SUSA GORGE: A DEMODULATION RESERVOIR FOR PONT VENTOUX HYDRO POWER PLANT[1]

Ezio Baldovin
Dr. Eng.
Geotecna Progetti – Consulting Engineers – Milano

Nicola Brizzo
Dr. Eng.
Iride Energia – Torino

ITALY

1. INTRODUCTION

Iride Energia S.p.A. (once A.E.M. of Turin S.p.A.) has completed the construction of the new Pont Ventoux-Susa Hydro Power and Pump Plant, now in phase of final acceptance.

Located in High Susa Valley, it will substitute two old flowing plants built in 1910 and 1923, doubling the production of electric energy with diurnal operation of the turbines and night repumping of the water.

The installed power is 150 MW and the foreseen production is bigger than 400 GWh/year.

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[1] *Gorge de Susa: un réservoir de démodulation pour l'Aménagement hydroélectrique de Pont Ventoux*

2. THE HYDRO POWER PLANT

The water is diverted at Pont Ventoux from Dora Riparia River, tributary of Po River, with a maximum flow discharge of 34 m^3/s and, after an average geodetic jump of about 515 m, it is returned to the same river about 1 km upstream of Susa Town (Fig. 1).

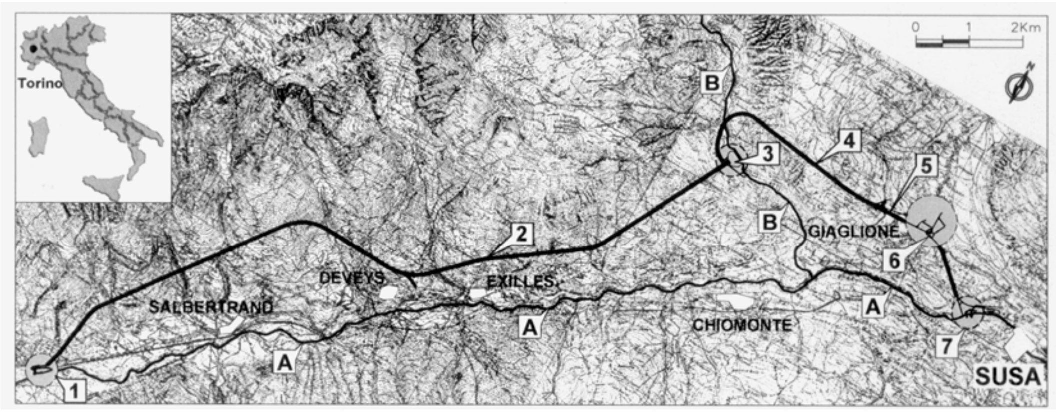

Fig. 1

Pont Ventoux – Susa Hydro Power Plant lay-out

Plan général de l'Aménagement Hydroélectrique de Pont Ventoux – Susa

A	Dora Riparia River	*A*	*Fleuve Dora Riparia*
B	Clarea River	*B*	*Fleuve Clarea*
1	Pont Ventoux gate-structure Dam	*1*	*Traverse de Pont Ventoux*
2	Conveyance tunnel	*2*	*Tunnel de dérivation*
3	Clarea Basin	*3*	*Bassin de Clarea*
4	Pressure tunnel	*4*	*Tunnel en pression*
5	Penstock in shaft	*5*	*Conduite forcée en puits*
6	Underground power station	*6*	*Usine hydroélectrique souterraine*
7	Susa Dam	*7*	*Barrage de Susa*

The plant lay-out is essentially as it follows:

- gate-structure dam, intake and ancillary works on Dora Riparia River;
- conveyance tunnel in left side of Dora Riparia River, 14 km long;
- regulation basin outside the river-bed in Clarea Valley;
- pressure tunnel, about 4 km long;
- surge shaft;
- penstock in shaft;
- underground power station, equipped with 2 Francis turbines with vertical axis; a 13 m^3/s pump is coupled with one of them;
- downstream surge shaft;
- tailrace tunnel to the demodulation reservoir created by Susa Gorge Dam.

3. UNDERGROUND POWER STATION

The underground power station has been excavated in a cavern 18.8 m wide, 51.35 m long and 46.0 m high, for a total volume of about 35.000 m3 (Fig.2), in Giaglione Municipality.

