کمیته ملی سدهای بزرگ ایران

برنامه کارگاه تخصصی
"ســـدهـــای بتـــن غلـطــکـــی"
۳۱ خرداد ماه ۱۳۸۶

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RCC : Use & Special Aspects

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Roller Compacted Concrete on Dams

Workshop - IRCOLD

Tehran- Iran- June 21st / 2007

RCC : Use & Special Aspects

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Many thanks!
Francisco Rodrigues Andriolo

ZIRDAN PROJECT and the RCC Dam, one of the constructions from….

Jahan Kowsar Construction Co.

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A- Presentation

This presentation is composed of 7 Parts: Presentation, International Experiences, Materials, Design RCC Dams on Weak Foundations, RCC Construction Technologies, and Quality Control.

The **Part B** referring to International Experiences shows some highlights. The **Part C**-Materials mentions the ample scenery open by the RCC Methodology for the best use of the materials available. The **D-** Design on Weak Foundations discuss some aspects concerning the Dams on Foundations.

The **E**- Site Mobilization for RCC Equipments shows a example for a Dam Construction and its facilities. The **F**- RCC Construction Technologies Part exposes in a comparative way different process to RCC Dam Construction. The text about **G**- Quality Control presents information about the RCC control in several jobs. We are trying through these two topics to evidence that the RCC is a CONCRETE, leaving no doubts about its performance.

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B- INTERNATIONAL EXPERIENCE ON RCC DAMS AND HIGHLIGHTS

B.1- RCC Concept and Start Up

During the Asilomar conference in California (1972), the faster and more economic construction of concrete dams was put forward. During the XIth International Congress on Large Dams (ICOLD Madrid, 1973) the same question was discussed. After this, a large numbers of Symposiums, Congresses, Technical Meetings abroad trough the word concerning the RCC technology.

B.2- Development and Most Significant Events on RCC Use

1964 **Alpe Gera Dam**, a 172m high concrete gravity dam in the Italian Alps was constructed like an earth embankment, using dumper trucks, dozers, and tractor-mounted immersion vibrators to place lean concrete in horizontal lifts;

1970 ***Jerome Raphael*** presents a paper **"The Optimum Gravity Dam"** in which its proposes the concept of an embankment made of cement-enriched, granular pit-run material placed and compacted with high-speed earth-moving equipment;

1970-1973 Research in the United States by the **Tennessee Valley Authority** at **Tims Ford Dam** and by the **Corps of Engineers** at Jackson, Mississippi, and at **Lost Creek Dam** helped to prove the economic feasibility of RCC and to develop the construction methods for its mass placement;

1974-1975 The emergency repair of a collapsed outlet tunnel at **Tarbela Dam** in Pakistan using RCC demonstrated the rapid placement rates possible: 460,000 yd 3 (350,000 M3) of RCC were placed in 42 working-days;

1978 Research started four years earlier by **Japan's Committee on Rationalized Construction of Concrete Dams** led to the start of RCC placement for the body of **Shimajigawa Dam**, a 89m high gravity dam;

1978 A full-scale trial of the use of high-fly-ash-content RCC together with laser-controlled slip-formed facing elements was successfully completed at **Wimblehall Dam** in England. This work on **High-Paste** RCC contributed significantly to the design in the early 198Os of the **U.S. Bureau of Reclamation's Upper Stillwater Dam** in Utah;

1980 **Shimajigawa** became the first dam in the world to be built using RCC for the main portion of the dam.

1982 The placement of 331,000 m3 of RCC in less than five months for the **U.S. Army Corps of Engineers' Willow Creek Dam** in Heppner, Oregon, confirmed the rapid construction rates and economic viability of dams built entirely of RCC; ***1983*** Construction started at **Tamagawa Dam**, the first RCC dam reaching 100m high, in Japan;

1984 RCC came to the southern hemisphere with the design and construction of Australia's 40m high **Copperfield Dam** in only 10 months.

1984 The construction of 21m high **Winchester Dam** in Kentucky using precast concrete panels and an attached polyvinylchloride (PVC) membrane to both form the RCC and provide an impervious upstream face initiated a concept that may be called a "concrete-faced RCC dam";

1985 The erosion resistance of exposed RCC was proven in the field when **Chervil Ponding Dam** in Texas, a 6.1m high RCC dam, was overtopped during a flood by 4.4m 30 days after construction was completed. It was overtopped by 4.9m due to an even greater flood two years later, with no appreciable wear of the RCC crest and downstream slope;

1986 The construction of 56m high **Saco de Nova Olinda Dam** in Paraíba State- Brazil, the first RCC arched dam, in the world and the first RCC Dam in Brazil and South America;

1988 Construction started at **Sakaigawa Dam,** 115m high, in Japan, the first RCC dam higher than 100m; The construction of 77m high **Urugua-i Dam** in Argentine, the first RCC with ("Pó de Pedra") crushed powder filler to adjust the grain size curve;

1991 The construction of 155m high **Myagase Dam**, in Japan, the first RCC dam higher than 150m;

1992 The construction of 75m high **Puding Arch-Gravity Dam in China**, using the conceptual criterion of arch dam.

In the 80s there was a progressive increase in the use and development of RCC concrete dam construction techniques.

As a general conclusion it can be said that all the ideas put forward around the subject of RCC dam construction techniques have already been used in isolated cases in the past, and that the only novelty is their combination and harmonization in order to obtain a quicker and more economical dam construction.

To emphasizes the development of the RCC construction methodology it is important to know that at the end of 1980, there were only 02 completed dams, and at the end of 1986, there were 15 completed RCC dams in the World, by the

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end of 1996 there were more than 150 RCC completed and under construction in the World, and by the end of 2006 there were more than 320 dams in the World.

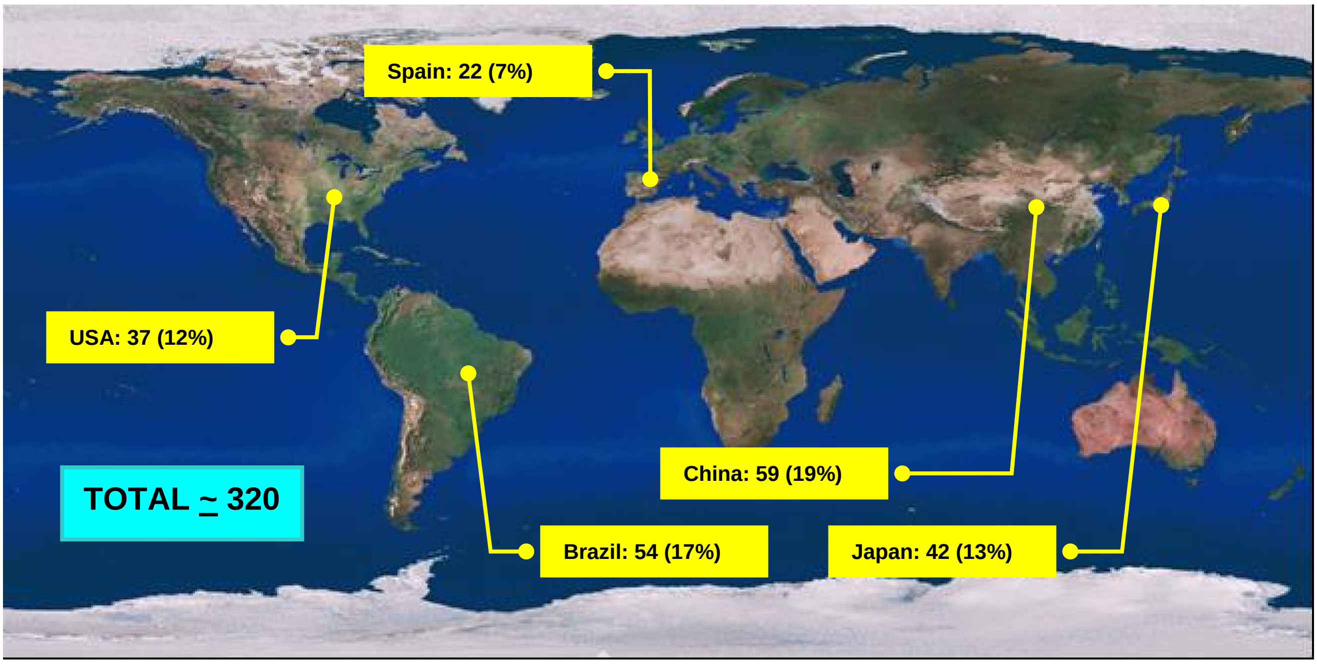

Figure B-01- RCC Dams in the World by the end of 2006

B.3- Actual Highlights

Statistical Aspect	Dam and Dettail	Country
Highest Finished Dam	Miel I - 190m	Colombia
Largest Volume-	Tha Dan Dam - 4,900,000 m3	Thailand
Simplest Dam	Beydag - 3.000.000 m3- Just one aggregate	Turkey

Number of Dams	Total = 320	Percentage (%)
China	59	19
Brazil	54	17
Japan	42	13
USA	37	12
Spain	22	7

It is important to note that these 5 countries are responsible for about 70% of the RCC Dams in the World.

Figure B-02a- Tha Dan RCC Dam in Thailand

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Figure B-02b- Tha Dan RCC Dam in Thailand


Figure B-03- Miel I RCC Dam in Colombia

Figure B-04- Beydag RCC Dam in Turkey

B.4- Tendencies- Materials Use and Mix Proportion

In the 1970's the evolution of the concept of the RCC dam followed various different ways:

- dams of lean mixtures, with a content of cement paste of 70 to 100 kg/m^3, and with the placing of mortar between layers. This was an alternative developed by the United States Army Corps of Engineers and other researchers, whose first important work was the Willow Creek Dam (United States), completed in 1982;
- Dams with high-paste contents of binding material of between 150 and 270 kg/ m^3, with a high proportion of fly ash. Examples of these are the Chinese and Spanish Dams, Upper Stillwater Dam (United States, 1987) with more than 1,125,000 m^3 of concrete with a mix of 247 kgs/m^3 of binding material.

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- Dams of average content of paste, with mixes between those of the two previous groups. The Les Olivettes Dam (France, 1987), with 130 kg/m^3 of a special cement, and Craigbourne Dam (Australia, 1986), with 170 kg/m^3, of binding material, are examples of this type.
- Japanese dams (**RCD**: **R**oller **C**ompact **D**ams): the difference with the previous types is not in the content of binding material (up to now it has oscillated between 120 and 130 kg/m^3), but fundamentally in the method of placing on the job. Layers of 50 - 100cm in thickness are extended in different sublayers, which are compacted all in one operation, instead of carrying out the compacting operation on each of the sublayers. Before carrying out the compacting, cuts are made in the fresh concrete every 15 m using a vibrating cutting tool, in which are inserted inductors of cracks or fissures. Bonding or union between layers is assured by way of careful cleaning of the surface and the extension of a thick layer (15mm) of mortar. The Shimajigawa Dam (1980) constituted the first application of this technique, by way of which, to date, more than twenty works have been carried out. The most notable example is the Tamagawa Dam (1986), with a total volume of 1,154,000 m^3 and Miyagase Dam (1994) with 1,930,000 m^3 between compacted and conventional concrete.
- Brazilian Dams, with a content of cement from 60 to 100 kg/m^3, with high fine content (8% to 12% finer than 0,075mm) and with the placing of mortar between layers and a conventional mass concrete as upstream membrane face. The fine material used can be a silt (as used in Saco Nova Olinda Dam) without pozzolanic activity or can be crushed powder filler, from some rock, as used in Jordão and Salto Caxias Dams, with low pozolanic activity.

B.5- Recent Advances

B.5.1- Design Focus

B.5.1.1- Dam Faces

B.5.1.1.1- Upstream

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

B.5.1.1.2- Downstream

No Over Topping Section

- CVC- Normally for High Durability
- RCC- Richer

Over Topping Section

- CVC- Normally for Specific Flow greater than 15m3/sec.m, or
- RCC- Richer

B.5.1.2- Drainage System & Galleries

- For Drainage (and Stability, and Cost),
- For Monitoring and Inspection;
- For Grouting

B.5.1.3- Crack and Temperature control

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- If the RCC was developed to simplify the concrete constructions; Which are the reasons to apply a temperature control, even thought 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 waterthigntness of the upstream face is very important for the dam, which is best system to be used?

B.5.1.4-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. The same question could be posed with respect to CSG dams in Japan. Also, what is the performance of an exposed hardfill mix when subjected to weathering such as freeze-thaw or wet-dry cycles?
- Comparing the trapezoidal shape of the FSHD with the traditional section of RCC dams, it is needed to know if the selection of the dam type is based on the low cost of the nearby in-situ materials or on the characteristics of the foundation to support the FSHD structure.
- 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?

B.5.2- 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 cementituious content(or lean vs.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.

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C - MATERIALS

C.1- RCC Concept

Roller **C**ompacted **C**oncrete (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.

The objective of the selection of the materials for and design of the mixture proportions of an RCC is to provide a stable concrete that meets all the in-situ properties as strength, durability, and permeability requirements of the structure. When considering the materials (and mixture proportions) for an RCC dam, the Designer must always bear in mind that it is the in-situ properties, including
those at the horizontal joints between the layers, that are important and not the properties that might be achievable in the laboratory.

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.

C.2- Aggregates

C.2.1- General

The selection of aggregates and control of aggregate grading are important factors influencing the in-situ quality and properties of RCC. The variability of aggregates during construction significantly affects the cementitious and water requirements, which in turn affect strength and yield. As the RCC is a concrete the Specifications should reflect an appropriate degree of control of aggregate quality and grading. The aggregates grading composition curve more often used in the RCC works has been of the cubical type as $p = (d/D_{max})^{1/3} * 100\%$ type, with **"*p*"** being the percentage of a material finer than the mesh with a ***"d"*** opening and ***"Dmax"*** the maximum size of the aggregate with the major dimension used in the mixing.

Observing the curves in Figure C-01 one can see that as the aggregates Dmax in the grading composition is reduced, a greater quantity of "sand" (material inferior to 5mm) is required, as well as a greater quantity of "fines" (material inferior to 0,075mm). These conditioning items are required so that you can have closed grading concrete (RCC), with a smaller number of air voids, therefore with a maximum density and lower permeability.

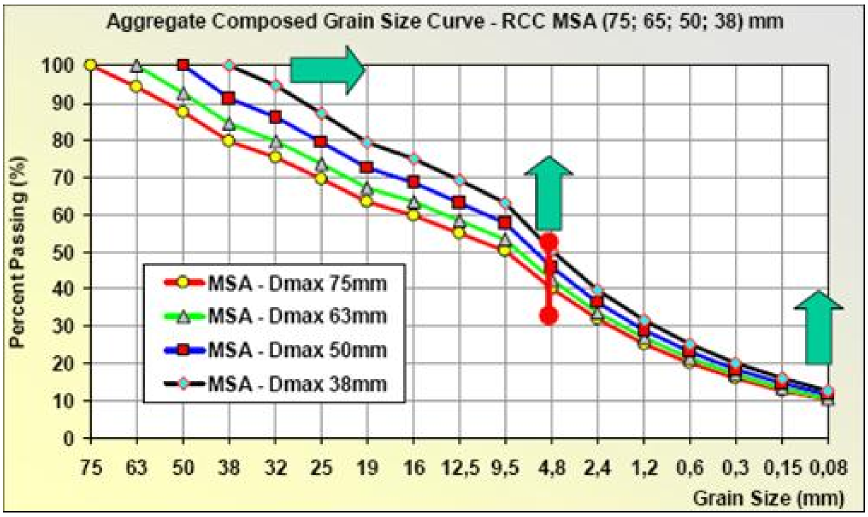

Figure C- 01- Usual Aggregates Grain Size Curves for RCC and CVC

The availability of natural materials with grading near optimum (curves in Figure 01) implies the need to process the aggregates, in order to attend the grading curve. In that situation, it is common the need of not only doing the sieving but also crushing the "over size" fractions so that the desired grading can be attained. Here attention is called to the content of "fines" desirable in the RCC mixes. The unavailability of "fines" will lead to the need of adopting an alternative to "close" the grading and minimize the air voids. This can be obtained by using pozzolanic material (if available at a low cost) either of Silt or of Rock Flour. The choice of the alternative must

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The presence of any significant quantity of flat and/or elongated particles is usually undesirable. However, RCC mixtures appear to be less affected by these particles than traditional concrete mixtures. This peculiarity may be because the compaction equipment provides more energy than traditional consolidation methods and because the higher mortar content tends to provide more separation of coarse aggregate particles, and the fact that the water content in RCC has not the same concept as in the CVC related to workability.

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.

Where there is a choice of source material, the material with the best combination of physical properties should be selected. Apart from the need for hard, durable aggregate, of high unit weight, characteristics that affect the thermal characteristics and cracking of the dam are important. A low elastic modulus and low coefficient of thermal expansion are desirable.

C.2.2- Coarse Aggregate

The most important factor to consider when selecting the source, shape and grading of a coarse aggregate is the avoidance of segregation. No matter how good the theoretical properties of an RCC are, if that concrete segregates when it is transported, spread and compacted, the in-situ performance will be less satisfactory than expected. In order to avoid segregation, it has been found that a well-graded aggregate, and with low amount of the coarsest fraction is more satisfactory. The maximum size of aggregate can have a very significant effect on segregation. Generally, the smaller the maximum size the less will be the tendency to segregate.

However the additional effort required to produce aggregates with a smaller maximum size has to be balanced against the need to avoid segregation. It has been found that an increase in the proportion of the fine aggregate within the total grading can reduce the tendency for segregation.

The most popular maximum size is in the 75- to 80- mm size, although there now seems to be a trend towards smaller sizes because of the problem of segregation. The maximum size 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.

C.2.3- Fine Aggregate

Gradings of fine aggregate conforming to traditional concrete limits 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 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 silty (no-plastic fines) material are usually acceptable.

C.2.4- Overall Grading

As can be seen in Figure C-01 there is a definite trend of a reduction in fine aggregate content with increasing maximum size of aggregate. 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 Figure C-02 it is shown an unique aggregate curve that is being used in Beydag RCC Dam in Turkey.

C.2.5- Gravel or Crushed Aggregates

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 admixtures comply with the properties, at a low cost.

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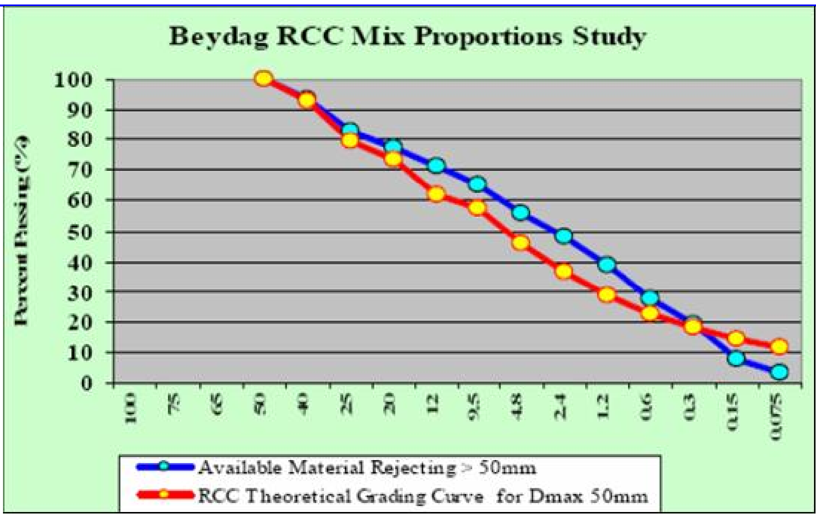

Figure C- 02- Natural aggregates at Beydag RCC Dam in Turkey

C.3- Cementitious Materials

C.3.1- General

RCC can be made with any of the basic types of cement or, more usually, with a combination of cement and a mineral admixture. It is very well known that the great majority of RCC mixtures contain mineral admixtures (usually a ground-granulated blast-furnace slag, fly-ash, natural pozzolan, rock flour and silt). 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.

C.3.2- Cement

RCC can be made from any of the basic types of cement. For RCC dams, cements with lower heat generation characteristics than Ordinary Portland cement (ASTM C150 Type I) may be beneficial, if they are locally available. They include Type II (moderate heat), Type IP (Portland pozzolan cement), and Type IS (Portland blast-furnace slag cement). Strength development for these 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.

C.3.3- Mineral admixtures

Mineral admixtures are finely divided siliceous materials that are added to cement. 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.

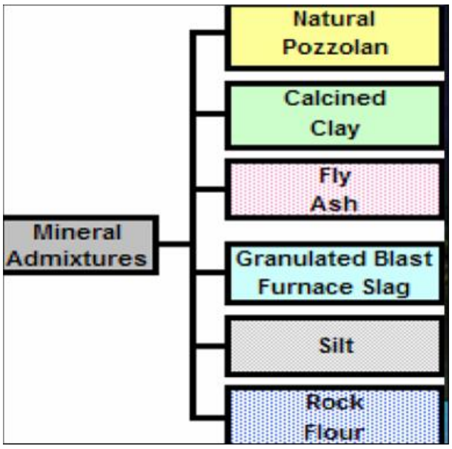

Figure C-03: Forms of mineral admixtures

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Some mineral admixtures can show pozzolanic activity (fly ash, natural pozzolan and calcined clay- Figure C-03), some others are cementitious (ground-granulated blast-furnace slag), whereas others are both cementitious and pozzolanic (high-lime fly ash).

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.

The convenience of adopting the cubic type of grading curve as previously mentioned, implies in having around 10 to 15% of fines (material inferior to 0.075mm), as shown in Figure C-01. In order to do that it is possible to rely on the use of “Silt”, obtained in natural deposits or by the production of fines using rock crushing, gravel or blast furnace slag. In these cases the rock crushing, producing the Rock Flour, may be even more beneficial, if, besides composing the desired grain curve, the rock has contents and mineralogical conditions (SiO_2; Al_2O_3 and Fe_2O_3) that have satisfactory pozzolanic activities.

The indiscriminate and irrational use of high contents of pozzolanic material is not advisable under two aspects:

- The occasional unavailability of Calcium composites, present in the Cement, to react fully with the components of the pozzolanic material.
- Costs

This is to say that the adequate content of Pozzolanic material to be used depends on the Pozzolanic Activity, to be shown together with the cement, in tests with different combination contents of **cement: pozzolanic material**.

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

- The 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…”*(See graphics in Figures C-04 & C-05);

- The 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…”*(See graphics in Figures C-06);

- The Brazilian studies – *“…Improved resistance obtained with the use of Filler on the CVC, plus the improvement observed in reduction of the RCC permeability prove that the use of this material is worthwhile…”*; *“…Pozzolanic Activity Indexes with various cements have proved to grow according to the age and Fineness (Blaine) of the incorporated Fillers;Fillers tested have demonstrated a substantial efficiency to reduce the expansions resulting from the Alkali-Silica Reaction thus demonstrating another important pozzolanic action; The set of data submitted in this report makes evident a substantial Pozzolanic characteristic of the Fillers studied which states the validity of its use in RCC and also in conventional types of concrete which corroborates the theoretical expectation mentioned in the text…”* (See graphics on Figure C-06);

- The Spanish experience – [Moises ICOLD 2003]

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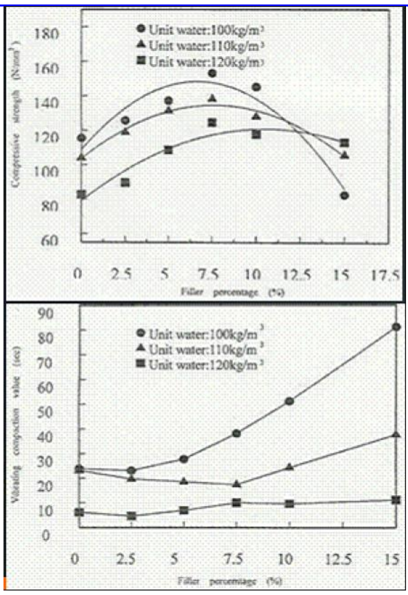
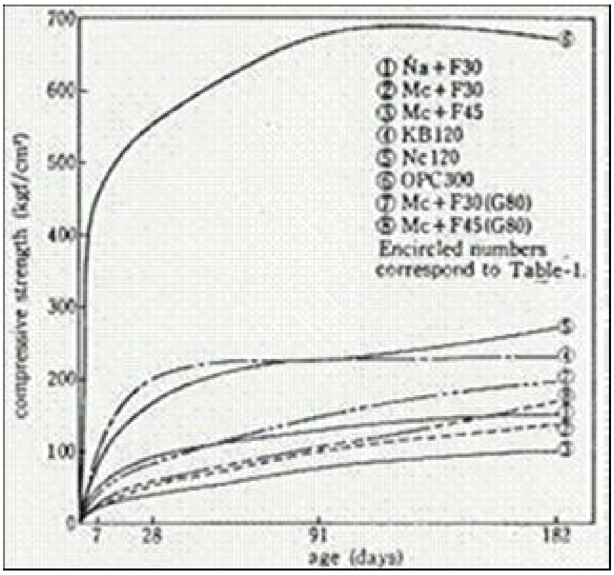
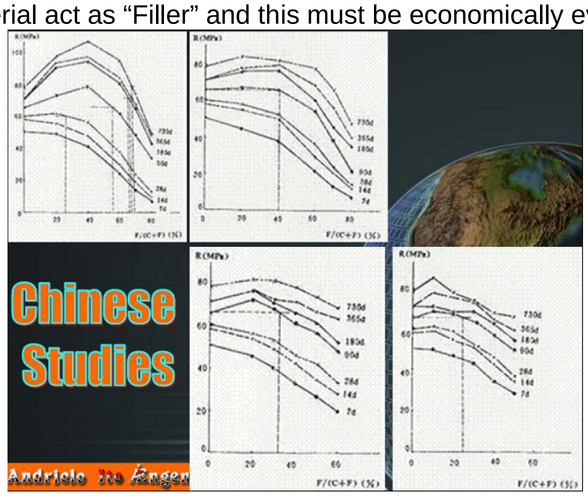




Figures C- 04- Compressive Strength and Vibrating Compacting Value with different Fines Content)

Figures C-05- Compressive Strength of RCC versus Age with different Fly Ash Replacement Ratios

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 makes part of the pozzolanic material act as “Filler” and this must be economically evaluated (as mentioned before).



