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Materials and RCC – Safety Uses!

But Design and Specification, also !

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Materials and RCC – Safety Uses! *But Design and Specification, also!*

***Andriolo**, Francisco Rodrigues*

Keywords: RCC- Roller Compacted Concrete, Design, Technical Specification, Process, Product, Properties, Simplicity, Cost, Quality, Safety, Control, Test, Inspection

ABSTRACT

☺ What can cause in a Site, a badly Engineered Project, and/or a specification, copied or badly elaborated, inadequate for the site of the Construction, for the Region or the Country?

☺ A contract that imposes responsibilities that should have already been evaluated, without transferring doubts and/or responsibilities?

☺ All the Professionals who work with concrete have knowledge of at least the properties of fresh concrete, meaning at least: Workability, Consistency, Setting Time, Segregation. How are they affected?

☺ What is most important for concrete, the Form of Sand grains or the Coarse aggregate?

☺ What is the difference in attitude to establish a Quality Assurance System of a project that produced 340.000m^3/month, or 14.495m^3/day or more than 800m^3/hours (with 6 concrete batch plants), with several system for placing CVC Mass with several proportions of cement, aggregates and 6 aggregates sizes, for a current RCC works, with practically one system for placement?

- None! Quite the contrary, for CVC Mass it was much more difficult, requiring much more attention!

☺ And what is the secret to not having problems, or the minimum of problems?

- Planning in advance!

☺ And what does this mean?

- Assessing the materials in advance; the mixtures, the aspects of the Project, Specifications and technical and human resources.
- Have control and command over them!

Without this it is of no use having a wide range of requirements for Quality Testing Methods, Procedures etc ...

The Quality Assurance is characterized more by preventive actions arising from the observation of facts and data, than the very recording of the data! It is not the flow of paper established by ISOs which will result in Quality. It helps but it does not resolve completely, and it is only Paperwork! It is of no use giving the Constructor the responsibility of a series of Standards and Method of Tests, if the very Studies do not provide adequate Confidence and Safety.

There are works executed after a long technical maturation. With studies that enable sedimentation of the information, of knowledge and minimization of doubts.

The Quality Assurance should include these aspects, and provide the actions that minimize the occurrence of disturbances to the concrete, and the structures that are constructed with this material.

Issues of this nature are approached and discussed in the text, reflecting on the methodology of construction, considering the period of more than two decades of the use of the RCC.

- Is there a need to establish conditions for the application of the methodology, and not to the product, because it is RCC?

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- Is there a need to Specify a Cement or Pozzolanic Material that is not available in a country or region, only with the purpose of applying the RCC?
- Is there a need to require a type of shape, or insertion of material at the Contraction Joint of a gravity-type dam, only because it is built with RCC?
- Should the technical specifications target the **process** or the product?

The RCC is a Construction Method which was established with the objective of simplifying the construction, and not to complicating it.

At times I have heard a stupid quote of the type: ***The Work of RCC should meet such ... and such ... Conditions because it is a Special Project***? ***Special- why***? Only because the author of this quote needs to justify himself to the Client?

The works of dams are already traditional and so are the RCC, only the METHODOLOGY of CONSTRUCTION has changed, the criteria of Concepts of the Projects has not changed (Stabilities and Durability) and the availability of materials is a feature of the region, and not an obligation of the Project and Process. But a condition to achieve the Properties (**PRODUCT**) based on the knowledge of these materials and properties.

1- PRESENTATION

The RCC is a Construction methodology designed with the objective of simplifying the construction of dams, and not to complicating it!

The amount of construction joints established by this methodology led to greater concern, when compared with the traditional concrete dams because it highlighted the doubtful percolation and adherence, which reduced the safety of stability in some of the first dams of RCC.

This situation made a large number of alternatives appear for the design of the system of watertightness and the treatment of the surface of the construction joints, in the most recent dams.

Faced with these two basic aspects the basic discussion is:

☺ Keeping the practicality of the methodology of the construction of mass dams, and ensure a system of watertightness and;
☺ Keeping the levels of the properties of traditional concretes and ensure a process that provides the building joints with properties not to undermine stability.

However, the technical specifications along the years, probably anxious to deal with emerging concerns, have focused on several points in the **process** not the **product**, given that the process is part of the responsibilities, activities of the Contractor, and the requirements of the product are part of the Design.

2- MATERIALS

It is prudent, convenient and even polite to Specify about a Project, trying to use the standards of that Country. Another procedure is to find out about the practice of each region, as well as stick to the availability of materials in the work environment and in the Country.

However, opposite to what is normally practiced in traditional dams, it has been observed that RCC Dams have been forced to establish a single dogma, sometimes unnecessary to the quality, simplicity and cost of a project.

The Concrete Faces Rock Fill Dam Design, although they have some critical conceptual points as recently published, seek to make the needs of materials compatible with their

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availability, therefore adapting the Project and the Specifications to the location.

However , in some technical Specifications of RCC, the following citations have been observed:

2.1- Cement

For a certain RCC dam in a certain country the Technical Specification established for the project stated that:

> *"... The Contractor should employ as a binder for the RCC, Portland cement produced in the country with the characteristics approved by Inspection ... ... In addition to what is Specified in this Chapter the cement shall have low hydration heat (maximum 70 cal/g at 7 days) and low alkali ratio (up 0.4%) and should be ... ... SiO2> 20%; C3A <8%...; Insoluble residue <0.75 %..."*

However, such Country was not able to comply with all requirements simultaneously. This country produced high-quality cement, with a high percentage of CaO (over 60%), which induces, when ground into desired Fineness, to produce rates of Hydrating Heat above what is required. Then, to inhibit that heat (and C_3A) there would be a need to include a certain percentage of Silica or Iron Oxides, which in turn (Silica) would lead to an increase in the Insoluble Residue, reaching about 2.8%, hence having to import iron ore to complete the correction.

Thus, what is the reason for specifying an RCC cement that does not exist in that country, when several concrete projects in dams have been built there?

2.2- Pozzolanic Material

In another project in another Country, the technical specification mentioned that:

> *"... The ash fly or natural pozzolan shall meet the requirements of Norm ASTM – C- 618, and the granulated cinder of the blast furnace with the Norm BS- 6699..."*

It so happens that in this Country there is no Pozzolanic Material that meets the indicated standards fully, in addition to the fact that if any of these products available could be used; there would be the need for intense grinding.
So, here too, what is the reason to specify for the RCC a Pozzolanic Material that does not exist in that country, only to justify the title of **High Paste Content**, given that several concrete projects for dams have been built there.

If the studies at had been carried out with the intention of inhibiting possible Alkalis Silica reaction, then it would have a good technical goal.

Another dam in another Country required:

> *"... The RCC for this project is a combination of fine and coarse aggregates, cement, fly ash, and chemical additives that will be mixed with water in order to have consistency ...*
>
> *... The Ash fly should be in accordance with ASTM C 618, in Class F. ..."*

The point here is that in the Country of this project, there is no Pozzolanic Material either that fully meets the specified standards, nor is there any fly ash. Also in this case, for the existing pozzolan to be used there would be the need for intense grinding.