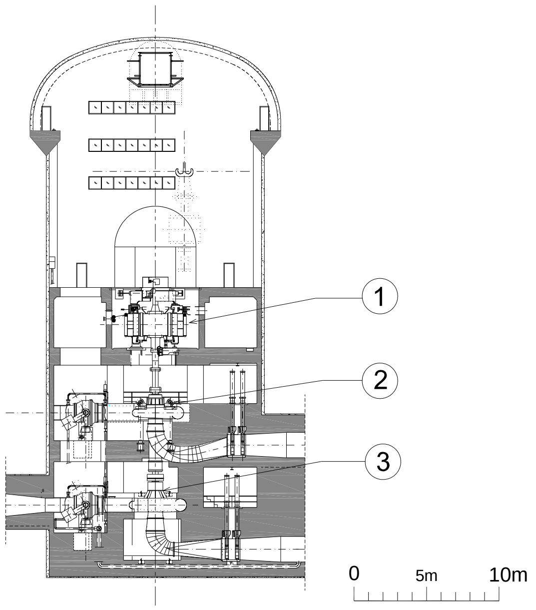

Fig. 2
Giaglione Hydro Power Station vertical section
Coupe verticale de l'Usine Hydroélectrique de Giaglione

1	Generator	1	Générateur
2	Turbine	2	Turbine
3	Pump	3	Pompe

The floor of the machines room is at 495,00 m a.s.l.; it can be reached by the main access tunnel about 1.170 m long; a second escape tunnel, about 460 m long, is available for emergency situations.

To warrant the safety of the operations, the transformers have been located in independent caverns; furthermore all the escape ways lead to elevations which are higher than the maximum water level of Susa downstream Reservoir.

The machines consist of a binary group (Francis turbine and generator) and of a ternary group (Francis turbine, generator and pump), both with vertical axis.

The turbine, with a runner of 15+15 paddles, has maximum diameter 1840 mm, power 75 MW and speed of 750 rpm. The generator has an apparent power of 85 MVA, nominal voltage of 15 kV and nominal speed of 750 rpm.

The groups are dimensioned for a discharge from 34 m3/s to 28.4 m3/s; the range covers in the best way the real availability of water in Dora Riparia River, concentrating the turbining operations in the full hours.

The pump is a mono stage centrifuge, with a maximum discharge of about 13 m3/s.

The connection of the power station with the 132 kV national transmission line is located in the TERNA transformation station of Venaus, connected through buried cables to an electric blinded station near the inlet of the access tunnel.

4. MODULATION RESERVOIRS

The production of energy and the pumping occur between two reservoirs of storage and modulation. Their location and features have been chosen, in the respect of the environmental conditions and ties, in order to simplify the operation and the maintenance and to fit the natural flow characteristics of the river.

4.1 UPPER RESERVOIR OF CLAREA

It has been obtained by means of large modelling works, including excavation and embankment of the alluvial and detrital deposits of the valley bottom and the diversion of Clarea River for 800 m on its left bank. The reservoir is harmoniously inserted in the natural configuration of the site, which has been accurately preserved in its typical succession of rock crests and more or less steep falls covered with alpine vegetation [2].

4.2 LOWER RESERVOIR OF SUSA

[2] ICOLD – XXII Congress R.51-Q.86.

This basin is formed by a dam on the Dora Riparia River, 1 km upstream of Susa Town (Fig.3). In a stretch of the valley named “Le Gorge” the river flows between narrow and steep characteristic rock walls assuming a meandering and turbulent course.

The reservoir demodulates the water discharged by the power station through a tailrace tunnel 1.6 km long. Several other solutions were investigated and eventually rejected for this impound: among them some considered indeed a big underground basin with an enlargement of the tailrace tunnel.

