COMMISSION INTERNATIONALE
DES GRANDS BARRAGES
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VINGT-TROISIEME CONGRES
DES GRANDS BARRAGES
Brasilia juin 2009
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# PLACE MOULIN ARCH-GRAVITY DAM DEFORMATIONS WITH HIGH WATER LEVELS (*)

Aldo MARCELLO
*Civil Engineer*, ING. C. MARCELLO S.R.L.

Sergio BALLATORE
*Chief Eng., Large Works Resp.* , CVA Compagnia Valdostana delle Acque S.P.A.

Paolo MEDA
*Civil Engineer*, ING. C. MARCELLO S.R.L.

ITALY

## 1. INTRODUCTION

The Place Moulin dam (Fig. 1) was realized in 1961-65 on Buthier River in the Western Alpes in Aosta Valley (Italy).

The valley at the dam site has a marked U-shape, and its geology is characterized by schist crystalline from metamorphism of sea sediments. The rock mass is rather homogeneous, with a compressive strength of the rock of ~ 100 MPa and a GSI index of the mass of 62÷70.

The dam is an arch-gravity structure, provided with a pulvino which makes symmetric the work (Fig. 2, 3).

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(*) *Place Moulin – Barrage poids voûte – Déformations avec hauts niveaux de la retenue*

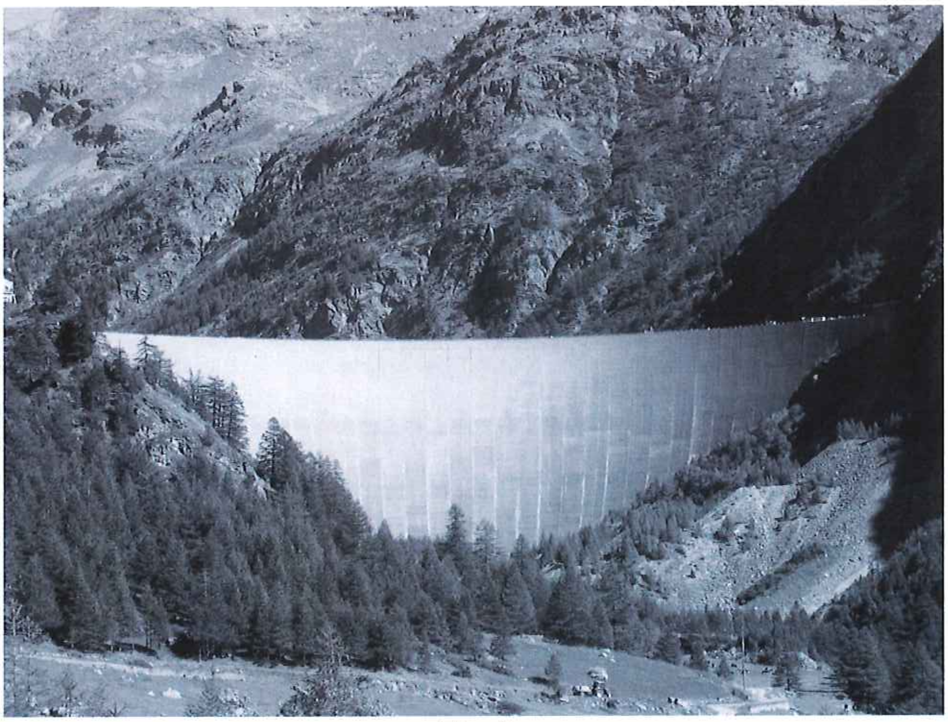

**Fig. 1**
The Place Moulin dam
*Le barrage de Place Moulin*

Its principal characteristics are:

| | | | |
|---|---|---|---|
| □ | Crest level: | 1970 | m El. |
| □ | Height above ground level: | 155 | m |
| □ | Crest length: | 678 | m |
| □ | Downstream base length: | ~ 200 | m |
| □ | Slenderness index[1]: | 18,8 | |
| □ | Top thickness: | 6,44 | m |
| □ | Base thickness: | 41,94 | m |
| □ | Concrete volume: | 1510000 | m3 |
| □ | Reservoir capacity: | 106 | hm3 |

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1 *In accordance with the formula proposed by Eng. G. Lombardi* $c = \frac{S^2}{V \cdot H}$ *where S, V, H are Surface, Volume and Height of the dam.*

