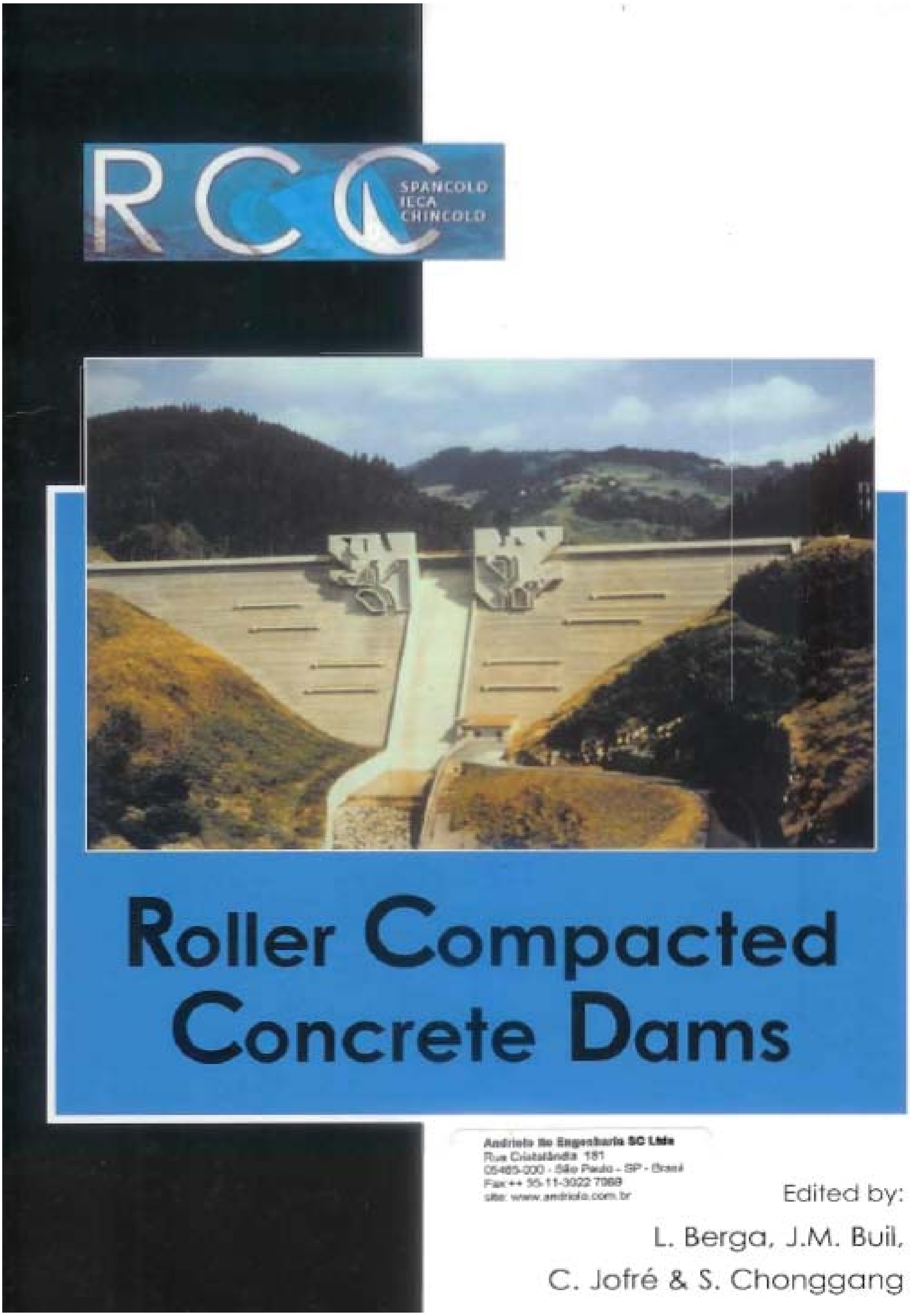

Review of Some Points in the RCC Practice for Dam Constructions

Review of Some Points in the RCC Practice for Dam Constructions

Andriolo, Francisco Rodrigues
ANDRIOLO ITO ENGENHARIA SC LTDA-
Rua Cristalândia 181- Alto de Pinheiros
05465-000 -São Paulo- Brazil
www.andriolo.com.br; fandrio@attglobal.net