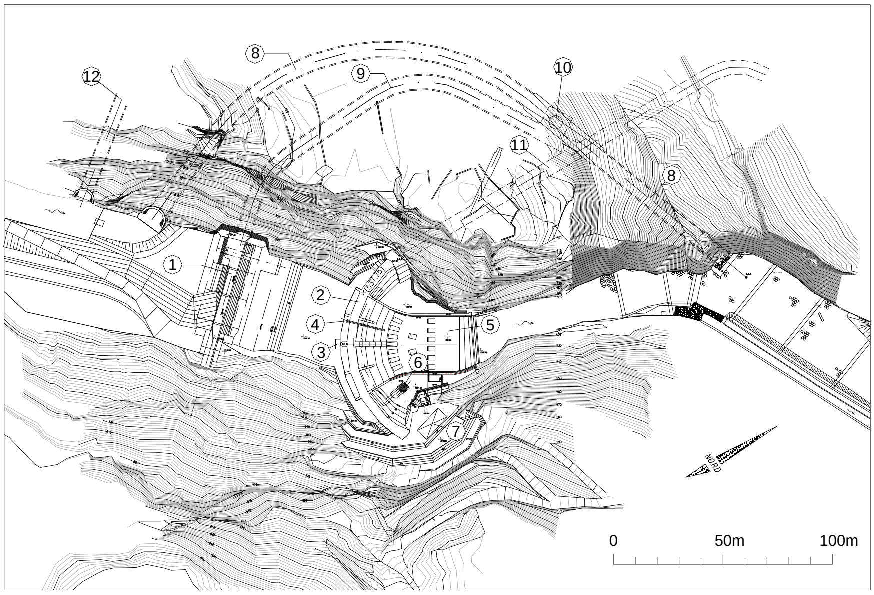

Fig. 3
Susa Gorge Dam general lay-out
Plan général du Barrage de Gorge de Susa

1 Cofferdam
2 Dam crest
3 Bottom outlet
4 Minimum vital flow pipe
5 Stilling basin
6 Access shaft to the gates chamber
7 Service house
8 Provisional diversion tunnel and bottom outlet tunnel
9 Access tunnel to the cofferdam crest
10 Gates shaft
11 Access tunnel to the dam crest
12 Tailrace tunnel

1 Batardeau
2 Crête du barrage
3 Vidange de fond
4 Tuyau pour le minimum débit vital
5 Bassin d’amortissement
6 Puits d’accès à la chambre des vannes
7 Maison de service
8 Tunnel de déviation provisoire et de vidange de fond
9 Tunnel d’accès à la crête du batardeau
10 Puits des vannes
11 Tunnel d’accès à la crête du barrage
12 Tunnel de restitution

The reservoir is about 1.100 m long. It has a capacity of 470.000 m^3 with the normal water surface at 531.2 m a.s.l.; its maximum water depth is 23.7 m.

For the regulation of the discharged flows and the pumping, the daily water level varies between 515.0 and 531.2 m a.s.l.

The hydraulic works of connection with the power plant, in particular the outlet of the tailrace tunnel from the power station, are all located on the left bank.

Not far from the dam, an underground bypass permits to discharge the water from the power station directly downstream, without entering the demodulation reservoir.

The main bottom outlet tunnel, designed for a maximum discharge of 142 m^3/s, is also located on the left.

The intake elevation of this outlet, as well as the arrangements of the river bed and of the cofferdam, allow to divert, with medium discharge flow, the river in conditions of minimum impound and so to determine the hydraulic transport of an important fraction of the alluvium cumulated upstream of the cofferdam.

Maintenance operations to remove the residual deposits are scheduled every 5÷10 years.

Finally a bottom outlet in the dam body with maximum discharge of 49 m^3/s rules the partial lowering of the reservoir until the elevation 521.0 m a.s.l.; its intake structure protected by the cofferdam makes it possible also to empty the dead storage by the dam.

The spillway is located in the central part of the dam and is able to discharge a flow of 1100 m^3/s, corresponding to a time return flood of 1000 years.

5. SUSA DAM

5.1 SITE GEOMORPHOLOGY

The Dora Riparia River is dammed in a section where the river bed elevation is 507.5 m a.s.l.; the catchment area is about 697 Km^2, reaching its maximum altitude at 3060 m a.s.l..

The river, from the intake of the power plant at Pont Ventoux until the section of the dam, flows for about 20 Km in a SW-NE direction, with gradients of 3% and has often stream-like characteristics.