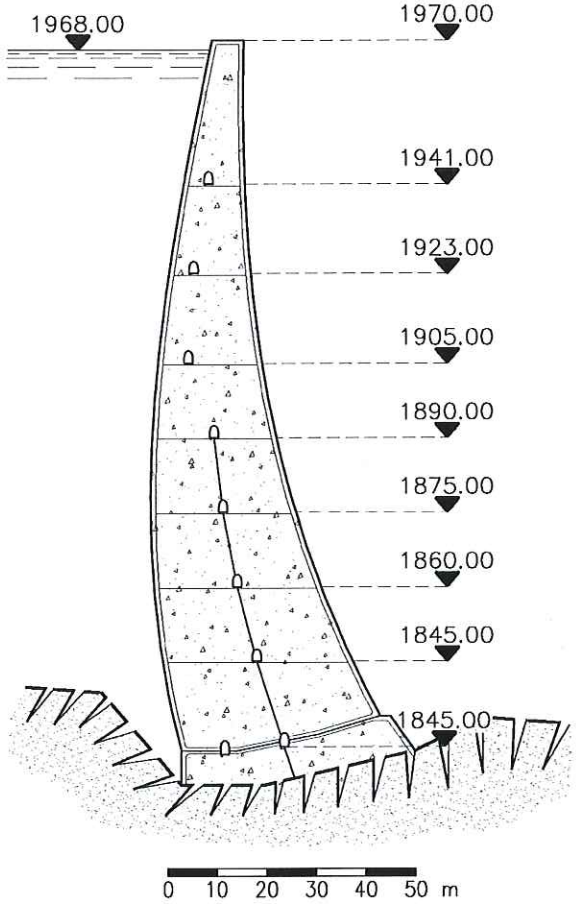


**Fig. 2**
Cross-section at crown
*Coupe en clé*

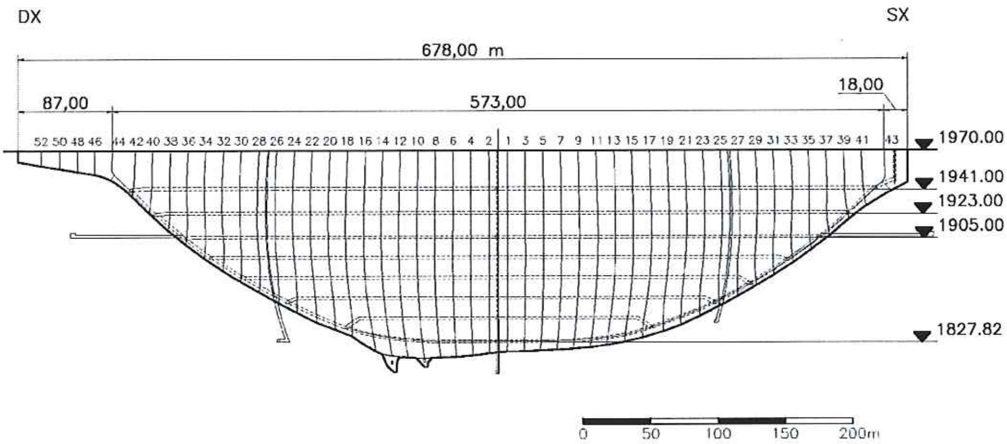


**Fig. 3**
Downstream view
*Vue aval*

## 2. THE BEHAVIOUR WITH HIGH WATER LEVELS

The dam, since the first years of operation, shows a loosening phenomenon of the foundation rock mass at the heel of the central part of the dam, with the increasing of the water level of the reservoir.

Also the last investigations prove that the loosening concerns a large layer of the rock mass (~20 m) and it is reported also by the increasing of the piezometric heads and of the seepages, at the drainage system in the gallery at the upstream toe (Fig. 4, 5 and 6).

The diagrams of the seepages and of the piezometric heads are reported in Fig. 7 for some cycles of reservoir operation. These diagrams well represent the reservoir levels with which the loosening phenomenon begins: ~ El. 1955 m for the piezometric heads, ~ El. 1960 m for the seepages.

Also the concrete temperature, of course, affects the phenomenon: at the same water level, seepages increase with cold conditions.

