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Andriolo Ito Engenharia SC Ltda
Rua Cristalândia 181
05465-000 - São Paulo - SP - Brasil
Fax ++ 55-11-3022 7069
site: www.andriolo.com.br

RCC DAMS- IMPERVIOUS SYSTEMS: DISCUSSIONS, SUGESTIONS AND USAGE

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RCC DAMS- IMPERVIOUS SYSTEMS: DISCUSSIONS, SUGESTIONS AND USAGE

Pacelli, Walton Andrade *(1)*
Andriolo, Francisco Rodrigues *(2)*

ABSTRACT

This paper discusses impervious systems used in numerous dams built with Roller Compacted Concrete. The study comprehends different trends and common practices.

The debate between conventional and RCC mass concrete membranes is based on permeability tests results.

1 - INTRODUCTION

It is common knowledge that RCC is a construction technique and not a design concept. However, when discussing projects that may use the RCC technique, two basic points are usually considered:

- Treatment and characteristics of construction joints between lifts; and
- Watertightness and durability, upstream face type, seepage and drainage factors and control.

The treatment of construction joints between lifts has been much debated in numerous occasions and papers. These discussions and data from Test Fill Sections lead to the conclusion that tests should be done for each design requirement in order to determine surface treatment.

So, for dams in non-seismic areas, a friction corresponding to 45^o stabilizes acting tensile forces. For arch-gravity dams, very high dams (more than 100m high) [1], or projects in seismic areas, there may be a need to increase friction above 45^o, and cohesion above 5 Kgflcm2.

Cohesion and friction parameters for specific projects must be given considering materials and mixes at the job.

The second point usually debated regards watertightness and durability, upstream face type, seepage and drainage control. This paper considers characteristics of the upstream face in RCC dams.

It is also common knowledge that a dam design must take into account seepage reduction and drainage control, technically and economically, whether it uses RCC methodology or not.

2- GENERAL CONSIDERATIONS

1 – FURNAS Centrais Eletricas SA- Laboratório de Concreto- Rodovia BR-153-Km 1290; 74001-970-Goiânia-GO-Brazil;Tel: 55-62- 283 6122; Fax: 55-62-223 3584; e-mali:concreto@furnas.com.br

2–AiE-Andriolo Ito Engenharia SC Ltda-São Paulo-SP-Brazil; Tel: 55-11-260 5613; Fax:55-11-260 7069; e-mail:fandrio@ibm.net; site:www.andriolo.com.br

The number of built RCC projects around the world is above 200 [2]. These dams show design requirements used to reduce seepage or, similarly, increase impermeability, as illustrated in Figure 2.1

