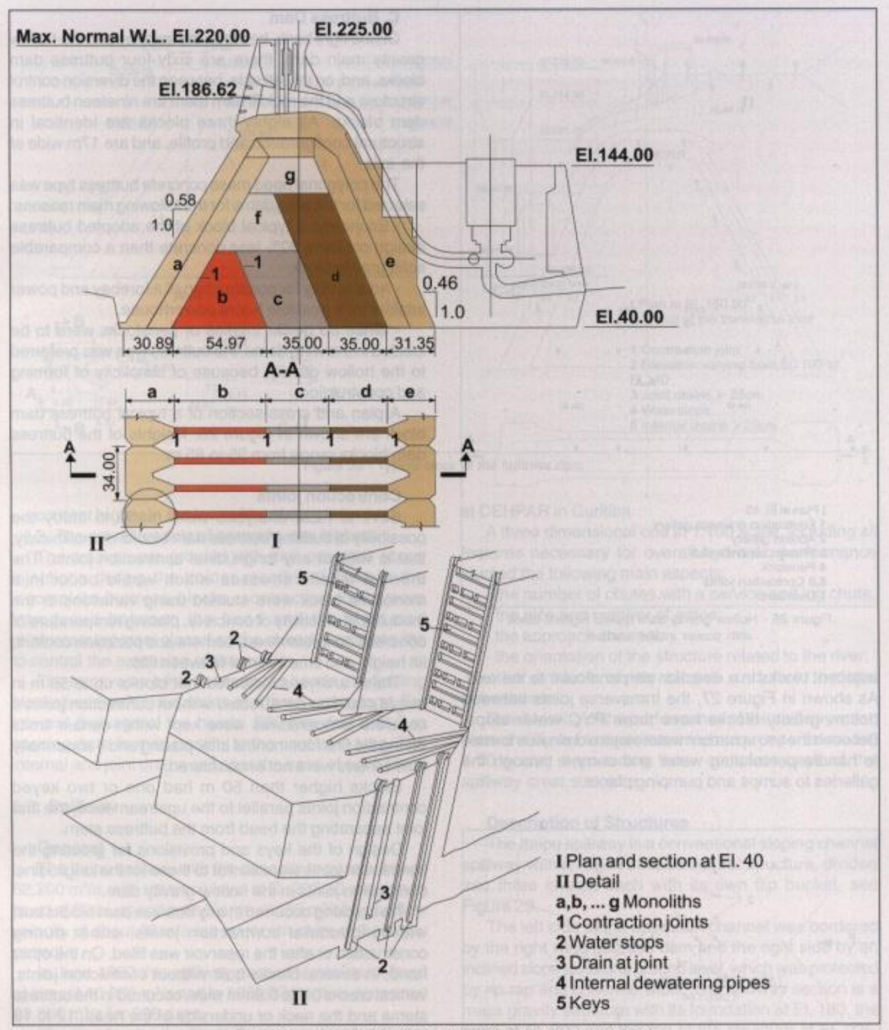


Figure 25 - Hollow gravity dam-details of typical hollow gravity block

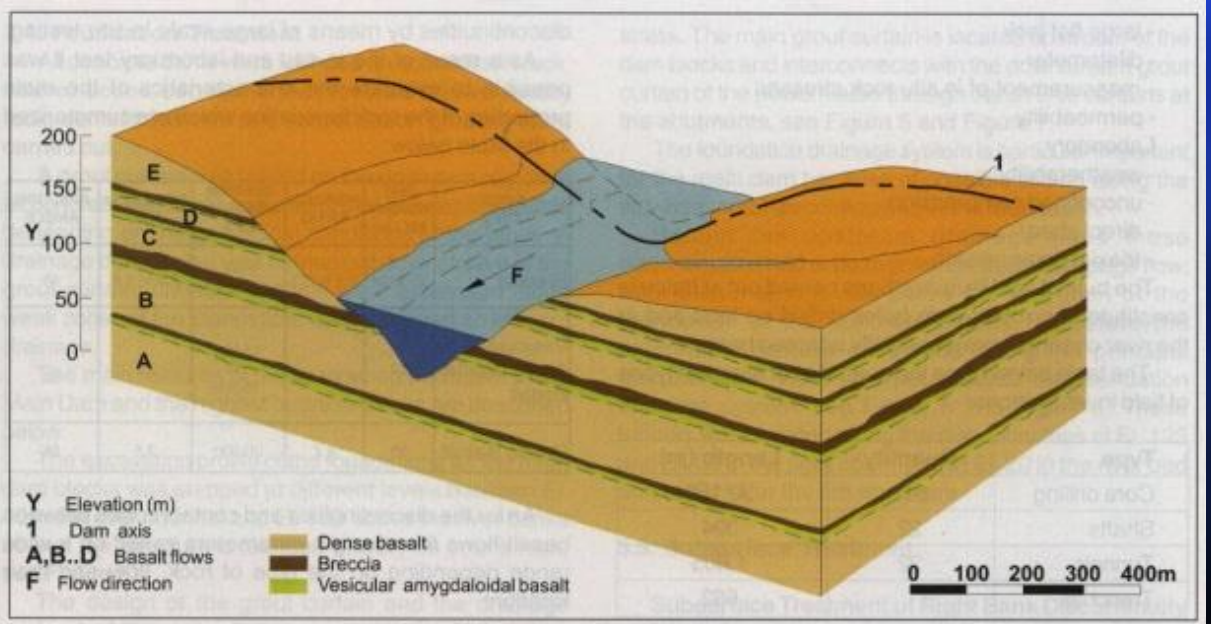


Figure 4 - Typical geologic section al Itaipu site

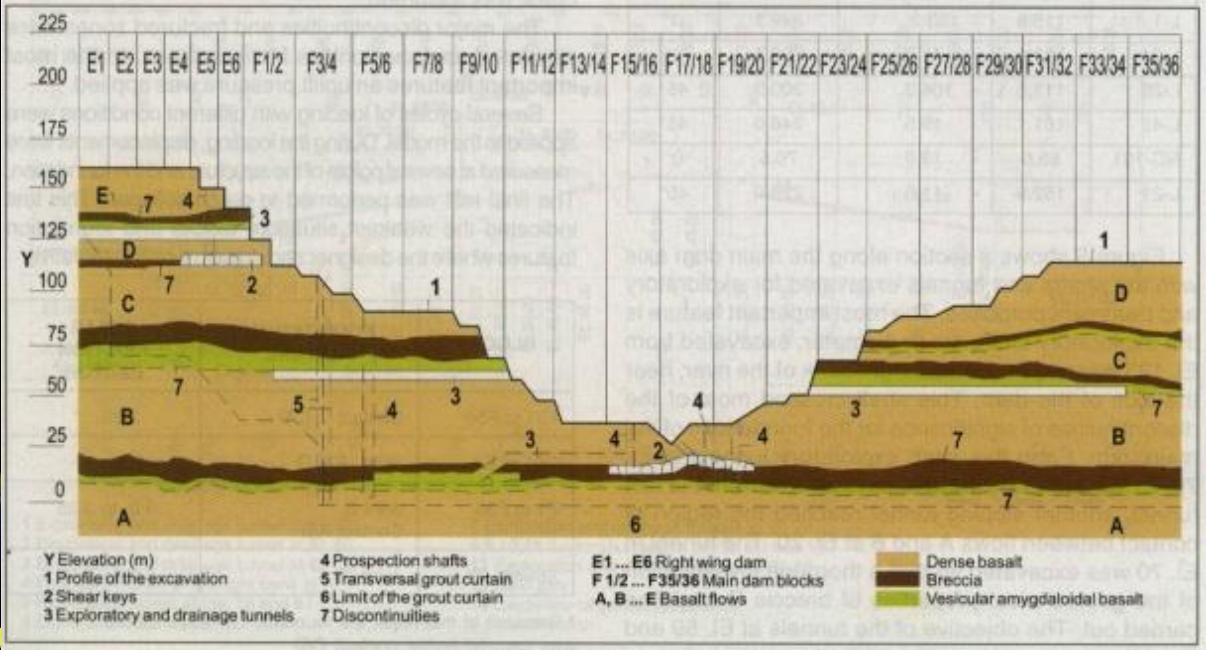
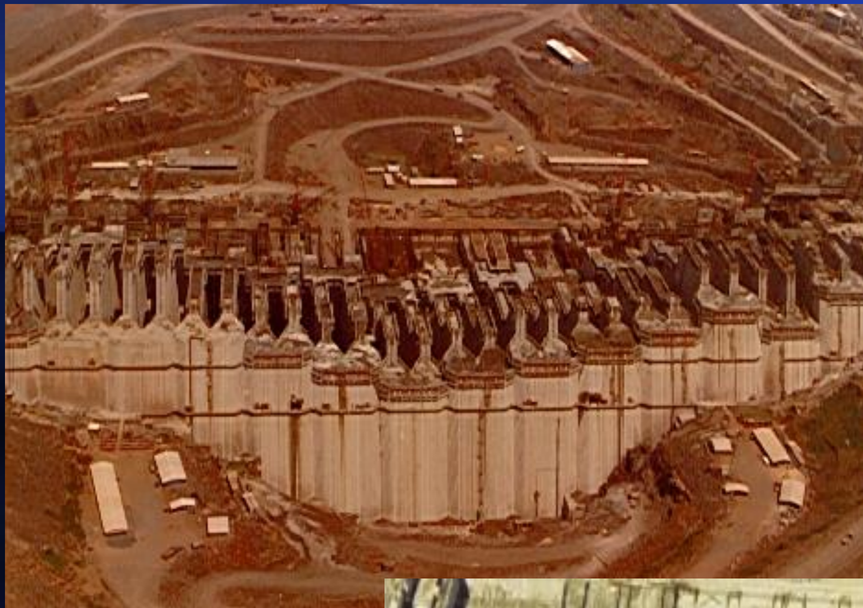


Figure 5 - Main dam geological foundation - Longitudinal section

RCC :

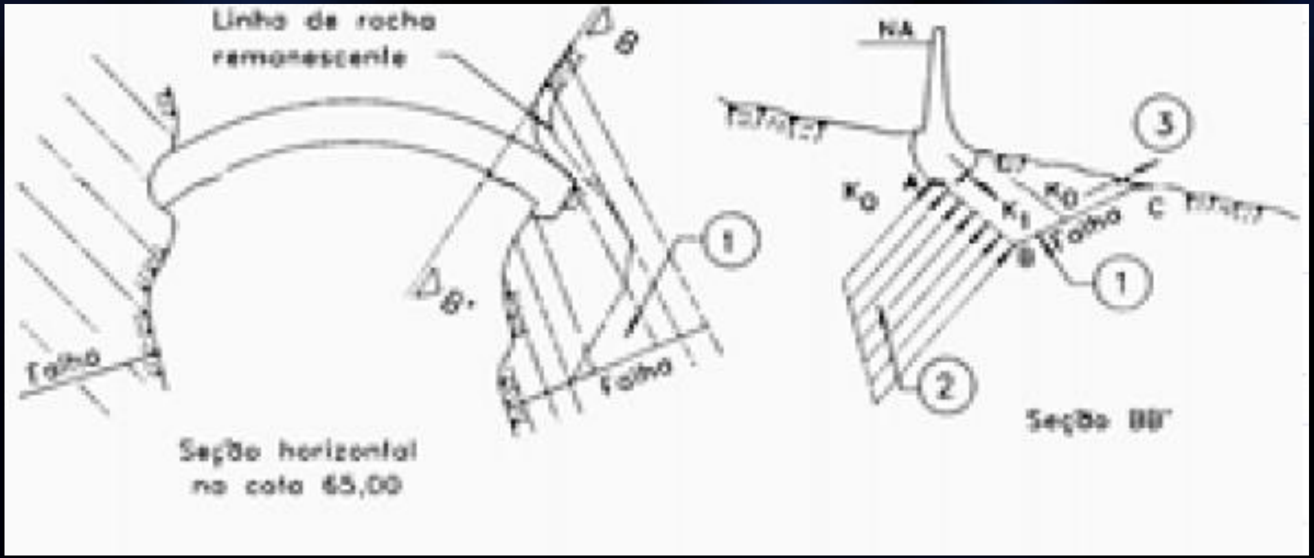
Andriolo Ito Engenharia



Arch Dams

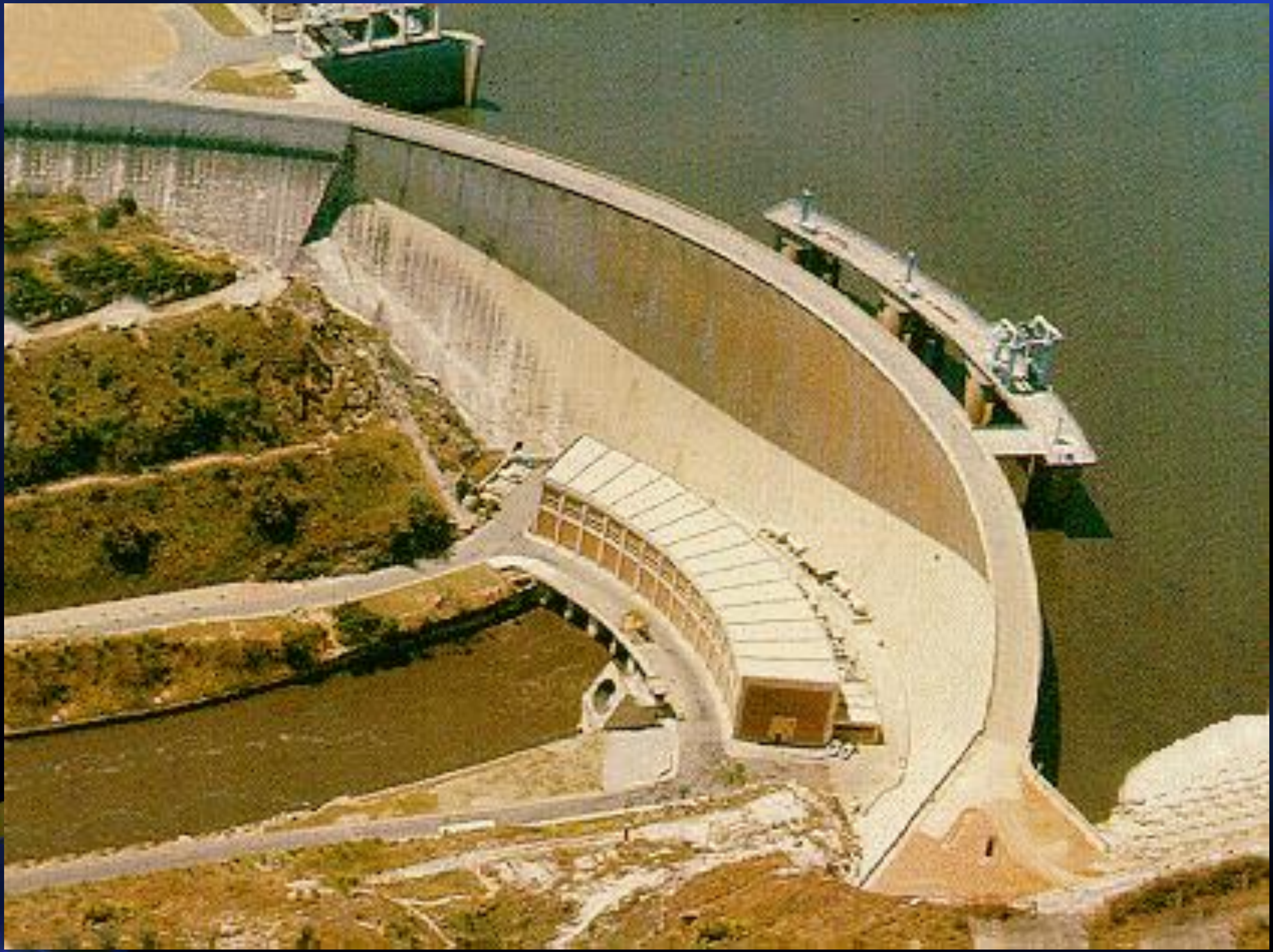
- ✓ Cylindrical Gravity
- ✓ Double Arch

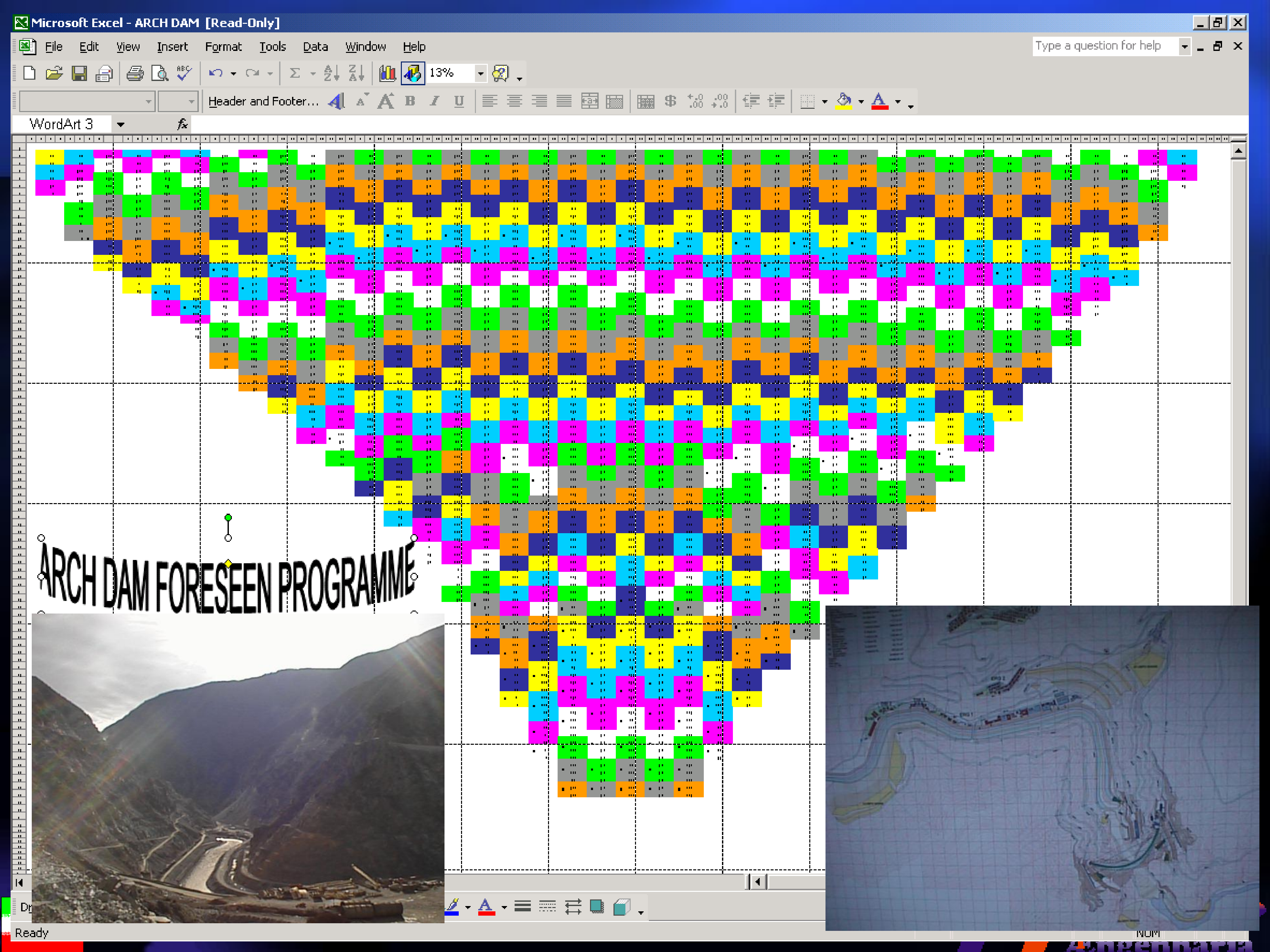
- Mobilize the loads against the abutments;
- Requires a “good” Foundation;
- Reduces the Concrete Volume,
- Requires “Reach” Concretes

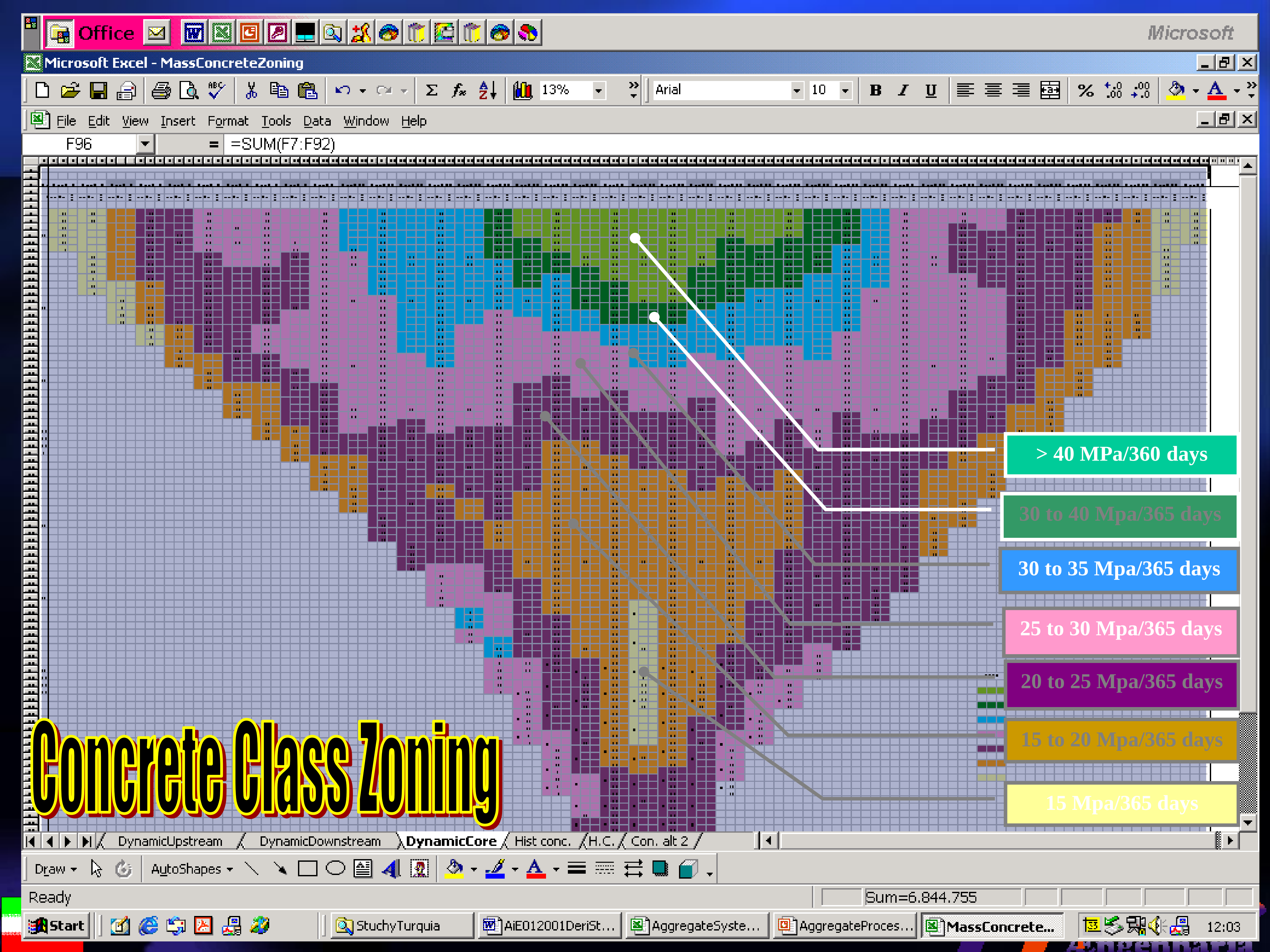


Cylindrical – “Gravity”Arch

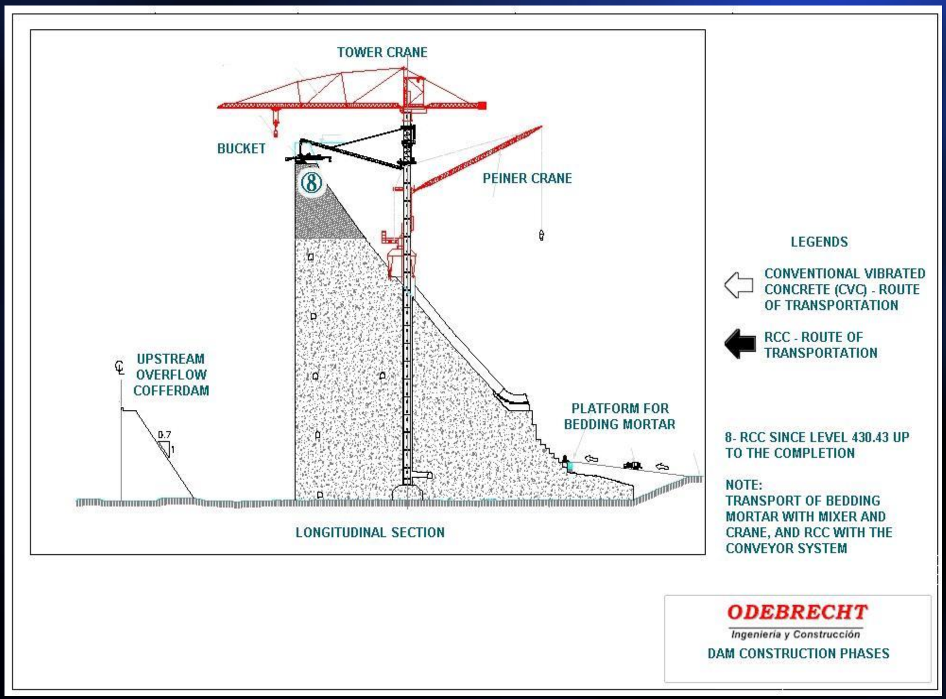
Double Arch




Microsoft Excel - ARCH DAM [Read-Only]
File Edit View Insert Format Tools Data Window Help
Type a question for help
13%
Header and Footer...
WordArt 3
ARCH DAM FORESEEN PROGRAMME
Ready
NUM

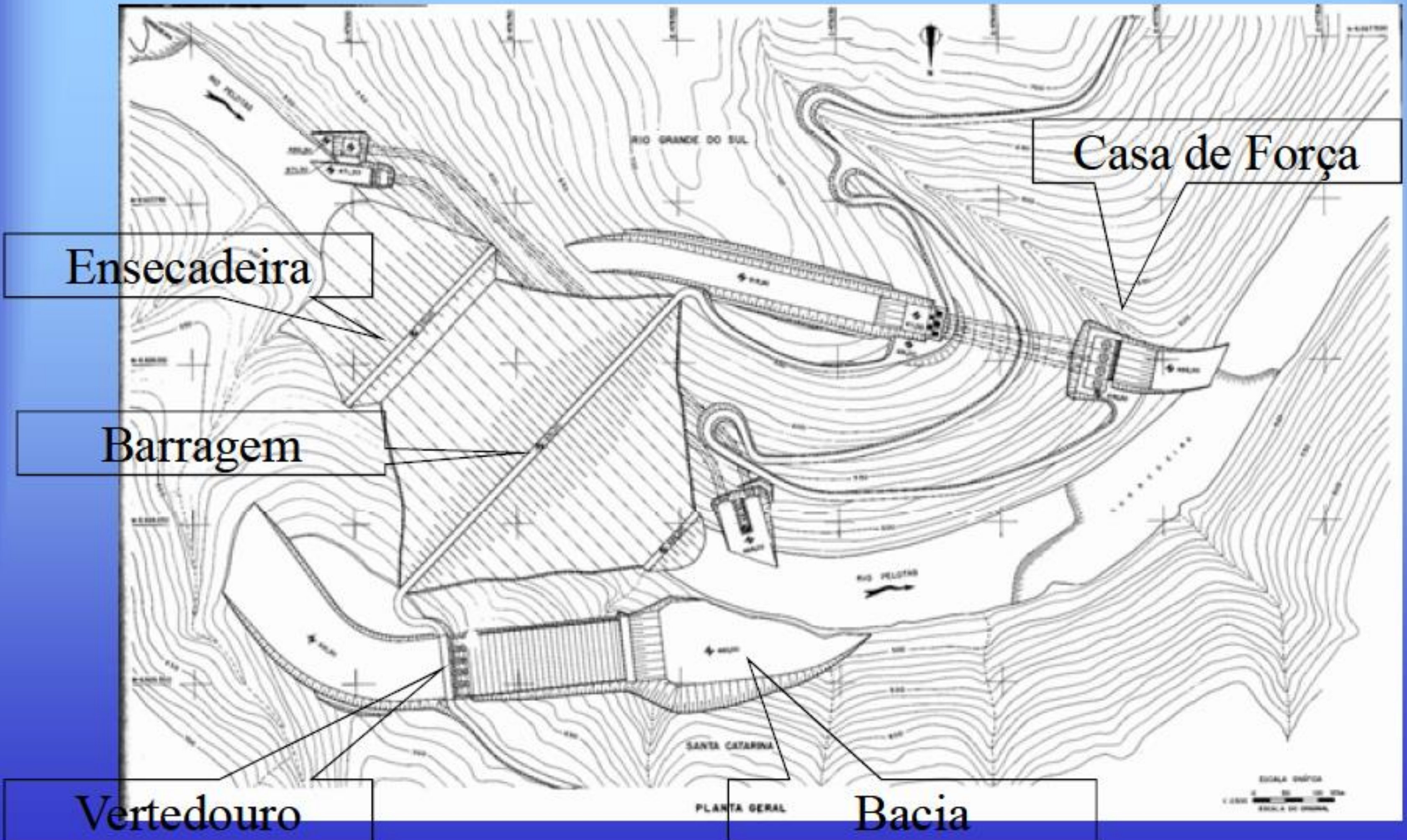

Microsoft Excel - MassConcreteZoning
F96
=SUM(F7:F92)
> 40 MPa/360 days
30 to 40 Mpa/365 days
30 to 35 Mpa/365 days
25 to 30 Mpa/365 days
20 to 25 Mpa/365 days
15 to 20 Mpa/365 days
15 Mpa/365 days
Concrete Class Zoning
DynamicUpstream
DynamicDownstream
DynamicCore
Hist conc.
H.C.
Con. alt 2
Ready
Sum=6.844.755

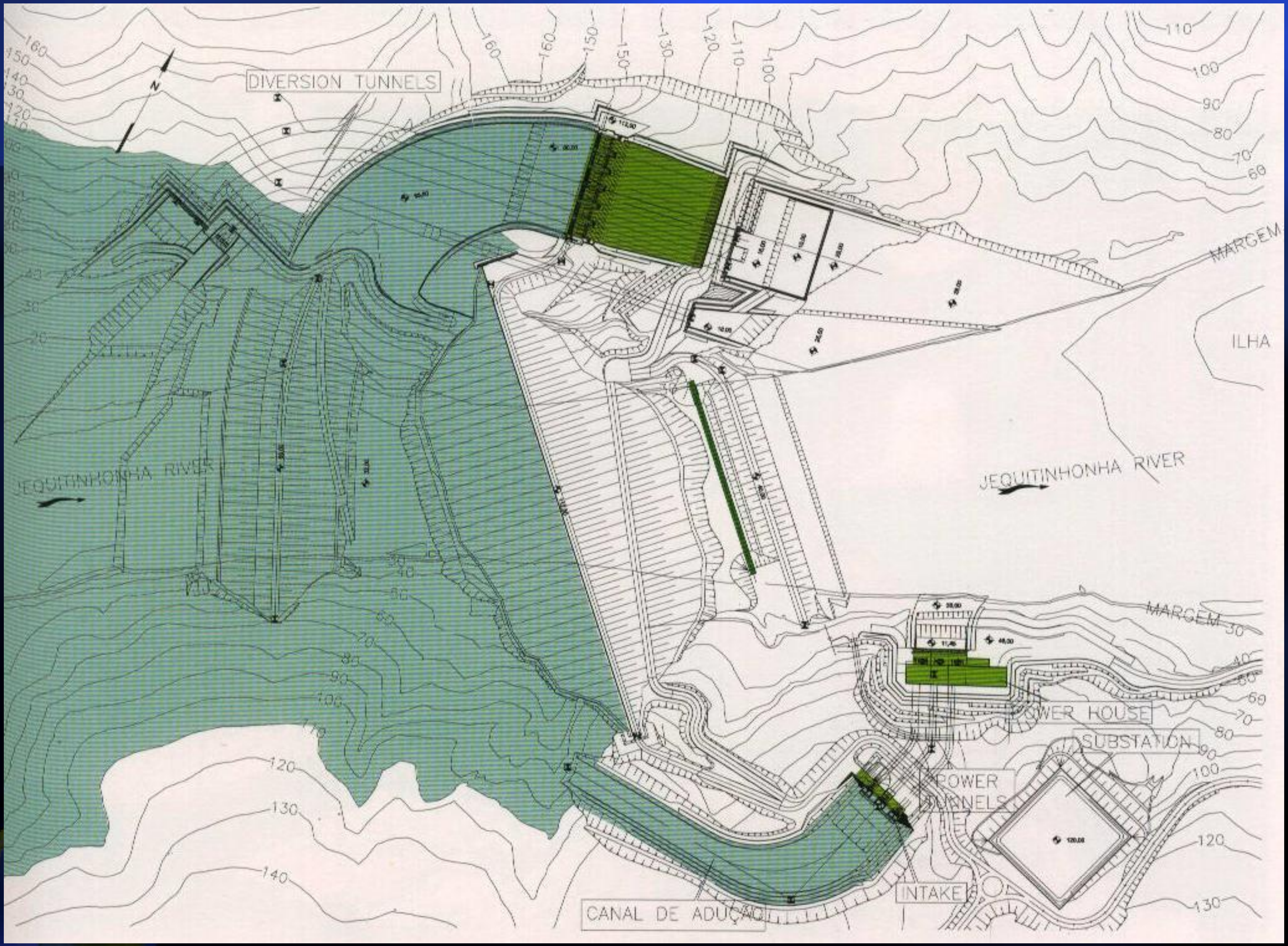
RCC Dams ("Rolcrete"; Concreto Rolado; RCC; RCD; CCR; Alta Pasta, Média Pasta, "Pobre"; GE-RCC; etc...)