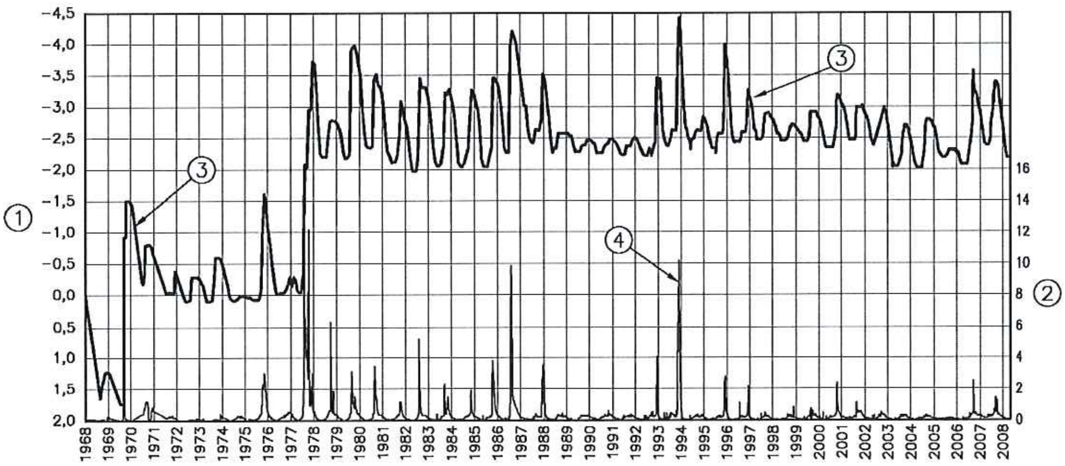


**Fig. 4**

Long-base extensometer in the rock foundation

*Extensomètre à longue base dans la fondation*

| | | | |
|---|---|---|---|
| 1 | Deformations in mm (negative the extension) | *1* | *Deformations en mm (négatif l' allongement)* |
| 2 | Seepage (l/s) | *2* | *Fuites (l/s)* |
| 3 | Extensometer measurement | *3* | *Mesures de l' extensomètre* |
| 4 | Seepage measurement | *4* | *Mesures des fuites* |

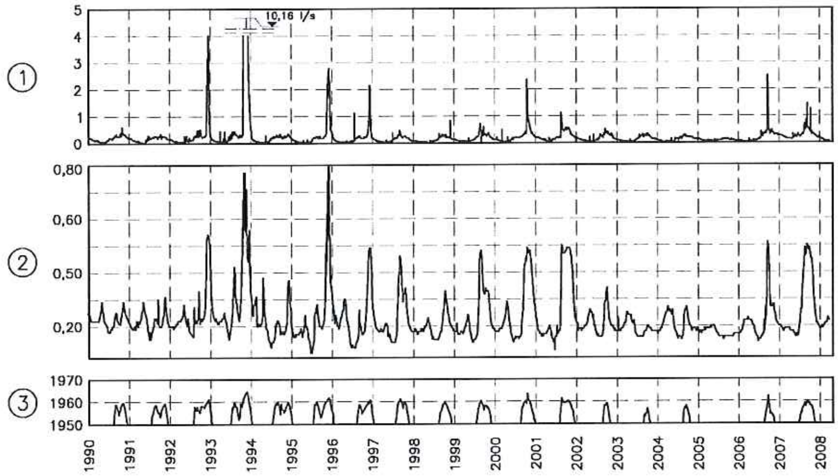


**Fig. 5**
Uplifts and seepages versus water levels
*Sous pressions et fuites en relation avec les niveaux du réservoir*

1 Seepages (l/s)
2 Uplifts / reservoir level
3 Reservoir level (El. m)

*1 Fuites (l/s)*
*2 Sous pression / niveau retenue*
*3 Niveau de la retenue (m)*

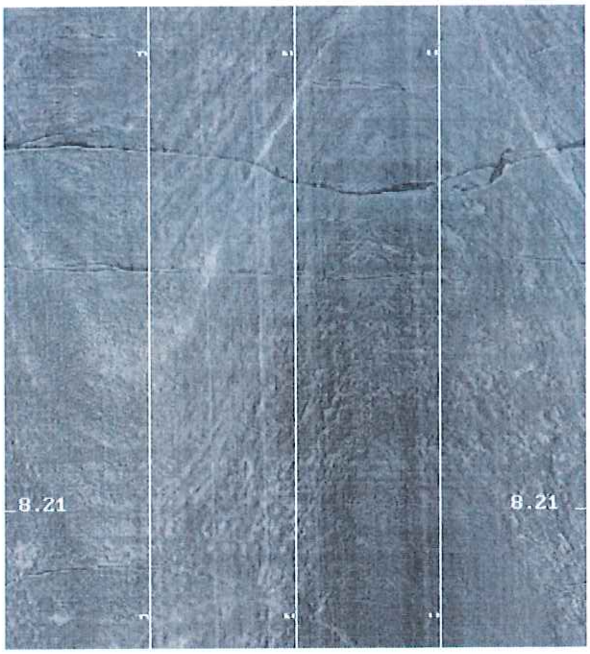


**Fig. 6**
Camera view of a drill hole. Crakes are visible at ~ 8 m of depth in the rock mass.
*Camera vue d' un forage. Les fissures sont visibles à ~ 8 m de profondeur dans la roche.*

