ROLLER COMPACTED CONCRETE DAMS

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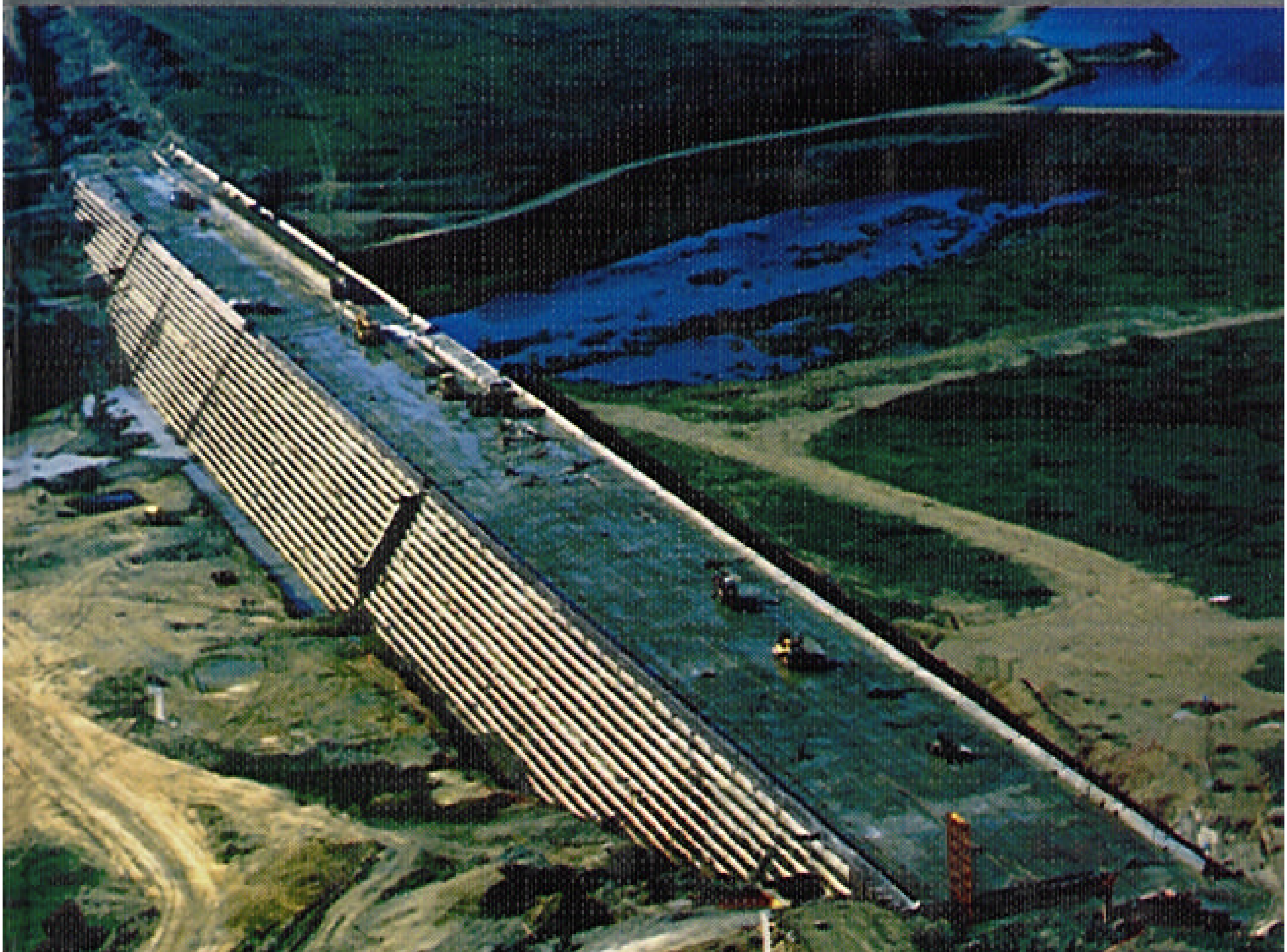
INSPECTION GALLERY AND DRAINAGE IN SMALL DAMS: PROBLEM OR SOLUTION ?



IECA Spanish Institute of Cement and its Applications (IECA)

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INSPECTION GALLERY AND DRAINAGE IN SMALL DAMS: PROBLEM OR SOLUTION ?

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ABSTRACT

The inspection galleries and drainage used in large dams, constructed on RCC, doesn't admit discussion about its materialization . In small dams (less than 40m) there are contraditions mostly since of the construction point of view.
Based on the experience of works, and since a furthermore ample angle, that includes since the project, construction, and operation, it can be considered that galleries conformation in the higher zones of the dam and the drain points in the lower part, connected to the dam, brings beneffits that overcome the few problems.
The development of the paper will be point the following themes:- Methods of construction of the galleries; - Comparison of transverse sections of a dam with differents of downstream slopes and the incidence of the gallery area;- Comparison between the pore-pressure of the drainage curtain for transverse sections with differents of downstream slopes;- Beneffits for the grouting curtain execution.

1 - GENERAL ASPECTS

Inspection and drainage galleries adopted in high dams, gravity type, in RCC, are already part of all projects, and the convenience of their execution is no longer discussed. But in RCC dams considered of small height (less than 40 m), the presence of the gallery is still questioned, mainly when seen from the angle of possible execution difficulties.
Seen from a wider point of view, starting from the Project's conception, its Construction and all the way to the dam's Operation, one might consider the conformation of a gallery in higher zones as a necessity, in which the few execution problems resulting from its materialization are minor if compared to the potential benefits that it yields.