Figures C-06- Compressive Strength curves for mortar with different Fly Ash contents and different types of Fly Ash

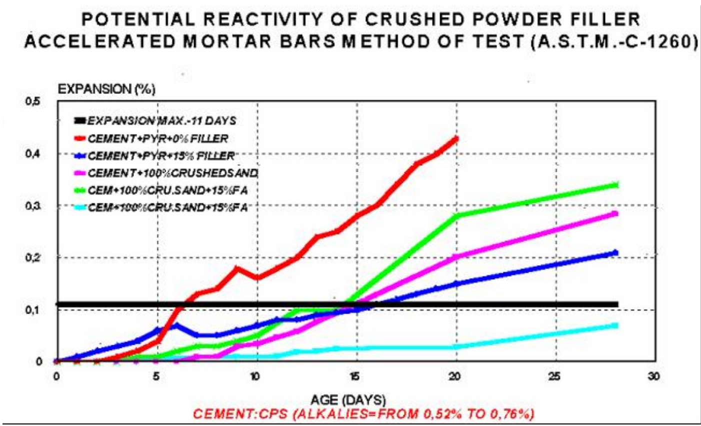


Figure C-07- Reduction of the Mortar Expansion due to the use of Rock Flour

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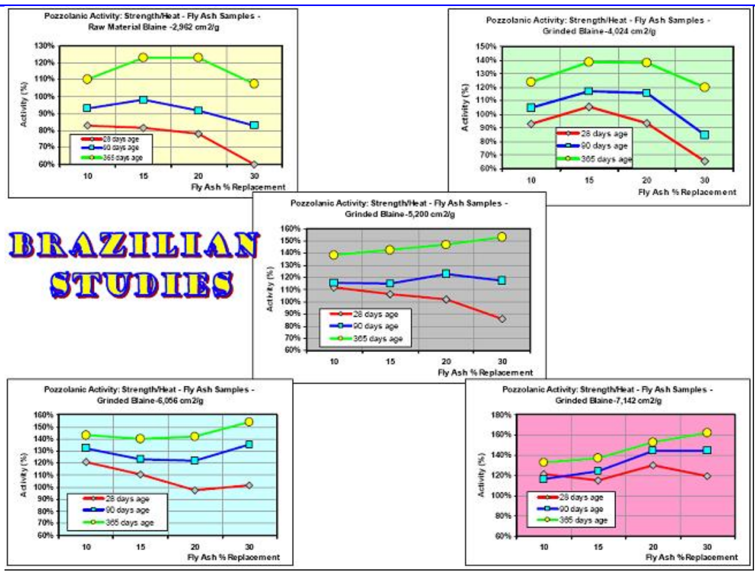
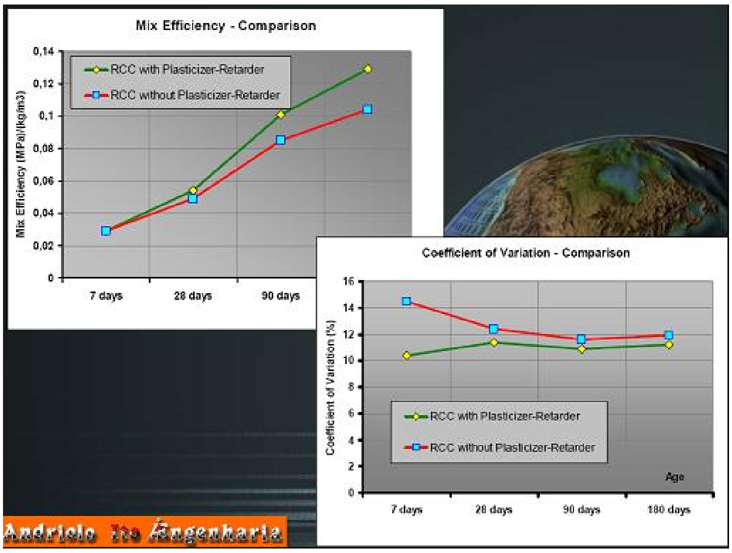


Figure C-08- Compressive Strength of Mortar with different contents of Fly Ash at different Fineness

C.4- 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 compactionIts 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 (see Figure C-09). The choice of any admixture should be confirmed by laboratory trial mixes and ideally after full-scale trials. Particular admixtures work well with particular cementitious materials and not so well with other materials.

The advantages of using admixtures that enhance workability and retard set for keeping conventional mass concrete alive and preventing cold joints, particularly during hot weather, are well established. Water-reducing and set-retarding admixtures have been used effectively in many projects mainly in China, Spain and hot climate zones as some parts in Brazil.



Figures C-09- Advantages in using Water Reducer/Set Retarderadmixtures, concerning the Mix Efficiency and the Uniformity (Coefficient of Variation)

C.5- 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 alkalis, acids, or organic matter that might inhibit proper strength gain.

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D- Design RCC Dams on Weak Foundations

D.1-General

The use of vibratory or other rollers to compact concrete in lieu of immersion vibrators does not change the basic design concepts for dams, locks, or other structures; however, it does affect construction procedures. Roller-compacted concrete has been used primarily for gravity-type dams, and nowadays for arched-gravity type dams. The design of these dam using RCC is fundamentally no different from the design of a similar dam constructed of conventional concrete.

During the definition stage of a project, when the type of dam is selected, the deficiencies of, or incidents that have occurred at, some smaller RCC dams should be carefully evaluated. The consequences of similar mishaps at a high and large dam during its life-time can be catastrophic.

These requirements include site specific design criteria, a suitable foundation, expeditious use of available construction materials, structural stability, and watertightness.

Can be accepted a "rock" foundation with a Modulus of Elasticity of 1,0 GPa, for a RCC Dam?

D.2- Site Selection

D.2.1- General

One of the most important conditions to build a concrete dam - either CVC or RCC - is that the foundation presents after treatment by grouting or reinforcement, the necessary strength, permeability and rigidity. Site investigations are always necessary for designing and building dams. Usually a requirement to build a concrete dam is that the foundation is in the rock, even altered or having clay bedding seams or shear zones that could be treated or reinforced. Otherwise, they are not safe. Geotechnical works such as borings, trenches, and galleries and geophysical investigations are needed. Permeability tests are generally carried out in the borings. Shear strength and deformability parameters of the foundation rock mass, especially along the weakest surfaces, are necessary for the design. Instead of tests, appropriate rock mass classifications can also be used to obtain a good estimate of such parameters, and in many cases it is not necessary to make tests.

A number of interrelated factors have to be considered when selecting the type of dam that is best for a given site including physiography, hydrology, foundation, schedule (reduction in time), weather, construction materials, constructability, environmental impacts and most importantly the intended use of the project and the particular needs of the owner. The fundamental requirements for an RCC dam to be considered at any site at any height are an adequate foundation and a suitable source of construction material for processing into RCC aggregate. The remainder of the dam type screening process is an economic comparison of RCC with other types of dams. At the screening level of dam type/size selection RCC should not be ruled out because of height alone.

A completed RCC dam should function as a monolithic elastic structure, integrally bonded to its rock foundations, that is, its structural performance should be equivalent to that of a CVC dam with a similar configuration. For the two types of dams to be equal in quality, safety and durability, they should have equivalent margins of safety against cracking, rupture, overstressing, shearing-sliding and leakage through the concrete and construction or layer joints.

The degree of monolithicity and elastic isotropy of a RCC dam depends on several factors. If there are vertical transverse cracks or ungrouted contraction joints, the structure's blocks would act as individual cantilever gravity dams, each independent of its neighbours. If no transverse contraction joints are provided, and no transverse cracks occur, the dam will function as a three-dimensional monolithic plug, transmitting some load in all directions, including longitudinally to the abutments. If the transverse cracks are inclined or curvilinear, the structural behaviour of the dam could be a hybrid between a cantilever gravity and a three-dimensional monolithic dam. If longitudinal cracking occurs, it would affect monolithicity in the transverse direction and cause internal tensile stress concentrations. All cracks alter, to varying degree, the stress field in the elastic mass with tensile stress concentrations occurring at the terminus of each crack within the body of the dam. Other factors which could significantly affect monolithicity are the bond, shear and tensile strengths of the horizontal construction joints

The current design, construction and performance of completed RCC dams indicates several issues which need to be resolved if the structural performance of a high RCC dam would be equivalent to that of a CVC dam. These issues are:

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- Quality of the foundations.
- Elastic monolithicity of construction joints.
- Stability against shearing-sliding.
- Structural cracks
- Transverse contraction joints.
- Longitudinal cracks and joints.
- Quality of RCC.
- Large spillways over an RCC dam.
- Drainage and seepage control.

D.2.2- Foundation

Foundation conditions for an RCC dam of any height must he equal to those of a CVC dam of the height being considered. If a satisfactory foundation exists there should not be a limit to the height of an RCC design based on foundation quality.

Structural design of the dam, again as in a conventional dam, includes correct interpretation of geology as it will affect stability and deformation of foundation rock. RCC dams are to be considered three-dimensional structures capable of responding to foundation strengths and weaknesses. Consequently, two-dimensional seepage and stability analyses may not accurately define the total resistance to the applied loads. If only two-dimensional analyses are made, significantly different foundation deformation modulus of elasticity across the site may cause portions of the dam and/or foundation to be more severely overloaded. This may or may not be acceptable or desirable.

Each project should be evaluated on a site-specific basis. Foundation shape irregularities such as would be seen in a cross-canyon profile could result in load transfer from depressed areas to intrusive areas, again causing variations in stresses and deflections computed from plane strain analyses. Such variations may or may not be significant.

When establishing design criteria for any type of dam, including RCC, at any height the paramount consideration should be the intended use of the structure, the particular needs of the owner and cost. Safety, watertightness, blood frequency, spillway capacity, schedule, seismicity and other site specific requirements must be established before dam design can begin.

Foundation, loading conditions, factor of safety, drainage, stress distribution and thermal cracking potential are all factors which must be considered when evaluating the stability of a very high dam and determining dam configuration and strength requirements.

Sound rock foundations are considered the most suitable for concrete dams because they possess high bearing capacity and have a high degree of erosion and seepage resistance. The RCC dams completed to date have been founded on many different rock types, such as basalt (Jordão, Salto Caxias, Urugua-i, Willow Creek), limestone (Winchester), marlstone (Middle Fork), granite (Copperfield), meta-andesite (Galesville), siltstone (Bucca Weir), quartzose sandstone (Upper Stillwater), meta-sandstone (Capanda) and quartzite (Saco Nova Olinda).

Assuming an adequate foundation, there is no structural height restriction for an RCC dam. Rock foundations that lack major faults and shears can be most suitable for RCC or CVC dams. Faults and shears do not necessarily eliminate a site from consideration, but it may be expensive to treat them to ensure an adequately safe foundation.

Because each site is unique, engineers experienced in evaluating foundations should investigate the site and determine possible treatments. A foundation investigation program, usually involving drilling, is considered essential in order to evaluate foundation conditions properly. The conditions from the rock surface down to 10 to 20 m are considered to be of the greatest importance, as they have the greatest effect on the ability of the foundation to withstand loads without unacceptable short-term and long-term deformations.

Foundation investigation and design is probably more important than the design of the dam section itself. History has shown that the potential for failure of a concrete dam, while extremely remote, is more likely in the foundation than in the dam itself. Special attention should be given to identifying potential sliding planes in the foundation rock

D.2.3- Foundation Rock properties

In the investigation program, five properties of the foundation rock needs to be determined, namely:

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- Compressive strength;
- Shear strength;
- Deformation modulus;
- Poisson's ratio, and
- Permeability.

The compressive strength of the foundation rock is an important consideration in determining the base dimension of the dam. Designers should calculate a minimum base dimension that reduces the maximum allowable bearing stress to allowable values as determined by dividing the compressive strength of the foundation material by an appropriate factor of safety.

The shear strength of the foundation rock, including any discontinuities, depends upon the cohesion and internal friction properties of the rock, together with the applied normal load. The total strength of the foundation rock can be determined using Mohr-Coulomb's equation in the same way it is used for the RCC material within the dam.

Because joints, shears, and faults possess little or no cohesion, the shear strength of a discontinuous rock mass is essentially derived from sliding friction. The shear strength of an existing joint in rock is nonlinear. Shearing resistance of rock with discontinuities should be based on physical tests (mainly “in situ”) of the material in order to plot a shear strength versus normal stress relationship. A unit shear strength for design can be determined once a range of normal stresses imposed by the dam is calculated. Factors of safety are then applied to the sliding friction shear strength depending upon the particular load combination being investigated.

When adequate shear strength data are not available for the foundation rock, a conservative approach for preliminary design is to assume zero cohesion and a conservative value for the sliding friction shear strength for the type of rock.

The magnitude of the foundation deformation modulus is often not as critical as the variation in modulus across the foundation. Conventional gravity dams have been successfully constructed on low modulus materials such as siltstone, claystone, gravel, and sand. Middle Fork, on marlstone, and Bucca Weir, on siltstone, are examples of RCC dams founded on rock with a relatively low (lower than 10,000Kgf/cm2) deformation modulus.

A determination of deformation patterns for complex foundation conditions may be determined with a joint-shear index and shear catalog. Poisson's ratio-the value of transverse strain to its corresponding axial strain-is needed for more rigorous mathematical analyses of the dam and its foundation.

Abrupt changes in deformation modulus can result in differential settlements that can cause cracking in an RCC dam. Therefore, the designer should identify low-modulus zones and plan improvement measures such as grouting the weak material or excavating and replacing it with conventional concrete or RCC.

Although permeability of the foundation rock is the main factor in determining whether a grout curtain is required, most designs for major dams include an upstream grout curtain to reduce seepage under the dam as a matter of course.

D.2.4- Quality Rock

High concrete dams, whether built of RCC or CVC, require rock foundations, which either in the natural state or after appropriate treatment, have adequate strength to receive the loads imposed upon them by the dam and the reservoir, without undergoing excessive deformations or instability. Invariably, rock foundations for high gravity dams need various types and degree of beneficiation treatment, and in some cases, foundation treatment can be as important an aspect of design and construction as the dam itself.

It is erroneous to assume that, because concrete in an RCC dam is placed in layers and compacted by rollers in a manner similar to earthfill or rockfill in an embankment dam, it would have the "flexibility" of an embankment to adjust to differential settlement or deformations of the foundation without adverse consequences for its stability. The response of an RCC dam to such foundation behaviour and the effects on its stability would be similar to that of a CVC dam. The consequences may comprise unacceptable reduction in reserve strength against shearing-sliding, cracking at the dam-foundation contact, increase in hydraulic uplift pressures, and cracking and overstressing in the dam itself.

At the 90m high Upper Stillwater Dam, a transverse crack which extended through the entire section of the dam was attributed to movement along a weak layer in the foundation which was either unanticipated or inadequately treated.

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While provision of a transverse contraction joint in the dam would have "controlled" the cracking, it would not have prevented the other adverse consequences of excessive foundation movement.

For high gravity dams, the weaker foundation features, such as shear zones, faults, contacts filled with gouge or clayey materials, or unfavourably dipping joints, can require extensive, expensive and time-consuming treatment. Often the critical consideration in the design of gravity dams is to assure adequate margins of safety against shearing-sliding and excessive non-elastic deformations at the weaker layers or zones in the foundations and the abutments.

The importance of thorough foundation exploration and treatment for high RCC gravity dams, may also be learned from experiences in the design and construction of some relatively smaller ones. For the 68m high Concepcion Dam in Honduras, the selection of an RCC dam was made before analyses were completed for resolution of such problems as: *"zones of poor foundations; very poor quality cement and pozzolan; low strength aggregate with high absorption and low density concrete".*

For non-engineering reasons, construction had to be commenced before final drawings or specifications were available and *"before the foundation level and axis of the dam were established"*. A similar programme would not be appropriate for a high and large RCC gravity dam, posing an unacceptable degree of risk to its safety and durability.

Shaping the foundations and abutments to eliminate site irregularities, is equally important for high RCC and CVC gravity dams. If not removed or rectified, they would cause internal stress concentrations, resulting in cracking and progressive deterioration of concrete.

Stability of the abutments of a high RCC gravity dam also requires special attention, if there is axial transfer of loads from the dam. Three-dimensional stability analyses of the abutments would be necessary to determine the type of treatment required; it may also influence the structural design of the dam. While stability of a gravity dam may depend more on the quality and behaviour of the weaker parts of the foundation, the conjunctive stability of the structure and the foundations can also be degraded by poor quality and performance of the dam.

Structural cracking, high internal pore pressures, uncontrolled leakage, leaching and alkali-aggregate reaction in the dam concrete can alter the stress patterns in the foundations and abutments to such a degree that the margins of safety against failure in the foundations are reduced below acceptable limits. Therefore the conjunctive stability of the dam-foundation complex must be studied as thoroughly for high RCC dams, as for comparable CVC dams.

D.2.5- Foundation Excavation Guidelines

The amount of excavation required depends on the depth of the overburden and weathered rock. All overburden covering a rock foundation, such as soil, alluvium, and talus, should be removed. Contract documents should be structured so that payment for unanticipated foundation improvements can be resolved quickly and fairly in order to prevent costly change-of-conditions claims by the contractor.

D.2.6- Foundation Improvement and Drainage

The usual methods of foundation improvement are the same one used for CVC dam. Curtain grouting is commonly used to control seepage beneath dams, even those founded on tight, low-permeability rock. The spacing can vary depending on the condition of the rock. The depth of the holes also depends on hydrostatic head and foundation rock conditions. The depth of the grout curtain can vary from 40 percent of the head for dense foundations to 70 percent in poorer-quality rock foundations according to USBR criteria.

Foundation grout treatment ordinarily would be developed based on the site-specific needs of each project. Where a complete grouting program is necessary, it will normally be similar to the following:

- standard consolidation grouting at 3m or 6m centers across the excavation contact area to 6m to 15m depths as determined from the geotechnical analyses; and
- deep curtain grouting at 3 m centers, or less, near and parallel to the dam axis.

Curtain grouting can be performed from the foundation gallery after the structure has reached an elevation so that there is sufficient weight to prevent upward movement of the concrete. Grouting can also be done using angled holes drilled from the upstream heel while the RCC placements continue above. This approach has proven to be conveniente effective, and a **"**time saver" on some RCC projects.

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If needed for stability or seepage control, drain holes should be drilled downstream of the grout curtain. Typically, they are about 76mm in diameter, drilled on 3m centers from the gallery or downstream face after the foundation grouting has been completed. Generally, depths may vary from 20 to 40 percent of the reservoir depth. Actual spacing, depth, and orientation are dependent on site conditions.

Foundation or so called "dental" treatment consisting of conventional concrete placements may be required if final excavation has uncovered faults, seams, or shattered or inferior rock extending to such depths that it is impractical to remove the areas entirely or to fill them with dental concrete. Most projects have found the use of RCC desirable in any area where it can be placed and compacted, with dental concrete kept to a minimum. Another approach has been to use dental concrete and mass backfill concrete extensively to create a level zone from which to begin placing RCC.

Drain holes are usually provided in rock foundations for all but some low to moderate-height dams to reduce uplift pressures in the foundation and improve the stability of the dam. The function of the drain holes is to intercept and remove any seepage water bypassing the grout curtain and thus reduce the buildup of hydraulic pressure (uplift) beneath the dam.

Because RCC is invariably less costly per unit volume than CVC, the designer should maximize the use of RCC in the foundation. However, CVC surfaces generally are built up first to facilitate the start of RCC placement. The size of the starting pad for RCC placement can be as small as one roller width by two roller lengths.

Handheld compactors or small rollers and equipment may be used for compacting RCC or CVC into areas that are inaccessible to the large rollers used for the remainder of the dam. Thin lifts usually are required when using such equipment in order to achieve roughly the same density as the RCC for the body of the dam. CVC should be used at the dam-abutment interface in order to assure bonding to the rock surface and to minimize seepage at this contact.

The impact of foundation treatment on costs and the construction schedule of the dam should not be underestimated at the time of selection of type and layout of the dam. The foundations should be shaped to eliminate irregularities which may cause stress concentrations in and cracking of the dam.

D.2.7- Very Low Modulus or Non-Rock Foundations

The principal considerations for low-modulus rock or non-rock foundations are differential settlement, seepage, piping, and erosion at the downstream toe. Nonrock foundations such as silt, sand, gravel, and clay may be acceptable for an RCC or CVC gravity dam. Such foundations are usually considered only for low dams, and a number of factors must be studied first. Foundations of this type may require special measures such as upstream and downstream aprons, cutoff walls, and a drainage system.

Lower Chase Creek (20m high) is an example of an RCC dam placed on a very low modulus foundation. The Cedar Falls (9m high) dam in the State of Washington is an example of low RCC gravity dam constructed on non-rock foundations. The site for Lower Chase Creek consists of a conglomerate overlaid by alluvium. The designers decided to construct the 20m dam atop an RCC foundation mat that extended through the alluvium and onto the conglomerate. Alternative designs consisting of a cutoff wall to conglomerate or building the dam on compacted alluvium also were considered.

It was determined from plate bearing tests that the conglomerate had a deformation modulus of 0.125 GPa. The analysis concluded "that a dam founded on the conglomerate would be more stable, experience less settlement, have reduced seepage potential, and be no more costly than the cutoff-wall alternative". The RCC foundation mat is as deep as 7.6m. It extends out 3m upstream and downstream from the dam section on a 1H:1V slope and then extends vertically down to the conglomerate surface.

Of course that under these conditions the Designer need be conscious of the Risks involved. Additionally it can be put that in a Gravity Dam it is quite Non Sense consider the Dam Rupture, but it is very important to consider the Foundation conditions to perform a long term life of the Project.

A "quite" safe foundation could be considered with a Modulus over 5GPa.

- **But why "quite" safe?**
- **Because it is important to take in consideration other aspects as Shear Indexes (Cohesion and Friction), Permeability, Compressive Strength and its Uniformity, and not "Only" the Modulus.**

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The durability and long-term performance requirements of the RCC dam are technical factors to be considered. The acceptance standards of quality and safety for RCC dams should be the same as those currently internationally accepted for comparable CVC dams. The performance of the completed RCC dams should be the same as those accepted for comparable CVC dams, without deficiencies with respect to selection of materials for RCC, foundation treatment, structural monolithicity, crack prevention and leakage.

An "acceptable" foundation could be with a Modulus ranging between 3 and 4 GPa. A "special" foundation could be ranging between 1 to 2 GPa.

- **Why "special"?**
- **In this situation, and there are some in the technical literature, can be included small dams/ reservoirs, in height and in volume.**

The magnitude of the foundation deformation modulus is often not as critical as the variation in modulus across the foundation. Conventional gravity dams have been successfully constructed on low modulus materials such as siltstone, claystone, gravel, and sand. **Middle Fork (H=38m; L=125m; V= 43.000m^3)** , on marlstone, and **Bucca Weir (H=12m; L=124m; V=24.000m^3)**, on siltstone, are examples of RCC dams founded on rock with a relatively low (lower than 10,000Kgf/cm2) deformation modulus.

In a General Scenario the conditions above can induces to each precaution, for each case.

As previously mentioned each project should be evaluated on a site-specific basis. One of the most important conditions to build a concrete dam - either CVC or RCC - is that the foundation presents after treatment the necessary strength, permeability and rigidity.

Shear strength and deformability parameters of the foundation rock mass, especially along the weakest surfaces, are necessary for the design.

A completed RCC dam should function as a monolithic elastic structure, integrally bonded to its rock foundations.

The degree of monolithicity and elastic isotropy of a RCC dam depends on several factors. If there are vertical transverse cracks or ungrouted contraction joints, the structure's blocks would act as individual cantilever gravity dams, each independent of its neighbours.

Foundation, loading conditions, factor of safety, drainage, stress distribution and thermal cracking potential are all factors which must be considered when evaluating the stability of a very high dam and determining dam configuration and strength requirements.

Foundation investigation and design is probably more important than the design of the dam section itself. History has shown that the potential for failure of a concrete dam, while extremely remote, is more likely in the foundation than in the dam itself.