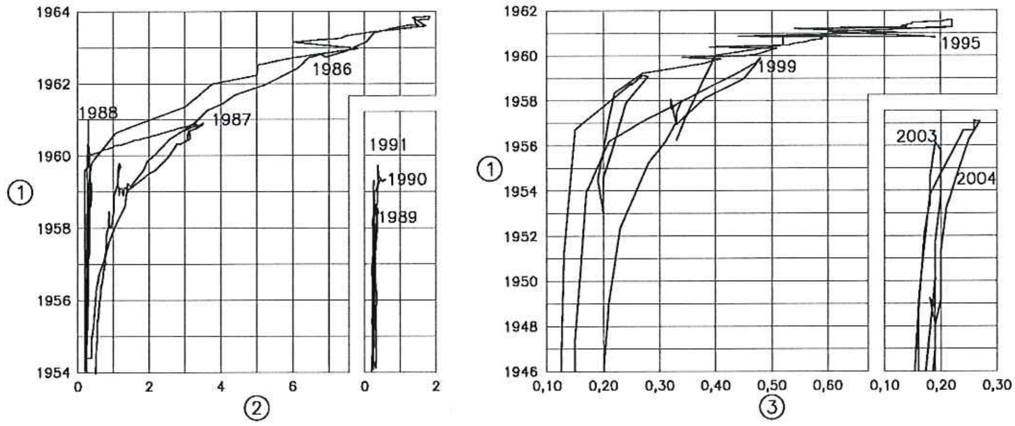


**Fig. 7**

Seepages and uplifts

*Fuites et sous pressions*

| | | | |
|---|---|---|---|
| 1 | Reservoir level (El. m) | *1* | *Niveau de la retenue (m)* |
| 2 | Seepages (l/s) | *2* | *Fuites (l/s)* |
| 3 | Uplifts / reservoir level | *3* | *Sous pression / niveau retenue* |

With the current reservoir operation, 8 m below the retention water level, there are very small flows in the rock mass: only limited seepages in the drainages are detected.

## 3. THE ALREADY EXECUTED WORKS

The bedrock has been widely treated during the dam construction works, with consolidation groutings: the grout curtain has been made on two lines, with a depth of 100÷40 m.

Just after the first fillings, the grout curtain has been integrated with chemical, phenolic (resorcine) and silicatic groutings, with a grout take higher than 100 l/m. These works continued throughout the years as a consequence of the increasing observed piezometric heads and seepage values.

After 15 years of operation, the treatment represented in Fig. 8 has been made at the upstream toe of the central part of the dam, with cement and chemical groutings, executed with the maximum retention water level (average grout take of resin: 128 l/m).

The immediate result of this treatment was successful, but his effect decreased in few years; however seepage detected values are lower than before the works.

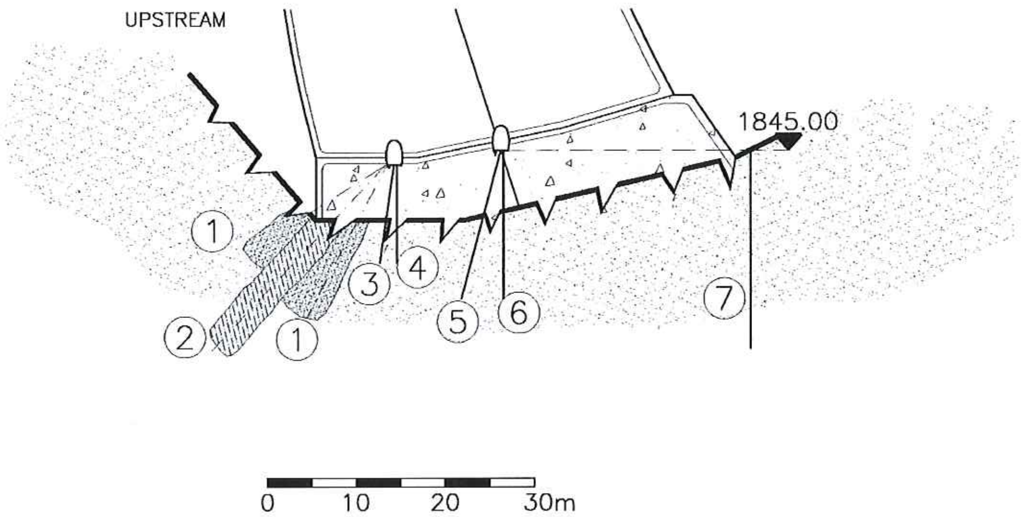


**Fig. 8**
Foundation treatment (year 1977-78)
*Traitement des fondations (année 1977-78)*

| | | | |
|---|---|---|---|
| 1 | Cement grouting | *1* | *Injection de ciment* |
| 2 | Resin grouting | *2* | *Injection de résine* |
| 3 | Existing drains | *3* | *Drains existants* |
| 4 | New piezometers | *4* | *Nouveaux piézomètres* |
| 5 | Existing drains | *5* | *Drains existants* |
| 6 | New piezometers | *6* | *Nouveaux piézomètres* |
| 7 | Downstream piezometers | *7* | *Piézomètres à l' aval* |

## 4. THE PLANNED WORKS

The Owner of the powerplant (C.V.A. S.p.A.), has promoted studies in the geomechanical and engineering fields with the purpose of recovering the total capacity of the reservoir.