2 - USUAL METHODS FOR GALLERY CONFORMATION

2.1 - Lateral Forms and Conventional Concrete (CVC)

In some job-sites, forms have been used, and the CVC has been thrown against them, with the same height as the RCC layers, and average thickness between 0.3m and 0.4m. The finishing obtained has good visual aspect. The conformation done this way is simple, and the forms are not subject to large stresses during compactation, for the thickness of the layer is small and the compactation of the CVC is executed by imersion vibrators.
This kind of lining, however, prevents one from having a clear visualization of the dam's behavior during its Operation phase, in view of seepage or percolation that might occur from the upstream face or from contraction joints existing in the upstream face and in the dam's body.

The ceiling of these galleries may be conformed with forms or precasted concrete elements. This process may have considerable incidence in its cost, due to the necessity of manufacturing, transporting and positioning in the proper site, since the placement of them requires the availability of a crane compatible with the weight of the pieces.

In the conformation of the ceiling, with templates or precasted concrete under-dimensioned pieces, the necessity of vertical supporting to allow the passage of equipment becomes also questionable.

2.2 - Side Forms and RCC

The forms normally used for the conformation of these galleries are usually metallic (see Figure 1) or prismatic pieces of precasted concrete. The pieces are locked internally by metallic anchorings, of an extensible tubular type, or by supports.

The RCC is poured directly against the forms and compacted by means of lighter equipment (vibrating plates, vibro-sockets) with an approximate width of 0.5m. This smaller equipment is capable of attaining a compaction level around 96% of the theoretical density normally prescribed in Technical Specifications.

2.3 - Metallic or wooden forms and filling with granular materials

In this case, the forms, whether metallic or wooden, are positioned by means of steel bars suitably fixed in the layers of RCC already executed. In its internal side, the forms are supported by means of a layer of granular material, with the same height as the RCC layer under execution. The RCC is poured directly against the forms and may be compacted with small sized equipment. It is convenient to carefully avoid segregation of the RCC near them. This methodology also allows the use of heavier equipment to compact the RCC poured near the forms, since the granular material allows vibratory rollers to run over it.

The ceiling of the galleries, in this situation, may be built by placing a plastic liner over the last layer of granular material with a slight curve (inside), with a thin layer of CVC being thrown over the lining, which may be the "bedding mix concrete" itself, finished with the RCC placement.

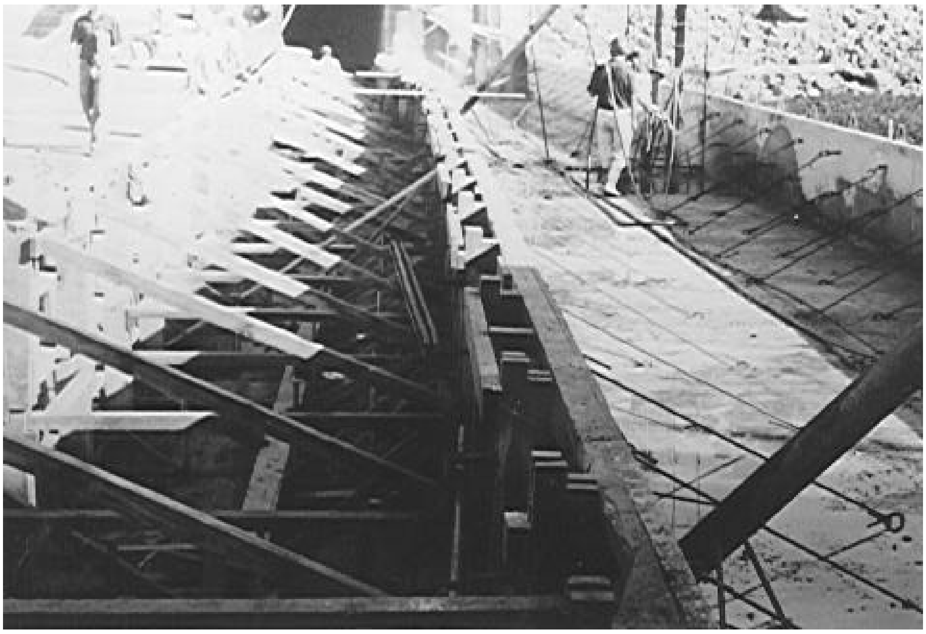

Figure 1 - Gallery casted with RCC against conventional forms

Figure 2 - Precasted concrete pieces for the shaping of the gallery

Figure 3 - Shaping of the gallery with granular material against wooden or metal forms

The granular material must be removed later, after the ceiling has achieved the capacity of supporting itself, the subsequent layers, and the working equipment. Normally a minimum height of 3m over the gallery has been adopted, for removing the granular material from inside the gallery.
The advantage of this methodology is that in the Operation phase, any infiltration may be observed and notified. The drawback is that removing the material is costly and the aspect, although satisfactory, is not customary in dams.

2.4 - Conformation with Container Filled with Granular Materials

The side walls of the gallery are conformed with the use of bags (plastic or fiber) filled with granular materials (normally sand) that are piled as the RCC layers are executed. In the internal side, between the rows of containers that will conform the walls of the gallery, there is a filling of agregates or wet sand. This method is questioned, for the walls display a satisfactory aspect, but not usual in dams. Removing the sand bags is a difficult task and has to be done manually.