The compressive strength of the foundation rock is an important consideration in determining the base dimension of the dam. **Designers should calculate a minimum base dimension that reduces the maximum allowable bearing stress to allowable values as determined by dividing the compressive strength of the foundation material by an appropriate factor of safety.**

The shear strength of the foundation rock, including any discontinuities, depends upon the cohesion and internal friction properties of the rock, together with the applied normal load. The total strength of the foundation rock can be determined using Mohr-Coulomb's equation in the same way it is used for the RCC material within the dam.

Because joints, shears, and faults possess little or no cohesion, the shear strength of a discontinuous rock mass is essentially derived from sliding friction. The shear strength of an existing joint in rock is nonlinear. Shearing resistance of rock with discontinuities should be based on physical tests (mainly "in situ") of the material in order to plot the shear strength versus normal stress relationship. An unit shear strength for design can be determined once a range of normal stresses imposed by the dam is calculated. Factors of safety are then applied to the sliding friction shear strength depending upon the particular load combination being investigated.

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Abrupt changes in deformation modulus can result in differential settlements that can cause cracking in an RCC dam. Therefore, the designer should identify low-modulus zones and plan improvement measures such as grouting the weak material or excavating and replacing it with conventional concrete or RCC.

Although permeability of the foundation rock is the main factor in determining whether a grout curtain is required, most designs for major dams include an upstream grout curtain to reduce seepage under the dam as a matter of course.
The principal considerations for low-modulus rock or non-rock foundations are differential settlement, seepage, piping, and erosion at the downstream toe. Nonrock foundations such as silt, sand, gravel, and clay may be acceptable for an RCC or CVC gravity dam. **Such foundations are usually considered only for low height dams, and a number of factors must be studied first. Foundations of this type may require special measures such as upstream and downstream aprons, cutoff walls, and a drainage system.**

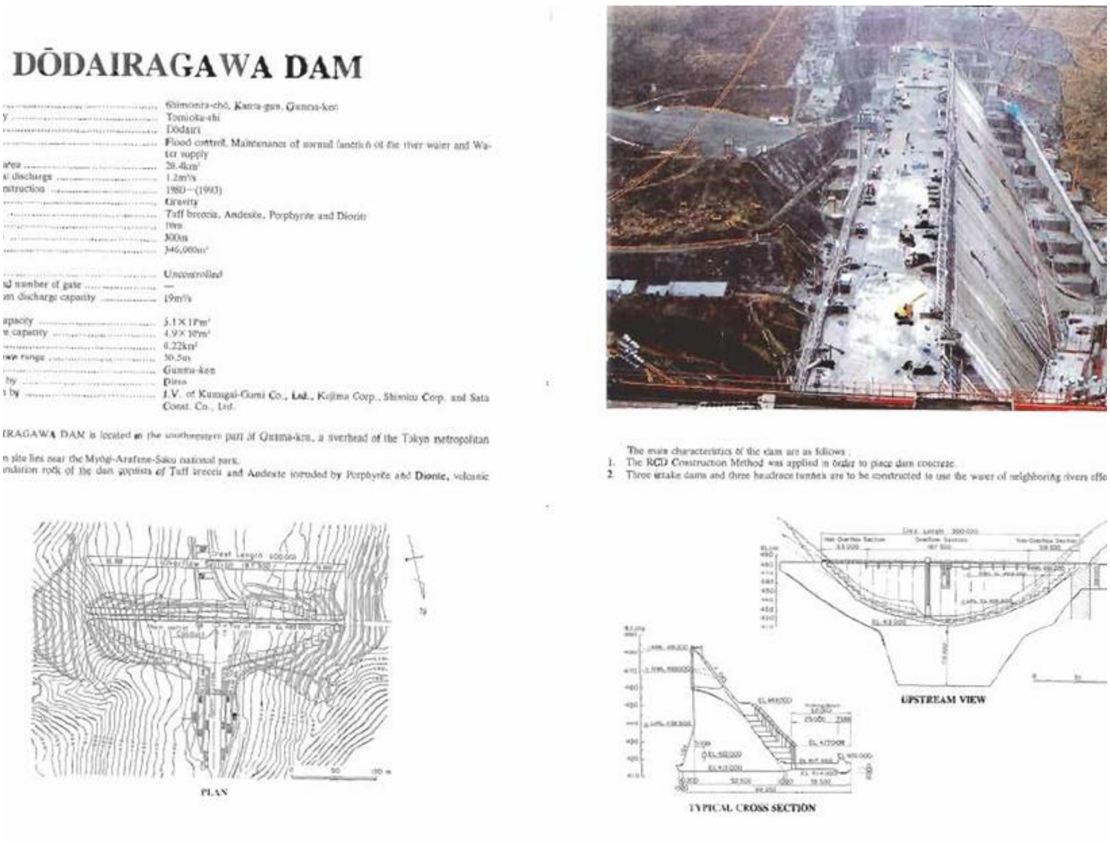

Figure D-01- Dodairagawa RCD Dam in Japan

The design of gravity structures is controlled principally by foundation considerations. Failure of a concrete gravity dam under sustained loading or flood conditions as a result of initial failure in the concrete section above base rock is extremely rare. Historically, the failure mode for concrete dams has been by sliding or shear failure of the foundation rock. Knowledge of bedding, orientation of fracture planes in the base rock, and other pertinent foundation information is essential. If there is a potential plane of sliding within the foundation, the choice is normally either to excavate below the plane or provide sufficient mass to reduce the sliding potential to a safe limit.

The upstream face of a gravity dam is usual vertical in order to concentrate the weight of concrete upstream to better resist the reservoir water loading and to simplify construction. It is common practice in Japan (Dodairagawa, Sakaigawa, Tamagawa, and others) and elsewhere (Puebla de Cazalla, Rialb and Val Dams, in Spain; Cindere in Turkey) to add a batter to the lower part of the upstream face to increase the base thickness and thereby improve sliding stability at the base. If a batter is used, stability and stresses should be checked at the elevation where the batter intersects the vertical upstream face.

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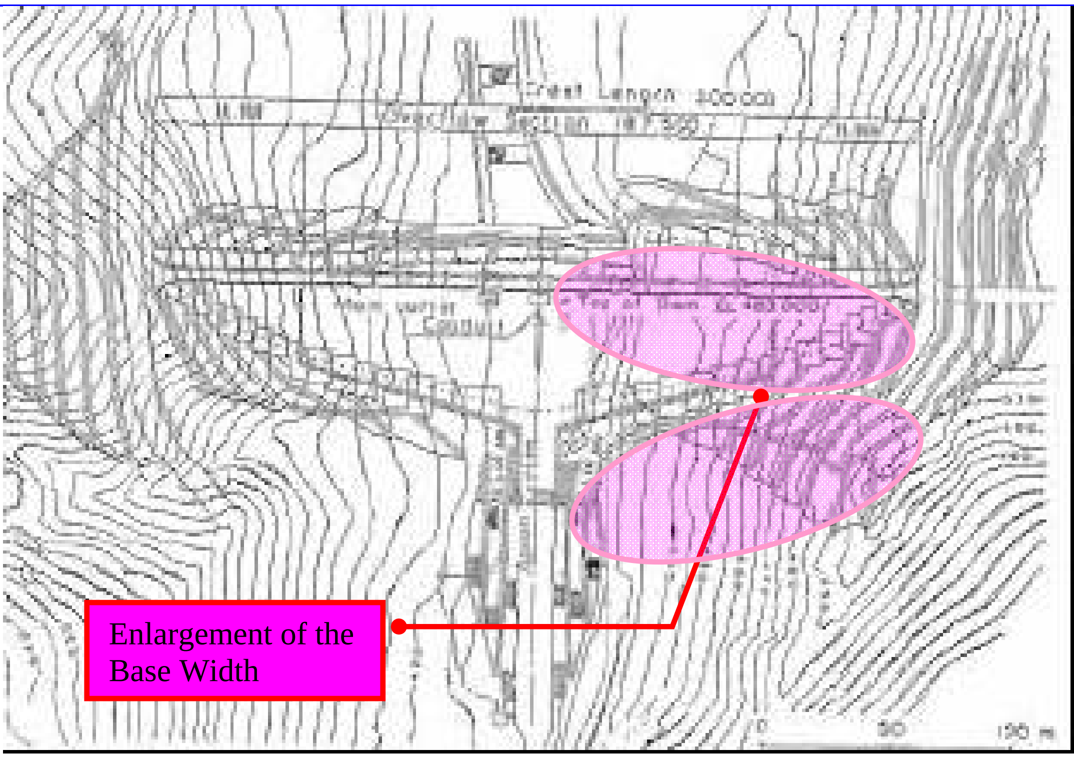

Figure D-02-Dodairadawa RCC Dam- 70m in Height- Japan

Figure D-03- Enlargement of the dam base at left bank- Dodairagawa RCC Dam – 70m in Height- Japan

Prudent design should follow the principals developed over the years for CVC dams to relieve hydrostatic pressures in the foundation and within the dam through drainage. This is normally done by the construction of galleries within the dam and sometimes addit in the foundation connected to a network of drain holes. Proper drainage is especially important in the design of very high RCC dams given the history of zones of relatively high permeability at horizontal construction joints between lifts (lift joints) that often occur in RCC dams and the potential for uplift along these planes. Most RCC dams have been designed assuming total uplift along horizontal lift joints. Proper drainage is a critical

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consideration when analysing the stability of very high RCC dams. Placement of drains and ensured lifetime effectiveness of those drains are critical considerations to be addressed. If lifetime effectiveness and continued efficiency cannot be ensured, then appropriate conservative uplift assumptions need to be made.

The uplift pressure at the foundation drains can be assumed at one-third of the uplift pressure at the drains corresponding to a linear pressure transition from headwater to tailwater. A linear decrease in uplift is then assumed from the uplift pressure at the foundation drains to tailwater pressure at the downstream face.

In highly seismic areas, extreme loading combinations change the internal stress distribution, and analyses indicate significant tensile stresses alternately at the upstream and downstream faces of the dam as it rocks back and forth during the seismic event.. Stability of a gravity dam against shearing-sliding, at construction joints, through weaker or cracked portions of the concrete, and at or near the dam-foundation contact, is a primary consideration. However, it is not the only factor governing the safety and stability of the dam.

D.3- Quality Rock

High concrete dams, whether built of RCC or CVC, require rock foundations, which either in the natural state or after appropriate treatment, have adequate strength to receive the loads imposed upon them by the dam and the reservoir, without undergoing excessive deformations or instability. Invariably, rock foundations for high gravity dams need various types and degree of beneficiation treatment, and in some cases, foundation treatment can be as important an aspect of design and construction as the dam itself.

D.4- Foundation Improvement and Drainage

The usual methods of foundation improvement are the same one used for CVC dam. Because RCC is invariably less costly per unit volume than CVC, the designer should maximize the use of RCC in the foundation. However, CVC surfaces generally are built up first to facilitate the start of RCC placement. The size of the starting pad for RCC placement can be as small as one roller width by two roller lengths.

D.5- Some Comments Related to the Specific Question and the Subsequent Scenario

Main Hypotesis	Subsequent Hypotesis	Result or Occurences	
Low Modulus	Differential Setlement between adjacent blocks	Waterstop can suport	No leakage. Poor view aspect at crest due to the displacement
		Waterstop can not suport	Seepage without piping and very poor view aspect due to the outflow
		Waterstop can not suport	Seepage and subsequent piping if the material has no cohesion. High Risk
Low Modulus and Low Shear Indexes	Differential Setlement between adjacent blocks	Waterstop can suport.	No leakage. Poor view aspect at crest. No safety for long performance. Some Risk
		Waterstop can not suport	Seepage without piping and very poor view aspect due to the outflow and possible flow increase at long age. High Risk
		Waterstop can not suport	Seepage and subsequent piping if the material has no cohesion. Very High Risk

It is important to add some precautions due to the Creep and Permeability aspects.

D.6- Suggestions

To reduce the Potential Risk **(JUST)** of a RCC Dam Foundation it can be considered:

- Go deeper in the foundation, reaching a level of an adequate range of the Modulus or;
- Enlarge the base width (as Dodairagawa Dam), or;
- Both (increasing the Modulus and taking into consideration the reduction in the displacement)

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E- SITE MOBILIZATION FOR RCC EQUIPMENTS,

E.1- Construction Programme – General

A Hypothetical Example is assumed here to be didactical.

With basis on the Construction Schedule, provided by Client or Contractor, it can be developed a General Planning Time-Chart where the following can be observed:

E.2- Detailed Construction Programme

The quantities of concretes, aggregates, forms and reinforcement, considered in the Planning must be based on the the Designs and Definite Quantitatives.

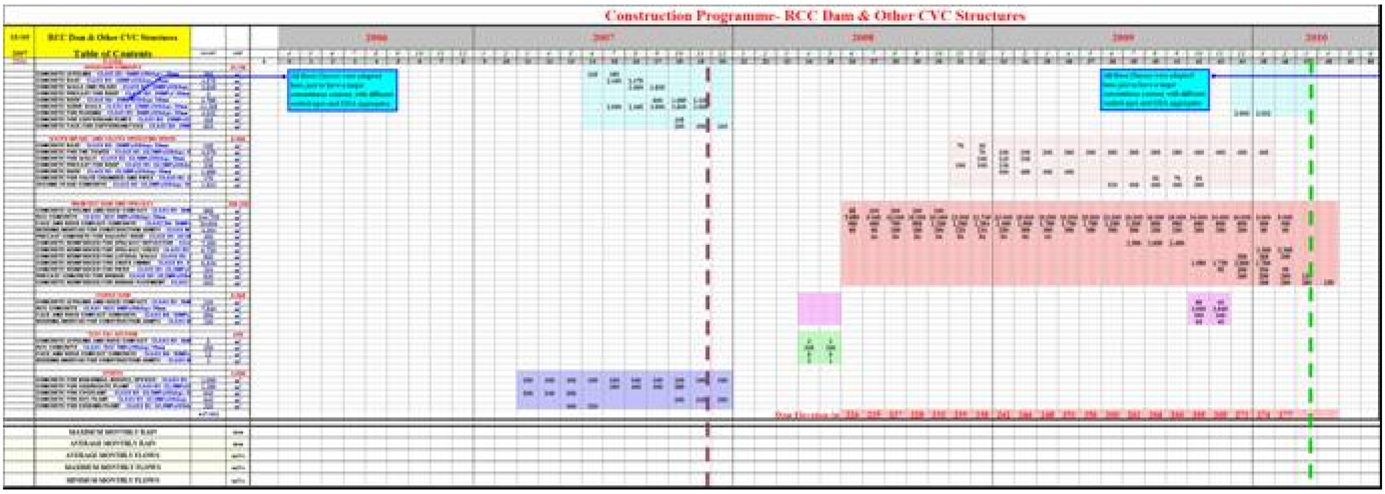

Figure E-01- Chart with monthly distribution of concrete volumes to be executed.

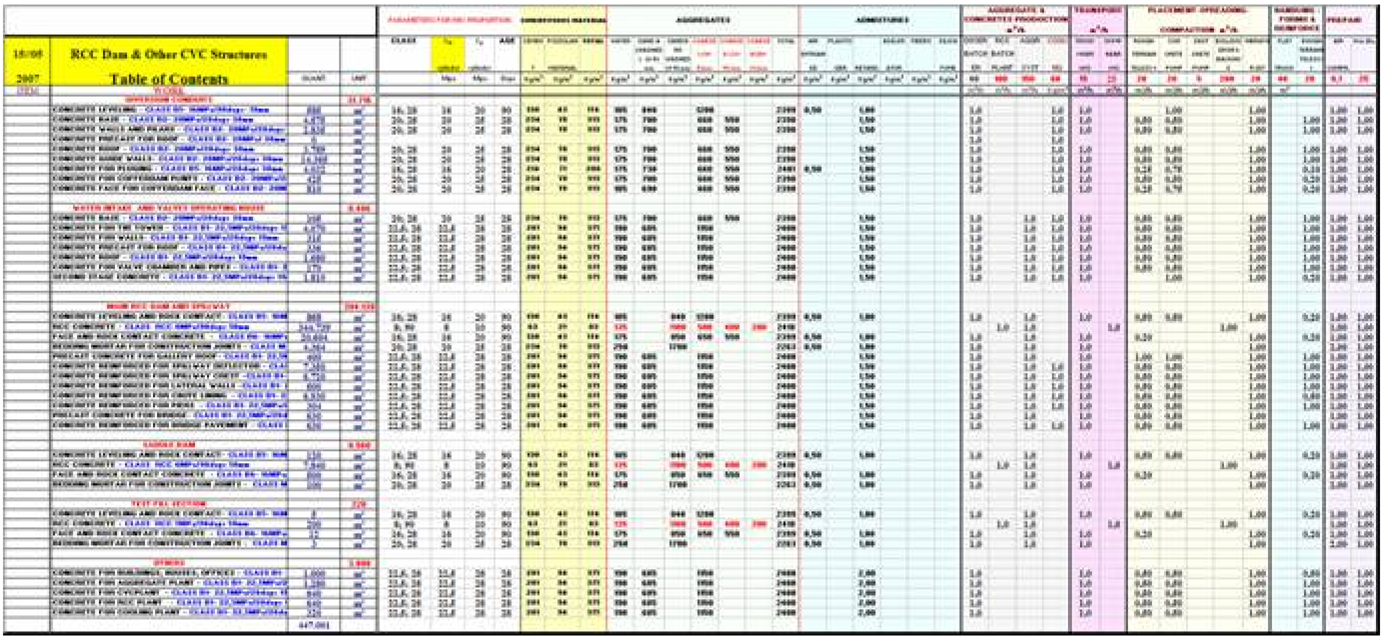

Figure E-02- Chart (Continuation of Figure E-01) of concrete dosage and recommendation on how to produce, transport and place during the construction of the Project.

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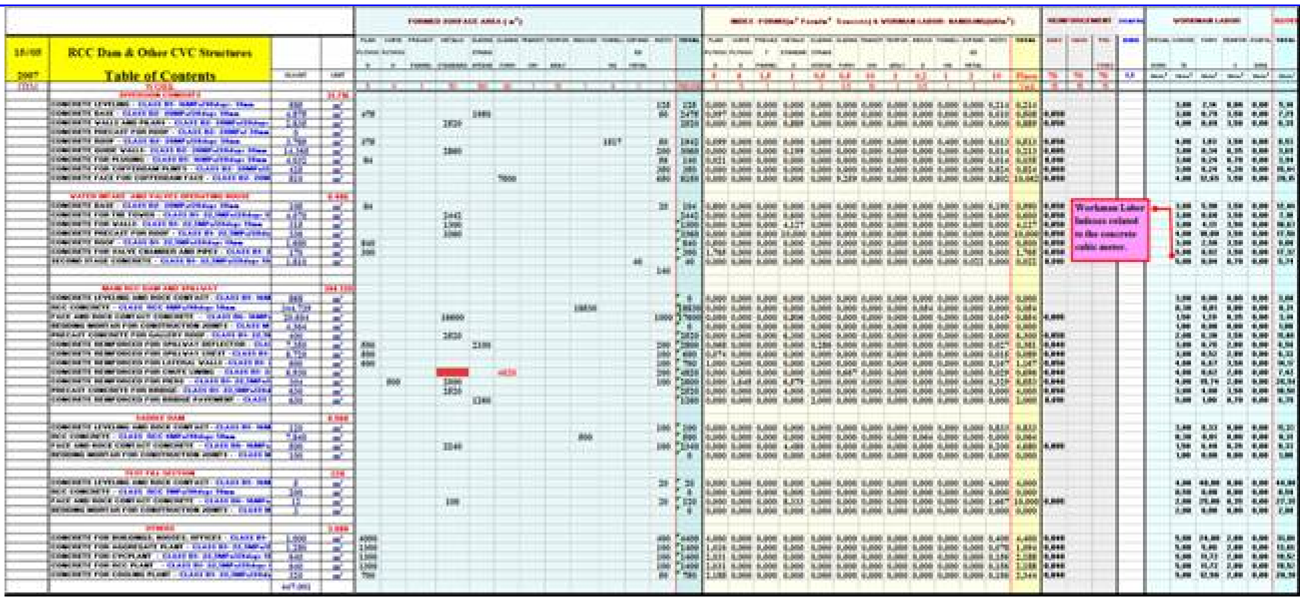

Figure E-03- Chart (Continuation of Figures E-01 and E-02) with molded areas and mold panels, as well as the time-charts for the Workmanship to execute the tasks of molds, reinforcements and concretes during the construction of the Project.

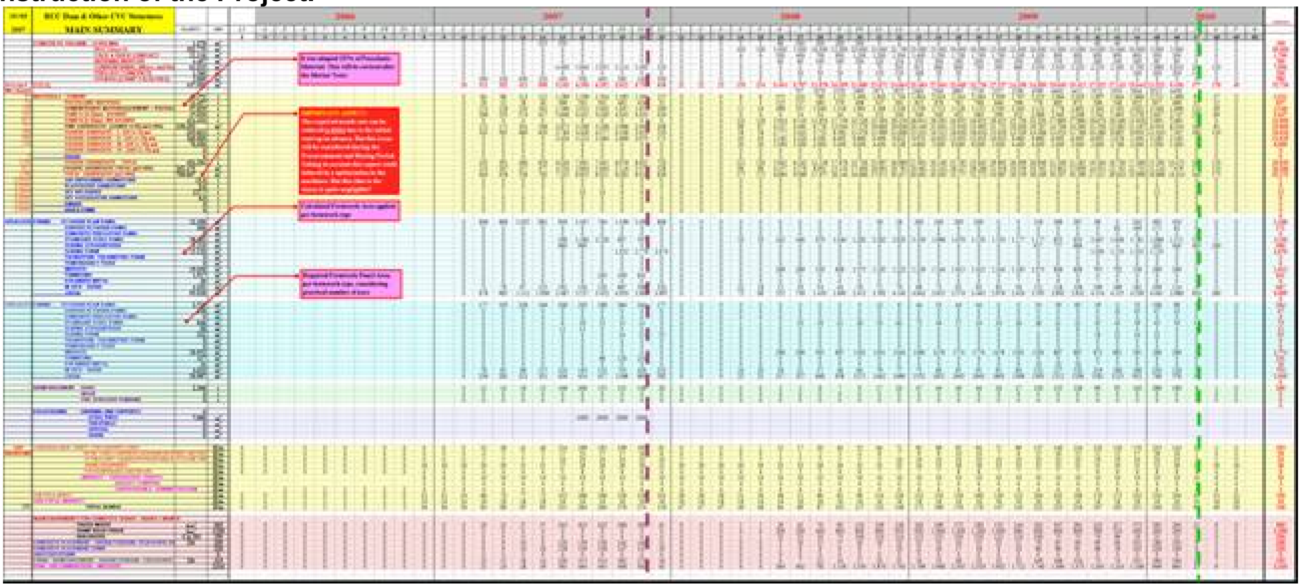

Figure E-04- Chart (corresponding to Figure E-01) with the monthly quantities of materials, molds, reinforcements and main equipment time, in addition to a time-chart for workmanship to execute the tasks of molds, armatures, and concrete during the construction of the Project.

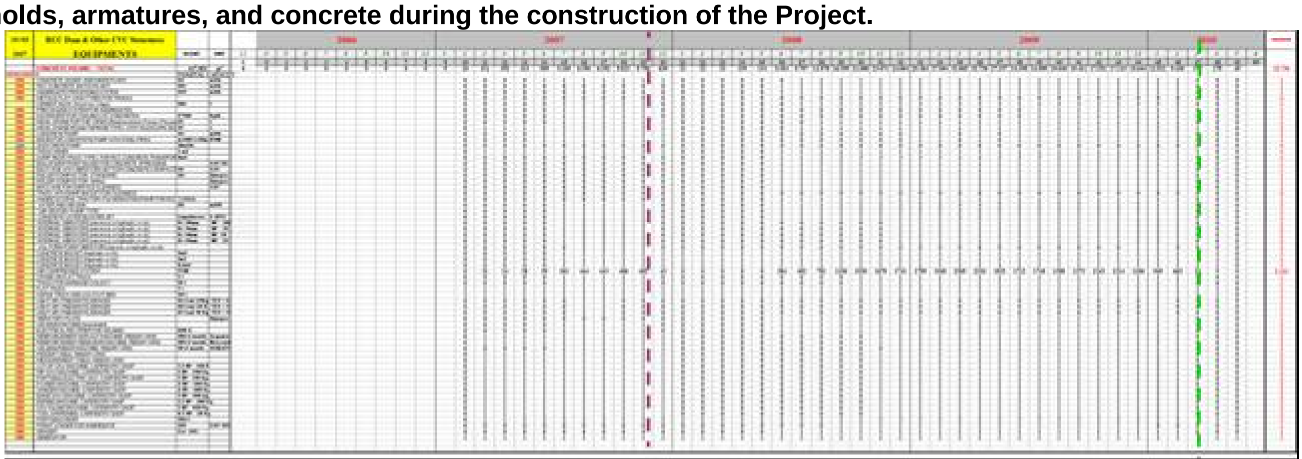

Figure E-05- Chart (corresponding to Figures E-01 and E-03) with the monthly quantities of equipment to execute the tasks of molds, armatures, and concrete during the construction of the Project.