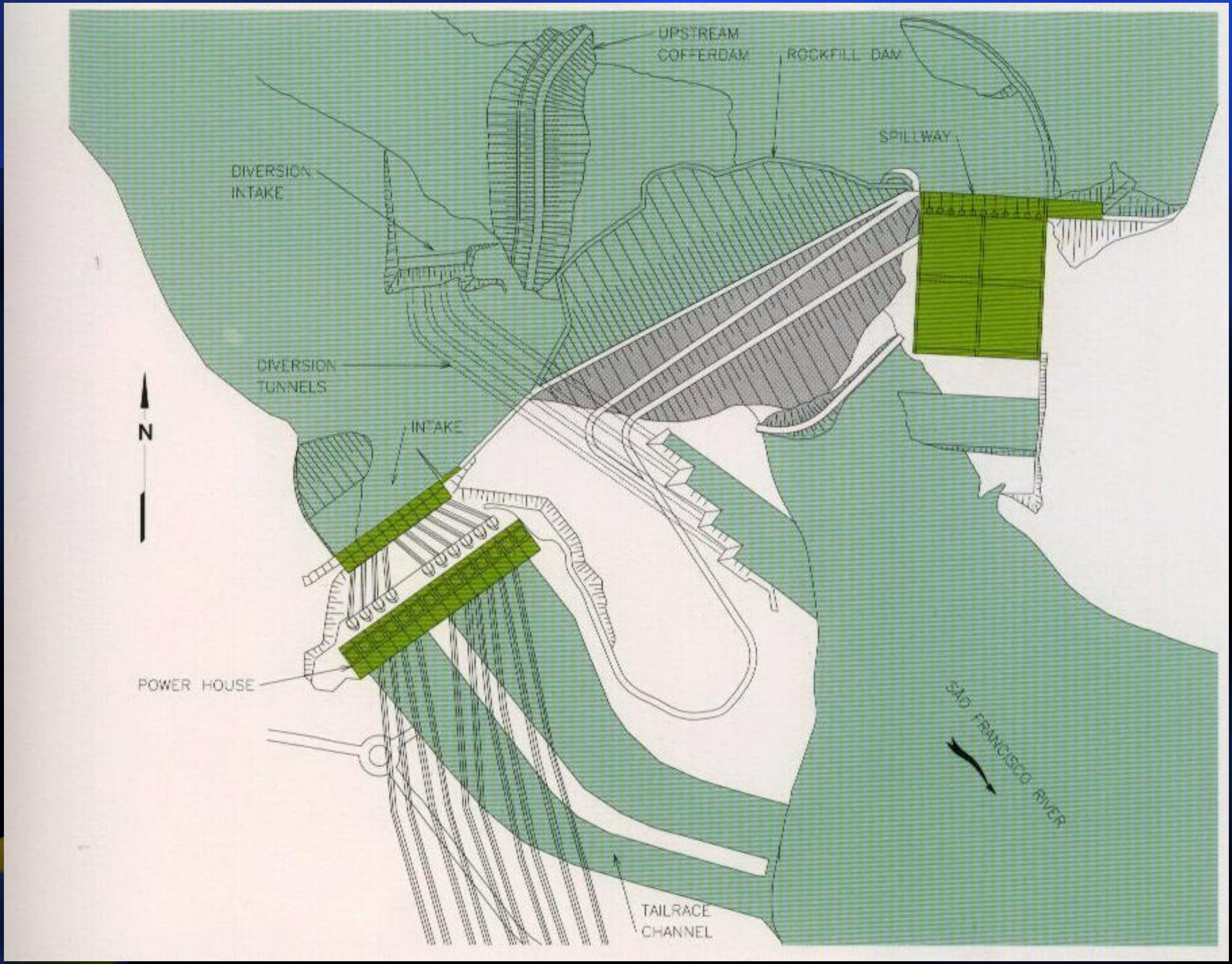
Lay Out

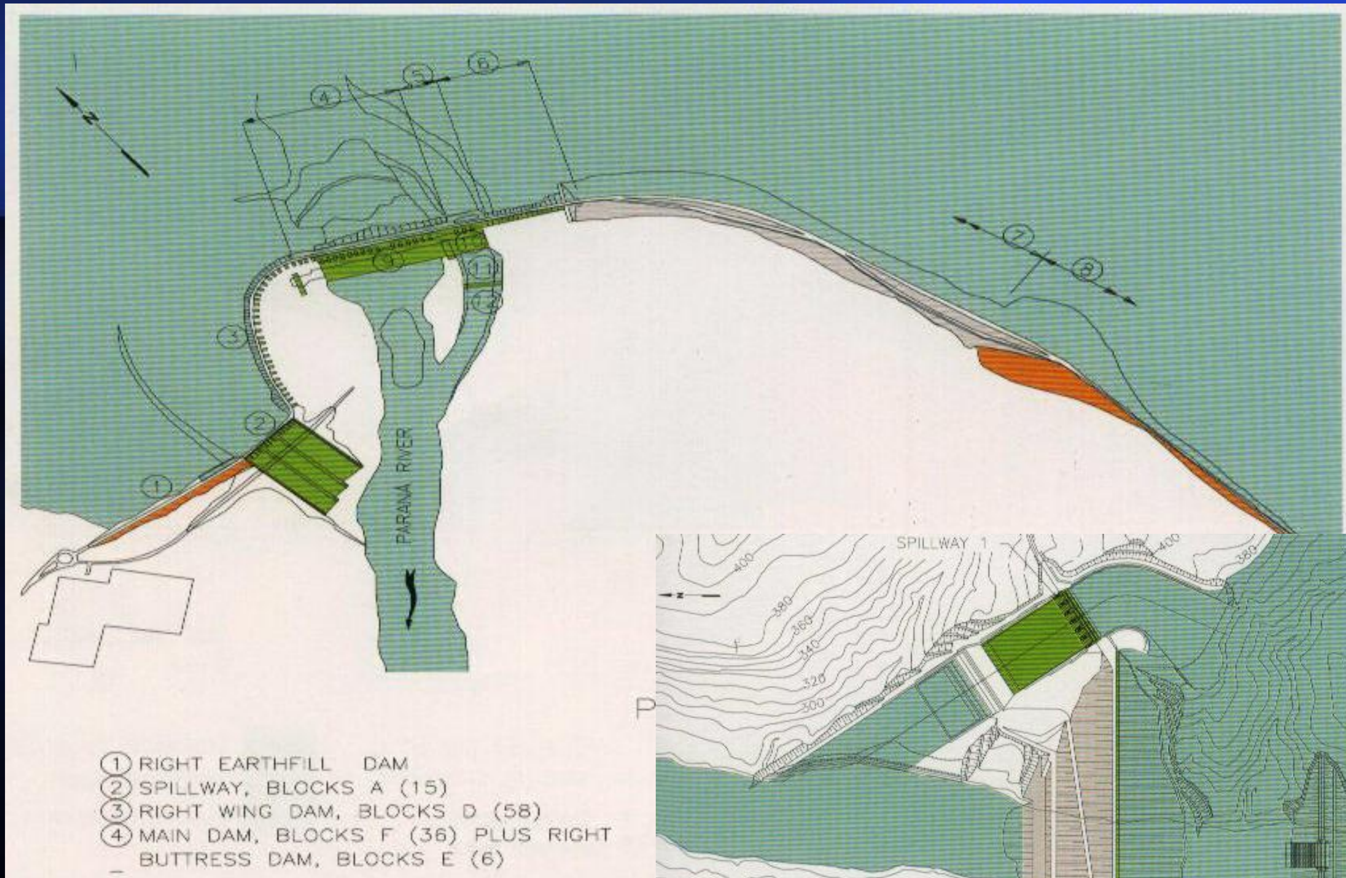
Arranjo Geral e Órgãos

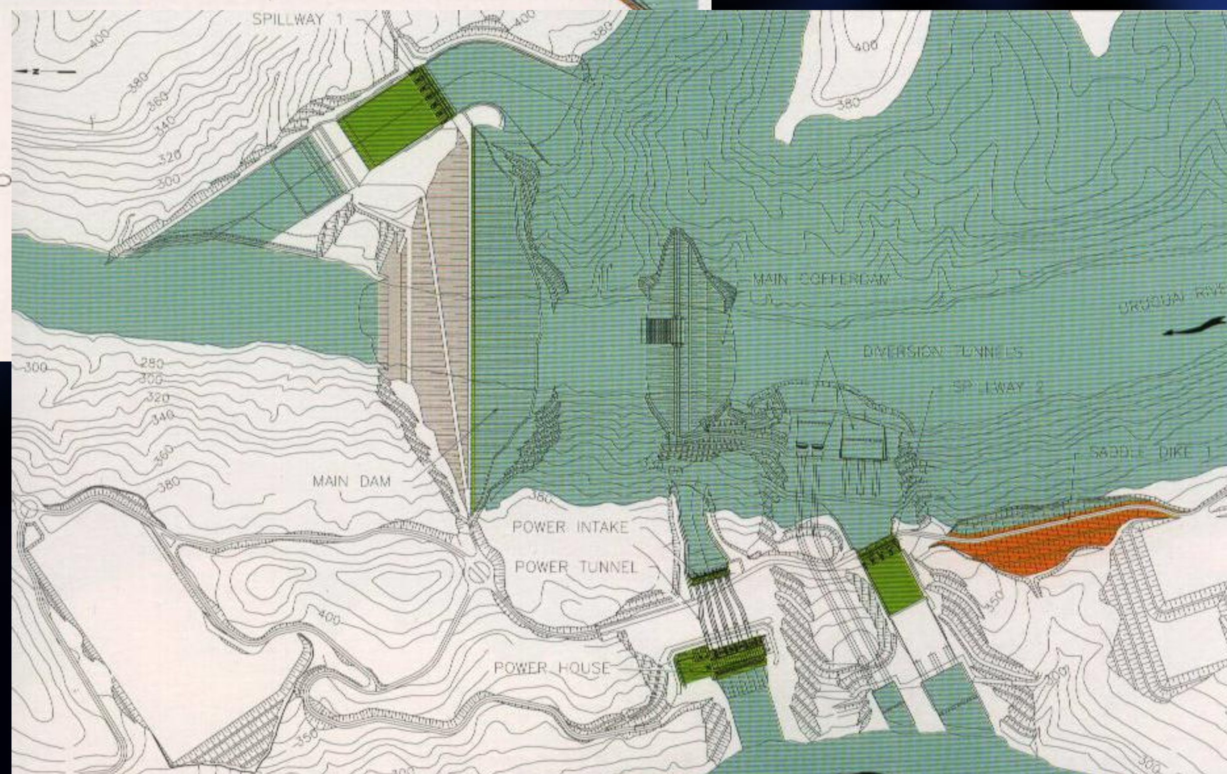




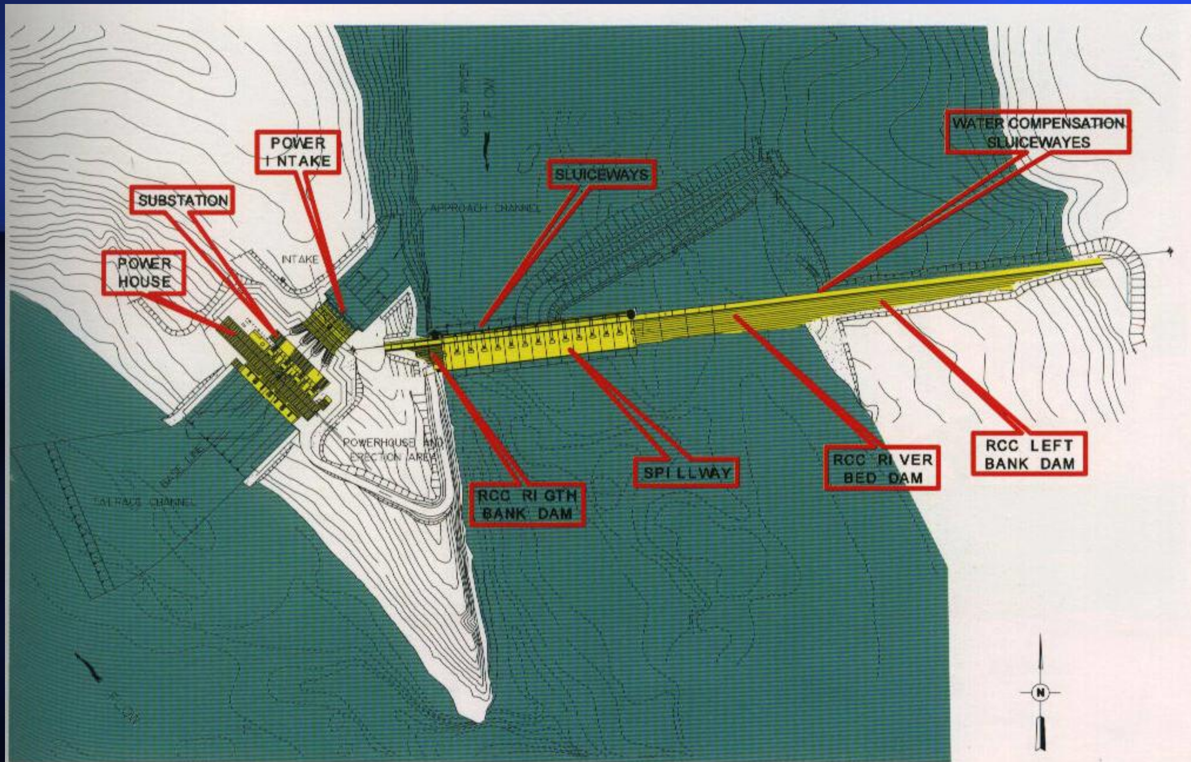
DIVERSION TUNNELS
MARGEM
ILHA
JEQUITINHONHA RIVER
JEQUITINHONHA RIVER
MARGEM
POWER HOUSE
SUBSTATION
POWER TUNNELS
INTAKE
CANAL DE ADUÇÃO


UPSTREAM
COFFERDAM
ROCKFILL DAM
SPILLWAY
DIVERSION
INTAKE
DIVERSION
TUNNELS
INTAKE
N
POWER HOUSE
SÃO FRANCISCO RIVER
TAILRACE
CHANNEL


PARANA RIVER
① RIGHT EARTHFILL DAM
② SPILLWAY, BLOCKS A (15)
③ RIGHT WING DAM, BLOCKS D (58)
④ MAIN DAM, BLOCKS F (36) PLUS RIGHT BUTTRESS DAM, BLOCKS E (6)


SPILLWAY 1
MAIN COFFERDAM
DIVERSION TUNNELS
MAIN DAM
POWER INTAKE
POWER TUNNEL
POWER HOUSE

1. DIVERSION TUNNELS
2. WATER INTAKE TOWER
3. POWER HOUSE
4. DOWNSTREAM COFFERDAM
5. SPILLWAY – FLIP BUCKET
6. SPILLWAY – CHUTE
7. SPILLWAY – GATE CHAMBER
8. SPILLWAY – APPROACH CHANNEL
9. INTERMEDIATE OUTLET TUNNEL
10. UPSTREAM COFFERDAM



RCC : Updating

Barra Bonita – R. Tietê SP

Itaipu R. Paraná

Jacareí -R. Jacareí - SP

Barragem da Penha – R. Tietê SP

Xingó – R. São Francisco

Ilha Solteira R. Paraná


23 9:12

Choosing the Best Location

Foundations that are suitable for massive internally vibrated concrete dams also are suitable for RCC dams with similar properties.

However, because of the low cost, construction techniques, and material properties of RCC, this type of dam can use a wider base and special design details to accommodate foundations that would otherwise be unsuitable.

To build a well-constructed RCC dam on unique foundations, proper attention to certain details is crucial.

These details include the width of the structure, isolation of monolith joints, foundation shaping (including use of steps), footings for the delivery system, and use of leveling concrete.

Considering Leveling Concrete

One particular foundation consideration worth noting is the use of "leveling" concrete.

Builders of some RCC dams have used leveling concrete to cover the foundation and provide a smooth base for the RCC.

For other RCC projects, builders have started with RCC directly on the foundation.

Each approach has merit, with each being more or less suitable to different conditions.

There are considerations for and against the use of leveling concrete.

Some Considerations in Designing an RCC Dam

By Ernest K. Schrader

Builders of roller-compacted-concrete dams need to consider several design elements before beginning construction.

These elements include choosing the best location, determining the need for leveling concrete, deciding the overall configuration of the dam, and designing to minimize the effects of features embedded in the dam.

Roller-compacted concrete (RCC) offers a range of economical and safe design alternatives to conventional concrete and embankment dams. And while the same basic dam design concepts apply, there are several unique considerations for RCC dams.

Some important considerations to address before proceeding with detailed final designs include but are not limited to: the basic purpose of the dam, the owner's requirements for cost, construction schedule, appearance, watertightness, operation, and maintenance.

A review of these considerations guides selection of several key components, including location, the use of leveling concrete, the basic configuration of the dam, and how to deal with conveyor supports.

To fully capture the advantages of rapid construction using RCC technology, the overall design should keep construction as simple as possible.

Leveling concrete simplifies the start of RCC placing and its initial production rate, but makes construction more time-consuming and costly;

On a foundation with substantial undulations and slopes, the leveling concrete will be very thick in most locations, requiring forced cooling;

Leveling concrete typically has long-term stiffness (modulus) values of 20 Giga- Pascals (GPa) to 35 GPa (3 to 5 million pounds per square inch), with low creep. If placed on a foundation with lower tensile mass modulus, this concrete creates added restraint and higher thermal stresses;

Any type of RCC mix can be placed directly onto foundation rock without leveling concrete. This is accomplished by first spreading a thin layer of high-slump bedding mix onto the rock, then spreading the RCC over the bedding and compacting it while the bedding is still fresh;

If the foundation is relatively poor and would deteriorate from exposure before placing RCC, it is common to use shotcrete or a thin "mud mat" to seal and protect it; and

Where shotcrete is placed against abutments and the foundation still tends to deteriorate, or where the abutment could not be cleaned to sound material before shotcreting, grout pipes have been used to ensure a seal between the shotcrete and foundation.

Determining the configuration of the RCC dam

RCC dams can be built with straight or curved axes, vertical or inclined upstream faces, and downstream faces varying from vertical to any slope.

The design type chosen, proposed height, and foundation characteristics strongly influence the basic dam cross section.

The overall design of an RCC structure must balance the use of available materials, selection of structural features, volume and strength requirements for different-sized dam sections, and proposed construction methods. Each factor must be considered in light of the others. For example, a particular dam section may require certain shear strength for stability.

However, available materials may not be capable of providing this strength or the construction method may not ensure sufficient lift-joint quality to provide the strength. In these situations, changes to the mix design, construction method, or section structure may be the solution

Other RCC dams

Many RCC dam designers have used the basic gravity dam section with a vertical upstream face and constant downstream slope on a vertical face.

The low cost of RCC often makes it reasonable to flatten the downstream slope of the dam and add more mass than is economically feasible with conventional concrete.

This reduces foundation stress, RCC strength requirements, and lift-joint concerns.

Reductions in cement content also result, with related reductions in unit cost and in thermal stresses.

However, the possibility of using higher cementitious contents with higher strengths also should be investigated if the thermal stresses can be tolerated and the volume reduction offsets the increase in cost due to higher unit costs of the RCC.

Influencing factors in this decision are the length of the dam, shape of the valley, cost and availability of cement and pozzolan, quality and production costs of the aggregates, and foundation quality.

A parapet wall can reduce costs of constructing larger dams by reducing the quantity of RCC. The wall also can act as a personnel barrier and curb.

Added height or “freeboard” for overtopping waves is not necessary with RCC.

Also, curving the top of the parapet wall outward can direct waves back to the reservoir.

The wall can be a continuation of upstream precast panels, if that option is used to form the upstream face of the dam.

A “breakaway” parapet (fuse plug) designed to fail during overtopping can be designed.

This can allow water to flow over one side of the dam while protecting any downstream powerhouse or access road on the other side

The width of the dam should be established after considering several factors, including:

✓ Cost of additional RCC and downstream vertical facing;

✓ Required width for access during operation and construction;

✓ Inertia (seismic loading) of the laterally unsupported top section of the dam;

✓ Effect of the mass on sliding stability due to the added confining load;

✓ Effect of the mass on the location of the resultant force for the section;

✓ Distribution of foundation stresses; and

✓ Possibility of causing tensile stress across downstream lift joints when the reservoir is empty.

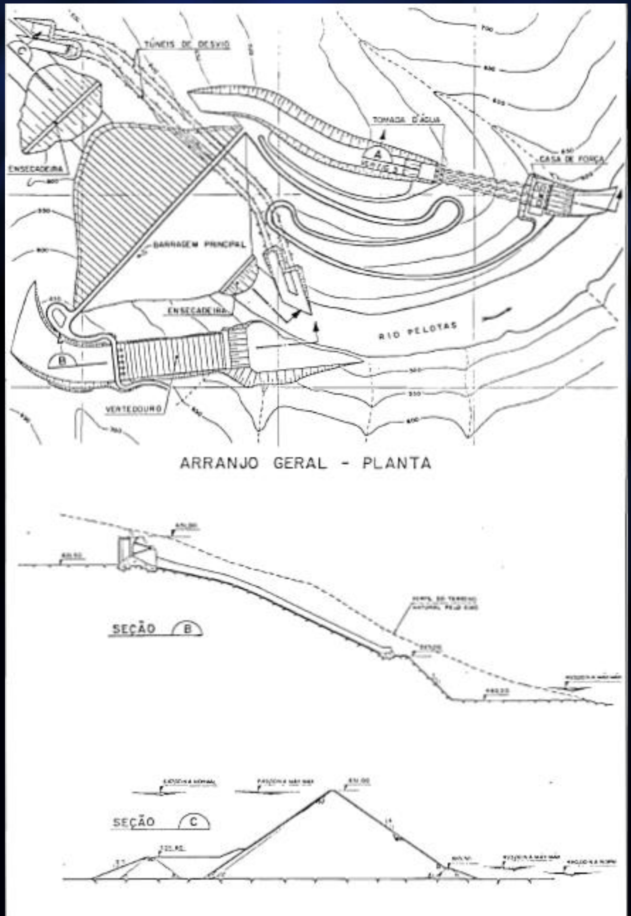


FIGURA 2 - ALTERNATIVA COM BARRAGEM DE ENROCAMENTO COM FACE DE CONCRETO - ARRANJO GERAL

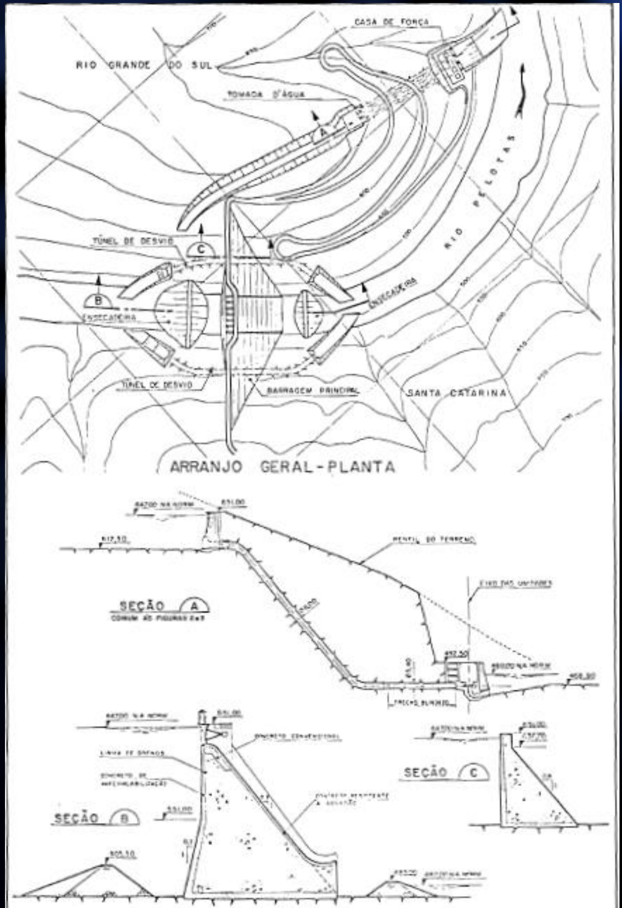


FIGURA 3 - ALTERNATIVA COM BARRAGEM DE CONCRETO GRAVIDADE EXECUTADO PELO MÉTODO DE CONCRETO ROLADO

As dimensões estimadas para a solução de envelopamento foram calculadas a partir de critérios conservadores, sendo adotada a equação desenvolvida por Bazant para a determinação da espessura de concreto de paramento e de fundação.

$$e = \sqrt{2.p.k.\frac{t}{\alpha}}$$

Onde: e = espessura de paramento; p = pressão da coluna d'água; k = coeficiente de permeabilidade; t = tempo de vida útil considerado ; α = volume de vazios após a hidratação (%).

Considerou-se para esse cálculo, que o coeficiente de permeabilidade do monolito fosse igual ao de juntas de construção tratadas de maneira convencional (10^{-10} cm/s) e um tempo de 100 anos para que a água percolasse através apenas do concreto de impermeabilização. Desta maneira, foi dimensionada a colocação de concreto massa convencional no paramento de montante e no contato com a fundação, sendo obtida uma espessura de 4,5 m junto ao pé de montante na seção de maior altura.

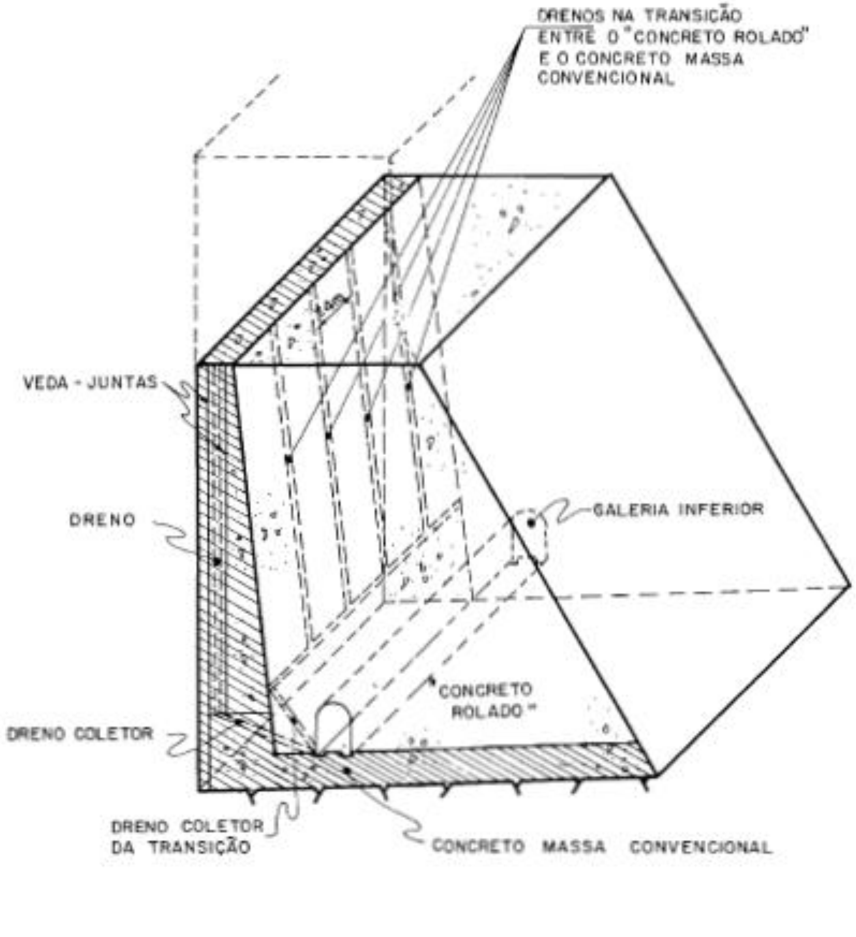


FIGURA 5 - SISTEMA DE DRENOS

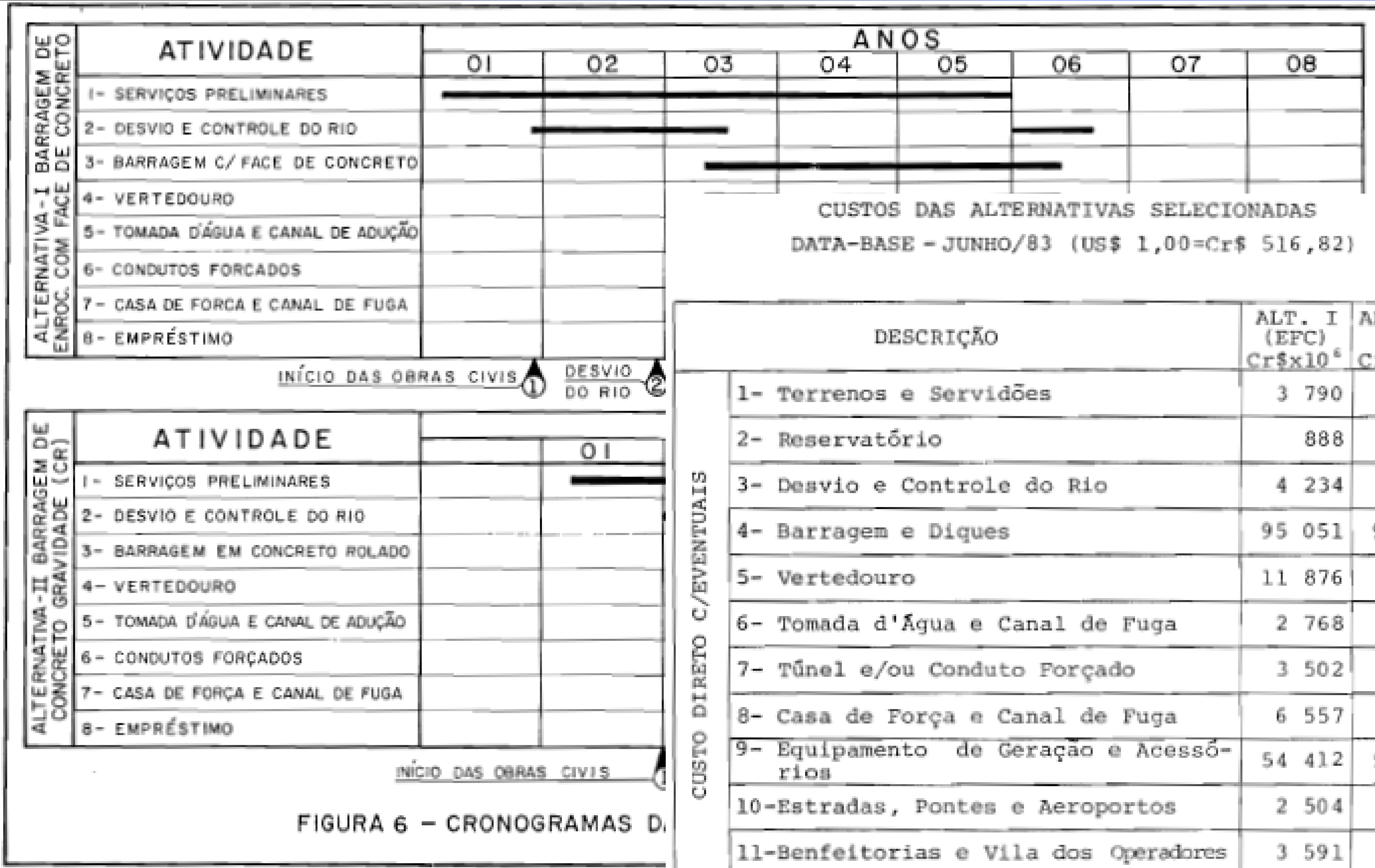


FIGURA 6 – CRONOGRAMAS D

CUSTOS DAS ALTERNATIVAS SELECIONADAS

DATA-BASE – JUNHO/83 (US$ 1,00=Cr$ 516,82)

	DESCRIÇÃO	ALT. I (EFC) Cr$x10⁶	ALT. II (CR) Cr$x10⁶
CUSTO DIRETO C/EVENTUAIS	1- Terrenos e Servidões	3 790	3 790
	2- Reservatório	888	888
	3- Desvio e Controle do Rio	4 234	3 591
	4- Barragem e Diques	95 051	92 581
	5- Vertedouro	11 876	5 321
	6- Tomada d'Água e Canal de Fuga	2 768	2 674
	7- Túnel e/ou Conduto Forçado	3 502	3 502
	8- Casa de Força e Canal de Fuga	6 557	6 557
	9- Equipamento de Geração e Acessórios	54 412	54 412
	10-Estradas, Pontes e Aeroportos	2 504	2 504
	11-Benfeitorias e Vila dos Operadores	3 591	3 591
Custo Direto c/Eventuais		189 173	179 411
Custo Indireto		52 893	44 743
Custo Total s/Juros Durante a Const.		242 066	224 154
Custo Total c/Juros (10%) Durante a Const.		319 185	282 378


2003

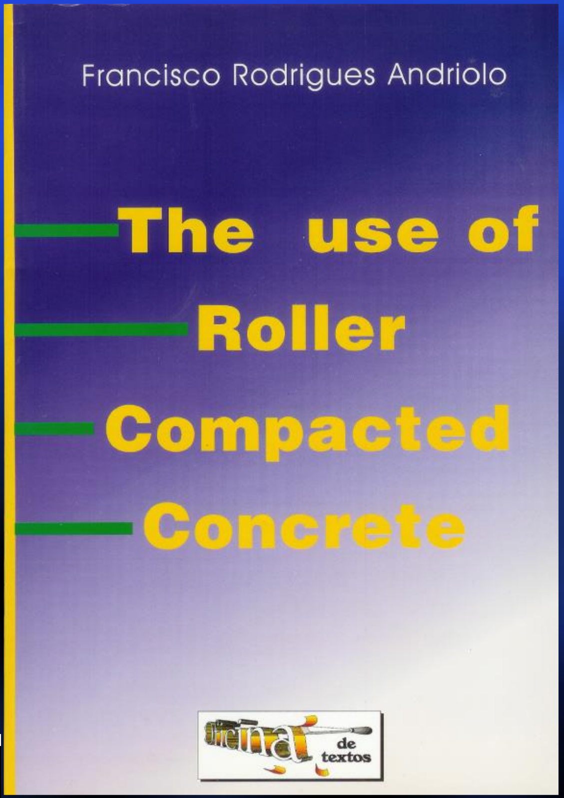

© 2011 Inav/Geosistemas SRL
© 2011 Google
© 2011 MapLink/Tele Atlas
Image © 2011 GeoEye
Google
Data das imagens: 7/10/2010
2006
21 J 744512.53 m L 7135818.17 m S elev 147 m
Altitude do ponto de visão 910 m

10 COSTS

10.1 Main Aspects

The use of RCC technique in the construction of dams and pavements has started formally in the beginning of the 70's and came to a summit ten years later. In 1996, about two hundred dams have already been built with this technology.

This constant evolution is meaningful and widely known. However, some issues are still under debate regarding costs of the many waterproofing face alternatives, the use of the bedding mix and the cost of RCC itself, as well.

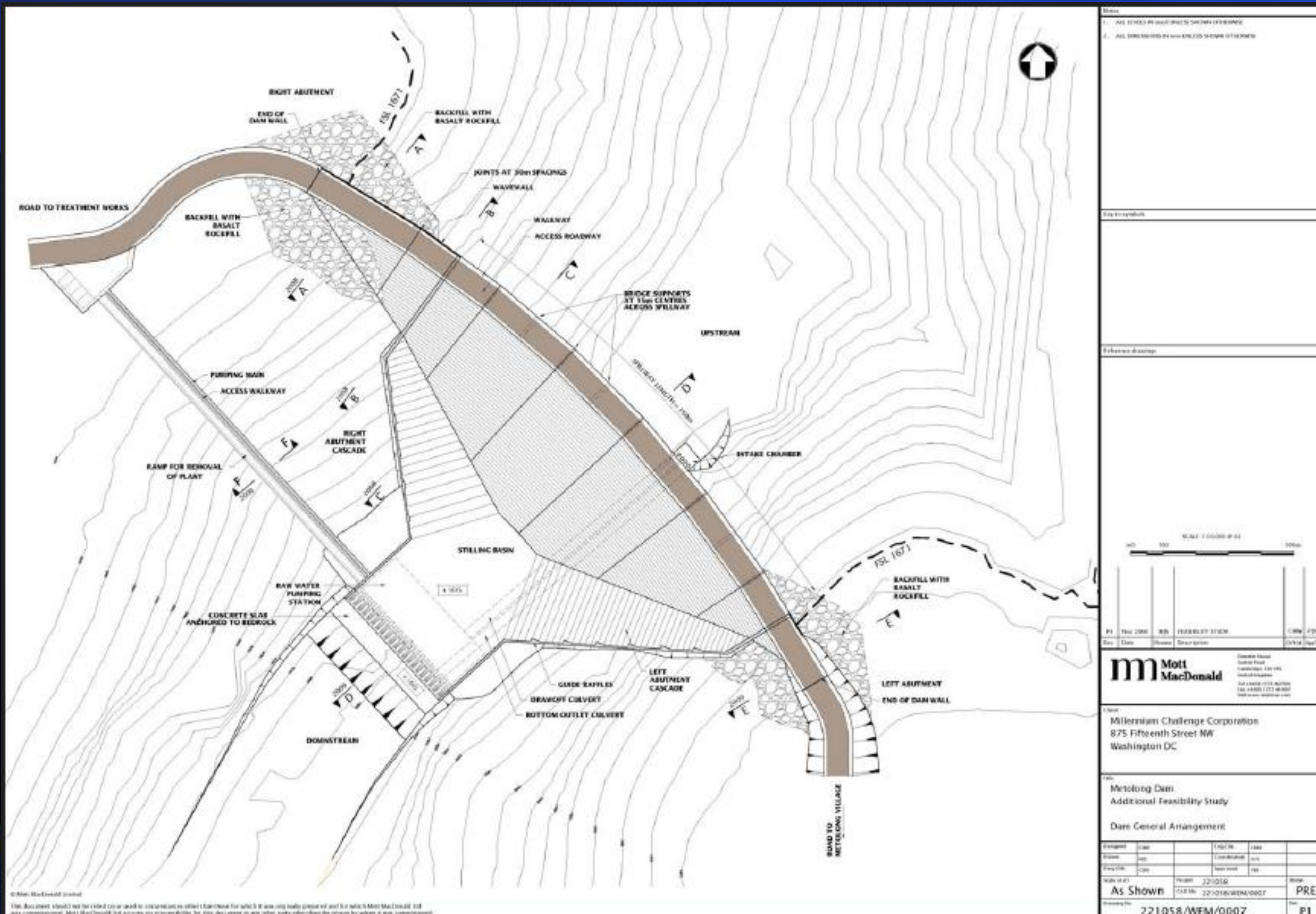


Payment Item Description	UNIT	Lowest RCC	Average RCC	Lowest CFRD	Average CFRD
Common Excavation	US$/m3	1.53	2.45	1.22	1.96
Rock Excavation in Pit	US$/m3	5.42	6.16	5.25	4.83
CVC Concrete- f'c 16 MPa	US$/m3	63.30	78.31	78.13	106.30
CVC Concrete- f'c 21 MPa	US$/m3	59.61	95.92	88.78	124.68
CVC Concrete- f'c 26 MPa	US$/m3	84.76	130.33	106.59	142.82
Furnishing and Installing Reinforcement Steel	US$/kgf	1.02	1.10	0.89	1.00
RCC Concrete- f'c 8,5 MPa (Less rock excavation for aggregates)	US$/m3	20.22	24.50		
Rockfill (Handling & Compaction)	US$/m3			0.50	0.65
Transition (Crushing + Handling + Compaction)	US$/m3			8.89	9.08

Figure 10.02 - Jordão bid unit costs comparison [10.11]

Payment Item Description	UNIT	Engineering Report CFRD	Engineering Report RCC	Bid Offers CFRD	Bid Offers RCC
Common Excavation	US$/m3	5.00	5.00	1.96	2.45
Rock Excavation in Pit	US$/m3	12.00	17.00	4.83	5.25
CVC Concrete- f'c 16 MPa	US$/m3	122.00	122.00	106.30	78.31
Furnishing and Installing Reinforcement Steel	US$/kgf	1.43	1.43	1.00	1.10
RCC Concrete-f'c8,5 MPa (Less rock excavation for aggregates)	US$/m3		44.37		24.50
Rockfill (Handling & Compaction)	US$/m3	4.10		0.65	
Transition (Crushing + Handling + Compaction)	US$/m3	18.60		9.08	

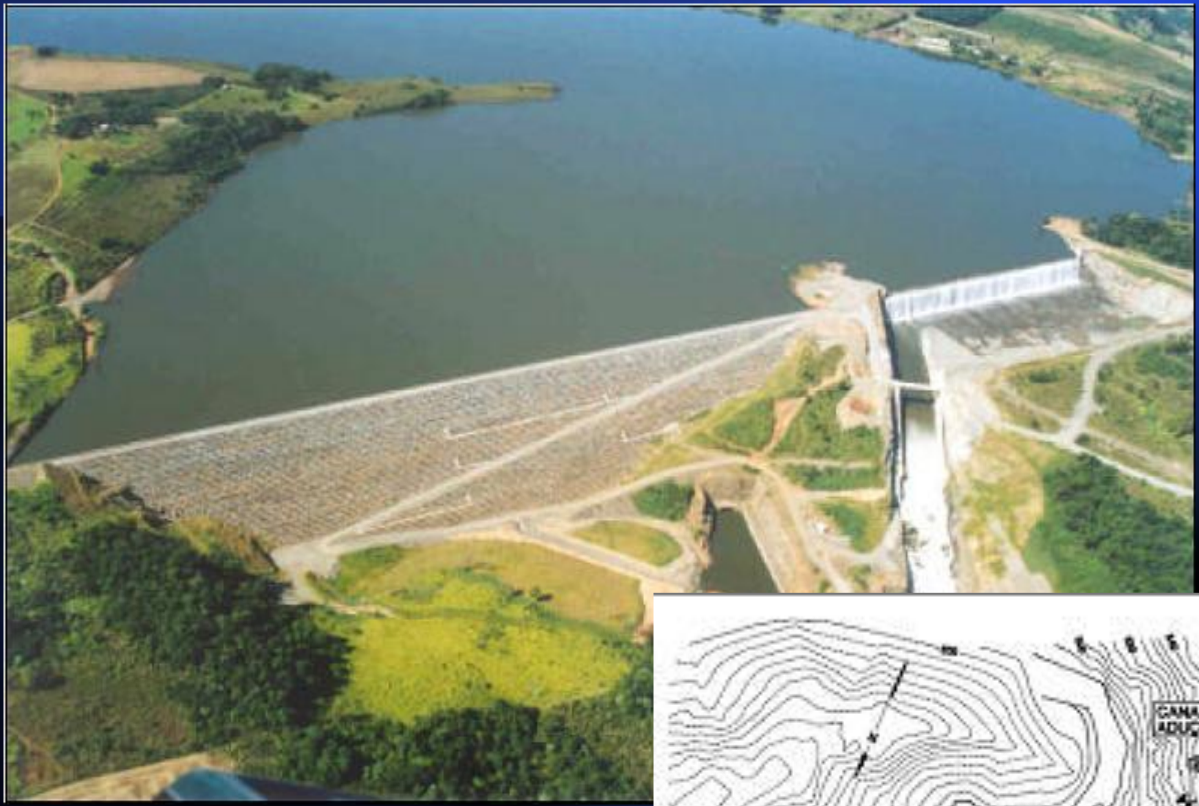

N
Image © 2008 DigitalGlobe
©2007 Google™
Ponteiro 15°15'44.37" S 58°43'12.96" O elev 229 m
Fluxo |||||||||| 100%
Altitude do ponto de visão 844 m