Figure 4 - Precasted concrete piece for the ceiling of the gallery

2.5 - Direct Conformation by Filling with Granular Materials

The conformation is done the same way described in items 2.3 or 2.4, except no other auxiliary elements, such as forms, are used beyond the granular material.

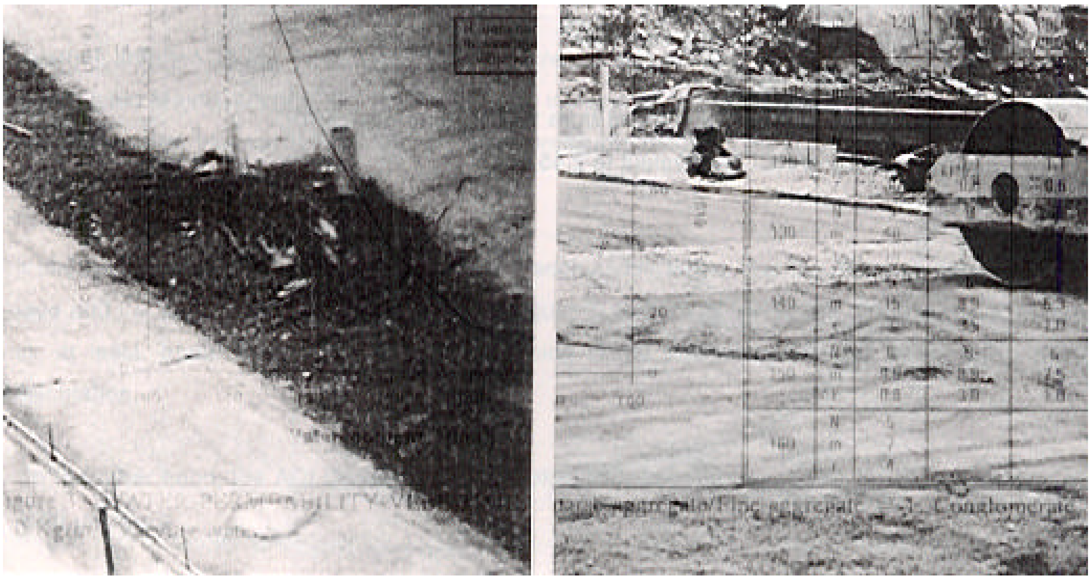

Figure 5 - Molding of gallery with granular materials acting as filling

Figure 6 - Containers with granular material for casting the gallery

3 - COMPARISON OF DAM SECTIONS WITH AND WITHOUT DRAINAGE GALLERY

Figure 7 illustrates the basic sections for comparing advantages and disadvantages of the drainage system in dams of small height (less than 40m).

For the evaluation it has been assumed:

- Transversal section with vertical upstream face and downstream slope (0.7h:1.0v); (0.8:1.0); (0.9:1.0);
- Gallery with dimensions 2.3m (base) and 2.6m (height), with drainage curtain located from 0.5m up to 9.0m from the upstream facer;
- Width of the dam crest: 4m;
- Variable heights of 4m, 6m, 8m and from 10m to 40m, each 5m.
- Specific gravity of RCC equivalent to 2.45 t/m3.