2.3- Aggregates

Regarding aggregates, by analyzing the different Technical Specifications of RCC dams, in different locations, it can be seen that:

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Country	Dam	Approx. Volume of RCC (m3)	Technical Specification Requirements	Foreseen Stock of aggregate
A	1	> 1,000,000	*... The Builder should send to the Inspection, the analysis and the testing results of the proposed aggregates a year before starting the construction of the dam...* *.... Aggregates for the RCC will be obtained from exploring the reservoirs "A" and "B", studied by the Inspection. However any change in the characteristics of the aggregates ... Will not be cause for complaint.* *.... The Builder should have stored before starting the project, the equivalent of 5 to 10% of the aggregate needed for the construction of the dam"*	5 a 10 %
A	2	> 1,000,000	*The Builder should have stored before the start of the project the equivalent of 50% of the aggregate needed for the construction of the dam ...*	50 %
B	1	> 1,000,000	*The Builder should maintain at all time of the work a volume of aggregate equivalent to a month of production, on a concrete floor and the fine aggregate should be protected by a metallic structure ...*	15%
C	1	> 1,000,000	*... The placing of the RCC in the dam will be initiated only after having at least 40% of all aggregate for the RCC processed and stored ...*	40%

Note that, there is no conceptual uniformity for this requirement, but only a requirement for a certain quantity.

On the other hand, in general, it has been observed in traditional dam projects that the minimum stock desired should be dimensioned to meet the demand during the equipment maintenance and repair period, or a repair part that takes longer; around one week. In other words, depending on the location of the work remote, or close to a region and easy to access, there should be a stock regulator for one or two weeks.

Another particularity required:

> ".... The Inspection may demand from the Constructor continuing sprinkling to maintain uniform the moisture in the aggregates, reduce segregation and cause evaporation by cooling ..."

In a region with more than 80% relative humidity, such as the project exemplified, it is clear that the effect of cooling by evaporation will be virtually nil!

Another Specification can also be mentioned (mentioned in the table above):

> *"... The Builder should maintain a volume of… at all time... On a concrete floor and the fine aggregate should be protected by a metal structure…"*

Why is there a need for a concrete floor? It could be a floor protected with the same granular material, which has a draining element and protects the main material.

The requirement to cover the stock may be true for the coarse aggregates in regions of intense rains, however it does not need to be metal, it can be simply canvas.

3- PORTIONS AND PROPERTIES

Regarding the Portions and Properties required, the following can be mentioned:

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".... The portions must comply with the characteristics arising from the Structural and Thermal Design of the dam ... ... The Builder will be responsible for providing the material components of the mixture, with the characteristics defined in these specifications and the dosage with the proportions set by the inspection..."
".... The dosages may be altered by the Inspection within a range of indicated values, and based on particular studies...."

Here lies a question: **If any of the properties required are not met by the dosage required in the specifications, who will be held the responsibility?**

This question is necessary because:

☞ The **Contractor** provides the material;

☞ The **Inspection** performs the portions and adjustment in question;

☞ The **Contractor** produces, transports, place, compacts and cures the RCC.

In the event of non-compliance of some property, who will be responsible? Could it have been the fault of the material? The dosage? The Process? Is it not more practical that the Contractor be held responsible for the dosage, to meet the properties required, and Inspection in fact perform - the **INSPECTION**?

In some situations, specifications such as the following have been observed:

"... For the portions of mixing RCC, criteria based on the requirements of minimum density, permeability, consistency, were adopted, among others, and the requirements for static loads, thermal and seismic and required:

Water (kg/m^3)	*Cement (Kg/m^3)*	*Pozzolanic Material (kg/m^3)*	*Aggregates (Kg/m^3)*
130	*140*	*90*	*2140*

Moreover, the paste relation: Cement should be a minimum of 0.42..."

It is noteworthy to mention what [A] affirms:

"....Both RCC concrete and what is known as conventional concrete are porous, cohesive and dynamic materials and have all intrinsic concepts in common. In RCC concrete the geometric distribution of solids and the quantity of water and additives should be the correct ones for obtaining a minimum initial porosity after placement; the characteristic distribution of solids - fines - should be suitable in order to obtain the desired characteristics of the hardened material....

...A well-mixed concrete is one containing an amount of fine aggregate - cement + fly ash + inert fine aggregate - which, for a given granulometry, produces a minimum post-placement porosity - the function of filling - and has a distribution of fine aggregate - cement + fly ash + inert fine material - which provides the hardened concrete with the desired characteristics. Therefore, it is possible to have a concrete with high paste content and a little amount of cement and fly ash..."

According to [B] another manner is:

"...despite the fact that it been clarified for years, the terms "high paste" and "low paste" are still erroneously used to describe types of RCC. All good RCC has a paste content of about 19% to 21% by volume, regardless of the cement and pozzolan or fly ash content. Paste includes all material finer than 75 microns- cement, slag, pozzolan (fly ash), aggregate fines, admixtures, water, and air.

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A review of RCC mixes shows that essentially all good and efficient RCC mixes, and almost all RCC in dams, meet the 19% to 21% criteria. Mixes with less paste are harsh and tend to segregate, whereas mixes with excess paste tend to produce less strength per kilogram of cementitious material. Therefore, low cementitious content RCC requires aggregates fines in order to provide adequate paste without excessive water, and high cementitious content mixes require aggregates. Instead of using the term "paste", RCC mixes can be described as having high or low "cementitious contents". Both types of mixes have been very successful. Both are common. Both types of mixes have advantages and disadvantages. The RCC cost of high cementitious content mixes tends to be greater due to the cost of increased cementitious material and increased cooling or thermal considerations, but low cementitious content mixes may require special lift joint treatment or other effort to provide total watertightness . It is incorrect to state that either type of mix is "best" for all applications. Each project should be fully evaluated based on its own needs and conditions.

RCC can also be described as having high, low, or no pozzolan. Fly ash is the most common pozzolan, but manufactured and commercial natural pozzolans are also used. Slag is also effective where available. Because of the paste requirement, aggregate fines are an essential part of low cementitious content RCC…"

[D] has already mentioned that:

"…There are a number of methods that have been used for the design of the mixture proportions of an RCC. For a determined design, structural element, environment and placement, the composition of a concrete is defined in such a way that the evolution of its behavior conforms to what was asked of it.

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. There are many ways of reaching an objective, in this case the design of a RCC concrete

It is the authors' opinion that design features should take advantage of the economies of RCC construction, looking for simplicity, quality, and economical. A mix design process must assure the required property values, no segregation occurs by handling operations and performance requirements met using the proper materials…"

4- EQUIPMENT

With the requirement of the equipment a number of inconsistencies have been observed as the examples to follow.

Generally the more sensible specifications indicate that:

☞ **A situation where a deadline for commissioning the work is required**
- the Contractor should submit a construction program in order to meet the deadlines set, and;
- The Contractor should submit for approval by the inspection, the ability of each of the equipment, professional staff, in order to comply with the proposed construction program, considering local, weather, availability of materials, and environmental conditions.

☞ **A situation that does not require a deadline for commissioning the project.**
- The Contractor should submit for approval of the inspection, the construction program along with the ability of the equipment, staff of professionals, in order to comply with this construction program, considering

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local, weather, availability of materials, and environmental conditions.