In the whole catchment area, Upper Pennidic formations outcrop; in particular, in its last stretch the river cuts a Piedmont Unit called “Calcescisti con pietre verdi”. The valley has here a typical glacial shape; its bottom is filled with coarse alluvial sediments, some tens meters thick.

In the dam section the valley has the aspect of a deep and narrow gorge (“Le Gorge”). Immediately downstream, the river bed suddenly changes its direction to the right (Fig. 4) and the valley carries on its final mountainous stretch, close to Susa Town.

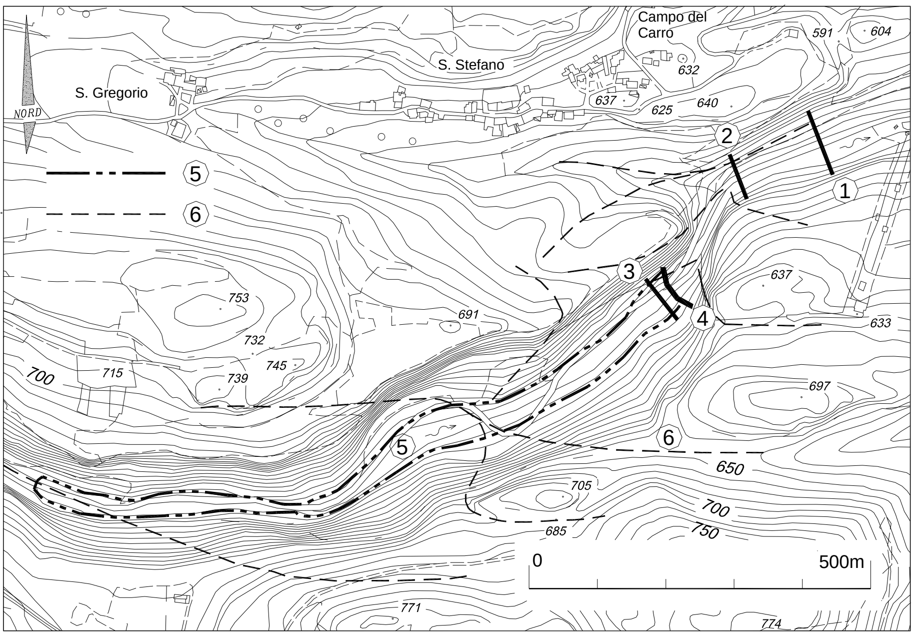

Fig. 4
Susa Gorge Reservoir geological plan
Plan géologique du Réservoir Gorge de Susa

1-2 1983 preliminary design dam sections
3 1990 preliminary design dam section
4 1996 final design dam section
5 Maximum water level
6 Main faults

1-2 Sections du barrage (avant projet 1983)
3 Section du barrage (avant projet 1990)
4 Section du barrage (projet final 1996)
5 Niveau maximum de l’eau
6 Failles principales

5.2 THE CHOICE OF THE DAM TYPE

The geostructural conditions and the favourable deformability, strength and permeability of the calcschists suggested to build a concrete dam. This solution obliged indeed to remove the alluvial material of the valley bottom for a depth of about 30 m, even if only for a width of 40-50 m.

Otherwise the slope of the sides (≈80°), the shape and the ratio width-height of the gorge, nearly 1.4, made it possible to realize a dam with arched axis, so that, with the final design optimization, the geometry of the structure resulted that of a typical arch-gravity dam.

Additional reasons to support this choice were the low seismic level of the site (a=0.04g) and the possibility to place, in the central part of the dam, the spillway to discharge the 1000 year time return design flood.

5.3 STRUCTURE OF THE DAM

The dam has a maximum height of 57 m on the foundation plan and of about 30 m on the river bed. The crest, at elevation 537.75 m a.s.l., is 4 m wide and has a length of 92 m.

The vertical axis section, oriented WSW-ENE, has the upstream face lightly curved, while the downstream profile is straight with an inclination of 0.3/1, but it is hidden, in the average and upper parts, by the thickening due to the spillway structure (Fig.5).