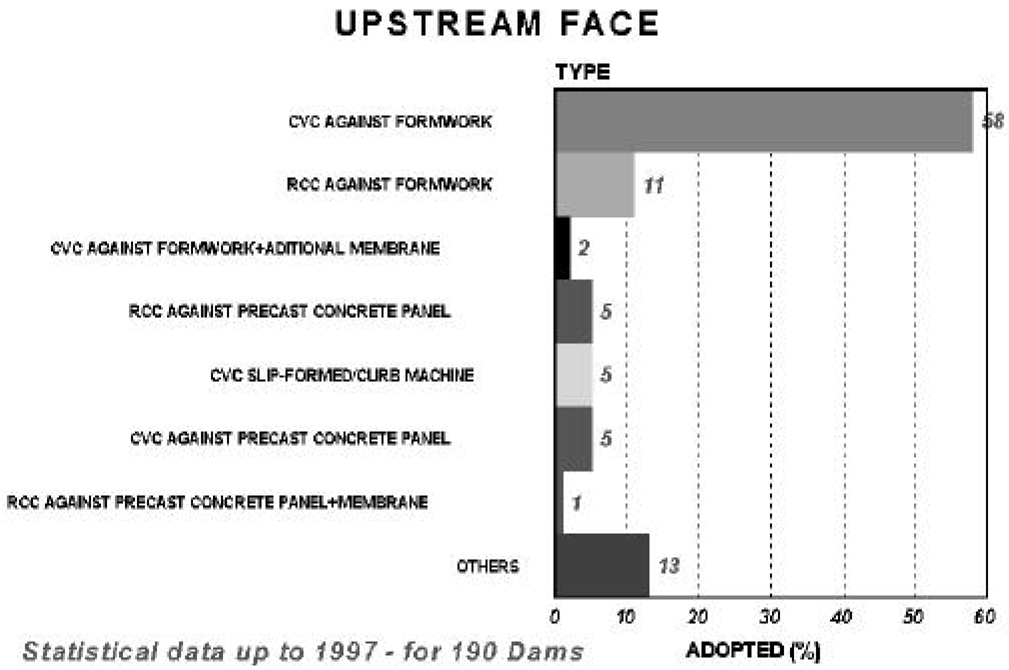

Figure 2.1- Statistic data on membrane types used for the upstream face of RCC dams

Reports shows that most RCC dams (57%) have Conventional Mass Concrete (CVC) membranes, built simultaneously with the RCC lifts; and represented mainly by jobs in Japan, China, United States and South Africa.

CVC (conventional mass concrete) Gravity Dam construction in Brazil, one of the largest practices in the world, demonstrates that Brazilian dams use concrete that complies with different durability and impermeability standards for the water-contact area. (*Examples of this are: Ilha Solteira; Água Vermelha; Porto Primavera; Tres Irmãos; Nova Avanhandava; ltumbiara; Marimbondo; São Simão; Tucurui, among others*), as illustrated in Figure 2.2.

In the case of Ilha Solteira Dam (Figure 2.3), concrete zoning, besides complying to resistance criterion, used an additional permeability requirement **"α"** with **$K < 10^{-9}$** cm/sec, for the face concrete.

Many RCC jobs in Brazil (Jordão; Saco Nova Olinda; Caraíbas) have used this concept.

Another concept employed, and statistically significant (10% of built dams), is the use of RCC to achieve watertightness. This has been adopted in Spain (in approximately 60% of the jobs), and China.

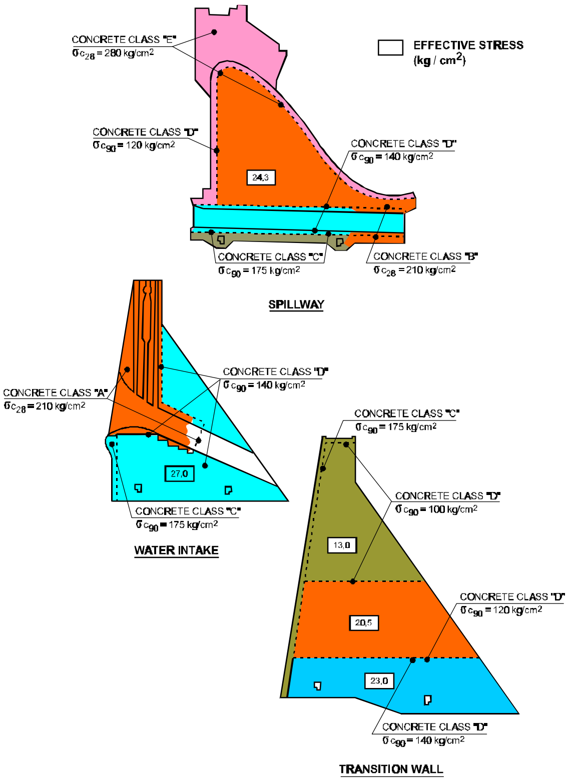

Figure 2.2- Concrete zoning adopted in large CVC Brazilian dams

Figure 2.3- Ilha Solteira Dam (CVC Mass) built in the beginning of the 70s.

This practice evolved as RCC properties became better known; it considers a special security RCC mix with a higher non-cohesive fines content (less than 0.075mm).