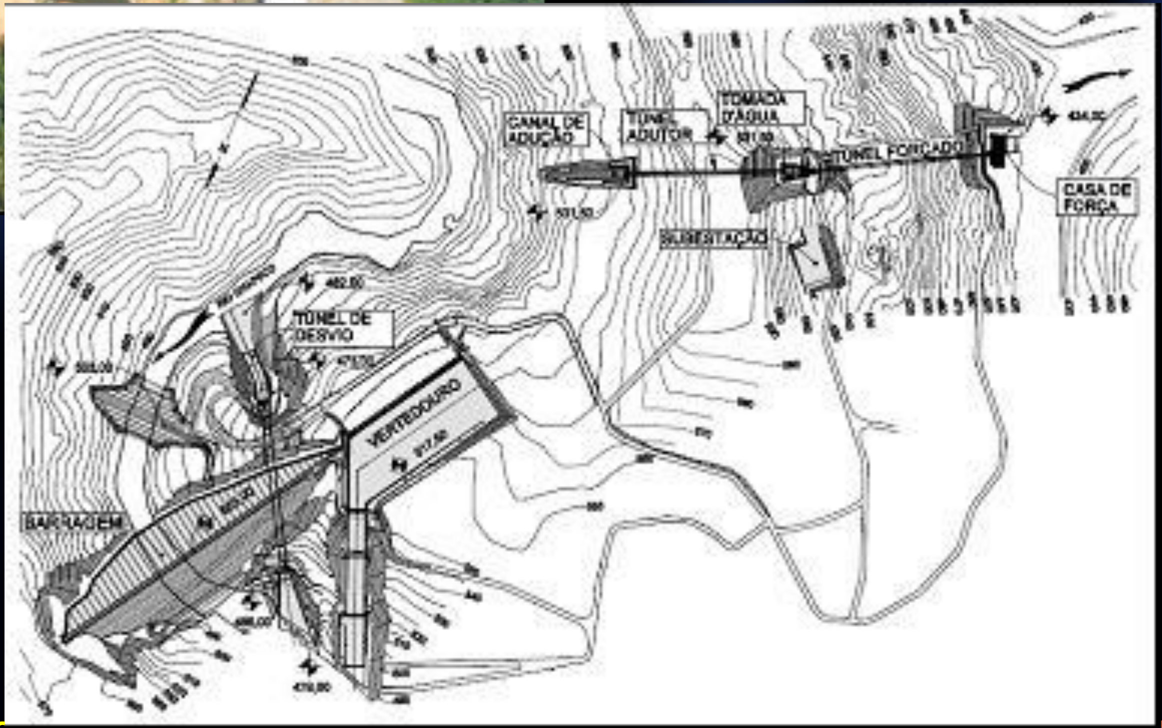


RCC : Updating the Information

Eng. *ANDRIOLO*, Francisco Rodrigues

AndrioloIto Engenharia

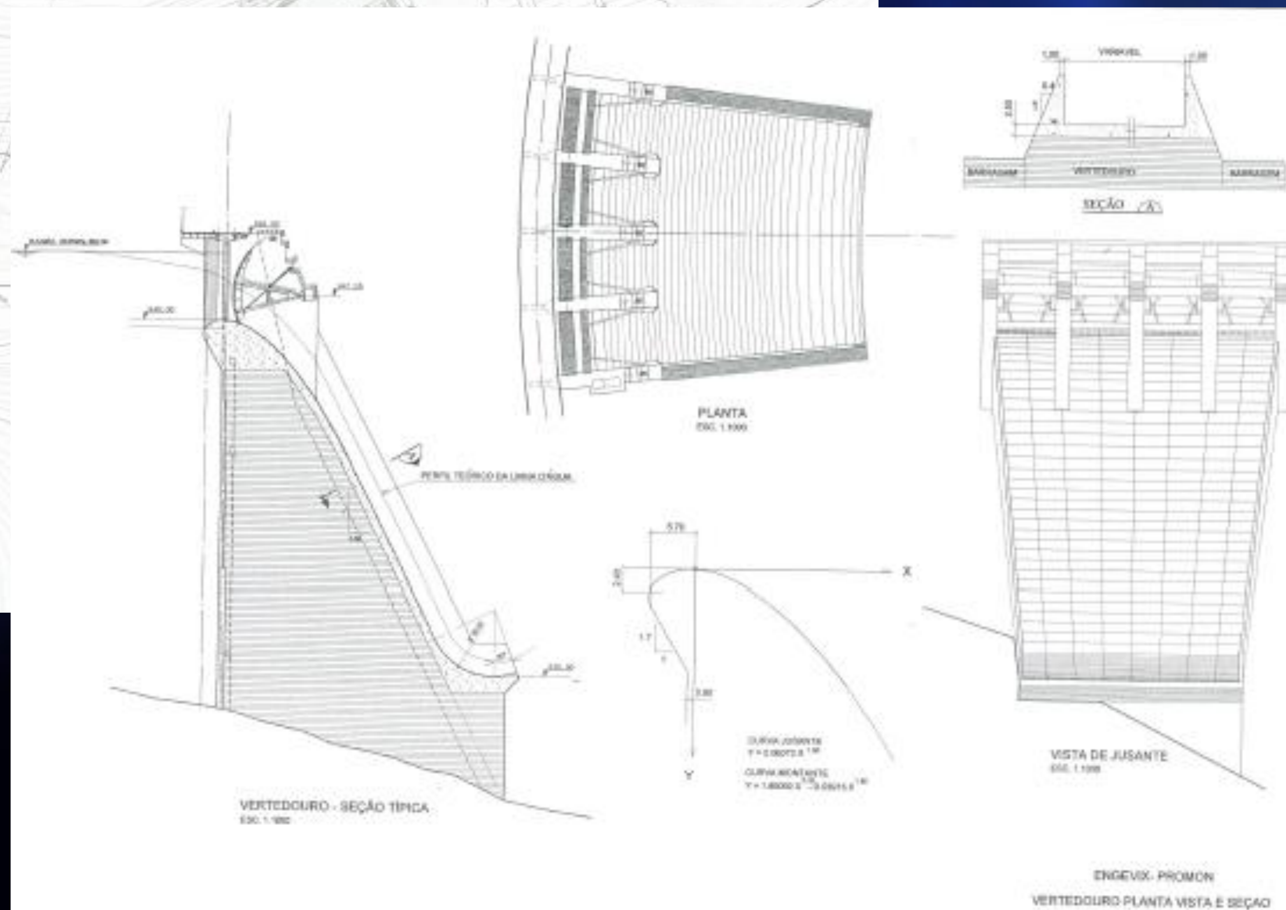


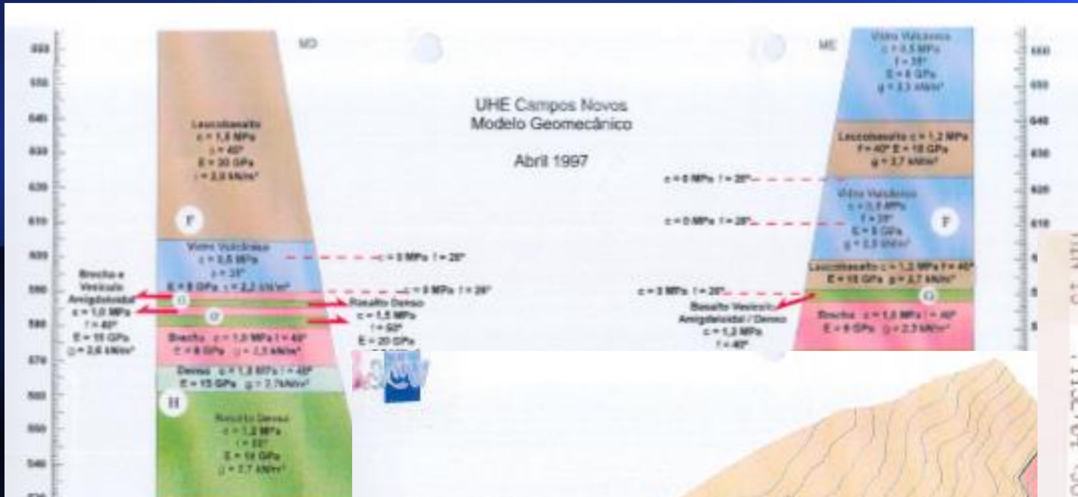

CANAL DE ADUÇÃO
TÚNEL ADUTOR
TOMADA D'ÁGUA
TÚNEL FORÇADO
CASA DE FORÇA
SUBESTAÇÃO
TÚNEL DE DESVIO
VERTEDOURO
BARRAGEM

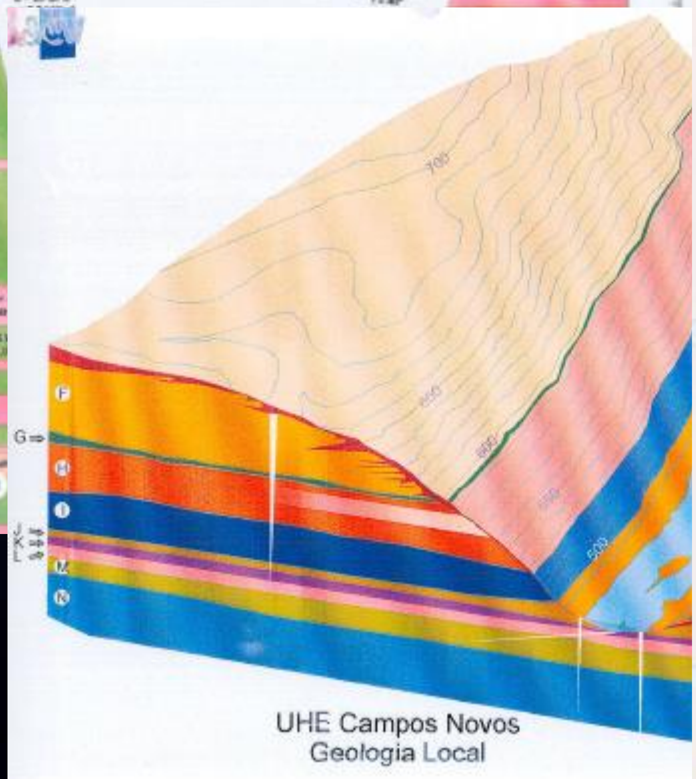
METOLONG DAM

DAM ALTERNATIVE - Summary of Quantities and Costs (not Prices)- 2008

Works	Unit	RCC DAM			CFRD DAM			Comments
		Quantity	Unit Cost (US$)	Total Cost (US$)	Quantity	Unit Cost (US$)	Total Cost (US$)	Main costs to be adjusted to Lesotho basis
Dam				15.808.878			9.845.416	
Commun excavation	m^3	9.500	4,20	39.900	25.000	4,20	105.000	
Open rock excavation	m^3	31.185	12,75	397.505	10.000	12,75	127.467	
Compacted soil	m^3		-	-		-	-	
Transition	m^3		-	-	25.000	14,80	370.000	
Rockfill	m^3		-	-	1.000.000	6,33	6.333.333	Rock Fill Compaction Cost
Conventional Concrete (Without Cement)	m^3	2.411	130,42	314.443	8.000	130,42	1.043.360	Concrete Face and Plinth
RCC (Without Cement)	m^3	256.000	31,81	8.142.507		-	-	
Cement	t	26.263	231,46	6.078.920	2.400	231,46	555.504	Review Cement Cost at site
Reinforcement Bar	t	255	3.276,88	835.604	400	3.276,88	1.310.752	Review Rebar Cost at Site
River Diversion			-	1.482.812		-	2.352.587	
Cofferdams	m^3	8.983	20,47	183.852	20.000	20,47	409.333	
Diversion Tunnel			-			-		
Commun Excavation	m^3		4,20		3.000	4,20	12.600	
Open rock excavation	m^3		12,75		10.000	12,75	127.467	
Underground Rock excavation	m^3		190,67		8.000	190,67	1.525.333	Cost for small section of Tunnel
Treatments	gb		-			-		This can be adjusted, enlarging the section
Conventional Concrete (Without Cement)	m^3		130,42		800	130,42	104.336	
Reinforcement Bar	t		3.276,88		36	3.276,88	117.968	Review Rebar Cost at Site
Cement	t		231,46		240	231,46	55.550	Review Cement Cost at site
Diversion Galleries			-			-		
Commun Excavation	m^3	4.000	4,20	16.800		-	-	
Open rock excavation	m^3	10.000	12,75	127.467		-	-	
Conventional Concrete (Without Cement)	m^3	3.000	130,42	391.260		-	-	
Reinforcement Bar	t	180	3.276,88	589.838		-	-	Review Rebar Cost at Site
Cement	t	750	231,46	173.595		-	-	Review Cement Cost at site
Pit Rock Excavation in	m^3	350.000	11,18	3.913.000	1.000.000	11,18	11.180.000	
Spillway			-	6.704.397		-	2.853.840	
Commun Excavation	m^3		4,20	-	3.000	4,20	12.600	
Open rock excavation	m^3		12,75	-	15.000	12,75	191.200	
RCC (Without Cement)	m^3		31,81	-		31,81	-	
Conventional Concrete (Without Cement)	m^3	10.000	130,42	1.304.200	5.000	130,42	652.100	
Conventional Concrete (Without Cement)	m^3	10.000	138,99	1.389.933	3.000	138,99	416.980	
Cement	t	6.000	231,46	1.388.760	2.300	231,46	532.358	Review Cement Cost at site
Reinforcement Bar	t	800	3.276,88	2.621.504	320	3.276,88	1.048.602	Review Rebar Cost at Site


PLANTA
SEÇÃO
VERTEDOURO - SEÇÃO TÍPICA
X
Y
VISTA DE JUSANTE
ENGEVIX- PROMON
VERTEDOURO PLANTA VISTA E SEÇÃO





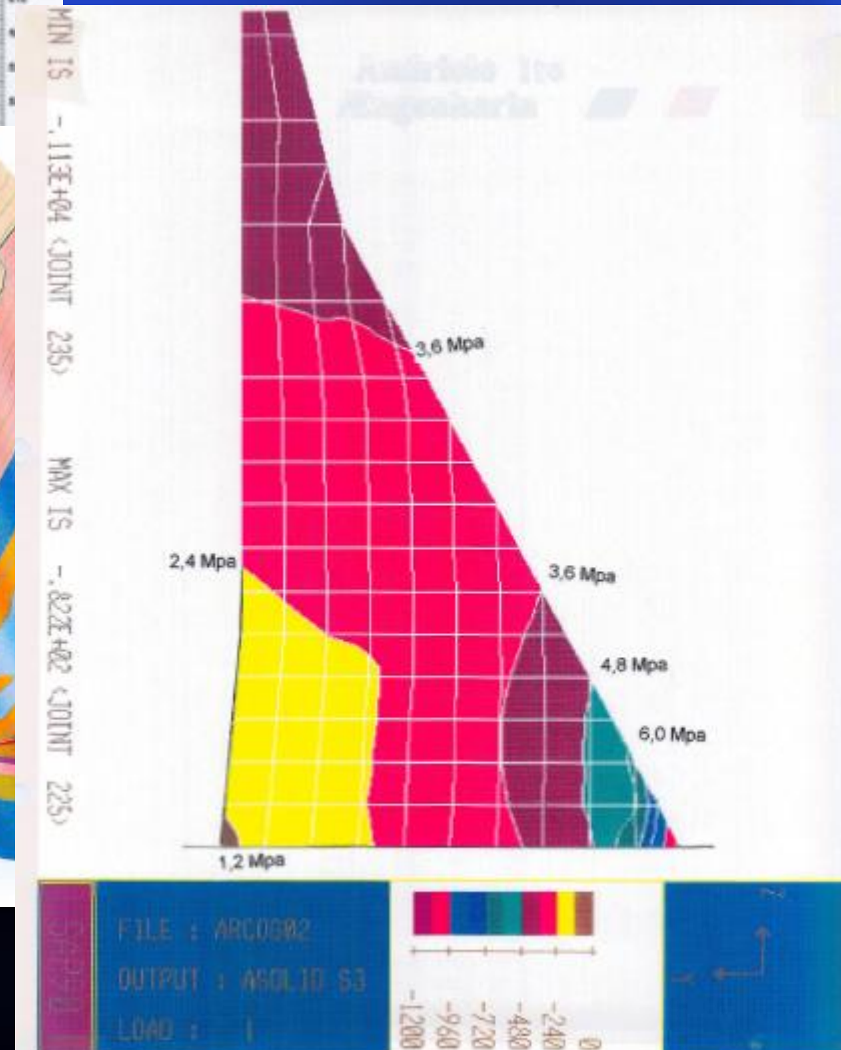
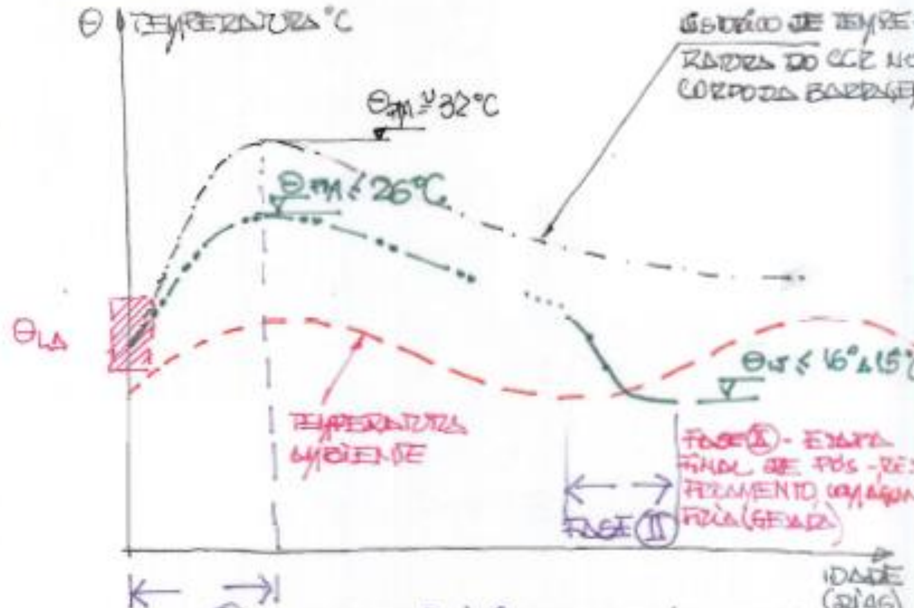


FIGURA 06- DIAGRAMA DE TENSÕES RESULTANTE DA ANÁLISE DE ELEMENTOS

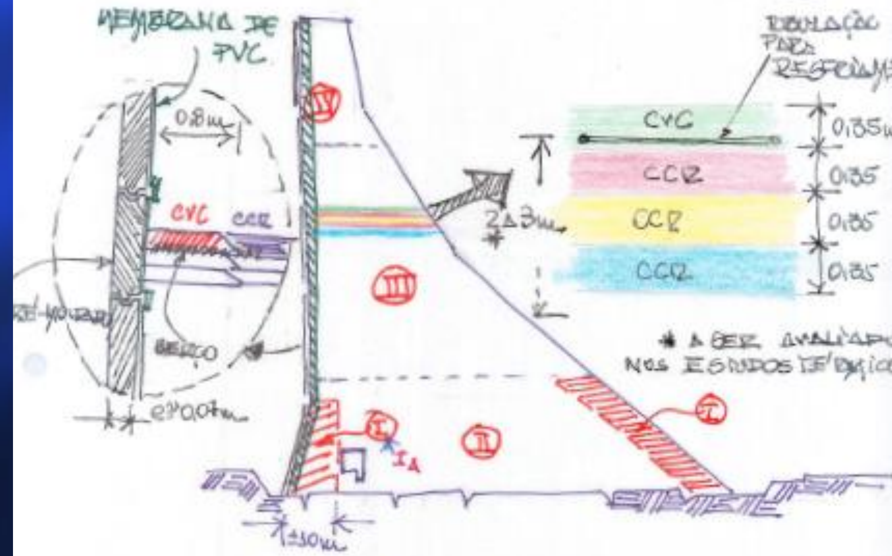
MODO A –

- CONTROLAR O PICO MÁXIMO NA ESTRUTURA
- REDUZIR A TEMPERATURA DA ESTRUTURA PARA PERMITIR A INJEÇÃO DAS JUNTAS DE CONTRAÇÃO.



FASE (I) – ETAPA INICIAL DE PÓS-RESFRIAMENTO NOS 5 A 10 PRIMEIROS DIAS. SERÁ AVALIADO O USO DE APENAS ÁGUA DO RIO PARA A CIRCULAÇÃO PELAS SERPENTINAS.

B- ZONEAMENTO DAS CLASSES DE CONCRETOS



ZONA	CLASSE	fck kgf/cm²	IDADE (DIAS)	CONSUMO kg/m³ CIMENTO	PREVISÃO MICROSÍLICA
I / IA	I IA	180 200	180	90 40 (0,1)	30/40
II	II	100	180	90 (0,3)	—
III	III	90	180	80 (0,3)	—
IV	IV	120	180	110 (0,3)	—

VALOR MÉDIO DE CONSUMO DE MATERIAL CIMENTÍCIO

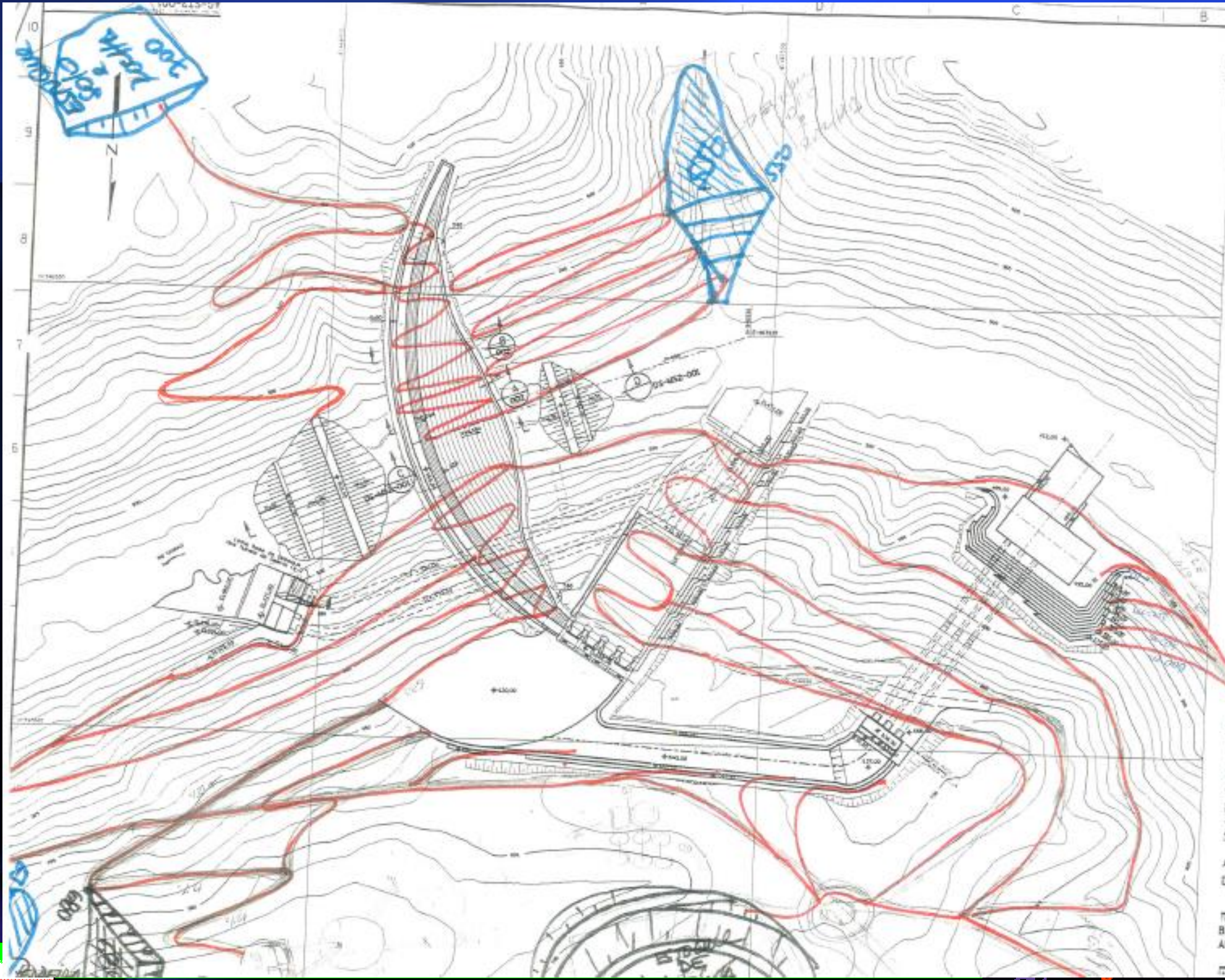
(90×0,1)+(90×0,3)+(80×0,3)+(110×0,3)

9+27+24+33=93

93 kg/m³

30×0,1=3

3 kg/m³



Aspect - Condition	Decisions		
Foundation	Good: Can accept all types of structures	Fair: The Structure or the shape must be adjust to it	Poor: Normaly induces the Decision for a Deformable Dam, or a large Base
Topographic	Open Valley: It is not remakable point. Just can be used to have a relaxed Lay Out, and to execise a better use of materials	Medium Valley: As Open	Narrow Valley: Induces to a better Lay Out, some time reduces the option for decision
Climatic Condition- Rain	Low Rain Level: It is not a relevant condition for decisions	Medium Rain Level: How it affects the Clay works?	High Rain Level: Induces to reduce the Clay Option; Induce to pay attention in concrete surface finishing
Climatic Condition- Temperature	Low Average Temperature: Good for Concrete. But if have High Amplitude induces Cracks	Medium Average: Pay attention	High Average: Pay attention- need be analyzed
Hidrological Condition	Need be analyzed for Diversion System, Cofferdams and Reservoir Filling. RCC can be overtoped		
Material availability	Need be analyzed for all dam type		
Alluvium	Available- Earth; rock Fills and concrete	Fair or far: need be cost analyzed	Non Availbale- Rock exploitation- Cost
Rock Quarry	Available- Earth; rock Fills and concrete	Fair or far: need be cost analyzed	Non Availbale- Rock exploitation- Cost
Clay	Available- Earth; rock Fills and concrete	Fair or far: need be cost analyzed	Non Availbale- Rock exploitation- Cost
Cements	Near Available- Concrete Cost	Fair or far: need be cost analyzed	Non Availbale- Cost Analyzed
Pozzolanic Materials	Near Available- Concrete Cost	Fair or far: need be cost analyzed	Non Availbale- Cost Analyzed
Handling- Transportation Cost	Need be analyzed for all dam type		
Earth Quake	Need be analyzed for all dam type		
Workman Labor Qualification	Need be analyzed for all dam type		
Remote Area	Need be analyzed for all dam type maintenance and repairs		
Specific Conditions	Need be analyzed for all dam type		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Part II- RCC Dam Construction- Methodologies

II.a) Materials Availability and Processing – Timely Material Production

II.b) Production, Handling, Pouring, Compaction

II.c) Upstream and Downstream Faces And construction Joint Treatments

II.d) RCC Arch Dams

Part II- RCC Dam Construction- Methodologies

II.a) Materials Availability and Processing– Timely Material Production

MATERIALS

RCC Concept

Roller Compacted Concrete (RCC) is a *CONCRETE,* but differs from traditional concrete principally in that it has a consistency that will support a vibratory roller and an aggregate grading and proportion suitable for compaction by such a roller.

MATERIALS

Objective of the selection of the materials for and design of the mixture proportions of an RCC :

- provide a stable concrete that meets all the in-situ properties as strength, durability, and permeability requirements of the structure.

Materials for RCC can be from pit-run minimally-processed aggregates with low cementitious (cement plus mineral admixture) contents to fully-processed concrete aggregates with different cementitious contents.

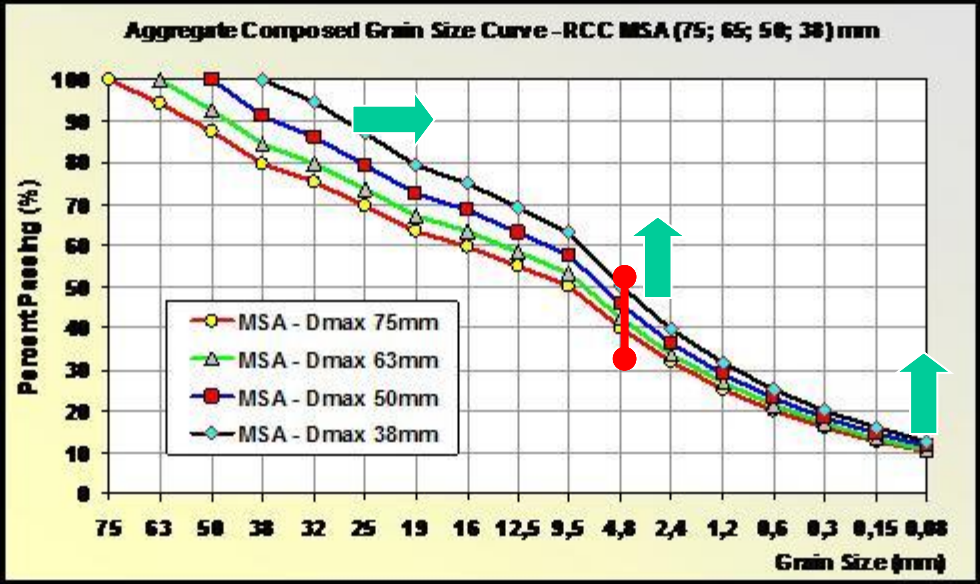
Aggregates

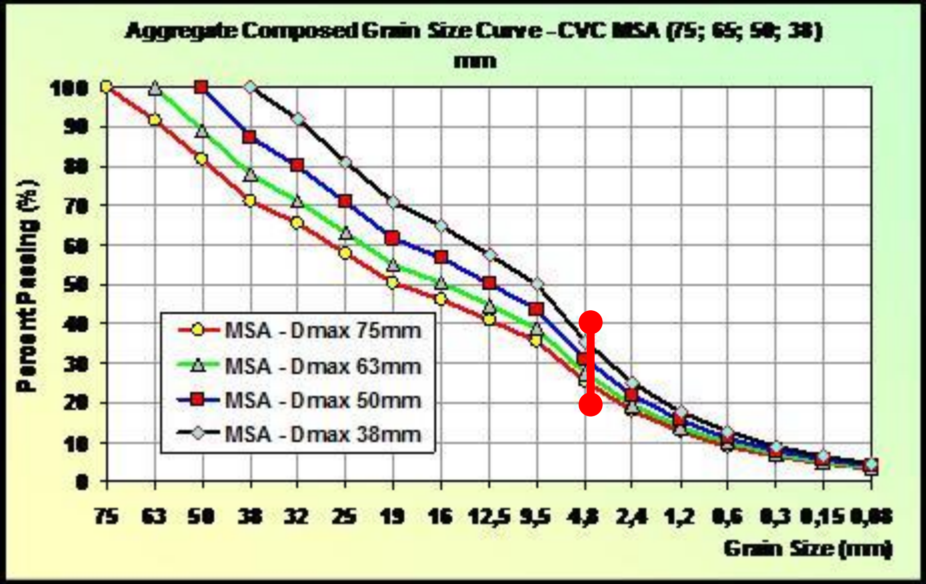
As the RCC is a concrete, the Specifications should reflect an appropriate degree of control of aggregate quality and grading.

✓ Selection of aggregates and control of grading are important factors influencing the in-situ quality and properties of RCC.

✓ Variability of aggregates- Significantly affects the cementitious and water requirements (affect workability- strength).

Aggregates grading composition curve (cubical type) as $p = (d/D_{max})^{1/3} * 100\%$





As the aggregates MSA in the grading composition is reduced, a greater quantity of “sand” (material finer than 5mm) is required, as well as a greater quantity of “fines“ (material inferior to 0,075mm).

• closed grading with a smaller number of air voids, with a maximum density and low permeability.

The unavailability of “fines” may lead to the need of adopting an alternative to “close” grading and minimize the air voids.

This can be obtained using pozzolanic material (if available at a low cost), either of Silt or of Rock Flour. The choice of the alternative must be made, prudently, on a technical and economical basis.

We can just finalize the aggregates aspects now….!

Designation: C 33 – 03

Standard Specification for Concrete Aggregates[1]

6.3 Fine aggregate failing to meet these grading requirements shall meet the requirements of this section provided that the supplier can demonstrate to the purchaser or specifier that concrete of the class specified, made with fine aggregate under consideration, will have relevant properties (see Note 4) at least equal to those of concrete made with the same ingredients, with the exception that the reference fine aggregate shall be selected from a source having an acceptable performance record in similar concrete construction.

8. Soundness

8.2 Fine aggregate failing to meet the requirements of 8.1 shall be regarded as meeting the requirements of this section provided that the supplier demonstrates to the purchaser or specifier that concrete of comparable properties, made from similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

Designation: C 33 – 03

Standard Specification for Concrete Aggregates[1]

COARSE AGGREGATE
9. General Characteristics

NOTE 7—The ranges shown in Table 2 are by necessity very wide in order to accommodate nationwide conditions. For quality control of any specific operation, a producer should develop an average grading for the particular source and production facilities, and should control the production gradings within reasonable tolerances from this average. Where coarse aggregate size numbers 357 or 467 are used, the aggregate should be furnished in at least two separate sizes.

NOTE 8—The specifier of the aggregate should designate the class of coarse aggregate to be used in the work, based on weathering severity, abrasion, and other factors of exposure. (See Table 3 and Fig. 1.) The limits for coarse aggregate corresponding to each class designation are expected to ensure satisfactory performance in concrete for the respective type and location of construction. Selecting a class with unduly restrictive limits may result in unnecessary cost if materials meeting those requirements are not locally available. Selecting a class with lenient limits may result in unsatisfactory performance and premature deterioration of the concrete.

The most popular MSA was in the 75- to 80-mm size (up to years 2000), although there now seems to be a trend towards smaller (60-50mm) sizes due to segregation aspect .

The MSA is tending towards 50 to 60 mm. The maximum size of aggregate is not related to layer thickness nor compaction machinery. Compactability is governed primarily by the workability of the concrete.

Field tests with up to 40% flat and elongated particles (with an average below about 30%) have shown to be no significant problem. The US Army Corps of Engineers currently has a limit of 25% on the allowable content of flat and elongated particles, but this aspect is more important for Pumpable Concrete than RCC.

☞ Gradings of fine aggregate conforming to traditional CVC have been successfully used for most RCC dams.

☞ Fine aggregates with these gradings may occasionally require more cementitious material than is needed for lean mixtures using aggregate with more fines than is generally allowed.

☞ Unwashed aggregates with a much broader grading range than is usually specified have also been used.

- The aggregate grading and low fines content affects the relative compactability of the RCC and may influence the minimum number of vibrating passes required for full consolidation of a given layer thickness.

- It also affects the water and cementitious material requirements needed to fill the voids in the aggregate and coat the aggregate particles.

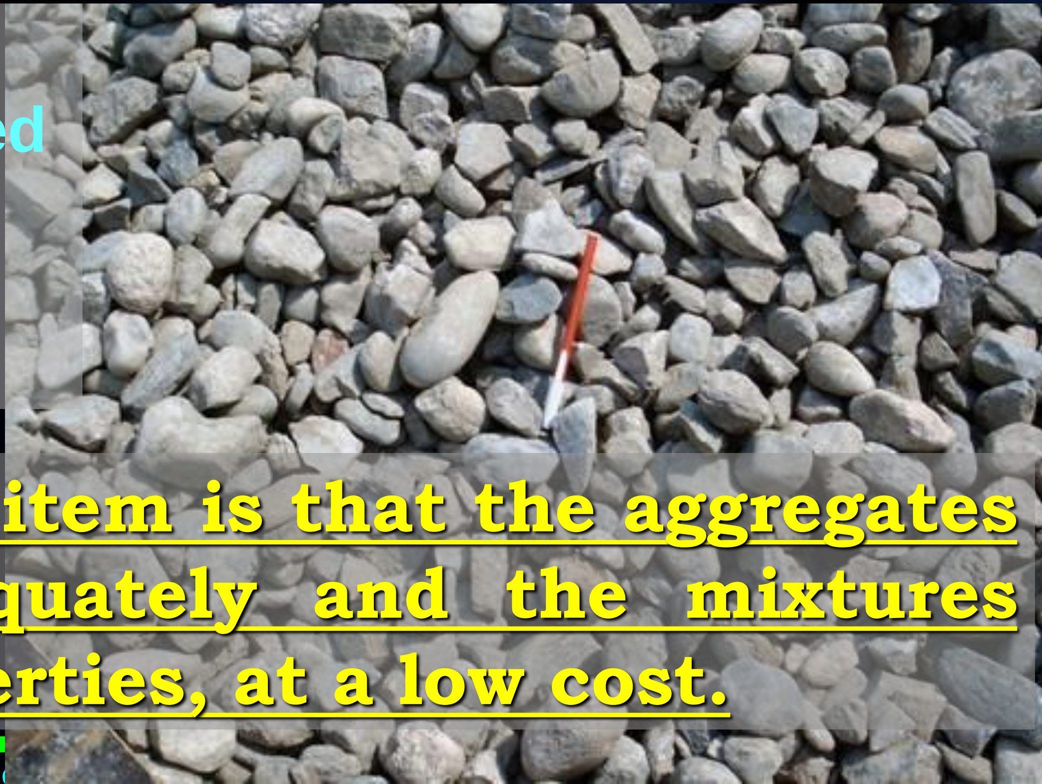
- Crusher fines and silt (no-plastic fines) material are usually acceptable.

• Some cost savings might be achieved by combining two or more size ranges to reduce the number of stockpiles.

• The Designer and/or Contractor must balance the potential cost savings in a reduction in number of stockpiles and separate handling and weighing facilities with the potential for increased variation in aggregate grading and its impact on uniformity of the RCC.

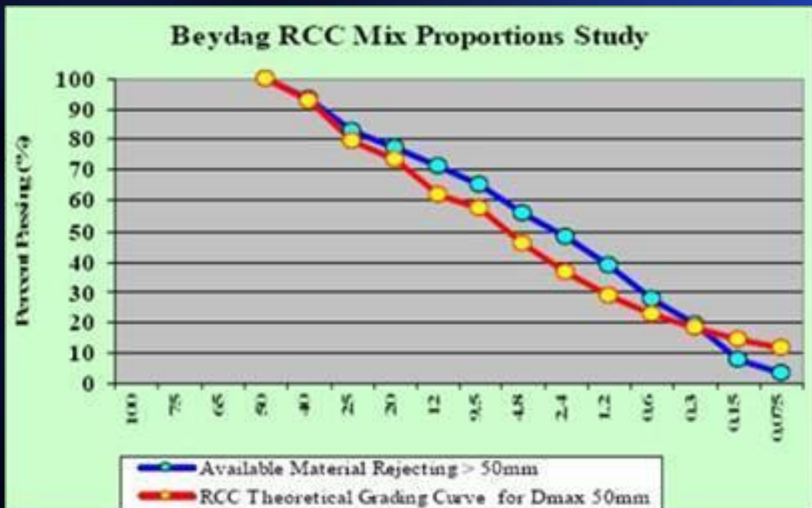
• Three or four aggregates sizes are mostly used in RCC dams.

The RCC can be proportioned and compacted with natural aggregates (gravel) or with crushed aggregates.



The most important item is that the aggregates be proportioned adequately and the mixtures comply with the properties, at a low cost.

The Designer and/or Contractor must balance the potential cost savings in a reduction in number of stockpiles and separate handling and weighing facilities with the potential for increased variation in aggregate grading and its impact on uniformity of the RCC. The Figure shows an unique aggregate curve that is was used in Beydag RCC Dam in Turkey



Just ONE Grain Size Fraction- Less than 50mm

Beydag RCC Dam in Turkey

Cementitious Materials

RCC can be made with any of the basic types of cement or, more usually, with a combination of cement and a mineral admixture.

The use of mineral admixtures has the desirable effects of reducing the Portland cement content, thus usually lowering costs and reducing the heat of hydration, and giving slower strength development which can reduce thermal stresses.

RCC can be made from any of the basic types of cement.

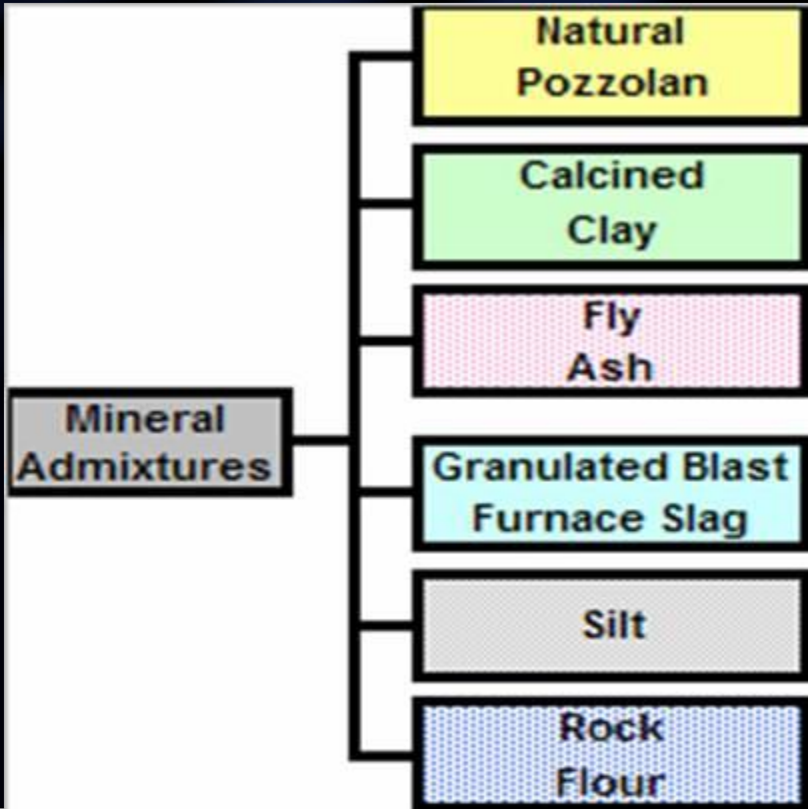
Strength development for lower-heat cements is usually slower than for Ordinary Portland cement at early ages.

At greater ages, the slower-early-strength-development cements usually ultimately produce higher strengths than Ordinary Portland cements.

Mineral admixtures

The use of pozzolanic materials in the massive concretes is an old and renowned practice, with the use of percentages around 15 and 25%, predominantly.

The advent of RCC led to the use of higher contents of pozzolanic materials. In a special range the blast-furnace slag can be placed, which also presents pozzolanic characteristics.



Prior testing of potential sources of pozzolanic material in the RCC mixture is advisable for all structures. If no other source of mineral admixtures is available, it is possible to obtain a certain pozzolanic activity using a siliceous filler by crushing rocks with certain amount and mineralogical condition of siliceous matrix. Even if these two last materials are generally less effective than other types of materials, they have been used in RCC for dams, particularly in Brazil, and some other countries.

Use of mineral admixtures or fillers in RCC mixtures may serve one or more of the following purposes:

☞ as a technical purpose to minimize the Alkali-Aggregate Reaction;

☞ as a proportion of the cementitious content to reduce heat generation;

☞ as an additive to provide supplemental fines for mixture workability, and impermeability, and

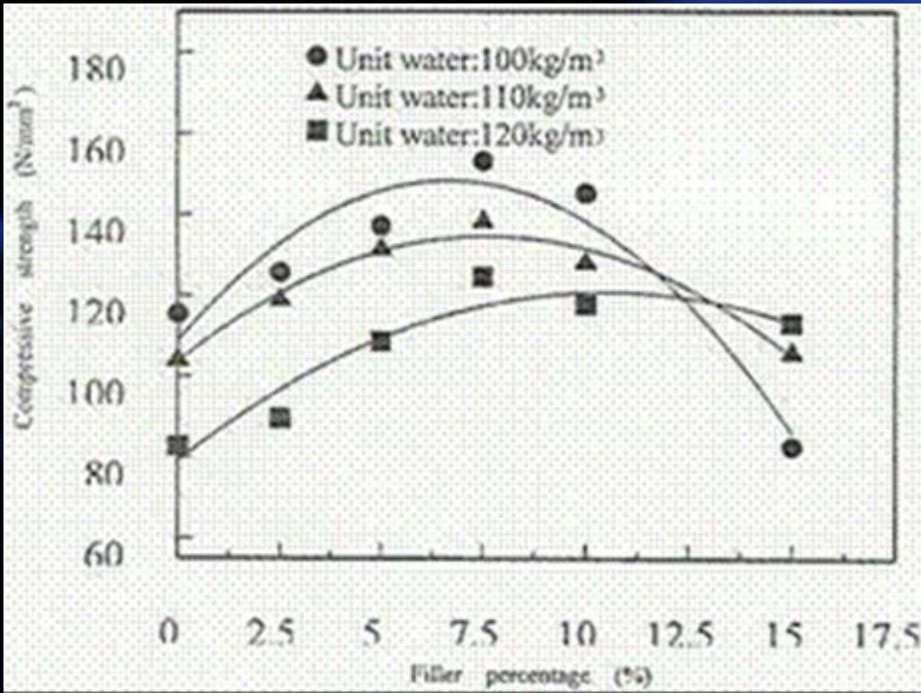
☞ as a proportion of the cementitious content to reduce cost.