The analysis and the evaluations started, obviously, from the data of the monitoring system.

In this analysis, the measures of the pendulum in crown of the dam show an inelastic movement (upstream-downstream), accumulated in the years, of 7 mm at the toe of the dam and of ~ 30 mm at the crest. The elastic deformation, with the water level limited at El. 1960 m, has a range of ~ 50 mm at the top of the dam.

In the gallery located in the body of the dam at El. 1941 m (29 meters below the crest), 24 dilatometers for the 42 dam joints are installed, which show an average opening of 0,5÷0,6 mm, due to the cooling of concrete, that in the normal operation of the reservoir is in accordance with the minimum water level, around El. 1870 m (Fig. 9).

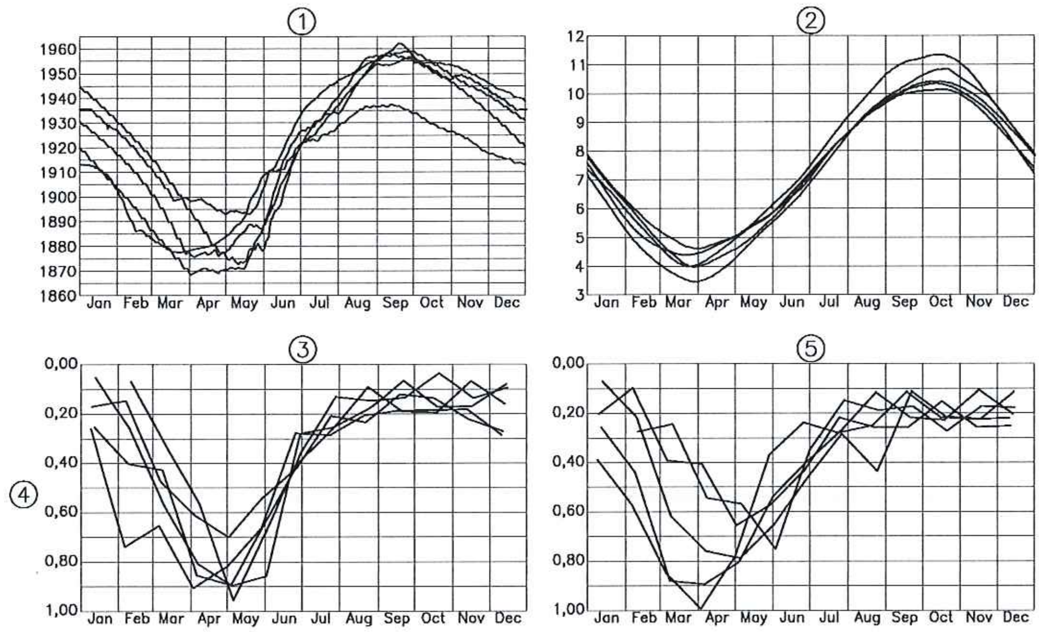


**Fig. 9**

Construction joints measurement

*Mesures des joints de construction*

1 Reservoir water level (El. m)
2 Concrete temperature (°C)
3 Joint n° 36
4 Joint opening (mm)
5 Joint n° 5

*1 Niveau de la retenue (m)*
*2 Température du béton (°C)*
*3 Joint n° 36*
*4 Ouverture du joint (mm)*
*5 Joint n° 5*

These observations are synthesized in an interesting diagram of the movements detected with the central pendulum during the annual cycles. In Fig. 10 only the cycle 2003-2004 is represented. The diagram shows, with the increasing of water level and the concomitant increasing of concrete temperature, that there is no cantilever deformation until a water level of 1945 m: the thermal expansion in fact counterbalances the joints closure and the cantilever inflection.

For water level at El. 1945 m begins the increase of the piezometric heads at the toe of the dam. For higher loads, the crest deformation increases, and, in the arch-cantilever scheme, the contribution of the more elevated arches grows of importance.