The use of CVC- conventional precast concrete panels (5% of the dams) as well as the use of a synthetic membrane (usually PVC), has been accepted in projects in China, Honduras, France and United States. This practice has increased in the last years.

The use of RCC against precast concrete panels (4% of the dams), has been accepted in projects in Australia, China, United States and Morocco.

Slip-form machines with horizontal sliding of the conventional concrete face (4% of the dams) have been used in Spain, the United States and Greece.

Other solutions have been less frequently used (approximately 20%), or were intended for specific design requirements:

- ♦ RCC against forms and additional PVC membrane;
- ♦ CVC against precast panels and additional PVC membrane;
- ♦ RCC against precast panels and additional PVC membrane;
- ♦ Reinforced concrete cast before RCC;
- ♦ Reinforced concrete cast after RCC;

Two technical trends diverge:

- The use of a CVC face built together with the RCC and,
- The use of a RCC face (with a different mix proportioning), popular nowadays.

It should be noticed that the use of a PVC membrane, applied after the structure is finished and against the RCC mass, has also been considered quite attractive in numerous studies and projects.

In a conservative manner, CVC face design has varied the binder content and face thickness.

The use of RCC as an anti-seepage element, based on a different proportioning mix, has increased these days. Until 1990, almost 77 dams had been built and only 4 had adopted this alternative, that is, approximately 5%. Today, (report until end of 1997) of the 190 dams, 11% have adopted this alternative.

This is due to a greater knowledge of RCC properties and a need for low-cost alternatives.

In addition to the trend in Spain, this alternative has also been used in China, and it is important to quote from [3]:

" 2.3- Upstream Face

For approving of impermeability of RCC dam, several kinds of anti-seepage structures were applied in practice. They are:

- *Asphalt mortar, applied on Kengkou RCC* dam;
- *Expansive reinforced concrete, applied on Longmentan RCC dam;*
- *Precast concrete blocks bedding mortar and deeply pointed joint, applied on Shuidong RCC dam;*
- *Conventional concrete nith 2 - 4m thickness, applied on Shuikou, Yantan, etc.*
- *Rich contens of cementitious material with maximum aggregate size 40 mm within 6 to 2 m on upstream face, applied an Rongdi dam.*

Compare all these types, the first two did not work very well, but the last one is more convenient to use 2 grade rich cementitious RCC, as RCC itself has high impermeability at least

10^{-6} to 10^{-10} m/s the problem is how to treat the surface of layers, if the technology of RCC approved good conection, no doubt the impermeability will satisfied to the design specification".

3- BASIC CONCEPT

Generally speaking, when considering the design of a dam, resistance parameters are not so important as durability. This condition has led most concrete dams, specially mass concrete, to use concrete zoning as shown in Figure 3.1

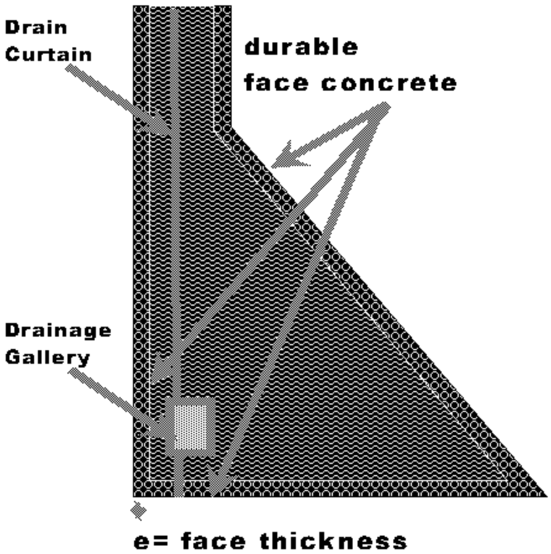

Figure 3.1- Concrete zoning adopted in many Brazilian dams with impermeable concrete on upstream face

The authors think that a conventional CVC mass concrete impermeable membrane, considering its watertightness measured by its permeability and deformation capacity (thermal tensile strength), evaluated by testing, has revealed itself the most attractive and adequate alternative for RCC dams.