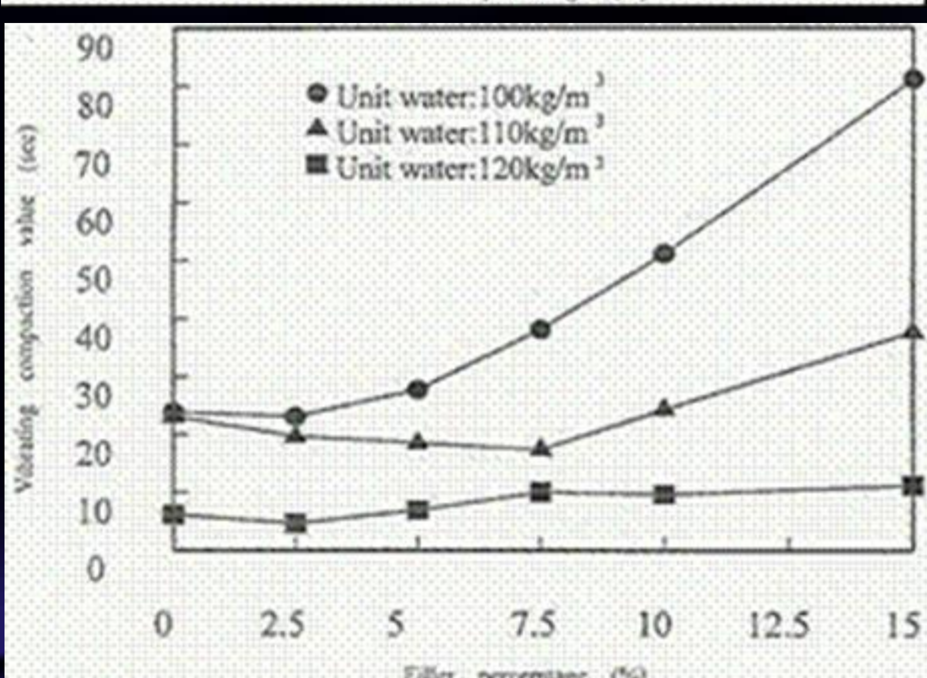
A good example about this evaluation can be observed in Japanese, Chinese, and Brazilian studies, where it is evidenced:

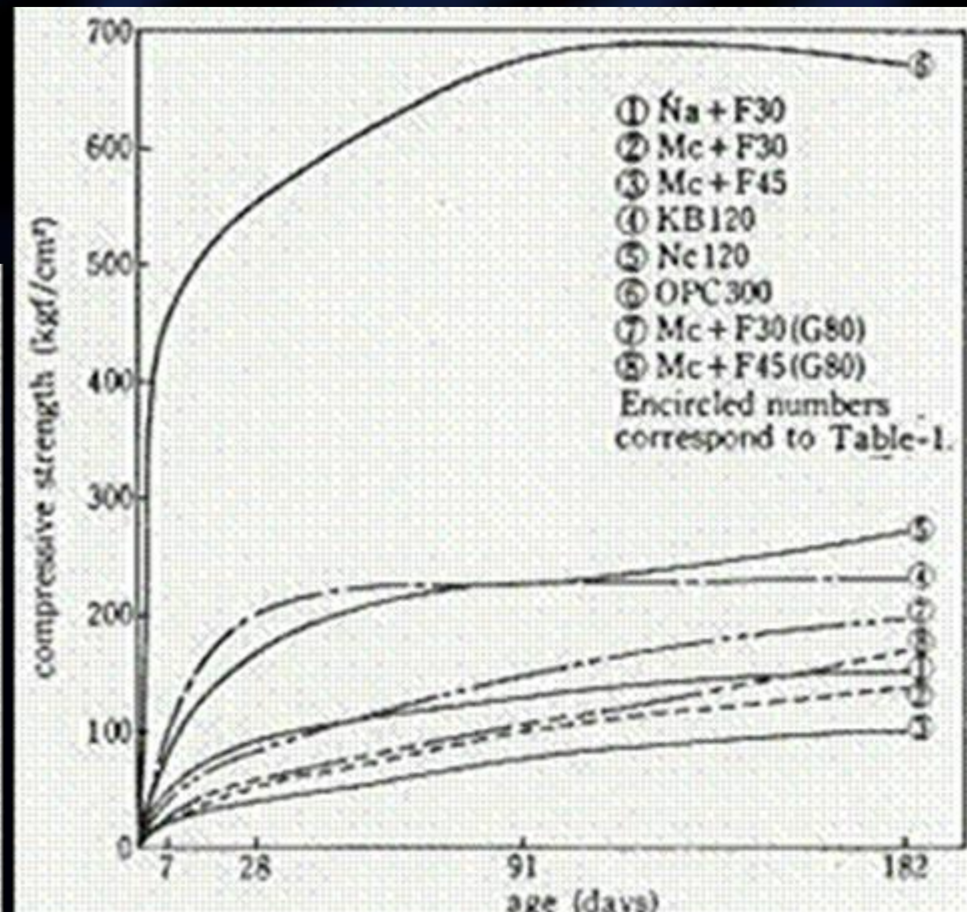
- Some Japanese studies - *"…As a result, it became clear that by mixing the filler of proper quantity, the VC value (Vibrating Compacting Value) of concrete quantity dropped, and compacting became easy, and compressive strength was increased. Moreover it is thought that the use non-washing crushed stone is possible…"*;

- Some Chinese studies - *"…The optimum content of Fly Ash should be determined according to the quality of Fly Ash, strength and strength design age of concrete, variety and strength grading of cement, price ratio of cement to Fly Ash and so on…"*;

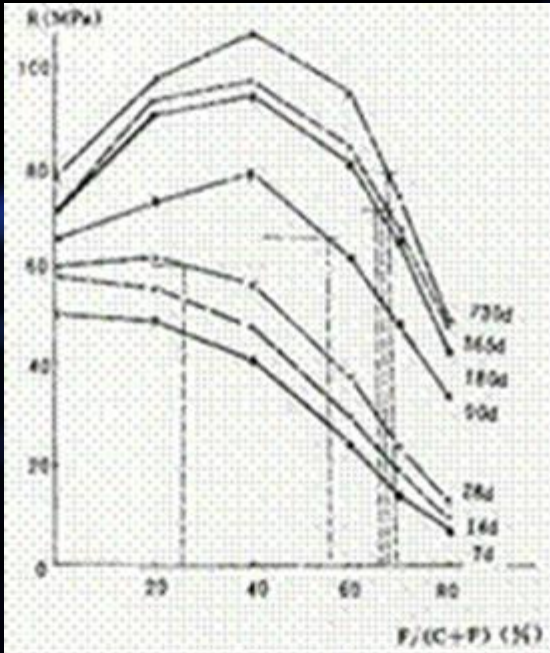
Japanese Studies

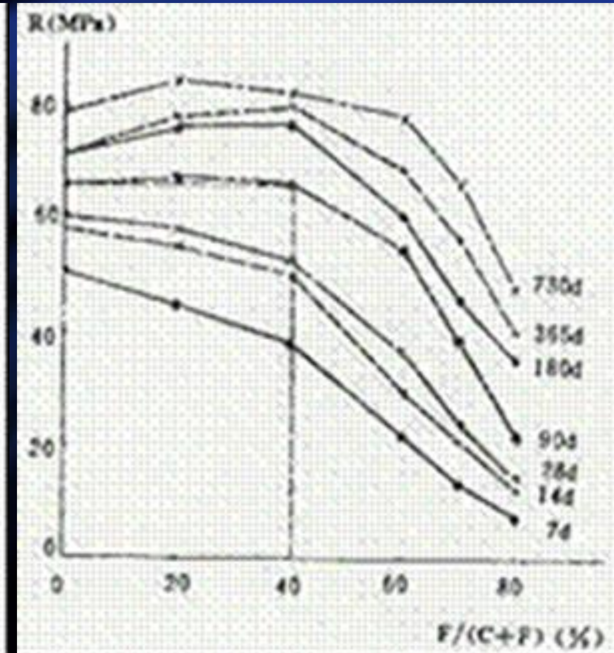


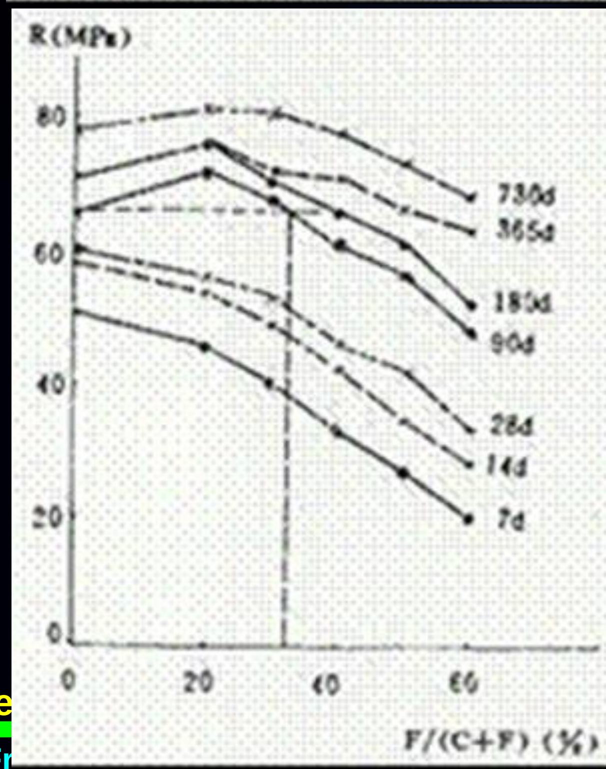


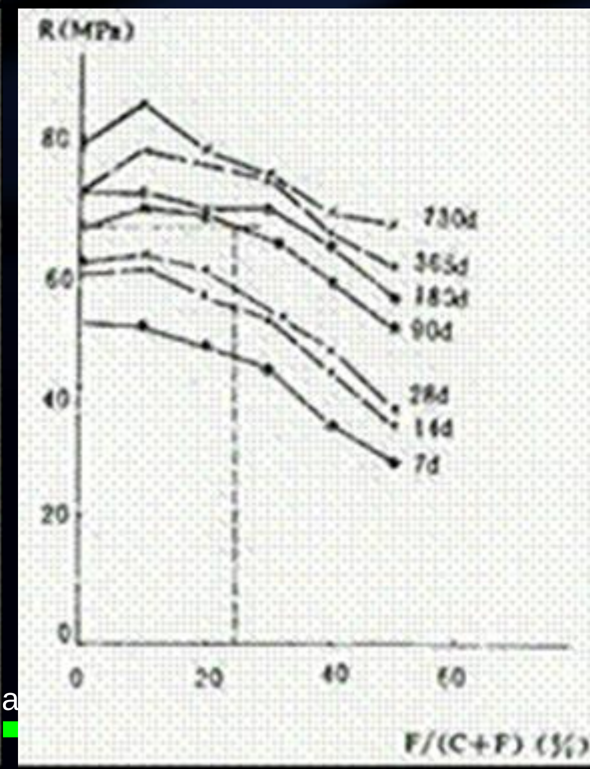


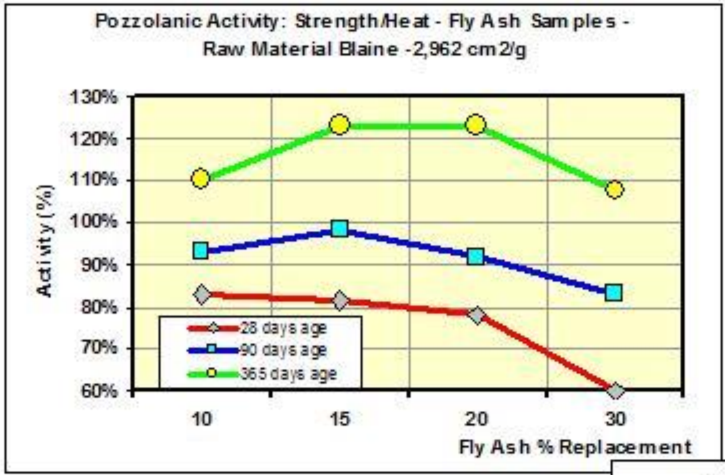
Chinese Studies

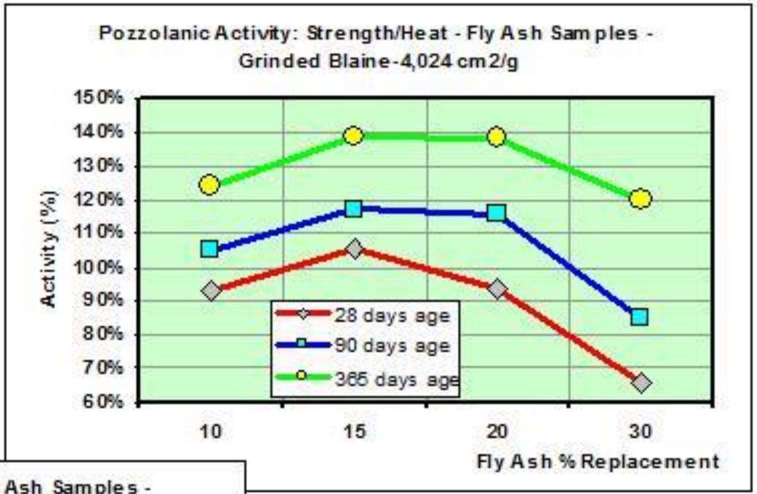




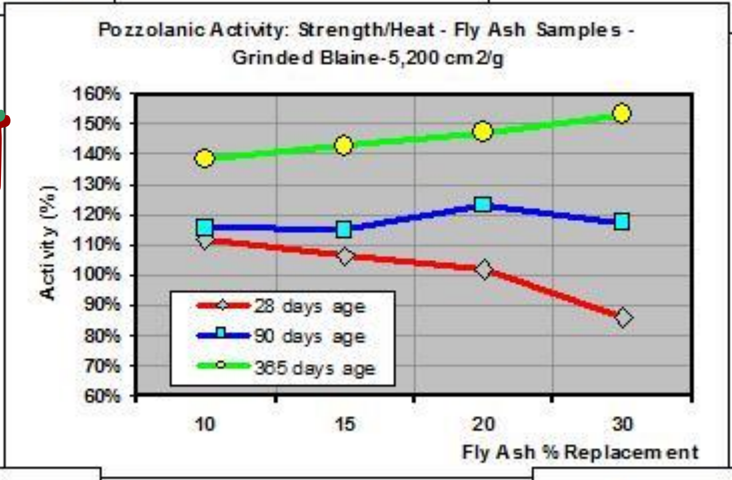


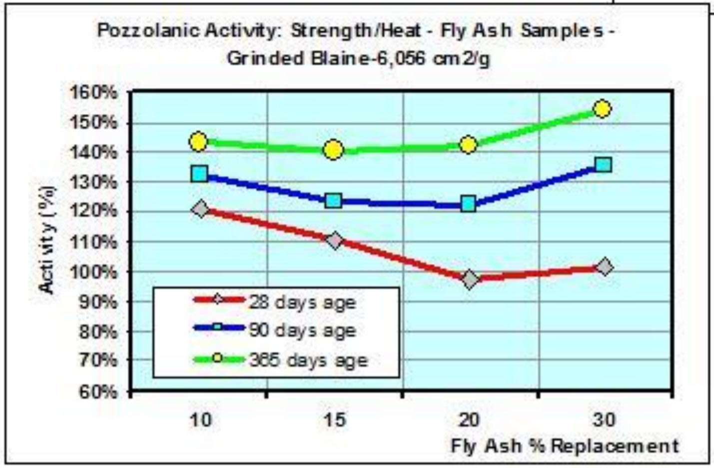


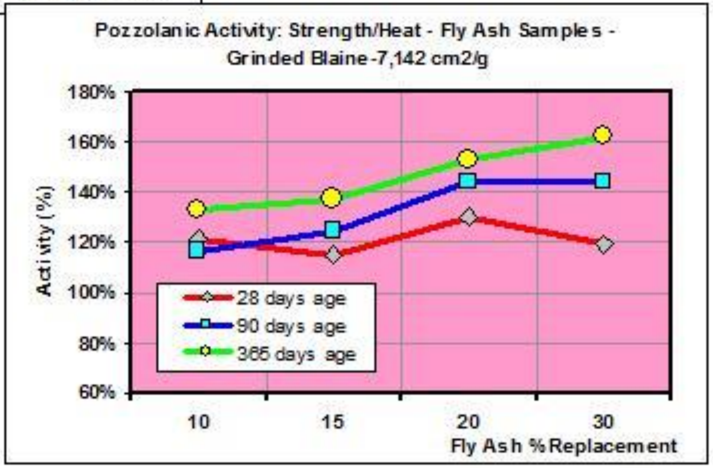




BRAZILIAN STUDIES



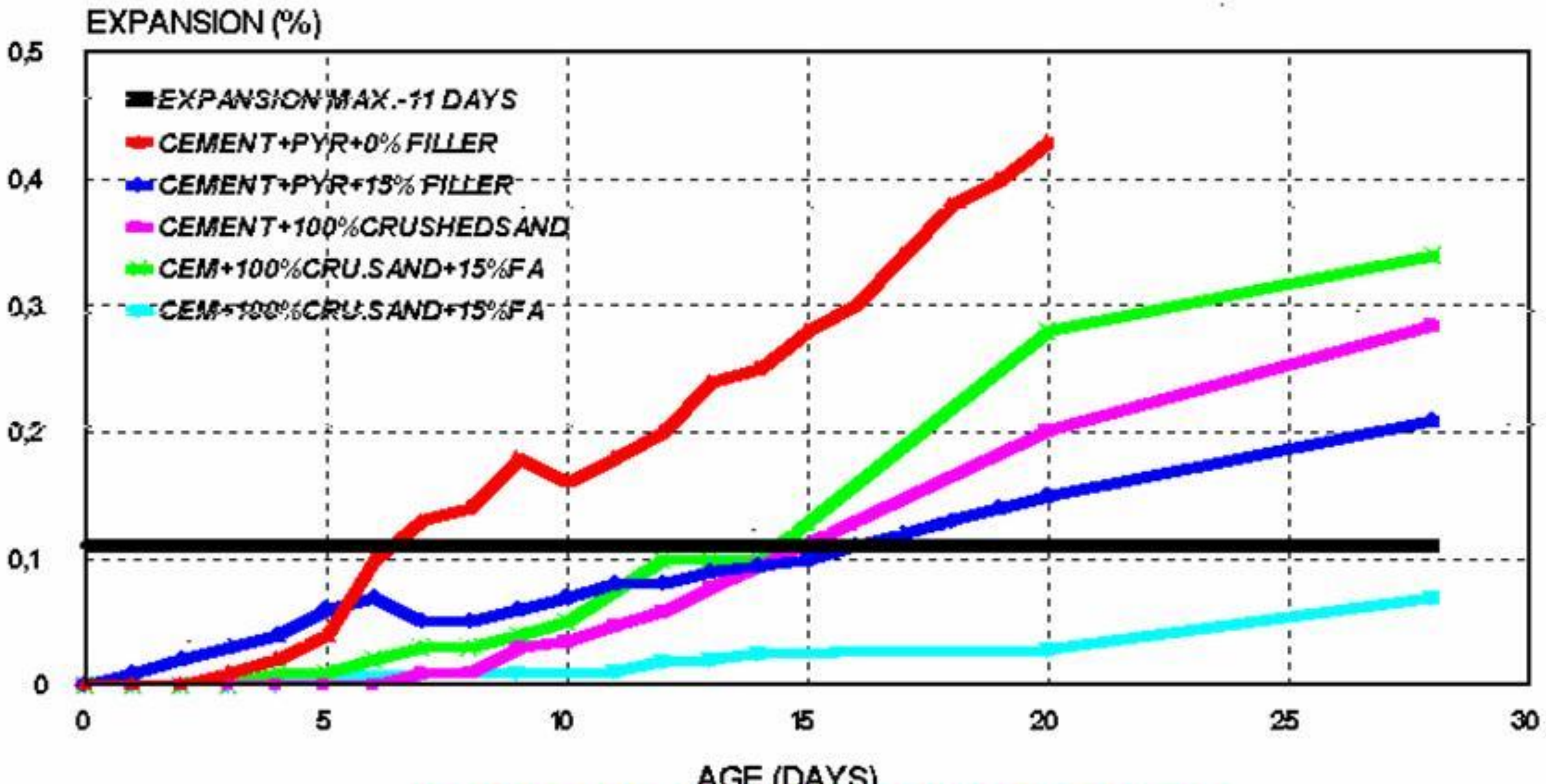




Mortar Test		Control	Sample as produced - Blaine 2,962 cm2/g				Sample grinded - Blaine 4,024 cm2/g			
Fly Ash Content (%)		0	10	15	20	30	10	15	20	30
Compressive Strength (kgf/cm2)	7 days	209	166	159	139	107	205	192	172	116
	28 days	331	254	243	233	169	319	318	282	199
	90 days	397	342	352	327	279	433	423	420	308
	365 days	426	435	471	472	389	548	538	537	466
Heat of Hydration (cal/g)	7 days	76	63	60	63	52	68	64	61	62
	28 days	80	74	72	72	68	83	73	73	73
Activity: Strength/ Heat	28 days	100%	83%	82%	78%	60%	93%	105%	93%	66%
	90 days	100%	93%	99%	92%	83%	105%	117%	116%	85%
	365 days	100%	110%	123%	123%	107%	124%	138%	138%	120%

Mortar Test		Sample grinded - Blaine 5,200 cm2/g				Sample grinded - Blaine 6,056 cm2/g				Sample grinded - Blaine 7,142 cm2/g			
Fly Ash Content (%)		10	15	20	30	10	15	20	30	10	15	20	30
Compressive Strength (kgf/cm2)	7 days	237	211	188	155	238	198	163	152	226	205	214	169
	28 days	351	325	296	253	365	339	303	298	391	372	377	345
	90 days	436	421	428	413	479	452	455	477	450	481	500	502
	365 days	559	563	548	579	557	553	566	583	551	569	569	605
Heat of Hydration (cal/g)	7 days	68	65	61	57	64	62	59	60	68	66	63	56
	28 days	76	74	70	71	73	74	75	71	78	78	70	70
Activity: Strength/ Heat	28 days	112%	106%	102%	86%	121%	111%	98%	101%	121%	115%	130%	119%
	90 days	116%	115%	123%	117%	132%	123%	122%	135%	116%	124%	144%	145%
	365 days	138%	143%	147%	153%	143%	140%	142%	154%	133%	137%	153%	162%

POTENTIAL REACTIVITY OF CRUSHED POWDER FILLER
ACCELERATED MORTAR BARS METHOD OF TEST (A.S.T.M.-C-1260)



CEMENT:CPS (ALKALIES=FROM 0,52% TO 0,76%)

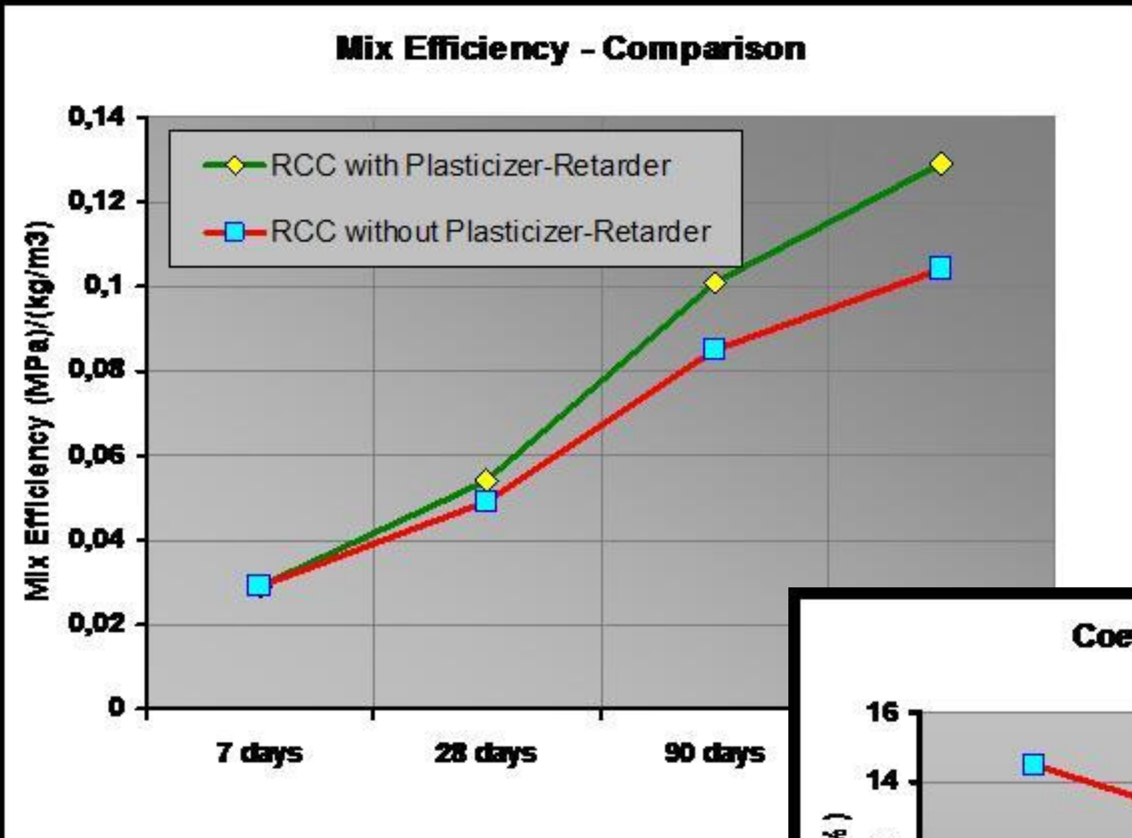
The use of pozzolanic material has made the designers revise the properties control age, which around the sixties was between 28 and 90 days, with very few countries using the ages of 180 days and one year, to the present situation where the properties began to be controlled mainly with more than 90 days.

The use of high contents- Part of the pozzolanic material can act as “Filler” and this must be economically evaluated.

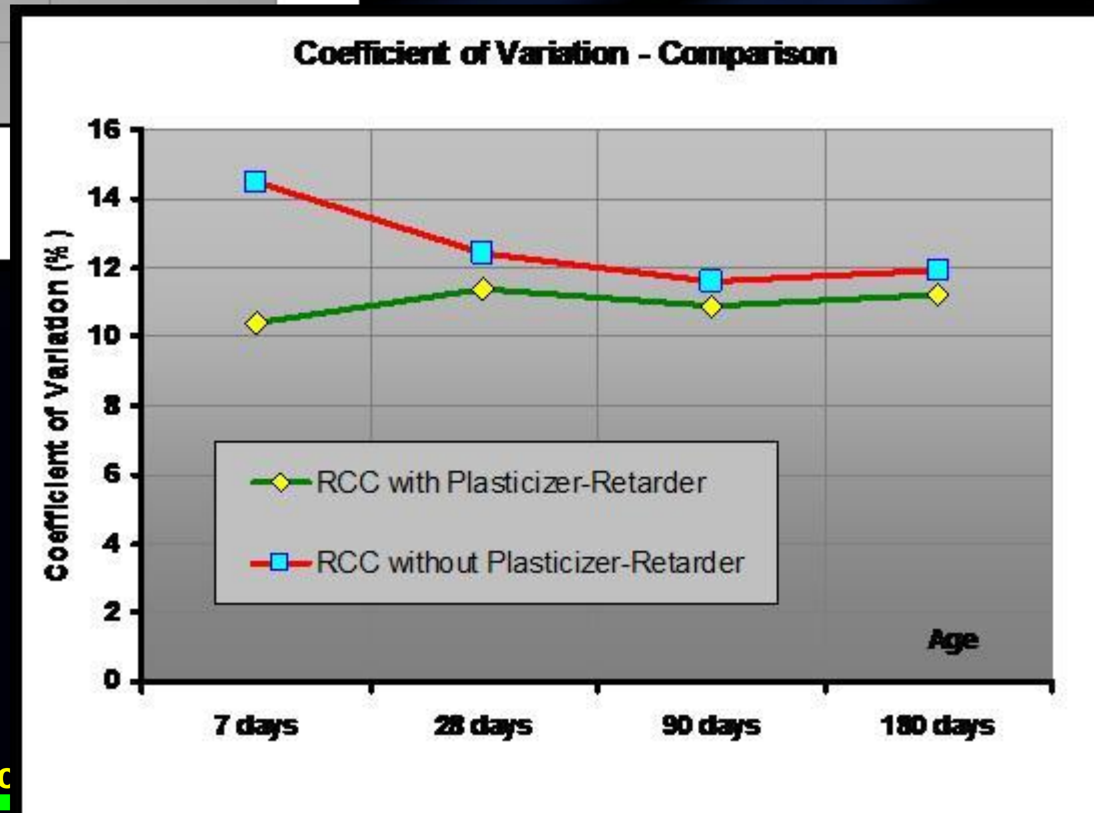
Chemical Admixtures

The use of additives in RCC is a relatively new approach. The use of chemical additives has increased since mid 90's, aiming at controlling the "Set" and broadening the operational margin for RCC transportation and compaction.

Its use has propitiated, besides control of the set, gains in resistant properties and that becomes a technical parameter with economic implications that must be analyzed.



Mix Efficiency - Comparison
Mix Efficiency (MPa)/(kg/m3)
0,14
0,12
0,1
0,08
0,06
0,04
0,02
0
7 days
28 days
90 days
RCC with Plasticizer-Retarder
RCC without Plasticizer-Retarder



Coefficient of Variation - Comparison
Coefficient of Variation (%)
16
14
12
10
8
6
4
2
0
7 days
28 days
90 days
180 days
Age
RCC with Plasticizer-Retarder
RCC without Plasticizer-Retarder

Water

As RCC is a concrete, the usual requirement for water in CVC is adopted for RCC mixes.

The requirement is that it be free from excessive amounts of alkalies, acids, or organic matter that might inhibit proper strength gain.

Part II- RCC Dam Construction- Methodologies

II.a) Materials Availability and Processing– Timely Material Production

CONCRETE MONTHLY PRODUCTION RATES (m^3/Month)

PROJECT	CONCRETE TYPE	Maximum Rate	Years	Country
Hoover	CVC Mass	190.000	1930	USA
Grand Dixence		200.000	1950	Switzerland
Dworshak		180.000	1960	USA
Itaipu		335.000	1970	Brazil/Paraguay
Tucurui		215.000	1980	Brazil
Huites		285.000	1990	Mexico
Shimajigawa	RCC	30.000	1980	Japan
Urugua- i		100.000	1980	Argentine
Upper Stillwater		204.000	1980	USA
Miel - I		118.000	1990	Colombia
Olivenhain		225.000	2000	USA
Beydag		150.000	2000	Turkey
Longtan		380.000	2000	China

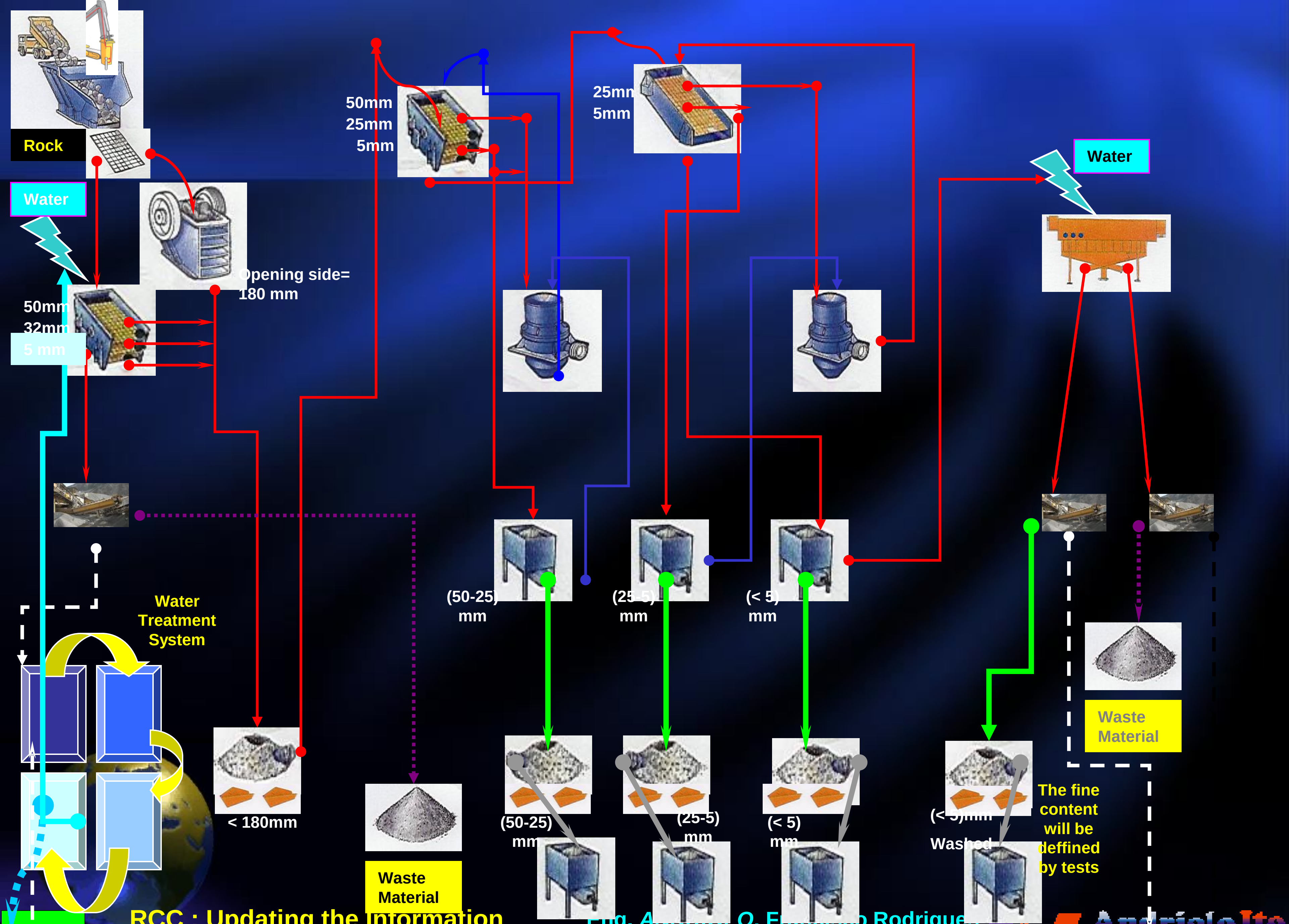
NOTE: No one of the CVC Mass Dams had required 40% or 60% of total aggregates being produced in advance

We can imagine if for the Itaipu Construction we had needed to stok 60% of the aggregates before start up the concrete placement ?

Histograms for the concrete works- Yellow –Planned; Red realized

Concrete Volume (m3)	60% of the Volume (m3)	Aggregate /m3 Concrete	Aggregate Volume requirede for the 60%	Stokage Area considering a Surge Pile height of 12m (as exemple)
13.000.000	8.400.000	2,2 t/m3	12.000.000m3	1.000.000m2
Total Area used during the Construction			**About 60.000m2 in both systems**	
Diference between the example and the Real situation			1.000.000-60.000= 940.000m2 it means about 16 times the really required	

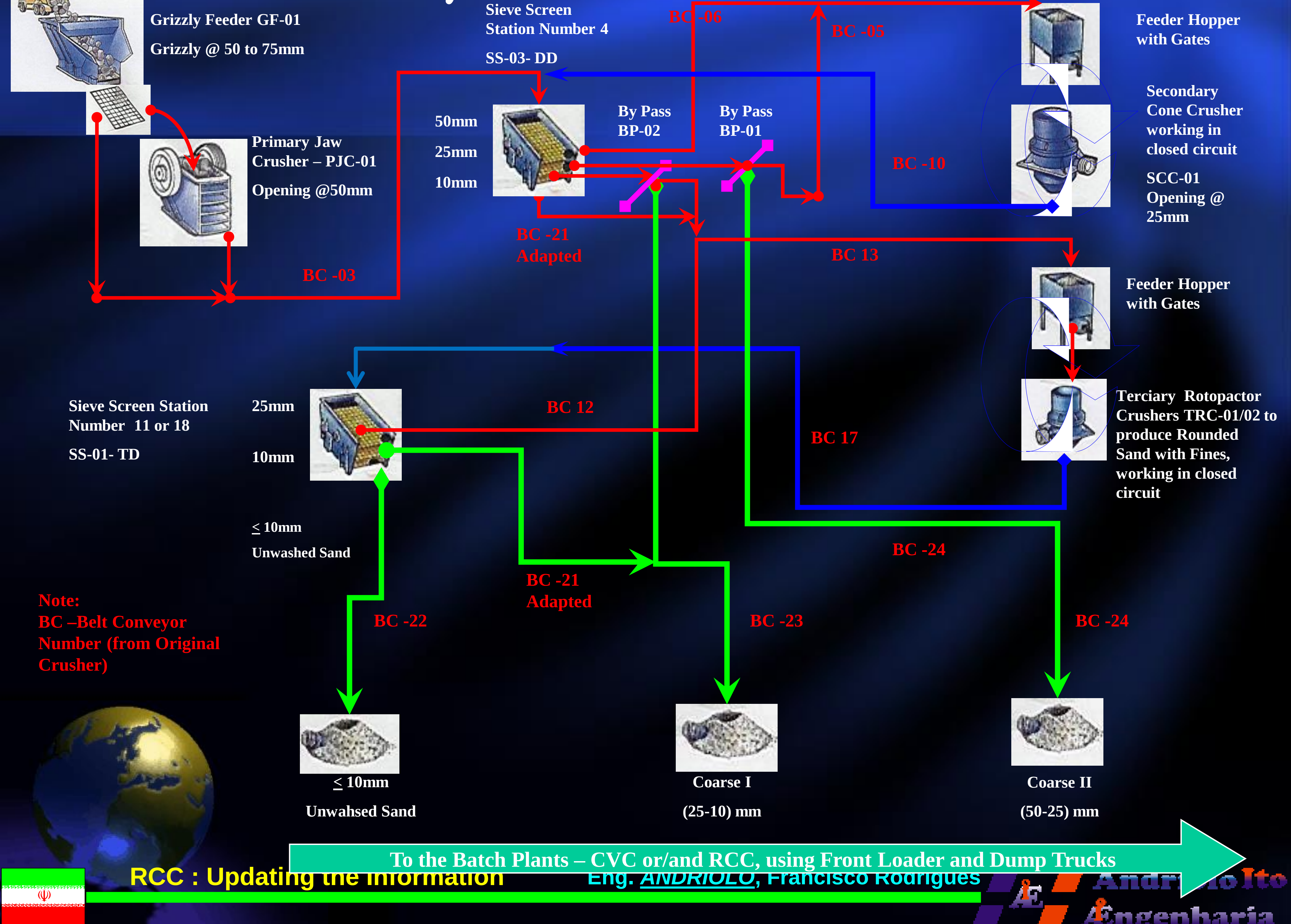
Areas of the Aggregate processing Systems and Aggregate pre-cooling with wet-belt , in both sides of the Parana River, during the Dam Construction



RCC : Updating the Information

Eng. ANDRIOLO, Francisco Rodrigues

Basic System



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Part II- RCC Dam Construction- Methodologies

II.b) Production, Handling, Pouring, Compaction

Hydroelectric- CVC Concrete Volume	Period	Event
Ilha Solteira- 3,680,000m3	1970-1972	Use of CVC Mass with an 84kg/m3 of cementitious consumption (61 cement + 23 Pozzolan). Concretes controlled at 180 days age.
Itumbiara- 2,080,000m3	1975-1980	Concrete class zoning, with age control from 90 to 180 days.
Itaipu- 13,000,000m3	1977-1982	Concrete class zoning, with age control from 180 and 360 days. 90 kg/m3 of cementitious content. Production rate above 750m3/h
Tucurui- 6,000,000m3	1978-1984	Concrete class zoning, with age control at 180 days. Up to 95 kg/m3 of cementitious content. Production rate above 500m3/h





Materials Analysis

Cement

The parameters of each type of cement are comparatively analyzed

Pozzolanic Material

The information concerning the availability – Technical and Economically of Pozzolanic Material

A Preliminary Program of Tests can (or must) be developed. This program will demonstrate the technical validity of the Pozzolanic Material or Rock Flour for eventual use as materials with pozzolanic characteristics.

Water and Admixtures

Tests Certificates from the available water must be obtained.