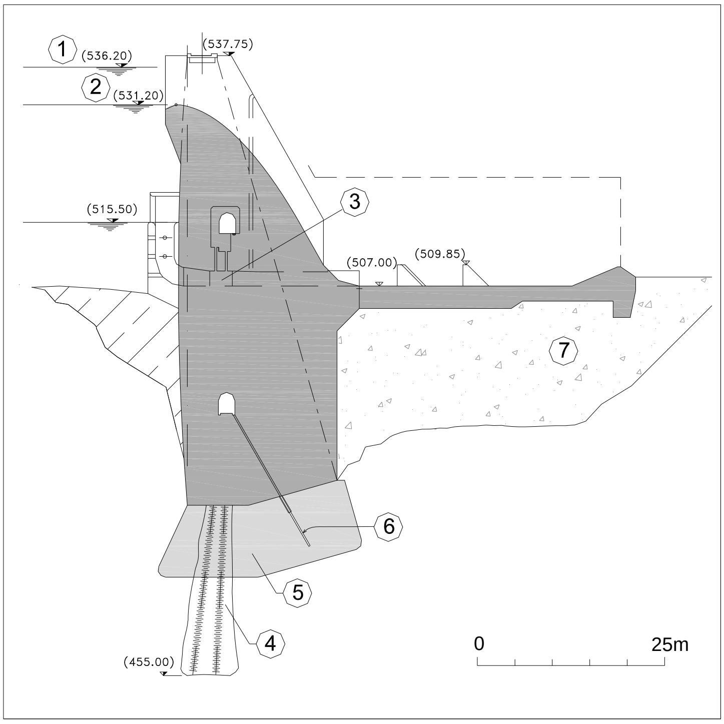

Fig. 5
Dam cross-section on the spillway
Coupe-type du barrage sur le déversoir

1 Maximum water level	1 Niveau maximum de l'eau
2 Normal water level	2 Niveau normal de service
3 Bottom outlet	3 Vidange de fond
4 Grout curtain	4 Ecran d'injection
5 Consolidation grouting	5 Injections de consolidation
6 Drainage holes	6 Trous de drainage
7 Rock blocks mixed with concrete	7 Enrochement enrichi avec ciment

The width at the base, in the maximum height section, is about 20 m.

The structure shape is a slightly asymmetric vault partially constituted by circular symmetric arches of constant thickness; near the abutments the arch thickness increases towards downstream.

Due to the presence of construction joints, no structural contribution is expected from the increasing section created by the spillway profile.

The upstream radius of the arches are between 50.0 m, on the crest, and 40.2 m; downstream they vary from 46.0 m to 20.2 m.

During the construction the structure has been divided in seven vertical elements 12÷16 m wide; the joints have been then sealed up with cement injections in the cold season. Their imperviousness is assured by a system of water-stops.

To avoid surface crack phenomena a reinforcement steel mesh has been placed just below the dam faces.

A system of drainage pipes (20 cm diameter) is located in the structure, 3÷4 m far from the upstream face.

The calculated main maximum stresses are the following:

Concrete compression (dead weight, hydrost. press., thermal, seismic)	= 1.5 MPa
Concrete tensile stress (dead weight, thermal)	= 0.8 MPa
Foundation compression (dead weight, hydrost. press., thermal, seismic)	= 1.2 MPa

The dam is equipped with a complete monitoring system, which can be interrogated also at distance. It gives information about the state of the structure, the levels of the water table and the deep seepages through the abutment and the shoulders.

5.4 THE ABUTMENT AND THE GROUT CURTAIN

The dam is completely founded on rock. To reach the bedrock, alluvial material about 30 m thick has been removed. The foundation falls entirely in the geological formation “Calcescisti con pietre verdi”, generally compacted and with good geotechnical quality (RQD > 75%).

The schistosity presents a dip direction towards SW of about 20° on the left bank and towards WNW of 30° on the right. The rocky mass is interested by a system of joints favourably oriented in regard to the arches abutments: in fact on both the banks they result normal or parallel to the direction of the resultant of the structure loads.

Among the main rock discontinuities only one (“”C””) is relevant for the foundation of the dam. It has a dip direction towards N of 45°: on the right bank it lies at elevations higher than the dam abutment; on the left bank it is located immediately under the maximum water level and dips in the thrust direction, rapidly leaving the foundation of the dam.