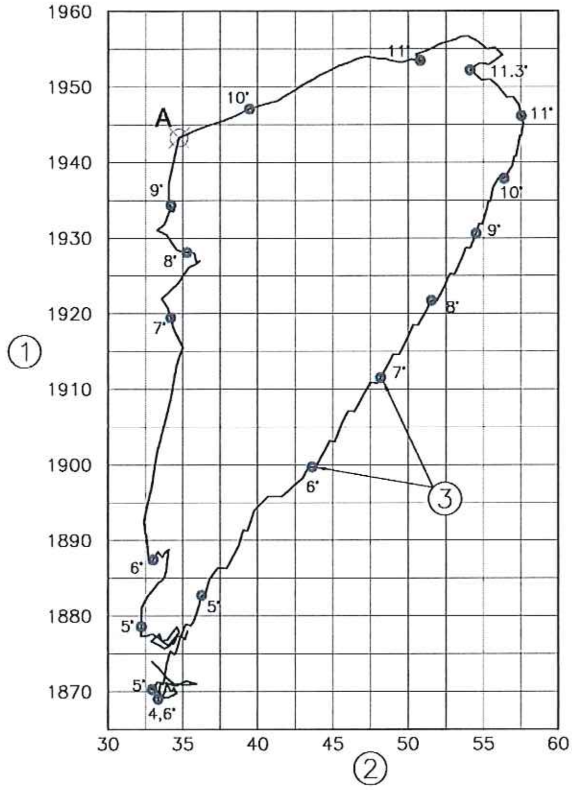


**Fig. 10**
Central pendulum annual (2003-2004) cycle
*Cycle annuel (2003-2004) du pendule central*

| | | | |
|---|---|---|---|
| 1 | Reservoir water level | *1* | *Niveau de la retenue (m)* |
| 2 | Crown deformation (mm) | *2* | *Déformation de la clé (mm)* |
| 3 | Concrete temperature (°C) | *3* | *Température du béton (°C)* |

The important hysteresis phenomenon, between the two phases of filling and emptying, is due to the behaviour of the foundation rock mass.

The numerical analysis, carried out including dam joints simulation, confirms that the cantilevers stresses get reduced during the filling of the reservoir, in particular at the abutments, taking advantage of the more elevated arches support (Fig. 11).

In other words, the behaviour of the dam shows that, at the lowest loads, the arches do not fully act, as if they have their springings in the stocky cantilevers at the abutments.

With the increasing of the water load, the cantilevers find the necessary stability resources in the amplification of the arch effect (in the horizontal direction towards the rock abutments, in the vertical one towards the crest of the dam).

These analyses suggested that the reduction of seepage and uplift at the upstream toe of the dam can be achieved through an arch effect of the more elevated arches of the dam, even for the lower loads.