When proportioning concrete mixes with volumetric stability, low permeability, and maximum density (lower void ratio) a concrete with greater "Durability" is characterized by the ability to bear the many agents that may act on it, not only the mechanic.

However these concretes must have a minimum cracking potential (maximum strain capacity), reducing possible loss of impermeability through cracks.

Besides technological aspects the membrane face must be easy to build, not complicating the simple RCC construction process.

This way, the project's functional security is established. The structure is equipped with an impervious durable face, with elastic mechanic strength, and safe and stable due also to its drainage system.

4- CONCRETE PERMEABILITY

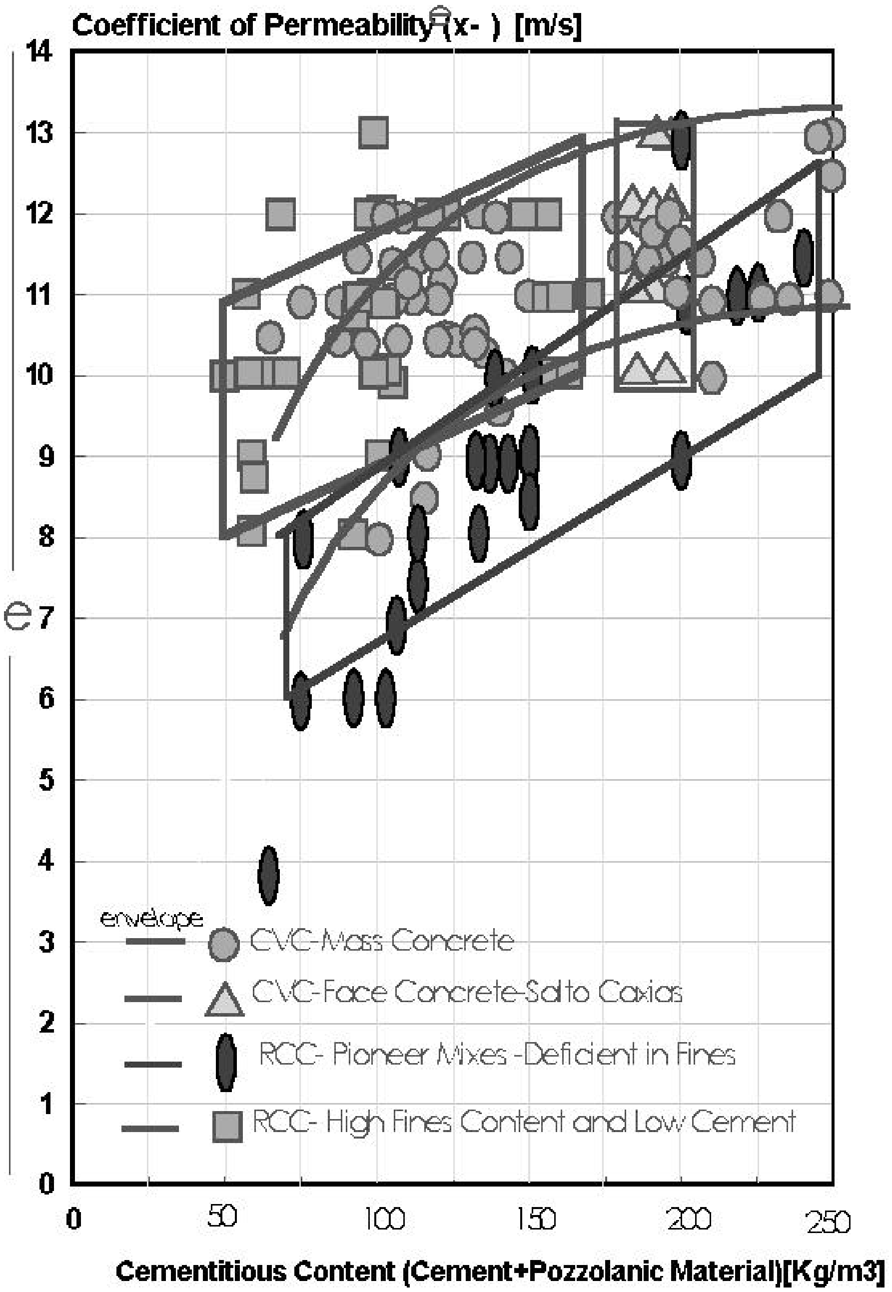

Figure 4.1- Permeability Coefficient values for rcc in comparison with cvc jobs and studies [4 to 7]