However, for many RCC projects the following has been observed:

Project	Reference	Observation
α	*....The concrete Center should have an adequate number of continuous mixers, or equivalent (commercial reference), with double axles the continuous mixing type.*	a) Reference type; b) Commercial reference
β	*... The builder should provide, install, operate and maintain a center that is totally automatic to produce RCC. ... ... it should have an effective minimum capacity of X00m3/hr.*	Reference of a capacity without knowing the Builder's chronogram
δ	*... The Builder should carry the RCC immediately after it is produced, from the Mixture Center to the dam, using conveyor belts that control the segregation, contamination and moisture changes .... The belts must operate at high speeds (4 m/s)... .... Systems of conveyor belts will be of the type (commercial reference!) And should be designed by professionals with extensive experience in...*	a) Specification in the Process; b) Commercial reference commercial

From the point of view of the author the technical specifications must impose requirements on the product (properties, performance limitations) and not on the processes, which fit in duties, competencies and responsibilities of the Cntractor to meet the construction program and meet the specifications of the product.

5- CONSTRUCTION PROGRAM

As mentioned previously the Construction Program can be to meet a deadline established, or to require from the Contractor a programmatic and organizational activities preview, and that at times the freedom of the Contractor to establish the program, can be subject to a disbursement program.

There are however picturesque situations as the documents of a particular project cites:

> *"…. The deadline for the full implementation of the RCC dam, should be submitted by the Contractor and should be between 10 and 20 months ... ... The Contractor must demonstrate having the equipment, personnel and methodology required to meet the proposed deadline.."*

The work was contracted in 1995, but the RCC was only executed in 2001 and 2002! What was the use of stipulating the period of 10 to 20 months?

6- CONSTRUCTION METHODOLOGY AND CONSTRUCTION DETAILS

In this item, as well as the equipment requirement, is the concept that the Contractor must submit for approval of Inspection, the Performance Methodology, considering local, weather, availability of materials, and environmental conditions. However by reading the different specifications evidence that:

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Project	Reference	Observation
ω	*"...The Constructor can apply the process "Sloped Layer Method" for a maximum of Xm height...*	a) Influence to using a PROCCESS; b) Provides implications to thermal behavior, which may not have been foreseen
π	*".. when the surface layer of RCC is over 600º C the treatment should*	The concept of maturity does not include all environmental variables that affect the properties of the concrete setting
λ	*"....The Builder should conform the vertical joints of contraction as shown in the drawings. The Constructor can choose one of the following alternatives:* *I. Such joints should be conformed by forms;* *II. Such joints should be conformed inserting metallic sheets vertically..."*	What is the need for metallic sheets? Cannot it be plastic?
ξ	*"...the downstream and upstream faces should be rebuilt using the form and GE-RCC (**G**rout **E**nriched RCC)*	The PROCCESS and not the PRODCUT was specified!

It can be seen, by the citations, that there is a clear lack of knowledge regarding the behavior of RCC, concerning its characteristic of Setting.

At this point it is worth remembering, as mentioned earlier, that the quantity of Construction Joints established with the use of RCC led to greater concern, when compared with the traditional concrete constructions, it highlighted the doubtful percolation and adherence, which reduced the security to stability in some of the first RCC dams.

This situation has shown a large number of alternatives for the design of the system of tightness and the treatment of the joint surfaces of construction, in the most recent dams.

The information allows to state:

It shows that there is still no fully accepted methodology, and that concerns about watertightness remains. They are vital to the performance of the dam and need objectiveness and pragmatism to minimize the problems!

7- DESIGN

7.1- Concerns

Although the RCC is a Construction methodology, the project that designs or permits its use, can be optimized to facilitate the adoption of the process.

So it is since the precedence of using RCC in the Alpe Gera dam (Italy) constructed between 1961 and 1964 contained many features that have recurred later in RCC construction. Lean concrete was used for this dam, and it was laid in 700-mm thick layers from one side of the valley to the other, thereby avoiding construction in traditional monoliths. Contraction joints were cut through each layer after placing and compaction. The dam was made watertight by completely covering the upstream face with steel sheets.

Also, the publication [C] describes the "**optimum gravity dam**" as being of a cement-stabilized material, optimized with respect to dam slope and cement content. The optimized structure would be somewhere between the extremes of the high-volume fill dam containing no cement and the lesser-volume concrete gravity dam.

The number of joints between the relatively thin layers and the related quality control can have a large influence on the overall stability of the dam in terms of uplift water pressure, tensile and shear [cohesion] strength at the joints between the layers.

Faced with this the RCC dam Designers can use two main design approaches:

☺ The "global approach" which relies on the dam water-tightness through the quality and proper treatment of each lift joint;

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☺ The “individual approach” which relies on an independent impervious barrier, which is usually placed on the upstream face of the dam in a similar manner to the earth or rock fill dams.
Apart from these design approaches, which are related to the water barrier, various other approaches are encountered internationally. For example Japan is the principal exponent of the Rolled Concrete Dam (RCD) method, using a CVC cast against formwork as upstream face. Brazil has developed the "high-fines" RCC, with the same type of the upstream face as the Japanese RCD Dams.

7.2- Safety Details and Remedial Actions

It is prudent and appropriate that, always, the project considers the possibility of actions and how these can be made by corrections. That is, the Designs must embed within its details the safety aspects, but also the conditions and aspects of WHERE the Project is being constructed, considering level of training.

7.2.1-Facing Techniques

It may be necessary to provide a durable exposed surface. Cast-in-place CVC concrete or other facing systems may also provide increased watertightness for the upstream face as well as increased resistance to erosion and damage by freezing and thawing. The design for any water-retaining structure constructed using RCC, however, should not put primary reliance on an upstream facing system to protect against seepage. The design for providing watertightness of the structure should rely primarily on the RCC itself; on proper mixture proportions, lift surface treatments, and RCC placement, spreading, and compaction techniques. The CVC concrete used as face also provides a medium for installing contraction joints with waterstops and joint drains.

Conventional cast-in-place or precast air-entrained concrete facing elements of adequate thickness can be used to protect the RCC from damage due to freezing and thawing.

The permeability and watertightness of concrete may be of more concern than the strength, especially with respect to hydraulic structures. The factors affecting the permeability of RCC are essentially the same as those that affect the permeability of CVC concrete.

7.2.2-Seepage Control and Drainage

One of the most important design considerations for RCC dams is the control of seepage. Excessive seepage is undesirable from the aspect of structural stability, possible long-term adverse effects on durability, adverse appearance of water seepage on the downstream face, and the economic value associated with lost water. Properly proportioned, mixed, placed, and compacted RCC should make as watertight a structure as CVC concrete. In addition to strength requirements, hydraulic structures must be designed to minimize seepage, control uplift pressures and assure long-term durability. The joints between RCC lifts are the major pathways for potential seepage through an RCC dam. Seepage can be controlled by incorporating appropriate design and construction procedures (bedding mortar, contraction joints with waterstops, draining and collecting seepage water). Collection methods include vertical drains with waterstops at the upstream face and vertical drain holes drilled from within the gallery near the upstream and downstream face.

7.2.3-Galleries

For any major high-head (higher than 12-15m) dam a gallery is necessary to provide a location from which to drill drain or grout holes, to provide drainage for leakage, and to provide access for

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inspection. Several different gallery designs have been tried in RCC construction. Galleries in dams must be located to provide adequate space for RCC placing and compaction equipment in all areas adjacent to the gallery.