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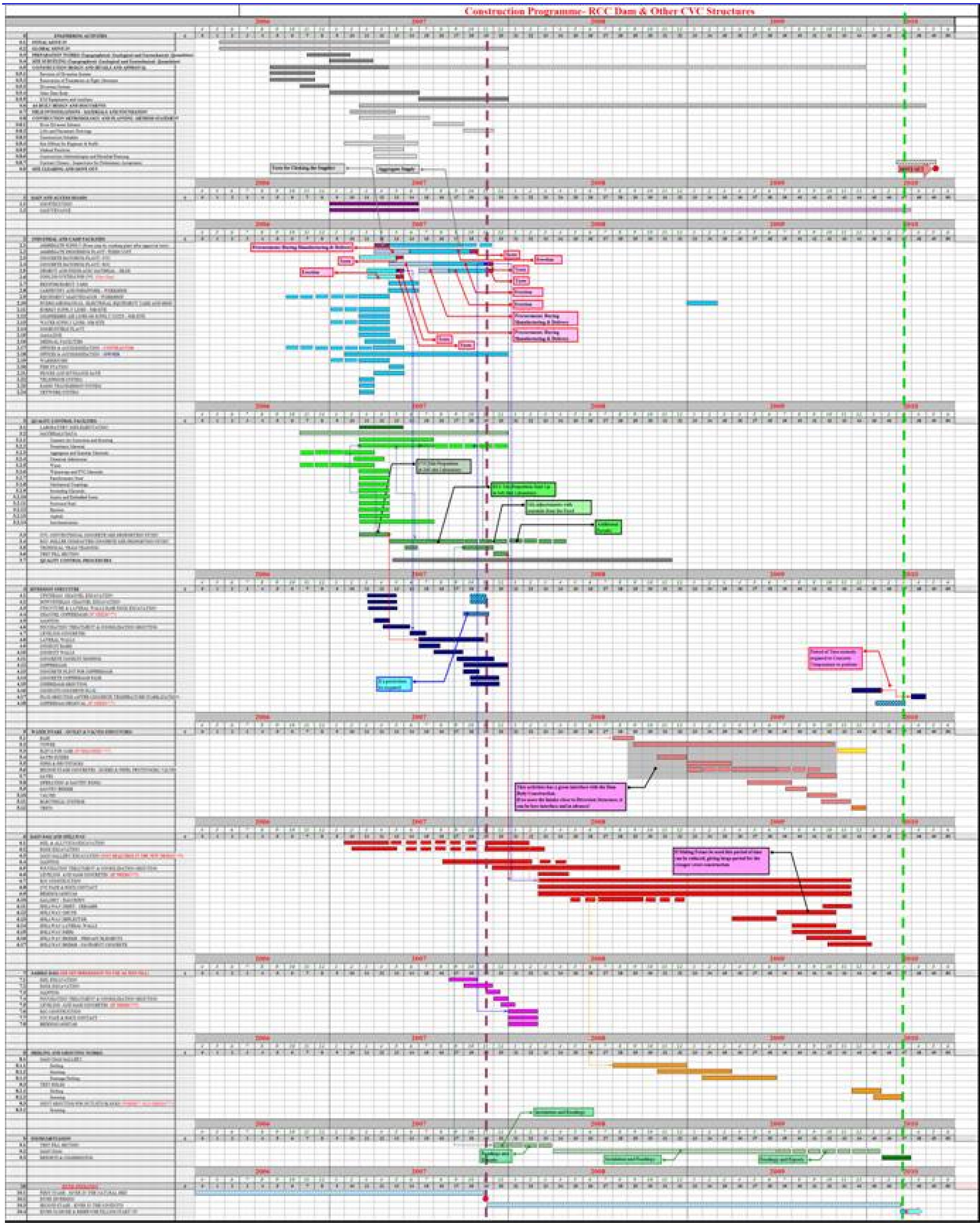

Figure E-06- Chart (corresponding to Figures E-01, E-03 and E-04) with the chronological stages for construction of the Project.

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E-3- Materials Analysis

E.3.1- Cement

The parameters of each type of cement are comparatively analyzed

E.3.2- 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.

E.3.3- Water

Tests Certificates from the available water must be obtained.

E.3.4- Granular Materials for Concrete Aggregates

A set of Test Certificates need be obtained with the (at least) following indexes or properties:

Physical and Chemical Properties of Rock Fragments					
Determination	Method	Unit	Result on	Result on	Comments
Rock Description					
Specific Gravity- Dry	ASTM C 127	t/m3			
Specific Gravity- SSD	ASTM C 127	t/m3			
Apparent Specific Gravity	ASTM C 127	t/m3			
Absorption	ASTM C 127	%			
Los Angeles Abrasion Loss at 200 Revolutions	ASTM C 131	%			
Los Angeles Abrasion Loss at 1000 Revolutions	ASTM C 131	%			
Ratio of Abrasion Loss at 200 to 1000 Revolutions	ASTM C 131				
Soundness - Loss after 5 cycles using Saturated Solution of Magnesium Sulfate	ASTM C 88				
Sulfate Content (as SO3)- Acid Soluble	ASTM C 114	%			
Chloride Content (as Cl)- Acid Soluble	ASTM C 114	%			
CHEMICAL COMPOSITION			Result on	Result on	
Rock Description					
Silicon Dioxide - SiO2	ASTM	%			
Aluminium Oxide - Al2O3		%			
Ferric Oxide - Fe2O3		%			
Calcium Oxide - CaO2		%			
Magnesium Oxide - MgO		%			
Sulphur Trioxide - SO3		%			
Sodium Oxide - Na2O		%			
Potassium Oxide - K2O		%			
Loss on Ignition		%			
SiO2 + Al2O3 + Fe2O3		%			

Figure E-09- Chart with the Physical and Chemical indexes of the materials of interest to the Project.

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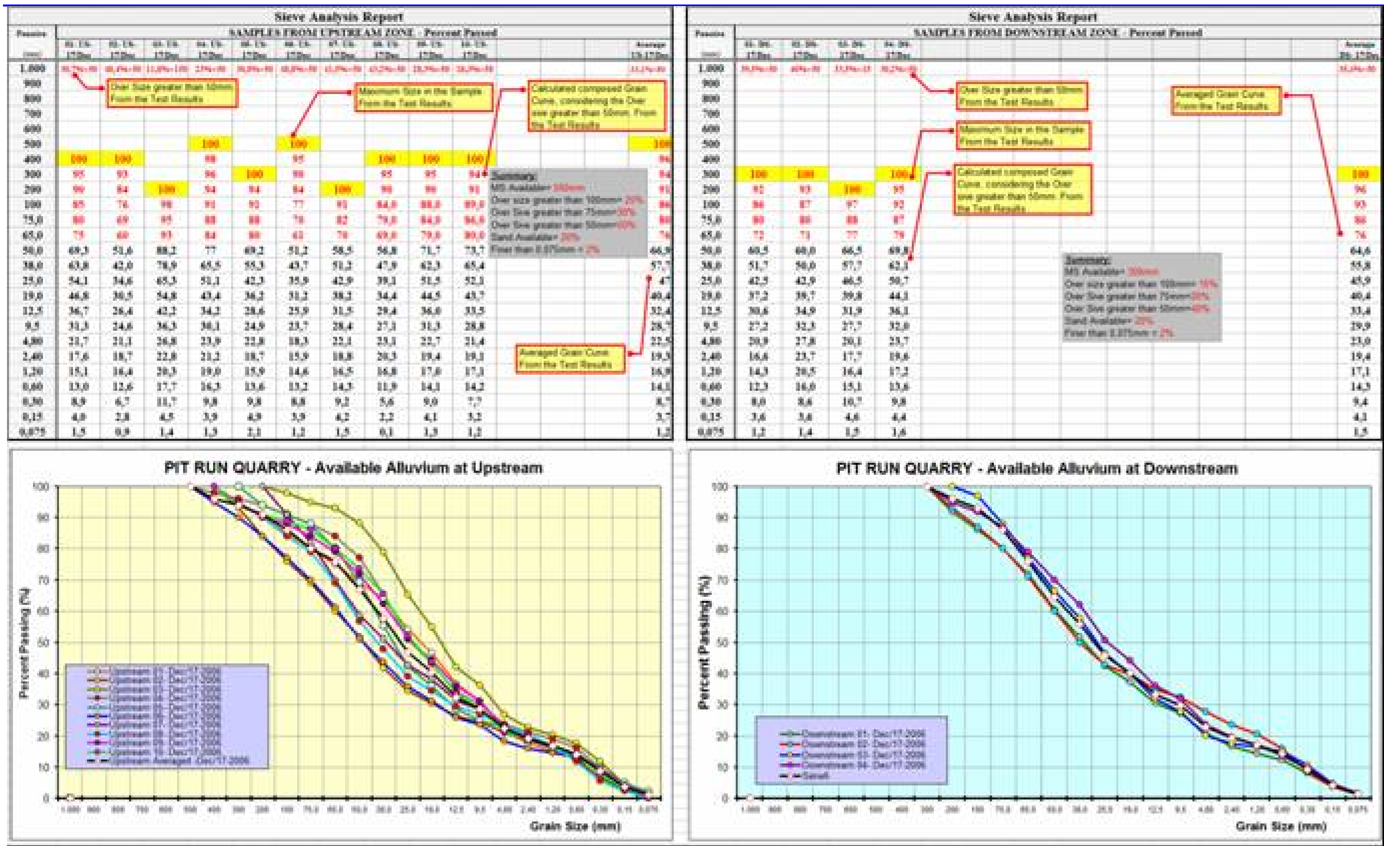

Figure E-10- Chart and graph, summing up the granulometric characteristics of the alluvium material in the region of the Project.

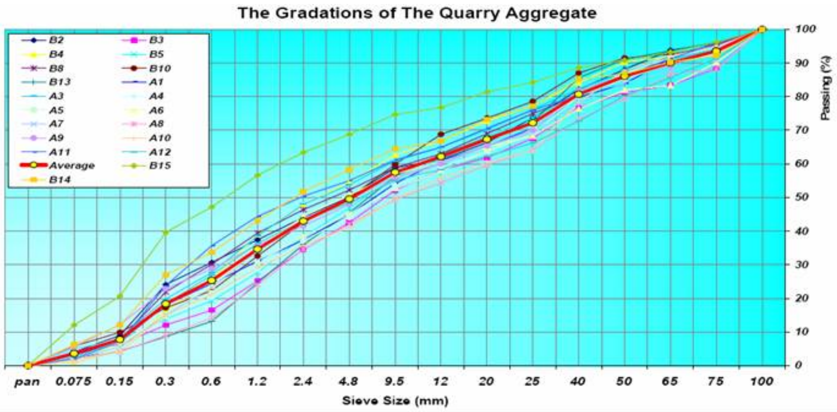

Figure E-11- Chart and graph, summing up the granulometric characteristics of the alluvium material in the region of another Project.

From the data obtained it can be resumed:

Order	Aspects	Upstream	Downstream	Comments
A	Maximum Size Available	500mm	300	In the Crushing option of the over size, the Entry of the Crusher must be bigger than 500mm
B	Size Over 100mm	25%	15%	25% will be the value considered
C	Size Over 75mm	30%	20%	30% will be the value considered
D	Size Over 50mm	50%	40%	50% will be the value considered
E	Sand Available	20%	20%	20% will be the value considered
F	Finer than 0,075mm	< 2%	< 2%	This index shows that the sand for Conventional Concretes has few fines, however this condition is not adequate for Roller Compacted Concrete.

Figure E-13- Resume of granulometric characteristics of alluvial material in the region downstream the Project.

From what was expounded above the following can be commented:

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- One could think of not crushing the gravel and adopt the sand content as determining factor for use of the aggregates, this would mean the need to explore much alluvium (close to 1.200.000m^3), therefore a waste of over 500.000m^3. This simplifies the production system, by using only the sieve stations, without installing the crushers. On the other hand, there would be insufficient filler (finer than 0,075mm), which would implicate in more use of Pozzolanic Material, due to RCC uniformity reasons;
- Another alternative may be adopted, as a system of aggregate processing, using the 50mm Over Size, crushing it to balance-out the production of coarse aggregates, thus complementing the sand production, as well as obtaining the filler (< 0,075mm) necessary for the RCC;
- The conventional granulometric zones, for the oversize aggregates indicate Size I (19mm-5mm) Size II (38mm- 19mm) and Size III (75mm- 38mm), however, at the job site there will be little demand for conventional mass concretes that indicate substantial use of dosed concretes with Size III, or greater. Moreover, there is no interest in using Maximum Sizes over 50mm for RCC concretes, as there is a tendency to increase segregation. The following options ensue:
  a) Adopt an Aggregate Processing System with the 3 Fractions stated above, plus sand, and deal with considerable segregation problems in the RCC, which is not entirely safe;
  b) Adopt a Processing System of Aggregates with the 3 Fractions, with two being Coarse I (20mm-5mm), and Coarse II (40mm-20mm) and one Coarse III (50mm-40mm), plus sand, with the 4 (I+II+II+ Sand) being used for RCC and the 3 (I+II+ Sand) available for CVC. In this option It would not include (until proven by tests) Fillers (<0,075mm) for CVC, and the one for RCC would contain these Fillers;
  c) Another option would be to have other grain sizes fractions, allowed by ASTM C 33, but not explicitly contained in the Project's Technical Specifications previously elaborated by Designers. It would be the situation of having Coarse 25 (25mm- 5mm) e Coarse 50 (50mm- 25m), plus Sand, which would reduce the stock types, the system and it would have ampler use in the concretes (CVC and RCC);
- From the stated options, the Consultant (myself) recommends to discard Alternative
  a) at this time adopting option
  b) and leaving option ***c***
  c) for an eventual conceptual acceptance by the Client. The alteration of System ***b)*** to ***c)*** requires little technical implication, without alteration in the type of Equipment and only simplification in the Sieve Stations and respective screen sieves;
- The processing system of aggregates can be enabled with extraction culvert/tunnels for direct feeding of aggregates to the concrete Batch Plants (CVC and RCC), which would implicate in costs (not too high involving the construction of culvert/tunnels) and acquisition of vibratory feeders, as well as conveyer belts. Another condition is to handle the feeding stocks to the Batch Plants through the frontal loaders and dump trucks. The decision depends on economic analyses (considering Investment, Operation and Maintenance).

E.3.5- Chemical Admixtures for Concrete

It is recommendable that some potential suppliers be selected and technical data being available regarding:

- Air Entraining Agents;
- Set Retarder
- Plasticizers;
- Super-Plasticizers

E.4- Equipments

E.4.1- Aggregates for the Start Up

It should be remembered that during the initial phase of the Construction – during the initial months, there will be a need of some aggregates, until the definitive Aggregates System is ready and in conditions to produce.

Material for the Initial Period	Required Total (t)	Required Monthly Máximum (t)	Period (Month)
Washed Sand (<5)mm			
Coarse I (20- 5)mm			
Coarse II (40- 20)mm			
Total Coarses			

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

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

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- Rely on a mobile classification system, fitted with a loader and feeding the trucks, as illustrated by Photos in Figure E-14. 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.

Figures E-14- Mobile equipment (Power Screen) suitable to classify aggregates from the alluvial deposits.

E.4.2- Aggregate Processing System for Main Concrete Works

In order to meet option ***b)*** recommended in item E.3.4, the Preliminary Flowchart was developed, see Figures E-16 and E-17, with a list of equipment seen in Figure E-18. The preliminary dimensioning was based on the required Demand indicated in the Tables of Figures E-01 to E-05, summed up in Figures E-15, to follow. It was considered that the production capacities refer to a production regime of 400 hours monthly, working in 2 shifts. A proportion of 20 hours/day in 25 days/month.

Materials After Diversion	Required Total (t)	Required Monthly Máximum (t)	Period (Month)
Washed Sand (<5)mm			
Unwashed Sand (<5 with fines 0,075)mm			
Coarse I (20- 5)mm			
Coarse II (40- 20)mm			
Coarse III (50- 40)mm			
Total Coartes			
Total de Sands			
Total Processed			

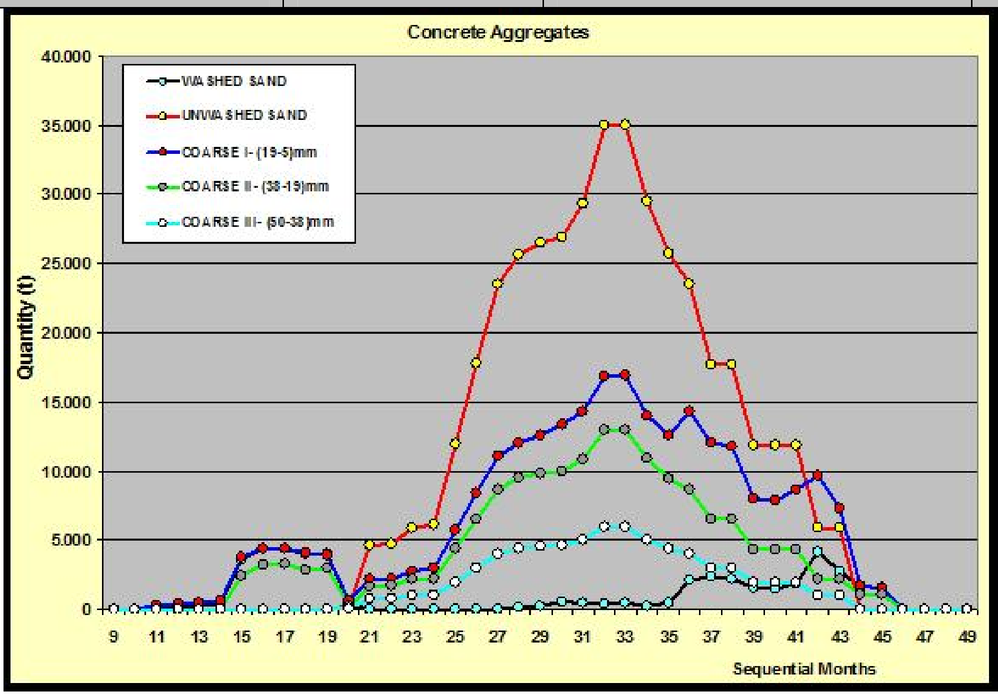

Figure E-15- Requirement of concrete Aggregates for the Project.

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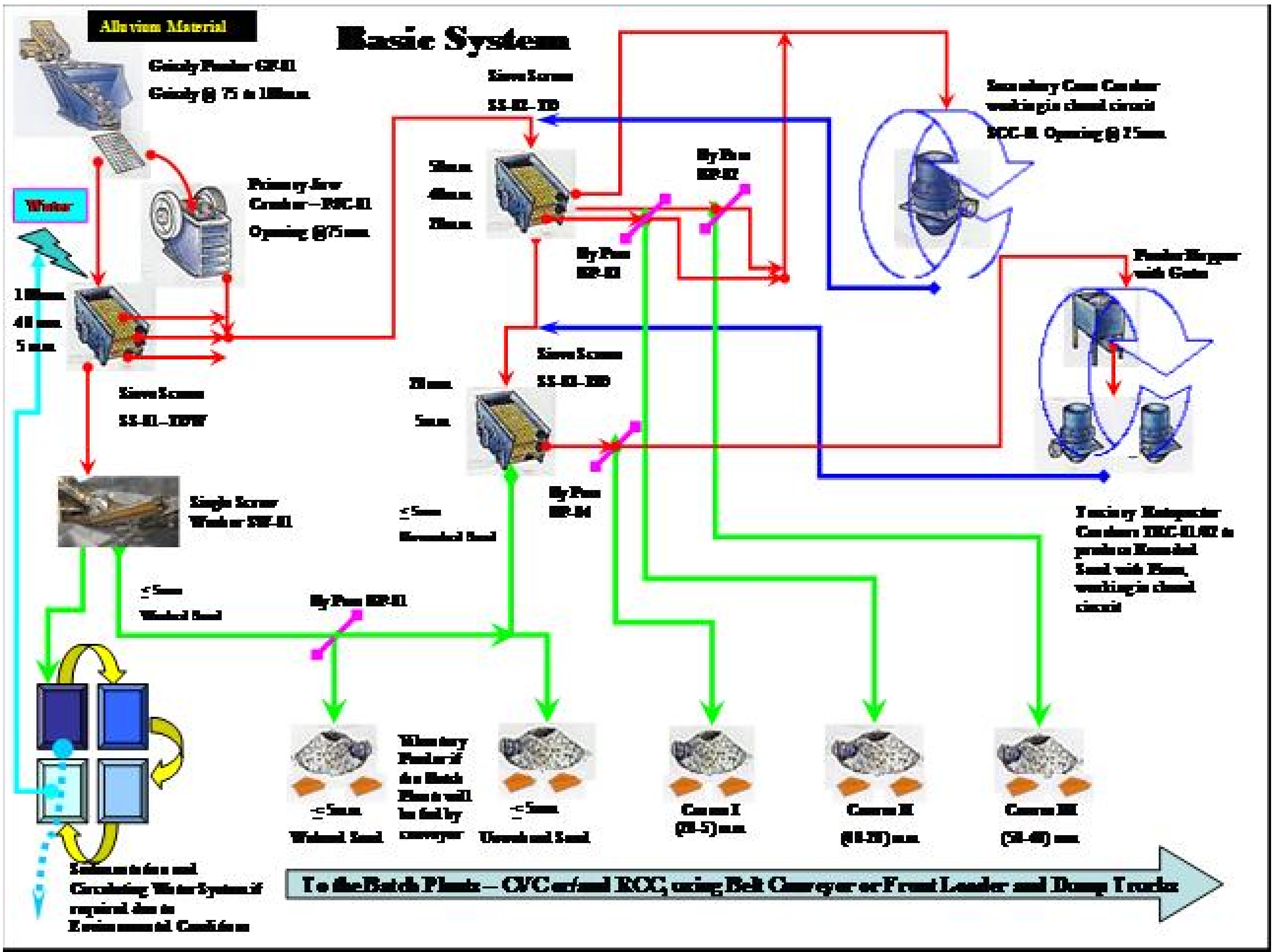

Figure E-16- Flowchart suggested for the Processing of concrete Aggregates for the Project

Ientification	Equipment	Basic Option - Equipment Conditions		
		Types	Opening	Capacity (t/h)
GF- 01	One Grizzly Feeder	Sandvik HGF 1148; Telsmith 48";	@ 75mm to 100mm	From 360 to 600 [01]
PJC- 01	One Primary Jaw Crusher	Sandvik JM 1108; Telsmith 30"x 42"	@ 75mm	From 140 to 500 [01]
SCC- 01	One Secondary Cone Crusher	Sandvik S 3800C; Telsmith 66S;	@ 25mm	From 100 to 300 [01]
TRC - 01/02	Two Tertiary Rotopactor	Sandvik VSI T 7R; Telsmith 48VFC;		From 75 to 150
SS- 01- TDW	One First Station Sieves Screen Triple Deck, with washing bar	Sanvik, or Nordberg, or Metso, or Telsmith or Cedarapids	Sieves 100mm; 40mm; 5mm	From 150 to 300
SS- 02- TD	One or Two Second Station Sieves Screen Triple Deck	Sanvik, or Nordberg, or Metso or Telsmith	Sieves 50mm; 40mm; 20mm	From 150 to 300
SS- 03- DD	One or First Station Sieves Screen Triple Deck, with washing bar	Sanvik, or Nordberg, or Metso or Telsmith	Sieves 20mm; 5mm	From 150 to 300
SW-01	One Fine material Washer- Single Screw Washer	Telsmith 36		up to 175
VF- 01 to N	Ten Pan Feeders -if use conveyors to feed the batch plants	Sandvik		400 hasta 500
FH	Hopper Metalic Feeder with 2 hydropneumatic gates			40m3 capacity
BP 01 to 04	Four By Passes			
Belt Conveyors		Around 20 conveyors with sizes to be adjusted to the Site Topography conditions		
Note	[01] Capacities related with opening size and feed "mouth"			

Figure E-17- Flowchart suggested for the Processing of concrete Aggregates for the Project.

E.4.3- Conventional Concrete Batch Plant

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At the beginning of the construction some amount of conventional concrete will be used, with a production near **X**.000m³/month, which under a policy of a single shift (250 hours/month) means close to **Y**0m³/hour of effective capacity. Considering this, a CVC Batch Plant with Nominal Capacity of **W**0m³/hour is sufficient.

Considering that in the second period of the construction, the conventional concrete requirements will peak out monthly close to **K**.000m³, which under a 2-shift policy (350hours/month, for the concrete) means a need for Effective Capacity of **K**.000/350=**M**m³/h, which is less than what was required at the beginning of the construction.

Even with these fairly small capacities, it is prudent for the Contractor to consider a main Central for the Conventional Concretes with Nominal Capacity of no less than **N**m³/hour.

E.4.4- Batch Plant for Roller Compacted Concrete

The established planning conditions that the RCC productions will be developed, from month **CC** onward, with maximum peak of close to **G**.000m³, (see Figure E-18), requiring for a 2-shift work policy (350 hour/month for the concretes) an Effective Capacity of **G**.000m³/hours/month ~ **Q**m³/hour, which would imply a Nominal Capacity of > **P**m³/hour.