WATER LEVEL : 1950

WATER LEVEL : 1968

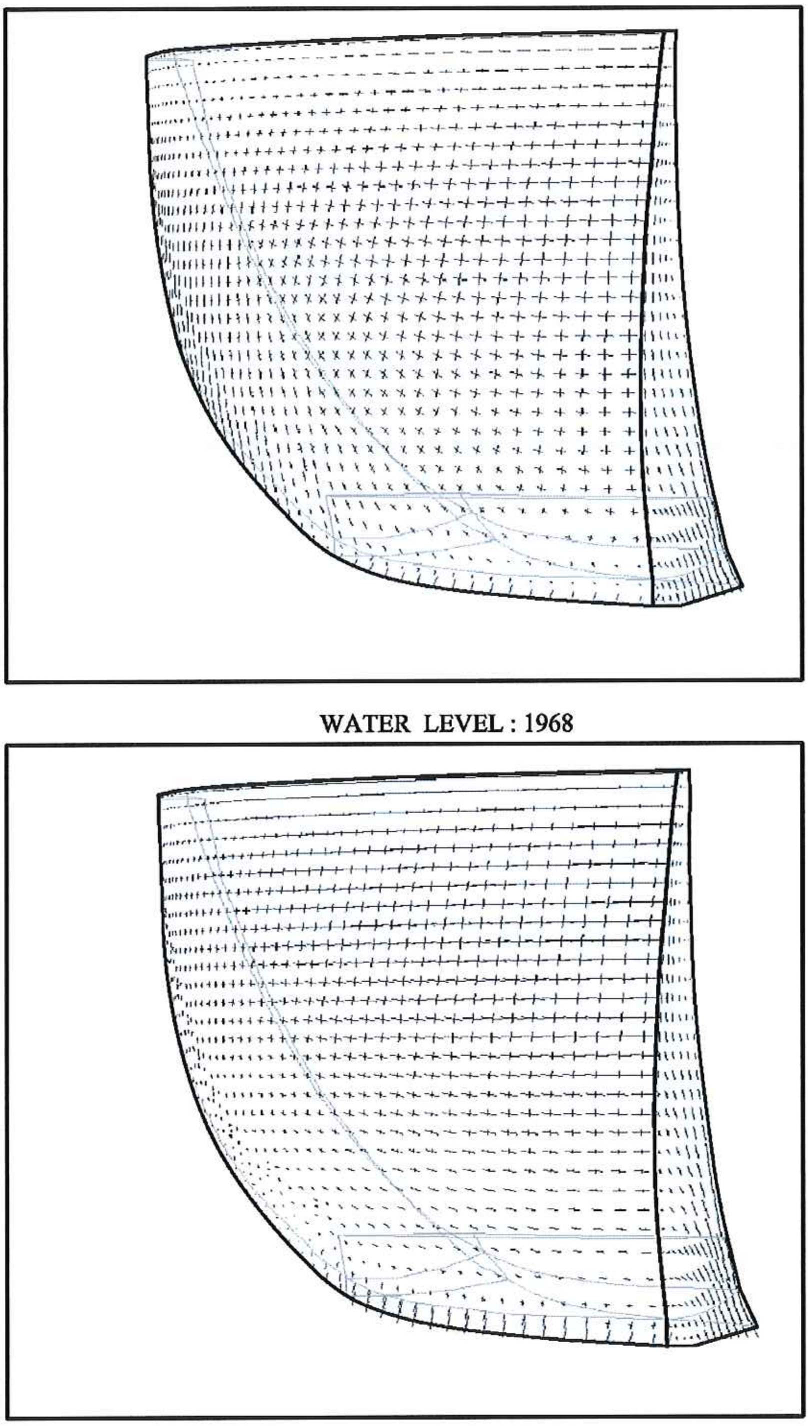

**Fig. 11**
Numerical model: principal stresses - extrados
*Modèle numérique : contraintes principales - extrados*

Consequently, was taken the decision to resume the grouting of the dam joints in the highest band of the structure (above El. 1923 m), with the purpose to cancel the actual winter opening of the joints, so as to take advantage of the contribution of the more elevated arches also at the lowest water levels. In this way, with the filling of the reservoir, all the cantilevers will have the " immediate" contribution of the arches, without needing to be inflected till the complete joints closure.

With reference to the diagram of Fig. 10, a moving back and a raising of the point A of the graph is expected, and consequently a reduction of the maximum absolute displacement of the crown and of the width of the hysteresis in the emptying phase of the reservoir.

The joints re-grouting is scheduled during winter 2009; for this reason today it is obligatory to speak only about the expectations.

## 5. THE JOINTS RE-GROUTING TESTS

In 2008, when the concrete temperatures and the reservoir levels were the lowest (April), tests on some joints have been executed, to define the operative procedures and the characteristics of the grout mixes to be used for the re-grouting interventions (scheduled for winter 2009). Two joints between the El. 1923 m and El. 1941 m. and four between elevation 1941 m and the dam crest have been tested.

The first result obtained concerned the impossibility to exploit the original circuits, used during the construction of the dam. In fact, the water circulation tests in these circuits showed that the original grouting valves, after more than 50 years, are no more operative because completely opened or strongly closed, also for the high pressures.

For this reason, the decision to make new drillings across the joints (Fig. 12) has been taken. For each grouting field, two grouting drillings at the base (length: 3,5 and 5,5 m) and two for the release of air (length: 2÷3 m) have been executed.

First of all, water circulation tests have been made, pumping from the new drillings. These tests have the purposes of verifying the efficiency of the new grouting system, of checking the connection along the joint plane, of executing a washing of the joint plane and of wetting the surfaces before of the grouting.

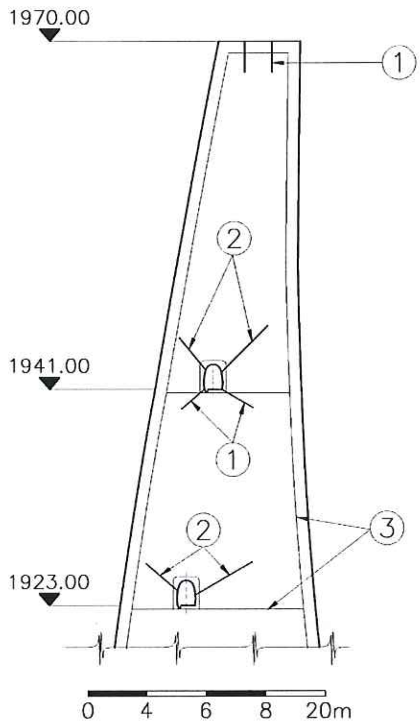


**Fig. 12**
Joint re-grouting
*Re-clavage des joints*

| | | | |
|---|---|---|---|
| 1 | Release air pipes | *1* | *Conduites de purge* |
| 2 | Grout holes | *2* | *Forages d' injection* |
| 3 | Sealing strips | *3* | *Lames d' étanchéité* |

The water pressures ranged between 5 and 10 bar at the intake of the hole. These tests have established that all the new drillings are in connection with the joint field and that the pumped water reaches the holes for air release at the top of the area.

Subsequently, the grouting has been carried on using a mix obtained with a microfine Portland cement, with a Blaine fineness of 800 $m^2/kg$. This grout mix has been made with a water/cement ratio of 0,7 and with the addition of a water reducing agent: 2,5 l every 100 kg of cement. The grouting pressures were between 6 and 15 bar. The grout mix, pumped into the drillings, reached the holes for air release in an average time of one hour from the beginning of grouting.