7.2.4-Thermal Control and Cracking

Temperature-control measures for RCC typically will be quite similar to those used for CVC. These measures include limiting heat evolution, using insulation, requiring night-time placement, and limiting placement to cool weather. The large RCC surface areas cannot be efficiently protected from high ambient air temperatures, drying winds and absorption of radiant solar energy, thus, experiencing greater early heat gain and more subsequent contraction and cracking. Precooling and/or postcooling techniques may not always be practical for RCC placements.

The extent of thermal cracking in an RCC structure will be affected by the type and degree of temperature control used. The selection of cement and fly ash proportions will significantly affect the heat of hydration and subsequent thermal cracking. To reduce temperature rise, low-heat-of-hydration cement, and the adequate pozzolan replacement of cement consistent with strength requirements, are generally used.

As in the case with most nonreinforced concrete structures, cracks do occur in RCC structures, and, if the structure involved is a dam or other water retention structure, leakage will also occur. Cracking may occur despite measures taken to prevent cracking. The possibility of unplanned cracking should be anticipated in design by providing for drainage conduits and sumps where necessary to remove water from the structure.

7.2.5-Contraction Joints

Placing vertical transverse contraction joints in dams constructed with RCC and installing waterstops in these joints near the upstream face should be considered for crack control. The number and placement of these formed construction joints can be determined by a thermal study, construction considerations, and by examination of the foundation profile parallel to the dam axis. Joints should be considered where changes occur in the foundation profile (or where the different RCC construction steps can induce different modulus of elasticity, due to different ages) which may cause a concentration of stresses.

If transverse contraction joints are used, standard or new developed waterstops should be installed in an internal zone of CVC at the joint near the upstream face. When RCC is specified designers must carefully consider construction details for such features to minimize their impact on RCC placement and to assure they will perform as intended.

7.3- Main Properties

7.3.1- Mechanical Properties

RCC structures are generally unreinforced and must rely on the concrete strength to resist compression, shear and tension of applied loads as well as internal stresses caused by non-uniform temperatures (gradients). The compressive strength of concrete is high enough, and seldom a limiting factor in structural design. Unreinforced RCC, as is the case with unreinforced CVC concrete, has limited capacity to resist shear and tensile stresses. Therefore, RCC structures are generally designed so that tensile stresses do not develop under normal operating conditions during the life of the structure.

The RCC construction process results in horizontal lift joints intervals. The strength at

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untreated lift joint surfaces is generally lower than that of the parent concrete. Therefore, mixture designs, placement procedures and quality control measures to assure maximum bond and strength at the lift joint surfaces are important. Test data from constructed projects indicate that RCC joint strengths are sensitive to:

I. The time interval between the placement of successive lifts;
II. The water and cementitious material content (cement plus pozzolanic material);
III. The joint surface condition and treatment used.

In general, the application of joint treatment (bedding mortar) and rapid placement of successive lifts will produce higher joint strengths. The design values for joint cohesion and tensile strength must be based on a laboratory test program.

7.3.2-Elastic Properties (Modulus and Creep)

Cracking in RCC structures is normally considered to be caused by thermal behavior, but sometimes they can be induced by creep deformation. Construction speed or deflection in the foundation plan or even RCC steps, can induce differential deformations (settlement) that can cause shear effects, and consequently cracking. This phenomenon is sometimes observed in CVC construction, but is normally controlled by using adequate reinforcement. In RCC construction this phenomenon must be considered in design. The adoption of a transverse contraction joint can be useful.

8- DESIGN – SPECIFICATION - CONSTRUCTION PROGRAM

If the RCC was developed to simplify the concrete constructions;

☺ What are the reasons to apply a temperature control, even thought for a thin layer thickness?
☺ Is it not better to request for a maximum temperature in the dam body?
☺ And so on, the Contractor develops its Construction Work Program with basis on the layer thickness, placement interval (construction speed), ambient, placement and maximum temperatures of the dam, and cementitious content?

8.1- Test Aspects

There is a need to establish concepts about:

- Validity and representativeness of the consistency test of VeBe (with or without weight) and its respective content of water and mortar, and the inter-relationship with the real consistency necessary regarding placement;
- The need to know, more in-detail and in-depth, aspects of Initial and Final Setting Time, in such a way to better evaluate and optimize the treatment of the surface of the construction joints;
- The determination of the Cement content is still a need associated with the control of continuous mixers, but the trend for using forced mixer with dual axis, coupled to intermittent dosing machines, will obviously reduce its determination.

8.2- Inspection Aspects

It is necessary to adapt the “modus operandi” of the Quality System, considering the Activity Dynamics and inspection procedures to the speed of the Production.

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8.3- Uniformity

The uniformity of RCC materials along the depth of the layers, have been a reason for assessments and adaptations of control procedures.

8.4- Monitoring

Generally the instrumentation for RCC dams, as well as the CVC dams have provided little technical assistance.

The temperature instrumental, has demonstrated practically with a small margin of difference or dispersion, the conditions provided in studies and projects.

The other instruments, such as jointmeters, tensometers and extensometers, have not yet provided benefits that can subsidize the designs, or by inadequate installation time, or by the discontinuity of the teams responsible for the installation, reading and interpretation, but also by the little credit given to listening.

This is a technical-professional situation that must be revised. There is the need to redeem the benefits and safety for using instrumentation.

8.5- Performance

The performance of RCC dams have been satisfactory, with failures credited more to:

- Lack of knowledge and/or lack of attention or awareness in the handling and/or understanding of the properties of both RCC and CCV;
- Stubbornness and not paying attention to systems traditionally adopted in designs;
- Vanities in trying to establish practices without the suitability of the properties inherent to the operation or parts of it
- Lack of care and attention in the performance, and
- Of course, the most important- **HUMAN FAILURE**!

In general many of the cracks seen in RCC dams have been attributed to temperature, but it should be noted that other characteristics can lead to the cracking of concrete.

Figure 01- Cracks in the Upper Stillwater dam, resulting from thermal generation

Also, many of the failures (as honeycombs, seepage) occurring in RCC dam, come from deficiencies in the implementation of the CCV, used as part of watertightness. This is a paradoxical situation, as it should be a more consistent practice.

9- OTHER USES

In Brazil RCC has been used for other applications, as previously declared, for:

9.1- Embankment Protection

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Figure 02- RCC Protection in the Porto Primavera Dam.

9.2- Protection for Overtopping

The previously mentioned solution, and adopted in Xingó Dam, for the part of the rock fill dam, as shown below.

Figure 03- Protection at the region downstream of the of Xingó CFR Dam.

9.3- Backfilling

Application already mentioned in other conferences.

9.4- Pavements

Progress has been observed in the RCC methodology application of pavement projects.

Figure 04- RCC applied in Port Terminal.

10- FUTURE- NEXT STEPS

Development, knowledge, and costs show that the methodology of RCC is consolidated, but there are opportunities for improvements, enhancements and greater command.

The studies, and revisions, regarding the possibility of employing soil-cement, preferably with a sandy matrix, must be analyzed.

The extent of the Brazilian territory, as an example, impedes single solutions becoming a doctrine. The need to seek cheaper solutions and more regional, are incentives that professionals should use in the search for new solutions, or at least adapted to the realities of each country

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Figure 05- Soil Cement used as embankment protection in dams in the United States- Resistance greater than 17 MPa

Figure 06- Aspect of the Soil-Cement used as embankment protection in the United States.