It is advisable to adopt a Batch Plant for the RCC, with a minimal Nominal Capacity of **P**m³/hour, counting on 2 mixers with Twin Shaft Mixer Type, for forced mixing with a volumetric capacity of **F**m³ of compacted concrete, each. Each mixer should be able to operate in 60 second cycles in theoretical time, depending on the dosing and filling system.

Concrete Use	Volume (m³)
Leveling	
RCC	
Face & Rock Contact	
Bedding Mortar	
Conventional – Mass & Reinforced	
Precast	
Others – Camp Facilities	
Total	

RCC DAM & Other CVC Structures

Elevation	Dam Height	Frontal Length	Base Length	Thicknes s	Layer Volume	Total accumulated Volume	US Face Concrete Volume	DS Face Concrete Volume	Volume Contato Rocha	Bedding Mortar Volume (100% Rgiement)	JUST RCC Volume	Accumulated RCC Volume	Accumulated Concrete Face	US Form Area & DS Form	DS Form Area	Induced Form Area (m2)
m	m	m	m	m	m	m3	m3	m3	m3	m3	m3	m3	m3	m2	m2	m2
225	52	110	47,6	2	10.472	10.472	220	110	57	126	9.959	9.959	330	220	220	524
227	50	125	46	2	11.500	21.972	250	125	55	138	10.931	20.890	375	250	250	575
229	48	135	44,4	2	11.988	33.960	270	135	53	144	11.386	32.276	405	270	270	599
231	46	150	42,8	2	12.840	46.800	300	150	51	154	12.184	44.460	450	300	300	642
233	44	170	41,2	2	14.008	60.808	340	170	49	168	13.280	57.741	510	340	340	700
235	42	190	39,6	2	15.048	75.856	380	190	48	180	14.250	71.991	570	380	380	752
237	40	210	38	2	15.960	91.816	420	210	46	191	15.093	87.084	630	420	420	798
239	38	230	36,4	2	16.744	108.560	460	230	44	200	15.810	102.894	690	460	460	837
241	36	245	34,8	2	17.052	125.612	490	245	42	203	16.072	118.966	735	490	490	853
243	34	260	33,2	2	17.264	142.876	520	260	40	206	16.239	135.205	780	520	520	863
245	32	285	31,6	2	18.012	160.888	570	285	38	214	16.905	152.110	855	570	570	901
247	30	300	30	2	18.000	178.888	600	300	36	213	16.851	168.961	900	600	600	900
249	28	315	28,4	2	17.892	196.780	315	315	34	215	17.013	185.973	630	630	630	895
251	26	330	26,8	2	17.688	214.468	330	330	32	212	16.783	202.757	660	660	630	884
253	24	255	25,2	2	12.852	227.320	255	255	30	154	12.158	214.914	510	510	630	643
255	22	280	23,6	2	13.216	240.536	280	280	28	158	12.470	227.384	560	560	630	661
257	20	305	22	2	13.420	253.956	305	305	26	160	12.624	240.008	610	610	630	671
259	18	320	20,4	2	13.056	267.012	320	320	24	155	12.237	252.245	640	640	630	653
261	16	440	18,8	2	16.544	283.556	440	440	23	196	15.446	267.691	880	880	630	827
263	14	470	17,2	2	16.168	299.724	470	470	21	190	15.017	282.708	940	940	630	808
265	12	500	15,6	2	15.600	315.324	500	500	19	182	14.399	297.107	1.000	1.000	630	780
267	10	530	14	2	14.840	330.164	530	530	17	172	13.591	310.698	1.060	1.060	630	742
269	8	560	12,4	2	13.888	344.052	560	560	15	159	12.594	323.292	1.120	1.120	630	694
271	6	590	10,8	2	8.424	352.476	590	590	13	90	7.141	330.432	1.180	780	780	421
273	4	594	9,2	2	7.250	359.726	594	594	11	76	5.975	336.407	1.188	788	788	362
275	2	598	7,6	2	6.050	365.775	598	598	9	61	4.784	341.191	1.196	796	796	302
277	0	600	6	2	4.800	370.575	600	600	7	45	3.548	344.739	1.200	800	800	240
Precast for Gallery Roof = 500m*2,5m*0,3m						375										
						371.000										
TOTAL						370.575	11.507	9.097	868	4.364	344.739	344.739	20.604	16.594	14.914	18.529

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Spillway	Description	Length (m)	Base (m)	Height (m)	Volume (m3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL (m2)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.350		490				2.100							200	2.790
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	600		600											100	700
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.720		448											100	548
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.950					4.620		4.620						200	4.820
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	304			494		1.976								100	2.570
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	630					2.520									2.520
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	630						1.260							100	1.360
																			0
TOTAL					25.164	TOTAL													15.308

Diversion Structure	Description	Length (m)	Base (m)	Height (m)	Volume (m3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL (m2)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	585													125	125
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.140			Not adopted		1.560								100	1.660
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.225					1.300								100	1.400
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.875		475				1.950							50	2.475
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.575					1.260									1.260
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.260					1.260									1.260
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	414														0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.789		375									1.517		50	1.942
[illegible]		[illegible]	[illegible]	[illegible]	4.032		84											56	140
																			0
TOTAL					30.481	TOTAL													10.262

Water Intake & Valves	Description	Length (m)	Base (m)	Height (m)	Volume (m3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL (m2)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105		86											20	106
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.070			Not adopted		2.442									2.442
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	126					506									506
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	189					756									756
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	396														0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.016		1.680											420	2.100
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	170		280												280
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16												32	32	64
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.794													100	100
																			0
TOTAL					8.486	TOTAL													6.350

Saddle Dam (Old Dam wings)	Description	Length (m)	Base (m)	Height (m)	Volume (m3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL (m2)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.120					2.240								200	2.440
RCC	[illegible]	[illegible]	[illegible]	[illegible]	7.840														
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	118														
TOTAL					9.078	TOTAL													2.440

Cofferdams (Old Dam wings)	Description	Length (m)	Base (m)	Height (m)	Volume (m3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL (m2)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	575													250	250
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150													100	100
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	750							7.000						600	7.600
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60							500						50	550
TOTAL					1.535	TOTAL													8.500

Others	Description	Length (m)	Base (m)	Height (m)	Volume (m3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	TOTAL (m2)
[illegible]	[illegible]				1.000		6.000											600	6.600
[illegible]	[illegible]				1.280		1.280											100	1.380
[illegible]	[illegible]				640		1.280											100	1.380
[illegible]	[illegible]				640		1.280											100	1.380
[illegible]	[illegible]				320		1.280											100	1.380
																			0
TOTAL					3.880	TOTAL													9.920

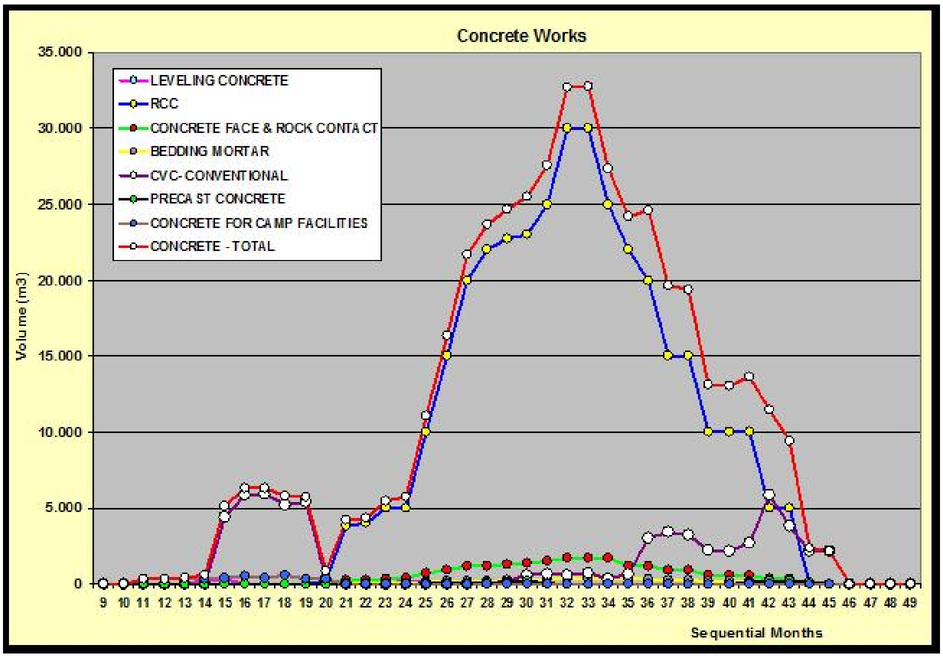

Figure E-18- Concretes (CVC & RCC) for the Project's Construction.

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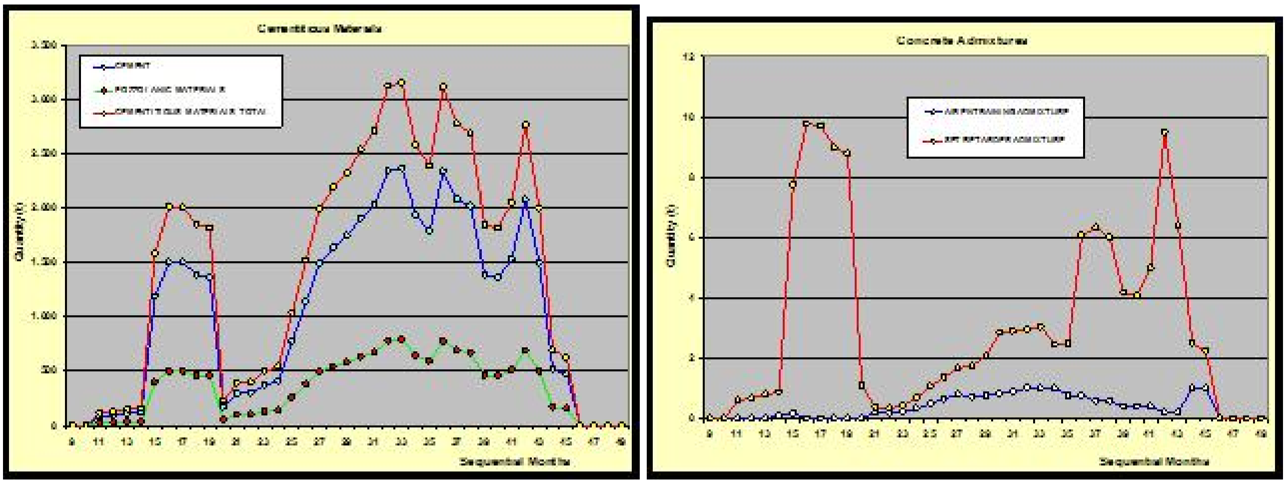

Figure E-19- Cementitious Materials and Chemical Admixtures for concretes production, for the Project

It is advisable that the 2 Batch Plants (one for CVC and the other for RCC) be installed within proximity, in order to simplify the procedure of supplying, feeding and controlling the 2 plants. Complementary and most efficient, and even better if both are near the aggregate processing plant.

Seeing that the mixers will have a volumetric capacity of Fm^3 (**it is suggested that they do**), which is less than the capacity of the dump trucks to be adopted, it is highly advisable to adopt at the exit of the mixers a Hopper, with quick-to-open hydraulic operated gates and with an open section compatible with the dumper of the truck to be used. A suggested Lay Out is shown in Figure E-20.

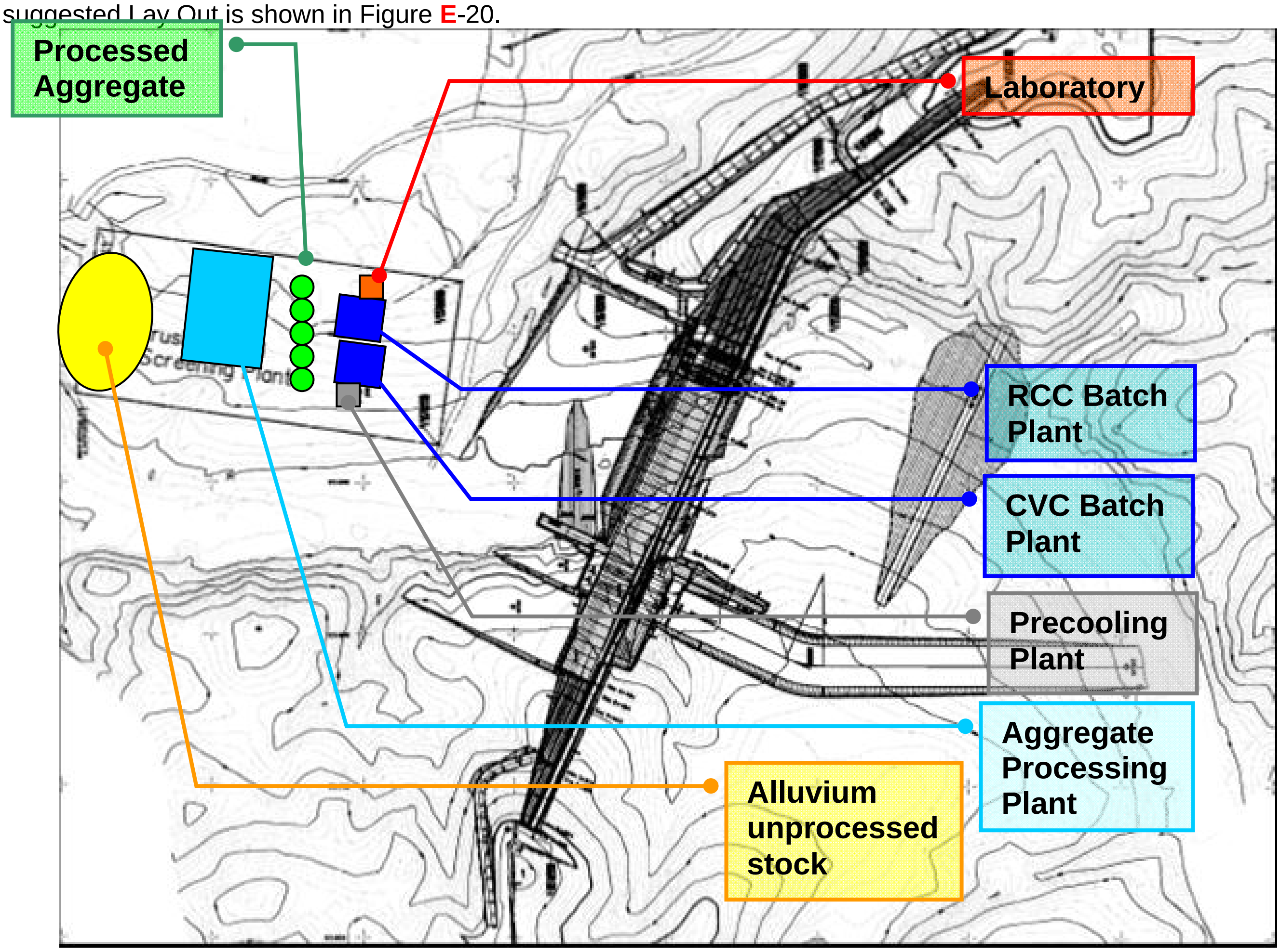

Figure E-20- Lay Out that can be adjusted to the site's Topographic conditions for the concrete batch plants (CVC & RCC).

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Currently, the market that supplies Concrete main Centers has many supply options, recommending that the rates be estimated at companies such as Liebherr, Euromix; Meka; Steter; Sicoma; Goker, etc...

The used (second hand) equipments market should also be considered.

The RCC Batch should have:

- Silos for 4 aggregates, with individual volumetric capacity of **T**m^3 and with separations between each silo;
- Silos for 2 types of cementitious material;
- Silos for 2 admixtures;
- Silos for water;
- Individual Dosers-Scales with the following capacities:
  - Cement: 1000kg;
  - Pozzolanic Material: 500kg;
  - Sand: 3000kg;
  - Coarse aggregates (individually): 3000kg;
  - Admixtures: 10kg;
  - Water: 500kg;
  - Ice: (if necessary adopt remarks to follow) 500kg
- The weighing tolerances should be in agreement with what is required in the technical specifications;
- Digital and computerized registration;
- Software for dosing and linking to the control system;
- Synoptic design in Display;
- The equipment must be able to mix concrete – No Slump- with high dose of coarse aggregates, with abrasive mineralogical characteristics, with high silica content;
- Transfer systems of aggregates from the silos to the scales;
- Transference and feeding Hopper after mixers and to the transport vehicles;
- Sampler for sampling tests;
- Independent Command Booth with thermal and acoustic insulation, with glass windows to view operations;
- Anti-dust system and air conditioning in the command booth;
- Anti-dust system in the silos;
- Covering in the different silos, compatible with the feeding system;
- The equipment should meet the CPMB-100-02 requisites and ASTM C 94 performance.

E.5- Precooling Systems

E.5.1- 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***

E.5.2- Precooling System for CVC concretes

Considering the calculations and options shown in Figures E-21 to E-25, one can see that in order to meet the Temperatures for concrete placing, the resume of activities cited in Figure E-26 can be adopted:

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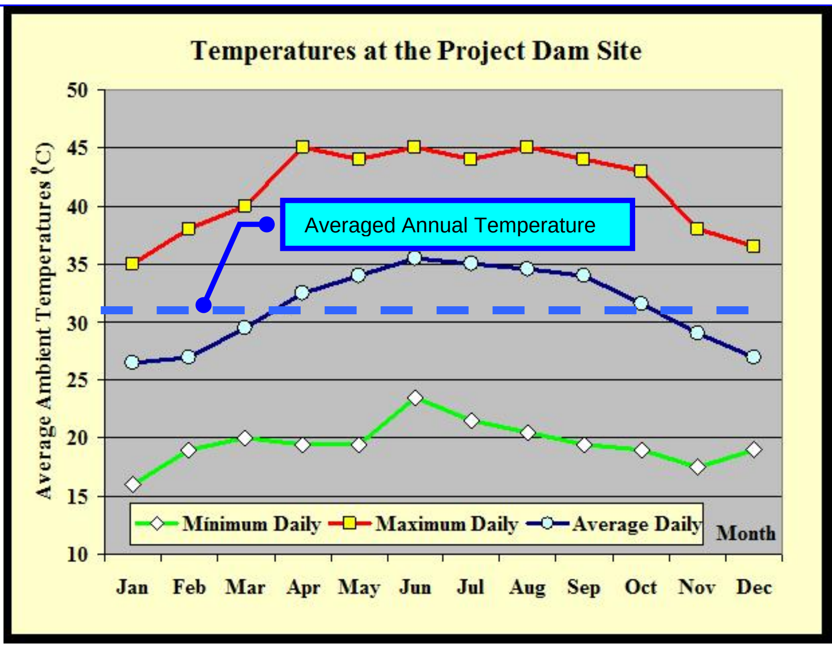

Figure E-21-Temperatures at Project Dam Site.

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	[redacted]
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	[redacted]
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	[redacted]
THERMAL CHARGE FROM MIXER					750
					0
CONCRETE		2398,0		0,225	21372
CONCRETE PLACEMENT TEMPERATURE =			42		

Figure E-22- Thermal Balance for Concrete - *Condition –Materials at Ambient Condition*

CONVENTIONAL CONCRETES THERMAL BALANCE - Project 2/4

AVERAGE MIX — 20 °C (JUST ICE)

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)		35,0	30	1	1050
ICE (2)-(1)-(3)		123,0	-1	80	-9838
THERMAL CHARGE FROM MIXER					750
					0
CONCRETE		2400,0		0,225	9596
CONCRETE PLACEMENT TEMPERATURE =			20		

AVERAGE MIX — 25 °C (JUST ICE)

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)		30,0	30	1	900
ICE (2)-(1)-(3)		114,7	-1	80	-9172
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2397,0		0,225	9691,7
CONCRETE PLACEMENT TEMPERATURE =			20		

POOR MIX — 25 °C (JUST ICE)

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)		35,0	30	1	1050
ICE (2)-(1)-(3)		105,3	-1	80	-8420
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2398,0		0,225	9794,9
CONCRETE PLACEMENT TEMPERATURE =			20		

Figure E-23- Thermal Balance for Concrete - *Condition-Materials at Ambient Temperature and using just Ice to place concretes at 20°C .*

.

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CONVENTIONAL CONCRETES THERMAL BALANCE - Project 3/4

AVERAGE MIX (JUST COOLED & SPRAYED WATER ON COARSE AGGREGATE)

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	5	685	35	0,18	4316
COARSE AGGREGATE 19 mm	1,5	1150	15	0,18	3105
COARSE AGGREGATE 38 mm	1	0	15	0,18	0
COARSE AGGREGATE 50 mm		0			0
COARSE AGGREGATE 75 mm		0			0
TOTAL HUMIDIT [1]		51,5	20	1	1030
TOTAL WATER [2]		190,0	5	1	
FREE WATER [2]-[1]		138,5	5	1	
MIX WATER [3]		138,5	5	1	693
ICE [2]-[1]-[3]		0,0	-1	80	
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2400,0		0,225	14843,0
CONCRETE PLACEMENT TEMPERATURE =			29		

AVERAGE MIX (JUST COOLED & SPRAYED WATER ON COARSE AGGREGATE)

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	5	700	35	0,18	4410
COARSE AGGREGATE 19 mm	1,5	660	15	0,18	1782
COARSE AGGREGATE 38 mm	1	550	15	0,18	1485
COARSE AGGREGATE 50 mm					0
COARSE AGGREGATE 75 mm					0
TOTAL HUMIDIT [1]		50,4	20	1	1008
TOTAL WATER [2]		175,0	5	1	
FREE WATER [2]-[1]		124,6	5	1	
MIX WATER [3]		124,6	5	1	623
ICE [2]-[1]-[3]		0,0	-1	80	
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2397,0		0,225	14180,4
CONCRETE PLACEMENT TEMPERATURE =			28		

POOR MIX (JUST COOLED & SPRAYED WATER ON COARSE AGGREGATE)

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	5	850	35	0,2	5950
COARSE AGGREGATE 19 mm	1,5	650	15	0,2	1950
COARSE AGGREGATE 38 mm	1	550	15	0,2	1650
COARSE AGGREGATE 50 mm		0			0
COARSE AGGREGATE 75 mm		0			0
TOTAL HUMIDIT [1]		57,8	20	1	1155
TOTAL WATER [2]		175,0	5	1	
FREE WATER [2]-[1]		117,3	5	1	
MIX WATER [3]		117,3	5	1	586
ICE [2]-[1]-[3]		0,0	-1	80	
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2398,0		0,225	14324,9
CONCRETE PLACEMENT TEMPERATURE =			29		

Figure E-24 Thermal Balance for Concrete - *<u>Condition-Coarse Aggregates just cooled by sprinkled cool water (2°C).</u>*

CONVENTIONAL CONCRETES THERMAL BALANCE - Project 4/4

AVERAGE MIX 20°C (ICE + COOLED & SPRAYED WATER ON COARSE AGGREGATE)

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	5	685	35	0,18	4316
COARSE AGGREGATE 19 mm	1,5	1150	15	0,18	3105
COARSE AGGREGATE 38 mm	1	0	15	0,18	0
COARSE AGGREGATE 50 mm		0		0,18	0
COARSE AGGREGATE 75 mm		0		0,18	0
TOTAL HUMIDIT [1]		51,5	20	1	1030
TOTAL WATER [2]		190,0	5	1	
FREE WATER [2]-[1]		138,5	5	1	
MIX WATER [3]		80,0	5	1	400
ICE [2]-[1]-[3]		58,5	-1	80	-4680
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2400,0		0,225	9870,5
CONCRETE PLACEMENT TEMPERATURE =			20		

AVERAGE MIX 20°C (ICE + COOLED & SPRAYED WATER ON COARSE AGGREGATE)

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	5	700	35	0,18	4410
COARSE AGGREGATE 19 mm	1,5	660	15	0,18	1782
COARSE AGGREGATE 38 mm	1	550	15	0,18	1485
COARSE AGGREGATE 50 mm				0,18	0
COARSE AGGREGATE 75 mm				0,18	0
TOTAL HUMIDIT [1]		50,4	20	1	1008
TOTAL WATER [2]		175,0	5	1	
FREE WATER [2]-[1]		124,6	5	1	
MIX WATER [3]		75,0	5	1	375
ICE [2]-[1]-[3]		49,6	-1	80	-3968
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2397		0,225	9960,4
CONCRETE PLACEMENT TEMPERATURE =			20		

AVERAGE MIX 20°C (ICE + COOLED & SPRAYED WATER ON COARSE AGGREGATE)

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	5	850	35	0,2	5950
COARSE AGGREGATE 19 mm	1,5	650	15	0,2	1950
COARSE AGGREGATE 38 mm	1	550	15	0,2	1650
COARSE AGGREGATE 50 mm		0		0,2	0
COARSE AGGREGATE 75 mm		0		0,18	0
TOTAL HUMIDIT [1]		57,8	20	1	1155
TOTAL WATER [2]		175,0	5	1	
FREE WATER [2]-[1]		117,3	5	1	
MIX WATER [3]		60,0	5	1	300
ICE [2]-[1]-[3]		57,3	-1	80	-4580
THERMAL CHARGE FROM MIXER					750,0
					0,0
CONCRETE		2398,0		0,225	9458,6
CONCRETE PLACEMENT TEMPERATURE =			20		

Figure E-25- Thermal Balance for Concrete - *<u>Condition-Coarse Aggregates cooled by sprinkled cool water (2oC) and using Ice to place concretes at 20°C.</u>*

From the stated options can be seen the followings actions:

Option	Condition	Placement Temperature (LT) °C	Required Action
I	Materials under conditions of Maximum Ambient Temperatures	Between **42**°C & **45**°C	None. This condition NOT COMPLY with the Technical Recommendations
II	Materials under conditions of Maximum Ambient Temperatures; and using just Ice to reach 20° C	**20°C**	Cool water to about 2 °C and 4°C, for consumption of roughly 120(kg of Ice)/(m3 of concrete)
III	Coarse Aggregates pre-refrigerated with cold and cold water for the concrete mix	Between **28**°C & **29**°C	Protect Aggregate Stocks (Shade); Cool water to about 2 °C and 4°C, for consumption of roughly
IV	Materials in the Shadow; Cold Water and Ice	**20°C**	Cool the Coarse Aggregates to about 15°C, using water about 2 °C and 4°C, for consumption of 140(kg of water)/(m3 of concrete) and use Ice in consumption of 60(kg of ice)/(m3 of concrete)

Figure E-26- Summary of the pre-cooling Conditions and actions.