Figure 4.1 [4],[5] shows a group of Permeability Coefficient values for RCC and CVC jobs and studies, emphasizing the importance of the fines content in RCC mixes, adopted for the second generation of RCC jobs, from the end of the 80s.

The data on CVC in Figure 4.1 refer to studies from CESP- Government Agency at São Paulo State- Brazil (Ilha Solteira, Água Vermelha) [6] and other studies performed at the ltaipu Binacional Laboratory (for ltaipu and Capanda jobs) [7].

Fumas Concrete Laboratory, a Brazilian Energy Government Agency, has completed an ample study on RCC and CVC permeability, and the results for a Permeability Coefficient of 250 Kgf/m3 appear in Figures 4.2 and 4.3 [8].

The figures referred to show that:

- Inclusion of fines (pozzolanic or not) reduces “second generation” RCC permeability ;
- The permeability level of current RCC, with fines content, is analogous to that of mass CVC, for equivalent consumption;

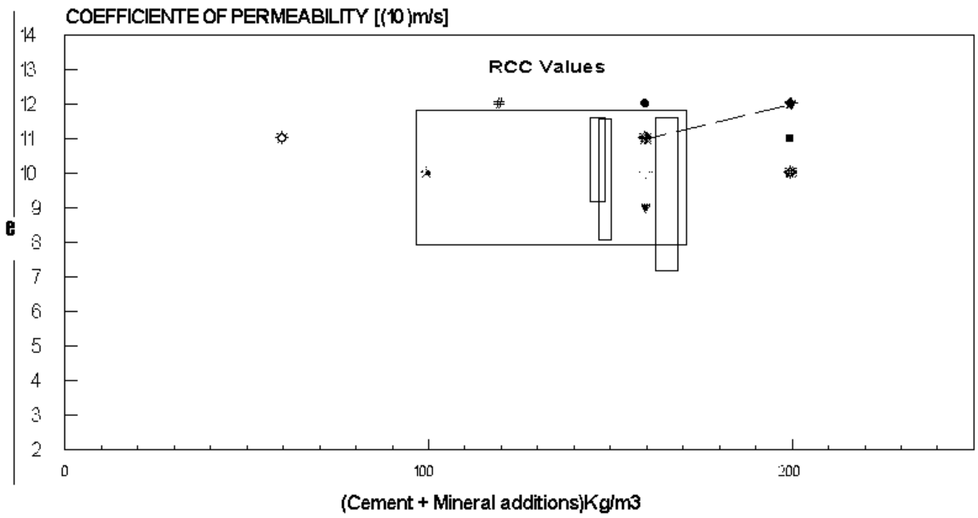

Figure 4.2- Permeability Coefficient of jobs and studies on RCC [8]