Due to the presence of this discontinuity, in the upper part of the left abutment a local reinforced “pulvino” has been introduced between the dam structure and the abutment in order to transfer the stresses directly to the compact rock (Fig.6).

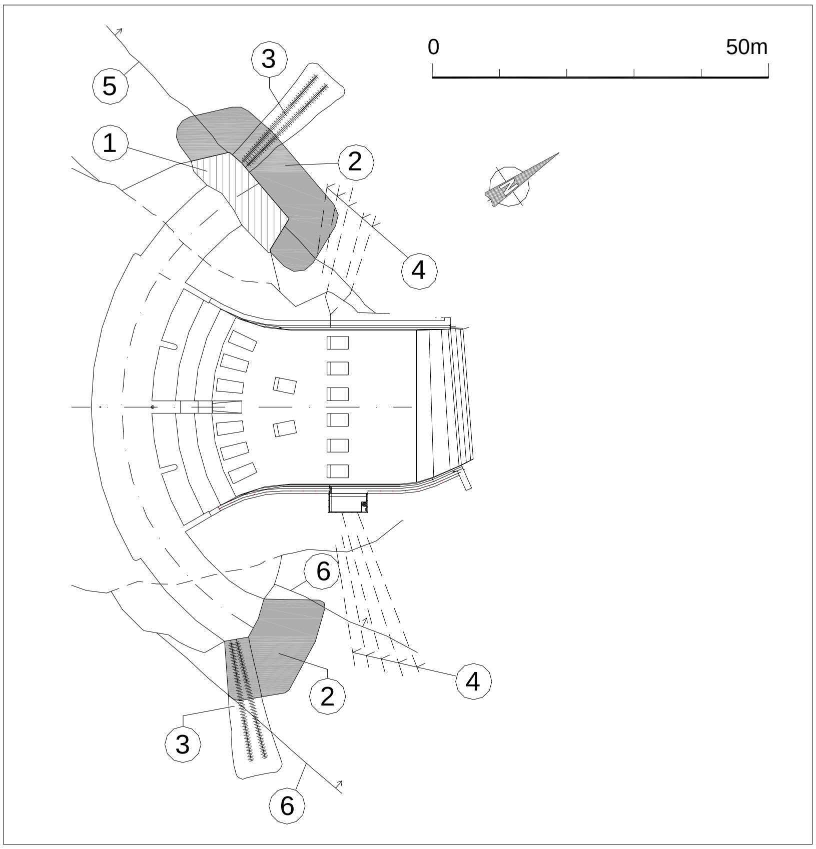

Fig. 6
Dam horizontal section at elevation 525 m a.s.l.
Coupe horizontale du barrage à élévation 525 m s.m.

1	Pulvino	1	Pulvino
2	Consolidation grouting	2	Injections de consolidation
3	Grout curtain	3	Ecran d'injection
4	Drainage holes	4	Trous de drainage
5	Main fault C	5	Faille principale C
6	Secondary faults	6	Failles secondaires

On the whole abutment surface a rock consolidation treatment has been carried out until 10÷13 m deep by cement grouting, through boreholes with 3 m mesh.

The foundation rock has, generally, a very low permeability, around 1 Lugeon. Nevertheless the deep imperviousness was improved by a grout curtain slightly inclined towards upstream (Figg.5, 6); its depth is around 23 m in the valley bottom and 20÷25 m on the banks (Fig.7). A mix of cement + bentonite + additives has been injected, with pressure up to 15 bar.