To provide these aggregates, at the beginning of the construction, two options can be viewed:

- Procure Local Producers, if any. In this case, **adopting a rigid System of Quality Control and Contracts** is advisable;

- Rely on a mobile classification system, fitted with a loader and feeding the trucks. Without any doubt, a simplified system of placing screens on the trucks may be adopted, however with less productivity and uniformity;

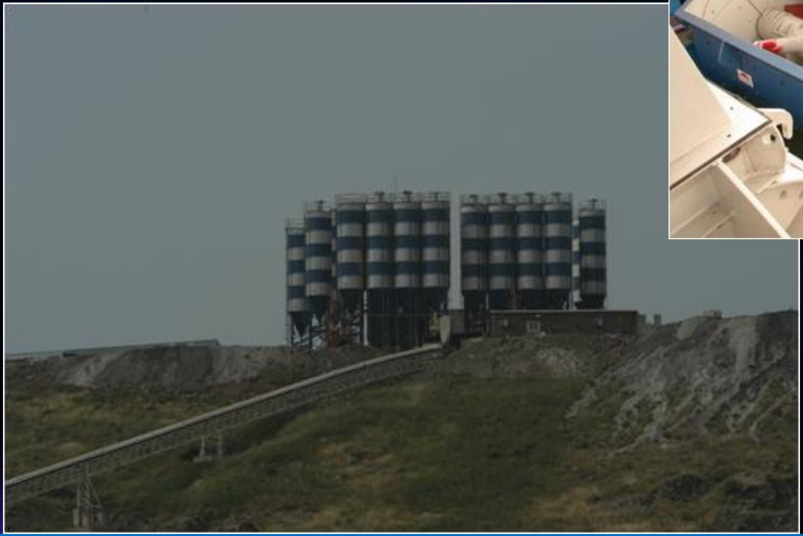
- In order to choose the options it is advisable to establish a Costs Analysis making them compatible with Contractor's Equipment Policy.

Construction Planning- Equipment & Techniques

- **Plant Requirements**:-The batching and mixing plant requirements are essentially the same as for a project built with conventional concrete. Experience indicates that forced mixers produce faster and more effective mixing and can be used for production of various concretes type.

- **RCC Placement Rates:-**One of the cost-saving features of RCC is the rapid rate at which it can be placed and consolidated by earthmoving and embankment compaction equipment.

CONCRETE BATCH PLANTS FOR RCC PRODUCTION



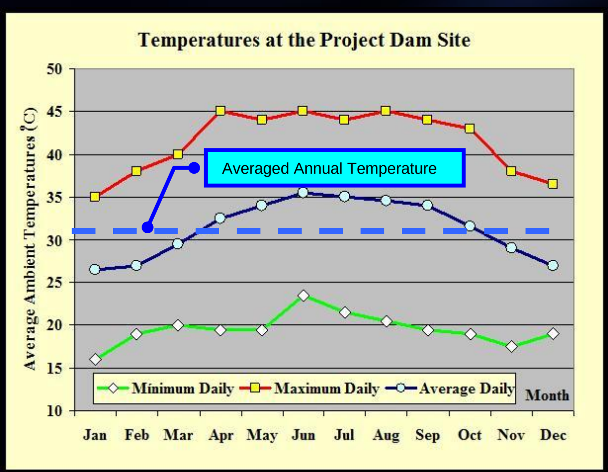
Precooling Systems

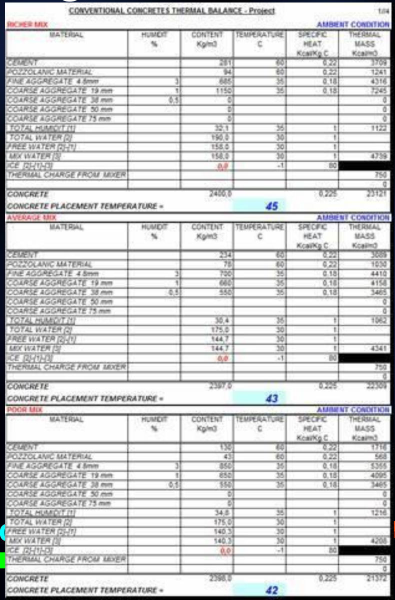
General

I, the Consultant, do not see a need for adopting a Pre-refrigeration system for the Roller Compacted Concrete, due to many reasons that can be understood from the Publication from the Consultant (myself) at the ***Symposium on RCC Dams that took place in November/2003 in Madrid, Spain***

Precooling System for CVC concretes

Considering the calculations and options shown ahead, one can see that in order to meet the Temperatures for concrete placing, the resume of activities cited it can be adopted:





CONVENTIONAL CONCRETES THERMAL BALANCE - Project 1/4

RICHER MIX — AMBIENT CONDITION

MATERIAL	HUMIDIT %	CONTENT Kg/m3	TEMPERATURE C	SPECIFIC HEAT Kcal/Kg C	THERMAL MASS Kcal/m3
CEMENT		281	60	0,22	3709
POZZOLANIC MATERIAL		94	60	0,22	1241
FINE AGGREGATE 4.8mm	3	685	35	0,18	4316
COARSE AGGREGATE 19 mm	1	1150	35	0,18	7245
COARSE AGGREGATE 38 mm	0,5	0			0
COARSE AGGREGATE 50 mm		0			0
COARSE AGGREGATE 75 mm		0			0
TOTAL HUMIDIT [1]		32,1	35	1	1122
TOTAL WATER [2]		190,0	30	1	
FREE WATER [2]-[1]		158,0	30	1	
MIX WATER [3]		158,0	30	1	4739
ICE [2]-[1]-[3]		0,0	-1	80	
THERMAL CHARGE FROM MIXER					750
					0
CONCRETE		2400,0		0,225	23121
CONCRETE PLACEMENT TEMPERATURE =			45		

AVERAGE MIX — AMBIENT CONDITION

MATERIAL	HUMIDIT %	CONTENT Kg/m3	TEMPERATURE C	SPECIFIC HEAT Kcal/Kg C	THERMAL MASS Kcal/m3
CEMENT		234	60	0,22	3089
POZZOLANIC MATERIAL		78	60	0,22	1030
FINE AGGREGATE 4.8mm	3	700	35	0,18	4410
COARSE AGGREGATE 19 mm	1	660	35	0,18	4158
COARSE AGGREGATE 38 mm	0,5	550	35	0,18	3465
COARSE AGGREGATE 50 mm					0
COARSE AGGREGATE 75 mm					0
TOTAL HUMIDIT [1]		30,4	35	1	1062
TOTAL WATER [2]		175,0	30	1	
FREE WATER [2]-[1]		144,7	30	1	
MIX WATER [3]		144,7	30	1	4341
ICE [2]-[1]-[3]		0,0	-1	80	
THERMAL CHARGE FROM MIXER					750
					0
CONCRETE		2397,0		0,225	22309
CONCRETE PLACEMENT TEMPERATURE =			43		

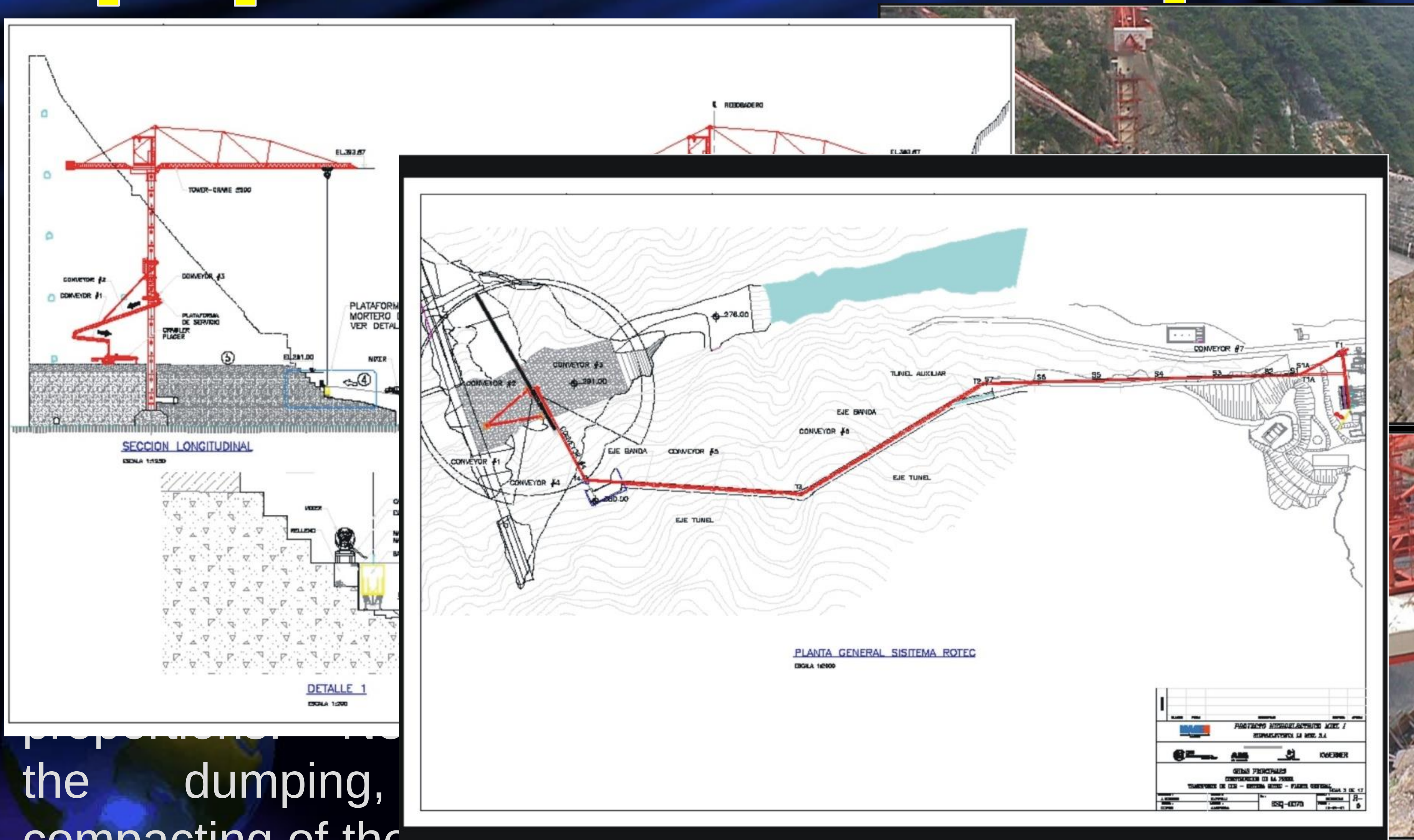
POOR MIX — AMBIENT CONDITION

MATERIAL	HUMIDIT %	CONTENT Kg/m3	TEMPERATURE C	SPECIFIC HEAT Kcal/Kg C	THERMAL MASS Kcal/m3
CEMENT		130	60	0,22	1716
POZZOLANIC MATERIAL		43	60	0,22	568
FINE AGGREGATE 4.8mm	3	850	35	0,18	5355
COARSE AGGREGATE 19 mm	1	650	35	0,18	4095
COARSE AGGREGATE 38 mm	0,5	550	35	0,18	3465
COARSE AGGREGATE 50 mm		0			0
COARSE AGGREGATE 75 mm		0			0
TOTAL HUMIDIT [1]		34,8	35	1	1216
TOTAL WATER [2]		175,0	30	1	
FREE WATER [2]-[1]		140,3	30	1	
MIX WATER [3]		140,3	30	1	4208
ICE [2]-[1]-[3]		0,0	-1	80	
THERMAL CHARGE FROM MIXER					750
					0
CONCRETE		2398,0		0,225	21372
CONCRETE PLACEMENT TEMPERATURE =			42		

Precooling System for RCC Concretes

As previously mentioned, there seems to be no need for the use of Pre-cooling of the RCC, even for temperatures of up to 35ºC, with layers of 30cm in height, placed daily, close near the rock foundation.

Construction Planning- Equipment & Techniques



- …
- … the dumping, … compacting of the RCC.

Concrete Handling

Concrete Transportation

Essentially, the transport system for the CVC and RCC should be foreseen, seeing that as previously considered, the following will be adopted:

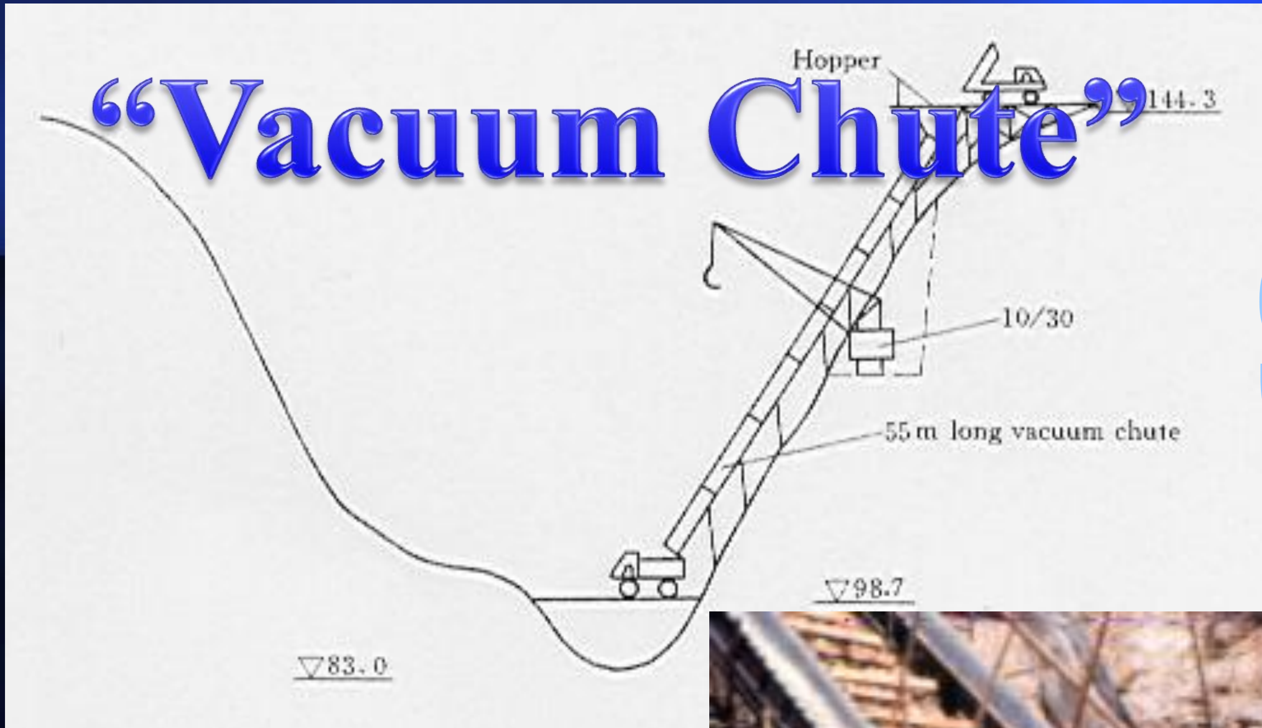
- Truck Mixers with capacity for $6m^3$, for the CVC, and mortars, and;
- Dump Rear Trucks with capacity about $8\text{-}18m^3$, for the RCC, and Processed Aggregates.

The structures Lay-Out and available area for the Installations indicate that distances for concrete Transport will be less than 1km.

The use of Conveyor Belts for concrete transport can be considered, since although it is perfectly adequate equipment, but it requires elevated costs.

However, there are technical possibilities for their use, even though the required productivities are very small.

“Vacuum Chute”



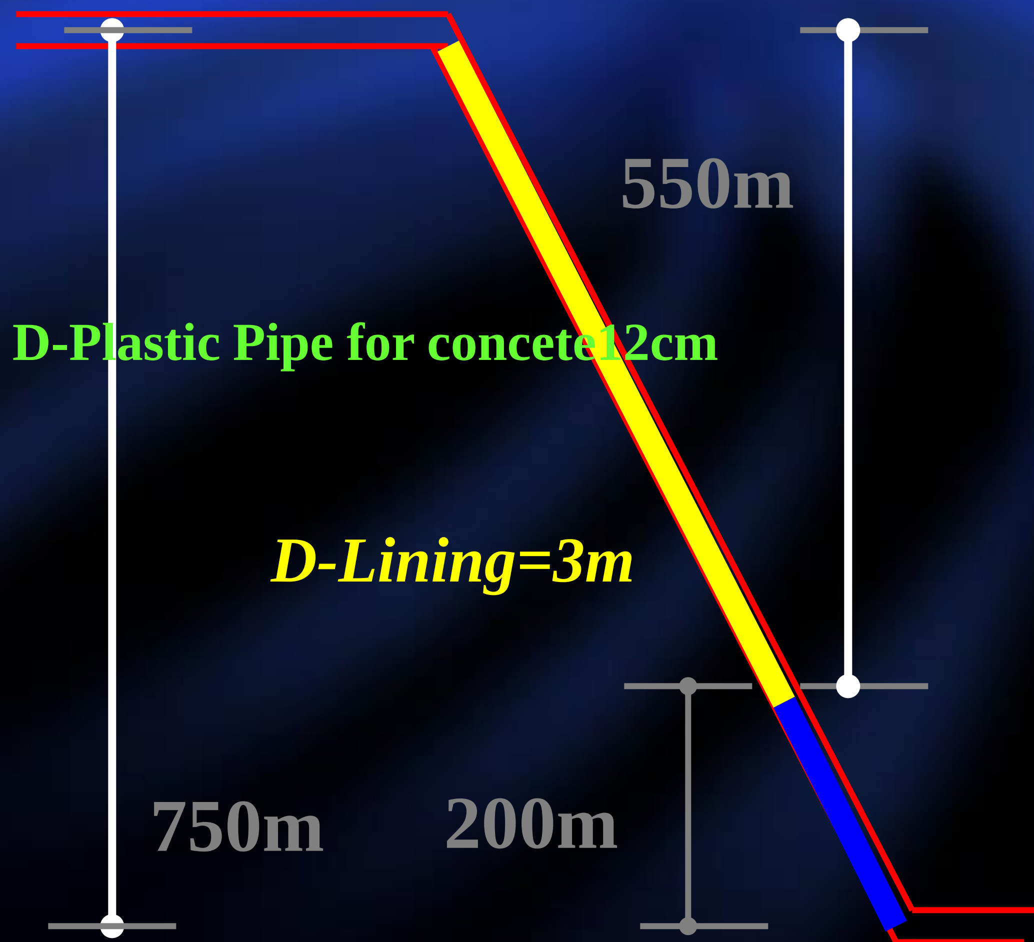
Shuidong

Jiangya

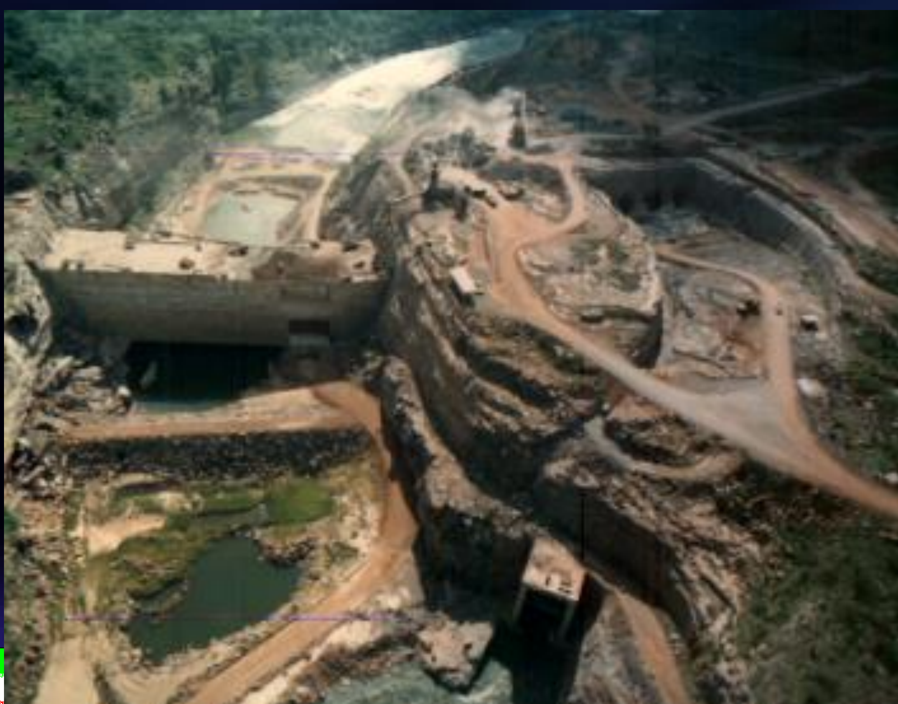
The Soviets, during the 50-60, were the users of this methodology to handling the concrete. Since the 70’s the Brazilians incorporated this metodology also

Ilha Solteira- 1972-73

San Gaban-Peru



Itaipu



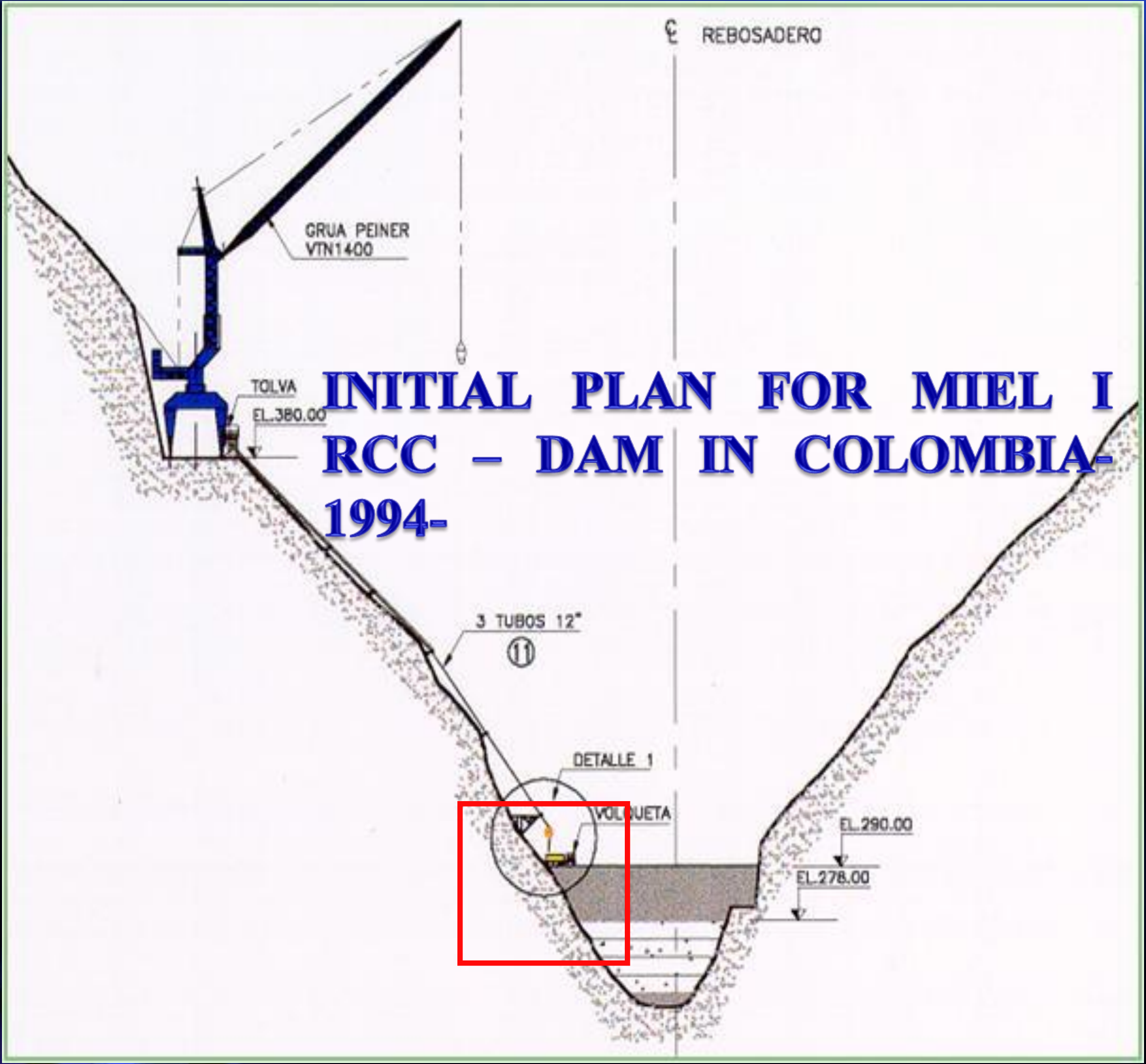
Vacuum Chute !

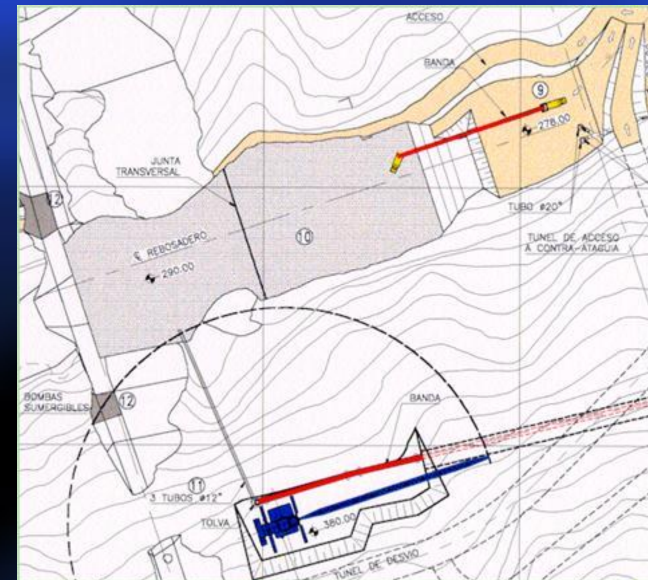
RCC – DAM CONSTRUCTION - CVC & RCC HANDLING

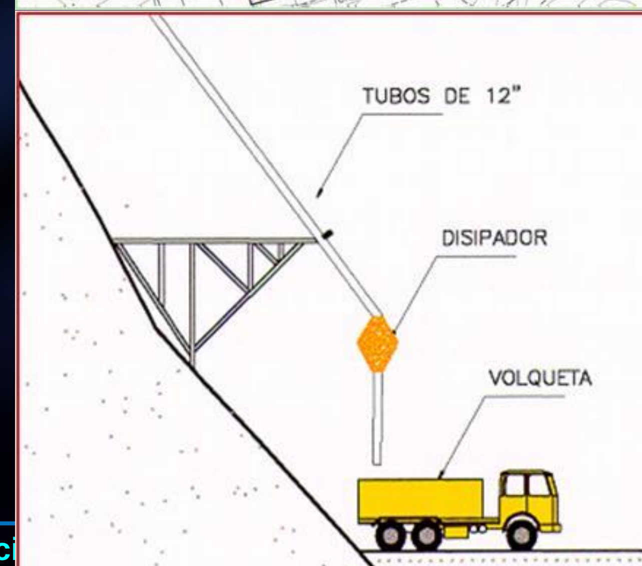
CVC & RCC HANDLING – HANDLING BY CHUTES & TRUCKS

CAPANDA RCC – DAM IN ANGOLA- 1987-

CVC & RCC HANDLING – HANDLING BY CHUTES & TRUCKS







CVC & RCC HANDLING – HANDLING BY CHUTES & TRUCKS

Construction Planning-Equipment & Techniques

Spreading RCC:-The design of dams with lift thickness greater than 300mm is based on the realization that constant spreading of the RCC with heavy dozers not only remixes and redistributes the concrete in such a way as to eliminate (and overcome) segregation, but also provides most of the required compaction. This also results in the paste and mortar becoming thoroughly distributed in the mass.

Compaction:-Roller speed has an important effect on compaction. Evaluating uniformity throughout the entire depth of the lift has caused control procedures to be adopted.

RCC Leveling and Spreading

Conditions of the Foundation Rock (Photos bellow) infer that there will be need for using some volume of Leveling Concrete, which was cautiously considered in the Planning.

Please- Pay attention: I am not commercial representative from Equipments

To spread RCC a Bulldozer with frontal blade type Cat D5 can be used, or equivalent, working jointly in more open areas with a Motor Grader.

Cat D5 bulldozers, or equivalent, can be used for the spreading of the RCC. A laser beacon can be fixed to the plate of the dozer for leveling of the RCC surface. Additionally the Cat 428 B backhoe-loader, or equivalent, can be used for re-mixing and for reaching the restricted areas.

The spreading should be in layers of 30cm maximum height (after compaction).

Construction Planning- Equipment & Techniques

- **Lift Surface Moisture Maintenance:-** For roller compression lift surfaces should be moistened and kept continuously damp until the next lift is placed or until the required curing period has ended. This is very important in hot weather conditions.

- **Lift Surface Preparation:-** Lift surface preparation prior to placement of the overlying RCC lift depends, to some extent, on construction procedures and routines being used.

- **Lift Joint Bedding:-**As previously mentioned, RCC structures designed for watertightness require bonding between lifts by applying a bedding mortar over the entire surface area between all lift placements.

Concrete Compaction or Densifying

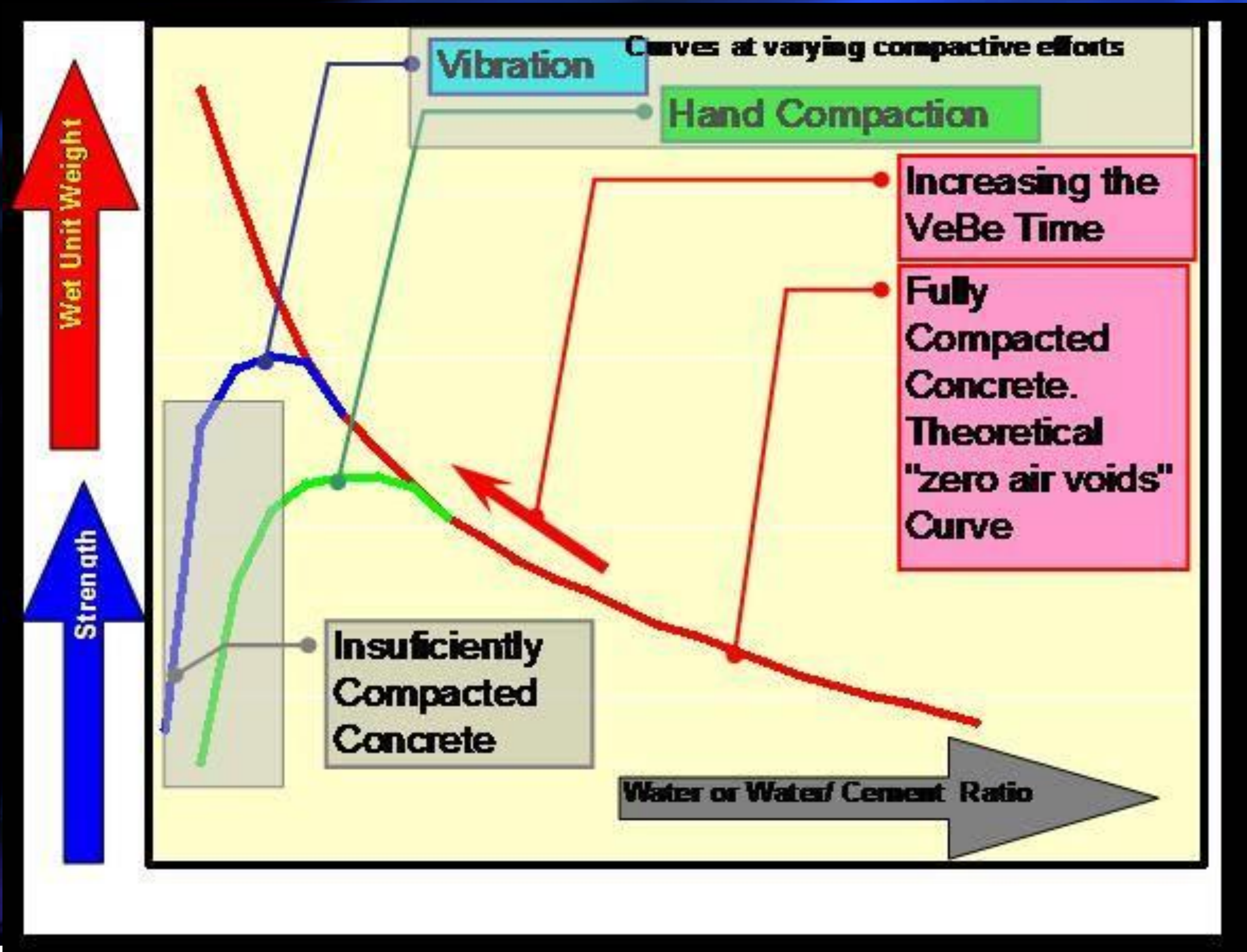
The CVC concretes should be densified by immersion vibrators, by Pneumatic, Hydraulic or Electric action (depending on Contractor's interest and Equipment policy) with sizes of 107mm; 77mm; 47mm and 26mm, advising to use an Effective Set (completely vibrating the concretes) with a minimum of 2 units per size.

After spreading, the RCC concrete will be compacted by Roller Compactors with the following characteristics

Flywheel power: 112kw-150hp.
Max. Operating Mass: 14.200kg.

Flywheel power: 23kw-29hp.
Max. Operating Mass: 2.400kg.

Reverse vibratory plate, with speed and compaction depth regulated by hydraulic servo control of the eccentric element.


Wet Unit Weight
Strength
Curves at varying compactive efforts
Vibration
Hand Compaction
Increasing the VeBe Time
Fully Compacted Concrete. Theoretical "zero air voids" Curve
Insuficiently Compacted Concrete
Water or Water/ Cement Ratio

Concrete Curing

Technically speaking, this activity is quite relevant for the success of the concrete work, considering the Region's Climate at the Job site.

From this, it be seen the need to foresee the water supplying system and sprinklers for the CVC concretes, in addition to an efficient protection system (during spreading) and RCC curing.

Agricultural Tractors with sprinklers, or sprinkler bars handled by the workers can be viewed, as suggested by Figure. The decision should be based on costs.

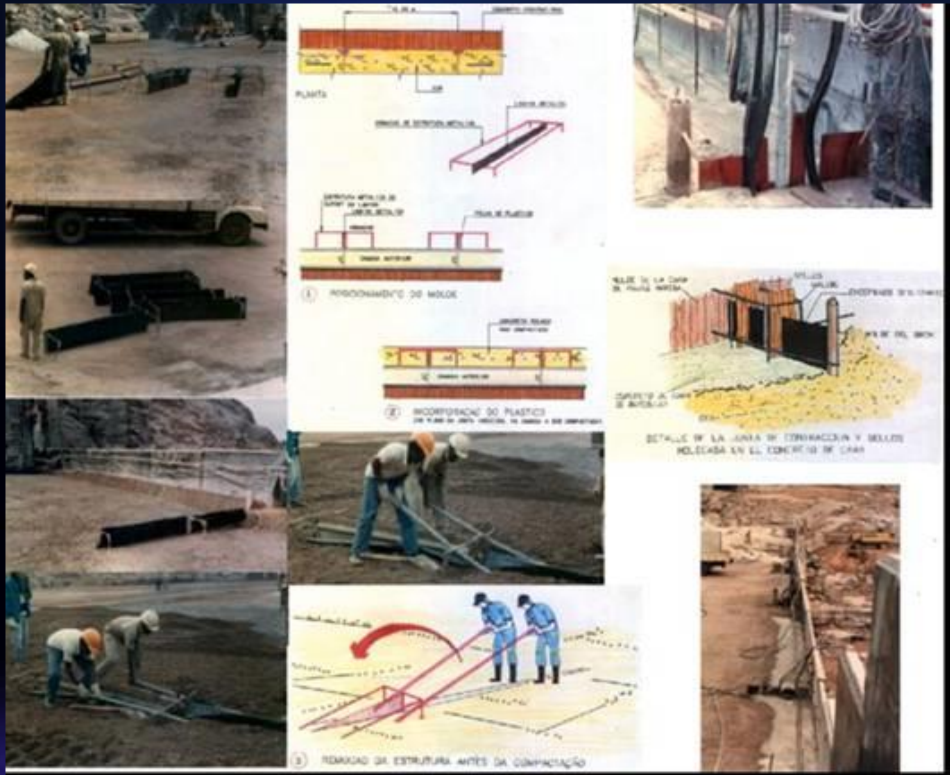
Construction Joint Treatment

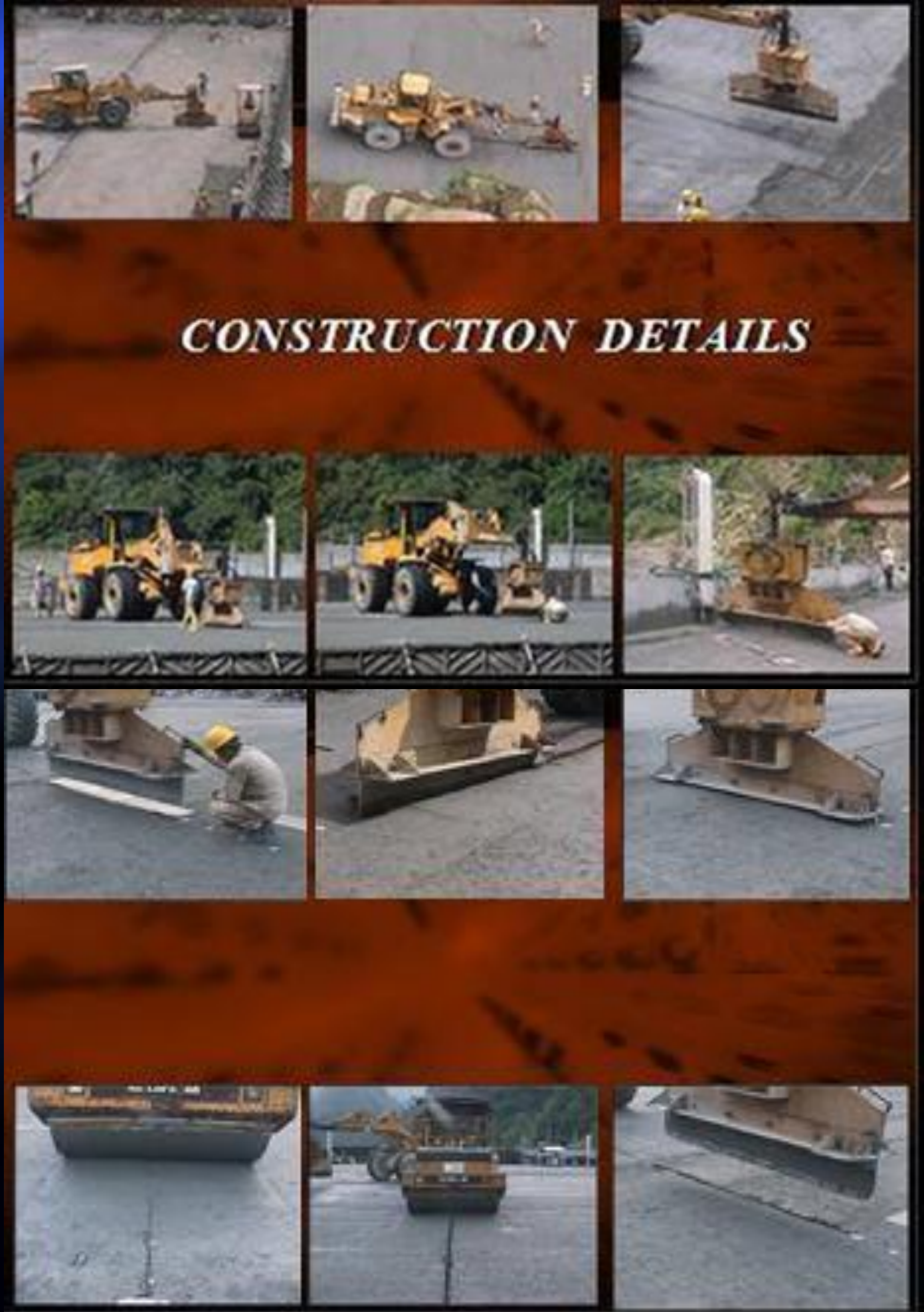
For the Construction Joints surfaces treatment, cleaning by humid air jets is foreseen for the RCC and high pressure water jet for the CVC.

After cleaning the construction joints of the RCC, it will be applied in the required regions of the Project Design, the Bedding Mortar, directly with the Mixer Truck's chute and complementary spreading with the aid of handle tools.

Contraction Joint Casting

Molding the Contraction Joints can be performed as illustrated by Figures bellow, depending on Contractor's criteria and cost.