From the above, the conditions III and IV can be considered for the CVC concretes in the construction of the Project. It is important remember that the Technical Specification requires 20°C for the CVC Placement Temperature, but the used Technical Recommendations permit up to 32°C, and adopting adequate Height of the Lifts and Interval Time between Lifts.

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From the Figures E-01 to E-04 it can be seen that the maximum rate for pre-cooled CVC will be around **R**.000m3/month (at month **MM**) for the **DGDGH** Structure, and about **B**.000m3/month (at month **NN** for the **MBVBM** Structure.

It was not considered the need for pre-cool the concretes of Diversion plugging. For this work it is recommendable to adopt a Post Cooling System, using just cool water through calculated coils, to be possible to reduce the period to stabilize the temperature and consequently the grouting work

Considering the adoption of the Condition IV, it will be required (**R**.000m3/month)*(**S**0kg Ice/m3 concrete)/(250hours/month) = **G**.000 (kg of Ice/hour). Considering that the Ice Machine can work all the day (24 hours, that can be considered to be 20hours), an adoption of 2 machines of **J**00kg/hour is satisfactory

E.5.3- 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 35^{o}C, with layers of 30cm in height, placed daily, close near the rock foundation.

E.6- Concrete Handling

E.6.1- Concrete Transportation

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

- Cement Truck Mixers with capacity for 6m^3, for the CVC, and mortars, and;
- Dump Rear Trucks with capacity for 8m^3, for the CVC, 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.

From the distances and velocities, the following productivities for transport can be estimated:

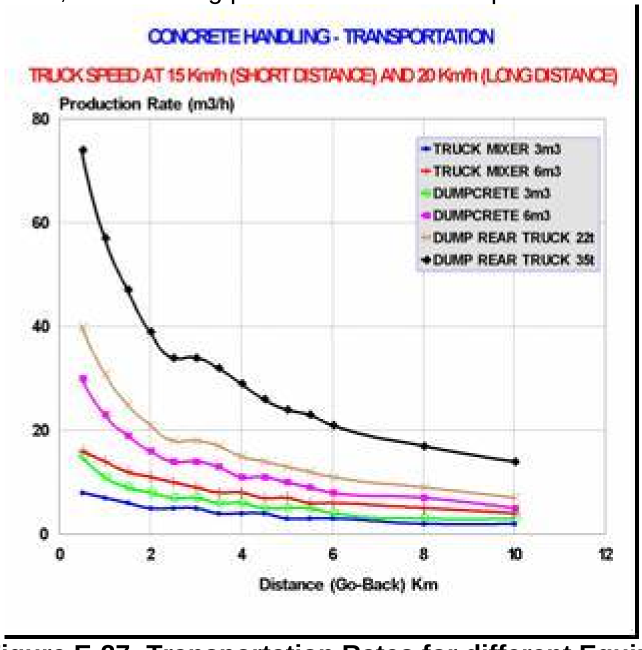

Figure E-27- Transportation Rates for different Equipments.

From Figure E-27, the following can be adopted:

- Truck Mixers – 6m^3 capacity- working at 15m^3/hour

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- Dump Rear Truck- 8m^3 working capacity at 25m^3/hour, for concrete and aggregates feeding.

This results in the theoretical need for 2 Truck Mixers for the CVC and 4 Dump Rear Trucks for the RCC, and 4 for the aggregates, therefore, the theoretical need for the following recommendation to be adopted:

- Truck Mixers (6m^3)- 3 Units;
- Dump Rear Trucks (8m^3/22t) - 10 Units.

E.6.2- Concrete Placement

The CVC concretes will be applied:

- Directly from the chute of the Mixer Truck, in the case of the Face Concretes and the Bedding Mortar;
- By Pumping;
- With the aid of Mobile Cranes with Trestle Jib or Telescopic, on Rough Terrain type tires.

The RCC concretes will be placed directly by Dump Rear Trucks.

In the case of the concretes, it is vital to keep in mind that the equipment of Forms handling can (and should) be used compatibly to place concretes and apply the reinforcements. Thus, for the conventional concretes as seen in Figure E-28, mobile cranes with application capacity of 20m^3/h of concretes or 20m^2/h of forms or 10t/hour of reinforcements, were adopted.

Concrete Pumping can be performed by conventional pumps with effective capacity of 20m^3/h.

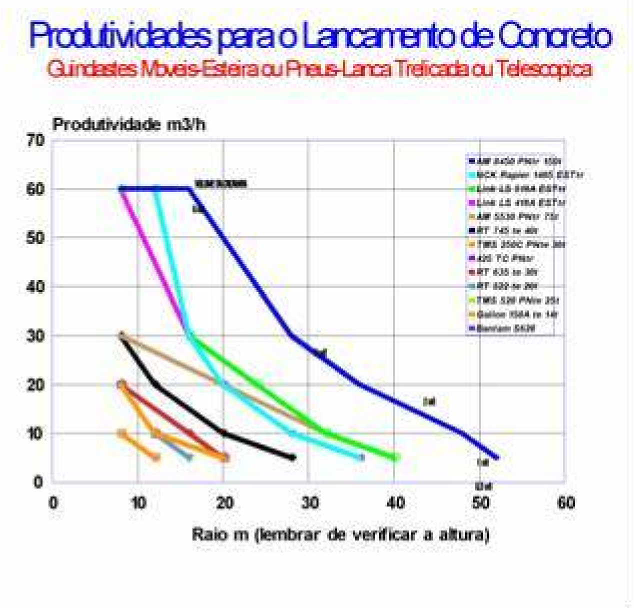

Figure E-28- Placement Rates for different Mobile Cranes

Keeping in mind that some pumping will encompass a reasonable area, as the **DSGD** Structure and the **NBVCNVC** Structure, it is advisable to use booms with articulated frames, as illustrated in Figure E-29.

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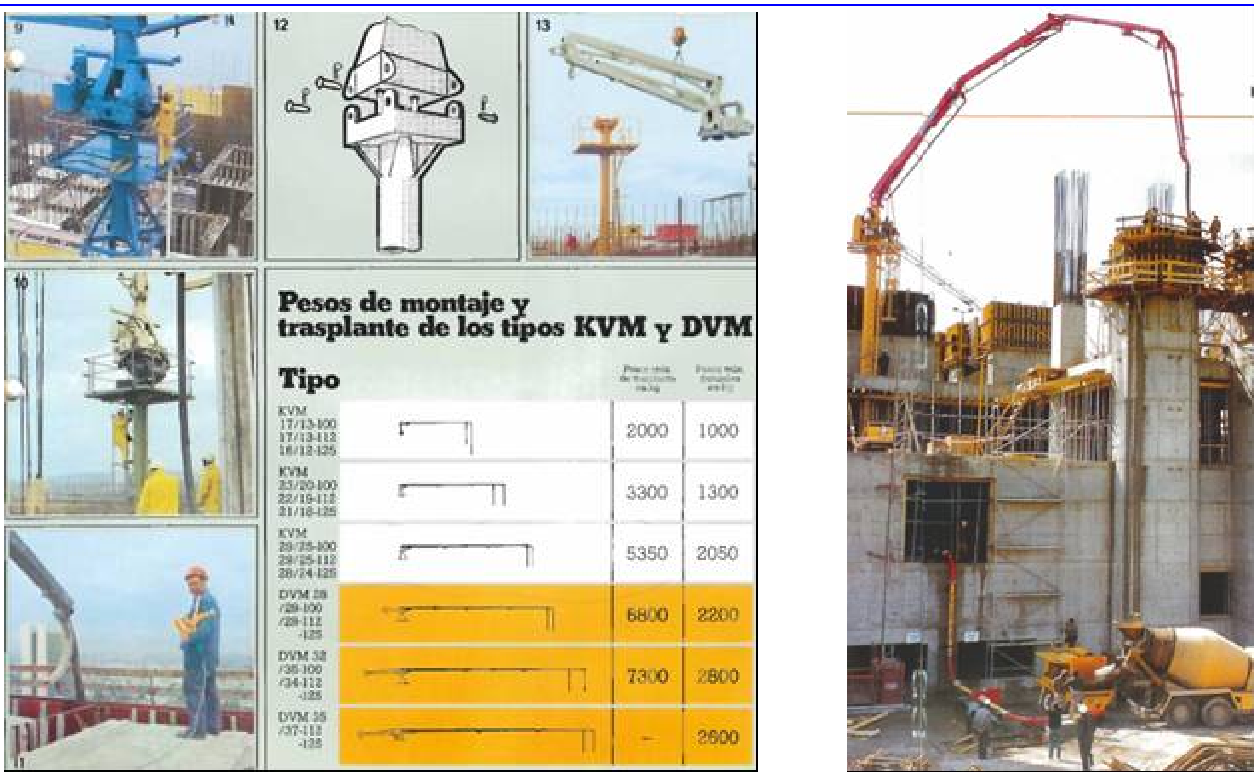

Figure E-29- Hydraulic Articulated Boom for concrete placement by pumping

E.6.3- RCC Leveling and Spreading

Conditions of the Foundation Rock (Photos in Figure E-30) infer that there will be need for using some volume of Levelling Concrete, which was cautiously considered in the Planning.

Figure E-30- River Bed Rock and close the River, showing some irregularities (not so smooth surface), that can requires some leveling concrete

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 technical information is given below for both equipments.

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Flywheel power: 67kw_90hp.
Operating weight: 8.919kg.

Figure E-31- General data for Cat D 5G, or equivalent

Power : 69 kw - 90 Hp
Operating weight : 7.250 kg

Figure E-32- General data for Cat 420 E backhoe-loader, or equivalent

Calculations demonstrate that one unit of each equipment is sufficient to execute the work.

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

E.6.4- 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.

Model	AY27	AY47	AY77	AY107
Tube diameter (mm)	26	47	77	108
Tube length (mm)	254	316	398	415
Tube weight (kg)	0,7	2,8	8,9	17,7
Frequency (rpm)	21.000	18.000	16.000	15.000
Hose length (m)	2	2	2	1,5

Figure E-33- General data for Dynapac types poker pneumatic vibrators, or equivalent

The Concrete Face must be intensely vibrated to avoid porosities and permeability increase.

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

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Model: CA 262 PD
Flywheel power: 112kw_150hp.
Max. Operating Mass: 14.200kg.

Figure E-34- General data for CA 262PD Roller, or equivalent

Also, there should be tampers or vibratory plates available, as the type illustrated in Figures 35 and 36.

Model: CC 102 C
Flywheel power: 23kw_29hp.
Max. Operating Mass: 2.400kg.

Figure E- General data for CC 102 C Small Roller, or equivalent

Model: LG140 compact forward/reverse vibratory plate, with speed and compaction depth regulated by hydraulic servo control of the eccentric element.

Figure E-36- General data for LG 140 vibratory plate, or equivalent

6.6.5- 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 Trucks with sprinklers, or sprinkler bars handled by the workers can be viewed, as suggested by Figure E-37. The decision should be based on costs.

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Figure E-37- Curing Alternative Systems for RCC

E.6.6- 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.

E.6.7- Contraction Joint Casting

Molding the Construction joints can be performed as illustrated by Figures E-38 and E-39, depending on Contractor's criteria and cost.

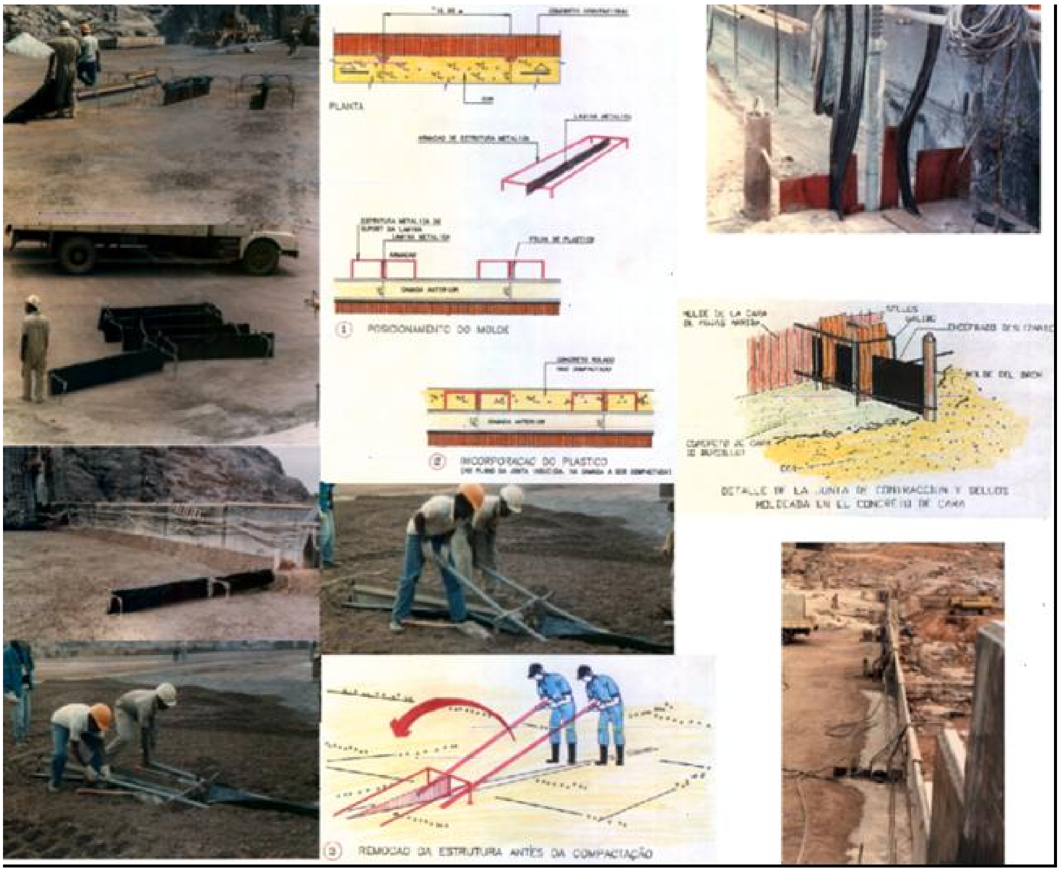

Figure E-38-Casting the Contraction Joint by handle tools

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Figure E-39- Casting the Contraction Joint by Joint Inserter machine.

E.7- Formwork

E.7.1- Form Types to be used

During the construction of the Project, the following types of Forms are foreseen, as shown in Figures E-40 to E-48.

Figure E-40-Wood and Plywood Plane Forms

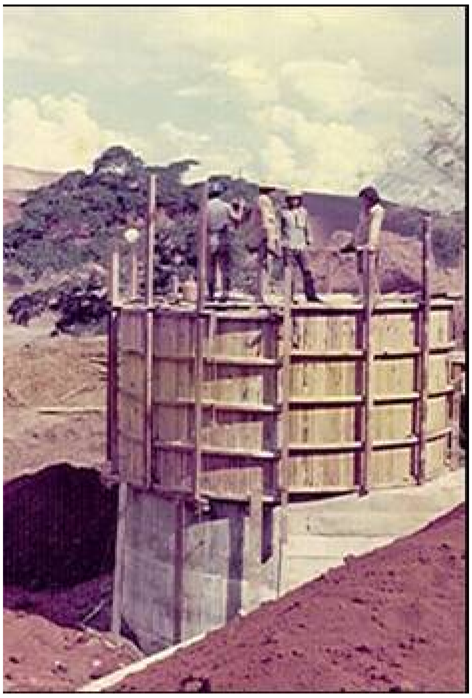

Figure E-41-Wood Curved Forms

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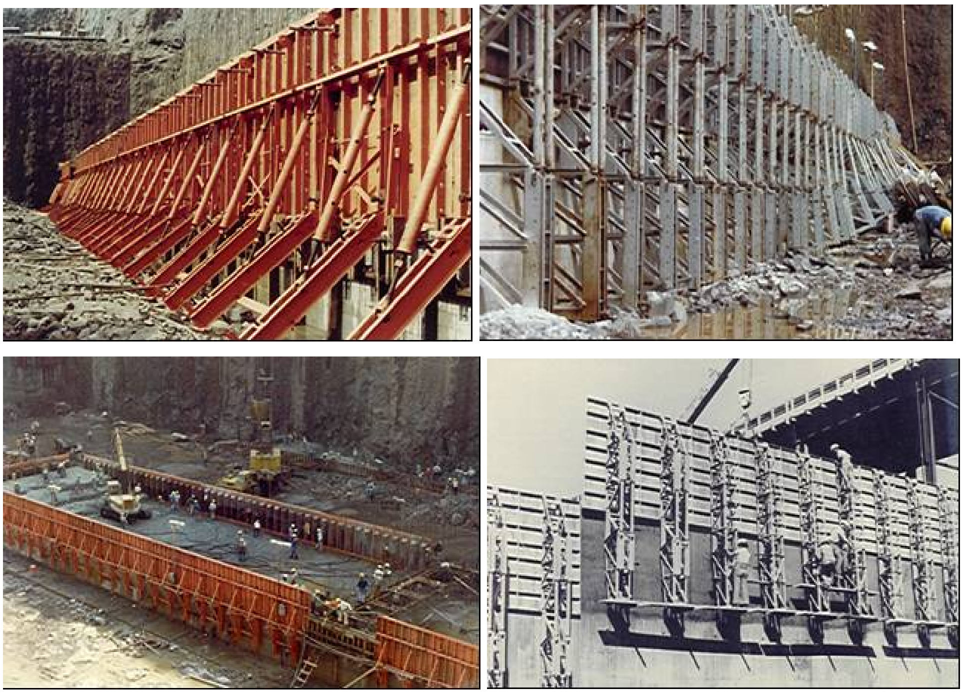
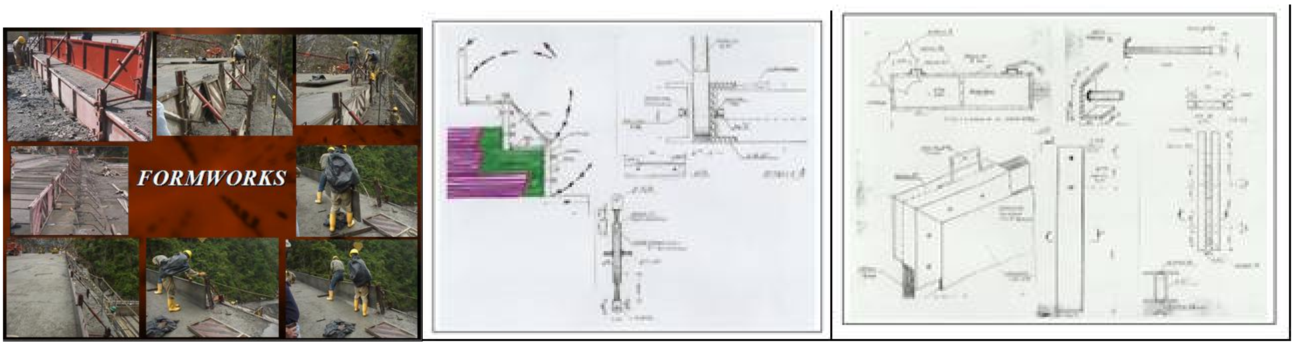


Figures E-42-Standard Metallic Panels



Figures E-43- Metallic Panels that can be used for the Downstream Face

Figures E-44-Straightedge sliding that can be used for the Deflector, Spillway Crest and flatted surfaces

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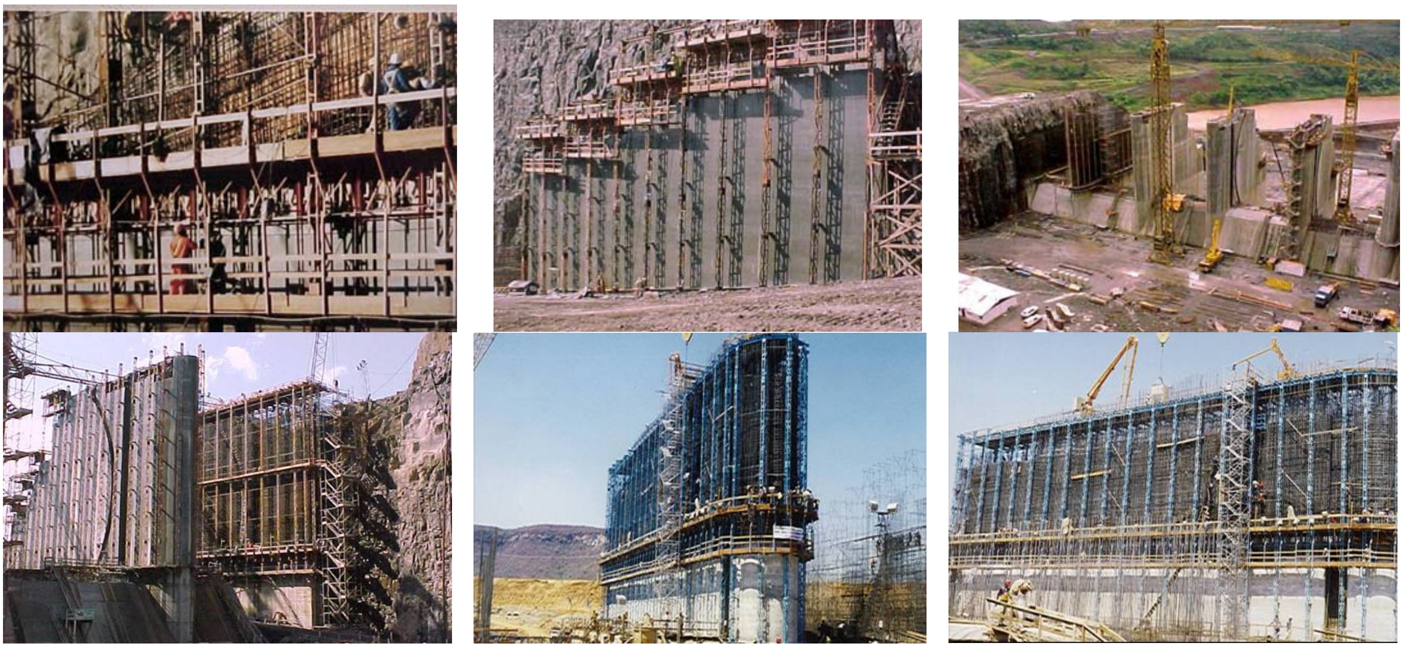

Figures E-45-Sliding Forms that can be used for Piers, Walls and Tower

Figure E-46-Tunneling Type Form that can be used for the Diversion Structure

Figure E-47-Expanded metal panel for mould between primary and secondary stages concretes

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Figures E-48- “In Situ” Wood form

At this time, it is vital to elucidate that the following areas of forms were calculated (approximately).