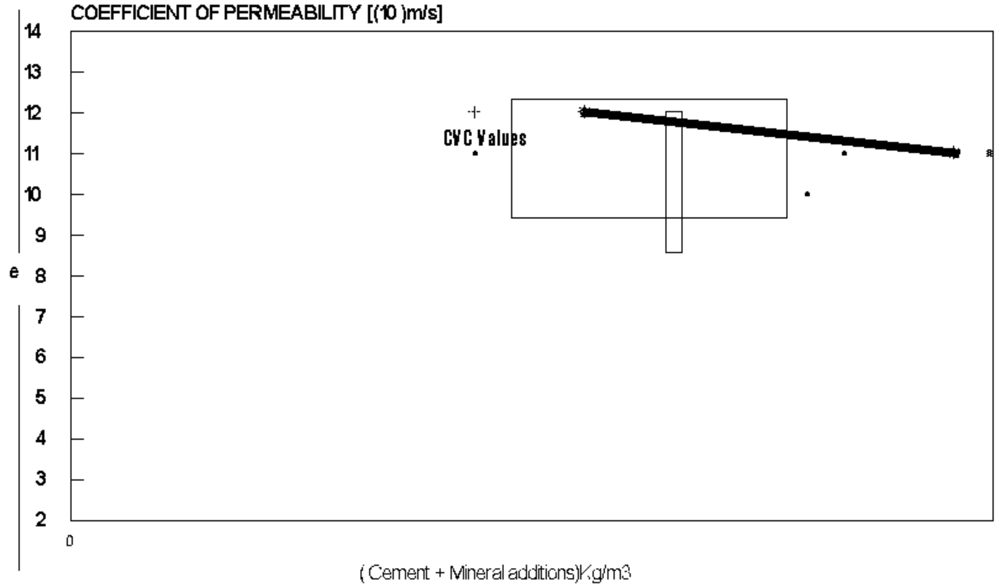

Figure 4.3- Permeability Coefficient of jobs and studies on CVC [8]

It should be emphasized that the inclusion of fines is more profitable if the “filler” used has pozzolanic activity. This way, besides reducing permeability it is possible to reduce the cementitious content and still minimize the expansive effects of the Alkali-Silica reaction.

The figures clearly show that the increase in binder consumption (cement +pozzolanic material) or cement and additions, from 150 Kg/m3 on does not allow for a permeability reduction. This means that the permeability reduction is not so significant for both CVC and RCC.

5- FACE THICKNESS

In the case of dam faces, a concrete thickness that guarantees watertightness of the core was adopted considering the size of the concrete-bucket of a $3m^3$. For layers less than 0.5m high, this resulted in a face thickness of approximately 2.5m. This can be seen in mass concrete Brazilian dams (see item 1) and Japanese RCC (or RCD) dams, independent of height (and respective hydrostatic load), concrete type or lifee-exposition period.

The search for a low-cost and technically safe alternative, prompted studies on a specific criterion for determining face thickness. Consequently, the Bazant [9] expression:

e = $(\mathbf{2* K* H* tla})^{1/2,}$ where:

e= thickness (m);
K= Permeability Coefficient (m/s);
t= Life-exposition time (s);
a= absorption or concrete void ratio (%),

has been suggested [9] to aid in dimensioning the thickness of the face membrane.

Another expression that can be used was developed by Carlson [10] for a permeability of approximately $5,66*10^{-12}$ m/s, for a dam with a 122m high water column, and a 5% absorption concrete:

$D = (\mathbf{0{,}02574*}\ T)^{\mathbf{1/2}}$ **,** where:

D= Percolation distance (m);
T= Time necessary for percolation D (days).