11- SISTEMATICAL CONTROL AND INSPECTION

11.1- 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. 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. Manual skills, technical knowledge, motivation, and pride of workmanship -all contribute to good workmanship, which is the real key to quality concrete construction. Workers in concrete jobs may have been exposed to some technical training but seldom adequately. Many workers have pride in their work and do make an attempt to attain satisfactory quality. However, the need to stay within cost limits often requires an emphasis on production rate. Credibility, statistical knowledge, records routines are very effective and efficient where properly applied.

11.2- Quality Plan

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Materials and RCC – Safety Uses! *But Design and Specification, also!*

***Andriolo**, Francisco Rodrigues*

An overall Quality Plan or System for a construction can describe in general terms the objectives and actions 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 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.

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.

Procedures need 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 be monitored and reported.

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. The Overall Quality Plan must be adjusted to local conditions taking into account the workman labor performance, equipment and technical knowledge. .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

All data and information relative to the Quality Control System must be collected in a standardized routine and accurate manner. RCC placing rates can be extremely high when compared to conventional concrete. With such rapid placement rates or short term construction periods, problems must be evaluated and solutions implemented in a short period of time. Any problems, which delay RCC placing essentially, delays all production. The most common placement delays are usually due to problems caused by:

- ☺ Insufficient materials
- ☺ Foundation preparation and cleanup
- ☺ Joint cleanup
- ☺ Equipment breakdown
- ☺ Weather condition (hot or cold ; wet or dry; rain)

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. Based on what was described above, it can be suggested that before the works start a “Quality Control Plan” and a “Manual for Quality Control”, as used for Concrete Quality Control during Itaipu Project construction, can be adopted. This "Manual" proposes measures which include the following basic points:

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- 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);

For an overall view of the scheme that can be adopted with the following points:

Action A - Pre-qualification and knowledge -This corresponds to the stage of initial studies, knowledge and selection of materials and suppliers.
Action B – Information on handling.
Action C - 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 will be performed by each supplier.
Action D - Control during production - This action is to evaluate the points or procedures that could be vulnerable during production.
Action E - Control of application- This point consists of disciplinary actions during production.
Action F - Inspection during execution- This action will have the function of evaluating the best procedures for executing the works.
Action G - Structure commissioning- This 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. 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.

Logistic conditions for construction of the development were also considered such as, procurement 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.

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.

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. 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.

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 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 assurance and are not an effective method of day-to-day quality control.

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Emphasis on thorough control of materials (gradation, cementitious content, and moisture content) and conditions during placement is essential to proper RCC. An advantage of RCC and the above approach is that unacceptable material is identified early and can be removed at relatively low cost

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.

Figure 07-Sampler used at CVC and RCC Continuous Plant

Variability tests can be used to establish minimum mixture retention times and the effectiveness of the mixer feed procedure for both batch and continuous type mixers. They also are used to determine the more important issue of how well and uniformly the RCC is mixed at the placement after it has been delivered and spread.

11.3- Quality Control During the RCC Production

To check homogeneity of cement proportioning or mixers efficiency, daily tests were made with reconstitution of cement contents in the RCC fresh mix. This correlation was called test calibration standard.

Once concrete proportions and cement content have been selected for the strength required and are being batched uniformly from the same aggregate, the consistency of the RCC is the primary item for inspection and control. A variable consistency is likely to add to variation in concrete strength. Excessive consistency usually decreases strength through increase water-cement ratio or stratification. RCC of insufficient consistency is likely to lead to poor compaction.

11.3.1- Batch Type Plant

Modern batch-type mixers are relatively uncomplicated to calibrate and operate. The primary concerns with RCC are matching aggregate feed rates and storage capacities to high production rates, finding the best batching sequence for each mixture, and getting all materials uniformly blended with a reasonable mix time. The combined charging, mixing, discharge, and return time determines the maximum production rate. Mixture proportions are input from manual or computer controls and are typically recorded by load cells.

11.3.2-Continuous Mixing Plant

Continuous mix plants ate relatively easy to calibrate and operate. Mixture proportions are

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converted to a continuous feed rate in tons/hr (kg/hr). Materials used for calibration tests are accumulated over a fixed period of time rather than being measured individually for a separate batch. As with batch type plants, materials may be individually fed into mixer from separate bins or they may be accumulated on a common final feed belt. This is determined by whether the mixer has, for example, one belt for all aggregate bins or multiple belts with one for each bin. Calibration with just one belt operating may not be the same as when the plant is in full operation with all feed belts operating. Load cells or weigh-bridges to provide weight controls rather than volumetric control, and computer print-outs have been used on some RCC projects but have not been necessary on other projects. Also, as with batch type plants, the mixer should be calibrated at the minimum, average, and maximum production rates expected.

11.3.3- Workability

Sufficient workability is necessary to achieve compaction or consolidation of the mixture. Workability is most affected by the paste portion of the mixture including cement, pozzolan, aggregate fines, water, and air. When there is sufficient paste to fill aggregate voids workability of RCC mixtures is normally measured on a vibratory table with a VeBe apparatus in accordance with ASTM C 1170. This test produces a VeBe time for the specific mixture, and is used in a similar way as the slump test for conventional concrete. RCC mixtures with the degree of workability necessary for ease of compaction and production of uniform density from top to bottom of the lift, for bonding with previously placed lifts, and for support of compaction equipment, generally have a VeBe time of 10 to 45 sec. However, RCC mixtures have been proportioned with a wide range of workability levels. Some RCC mixtures have contained such low paste volume that workability could not be measured by the Vebe apparatus. This is particularly true of those mixtures proportioned with a very low cementitious materials content. Workability of these type of mixtures need to be judged by observations during placement and compaction, together with compacted density and moisture content measurements. The water demand for a specific level of workability will be influenced by the size, shape, texture and gradation of aggregates and the volume and nature of cementitious and fine materials.

The VeBe apparatus used to measure the consistency of no-slump CVC concrete is used to measure the consistency of wetter RCC mixtures. It provides an indication of the workability or ease of consolidating the concrete in place. When it is used for the wetter types of RCC mixtures, typical VeBe times are 10 to 30 seconds.

To check the influence that not applying the overload would have to the test results, the same sample of RCC was tested indicating a smaller dispersion in tests made with overload. Technique achieved with the Capanda RCC Dam did "**NOT**" produce evidence of absolute applicability of this method, probably due to the low plasticity of the RCC, because of the cement content adopted and also the different cohesiveness of fine aggregates content. It was shown that extreme remolding-consistency time values do not always correspond to RCC with deficient compaction.

The moisture or water content is important for several reasons:

- ❑ to determine the W/C or W/(C+PM) ratio on projects that may use it in design or design specification requirement;
- ❑ to assure the optimum or desired moisture content for workability and compaction, and
- ❑ as one of the indicators of mixture variability.

Some moisture test methods are:

(a) Chemical tests (ASTM C-1079)
(b) Drying tests (hot-plate, oven, microwave)
(c) DMA- Brazilian

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(d) Nuclear tests- mostly useful for compaction control during the RCC placement

Pacelli and al developed a very simple and rapid method of test to determine the water content and unit weight of RCC. Aiming to establish an alternative to usual methods, a procedure for controlling the unit water of RCC and the unit weight of fresh concrete has been developed. Such method, known as " Water Measurer Device - WMD (DMA in Portuguese), allows the prompt control of unit water during the RCC fabrication.