RCC CONSTRUCTION TECHNOLOGIES

General

RCC is a technique in permanent development. New challenges have been afforded from the last meetings, symposiums, congresses, seminars and, consequently, trends and technologies have been either updated or developed. It always means an improvement in our techniques related to the construction and the quality

A new factor has much to do with this new frame of mind among the RCC dam professionals. Some questions were put in the last RCC Symposium (Spain-2003)

- *What is more Contractor's friendly, RCCs with high VeBe times (>20 sec) or with low VeBe times (<20 sec), regarding segregation and 'compactability' of the material?*
- *How is solved the placement at the starting and ending areas against the abutments with the sloped-layer method?*
- *What is the cost difference (capital cost & running cost) between the all-conveyor system and the option of conveyor+trucks on the lift, for the same real system outputs?*
- *Description of the handling process of the rock-powdered fines at the job site installations (silos, transportation systems, concrete plants) in the Brazilian experience. Are any special cares required?*
- *What is the maximum practical moisture content of the fines at the entrance of the mixer?*

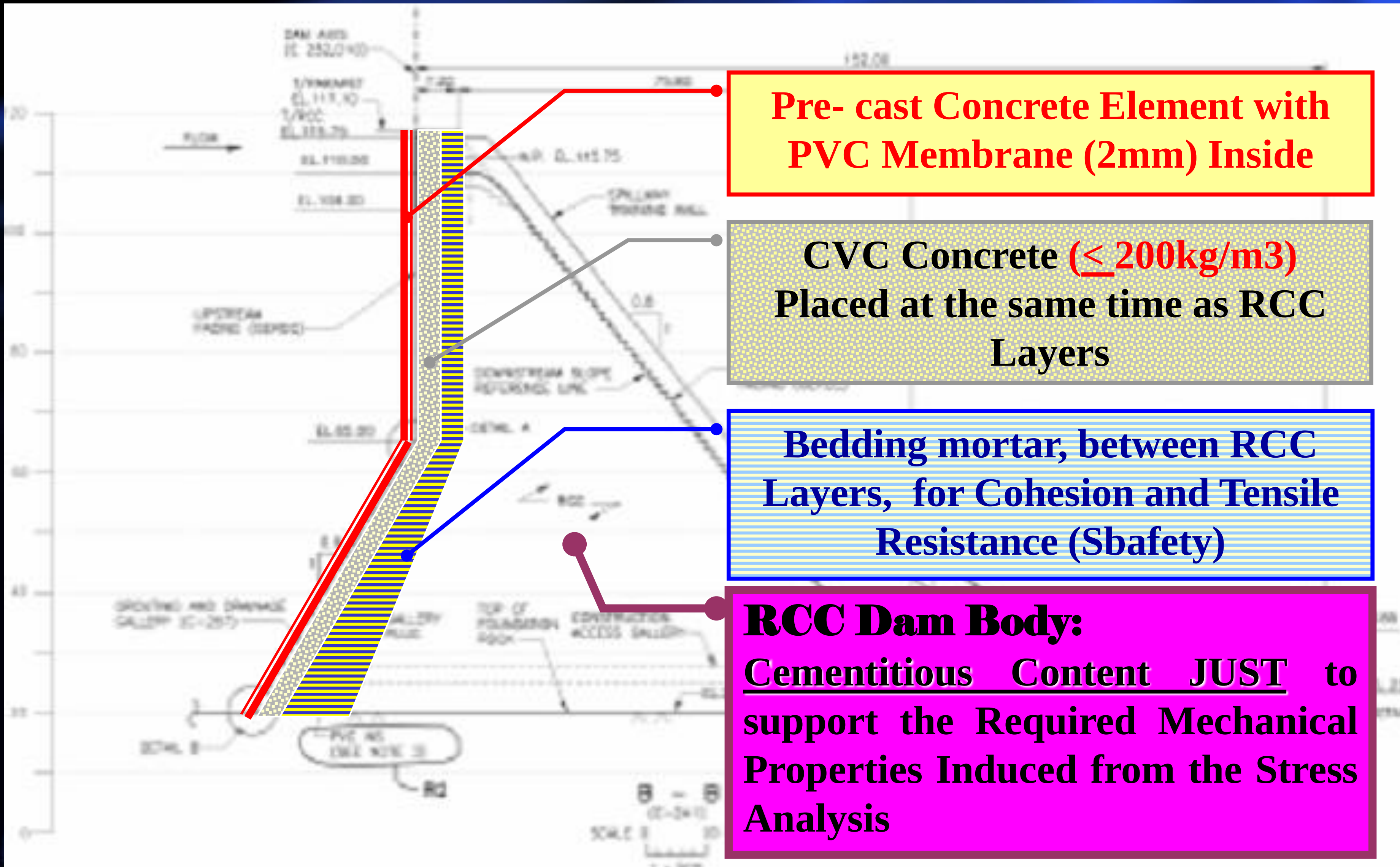
INTERFACE- DESIGN & CONSTRUCTION

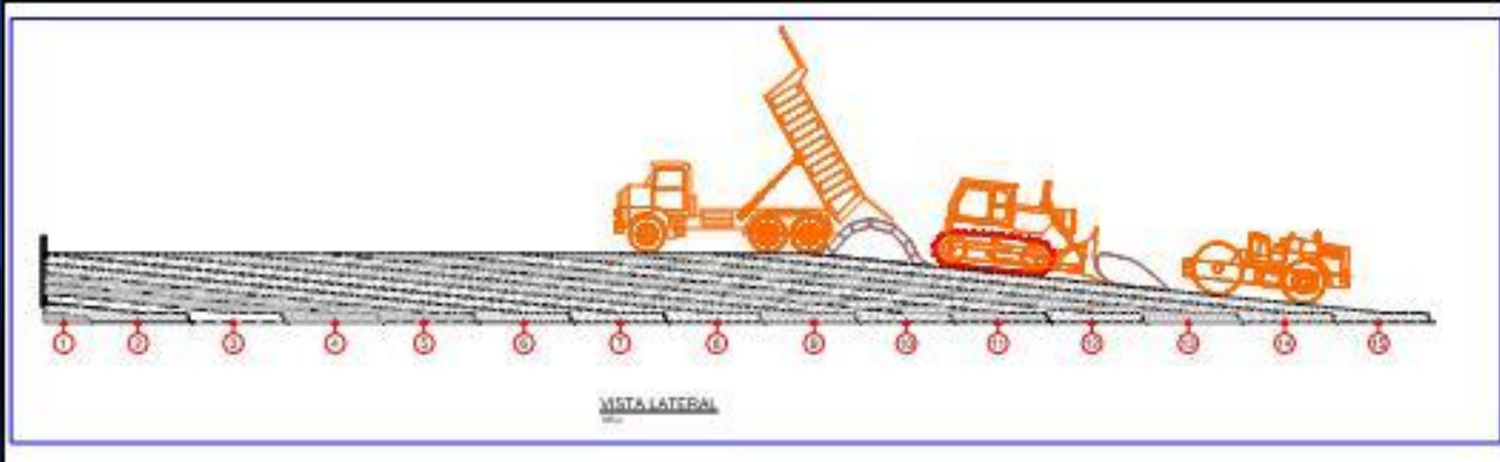
✓ **RCC arch dams**

RCC CONSTRUCTION TECHNIQUES

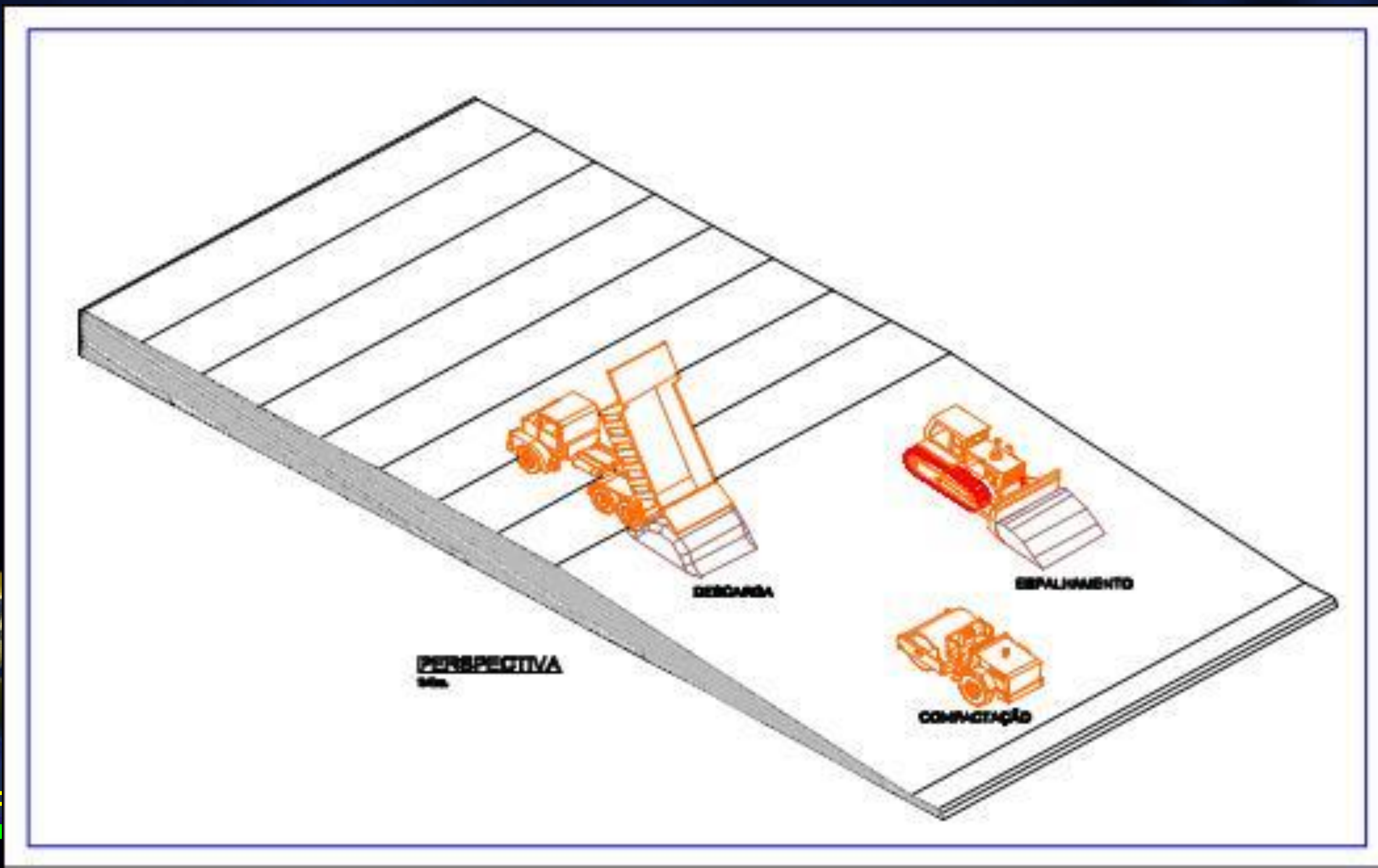
- Faces
- Mass Dam Body Materials
- RCC Handling and Accesses
- RCC Placement
  - Horizontal Layers
  - Sloped Layer Method
- RCC Contraction Joint Interval
- RCC Construction Joint Surface Treatment

✓ **MONITORING** - Instrumentation


Pre- cast Concrete Element with PVC Membrane (2mm) Inside
CVC Concrete (≤ 200kg/m3) Placed at the same time as RCC Layers
Bedding mortar, between RCC Layers, for Cohesion and Tensile Resistance (Sbafety)
RCC Dam Body:
Cementitious Content JUST to support the Required Mechanical Properties Induced from the Stress Analysis



VISTA LATERAL

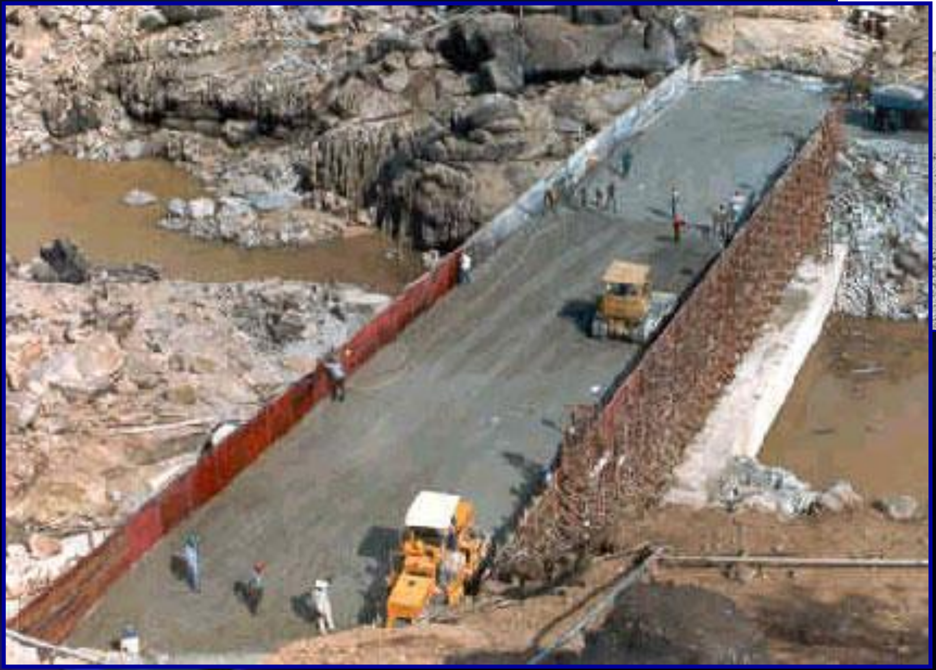


DESCARGA
ESPALHAMENTO
COMPACTAÇÃO
PERSPECTIVA

RCC – TRADITIONAL METHOD

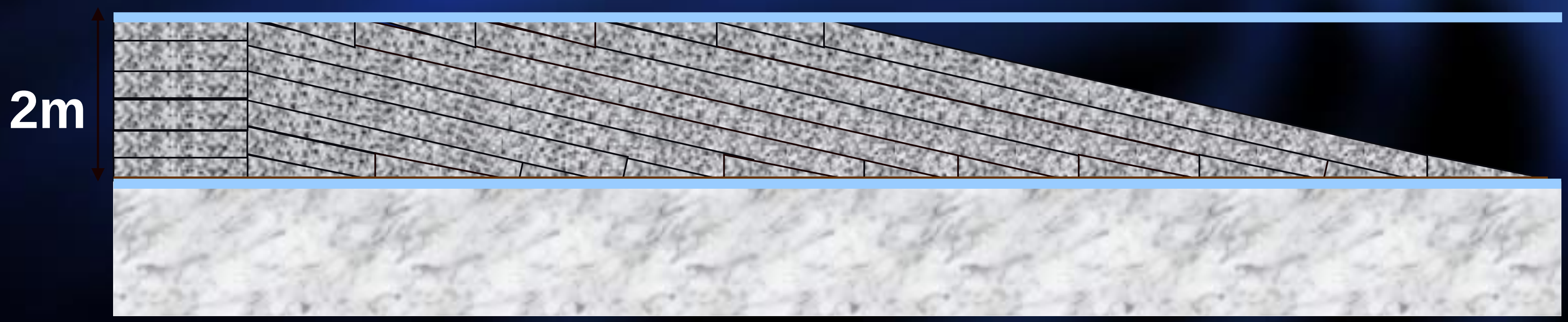
✓ 6 layer with h=0,33m

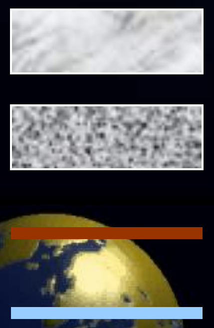
METHODOLOGY



RCC – SLOPE LAYERED METHOD

✓ Sub-layer continuous with h=0,33m





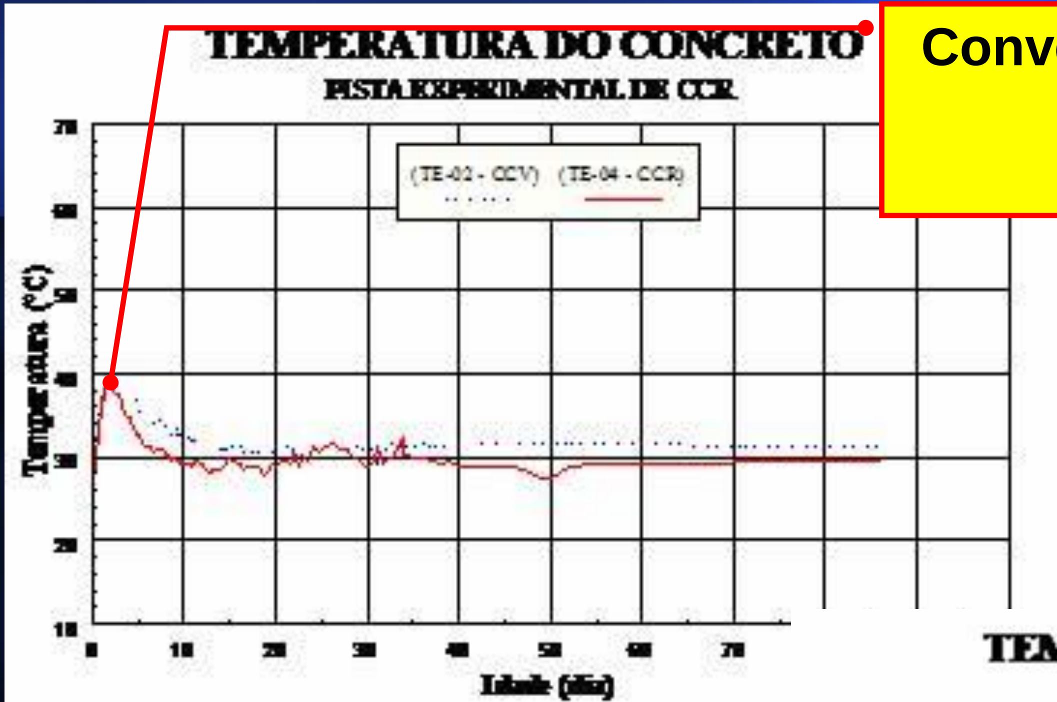
METHODOLOGY

Spread and compaction of RCC.

Traditional method

Sloped layer

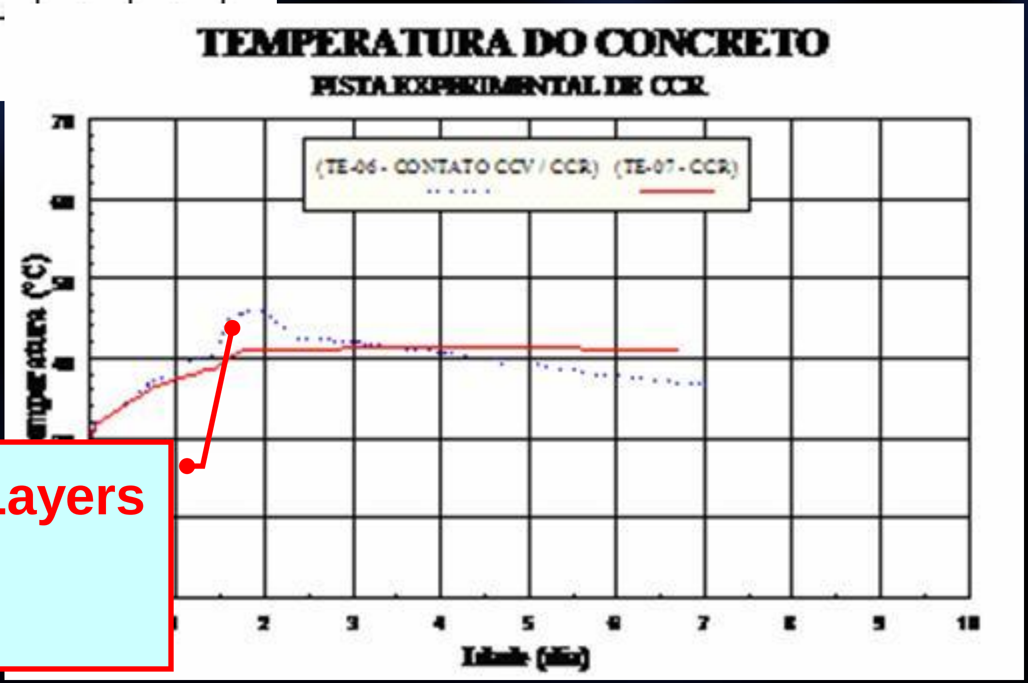

8. 1. 2001



Conventional – Horizontal Layers

Θ_{MAX} CVC= 39°C

Θ_{MAX} CCR= 39°C



***"NEW FASHION !"*- Sloped Layers**

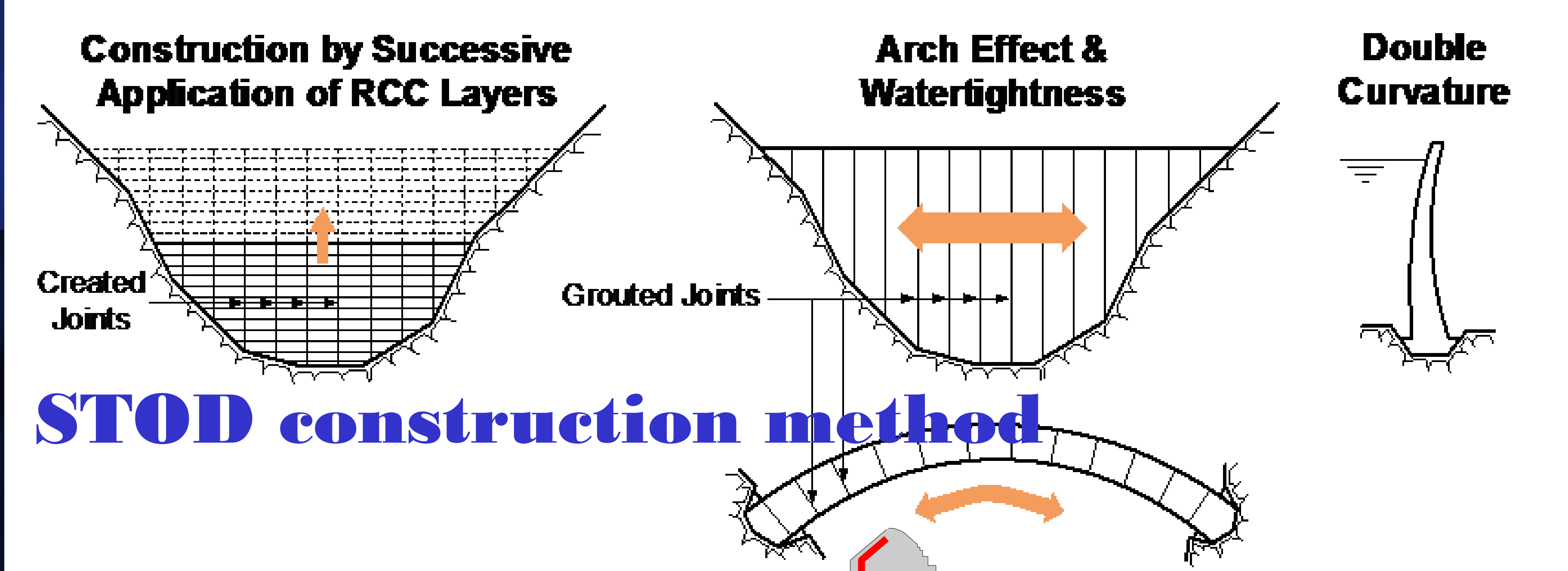
Θ_{MAX} CVC= 45°C

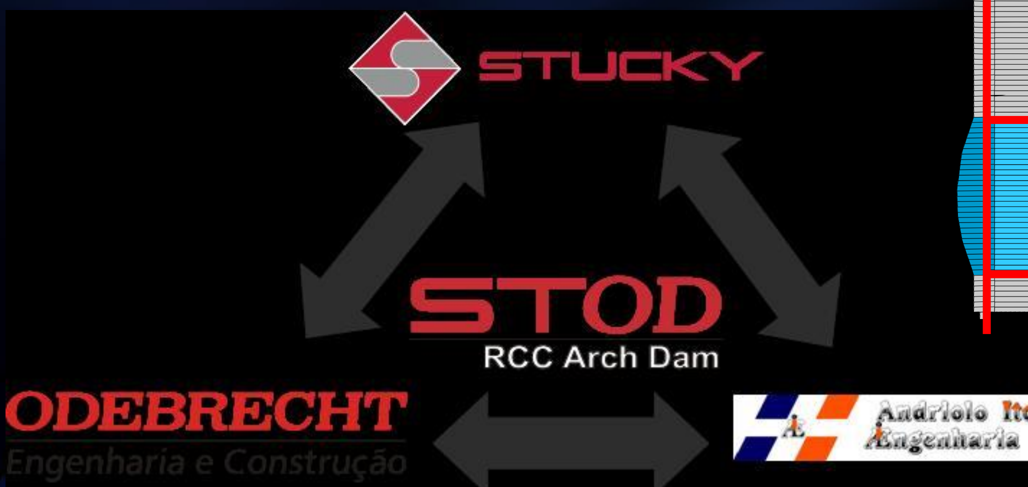
Θ_{MAX} CCR= 41°C

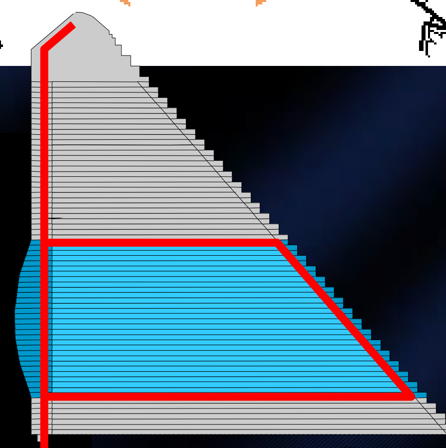

Why this is not NEW?
Years 77- 78
Years 97- 98
PERSPECTIVA
Itaipu
Tucuruí
Just Mass CVC,
with < 100 Kg/m3

Extended Layer Method

STOD construction method







From the previous considerations, it is important to mention that the best alternative for a RCC dam should be analyzed depending on the particular conditions of the foundation, the materials locally available and their local cost of exploitation and processing.

Part II- RCC Dam Construction- Methodologies

II.c) Upstream and Downstream Faces And construction Joint Treatments

Watertightness and seepage control.

Achieving watertightness and controlling seepage through RCC dams are particularly important design and construction considerations.

Excessive seepage is undesirable from the aspect of structural stability and because of the adverse appearance of water seeping on the downstream dam face, the economic value associated with lost water, and possible long-term adverse impacts on durability.

RCC that has been properly proportioned, mixed, placed, and compacted should be as impermeable as conventional concrete.

The joints between the concrete lifts and interface with structural elements are the major pathways for potential seepage through the RCC dam.

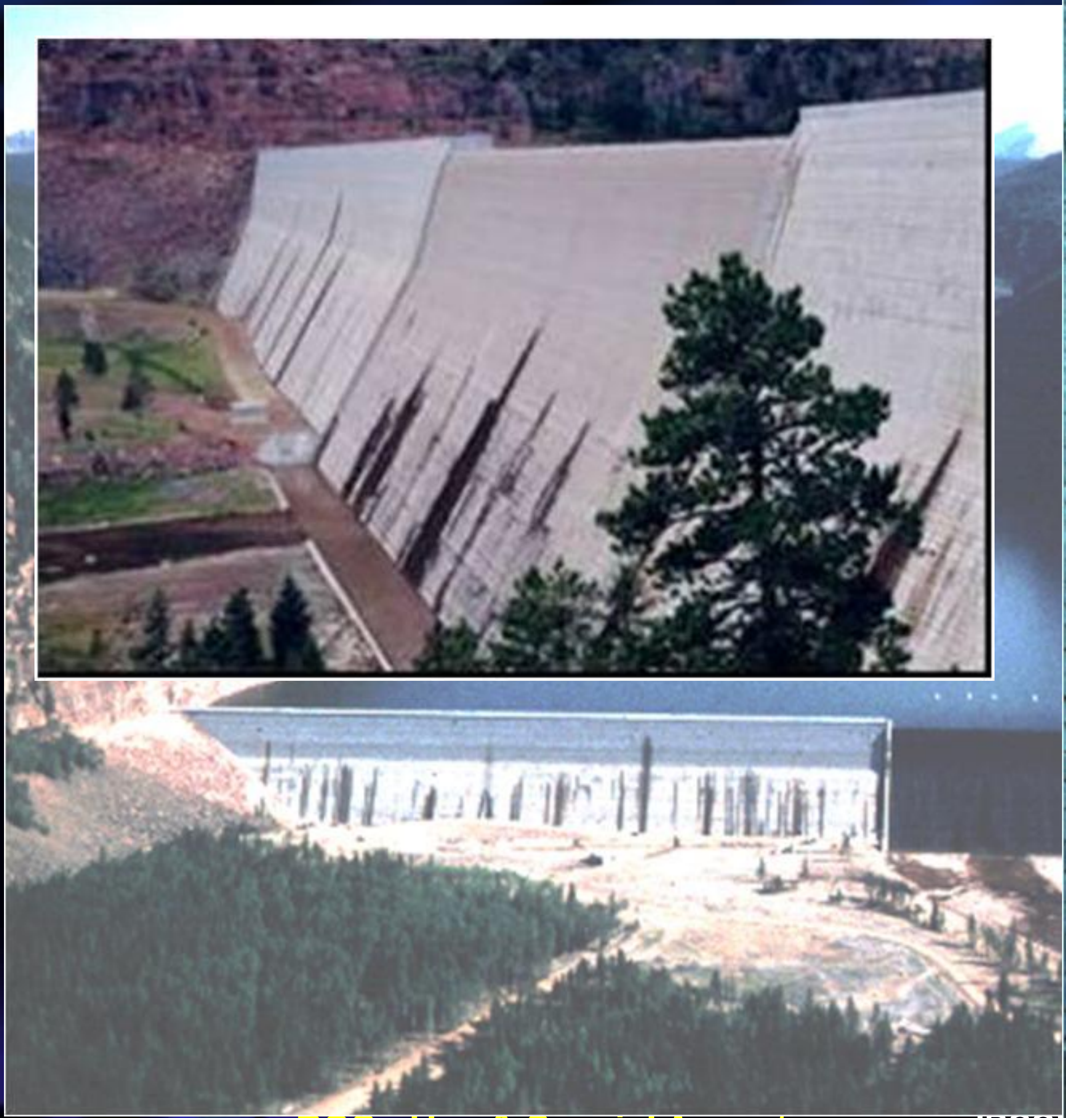
Horizontal joint treatment.

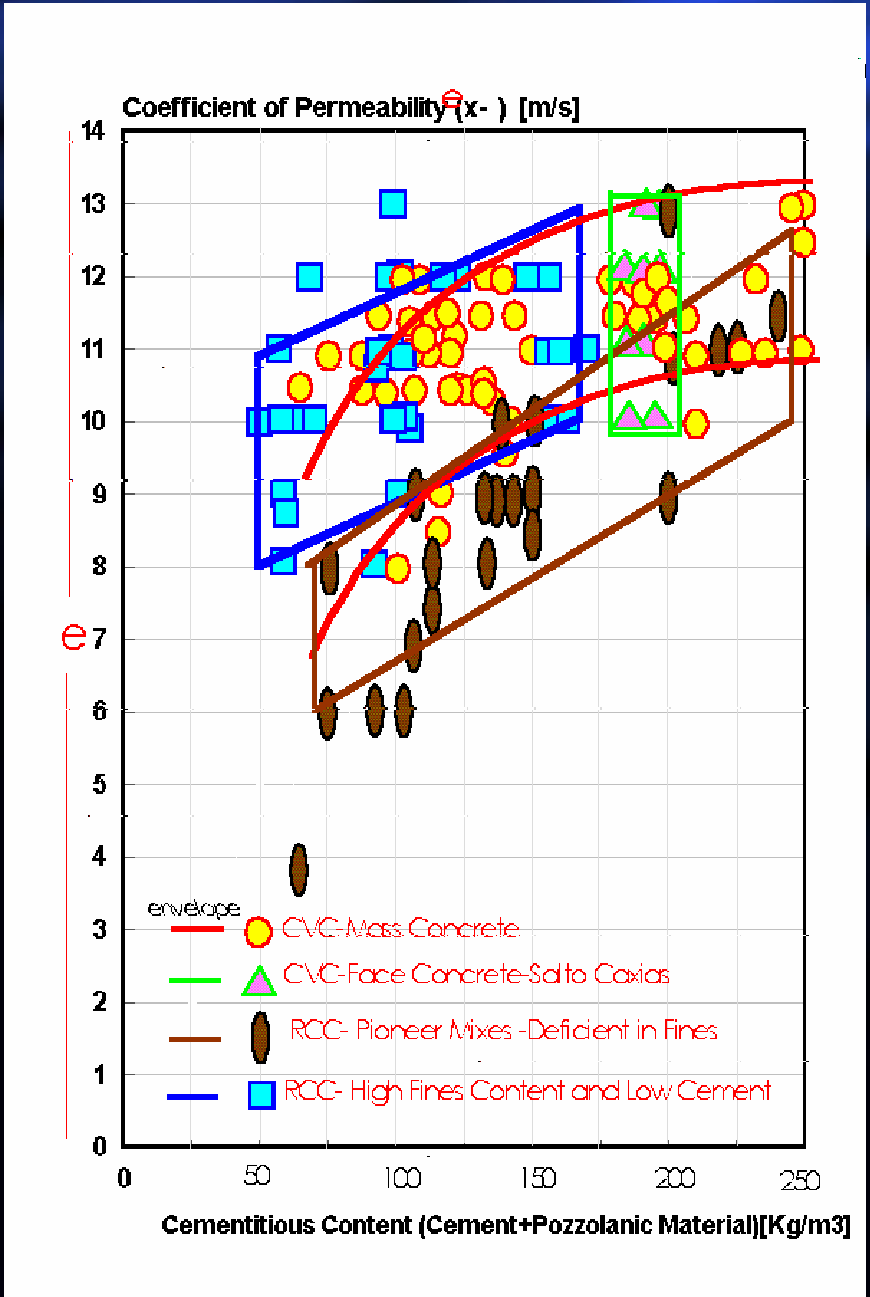
*Bond strength and*permeability are major concerns at the horizontal lift joints in RCC.

Good sealing and bonding are accomplished by improving the compactibility of the RCC mixture, cleaning the joint surface, and placing a bedding mortar (a mixture of cement paste and fine aggregate) between lifts.

When the placement rate and setting time of RCC are such that the lower lift is sufficiently

USA




Coefficient of Permeability (x-) [m/s]
14
13
12
11
10
9
8
e 7
6
5
4
3
2
1
0
0
50
100
150
200
250
Cementitious Content (Cement+Pozzolanic Material)[Kg/m3]
envelope
CVC-Mass Concrete
CVC-Face Concrete-Salto Caxias
RCC- Pioneer Mixes -Deficient in Fines
RCC- High Fines Content and Low Cement

As dimensões estimadas para a solução de envelopamento foram calculadas a partir de critérios conservadores, sendo adotada a equação desenvolvida por Bazant para a determinação da espessura de concreto de paramento e de fundação.

$$e = \sqrt{2.p.k.\frac{t}{\alpha}}$$

Onde: e = espessura de paramento; p = pressão da coluna d'água; k = coeficiente de permeabilidade; t = tempo de vida útil considerado ; α = volume de vazios após a hidratação (%).

Considerou-se para esse cálculo, que o coeficiente de permeabilidade do monolito fosse igual ao de juntas de construção tratadas de maneira convencional (10^{-10} cm/s) e um tempo de 100 anos para que a água percolasse através apenas do concreto de impermeabilização. Desta maneira, foi dimensionada a colocação de concreto massa convencional no paramento de montante e no contato com a fundação, sendo obtida uma espessura de 4,5 m junto ao pé de montante na seção de maior altura.

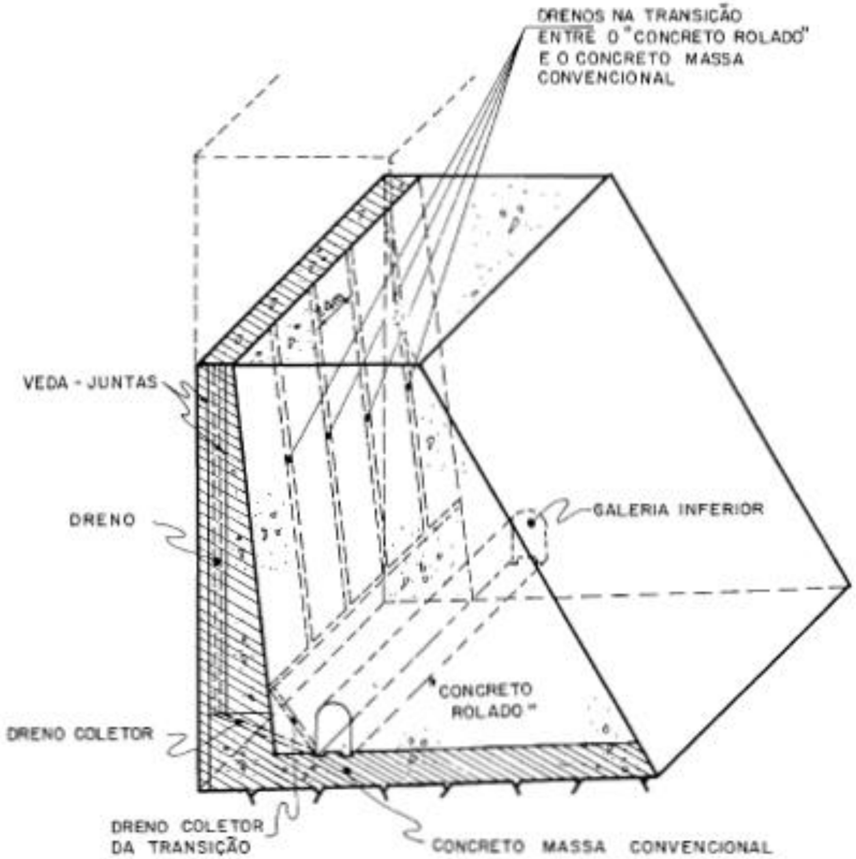


FIGURA 5 - SISTEMA DE DRENOS

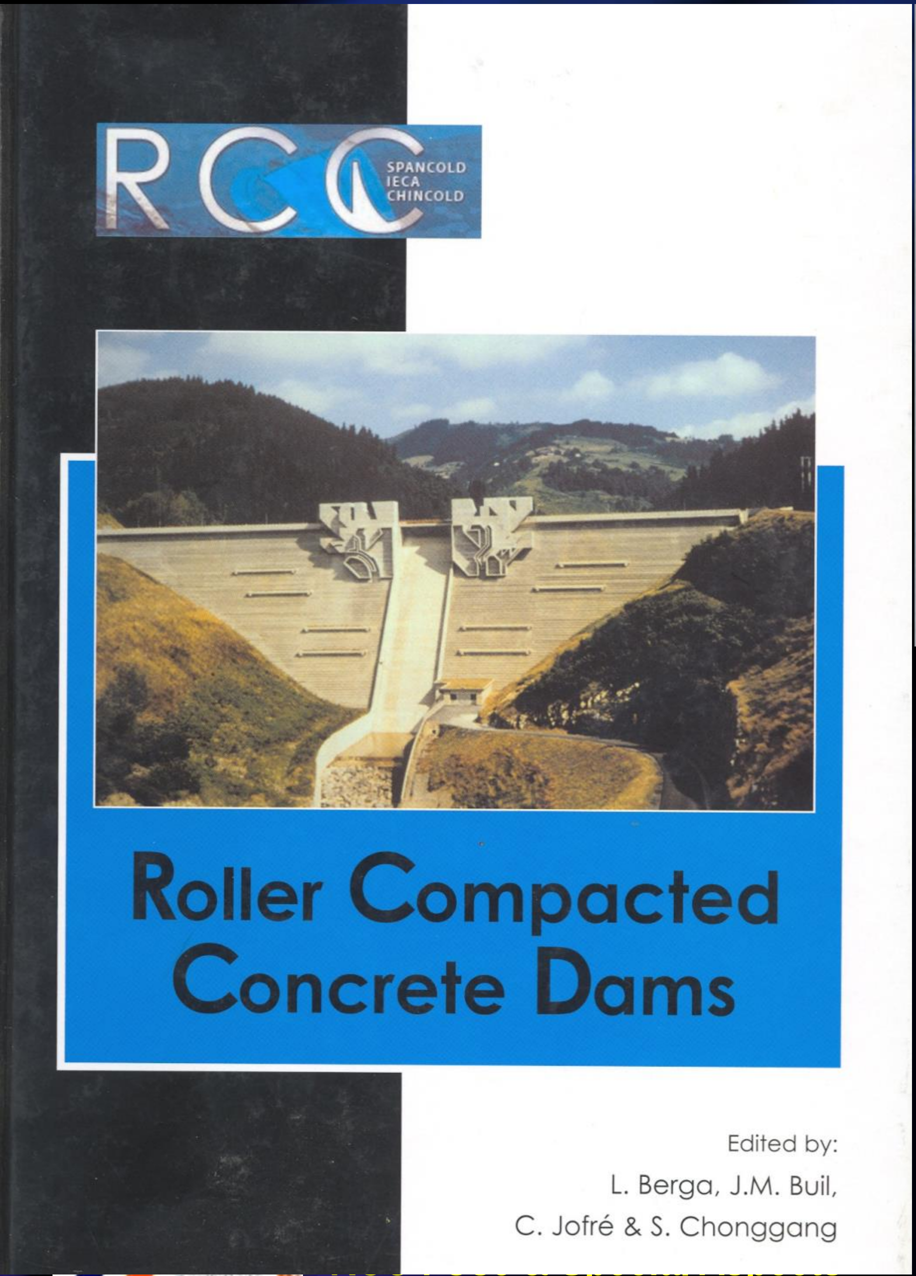


21 12:37

CVC against Formwork and RCC poured at same time

BUT, IF IN OLIVENHAIN RCC DAM THE GE-RCC ASPECT WAS LIKE...