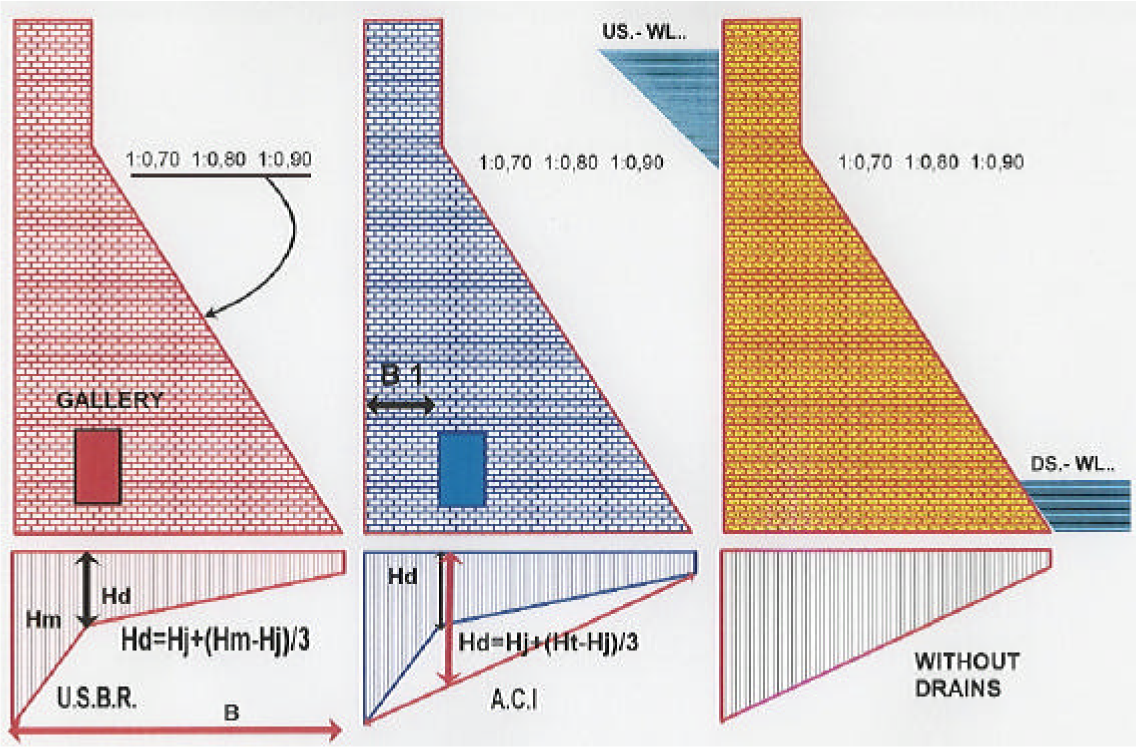

Figure 7 - Typical sections of dams with and without drainage gallery

4 - CALCULATION OF UPLIFT PRESSURE

In the absence of drains, the consideration of the uplift pressure effect is done by means of a linear diagram between the values of hydrostatic pressure upstream and downstream, according to the scheme of Figure 7.

Considering the action of the drains, the uplift pressure diagram on the dam surface in contact with the foundation material is done with several criterion, the USBR (United States Bureau of Reclamation)[1] being one of the most used, as also shown in Figure 7.

Another criterion is the ACI's (American Concrete Institute), through the Committee 207 - "Roller Compacted Mass Concrete" [2], also mentioned in Figure 7, and which takes into account the position of the drainage line for determining the uplift pressures diagram, something that is not done by the USBR criterion.

It should be stressed that the USBR Criterion additionally states that the distance between the dam face and the gallery wall (displayed as B1 in Figure 7) is 7.5% of the height of the hydrostatic column or, at least, about 3 m, although this positioning is not taken into account in the uplift pressure calculation.

On the other hand, the ACI Criterion considers the positioning of the gallery for the calculation of the uplift pressure.

5 - EVALUATIONS

The construction of galleries in gravity dams in RCC with height under 40m, apparently generates difficulties during the construction. However, these small height dams normaly do not have a system of instrumentation of the monitoring during the phases of construction and operation. In this situation, the galleries could be a direct access for visual evaluation of the structure. Beside that, they allow corrective actions to be taken in a clear and objective way.

By calculating the uplift pressures acting in the three cases mentioned in Figure 7, the following comparisons can be done:

5.1 - Comparison Between the Total Uplift Pressure Criterion and the USBR Criterion

As observed in Figure 8, the inclusion of the gallery provides dam (small height) weight reduction. On the other hand, the functioning of the drainage, admitted by USBR, allows a substantial reduction in uplift pressure, as evidenced in Figure 9.

5.2 - Comparison Between the ACI Criterion and the USBR Criterion

Figure 10 shows that applying the ACI Criterion, when compared to the drainage located in analog positions (about 3m from the face) of the USBR Criterion allows a reduction of uplift pressure in the order of 20% (for dams 8m high, for in this comparison it is not suitable to compare dams with smaller height, because of the position of the gallery and its dimensions) up to 8% or 6% (in dams 40m high).

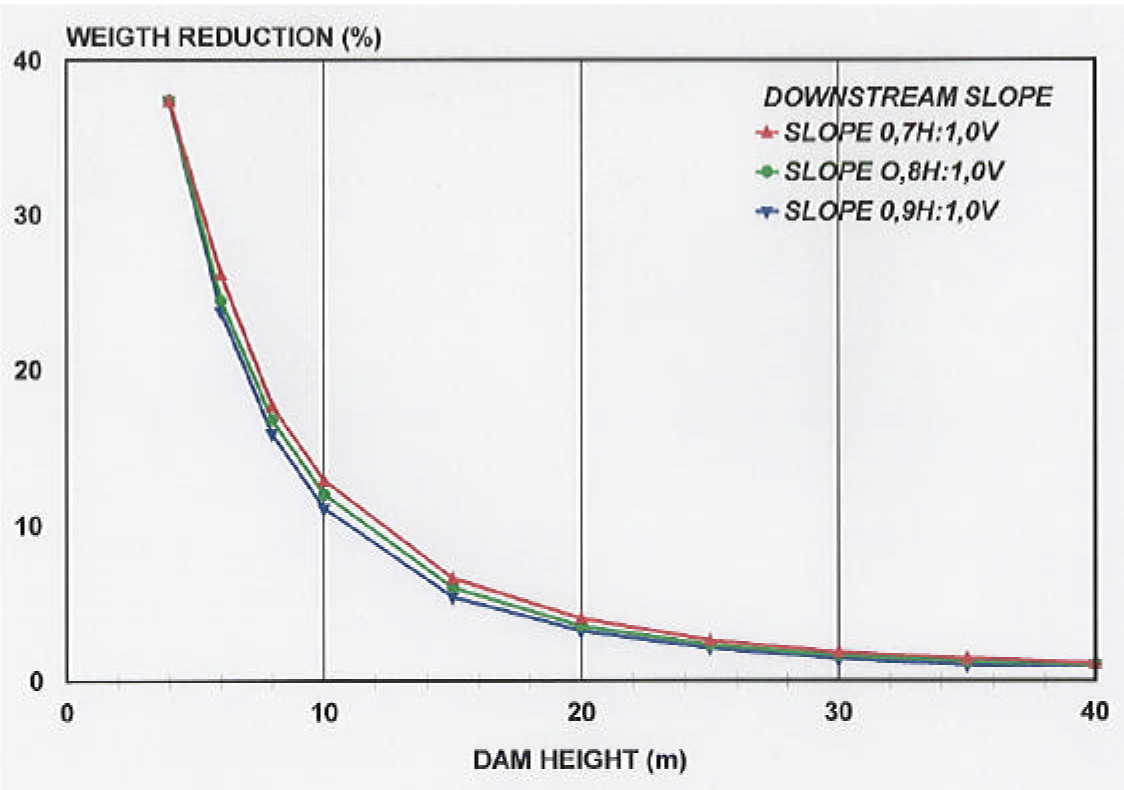

Figure 8 - Weight reduction due to the inclusion of the gallery (USBR Criterion)