ABSTRACT: Is it necessary to specify a cement or pozzolanic material that is not available in a Country or Region, just with the objective of applying CCR? Is it necessary to establish conditioning items for application of the methodology and not for the Product, due to the fact it is RCC? Is it necessary to require a typology of form or insertion of material in the contraction joint of a gravity type dam, just for the reason that it is built with RCC? RCC is a Construction Methodology that was established with the objective of simplifying the construction and not to complicate it. The Technical Specifications must aim at the Process or the Product? Questions of this kind are approached and discussed along the text, where a reflection on Construction Methodology is made, considering the period of more than two decades of RCC use.

1- PRESENTATION

RCC is a Construction Methodology conceived with the objective of simplifying dam construction and not to complicate it!

As usually known and understood, the term **R**oller **C**ompacted **C**oncrete (RCC) conceives a construction methodology that combines economicity, speed and the construction process of embankments (of earth and rock), through construction in layers, with the concrete properties, to obtain an economic and durable structure. As mentioned in several literatures and references, RCC properties are similar to those of the **C**onventionally **V**ibrated **C**oncrete (CVC).

The amount of construction joints established by that methodology induced to a major concern when compared to the traditional concrete constructions, it evidenced percolation and doubtful adherence, which reduced safety in terms of stability in some of the first RCC dams.

This situation gave rise to a great number of alternatives for the conception of the watertightness system and of the treatment of the construction joints surface, in the most recent dams.

In face of that, two basic points arise for discussion:

2. To keep the practicality of the construction methodology for dam bodies and guarantee a system of watertightness, and;
3. To keep the levels of properties of traditional concrete and guarantee a process that provides construction joints with properties not to harm stability.

The technical specifications, however, along the years and probably eager to cover for the arising concerns, have focused the ***Process*** and not the ***Product***, in several points. It is a matter of fact, though, that the process is comprised in the responsibilities-activities of the **Contractor**, and the requisites of the product in the **Design**.

These points are approached in the several following items.

2- MATERIALS

It is prudent, convenient and even gentleman-like to specify about a work, viewing earnestly to abide by the Norms in practice in the Country. Another procedure is to try and learn about each region's practice, as well as hold to the availability of materials in the surroundings of the work and in the Country.

Opposite to what is usually practiced for traditional dams, however, it has been observed that for RCC Dams there has been a push to establish a unique dogma, sometimes unnecessary to the quality, simplicity and costs of a work.

In some Technical Specifications the following statements have been noted:

2.1- Cement

For a certain RCC dam in one given Country the Technical Specification established for the work indicated:

"... The Contractor shall apply as RCC binder, Portland-type cement produced in the Country with the characteristics approved by Inspection... ... further to what is specified in this chapter, the cement should have low heat of hydration (maximum 70 cal/g at 7 days) and low alkali content (maximum 0,4%) and shall have... ...$SiO_2 \geq 20\%$; $C_3A \geq 8\%$...; Insoluble Residue $\leq$ 0,75%..."

In that Country, however, it was not possible to comply with all the requisites simultaneously. The cements produced in said Country are high-quality, with great percentage of CaO (superior to 60%), what induces, when ground in fineness as required, to production of heat of hydration indexes above what is required. On the other hand, to reduces this heat (and the C_3A) it would be necessary to include a given percentage of silica or iron ore, which in turn (the silica), would induce to an increase of insoluble residue, reaching around 2,8%, being necessary to import iron ore to complete the correction.

Then, what is the reason to specify a type of cement for the RCC that does not exist in that Country, bearing in mind that several concrete works in dams have been constructed there.

2.2 - Pozzolanic Material

In one other work in a given Country, the Technical Specification read:

"*...The fly ash or the natural pozzolan shall comply with the requisites of ASTM - C-618, and the granulated blast-furnace slag with Norm BS-6699...*"

It occurs that in the Country of said work there is no pozzolanic material that complies fully with the norms indicated, and furthermore, in order that some of the materials available might be used there would be the need to effect an intense grinding.

Then, 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 **High Paste Content**, bearing in mind that several works of concrete in Dams have been constructed there.

If only the studies had been carried out with the purpose of inhibiting possible eventual alkali silica reaction they would have had a good technical objective.