This method has been conceived based on a physical principle, the density of materials compounding concrete. Water being a material with lower density, the more water in a RCC mix, the lower the density.

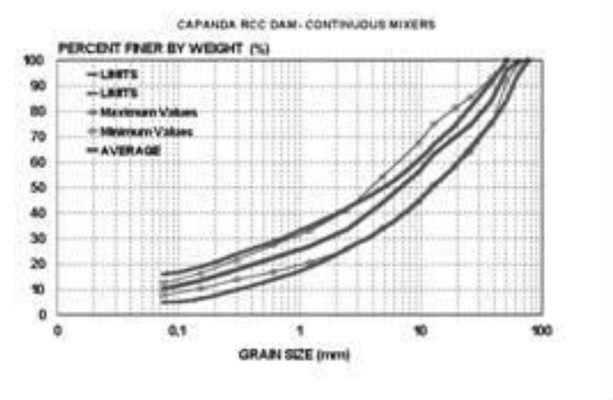
11.3.4 – Grain Size Curve Reconstitution of RCC Mix

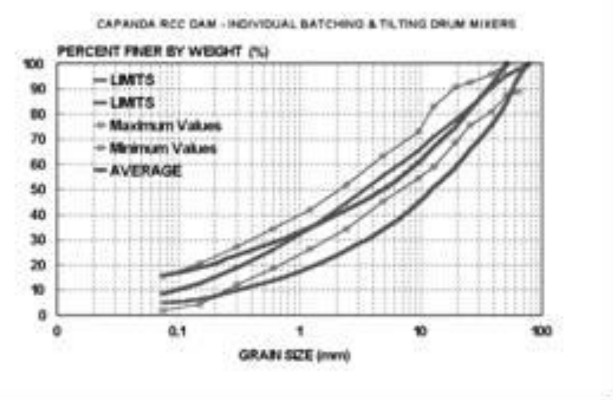
The RCC mixes used in Brazilian RCC Dams, were proportioned with aggregates having specific gravity of about 2,65-2,95 t/m3, combined so as to obtain the smaller void index. To achieve this, a reference grain size curve was initially adopted for aggregates as follows:

$$P = (d/D_{max})^{1/3} \times 100\% \quad \text{where}$$

P = Percent Passing;
d = size of the sieve (mm)
D_{max} = MSA (mm)

Figures shows grain size range specified for the RCC, together with the ranges effectively obtained and their dispersions, in batch and continuous mixing plants. The grain size range specified was determined by the equation mentioned before, with small adjustments for fractions less than 0.3 mm.





Figures 08 - Granulometric curves for RCC Mixes from reconstitution tests.
Note the proximity of average values compared with theoretical value used

The use of batching proportioning instead of continuous type allows for elimination of this type of control.

11.3.5- Molding of RCC Cylindrical Test Specimens and Compressive Strength

RCC test cylinders (150mm by 300mm) can be made using procedures suited to the consistency of the mixture, the maximum size aggregate (MSA), and the number of samples to be made before the mixture begins to dry out. Test specimens should be compacted in rigid molds or in removable liners supported during compaction by rigid molds. Wetter consistency

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mixtures with a VeBe time less than about 30 seconds are well suited to consolidation. The RCC is consolidated in three or four layers. Other surcharges and modifications have also been used.

The importance of performing concrete strength tests carefully and precisely cannot be overemphasized. In most acceptance confrontations the indicated strength of the concrete is the deciding factor. Usually other questions can be worked out if strength tests are good. If they are not, there is a real problem. So it is important that the tests results are not low due to carelessness and incompetence in sampling, molding, curing, and testing. Aside from dishonesty, there is little that can be done to make a test cylinder stronger than the potential of the original concrete. But there are many things that can reduce its strength. Well trained and supervised people should do this work with care to see primarily that the sample is truly representative and that the cylinder specimens are evenly filled and fully consolidated without voids or rock clusters in any portion; that they are kept wet with visible moisture on the surface at all times and in moderate room temperatures until testing; that capping for testing should be strong, thin, precisely flat, and especially not convex. This need for perfect planes applies also to the two loading surfaces of the testing machine. Convexity or other irregularity of end surfaces has seriously reduced test values and caused needless trouble and concern on too many occasions.

11.4- Quality Control During RCC Handling

The system of handling and transporting the RCC, in Brazil, is based on the use of dumper trucks with carrying capacity, predominantly, of about 20t. But that should be reviewed and considered with the costs of Labor and workmanship and equipment availability. There has been a growing use of vertical transportation through tube-shafts, as in Capanda, Platnovryssi, Jiangya and others. This system is known in the Brazilian technology of Mass concrete since 1973. What is important is that the Quality System minimizes the Segregation and flow continuity to placement.

11.5- Quality Control During the RCC Placement

RCC methodology has established the convenience of adopting additional controls on site during placement and compaction phases.

Appearance tells much of how well the work was done, but by no means all. And if it is not what it should have been, it is too late to do much about it. Unlike the neatly tabulated results of strength tests in proof of the quality attained, the often hidden good results of construction inspection are not readily documented even though daily shift reports are required. Accordingly, construction inspection will encourage quality by seeing and approving or disapproving, step by step, while action can still be taken if necessary for corrections.

The inspector on the placement operations should watch all details that are related to the overall success of RCC placement operations. The following list indicates some of the items to be checked:

(a) Lift surfaces have been adequately cleaned prior to placement of bedding mortars or RCC;
(b) Bedding mortar (if used) is placed at the required thickness and correct consistency and is adequately spread;
(c) RCC is deposited, spread, and compacted only on fresh bedding mortar (if used) that has not begun to dry or set;
(d) RCC is deposited on lift surfaces in the proper location and spread in the required layer thickness, and the action of the dozers is controlled in a manner to eliminate voids and ensure proper compaction;

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(e) RCC as it is deposited and spread is of the required workability as determined by the VeBe tests and by observing spreading and compaction operations;
(f) Compaction of the RCC occurs while RCC is still fresh and has not begun to lose workability;
(g) Lift surfaces are maintained in a moist state at all times;
(h) Internal vibration at interfaces between RCC and CVC concrete is in the right location and done correctly with immersion vibrators in the right number and adequate size and for sufficient duration;
(i) CVC concrete is deposited and consolidated in those areas where it is required such as around waterstops and drains, against abutments, and other locations as shown on the plans;
(j) Installation of contraction joints, if required, is completed prior to compaction by rollers and before RCC has begun to lose workability;
(k) The passes in a specified translation speed for the vibratory roller on each lift of RCC are obtained.
(l) All testing, including VeBe tests, nuclear density tests, aggregate moisture, and grading tests are taken, monitored, and evaluated.

The importance of identifying the setting times on the RCC which has just been compacted and stills fresh, is based on assuring an adequate adherence between layers. The horizontal joints between layers, where the bond is required, becomes from the impermeability point of view, one of the most vulnerable parts of the dam. The correct identification of the setting times, for different atmospheric conditions, allows to establish the limits in time, for which a superficial treatment on the joint should or should not be done, or the use of mortars of bond, in order to guarantee the level of adherence of design between layers.