AND AN ADDITIONAL CARPI PVC MEMBRANE WAS APPLIED



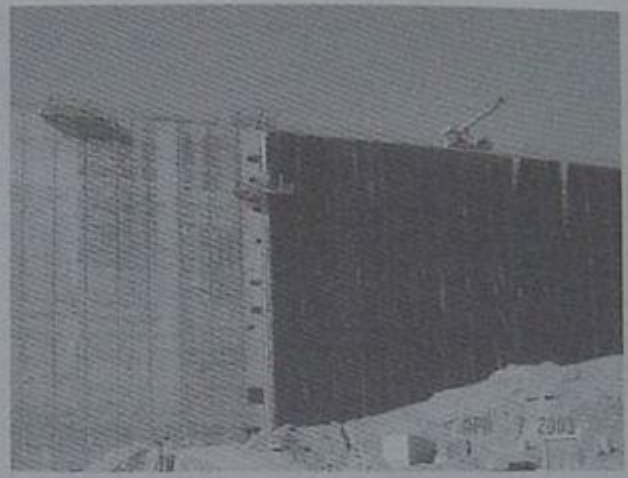
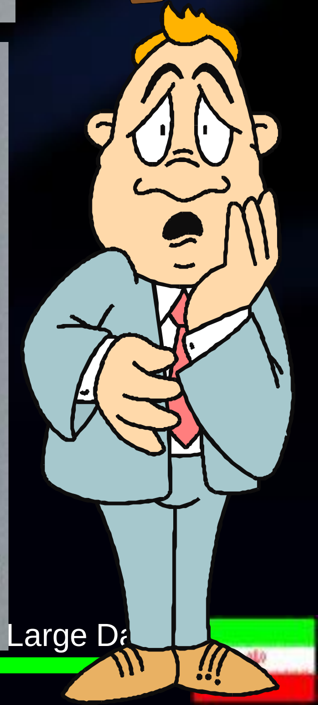


Figure 8. Olivenhain, USA: the drainage geonet is placed on the RCC and under the PVC geocomposite to enhance drainage collection and discharge.

Figure 9. Olivenhain, USA: the PVC geocomposite under installation at left abutment.

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Dams — Innovations for Sustainable Water Resources

DESIGN OF ROLLER-COMPACTED CONCRETE FEATURES FOR THE OLIVENHAIN DAM

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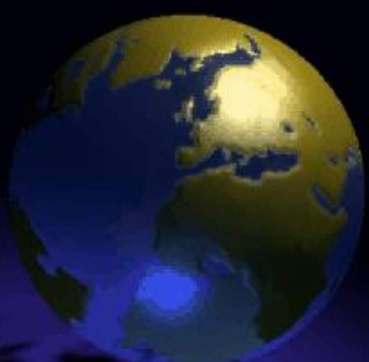
Rodney E. Holderbaum, P.E.[2]
Randall J. Hartman, P.E.[4]

ABSTRACT

The Olivenhain Dam will be a new roller-compacted concrete (RCC) gravity dam located near San Diego, California. At 318-feet-high (97 meters), the Olivenhain Dam will be the largest RCC dam in North America and the first RCC dam in the state of California. The Olivenhain Dam will create a 24,000 acre-ft reservoir as part of a 12 year, Emergency Storage Project (ESP) for the San Diego County Water Authority. The ESP is being developed to protect the residents in the San Diego region against a disruption in water deliveries from outside the County, including earthquake and drought.

This paper presents the design approach and results for RCC-specific features for this record-setting project. These features include upstream and downstream facing systems, foundation gallery, and thermal stress cracking computer modeling.



SELECT RCC DESIGN FEATURES

Facing Systems

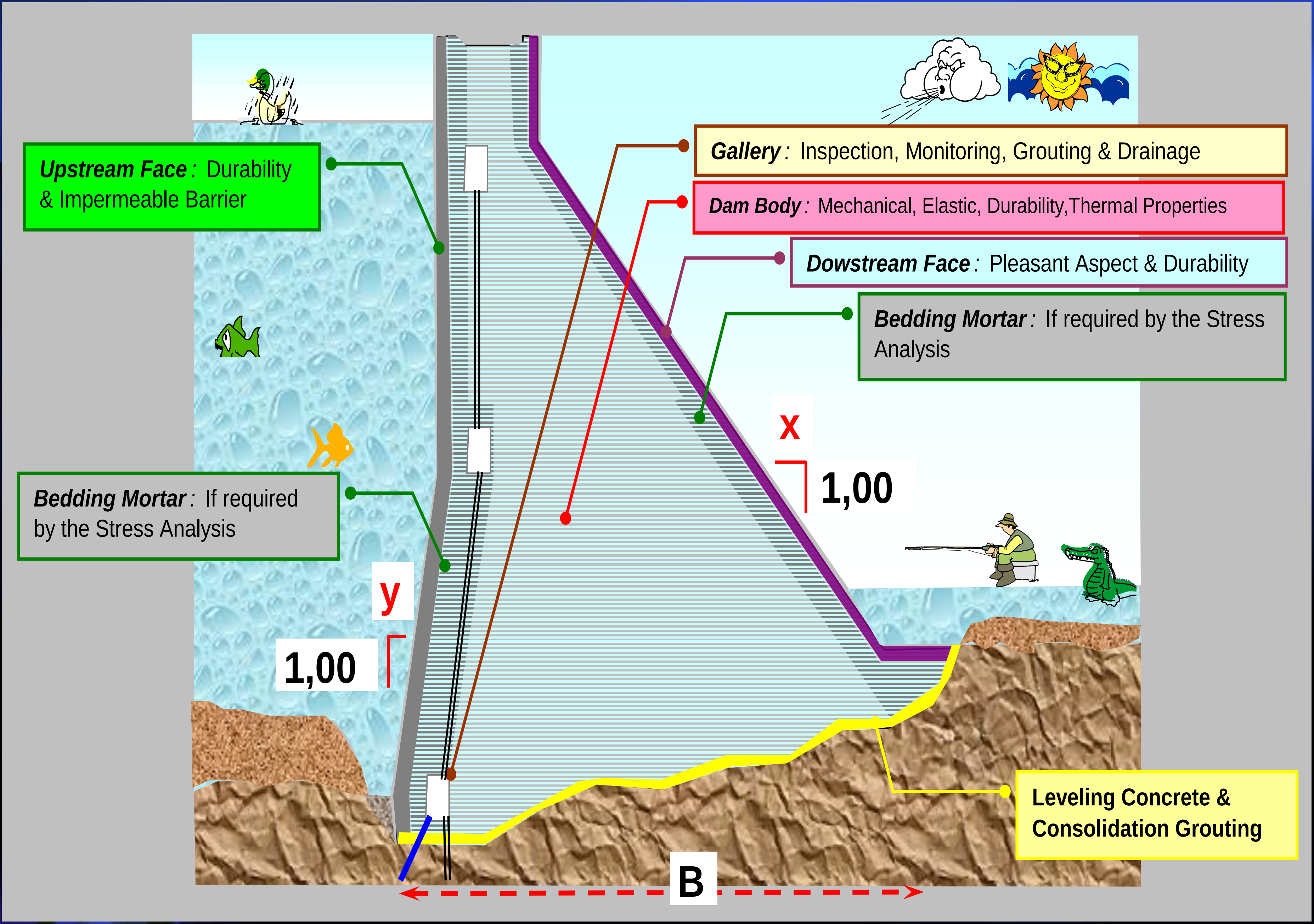
Prior to RCC dams, the upstream and downstream faces of conventional mass concrete dams were generally not considered as a separate design element, and there was no special costs allocated to the faces of the dam. The introduction of RCC construction techniques sought to reduce the cost of the forming materials for the dam faces and the associated high labor and equipment costs of setting, stripping, and resetting forms. This led to innovations for building both the upstream and downstream faces of RCC dams. A variety of upstream and downstream facing systems have been used on RCC dams with varying degrees of success.

Selection of a facing system for an RCC dam is site specific and must consider the intended purpose of the dam, operation and performance criteria, local climatic conditions, materials availability, structure size, and owner and public perception of the finished product.

the upstream face. Since the early 1990's, geomembrane liners have and are being used on a higher percentage of RCC dams due to these performance characteristics. Some of the advantages of the geomembrane liner are further described below:

1. Permeability: Dams constructed or retrofitted with a geomembrane liner system have unit seepage rates per upstream face surface area that are markedly lower than other upstream facing system alternatives.
2. Contraction Joints: The liner system eliminates the need to construct cumbersome and sometimes ineffective traditional waterstop systems concurrently with RCC placement operations at contraction joints within the dam. The liner can also span a high degree of differential movement at contraction joints and continue to function as intended.
3. Crack Propagation Reduction: Geomembrane liners have a significant impact on minimizing the potential for short and long-term cracking in the dam because of the reduction of reservoir pressure acting on shallow thermal stress cracks in the RCC at the upstream face, commonly referred to as surface gradient cracks.
4. Internal Drainage: Internal drainage is incorporated into an external liner system via a geogrid placed behind the liner at upstream face of the dam. This drainage layer is much more effective in reducing uplift pressure within the dam than conventional drilled drain holes positioned within the interior of the dam.
5. Seismic Stability: With the risk of horizontal crack development resulting from seismic-induced tensile stresses that exceed the RCC's ultimate tensile strength, the liner system material can elongate as much as 200% to span crack openings. Following a seismic event, the liner will prevent seepage losses through any resulting cracks.

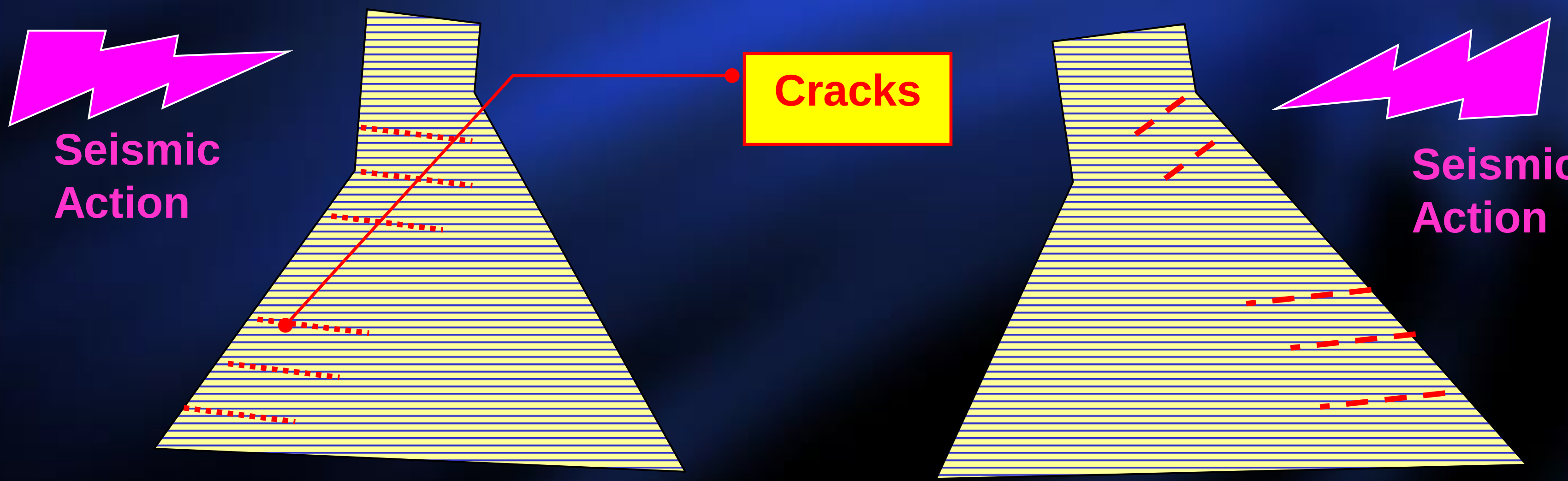

22 10:24



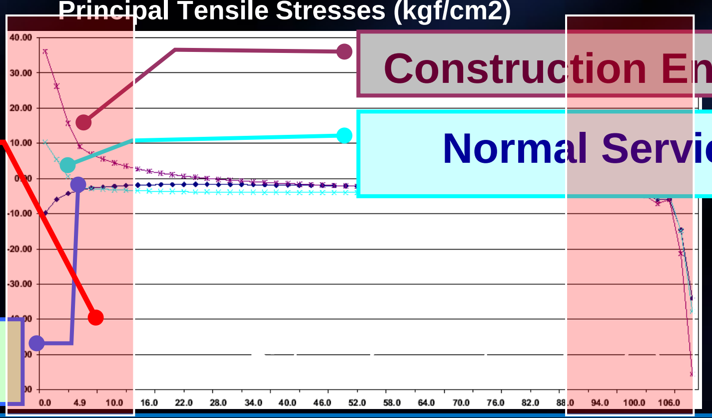
Upstream Face : Durability & Impermeable Barrier
Gallery : Inspection, Monitoring, Grouting & Drainage
Dam Body : Mechanical, Elastic, Durability,Thermal Properties
Dowstream Face : Pleasant Aspect & Durability
Bedding Mortar : If required by the Stress Analysis
x
1,00
Bedding Mortar : If required by the Stress Analysis
y
1,00
Leveling Concrete & Consolidation Grouting
B

SPECIFIC DETAILS – POURING & SPREADING THE BEDDING MORTAR

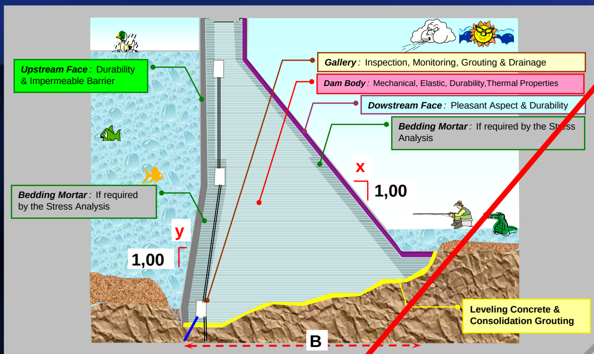
RCC – DAM CONSTRUCTION - CVC & RCC HANDLING

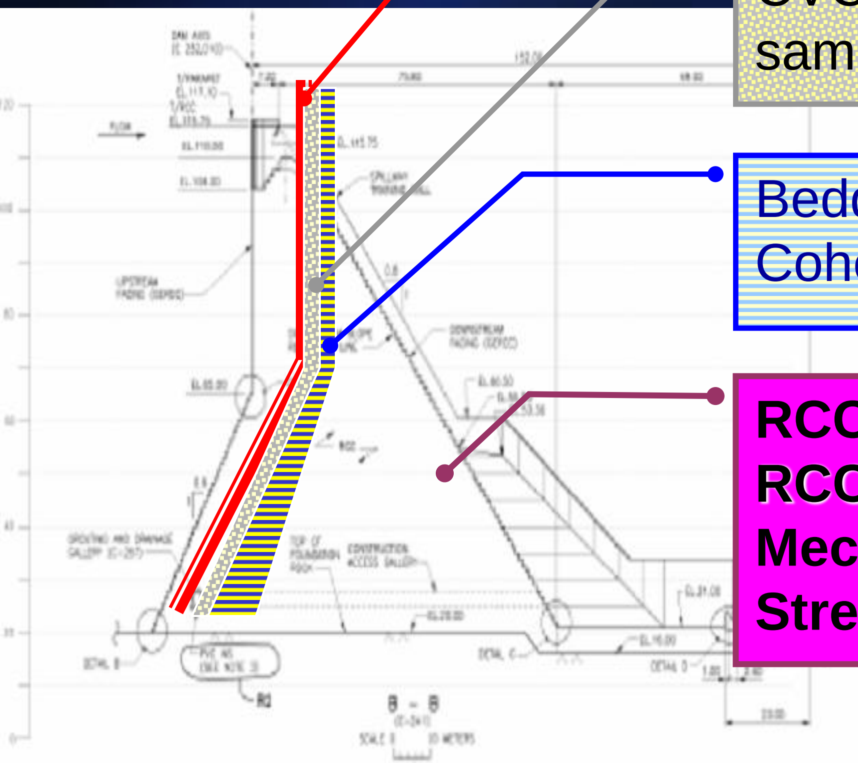


Section 1-1: PRINCIPAL TENSILE STRESSES



RCC – DAM CONSTRUCTION- CONCEPTUAL ASPECTS





Pre- cast Concrete Element with PVC Membrane (2mm) Inside.
Additional Impermeable & Safety Barrier

CVC Concrete (< 200kg/m3) Placed at the same time as RCC Layers

Bedding mortar, between RCC Layers, for Cohesion and Tensile Resistance (Safety)

RCC Dam Body:
RCC Mixes to support the Required Mechanical Properties Required in the Stress Analysis

SPECIFIC DETAILS – SURFACE TREATMENT OF THE CONSTRUCTION JOINT






RCC – DAM CONSTRUCTION - CVC & RCC HANDLING

SPECIFIC DETAILS – PROVIDING THE IMPERMEABLE BARRIER

Eng. AND

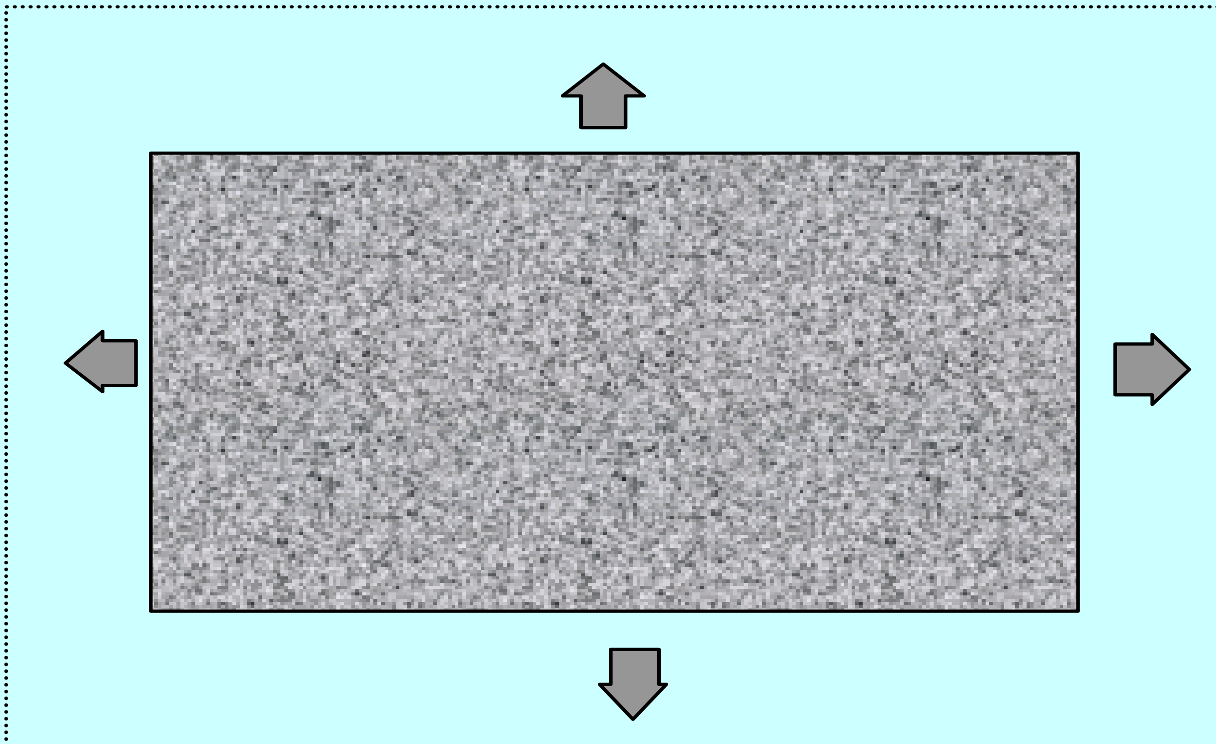
Part II- RCC Dam Construction- Methodologies

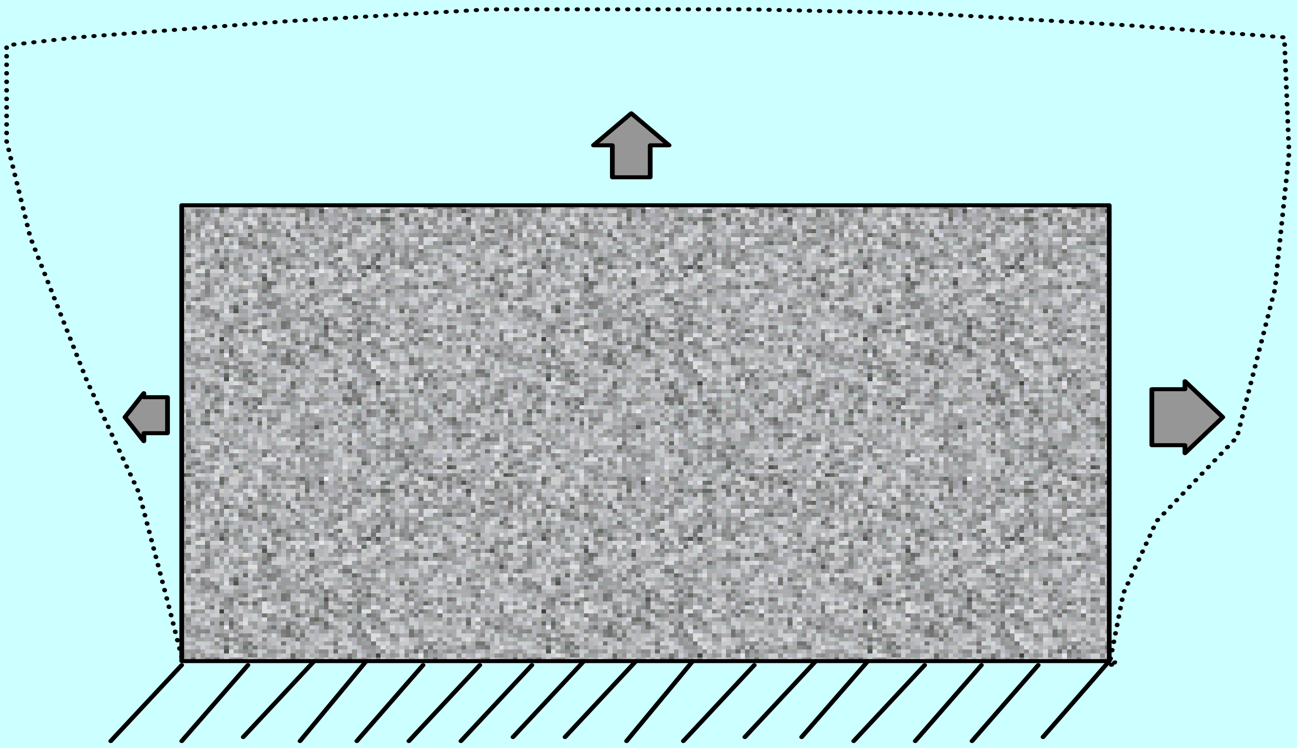
II.c) Upstream and Downstream Faces
And Thermal Aspects

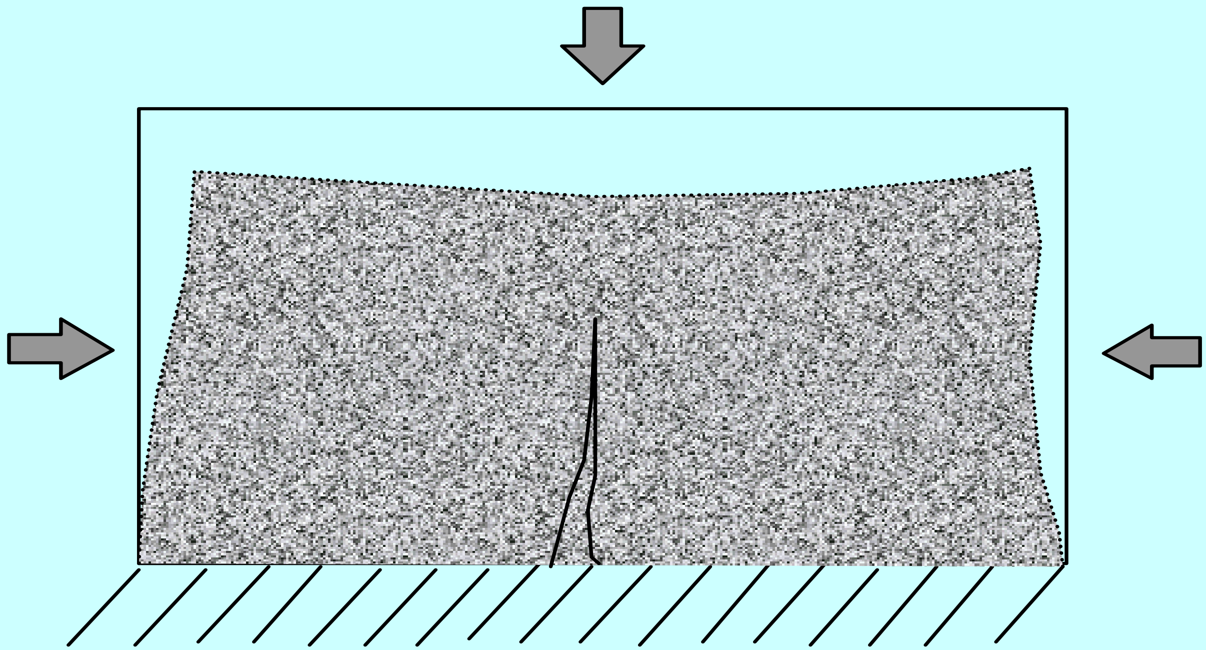
And the Thermal Aspect ??

Basic Relations

ε=	Cte * ΔT * (K_f) * (K_r)
ε=	Strain induced in RCC
Cte =	Coefficient of thermal expansion
ΔT =	Temperature change of RCC
(K_f) =	Foundation restraint factor
(K_r) =	Structure restraint factor







If

$[\Theta_A+\Delta\Theta_R] - \Theta_M > 0$ - No cracks – concrete can support the total temperature drop

$[\Theta_A+\Delta\Theta_R]-\Theta_M < 0$- Thermal cracks - concrete can not support the total temperature drop

Where

Θ_A = Average ambient temperature considered for the thermal equilibrium (Concrete structure and Ambient)

$\Delta\Theta_R$ = Equivalent in temperature drop gradient that the concrete can support without crack;

Θ_M = Maximum temperature reached in the concrete structure, due to the conditions adopted

$$\Delta\Theta_R = \varepsilon_f / \alpha$$

Where

$\Delta\Theta_R$ = **Equivalent in temperature drop gradient that the concrete can support without crack;**

ε_f = **Strain capacity at final load (tensile strain due to temperature drop) under slow load**

α = **Coefficient of thermal expansion**

$$\varepsilon_f = \{[\sigma_{tf}/ E_{cf}] + [(\sigma_{ti}+\sigma_{tf})*f_c/2]\}$$

Where

σ_{tf}/ E_{cf} = **Strain Capacity at final load under rapid load test**

ε_f = **Strain Capacity at final age under slow load test;**

σ_{tf}= **Modulus of Rupture at final age;**

E_{cf}= **Modulus of Elasticity at final age under compressive load test;**

σ_{ti}= **Modulus of Rupture at age that start the load;**

f_c = **Creep coefficient for the period between the initial and final loads**

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e-mail: fandrio@attglobal.net site: www.andriolo.com.br

Figura 5-I-01- Preparativo para a concretagem de um dos Blocos, através do bombeamento

Figura 5-I-02- Vista geral antes do início da concretagem.

Figura 5-I-03- Posicionamento do caminhão betoneira para a descarga do concreto na bomba

Figura 5-I-04- Descarga do concreto do caminhão na bomba

Figura 5-I-05- Bombeamento do concreto

Figura 5-I-06- Lançamento no molde do Bloco de Medição de temperaturas

7- MEDIÇÕES DE TEMPERATURAS NOS BLOCOS MOLDADOS

7.1- Registros

As medições das Temperaturas lidas no histórico térmico dos Blocos moldados, bem como da Temperatura Ambiente no instante das referidas leituras de temperatura do concreto, foram registradas em planilhas que se mostram no ANEXO II. A partir dos registros foram elaborados gráficos dos históricos térmicos como se mostram nas Figuras 7-I e 7-II, a seguir.

7-2- Etapa I

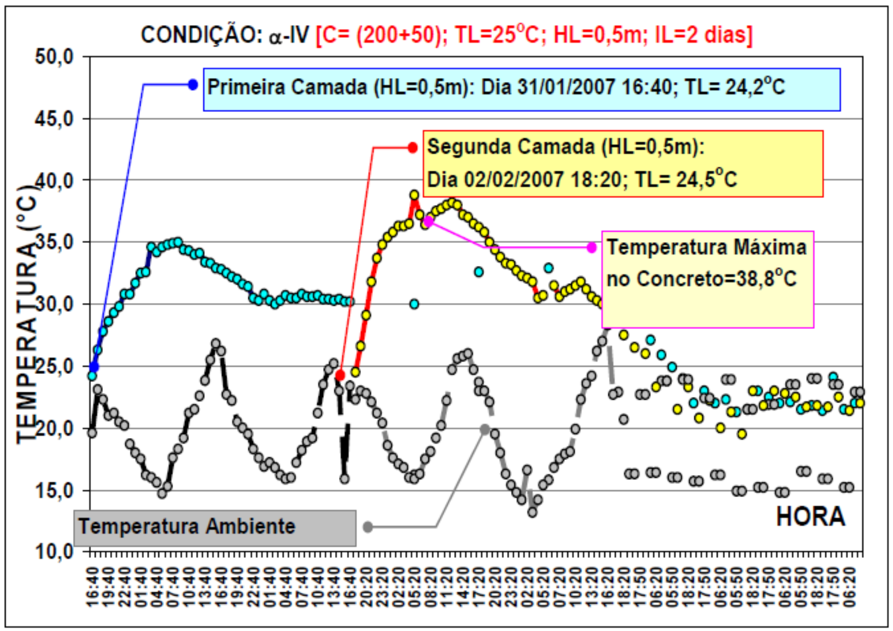


Figura 7-I- 01- Condição α-IV, com 200kg/m³ de Cimento e 50kg/m³ de Pozolana, Lançado a 25° C, em Camadas de Altura de 0,5m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 38,8° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 40,4° C.

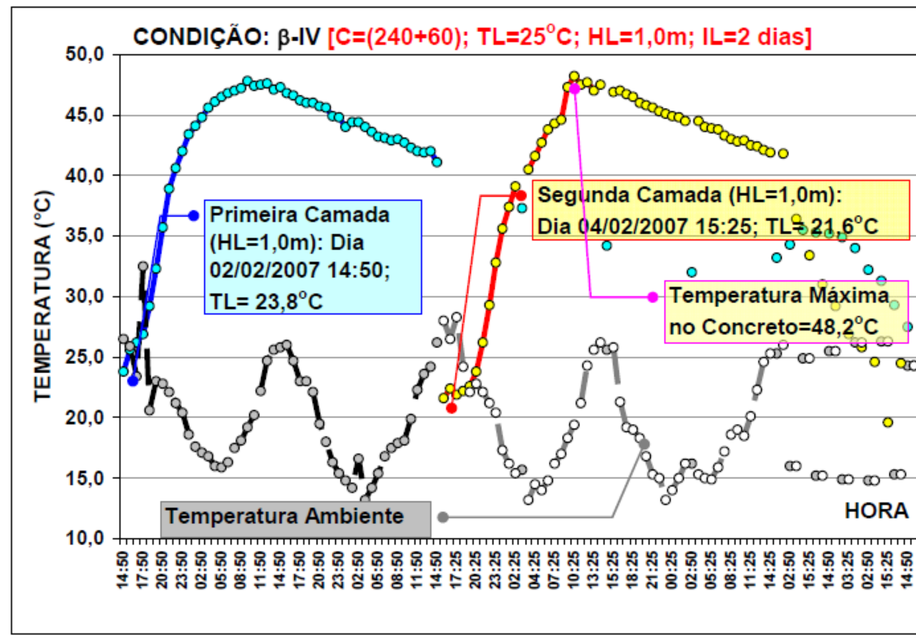


Figura 7-I- 02- Condição β-IV, com 240kg/m³ de Cimento e 60kg/m³ de Pozolana, Lançado a 25° C, em Camadas de Altura de 0,5m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 48,2° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 46,6° C.

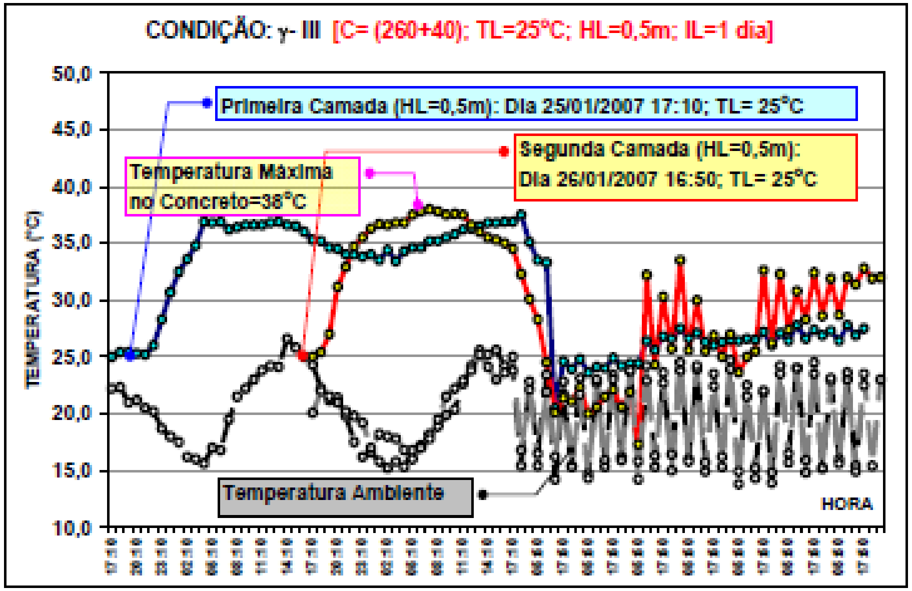


Figura 7-I- 03- Condição γ-III, com 260kg/m³ de Cimento e 40kg/m³ de Pozolana (ver nota 1 na Tabela do Item 5.1), Lançado a 25° C, em Camadas de Altura de 0,5m, em Intervalos de 1 dia. Temperatura Máxima atingida igual a 38° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 40,4° C.

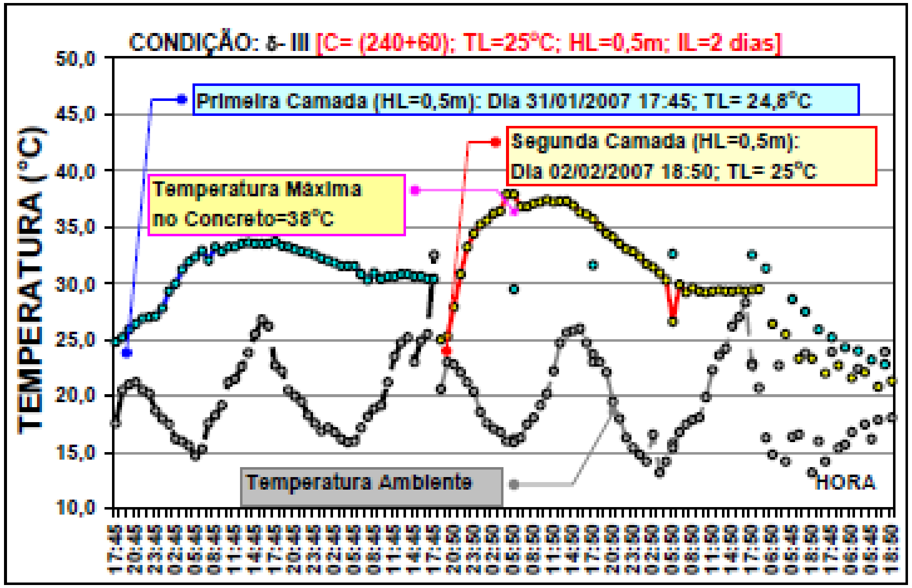


Figura 7-I- 04- Condição δ-III, com 240kg/m³ de Cimento e 60kg/m³ de Pozolana, Lançado a 25° C, em Camadas de Altura de 0,5m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 38° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 36,3° C.

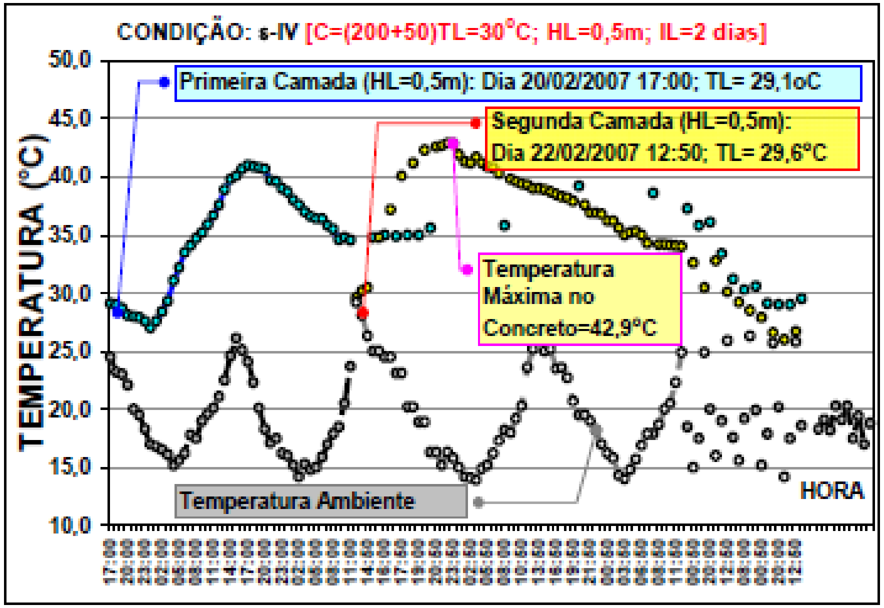


Figura 7-I- 05- Condição ε-IV, com 200kg/m³ de Cimento e 50kg/m³ de Pozolana (ver nota 2 na Tabela do Item 5.1), Lançado a 30° C, em Camadas de Altura de 0,5m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 42,9° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 42,4° C.

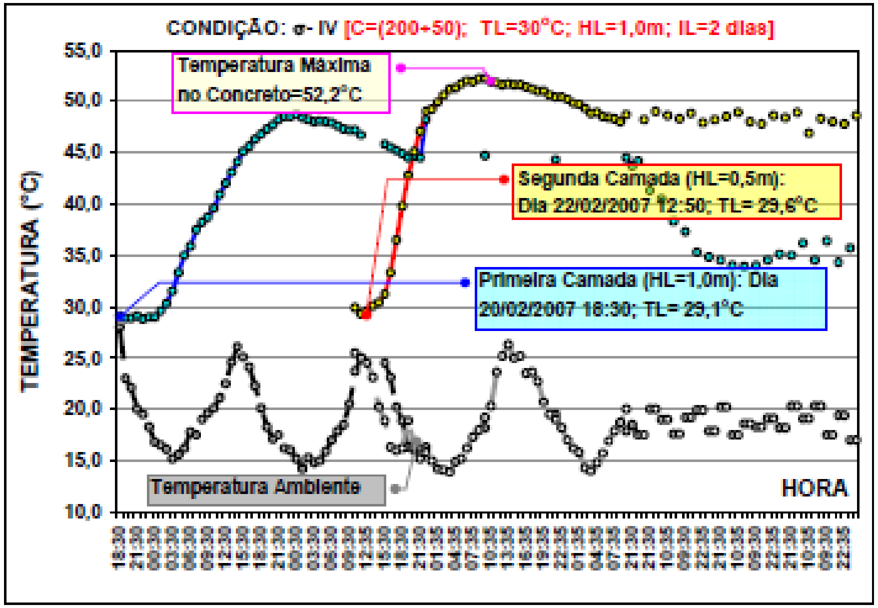


Figura 7-I- 06- Condição σ-IV, com 200kg/m³ de Cimento e 50kg/m³ de Pozolana (ver nota 2 na Tabela do Item 5.1), Lançado a 30° C, em Camadas de Altura de 1,0m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 52,2° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 49,7° C.