For one other dam in another Country it was required:

"...The RCC for this Project is a combination of fine and coarse aggregates, cement, fly ash, and chemical admixture that will be mixed with water in a way to have a consistency...

...The Fly Ash shall be in agreement with the ASTM C 618, in Class F..."

It occurs that in the Country of said work also, there is not pozzolanic material that complies fully with the norms indicated, neither fly ash. Here too, in order that the existing pozzolan could be indicated, there would be the need of effecting an intense grinding

2.3-Aggregates

Regarding aggregates, analyzing the different Technical Specifications of several RCC dams at distinct locations, it is noted:

Country	*Dam*	*Approximate Volume of RCC (m3)*	*Requisites of the Technical Specifications*	*Anticipated Stock of Aggregates*
A	**1**	**> 1,000,000**	*"....The Contractor shall send to Inspection, one year before starting construction of the dam, the analyses and results of the tests of aggregates proposed...* *...the aggregates for the RCC will be obtained from the exploration of quarries "Ä"and "B", studied by the Inspection. However any change in the characteristics of the aggregates...will not be cause for claim..* *...The Contractor shall have stocked before the start of the work the equivalent of 5 to 10% of the aggregates necessary for construction of the Dam...*	5 a 10 %
A	**2**	**> 1,000,000**	*"..The Contractor shall have stocked before the start of the work the equivalent of 50% of the aggregates necessary for construction of the Dam..."*	50 %
B	**1**	**> 1,000,000**	*"...The Contractor shall keep at any moment of the work a volume of aggregates equivalent to a month of production, over a concrete floor, and the fine aggregate shall be protected by a metallic structure...".*	15%
C	**1**	**> 1,000,000**	*"...The placement of the RCC in the dam will only be started after having at least 40% of all aggregates for the RCC processed and stocked..."*	40%

It is noted that there is not a conceptual uniformity for that requisite, but rather only a requirement for a certain quantity.

On the other hand, and generally speaking, it has been observed in the traditional dam works that the minimum stock required must be dimensioned to comply with the demand during a longer period of maintenance and repair of a given equipment or replacement part, which would be of around a week. In other words, depending whether the location of a work is remote or near a region of easy access, a regulating stock for one or two weeks.

One other particularity required:

"... The Inspection may order to the Contractor a continuous spraying to keep the humidity of the aggregates uniform, reduce segregation and provoke cooling by evaporation..."

In a region with over 80% of relative humidity, as that of the work, it is clear that the effect of refrigeration by evaporation will be practically null!!

It can also be quoted from another Specification (mentioned in the frame above):

"...The Contractor shall maintain at any moment of the work a volume.. ... over a concrete floor, and the fine aggregates shall be protected by a metallic structure

What is the need of having the concrete floor? It could be a floor protected with the same granular material that is constituted of draining material and protects the principal material.

The requisite of covering the stock can be valid for the coarse and fine aggregates in regions of intense rainfall, however, it does not have to be metallic, it can simply be of canvass.

3- DOSING AND PROPERTIES

In the aspect of Proportioning mix and the Required Properties it can be mentioned:

"....The proportioning shall comply with the characteristics arising from the Structural and Thermal Design of the Dam..…. the Contractor shall be responsible for the supply of the component materials of the mixtures, with the characteristics defined in these Specifications, and of the dosing with the proportions fixed by the Inspection...

"...the proportions may be altered by the Inspection within an indicated range of values, and based on their own studies..."

It is fit to ask now: in case any of the properties required are not complied with, who will bear the responsibility?

This question becomes necessary since:

- The **Contractor** supplies the materials;
- The **Inspection** executes the dosings and the adjustments of interest:
- The **Contractor** produces, transports, applies, compacts and cures the RCC.

In case of non-compliance with any property, who will be the responsible individual? It may have been a material failure? Or dosing? Or Process?

Is it not more practical that the Contractor be responsible for the dosing, to comply with the Properties Required, and the Inspection - really - performs the **INSPECTION**?

In some specifications, situations of the following kind have been observed:

".... for the dosing of the RCC admixtures, were adopted criteria with basis on the requisites of minimum density, permeability, consistency, among others, and the requisites of static, thermal, and seismic loads, having been required:

Water (kg/m3)	*Cement (Kg/m3)*	*Pozzolanic Material (kg/m3)*	*Aggregates (Kg/m3)*
130	*140*	*90*	*2140*

Additionally, the Ratio Paste: Mortar shall be at the minimum 0,42..."