For the RCC that has been compacted in situ forming a layer ***(n)***, previous studies have identified the initial time of setting the limit[i] up to when is possible to extend and compact a new layer ***(n+1)***, obtaining an appropriate adherence in the joint, without any superficial treatment on the base layer ***(n).***

This modality, where a treatment between the joint of two subsequent layers is not needed (n, n+1) it has been named as *hot joint*. This system which is very economical in comparison to the alternative of surface preparation or use of mortar of bond, is the one who permits to reach high placing rates.

11.6- Setting Time

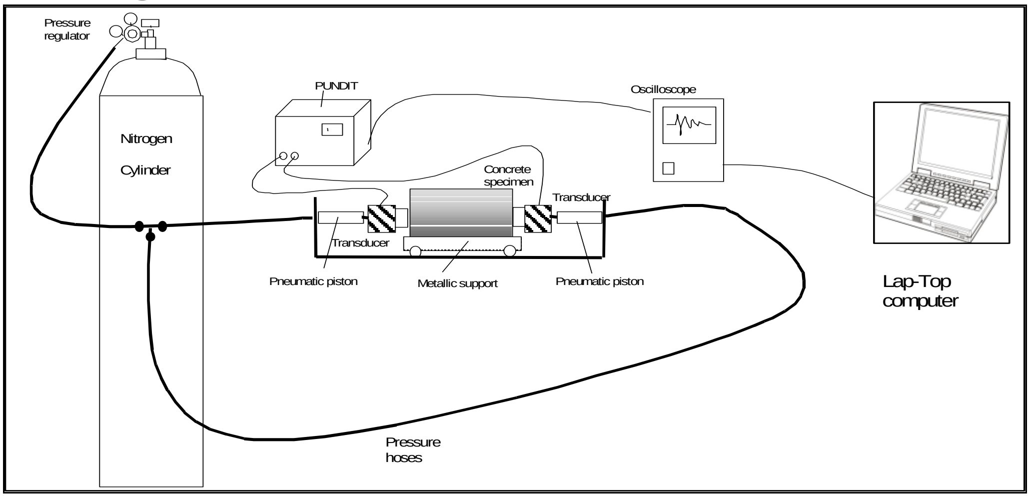

Figure 09- Schematic view of the Setting Time Test Aaratus

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The study of RCC on the fresh stage with ultrasonic energy permitted to identify the time of settings of the material under different atmospheric conditions. The evolution of the values of ultrasonic energy showed the effect of the use of different doses of a plasticizing-retarding admixture on the times of RCC setting. According to this the appropriate dose should be selected according to the construction needs.

11.7- Compacting Control - Density and Compaction Ratio

Most vibrating rollers have multiple frequency, amplitude settings and travelling speed. Frequency and amplitude may be displayed on the roller or indicated by “compaction meters” installed in the equipment. Normally, the vibration is interlocked with the motor drive and cannot be checked without the roller moving. Portable tachometers can be placed on the lift surface to test the equipment as it passes by. Amplitude is not easily tested in the field. This is usually a factory calibration test. If there is reason to believe the equipment is not working properly, the equipment manufacturer should be consulted

Compaction is affected by the roller travelling speed. This condition must be considered during the RCC layer compaction and the speed should be recorded.

Low densities are the result of various deficiencies including high or low moisture, incomplete rolling, incorrect vibratory amplitude or frequency or speed time delay before rolling, poor gradation or segregation, and non-representative testing.

The in-place density of RCC layers can be determined using various procedures. It is however advisable that the procedure used enables not only determination of the compaction value but possibly a supplementary or corrective action of the compacting operation based on the results obtained. Therefore, process swiftness and safety are fundamentally important.

For the RCC used in Salto Caxias Dam, the minimum required compressive strength was (f’ck) of 8 MPa, at age of 180 days, with a deficient fractionof 20% (reduced normal variable "t"= 0,84).

The Figures show coefficients of variation obtained in the control of RCC for Capanda, Salto Caxias, Jordão and Val de Serra, compared with the same parameters for other projects, as well as with same control parameters for CVC mass concrete with cementitious content (cement+pozzolanic material) between 84kg/m3 and 134kg/m3, used in projects for Ilha Solteira Dam, Tucurui Dam and Itaipu Dam. Parameters of these conventional concretes refer to a universe of approximately 25,000 samples representing about 8,800,000 m^3. The Figures also show comparison values for coefficients of variation, for compressive strength for CVC concrete mainly used in those Projects.

Quality performance of concrete plants, concrete and operators control may be evaluated by the dispersion in the results for compressive strength obtained from the concrete produced by them. In the same way, quality of the strength tests may be evaluated from its own internal dispersion from control. Internal dispersion of the test is evaluated from the difference between the individual values obtained for strength tests in specimens of the same series, broken at the same age

12- SUMMARY AND RECOMMENDATIONS

The following recommendations can be summarized:

Inspection is not an end in itself, but rather a part or

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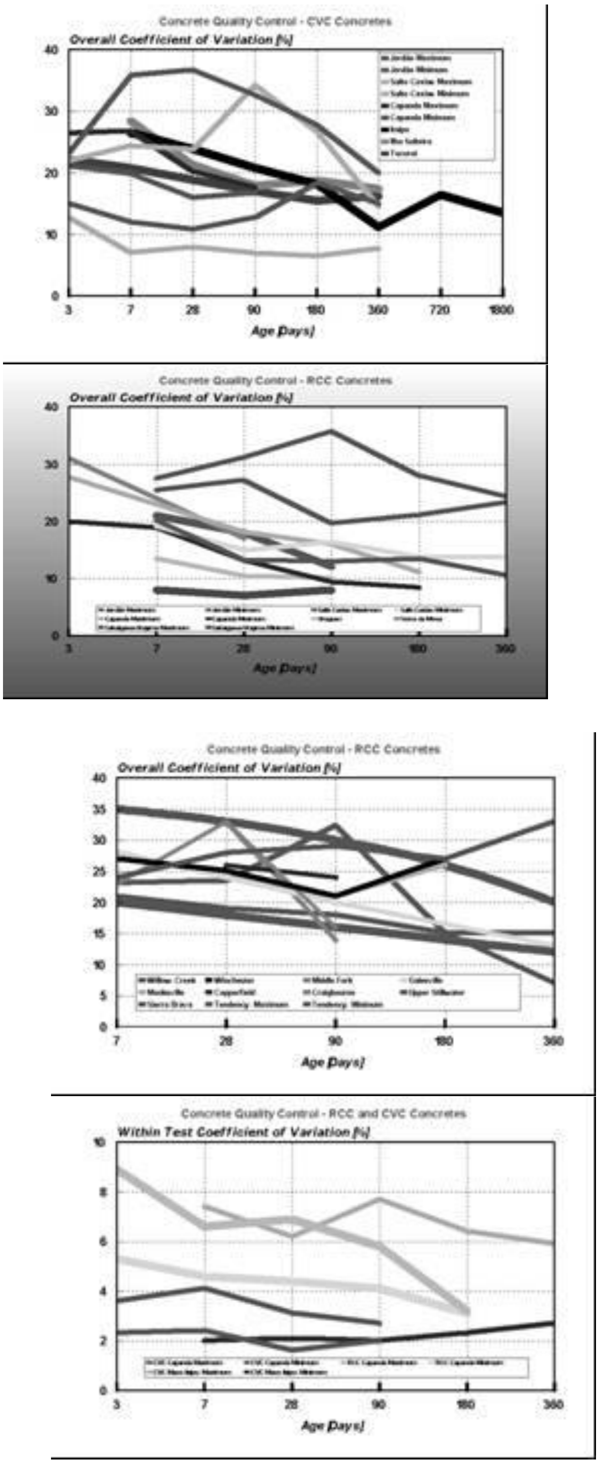

Figures 10- Data on Coefficients of Variation obtained in RCC control compared with values of Coefficients of Variation for Compressive Strength of CVC Mass concrete

and RCC in other Projects.