5.3 - Action of drainage position in ACI Criterion

Figures 11 and 12 depict the significance of the drainage system as related to the effect of reducing uplift pressure and weight due to the inclusion of the gallery. By adopting a Safety Factor of 2.0 applied to the action of uplift pressure, one might notice that the point of interest of the gallery location provides positive effects (translated as enhanced safety - in excess of 2.0; and advantages of lessening uplift pressure) starting from dams with height above 12m.

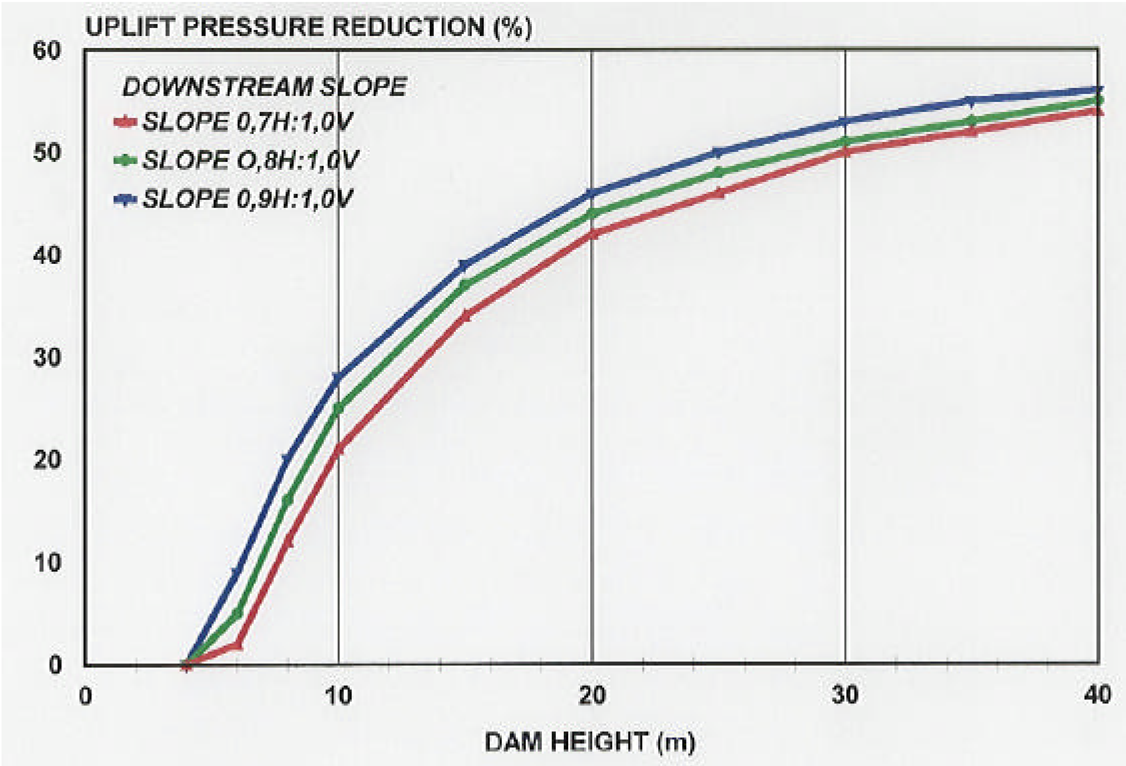

Figure 9 - Uplift pressure reduction due to the gallery relief action (USBR Criterion)