- Quantity of AREAS to be molded by Form Type, and;
- Quantity (m^2) of Forms necessary for the construction by types, considering adopting re-use (which should undergo a more detailed analysis)

The following table can be used as a Service Table (from Figures E-01 to E-04)

Formwork Type	Formed Surface (m^2)	Number of uses adopted	Panel Formwork Area to be manufactured or buying (m^2)
PLAN PLYWOOD	12.358	5	2.719
CURVED PLYWOOD	500	4	138
STANDARD METALLIC	38.462	50	846
SLIDING STRAIGHTEDGE	5.310	100	58
SLIDING FORM	12.120	60	222
INDUCED	19.030	1	20.933
TÚNNELING	1.517	4	417
EXPANDED METAL	40	1	44
IN SITU – WOOD	4.191	1	4.610
TOTAL	93.528		29.987

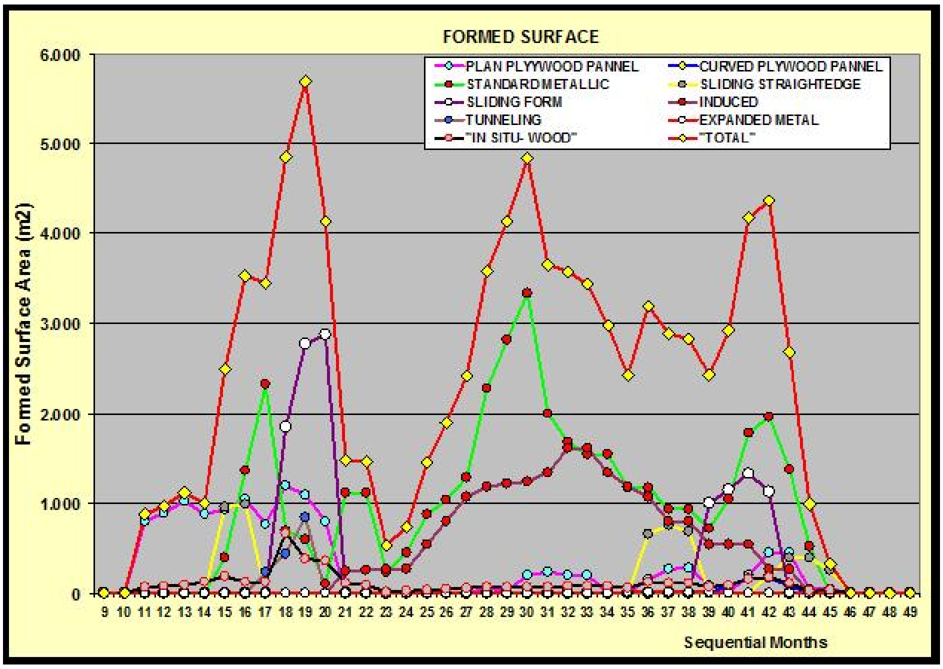

Figure E-49- Formed Surfaces per Form Type

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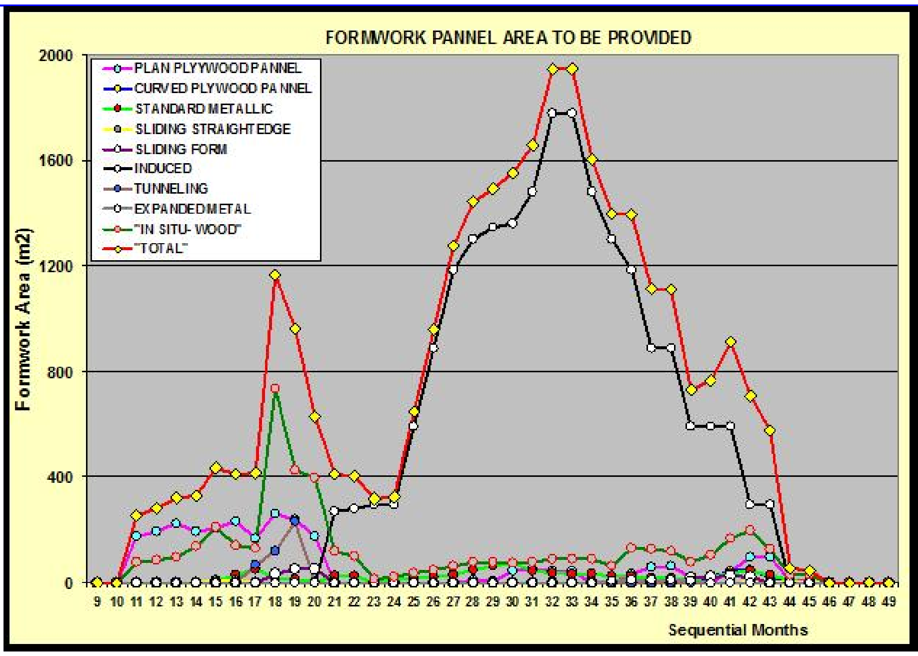

Figure E-50- Formwork Panels Area to provided per Form Type

E.7.2- Equipments for Formwork Handling

As mentioned in item E.6.2, mobile cranes will be used on rough terrain tires for:

- Carpentry Patio;
- At front placing

These cranes must have a 10t capacity and a 20 by 25m reach.

E.8- Reinforcements

Reinforcement ratios were adopted, as resumed in Figure E-02 and summarized in the graph of Figure E-51.

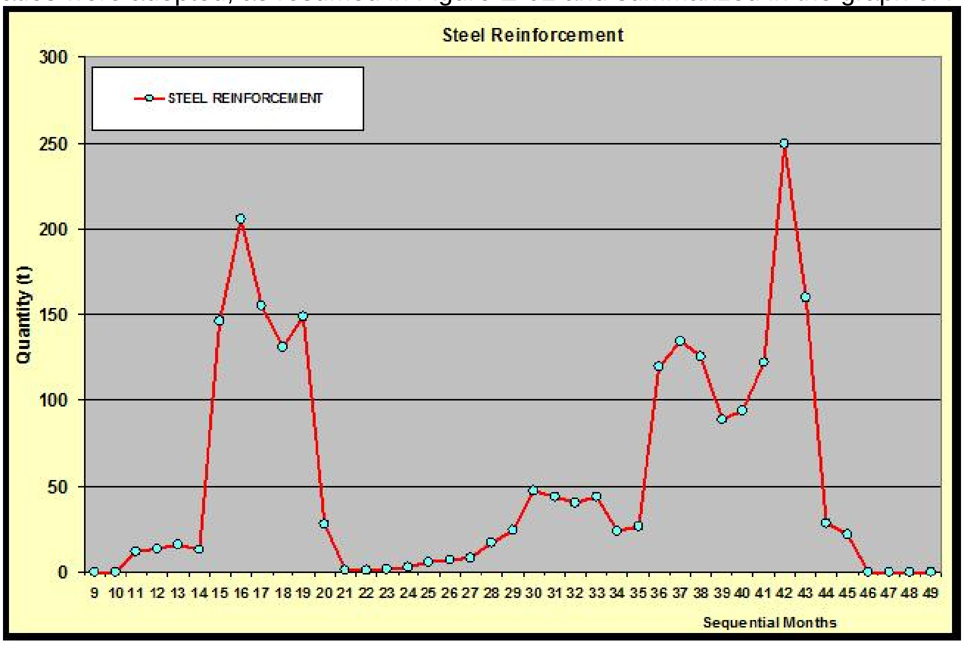

Figure -51- Estimated quantity of reinforcement Steel

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E-9- Laboratory and Facilities for Control

For RCC control the facilities of the Laboratory installed at job site can be used. Some additional improvement is recommended. The equipment list can be as follows:

Order	Technical Description	Quantity	Reference (*)
1	Stainless steel caliper- Range 0-200mm. Jaw depth 100mm	01	H-2817
2	Concrete mixer. V=800 liters	01	H-3848
3	Air Entrainment meter, pressure meter type	01	H-2786 C
4	Specific Gravity and Absorption Kit	01	H-3373
5	Slump Cone Test Set	02	H-4635
6	Steel cylinder molds- 150 mm diameter- 300m height- steel wall thickness=4mm, and base	50	H-2950
7	Vibrating table- 500mm*500mm	01	H-3755
8	Electrical vibrator- d=25mm	03	H-2999
9	Vertical cylinder capper set with base, for 150*300mm cylinders	01	H-2952
10	Compound melting pot, for capping, with automatic temperature control	01	H-2955
11	Electrical Compression Tester Digital System, with Cylinder Splitter and Flexure attachment	01	H-2765.6; H-2767; H-2768
12	Compressometer Extensometer	01	H-2912
13	Moisture/ Density Nuclear Gauge, for RCC density measurement	01	Troxler (see Figure 12)
14	Electrical Sieve Shaker for fine aggregate	01	H-4318
15	Electrical Sieve Shaker for coarse aggregate	01	H-4283
16	Screen Tray- 457x660mm, for H-4283 Shaker- in the nominal openings: 4", 3", 2-1/2", 2", 1-1/12", 1",3/4", 3/8"	02	H-4278
17	Screen Tray- 203mm diameter, for H-4318 Shaker- in the nominal numbers: no.4; 8; 16; 30; 50; 100	04	H-4335
18	Screen Sieve- 203mm diameter, for H-4318- with nominal number: No. 200	06	H-4335
19	Bench oven	01	H-30140
20	Gas hot plate,	02	H-4949
21	Balance- Capacity 600g, Readability 0,1g	01	H-4726
22	Balance- Capacity 12000g, Readability 0,1g	01	H-4506V
23	Balance- Capacity 50 kg, Readability 5g	01	H-4762
24	Graduated Polypropylene Cylinder, set of 10ml; 25ml; 50ml; 100ml; 500ml; 1000ml	03	H-4916P
25	Graduated Polypropylene Beaker, set of 50ml; 100ml; 400ml; 1000ml	03	H-4912P
26	Thermometer – Pocket Type- 0 to 150 oC	03	H-3553
27	Shovels, Scoops, Trowels, Pans, Bowls, etc- Set		
28	VeBe Consistometer	01	ASTM-Method (see APPENDIX V)
29	Pneumatic or electric hammer for RCC specimen compaction	02	

Reference- Humboldt Catalog- www.hmc-hsi.com

Figure E-52- Estimated equipments for the Project Laboratory

It is highly recommendable that the Laboratory Site be very close the Concrete Batching Plant Site

Figures E-53- Vibratory table for Consistency Test and for Cylinders Specimen

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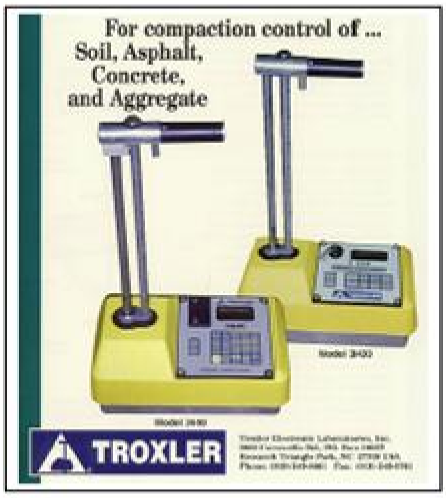

Figure E- 54- Nuclear Densometer for compaction control

E-10- Workmanship Labor

Figure E-55 illustrates the amount of estimated workman labor, as a result of the parameters adopted for executing the Services concerning the concrete work in the Project.

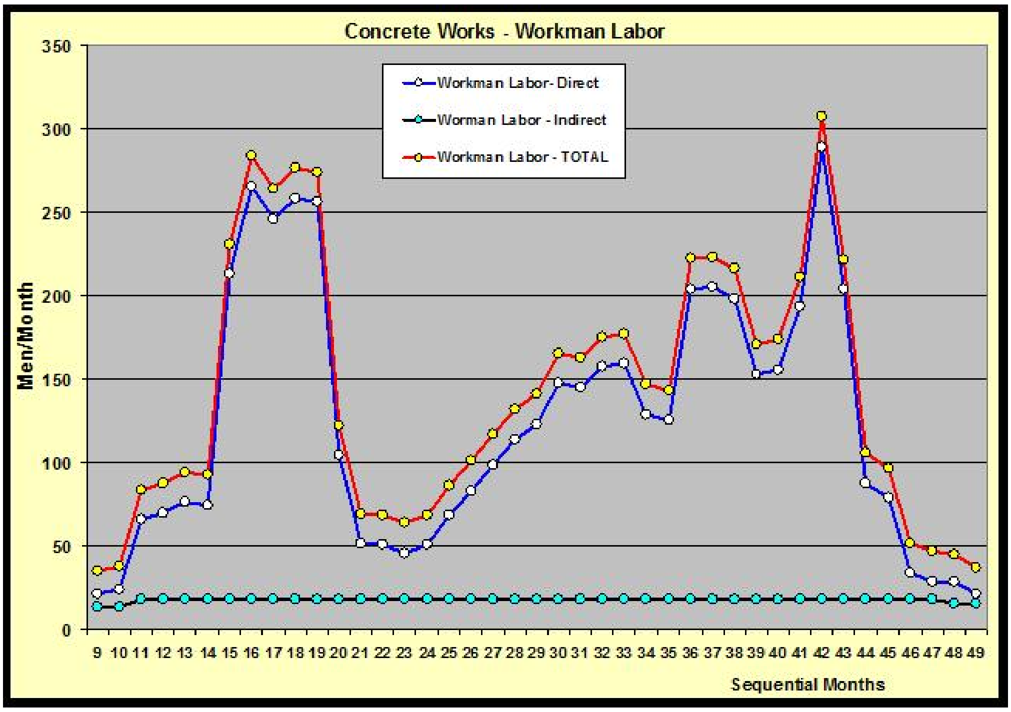

Figure E-55- Workman Labor estimated for Concrete Works during the Construction of the Project.

From the quota of workman labor required (Men/month), which comes less than 310 men/month. It can be envisaged that an additional Time Reduction can be obtained after an adequate Training Period

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F- RCC CONSTRUCTION TECHNOLOGIES

F.1- 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 seg), 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?***

It has been well established that, regardless of cement content, ash content, aggregate fines content, or water content, all non-air entrained RCC mixes require about 19%-21% "paste" by volume in order to avoid segregation, be constructable, and have the best cementitious strength efficiency. Why does the industry still use the terms "high paste" and "low paste?" Should the terminology be "high cementitious" and "low cementitious" content. Paste consist of the material that makes paste. This is normally considered to be everything that passes the 75 micron (#200 sieve). This includes water, aggregate fines, cement, fly ash or other pozzolan (the portion passing 75 microns), slag (the portion passing 75 microns), and air. Mixes with less than 19% paste typically are very harsh and not very constructable. They tend to segregate and result in poor contact at lift joints. Mixes with more than 21% paste tend result in less strength per kilogram of cementitious material.

Why are the terms "concrete approach" and "soils approach" used to describe different mix design methods? What some people (who did not develop the procedure) refer to as a "soils approach," is very much a concrete approach. It was developed with concrete technology. In reality, all RCC mix design methods use "concrete" technology. They optimize the gradation within certain limits. They establish the minimum amount of water that is needed for compactability or workability. They consider the reduction of strength resulting from water that is added beyond the amount necessary for a constructable mix. They evaluate the benefits of pozzolan and admixtures. They develop a "paper" mix design and then make the real mix to determine if adjustments are necessary. Regardless of the mix design procedure, test samples are then made to determine traditional concrete properties of density, strength, modulus of elasticity, air content, etc.

Does hard evidence exists to show when truck traffic for delivery of RCC on the dam causes damage to the lift surface and to RCC below the lift surface, and when it does not casue damage?

Under what conditions does a conventional concrete facing mix improve watertightness of a dam. If facing mix is placed simultaneously with the RCC, what are the advantages and disadvantages of making it the facing wider (say 1 meter) and making it narrower (say 300 mm).

F.2- INTERFACE- DESIGN & CONSTRUCTION

- RCC arch dams

F.3- RCC CONSTRUCTION TECHNIQUES

- Faces
- Mass Dam Body Materials
- RCC Handling and Accesses
- RCC Placement
    - Horizontal Layers
    - Sloped Layer Method

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- RCC Contraction Joint Interval
- RCC Construction Joint Surface Treatment

F.4- MONITORING

- Instrumentation

PVC membranes have been successfully used for many years in repairing and rehabilitation of old dams and lately in building new dams. While RCC theory and practice have been developed over the last 20 years, PVC membranes have been successfully used for more than 30 years. The use of PVC membranes becomes more evident not only in rehabilitation works, but also in building new dams.

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 impermeabilisation 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?
- Is it true that these dams present less risks with regard to expansions. On the other hand, the type of addition can trigger posible expansions?
- Have expansion phenomena been observed in RCC dams?
- Under what conditions does a conventional concrete facing mix improve watertightness of a dam. If facing mix is placed simultaneously with the RCC, what are the advantages and disadvantages of making it the facing wider (say 1 meter) and making it narrower (say 300 mm).
- Comparing the trapezoidal shape of the FSHD with the traditional section of RCC dams, it is needed to know if the selection of the dam type is based on the low cost of the nearby in-situ materials or on the characteristics of the foundation to support the FSHD structure.
- 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?

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.

Additives for RCC are beneficial for RCC and there are a lot of interesting publications about the benefits obtained from the use of additives on RCC. The use of additives on RC mainly depends on their costs, which vary significantly from one country to another.

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G- QUALITY CONTROL

G.1- **General**

Roller Compacted Concrete (RCC) is a relative easy and simple construction technique, but unfortunately up to now, has not yet a consolidated methodology for design, mixes proportioning and laboratory tests. Some authors or technical groups have shown tendencies or advantages in adopting a procedure for mix design. In a general point of view this could be summarized in specific tendency or experience that could not be accepted as a general rule. There are a number of methods that have been used for the design of the mixture proportions of an RCC.

RCC mixture proportions should follow the convention used in traditional concrete that is:

- ***identifying the mass of each ingredient contained in a compacted unit volume of the mixture based on saturatedsurface- dry (SSD) aggregate condition***.

A practical reason for using this standard convention is that most RCC mixing plants require that mixture constituents be thus identified for input for the plant-control system.

A number of mixture proportioning methods have been successfully used for RCC structures throughout the world. Projects have differed significantly due to the location and design requirements of the structure, the materials, the mixing and placing equipment, and time constraints.

Emphasis is placed on determining optimum water content for compactability at fixed cementitious materials content. Selection of cementitious materials content and water content is determined from design requirements, (Compressive, Tensile, Shear Strengths; Permeability, etc…), with consideration of minimizing the cementitious materials content to avoid thermal cracking. It could be said that the mix design of a concrete is a process by which can be obtained an adequate and economic combination of binder, aggregate, water and admixtures producing a concrete which performs to the required specifications throughout its service life. It is the authors' opinion that design features should take advantage of the economies of RCC construction, looking for simplicity, quality, and being economical.

A mix design process must assure the required property values; no segregation occurs by handling operations and performance requirements are met using the proper materials. The diversity of the structural designs, the environmental, geographical and other conditions reflected, justifies why several types of concrete exist which differ in their composition and characteristics.

RCC requires a mixture that will not subside excessively under the weight of a vibratory or other roller but which will have an appropriate grading and paste volume to consolidate adequately under the roller.

The principal methods and ideas around mixing processes have numerous aspects in common such as the need to adjust the concrete to the available materials, required characteristics, and the placement as well as to the economic conditions. RCC presents two fundamental differences in composition with respect to their CVC counterparts:

- Firstly, RCC generally use an aggregate combination that reduces the coarse fraction and increases the use of fine material, as previously mentioned, and;
- Secondly, RCC contains a reduced quantity of mixing water which is compatible with the transit of heavy duty earth-moving equipment over its surface while it is still in a fresh state. This peculiarity of its placement means that RCC concrete must he studied and controlled when it is in a fresh state.

G.2 Routine for RCC Mixes

As very well known, there are several methods that use the **'concrete'** approach for the design of the mixture proportions of an RCC including that used for the design of RCD mixtures. All the methods have similarities and follow similar procedures although there are minor differences.

The routine below show the main conceptual points of the mentioned approaches. The suggested procedure is as follows:

I. Optimize the gradation of the fine and coarse aggregates to produce minimum voids in each using additional mineral fines in the fine aggregate or available pozzolanic material if necessary. The mixes

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were proportioned in attempting the main objective to reach the maximum specific gravity. So the aggregates can be combined to adjust as near as possible from a curve type ***p= (d/Dmax)1/3 *100%;***

II. Proportion the Portland cement, pozzolanic material (if any), water and admixture (if any) to obtain the required property to obtain the proportions of the paste. This can be modified to choose the minimum cost mixture. For example if the pozzolanic material is cheap relatively to the cement and/or the available fine material (silt, crushed powder filler or other equivalent), a higher proportion of the cementitious content would be pozzolanic, while if it is near the cost of the Portland cement, a lower proportion would be used;
III. Check that there is sufficient cementitious material (and a proportion of mineral fines, if used) to provide the design permeability and durability;
IV. Check that the fine aggregate/coarse aggregate ratio is close to the optimum;
V. Check that the heat of hydration is within the expected limits;
VI. Make any adjustments that are necessary (laboratory and field) and re-check the design.

G.3- Inspection and Quality Control Requirements and Practices

- Who is it that does not want assurance that the concrete job in which he is involved will achieve the quality necessary to give good performance and great appearance throughout its intended life?
- Probably no one.

Quality control is no different on concrete construction work. Basically this is inspection and the related testing of materials and concrete. It is however, more than making a few slumps (CVC construction) or consistency tests (RCC construction) and cylinders for strength tests. The full scope of duties and responsibilities of the inspection and testing staff are only effective if it includes everyone interacting with them.

G.4-The Need for Inspection

The purpose of inspection is to assure that the requirements and intentions of the contract documents are faithfully accomplished. The term *inspection* as used in concrete construction includes not only visual observation and field measurements, but also laboratory testing and the assembly and evaluation of test data. One important responsibility for the concrete inspector is the quality of the materials used in the concrete. Often low quality raw materials, particularly aggregate materials, can be used to produce concrete of satisfactory quality if they are suitably processed or prepared.

However, the final materials entering the concrete mixture must be of specified quality. It is difficult and usually impossible to produce specified concrete from nonconforming materials. On the other hand, a principal ingredient needed for specified concrete construction is good *quality workmanship* in all operations and processes. It has been said that most good concrete is made from tested and certified cement; sound, durable, well graded, and properly tested aggregates; suitable admixtures; and clean, pure water-and most nonconforming concrete is made from the same good materials.

G.5- Specification Inclusions

A good specification is that which only requires things that need to be done to make the concrete suitable for its purpose. It contains no requirements that can be ignored or slighted and omits no requirements that must be met. With a "**good specification**" neither the contractor nor the inspector has any doubt as to what must be done. With such a specification, any part of the work that is not in accordance with the requirements must be changed so that it does comply. The question of whether it is "good enough," even though not as good as required by the contract will not arise.

Inspection is not an end in itself. Inspection and testing by themselves do not add quality to the product or process being inspected. Inspection and testing only confirm whether the product or process meets the criteria established. The information derived from the inspection and testing process, however, when properly evaluated and with conclusions and decisions implemented, will result in improvement of the quality of the product or process. It must also be recognized that quality is achieved only by implementation of an adequate quality program from planning through design and construction, to acceptance by the owner.

Quality during the construction phase is achieved almost entirely by the contractor or producer's quality control program. This quality control program involves everyone from management to field supervisors to the workmen themselves.

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Quality control must have the strong active support of top management, and the active concern and participation of everyone involved in the construction process.

G.5- Statistical Concepts in Quality Control

The science of statistics is a versatile tool. Its use permits decisions to be made with an established degree of confidence.

Contract documents can be written using statistical concepts to express quality requirements as target values for contractors, and to express compliance requirements as plus or minus tolerances.

Tolerances for the target value, prescribed by design needs, can be based on statistical analyses of the variations in materials, processes, sampling, and testing existing in traditional construction practices. Tolerances derived in this manner can be both realistic and enforceable. They take into account all the normal causes of variation and allow for the expected distribution of test results around the average. Provisions can be made both for control to the stated level and for control of the variation from this
level.

G.6- Records

Quality control in construction is not a reality without records that give that assurance. These records must be systematically and presentably kept. They must be accurate, consistent, and believable. But they need not be excessive in coverage and should not be redundant.

G.7- Quality Plan

An overall (Total?) Quality Plan or System for a construction can describe in general terms the Quality Control System used for the a project with emphasis on:

- The quality objectives to be attained;
- The specific allocation of responsibilities and authority during the different phases of the project;
- The specific procedures, methods and work instructions to be applied;
- Suitable testing, inspection and examination at appropriate stages;
- A method for changes and modifications in a quality plan as the project proceeds;
- Other measures necessary to meet objectives.

The main objective of each quality plan is to give the project manager the overall tool assuring that the work in the different phases is executed in a controlled manner.

Personnel performing activities affecting quality must be appropriately trained and records will be kept of executed training. Records of training and a list of persons authorized to perform certain tasks must be kept and maintained by the respective members of the team.

Procedures need to be established, maintained and documented in order to perform, verify and report that the service meets the specified requirements. The reliability, availability and maintainability of the operation need to be monitored and reported.

The Quality Control System tries to increase the quality and productivity of the works and reduce costs. It must be designed to prevent and eliminate or reduce mistakes during the construction works, and provide repairs, if and when mistakes occur. The design of a structure should be accomplished considering what measures will be required to insure that the required quality is achieved. It is obvious that the design of projects where little quality control is anticipated should be more conservative than the design of a project where a very effective quality control program is anticipated.

For most projects the quality control requirements are specified in the contract documents, or by separate agreement with a quality control organization. The preparation of those documents should be coordinated with project designers so that the design requirements are suitable.

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While quality control is usually considered to be an activity performed during RCC placement, it is also important that quality control issues be considered during design, planning, and the initial phases of construction of an RCC project.

A viable Quality Control System should consider the numerous construction operations basic not only to RCC but also to the CVC, and how they are performed.

Preparation and advance planning are the key to success and quality construction. Pre-construction meetings, pre-construction testing, and pre-construction evaluations such as test sections are critical parts of the quality program. Once the concrete (RCC and CVC) placement is under way, the more traditional concepts of quality control become evident, but advance planning and preparation continue to be important.