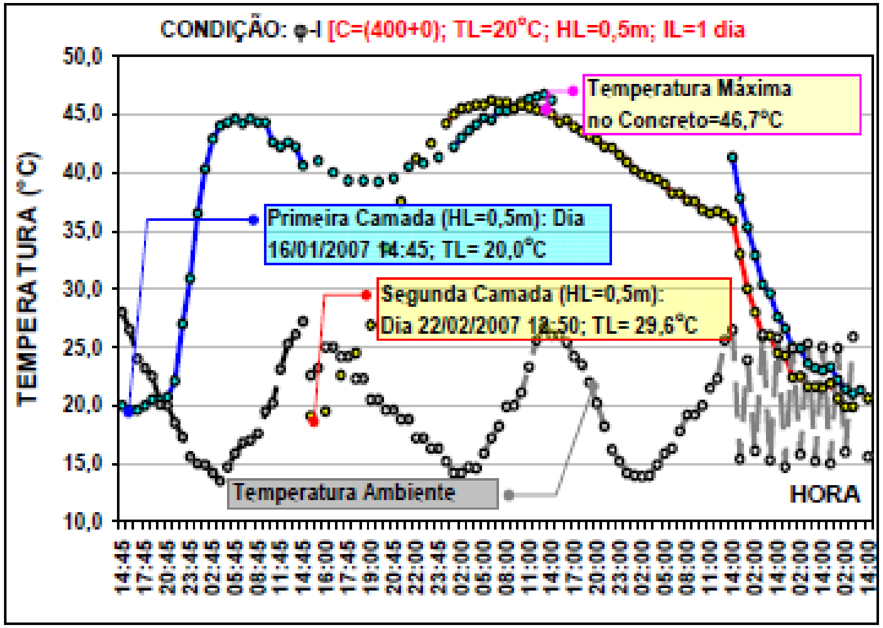


Figura 7-I- 07- Condição φ-I, com 400kg/m³ de Cimento e (zero)0kg/m³ de Pozolana, Lançado a 20° C, em Camadas de Altura de 0,5m, em Intervalos de 1 dia. Temperatura Máxima atingida igual a 46,7° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 58,5° C.

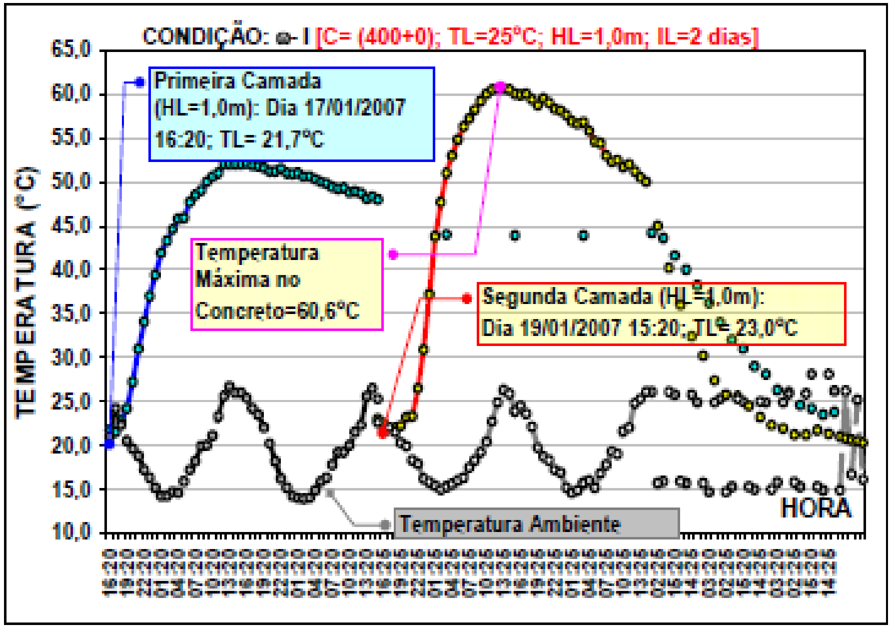
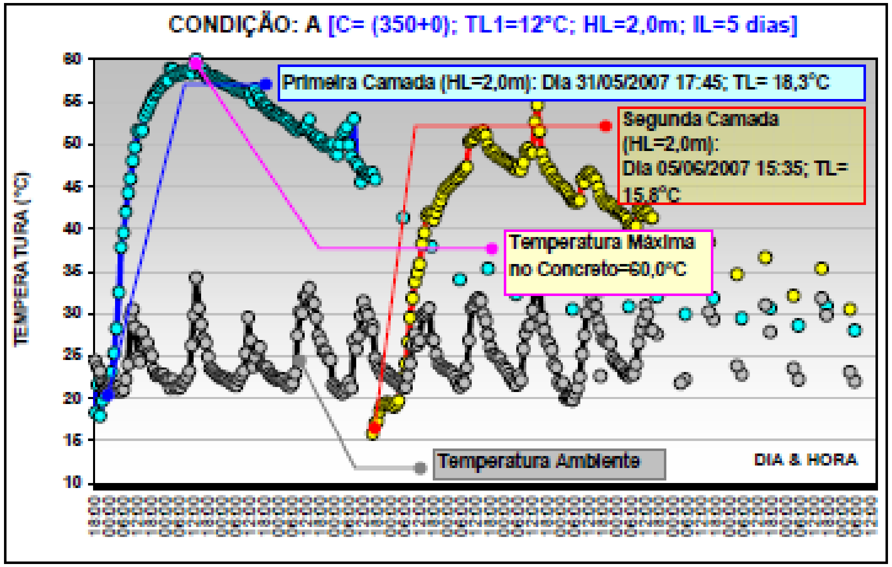


Figura 7-I- 08- Condição ω-I, com 400kg/m³ de Cimento e (zero)0kg/m³ de Pozolana, Lançado a 25° C, em Camadas de Altura de 1,0m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 60,6° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 56,9° C.



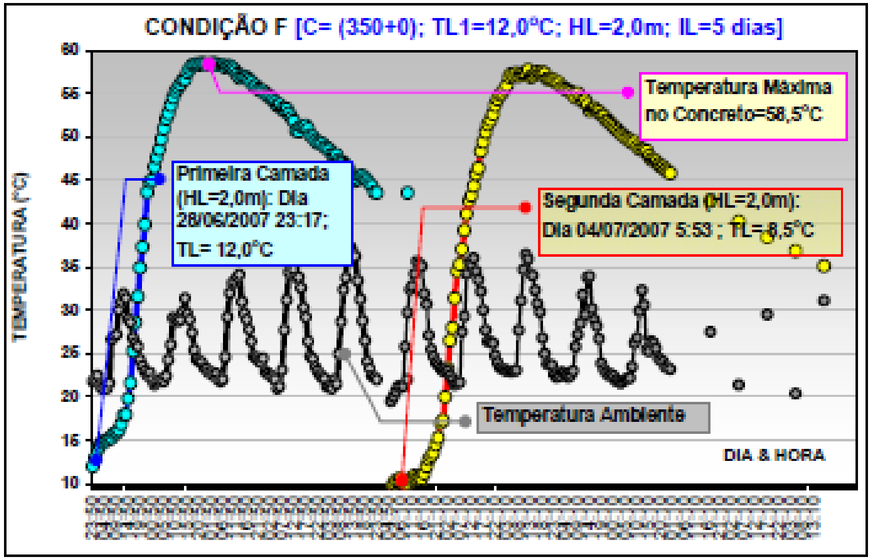


Figura 7-II- 01- Condição A, com 350kg/m³ de Cimento e (zero)0kg/m³ de Pozolana, Lançado a 12° C, em Camadas de Altura de 2,0m, em Intervalos de 5 dias. Temperatura Máxima atingida igual a 60,6° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 48° C.

Figura 7-II- 02- Condição A, com 350kg/m³ de Cimento e (zero)0kg/m³ de Pozolana, Lançado a 12° C, em Camadas de Altura de 2,0m, em Intervalos de 5 dias. Temperatura Máxima atingida igual a 58,5° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 48° C.

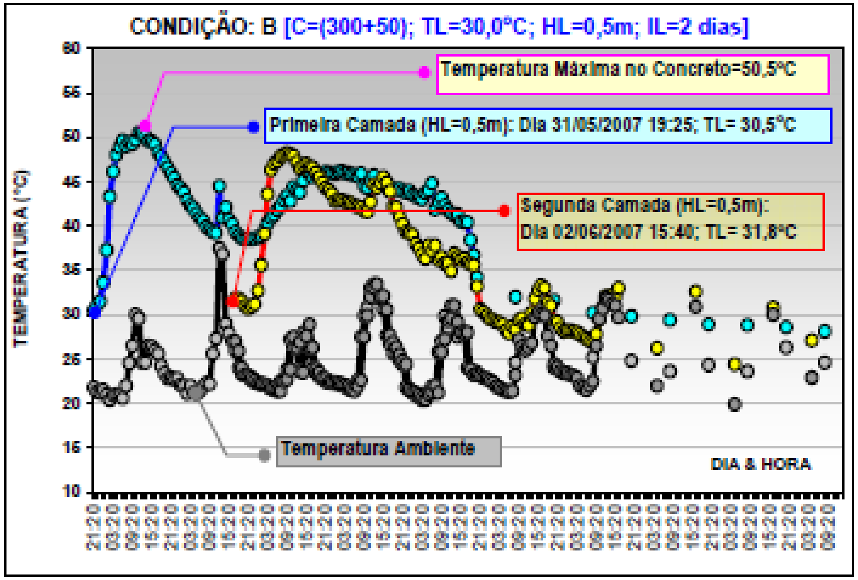


Figura 7-II- 03- Condição B, com 300kg/m³ de Cimento e 50kg/m³ de Pozolana, Lançado a 30° C, em Camadas de Altura de 0,5m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 50,5° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 49° C.

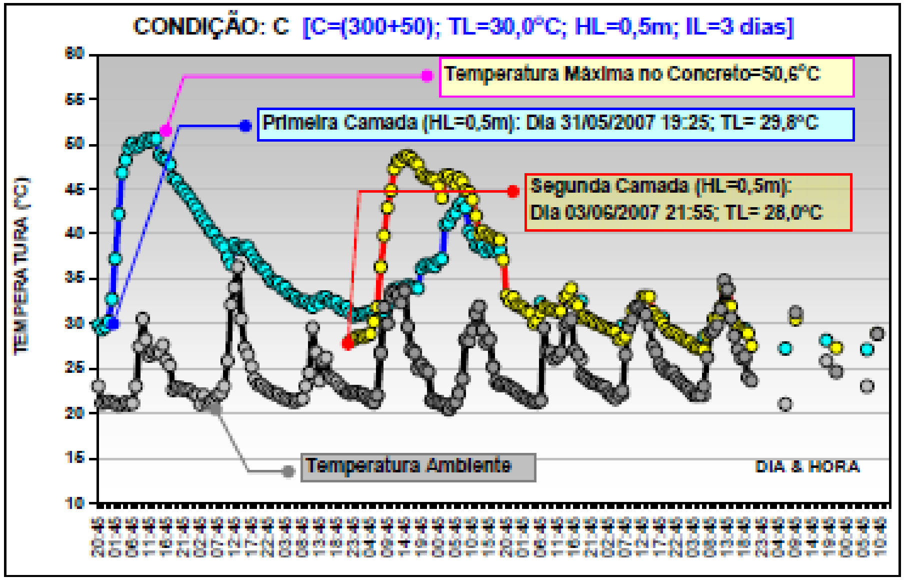


Figura 7-II- 04- Condição C, com 300kg/m³ de Cimento e 50kg/m³ de Pozolana, Lançado a 30° C, em Camadas de Altura de 0,5m, em Intervalos de 3 dias. Temperatura Máxima atingida igual a 50,6° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 48° C.

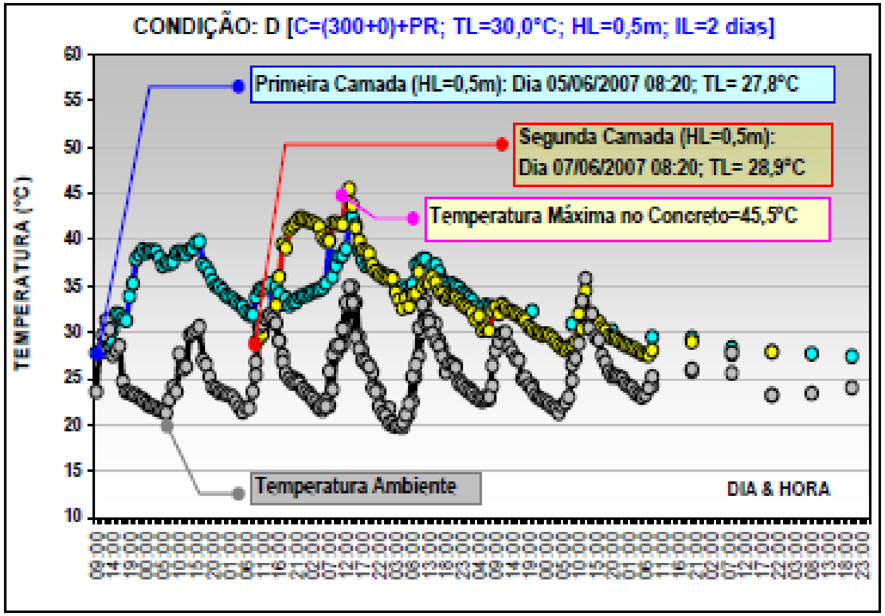


Figura 7-II- 05- Condição D, com 300kg/m³ de Cimento e Pó de Pedra, Lançado a 30° C, em Camadas de Altura de 0,5m, em Intervalos de 2 dias. Temperatura Máxima atingida igual a 45,5° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 45,7° C.

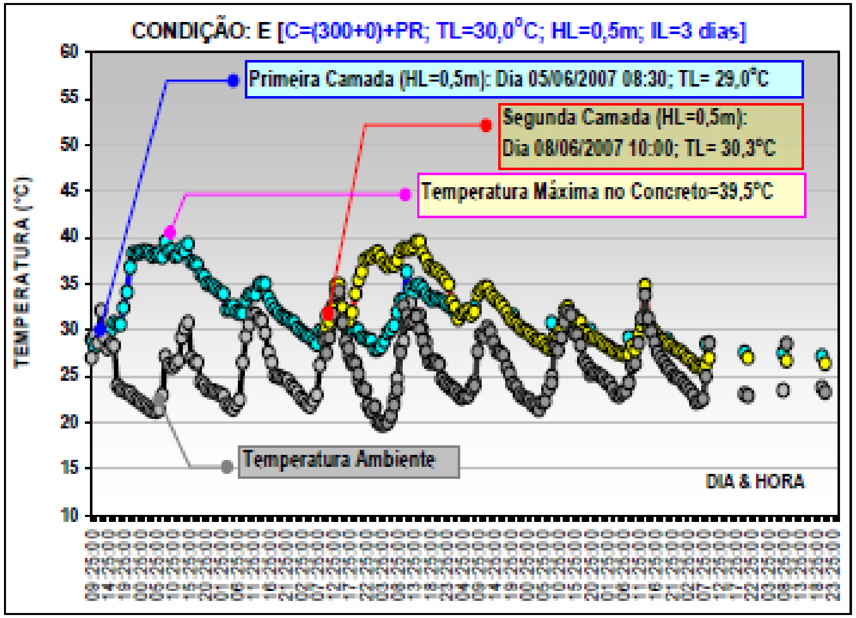


Figura 7-II- 06- Condição E, com 300kg/m³ de Cimento e e Pó de Pedra, Lançado a 30° C, em Camadas de Altura de 0,5m, em Intervalos de 3 dias. Temperatura Máxima atingida igual a 39,5° C. Para essa condição a Temperatura Máxima Prevista pelos Estudos foi de 41,5° C.

Etapa	Bloco-Condição	Camada e Altura (m)	Data	Cimento	Cinza	Aglomerante	Temperatura de Prevista para a Colocação (°C)	Temperatura Medida na Colocação (°C)	Temperatura Máxima Prevista no Estudo Térmico (° C)	Temperatura Máxima Medida nos Blocos (° C)	Variação da Temperatura Ambiente Durante o Período das Medições (Máximo Dia-Mínimo Noite) (° C)
I - Janeiro a Fevereiro	α IV- 1	1a. de 0,5m	31/jan/07	200	50	250	25	25,0	40,4	35,0	32,5 a 13,2
	α IV- 2	2a. de 0,5m	02/fev/07	200	50	250		24,5		38,8	
	β III- 1	1a. de 1,0m	02/fev/07	240	60	300	25	23,8	46,6	47,8	
	β III- 2	2a. de 1,0m	04/fev/07	240	60	300		21,6		48,2	
	γ III- 1	1a. de 0,5m	25/jan/07	260	40	300	25	25,0	40,4	36,9	
	γ III- 2	2a. de 0,5m	26/jan/07	240	60	300		25,0		38,0	
	δ III- 1	1a. de 0,5m	31/jan/07	240	60	300	25	24,8	36,3	33,7	
	δ III- 2	2a. de 0,5m	02/fev/07	240	60	300		25,0		38,0	
	ε IV- 1	1a. de 0,5m	20/fev/07	200	50	250	30	29,1	42,4	41,0	
	ε IV- 2	2a. de 0,5m	22/fev/07	240	60	300		29,6		42,9	
	σ IV- 1	1a. de 1,0m	20/fev/07	200	50	250	30	29,1	49,7	48,7	
	σ IV- 2	2a. de 1,0m	22/fev/07	240	60	300		29,9		52,2	
	φ I- 1	1a. de 0,5m	16/jan/07	400	0	400	20	20,0	58,5	44,6	
	φ I- 2	2a. de 0,5m	17/jan/07	400	0	400		19,0		46,7	
	ω I- 1	1a. de 1,0m	17/jan/07	400	0	400	20	21,7	56,9	52,1	
	ω I- 2	2a. de 1,0m	19/jan/07	400	0	400		23,0		60,6	
II - Maio a Julho	A- c1	1a. de 2,0m	31/mai/07	350	0	350	12,0	18,3	48,0	*60,6*	37,5 a 19,5
	A- c2	2a. de 2,0m	05/jun/07	350	0	350		15,8		*54,6*	
	B- c1	1a. de 0,5m	31/mai/07	300	50	350	30,0	30,5	49,0	50,5	
	B- c2	2a. de 0,5m	02/jun/07	300	50	350		31,8		48,2	
	C- c1	1a. de 0,5m	31/mai/07	300	50	350	30,0	29,8	48,0	50,6	
	C- c2	2a. de 0,5m	03/jun/07	300	50	350		28,0		48,7	
	D- c1	1a. de 0,5m	05/jun/07	300	0	300	30,0	27,8	45,7	42,4	
	D- c2	2a. de 0,5m	07/jun/07	300	0	300		28,9		45,5	
	E- c1	1a. de 0,5m	05/jun/07	300	0	300	30,0	29,0	41,5	39,5	
	E- c2	2a. de 0,5m	08/jun/07	300	0	300		30,3		39,5	
	F- c1	1a. de 2,0m	28/jun/07	350	0	350	12,0	12,0	48,0	58,5	
	F- c2	2a. de 2,0m	04/jul/07	350	0	350		8,5		57,7	

- As condições de usar Camadas de Altura entre 0,5m e 1,0m, mesmo quando os Intervalos de Colocação são ao redor de 2 a 3 dias, e com Temperaturas de Colocação entre 25° C e 30° C se mostram mais favoráveis ao concreto, atingindo Temperaturas Máximas, menores que ao se considerar Camadas de Altura de 2,0m, Intervalos não menores que 5 dias e Temperatura de Colocação ao redor de 12° C;
- Ao observar os Intervalos de Variação das Temperaturas Ambientes e as Curvas dos Históricos de Temperatura pode-se comentar:
  - Os concretos aplicados a intervalos de lançamentos entre 1 e 3 dias, mostram gradientes de abaixamento de temperatura inferiores a 10° C, sendo que;
  - Os concretos aplicados a intervalos de lançamentos não menores que 5 dias, mostram gradientes de abaixamento de temperatura maiores a 15° C (ver gráfico da Figura 7-II-02);
  - Isso induz fissuras superficiais no concreto, a partir do 2°. ou 3°. dia após a concretagem, e que podem prosseguir para a o interior da massa do concreto.
- Comparando os Casos "F", com "B" e "C", evidencia-se que a redução da Altura da Camada para valores de 0,5m, mesmo com temperaturas de Lançamento entre 25° C e 30° C, é mais eficiente (mais favorável a termogenia do concreto) do que manter uma Altura de Camada de 2,0m, mesmo com a redução da Temperatura de Lançamento para 12° C. Esse conceito aqui evidenciado, é o que faz o sucesso das construções de Concreto Compactado com Rolo, por utilizar camadas de pequena altura (0,3m) lançadas sucessivamente (de uma a 3 camadas por dia), sem haver necessidade de precauções térmicas;
- Ao se reduzir a Altura das Camadas, simultaneamente com a minimização dos Intervalos entre Camadas, praticamente não se estabelece conflitos cronológicos-programáticos como se comenta mais à frente.

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12- CONSIDERAÇÕES FINAIS

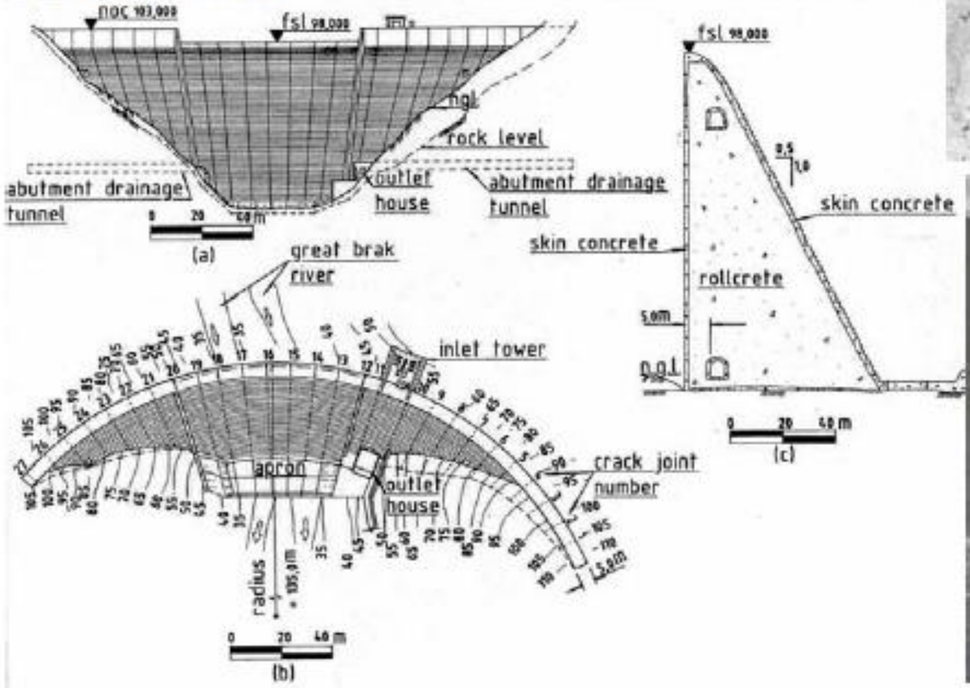
A comprovação dos Estudos Térmicos através de de medições de temperatura em blocos e concreto, moldados na Obra, permite estabelecer condições metodológicas que:

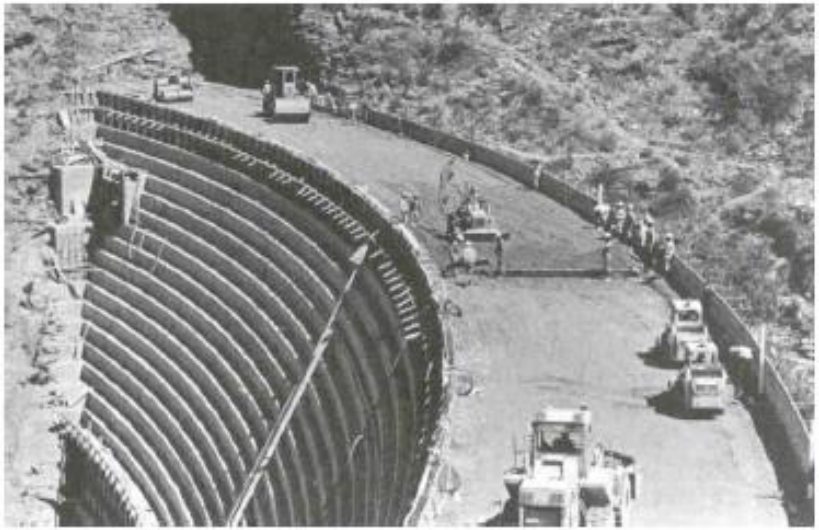
- Viabilizam o lançamento dos concretos, mesmo à temperatura de até 30° C, com menor potencial de Fissuração, bastando para isso reduzir a Altura de Camadas e trabalhar a Intervalos entre Camadas de 2 a 3 dias;
- Viabilizam o emprego de Material Pozolânico, e o translado da idade de Controle do concreto das Estruturas massivas, para 90 dias
- Viabilizam reduções de Prazo.

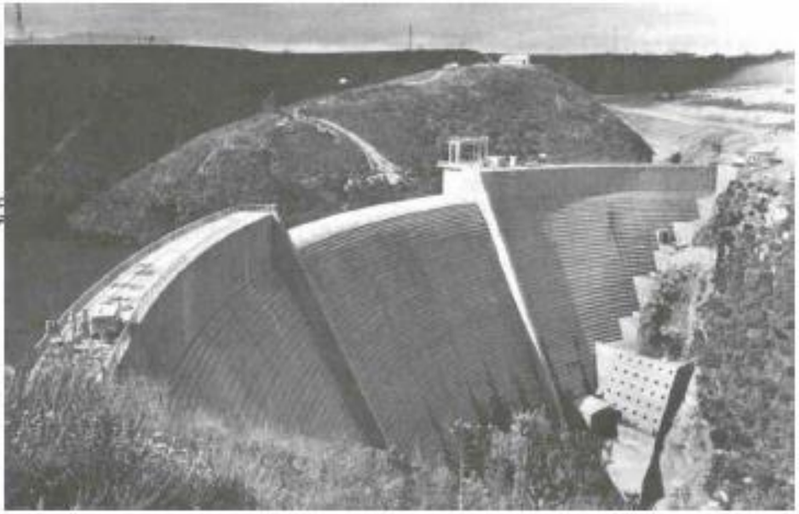
Part II- RCC Dam Construction- Methodologies

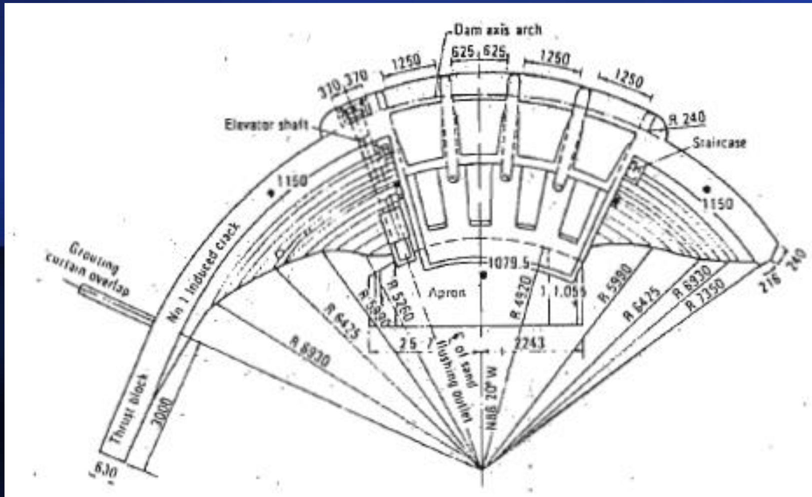
II.d) RCC Arch Dams

- Knellpoort Dam, 1988-89, h=50 m
- Wolwedans Dam, 1987-90, h=70 m

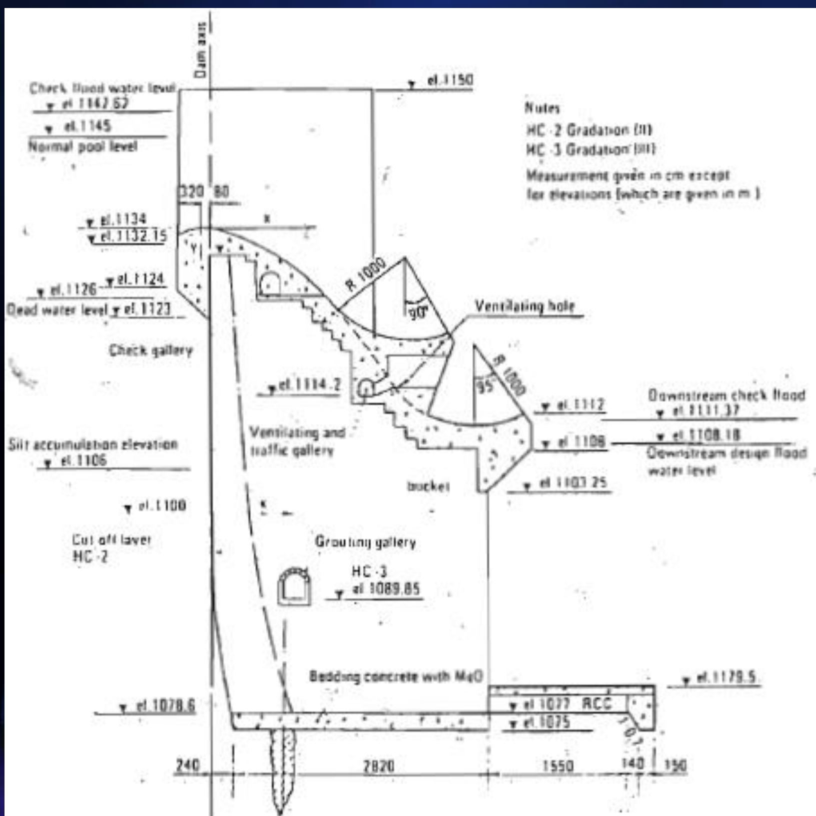




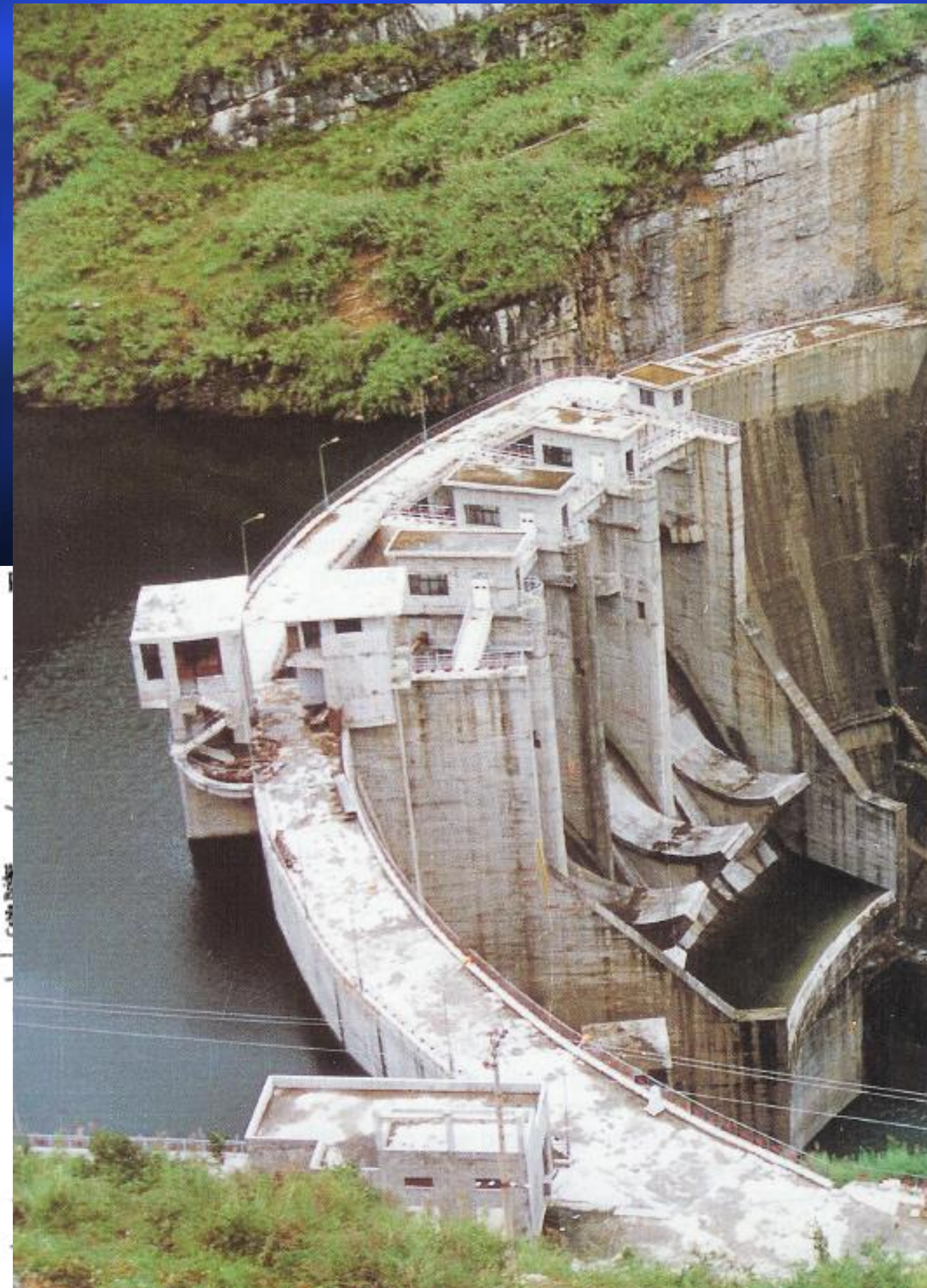




Dam axis arch
625 625
1250
1250
1250
310 370
R 240
Elevator shaft
Staircase
1150
1150
Grouting curtain overlap
No 1 induced crack
1079.5
Apron
R 4920
R 5260
R 5990
R 6425
R 6930
R 7350
R 6425
R 6930
2243
Thrust block
3000
610
216
240



Dam axis
el.1150
Check flood water level
el.1142.62
el.1145
Normal pool level
Notes
HC-2 Gradation (II)
HC-3 Gradation (III)
Measurement given in cm except for elevations (which are given in m)
320 80
el.1134
el.1132.15
R 1000
el.1126
el.1124
Dead water level el.1123
90°
Ventilating hole
Check gallery
R 1000
el.1114.2
95°
el.1112
Downstream check flood
el.1111.37
el.1108.18
el.1108
Downstream design flood water level
Silt accumulation elevation
el.1106
Ventilating and traffic gallery
bucket
el.1103.25
el.1100
Cut off layer HC-2
Grouting gallery
HC-3
el.1089.85
Bedding concrete with MgO
el.1079.5
el.1078.6
el.1077 RCC
el.1075
240
2820
1550
140
150



Creating a strong team around the innovation

- World leaders
- Competence
- Complementarity
- Shared vision
- Entrepreneurial spirit

STUCKY

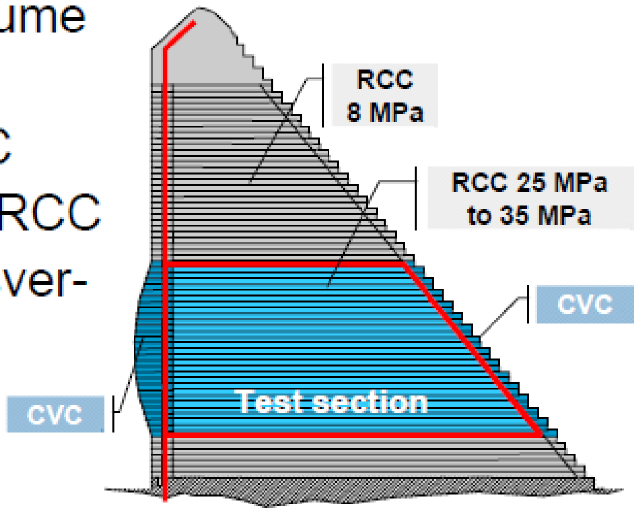
STOD
RCC Arch Dam

ODEBRECHT
Engenharia e Construção

Andriolo Ito Engenharia

Practical tests performed in 2004-2005 on Picada RCC dam in Brazil

- 4’000 m^3 RCC volume
- Formwork
- High strength RCC
- Series of tests on RCC
- Two types of transversal joints
- Post-cooling
- Monitoring

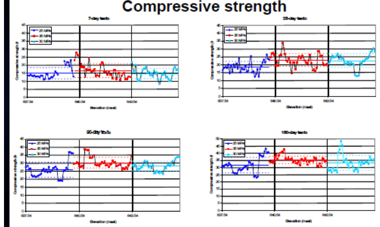


1:1 scale tests on Picada dam

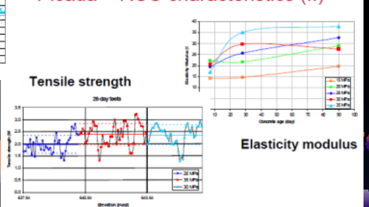
Picada – Double curvature formwork (II)

Picada – Post-cooling system

Picada – RCC characteristics (I)



Picada – RCC characteristics (II)



Francisco Rodrigues

Some- Other- Mistakes


29 9:25


393

RCC : Use &


JAN 14 2004


23 9:11

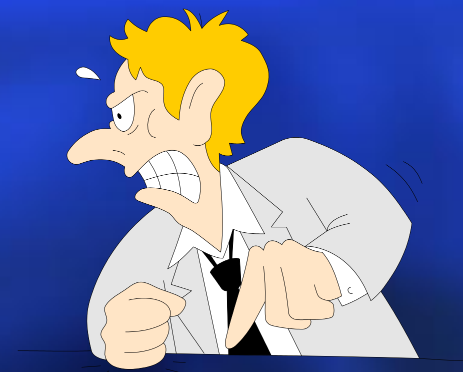
ACKNOWLEDGMENTS

I want to express my gratitude and sincere appreciation to ***Jahan Kowsar Construction Co***, and the **Organization Committee of this Workshop** for the invitation to present this paper.

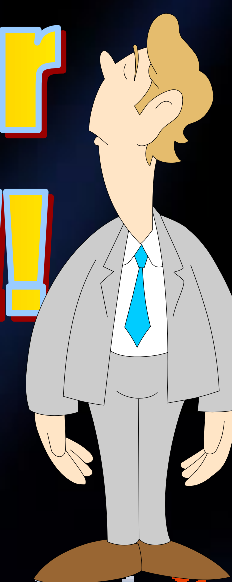
Many thanks!

Jahan Kowsar Construction Co.

PLEASE !



RCC comes to SIMPLIFY the Dam Construction, BUT NOT TO BE POOR or UNSAFE STRUCTURE !!!



And:

My [particular, modest and sometime innocuous] recommendation:

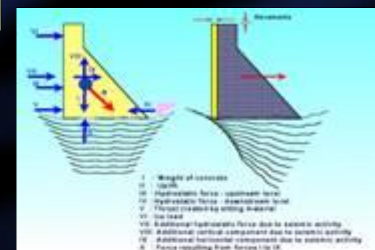
Develop YOUR OWN Solution, Methodologies, Practices, looking for YOUR advantages and disadvantages, NOT just the others perform some !!!

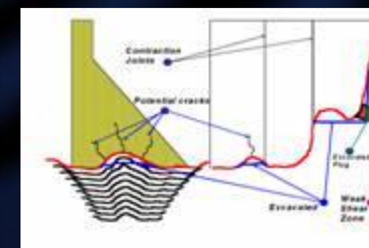
The Design MUST to consider the DEFENSES considering the LOCAL Aspects (Materials, Equipments, Logistics, Remotes Areas, and LABORS!)!

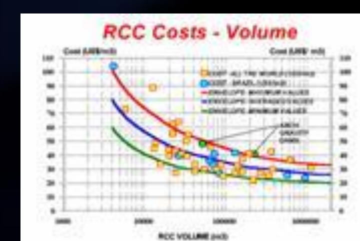
Main Recommendations:

✓ Site Conditions
- ☞ Lay Out;
- ☞ Shape;
- ☞ Flows and Periods;
- ☞ Available Material;

✓ Design
- ☞ Foundation Aspects- Shape;
- ☞ Spillway- Discharge;
- ☞ **Stress Analysis (Fundamental Requirement);**
- ☞ Balance: *Shape*Stress*Properties Requirements;*
- ☞ Defenses: *Faces, Drainage, Contraction Joints*;
- ☞ Details and Simplicity: ***Intakes, Conduits, Shafts***;







✓ Construction
- ☞ Materials & Equipments Availability;
- ☞ Facilities (*Aggregates, Concretes [CVC &RCC], Cement; Poz. Mat.*);
- ☞ Workman Labor

✓ Cost (***Balance ALL PREVIOUS POINTS!!)***

Many thanks !!!