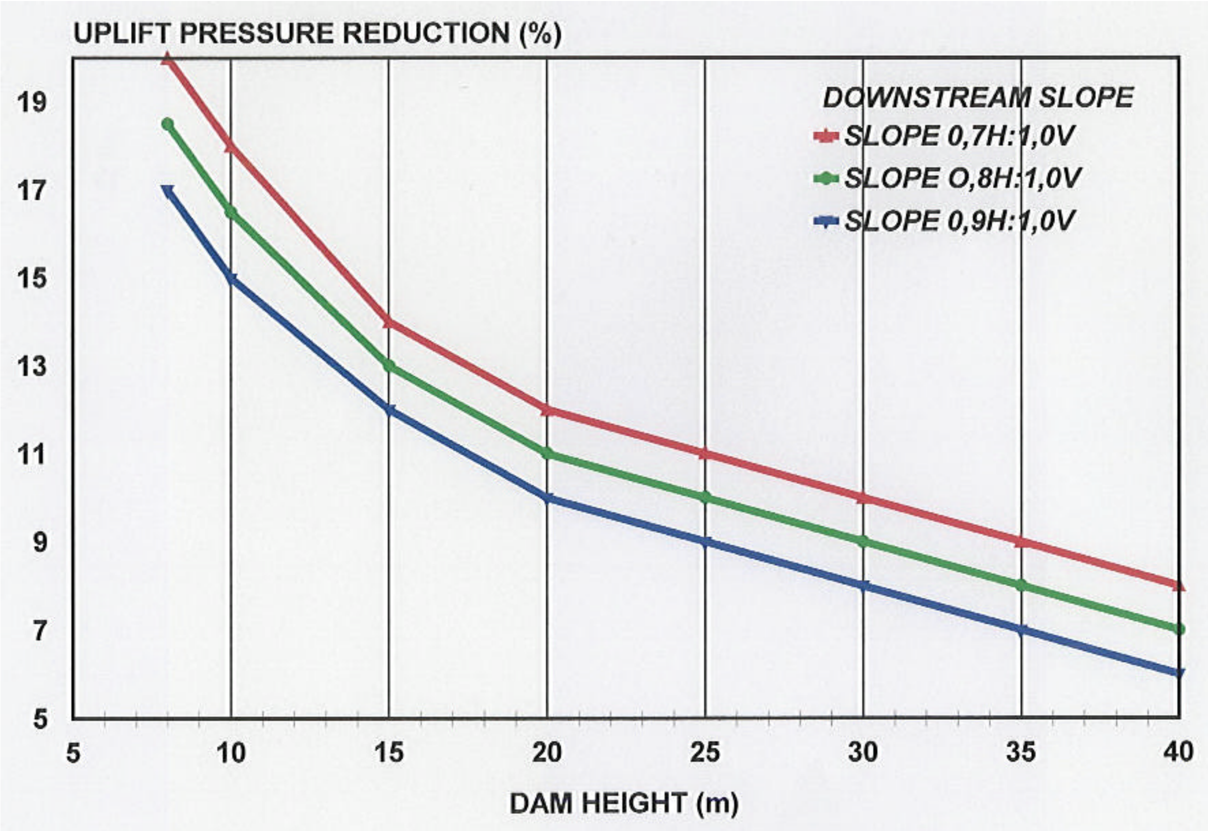

Figure 10 - Uplift pressure reduction when comparing the ACI Criterion with the USBR Criterion

It is also observed that, as the drainage system is positioned downstream, its advantage is reduced (from about 30%-25% with the system placed at 0.5m from the upstream face to 25%-15% for the drainage placed at 9.0m from the upstream face) and it shows as advantageous for dams with height above 12m for the system placed at 0.5m from the upstream face and 18m for the system at 9.0m from the upstream face.

5.4 - Filling Between the Upstream Face and the Gallery due to the positioning of the Drainage, according to the ACI Criterion

The positioning of the gallery, as related to the upstream face, creates the necessity to fill up this region with a type of concrete.

At this point it is worth considering the possibility of this concrete acting as a "Face Concrete" for the safe impermeability of the dam.

The dimensioning of the thickness of this "Face Concrete" may be done based in [3], where it is adopted that the distance (thickness) of percolation is stated by the expression $\mathbf{e = (2xPxKxT/a)^{1/2}}$ where:

e = Thickness of the concrete face with permeability "K";

P = Height of the water column acting on the dam;

K = Concrete Coefficient of Permeability;

T = Time considered for the percolation to happen and cross all the " Concrete Face";

a = Absorption of the " Concrete Face".

The thickness of this face concrete, calculated by the expression, with absorption of 5%, is shown in Figure 13 for several values of "**T**" and of "**K**'.

By the curves shown in Figure 13, it is evident that the use of concretes with permeability of 10^{-12} m/s is convenient only for dams with height under 40m, for filling the space from face to gallery, when the latter is placed less than 3m from the face of the dam. In situations of dams with height under 40m, with drainage gallery placed at more than 3m away, there is the possibility of allowing the use of face concretes with Coefficient of Permeability higher than 10^{-12} m/s.

6 - COMMENTS

The incorporation of a gallery together with a system of drainage, even in RCC dams of small height (from 10m to 40m) reduces the possibility of the onset of pore-pressure in the body of the dam.

Not using a gallery may result in the need of building a "step" or “Plinth” near the upstream face toe, for the execution of the grounting curtain. This cost is to be compared to those resulting from the execution of the gallery. The gallery yields the advantage of allowing the grouting curtain and drainage to be executed at any time, before the filling of the reservoir