During the water circulation tests and the successive groutings, the width of the treated joints and of the two neighbouring ones, has been monitored through extensometers installed across the joints in the gallery at El. 1941 m. The analysis of these measures show a minimum and completely reversible opening of the joint during the water circulation test. The grouting caused instead a considerable expansion of the joint, not recovered during the successive weeks. For the joints treated during the tests, the expansion due to grouting was between 0,2 and 0,5 mm, compared with the annual cycle that causes an average opening of 0,5 mm. The measures also show that the neighbouring joints to the treated one have not been practically influenced.

In Fig. 13 are represented the only results obtained at the field El. 1923-1941 m of the joint n. 2 (in crown). The last six years measures of the joint extensometer at El. 1941 m are reported in function of the months of the year. The detail of the executed measures during grouting and in the immediately successive period is also represented.

The positive result of the tests has allowed the definition of the preparatory works which will be all executed in summer 2008, so that the groutings of the 85 fields could be executed during the short available period (two winter months), due to the thermal conditions of concrete and the reservoir water levels.

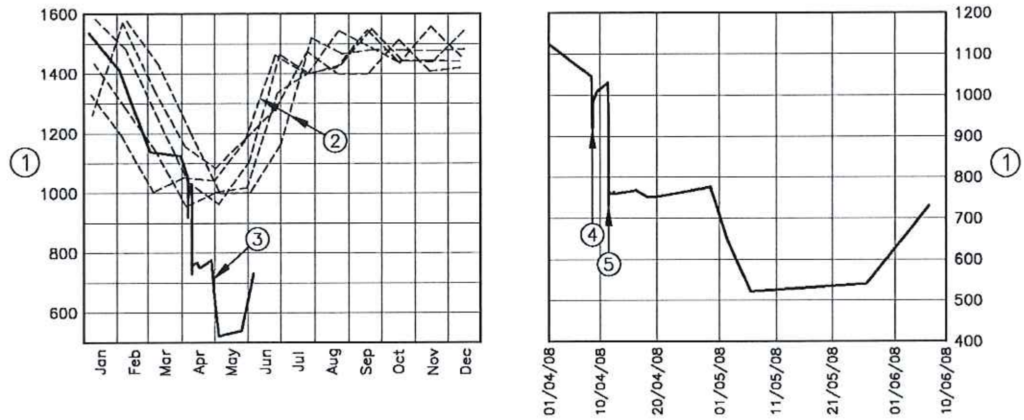


**Fig. 13**
Joints re-grouting tests
*Essais de re-clavage des joints*

| | | | |
|---|---|---|---|
| 1 | Joint expansion (μm) | *1* | *Ouverture du joint (μm)* |
| 2 | Annual joint measurement | *2* | *Mesures annuels* |
| 3 | During re-grouting test measurement | *3* | *Mesures pendant l' essai de re-injection* |
| 4 | During water test | *4* | *Mesures pendant l' essai d' eau* |
| 5 | Re-grouting phase | 5 | *Phase de re-injection* |

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## SUMMARY


Place Moulin Dam is located in Valle d' Aosta (Italy) and it was built during the period 1961-1965 in Valpelline, a U-shaped valley. It is a 155 m high, double-curvature, arch-gravity dam. The crest elevation is 1970 m a.s.l., and its length is 678 m. The structure is subdivided by 42 radial joints, and bounded by a perimetral joint.

Like many others arch-dams built in U-valleys, this dam is affected by a loosening phenomenon into the bedrock at the upstream toe. The typical behaviour of the dam is characterized by a marked discontinuity while increasing the reservoir level: above certain water levels, it is observed the rise of extensimeter measures, seepages and piezometric heads in the foundation. Past interventions, concerning various grouting supplementary works in the rock under the upstream toe, gave satisfying initial results, but their efficacy reduced in a few years.

The results of a three-dimensional numerical model of the dam, allow to assert that the cooperation of the higher arches becomes important only with the loads due to higher water levels. The study of the data from the monitoring system confirms the numerical model results, and shows that radial joints, open at low reservoir levels (concomitant with low concrete temperatures), are always closed with higher levels.

At the end of these analyses, it seems clear the opportunity to re-grout radial joints in higher arches of the dam. Objectives are to cancel the strain now required to close joints and to make higher arches able to collaborate even with lower reservoir levels.

This year in April, when the concrete temperatures and the reservoir levels were lowest, re-grouting tests on some radial joints were executed.

The positive results of these tests confirm the executive possibility of re-grouting all the 42 radial joints of the dam and allow to define the operative procedures for these interventions, scheduled for winter 2009.