Here it is important to mention what is quoted in [1]:

"....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..."

It can also be mentioned as seen otherwise in [2]:

"...despite the fact that it has been clarified for years, the terms "high paste" and "low paste" are still erroneously used to describe types of RCC. All good RCC have 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.

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 fines aggregates 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…"

As already mentioned by this author [3]:

"…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 be 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…"

4- EQUIPMENTS

In the equipments requisites it has been observed a series of inconsistencies as follows:

Generally speaking, the most critical specifications indicate that:

- Situation where a scheduled period of time is required for execution of work-
  - The Contractor shall present a Construction Work Program in a way to comply with the established schedules; and
  - The Contractor shall present for Inspection approval, the capacity of each one of the equipments, professional team, in order to comply with the proposed Construction Work Program, considering the local climatic, material availability, and environmental conditions
- Situation where a scheduled period of time is not required for execution of work -
  - The Contractor shall present for Inspection approval the Construction Work Program together with the capacity of each of the equipments, professional team, in order to comply with that Construction Program, considering the local climatic, material availability and environmental conditions.

It has been observed, however, for several RCC works:

Job	Statement	Comments
α	*....The concrete Plant shall have an adequate number of continuous mixers type (**commercial quoting**) or equivalent, of double axis, of the continuous mix type...*	a) Type quoting; b)Commercial quoting
β	*....The Contractor shall supply, install, operate, and keep a totally automatic Plant for RCC. production... ... shall have an effective minimum capacity of **XOO**m3/hour*	Quoting of a capacity, without knowing the Contractor program
δ	*...The Contractor shall transport the RCC immediately after being produced, from the Mixing Plant to the Dam, using conveyor belts that control segregation, contamination and changes of humidity... ... the belts shall operate at high speed (**4m/s**) ... ...the systems of conveyor belts will be of the type (commercial quoting) and shall be projected by professionals with broad experience in ...*	a) Specification in the Process; b) Commercial Quoting

In the author's point of view the Technical Specifications must impose requirements over the PRODUCT (properties, performance limitations) and not over the PROCESSES, which are inserted in the attributions, competencies and responsibilities of the Contractor, to comply with the Construction Program and achieve the specifications of the Product.

5- CONSTRUCTION PROGRAM

As previously mentioned, the Construction Program may be one to comply with an established time schedule, or to demand from the Contractor a programmatic and organizational visualization of the activities, being that sometimes the freedom of the Contractor in establishing the program, may be conditioned to a payment program.

There are however picturesque situations as the one quoted from the documents of a given work:

".....The total time schedule for execution of the dam RCC, shall be presented by the Contractor and shall be comprehended between 10 and 20 months... ... The Contractor shall demonstrate that he disposes of equipments, personnel and methodology required to comply with the proposed time schedule..."

The work was contracted in 1995, but the RCC was performed only in the years 2001 and 2002! What value was it of, to stipulate the period between 10 to 20 months?

6- CONSTRUCTION METHODOLOGY AND CONSTRUCTIVE DETAILS

In this item, as well as in the requisite of equipments, the concept is that the Contractor shall present for Inspection approval, the Construction Methodology, considering the local climatic, materials availability and environmental conditions.

However, the reading of distinct Specifications evidences:

Job	Statement	Comments
ω	*"...The Contractor can apply the process "Sloped Layer Method" for a maximum of Xm of height...*	a) Induction to the use of a PROCESS; b) Gives rise to implications regarding thermal behavior that might not have been forecast
π	*"...when the surface of the RCC layer has over 600℃*H the treatment should*	The concept of maturity does not encompass all the environmental variables that affect the property (**Setting Time**) of the concrete.
λ	*"....The Contractor should conform the vertical contraction joints as shown in the drawings. The Contractor may opt for one of the following alternatives:* *I. These joints shall be conformed by the use of formwork;* *II. These joints should be conformed leaving metallic blades inserted vertically..."*	What is the need of being a metallic blade? Can't it be plastic?
ξ	*"... the upstream and downstream faces should be built using formwork and the GE-RCC (**G**rout **E**nriched RCC)*	The PROCESS and not the PRODUCT was specified.