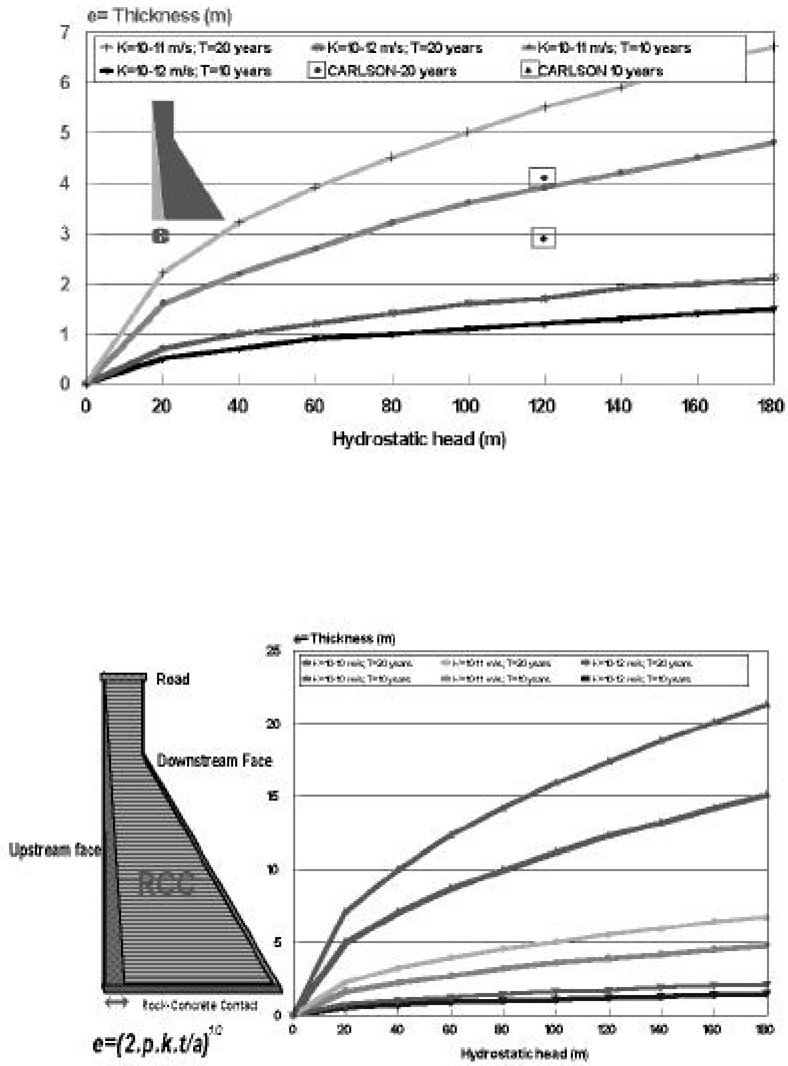

Figure 5.1- Impervious upstream membrane thickness

Doubts could arise on the choice of the value T (or t) for the expressions above.

For this purpose, may be considered that percolation, or the passage of fluid through permeable pores, can only occur after the hydration reaction of the mass concrete cement has stabilized. As a preliminary assumption, and by way of an exaggerated correlation, let's consider that concrete has shown a obvious evolution until 10 to 15 years; a plausible "T" would then be between 10 and 20 years, in order to calculate the membrane thickness (Figure 5.1).

This way, Figure 5.1 shows thickness 'e' according to Bazant, or 'D' by Carlson.

Another conditioning factor to be considered is the thermal aspect resulting from the concrete type adopted for the face (cement type and content), thickness and technical placement conditions.

As affirmed in item 4, the benefits of increasing the cementitious content higher than 150 Kglm3 are questionable. The mix proportion of the concrete face used woulld have cementitious content approaching this value resulting in a technical point of debate for this option.

The authors recommend that the alternative is chosen based on permeability tests and strain capacity (considering the variables: cement, pozzolanic material, fines content, aggregate Dmax); these should be performed in advance, before construction starts.

The new generation of RCC mixes with high fines content strengthen the trend adopted by the Chinese and the Spanish: the use of a different proportioning RCC mix for the impervious membrane.

6-SUGGESTIONS

Based on permeability tests, the thickness of a dam's impervious membrane, for both CVC mass concrete and RCC dams, can be dimensioned bearing in mind:

- minimizing cementitious content in order to keep concrete volume stable;
- compatibility of structures with thermal aspects through studies that regard control of face concrete temperature;
- optimization of non-cohesive fines content (pozzolanic or not, but preferably pozzolanic) in the mix;
- search for construction simplicity with less mistakes and/or failures;
- search for a low-cost, technically safe, alternative.

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