The control can be based on the following main items:

- A qualified team;
- Adequate and modern technology;
- Adequate equipment and facilities;
- Elimination of mistakes and defects;
- Monitoring of the process;
- Standardizing

The objective of Quality Control is to ensure that the characteristics of received or produced materials and equipment are preserved. Adequate care and methods will be employed in the handling of materials and equipment.

Whenever necessary, specific arrangements will be made for the handling of sensitive equipment.

All data and information relative to the Quality Control System must be collected in a standardized routine and accurate manner, to give evidence of the required quality for materials and equipment. Records will include the following features:

- Quality Control as used herein refers to all functions involved in obtaining quality materials to provide satisfactory services;
- Periodical reports based on statistical analyses must be made for all items in the project;
- Before concrete production starts, all materials will be analyzed according to their properties and only those in conformity with the standards will be chosen.

RCC placing rates can be extremely high when compared to conventional concrete. Placing rates in excess of 400m3/hr has been achieved on some large projects. Small structures have been constructed in only a few days or weeks. With such rapid placement rates or short-term construction periods, problems must be evaluated and solutions implemented in a short period of time. Any problem that delays RCC placing essentially delays the whole production. Good communication among the owner, engineer, inspection personnel, and contractor personnel is essential. The most common placement delays are usually due to problems caused by:

1) Insufficient materials
2) Foundation preparation and cleanup
3) Joint cleanup
4) Equipment breakdown
5) Weather condition (hot or cold ; wet or dry; rain)

After the selection of the materials (cement, pozzolanic materials, aggregates, water and admixtures) available for use according to the standards and specifications, concrete mixes must be designed by the laboratory, in compliance with an adopted **"Recommended Practice"** or Standard. Materials inspected for acceptance before being shipped to the job site can have their status checked for damage during shipment and storage.

It must be assured that all personnel are correctly selected, trained, qualified and motivated so that the results anticipated by the company will be attained and even surpassed. A key element in resolving potential problems in advance is to assure that all participants understand the project requirements, and that necessary procedures are clearly understood. Basic issues that must be considered in advance are:

- **Staffing**- Sufficient laboratory and inspection personnel should be trained and available for the anticipated production operations. Shift overlaps and transitions require advance planning. All staff members must know

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what is *acceptable* and *unacceptable*, and they must consistently apply acceptability criteria. Whenever necessary, the work will keep proof on file showing that executive and quality personnel are qualified and/or certified by an agency of recognized competence.

- **Facilities and equipment**- Appropriate testing facilities and equipment for the size and volume of tests that may become necessary must be available in advance of RCC related work. Technicians should be trained in the proper use of the equipment and in the proper implementation of the test methods.
- **Communications-** The project staff should meet with the contractor to review and discuss requirements and procedures for RCC material production, placement, testing, inspection, and job site safety. Adequate radio communication at the job site among key personnel of the contractor, inspection/quality control organization, and field design personnel has been responsible for avoiding work stoppages and unnecessary removal of questionable material.

Based on what was described above, it can be suggestedthat before the works start a “Quality Control Plan” and a “Manual for Quality Control” should be adopted. This "Manual" proposes measures which include the following basic points:

- Be aware of possible problems;
- Anticipate possible corrections;
- Guarantee quality;
- Seek modifications and improvements;
- Be objective, dynamic and compatible with the pace of construction;
- Controls must include materials and concretes (RCC and CVC);

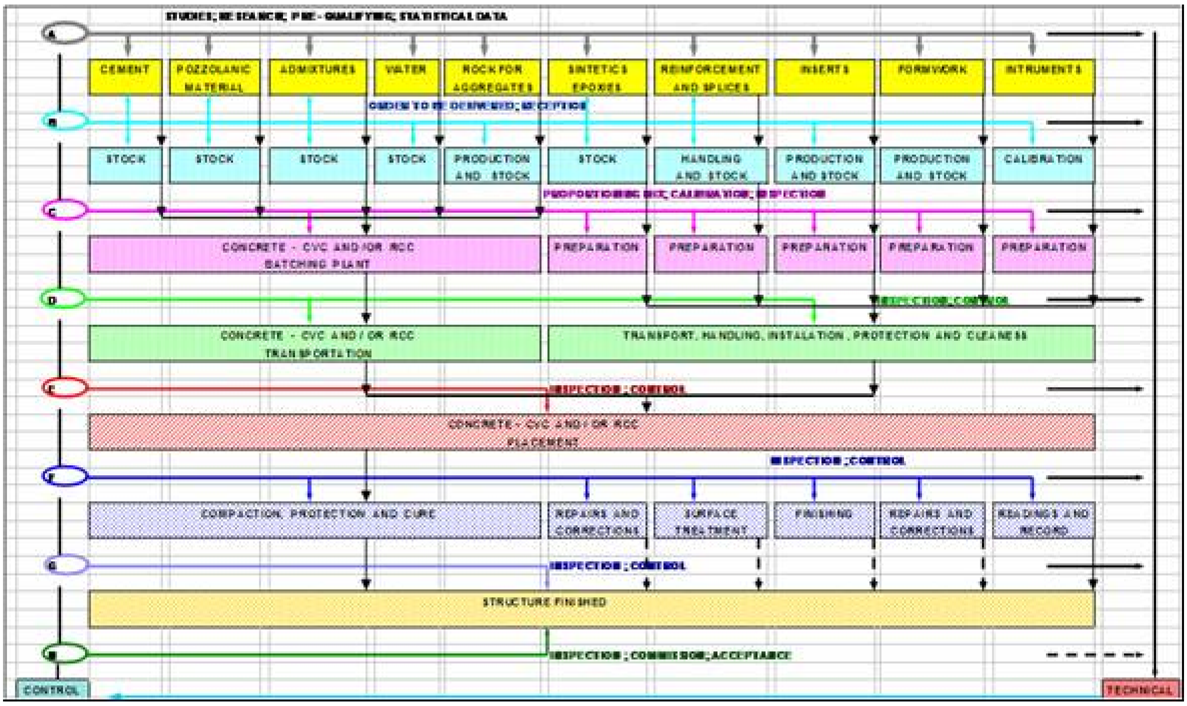

Figure G-01- Flow Chart as Guideline for Quality Control

For an overall view of the scheme that can be adopted Figure G-01shows a flow chart of actions with the following points:

Action 1 - Pre-qualification and knowledge – This corresponds to the stage of initial studies, knowledge and selection of materials and suppliers;
Action 2 – Information on handling;
Action 3 - Control of arrival (delivered) of material - This action seeks to guarantee quality and uniformity of the material and products, based on pre-qualification data. These tests are proven by certificates, and can be performed by each supplier;
Action 4 - Control during production - This action is to evaluate the points or procedures that could be vulnerable during production;
Action 5 - Control of application - This point consists of disciplinary actions during production.

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Action 6 - Inspection during execution - This action will have the function of evaluating the best procedures for executing the works;
Action 7 - Structure commissioning – This item will have the function of formal commissioning of each stage of structures or services.

In addition to inspection activities, a comprehensive RCC quality control program should monitor the aggregate properties, RCC mixture proportions, fresh concrete properties, hardened concrete properties, and in place compaction. An example of possible tests and test frequencies are given in Figure G-02, which was successfully adopted during Capanda RCC Dam construction in Angola and others RCC jobs where the author have cooperated. The frequency and extent of testing should be adjusted according to the size of the project, the sensitivity of the design to variations in quality, and the rate of RCC production.

Quality control of the material and concrete used for the Capanda project, was the Contractor's responsibility. To perform these activities, a "Quality Control Plan" was devised, in order to comply with design and specifications requirements. Logistic conditions for construction of the development were also considered such as, purchase of basic materials, distance from site to production centers, quantity and quality of labor available, schedules, and assurance of quality parameters compatible with the magnitude of the works. Figure G-02 shows, in schematic form, the Quality Control Plan established.

The "goal" of quality control is to identify problems before they occur or sufficiently early in the process so they can be corrected. Monitoring and reacting to the trend in performance is preferable to reacting to specific test results. The trend, identified by a series of tests, is more important than data provided by a single test. By continuously tracking trends it is possible to identify detrimental changes in material performance and initiate corrective actions. Further, it is possible to modify the frequency of testing based on trend performance. For example, it is common to specify a high testing frequency during the beginning of aggregate production and to later reduce the testing frequency as production stabilizes and the trend in grading stabilizes. Tests must be performed rapidly. The rapid placing rates and typical 20 or 24 hour per day construction timetables require careful attention and interaction between Quality Control testing, inspection personnel, and production personnel.

If Quality Control System activities cause significant delays to any stage of RCC production such as mixing, placing, compacting, or foundation cleanup, all construction may be affected and possibly stopped.

Fresh RCC properties may vary with daily, weekly, or monthly fluctuations in ambient weather conditions. This, in turn, affects water requirements, compaction characteristics during construction, and the quality of the concrete. Normally, construction activities continue throughout a variety of warm, cold, wet or dry ambient conditions. Quality Control System personnel should assure that continuous adjustments in moisture and, if appropriate, other mixture proportions are made to adapt to these conditions. All personnel must communicate between shifts about these adjustments in order to achieve continuity of the product.

Even more than in CVC, the use of compressive strengths test on concrete specimens as a method of control in RCC construction has a major disadvantage in the time required in obtaining results. Because of the rapid rate of placement in RCC construction, and the fact that layers of material can be covered with new lifts within hours, test cylinders serve as record data for quality and are not an effective method of day-to-day quality control.

Emphasis on thorough control of materials (gradation, cementitious content, and moisture content) and conditions during placement is essential to proper RCC. If the aggregates are as specified with regard to source and quality, the cementitious materials are pre-tested from pre-qualified sources, the technique and timing of mixing, spreading, and compacting are within the designated guidelines, and an appropriate method of curing is followed, the end product will be acceptable.

An advantage of RCC and the above approach is that unacceptable material is identified early and can be removed at relatively low cost. For example, a zone of low-density material can be identified by nuclear density gage testing within a short time of placing and then can be re-compacted or removed prior to achieving final strength.

It is important that qualified personnel be in close contact with the mixing plant at all times to maintain water contents at the optimum level for compaction. The control measures that should be instituted in RCC construction are essentially material-dependent. If the mixture was designed for strength and consistency requirements, measurements of consistency should be performed to maintain consistency within the desired range and to expand the judgment based on observations of the inspector and placing foreman. Adjustments in batch water can be made prior to placement when consistencies approach control limits.

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MATERIAL OR SYSTEM	SAMPLE POINT	STANDARD REFFERED	TYPE OR INTENTION	FREQUENCY	LABORATORY	TESTS OR EVALUATION
REINFORCING STEEL	STOCKS		RECEPTION	EACH TRUCK (30t)	JOB SITE	WEIGHT/LINEAR, YIELD STRENGTH, RUPTURE STRENGTH, ELONGATION, BENDING
REINFORCING SPLICES	STRUCTURES		CONTROL	2 % OF TOTAL SPLICES	JOB SITE	RUPTURE STRENGTH
WATER	BATCH PLANT		CONTROL	WEEKLY	JOB SITE	SOLIDS, pH, O2, SO4, Cl
ADMIXTURES	BATCH PLANT		CONTROL	ONE / 1000Kg	JOB SITE	SOLIDS, pH, SPECIFIC GRAVITY
WATERSTOP	SUPLIER		DELIVERY	ONE / 200m	OFFICIAL LAB.	ALKALIES, HARDNESS, TENSILE STRENGTH ELONGATION AT RUPTURE
CEMENT	SUPLIER		DELIVERY	ONE / 2 HOURS OR ONE / 100t	CEMENT FACTORY	FREE LIME, FINENESS BLAINE TIME OF SET, LOSS ON IGNITION
			CONTROL	ONE / DAILY ONE / 500t	CEMENT FACTORY	SiO2; Fe2O3; Al2O3; SO3; CaO; MgO; FREE LIME; LOSS ON IGNITION; INSOLUBLE RESIDUE; TIME OF SET; RESIDUE ON # 200; # 325 SPECIFIC GRAVITY; AUTOCLAVE EXPANSION EXPANSION "LE CHATELIER" COMPRESSIVE STRENGTH
	CONTAINERS		RECEPTION	ONE / 100t	JOB SITE	
	BATCH PLANT		CONTROL	ONE / WEEKLY	JOB SITE	
		ADOPTED STANDARD IN THE COUNTRY	INTER-LABORATORY	ONE / 5000t	OFFICIAL LAB.	
AGGREGATES	CRUSHER SYSTEM		PRODUCTION	ONE / WEEKLY	JOB SITE	GRAIN SIZE; APPARENT AND ABSOLUTE DENSITIES ABSORPTION; FLATNESS
	BATCH PLANT		CONTROL	ONE / SHIFT	BATCH PLANT	UMIDITY; ADJUSTMENT MIXES
				ONE / WEEKLY	JOB SITE	GRAIN SIZE; APPARENT AND ABSOLUTE DENSITIES ABSORPTION; FLATNESS
CONCRETES CVC	BATCH PLANTS		CONTROL	ONE / 200m3	JOB SITE	SLUMP; AIR; TEMPERATURE; SPECIFIC GRAVITY COMPRESSIVE STRENGTH
				ONE / 2000m3	JOB SITE	SLUMP; AIR; TEMPERATURE; SPECIFIC GRAVITY COMPRESSIVE STRENGTH, MODULUS, TENSILE SPLITTING
CONCRETE RCC	BATCH PLANTS		CONTROL	ONE / SHIFT	BATCH PLANT	GRAIN SIZE; CEMENT CONTENT; CONSISTENCY (VeBe) COMPRESSIVE STRENGTH; SPECIFIC GRAVITY
	DAM BODY		CONTROL	ONE / 100m3	DAM SITE	SPECIFIC GRAVITY, COMPACTION RATIO, UMIDITY
DRILLED CORES	DAM BODY		CONTROL	ONE / 10000m3	JOB SITE	SPECIFIC GRAVITY; MODULUS; PERMEABILITY COMPRESSIVE STRENGTH
CRUSHER PLANT			INSPECTION	DAILY	SYSTEM	CHECK LIST
BATCH PLANT			INSPECTION	DAILY	SYSTEM	CHECK LIST

Figure G-02- Test plan and frequency adopted for the Capanda Dam- Angola

G.8- Training and Communication

Quality is best assured when the inspection and testing force is well trained and skillfully supervised. This includes seeing that the inspectors know at least what they need to know and that they have the correct attitude of firm but pleasantly detached authority, although endeavoring to be helpful wherever they properly can. For these important reasons of supervision and training, it is usually better to include these functions in the owner's or engineer's organization than to assign this great responsibility to an outside organization over which supervision and control is difficult at best. This condition is more important in RCC than in CVC construction due to the rapid rate of concrete placed. The cost of quality concrete work will be least when all concerned really want it and work harmoniously together to see that they get it.

An important early move in this direction is to hold pre-bid and pre-construction meetings attended by responsible representatives of the owner and builder, engineer, inspection and testing people, and materials suppliers.

Thus mutual understanding of specifications and potential problems is promoted, and acquaintance and communication is established. Such meetings can also be helpful during construction.

As part of the quality control program, orientation and training sessions should be held for supervisors, inspectors, and workmen. The differences in technique between CVC and RCC as well as granular embankments should be discussed and understood by all. Key issues should be explained, such as time limitations for mixing, spreading, and compacting, and concerns about segregation, joint integrity, and curing. It should be emphasized that although RCC looks and behaves like granular fill in its early stage, it is concrete and should be treated as carefully as conventionally placed concrete. This includes cure, protection, and care of compacted concrete surfaces.

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During construction of an RCC structure, both the designer and inspection personnel should be aware that, as with other construction methods, undesirable material will be placed occasionally. Field personnel should not overreact to isolated cases of placement of "rejectable" material that does not jeopardize the overall function of the structure and where remedial action would create a worse condition than leaving the material in place. Critical operations should be identified and given more attention during construction and inspection to prevent placement of marginal material. It is very important to take in account that in RCC construction, due to its speed, the construction planning and the quality control system must be considered in advance, and very well adjusted.

While Quality Control (QC) is customarily considered to be an activity performed during RCC placement, it is also important that the degree of control be considered during design, specification, planning and the initial phases of construction of an RCC dam.

Rapid construction, which is one of the keys to the economics of RCC dams, causes quality control of the concrete constituents and the production facilities to be a most important factor in ensuring concrete quality. Once the RCC has been produced and compacted in the dam, it is expensive and unrealistic to remove the deficient material. Quality control after production should provide final verification of the concrete properties. At the dam, quality control of the fresh concrete must thus emphasize test methods that can give a quick indication of concrete quality and an indication of any minor adjustments required to maintain the concrete within the Specification.

Further testing will of course be required for documentation of concrete properties, as for any other concrete construction.

G.9- Full-Scale Trial

The full-scale trial is an essential part of the QC program. In addition to the testing of the production and placing equipment, the testing done at this stage can form the database required to judge the RCC quality from preliminary test data. For all but the smallest dams, it is strongly recommended that a full-scale trial be constructed prior to the start of placement in the dam.

The first RCC that will be placed in the dam will be typically at the lowest point and thus amongst the most critical concrete in the dam. Consequently the trial should be outside the dam body or in a less-critical section of the work such as high on one abutment or as part of a stilling basin. The objectives of the trial are typically:

I. To train the personnel who will work on the dam; only those that have worked on the full-scale trial should be allowed to work on the initial stages of the RCCplacement;
II. To demonstrate and confirm the suitability of the equipment and procedures the Contractor intends to use for mixing, handling and placing the RCC (and any traditional concrete to be placed in conjunction with it). However, the trial should not be at the time that the Contractor commissions his plant; all the plant should be fully operational before the trial commences;
III. To evaluate the RCC mix performance, i.e. segregation, proportions and compactability, including under unusual conditions, such as heavy rain;
IV. To establish correlations between tests done at the time of concrete placement and the properties of the hardened concrete. Experience shows that it is often advantageous to evaluate the mixture performance including the consistency separately from, and in advance of, the full-scale trial.

G.10- Inspection and Testing During Placement

Quality control during RCC placement involves two operations, inspection and testing. Inspection is the first opportunity to observe an RCC problem and institute measures to correct it. The RCC testing program should monitor the aggregate properties, RCC mixture proportions, fresh-concrete properties, hardened-concrete properties and in-situ compaction.

G.11- Control of Fresh Concrete

Quality control of the fresh concrete at the dam involves careful judgment and quality consideration of the following components and works:

- spreading and compaction
- density and moisture content
- lift joint bonding

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- curing
- temperature control

Density control is more important for RCC as compared to traditional concrete. Insufficient density can be the consequence of too high or too low moisture, poor grading or segregation, incorrect spreading, inadequate vibratory amplitude or frequency and vibration energy, delays to compaction, inaccurate layer thickness or too low a number of roller passes.

Density control is typically done by nuclear densimeter that measure density at different depths in the layer.

Normal frequency of measurements ranges between one test per 200 to 500 m3 of RCC placed depending upon the size of the project.

Quality control of intended lift joint bonding comprises the detection of possible contamination at the surface and the identification of cold joints. The first will be accomplished by specifying cleanliness of equipment at the RCC surface, method and equipment to be used on lift surface cleanup and preparation and by its visual inspection prior to placing the next layer. It is common practice for large RCC projects to limit all traffic to vehicles staying on the dam or to clean the tires of vehicles entering the concrete surface. Records should be kept that identify cold joints and that distinguish between joints which may or may not require special treatment.

G.12-Control of Hardened Concrete

The methods of quality control of hardened RCC in the dam are the same as those employed in the full-scale trial. Concrete cylinders are made at the time of placement, cured and then tested for strength and modulus.

Further specimens are typically obtained by coring and are subject to the same tests. Core samples contain the joints between lifts that can be subjected to detailed inspection and strength testing.

As with traditional concrete, the test results from the RCC are typically evaluated statistically and compared with the design requirements. One method of assessing strength control of RCC is to review the Coefficients of Variation (CV).

Careful curing and handling of the test specimens can reduce the coefficient of variations of strength. Detailed investigations on such individual influences on the CV of the compressive in-situ strength should be evaluated.

G.13- **The Author's Comments on RCC as a Construction Material**

Regarding the structural behavior of RCC, the main conclusions drove from the use and observations carried out for years, are as follows:

a) It is possible to construct dams of RCC with the same watertightness as that of concrete dams built with traditional methods;
b) RCC dams with CVC faces, or a special RCC proportion mix, and joints having water-stops (including among these the dams constructed with the Japanese method), as those with faces formed by prefabricated concrete panels, lined with an impermeable membrane, have shown a high degree of watertightness;
c) The impermeability of RCC can be improved by increasing its fines content;
d) RCC dams present less danger of cracking than those of conventional concrete, due to their lower shrinkage, combined in general with a reduced modulus of elasticity and higher creep. The lower shrinkage of roller compacted concrete originates from its lower water and cement contents, in comparison with those of a vibrated concrete;
e) The majority of the cracks in RCC dams can be attributed to stresses of thermal origin in most of the richer mixes;
f) The transverse construction joints, having waterstops upstream and drainage holes, are an efficient system for cracking control. When distance between joints is too large, intermediate cracks are produced. Their width is smaller though than that of the joints;
g) Cracks are always produced in transverse joints where transverse sections have been deliberately reduced, as well as in other points with smaller transverse section, as a consequence of a lower total tensile strength. Examples of these latter points could be a protrusion of rock foundation, giving rise to a stress concentration; a central spillway, or a joint on a face of conventional concrete;

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h) Cracks of RCC dams are in general vertical, perpendicular to the axis of the dam, and do not affect its structural stability;

I. Initial cracking can be attributed in general to stresses induced by restraining the deformations of thermal origin, due to the greater temperature of the inner concrete of the dam and that of the external faces.

Durability of RCC dams is logically related to the properties of the face materials, either being of CVC or RCC. In both cases, a greater strength of the mix and a better quality of the aggregates are required to provide a greater durability. In the case of CVC concrete, the inclusion of air improves significantly frost resistance and watertightness. RCC surfaces submitted on occasions to overtopping, with great flows running at high speed, have shown an adequate resistance to erosion, except in some badly compacted zones, such as those observed in faces built directly against formwork. The resistance to freezing-thawing cycles has also been very good.

Evaluation of actual and anticipated performance of RCC incorporated into the dam poses issues and problems either similar as dissimilar to those posed by CVC placed by traditional methods. The premise is that proper planning, material selection, mixture proportioning, and construction practices were all followed as set in the contract documents and pointed in preceding chapters. Performance evaluation involves the verification that quality control operations and quality assurance programs were effective so that the concrete in the finished structure has appropriate properties. For example, if sulfate-resisting cement was needed, it is assumed that it was specified, obtained, delivered, and used, and that it is the product intended by the specification.

G.14- Structural and Materials Properties

The comparison of important physical properties of RCC and CVC indicates that modern RCC is ***"a concrete"*** and that high and large RCC dams, of the same quality as existing major CVC dams, can be designed and built, provided strict quality control is practiced in material selection, design of RCC mixes, and during construction. All materials used in a high RCC dam including cement, pozzolanic material, filler and fine and coarse aggregates, should be of similar quality as those considered suitable for comparable CVC dam or pavement.

Particularly important are the physical properties related to specific gravity, susceptibility to alkali aggregate reaction or excessive thermal expansion. RCC mix should be designed with the lowest necessary cementing content to obtain the desired consistency and specified properties at prescribed ages, and with the lowest rise in temperature possible.

Experience accumulated in design and construction of RCC dams indicates that RCC can be successfully employed to build high dams of the same quality as comparable CVC dams and pavements which have been in satisfactory service for several years. The acceptance standards of quality and safety for RCC dams should be the same as those currently internationally accepted for comparable CVC dams and pavements. However, the performance of several completed RCC dams has demonstrated the need to improve certain shortcomings regarding selection of materials for RCC, foundation treatment, structural monolithicity, cracking and leakage prevention, when compared to the standards for CVC dams.

Adequate bond, uniformly distributed over the entire surface of each construction joint, is essential to obtain the necessary degree of elastic monolithicity in a high RCC gravity dam. Without such adequate bond, there may occur higher shear stresses than admissible and an unacceptable risk of shearing at a weak construction joint. Adequate bond at the construction joints can be obtained with a correct treatment.

The scope of exploration, analyzing and rock foundations treatment of a high RCC gravity dam should be the same as required for a comparable CVC dam. The impact of foundation treatment on costs and construction schedule of the dam should not be underestimated at the time of type and layout selection of the dam. The foundation should be shaped smooth since irregularities may cause stress concentration and cracking of the dam. Prevention of structural cracks in a high RCC dam should be a mandatory goal. Transverse construction joints for the full section of the dam, provided at intervals not exceeding 20m to 25m and along the entire length of the dam, are effective in preventing transverse cracking.

G.15-Cost

The cost of RCC is less than CVC for unit volume. The cost of RCC dam can be less than other type of dam. A large number of factors and conditions, especially site conditions, can affect cost and construction time. Past standards to choose one or other type of dam need to be reviewed considering all factors, conditions, time scheduled, and costs.