It can be noted by the statement that there is a lack of full knowledge of the RCC behavior as to its setting time characteristic.

It is worth to remember at this point, as previously mentioned, that the amount of construction joints established by the use of RCC induced to a major concern when compared to the traditional concrete constructions, it evidenced percolation and doubtful adherence, which reduced safety as to stability, in some of the first RCC dams.

This situation gave rise to a great number of alternatives for the conception of the watertightness system and of the treatment of the construction joints surface, in the most recent dams. The statistic data of the use of different execution Methodologies of the upstream face evidences [4]

It is demonstrated from it that there is not a methodology plainly accepted yet, and that the concerns as to watertightness remain.

7- PROJECT

Although RCC is a Construction Methodology, the Project that conceives or permits its application may be optimized with the purpose of facilitating adoption of the process.

So it is that since the precedence of the use of RCC, 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.

The [5] publication otherwise 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.

In face of that RCC dam Designers can use two main design approaches:

- The “global approach” which relies on the dam watertightness through the quality and proper treatment of each lift joint;
- 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.

In Spain, the weight and impermeability functions depend upon the RCC in most of the dams.

The information from Figures 01 and 02 permits to affirm:

Face Type	Present Use	Performance and Use	Countries of Major Use
CVC against formwork	55%	Traditional and without use has increased	Japan, South Africa and Brazil
RCC against formwork	13%	Its use has decreased	Spain
CVC against precast concrete panels	5%	Its use remains constant	
RCC against formwork + external geomembrane	2%	Its use has increased	China
CVC against precast concrete panels with geomembrane	3%	Has been used additionally	USA

8- COMMENTS

Through the examples mentioned, we try to bring to discussion and make possible the comprehension, several points, among which it is worth to highlight:

8.1 - Materials

The technical specifications for the RCC materials, not necessarily distinguished from the CVC materials and with basis on the normal standards, do not need to induce to additional worries only due to methodology

8.2 - Equipments

At this point attention is called for the specifications to perceive the requisites of the Products and not the characteristics of the Process which are inherent to the Contractor competence and responsibility.

8.3 - Methods and Details

Must be within the Contractor responsibilities, and this must be underscored, not the induction or demand of a particular methodology or process.

8.4 - Project

It is prudent and convenient that the Design always considers the possibility of actions and how these can be executed for eventual corrections. In other words, the Design must bear within its details the safety aspects but also the conditions and aspects of **WHERE** the Project is being constructed, considering the degree of availability and capability of Labor, Construction Speed and eventual risks of augmenting chances for errors.

9- REFERENCES

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

[2]- *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;

[3]- *Francisco Rodrigues Andriolo*- **“The Use of Roller Compacted Concrete”**- Editora Oficina de Texto www.ofitexto.com.br - São Paulo – Brazil- 1998;

[4]- *M.R.H. Dunstan*- **“RCC Dams”**- The international Journal on Hydropower & Dams – England – 1990 to 2002;

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

Figure 01- Upstream Face Type Statistical Data [from 4]