I. subsystem of an overall Quality Assurance system;
II. The overall Quality Assurance system starts with essential and key social parameters that have to be considered and met;
III. The engineer should be involved in order to be able to provide his input and influence the overall decisions;
IV. When the engineer is responsible for the design, he determines what is needed in the drawings and specifications in order to provide the owner with the structure or plant that will perform the service needed at a minimum cost and consistent with the quality required;
V. Quality is more than quality of materials. It should be thought of as the quality of the finished project judged by how well it serves society: physically, functionally, emotionally, environmentally, and economically;
VI. Specifications should be in tune with nature and designed to provide clear requirements that can be met by reasonable men trying to do the work;
VII. Inspection starts during the construction phase or subsystem. There are three basic approaches to conducting the construction operations:

- ❑ Conventional construction where the owner is represented by the engineer and a contractor does the work - still the best approach in most situations;
- ❑ Turnkey type of construction, most useful in very complicated and highly technical and specialized facilities;
- ❑ Construction-manager approach in which the owner delegates the managing of the construction phase to a construction manager, who may differ from the design organization, with a contractor doing the actual work - lack of continuity;

VIII. Quality Control by the various producers or contractor requires inspection as well as inspection for acceptance by whoever represents the owner;
IX. Inspection is, therefore, a key element in the construction phase;

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X. Inspection is seeing that good construction in accordance with the plans and specifications is accomplished;

XI. The inspector has to be technically knowledgeable in the field of inspection he is charged with;

XII. All these qualities are expected and proper training and aatitudes are requirements and have to be adequately paid for. It is time that proper training be required and commensurate pay be allowed for this work. Maybe a practical school with a degree in inspection can find a place in our educational systems;

XIII. Communication is the most essential element in inspection. Pre-construction conferences and regular meetings during construction between all parties are essential to get the work done properly and efficiently, to eliminate adversary relationships, and to maintain a team effort;

XIV. The inspector should be proud of his work and be a full-fledged member of the engineering team.

13- BIBLIOGRAPHY RECCOMENDED BY THE AUTHOR

[A]- Joaquín Díez Cascón Sagrado- **"*General Report*"**- Roller Compacted Concrete Dams- International Symposium- Santander- Spain- October 1995;

[B]- Ernest Schrader- **"*Experiences and Lessons Learned in 30 Years of Design, Testing, Construction & Performance of RCC Dams*"**- International Conference on RCC Dam Construction in Middle East- Irbid – Jordan- April 2002;

[C]- Jerome M. Raphael**-"*The Optimum Gravity Dam, Construction Method for Gravity Dams*"-** Rapid construction of concrete dams- ASCE- New York- 1970

[D]- ANDRIOLO, F.R.- Book-" ***The Use of Roller Compacted Concrete***"- Oficina de Textos Editor- Sao Paulo-Brazil-1998

[1]- ACI- 207.5R- Roller-Compacted Mass Concrete;

[2]- ACI 230.1R- State-of-the-Art Report on Soil Cement;

[3]- ACI 309.5R- Compaction of Roller-Compacted Concrete;

[4]- ACI 325.10R-Report on Roller-Compacted Concrete Pavements

[5]- ASTM Method of Tests

[6]- BERNARD BOUYGUE; ANDRE P. LANGOIS; JEAN PIERRE MARTIN- **"*Quality of Works in RCC in France- A Contractor's Solution*"**- Roller Compacted Concrete II- Proceedings of the Conference Sponsored by the Constructon, Geotechnical Engineering and Materials Engineering Divisons of the ASCE- San Diego, California- USA- February/March- 1988;

[7]- BERNARD BOUYGE- ***"Fifteen Years of Experience in RCC Dam Construction"***- Proceedings of the 2002 International Conference on Roller Compacted Concrete Dam Construction in Middle East- Irbid- Jordan- 2002;

[8]- BRIAN A. FORBES- ***"RCC in Australia"***- Roller Compacted Concrete II- Proceedings of the Conference Sponsored by the Constructon, Geotechnical Engineering and Materials Engineering Divisons of the ASCE- San Diego, California- USA- February/March- 1988;

[9]- M. TAVARES; M.T. SCHMIDT; F.D. RESENDE; P.A.F. FONTOURA; F.R.ANDRIOLO- "***Capanda- Angola- Hydroelectric Development- Quality Control of Materials and Conventional and Roller Compacted Concretes***"- Proceedings of the I Symposium on Roller Compacted Concrete Dams- Santander-Spain- October- 1995

[10]- ANDRIOLO, F. R. ; WALTON PACELLI A. – ***"RCC Mix Proportioning : High Paste, RCD, Lean or Adequate Fines Content"***- Proceedings of the II International Symposium on Roller

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Compacted Concrete Dam- Chengdu- China- April-1999;
[11]- ANDRIOLO, F. R.- "***RCC Dams – Discussions Related to- Design, Construction Planing and Quality Control Interfaces***"- Proceedings of the II International Symposium on Roller Compacted Concrete Dam- Chengdu- China- April-1999;
[12]- ANDRIOLO, F.R.; OLIVEIRA, L.F.P.; MOSER, D.E.; MUSSI, J.M.P.-"***Salto Caxias RCC Dam- Materials and RCC Quality Control***"- Proceedings of the II International Symposium on Roller Compacted Concrete Dam- Chengdu- China- April-1999;
[13]- ANDRIOLO, F.R- "***Materials Availability- Properties and Practices in Different Regions***"- Proceedings of the 2002 International Conference on Roller Compacted Concrete Dam Construction in Middle East- Irbid- Jordan- 2002;
[14]- ANDRIOLO, F.R.; HERMIDA, G.; SANCHEZ, J.; ARFELLI, E.- "***Ultrasonic Energy, an effective method to determine the setting times on RCC and the maximun time to obtain a hot joint. Miel-I dam- (Colombia)***"- Proceedings of the 2002 International Conference on Roller Compacted Concrete Dam Construction in Middle East- Irbid- Jordan- 2002;
[15]- MARULANDA, A.; CASTRO, A.; RUBIANO, N.-"***Construction Issues of Miel I Dam — The World's Tallest RCC Dam***" Proceedings of the Dams— Innovations for Sustainable Water Resources- 22nd Annual USSD Conference - San Diego, California, June 2002
[16]- ANDRIOLO, F.R ; MOREIRA, J.; ARFELLI, E.; PERES, M.- "***Miel I in Colombia — The Highest RCC Dam in the World: Some Practices Adopted to Improve the Constructibility, Quality and Safety***"- *Proceedings of the* Dams— Innovations for Sustainable Water Resources- 22nd Annual USSD Conference - San Diego, California, June 2002;
[17]- BERNARD BOUYGE, BRIAN A FORBES- "***A High RCC Dam with Low Grade Aggregates***"- Proceedings of the Fifth International Symposium on Roller Compacted Concrete (RCC) Dams- Guiyang, China - November 2007,

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