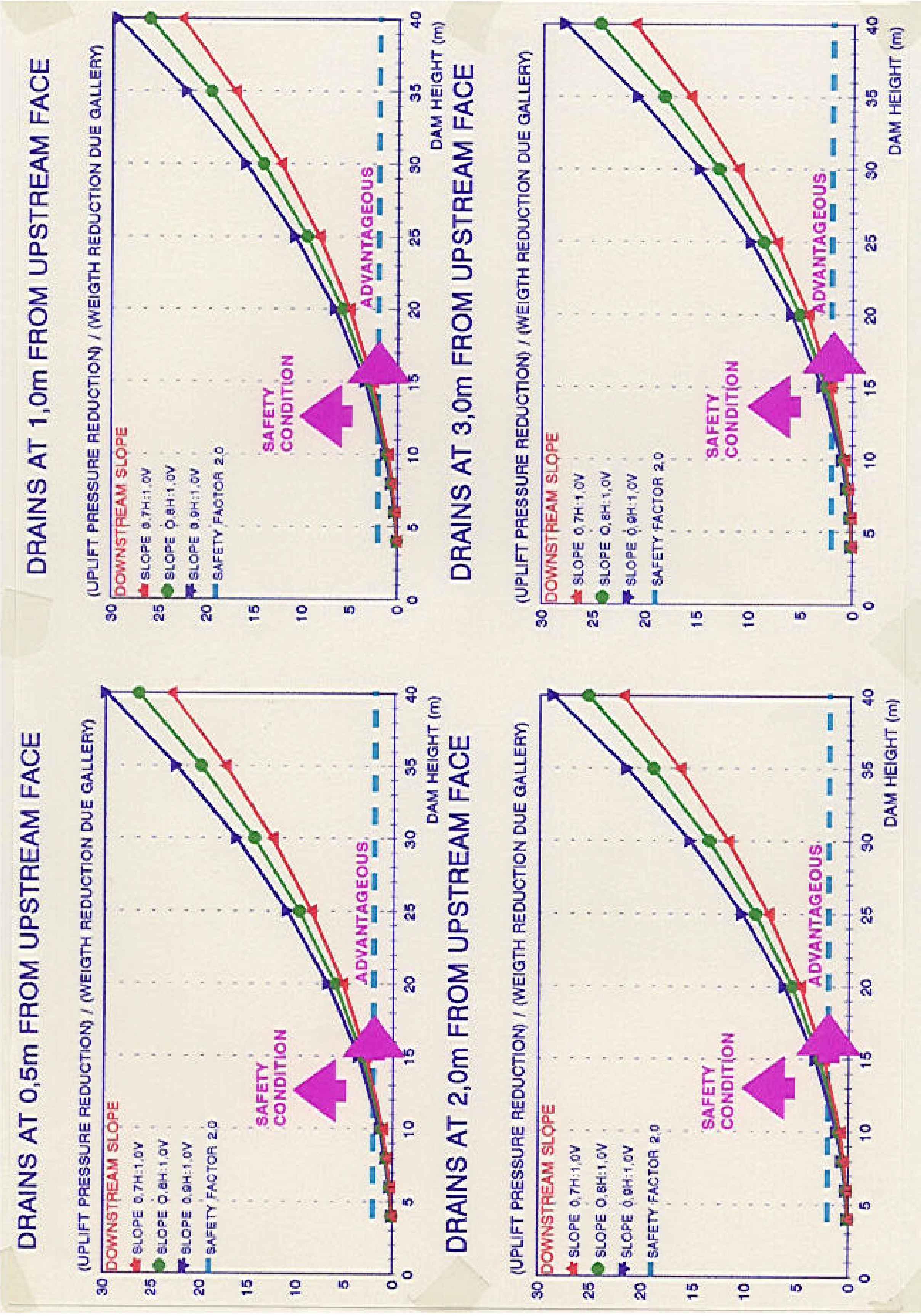

Figure 11 - Action of the drains position, ACI Criterion. (Drains from 0.5m up to 3.0m)