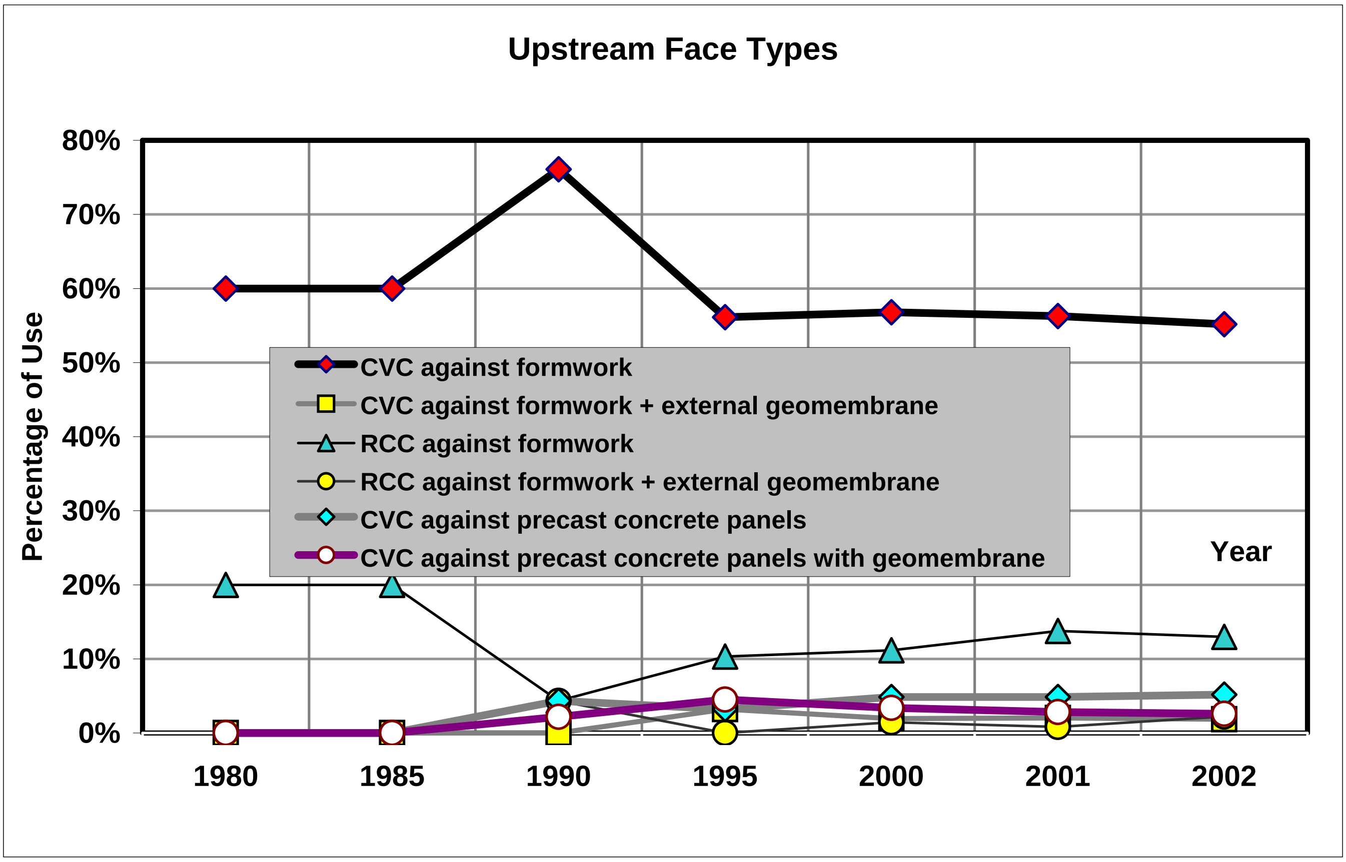

Figure 02- Upstream Face Type Satistical Data [from 4]

Upstream Face Type	1980	1985	1990	1995	2000	2001	2002	Japan	China	USA	Spain	Brazil	South Af-rica	Aus-tralia
CVC against formwork	60%	60%	76%	56%	57%	56%	55%	100%	57%	47%	25%	90%	93%	22%
CVC against formwork + external geomembrane				3%	2%	2%	2%							
RCC against formwork	20%	20%	4%	10%	11%	14%	13%		19%	7%	60%			22%
RCC against formwork + external geomembrane			4%		1%	1%	2%		5%					
CVC against precast concrete panels			4%	3%	5%	5%	5%							
CVC against precast concrete panels with geomembrane			2%	5%	3%	3%	3%		2%	17%				
RCC against precast concrete panels	20%	20%	2%	5%	5%	5%	4%		5%	10%				33%
RCC against precast concrete panels with geomembrane				1%	1%	2%	2%			7%				11%
RCC against precast concrete panels with hot poured membrane			2%	3%	2%	2%	2%		10%					
Reinforced CVC cast after RCC placement			2%	3%	1%	2%	1%		2%	3%		5%		
Reinforced CVC cast against precast units or slip formed facing elements				1%	4%	3%	3%			3%		5%		
Slip formed/extruded facing elements			2%	5%	4%	3%	3%			6%	15%			11%
Number of RCC Dams	*5*	*5*	*46*	*155*	*206*	*247*	*270*	*43*	*50*	*36*	*22*	*39*	*13*	*9*