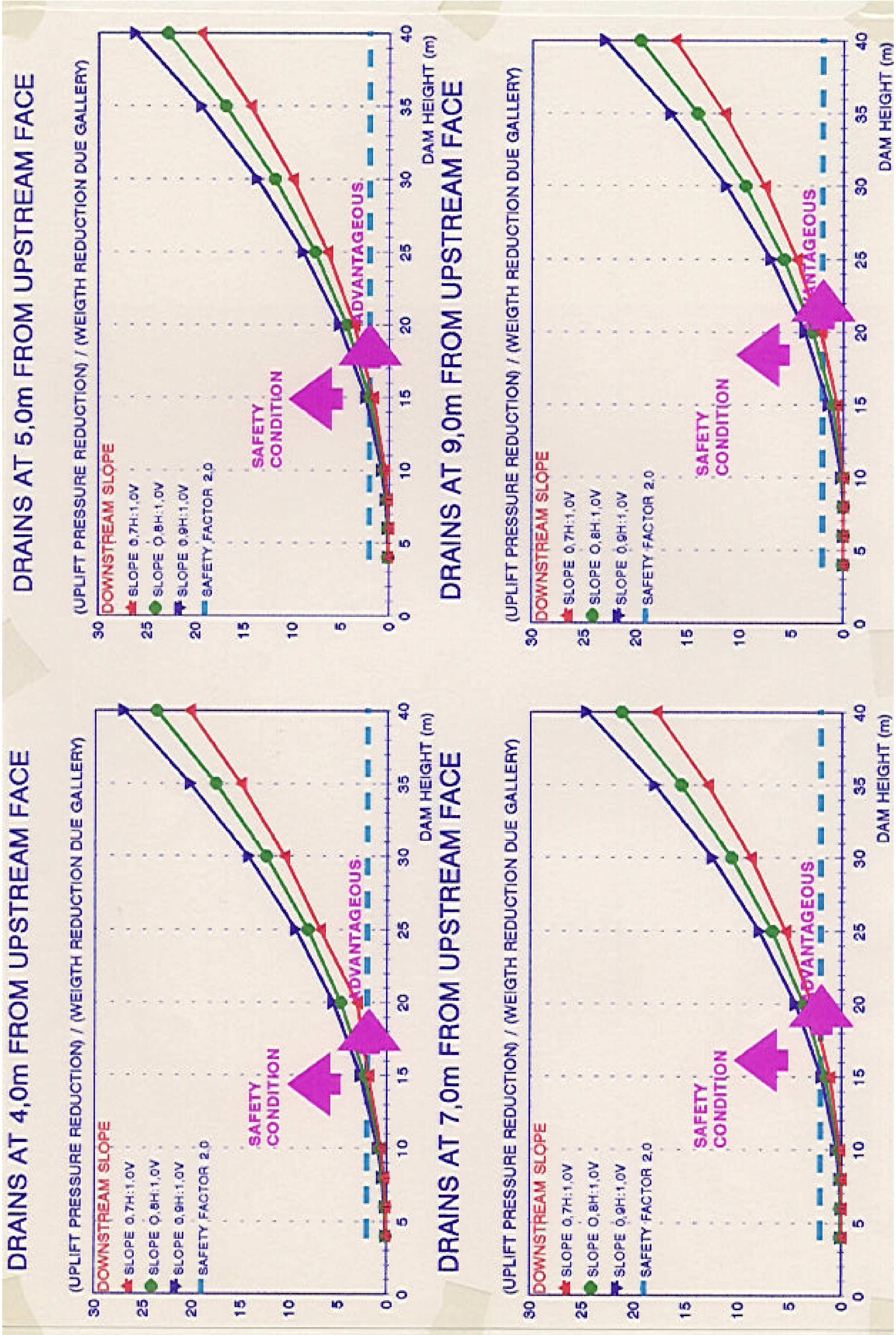

Figure 12 - Action of the drains position, ACI Criterion. (Drains from 4.0m up to 9.0m)

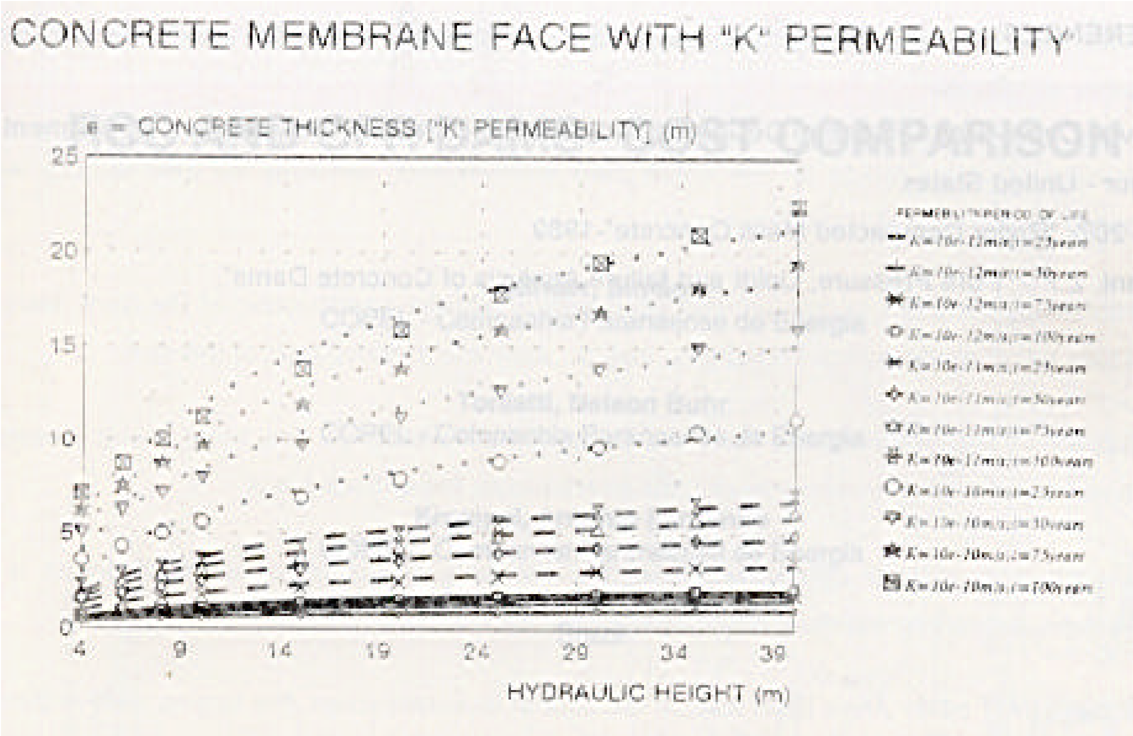

Figure 13 - Thickness of Concrete Face for several values of Permeability and Time

The gallery provides the advantage of a complementary action at any time, even during the Operation phase of the Dam.

It also allows the evaluation and monitoring of the process of percolation and to differentiate in a clear and precise way the origins of the percolations that are originated at the foundations, contraction points or from the concrete face.

It allows the water collected in the drainage curtain executed in the body of the dam to be suitably quantified, routed to the outside of the dam's body.

The evaluations conducted lead to the following statements:

- It is advantageous to incorporate the inspection and drainage gallery in dams with height over 10m;
- It is convenient to evaluate the properties (Permeability and Thermo-Volumetric Stability) required for the "Face Concrete" when considering the placement of the gallery;
- The methods of execution of the gallery have yielded simplification of the RCC methodology;
- The few occasional execution difficulties that may result from adopting the gallery for small height dams may never offset the potential benefits that it yields, and safety of being able to run inspections inside the body of the dam for remedial and monitoring actions.

7 - REFERENCES

[1]- "Gravity Dams- Part I- General Design Considerations"- Bureau of Reclamation- Department of the Interior - United States

[2]- ACI- 207- "Roller Compacted Mass Concrete"-1989

[3]- Bazant, Z.P.- "Pore Pressure, Uplift and failure Analysis of Concrete Dams".