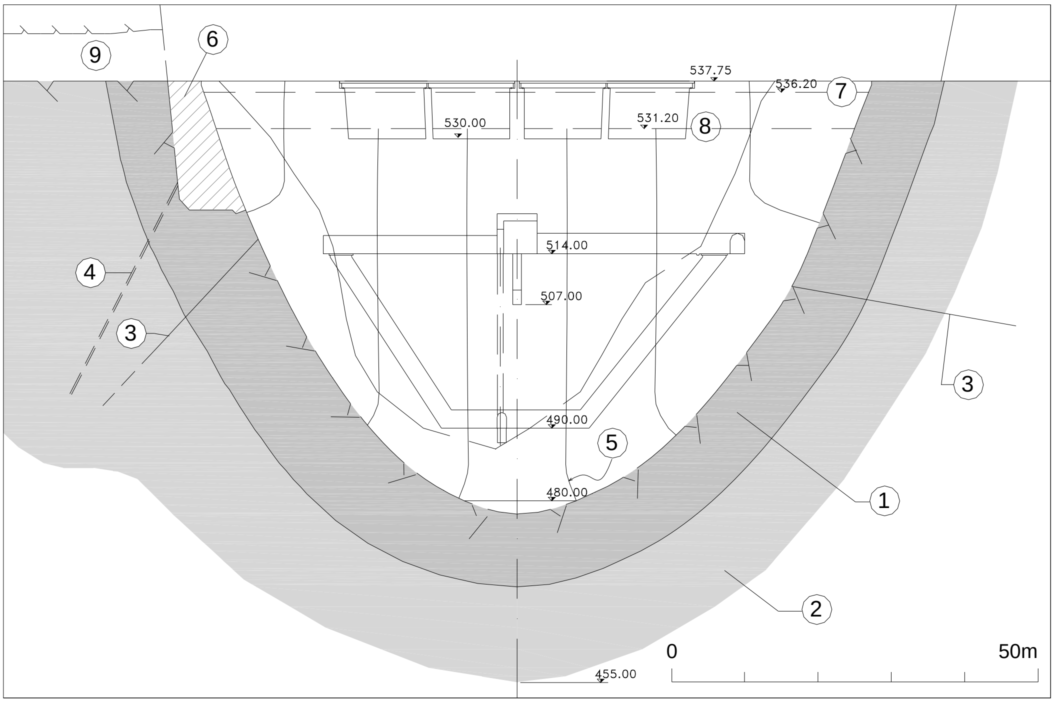

Fig. 7
Dam longitudinal section with grout curtain
Coupe longitudinale du barrage avec l'écran d'injection

1 Consolidation grouting
2 Grout curtain
3 Secondary faults
4 Main fault C
5 Construction joints of the dam
6 Pulvino
7 Maximum water level
8 Normal water level
9 Access tunnel to the dam crest

1 Injections de consolidation
2 Ecran d'injection
3 Failles secondaires
4 Faille principale C
5 Joints de construction du barrage
6 Pulvino
7 Niveau maximum de l'eau
8 Niveau de service de l'eau
9 Tunnel d'accès à la crête du barrage

Downstream of the grout curtain, a system of subvertical drainage holes has been bored from the service gallery (Fig.5) and from the surface of the rocky slopes (Fig.6).

5.5 SPILLWAY

The sill of the spillway, at elevation 531.2 m a.s.l. on the top of the dam, is shaped according to the Creager profile and has a total length of 47.2 m, divided in 4 sectors.

For the design flood with a return time of 1000 years, 1100 m^3/s,the hydraulic head is 5.0 m.

At the base of the chute of the spillway a stilling basin, which has been tested on physical model at the Politecnico of Turin as well as all the hydraulic works, has the bottom at the elevation 507.0 m a.s.l., is 25 m wide and 30 m long. It is arranged with 6 chute blocks and 8 buffle piers for energy dissipation. All the piers are reinforced with steel plate (20 mm thick), anchored to the bedrock with 2÷3 tendons and protected against cavitation phenomena by special air conduits.

The stilling basin is founded on a fill of rock blocks mixed with concrete, which restores the downstream river profile.

5.6 MODELLING OF THE SLOPES

The very steep morphology of the slopes overhanging the dam site required an important modelling of the rocky slopes above the crest of the dam.

On the right side, the excavation geometry was conditioned by the presence of the fault “C”, including cataclasites and cemented breaches about 1 m thick, and upstream, at lower elevations, by two other minor faults, “B” and “E”, generally closed.

All these faults show dip directions in the NW quadrant with average dips of about 45°÷50°.

In the zone of the fault “C”, the excavation was shaped, expanding as an amphitheatre, with the central part parallel to the dip direction of the main fault. The banks are 20 m distant in elevation and the slope gradient is 1/10.

On the excavation, altogether 100 m high, systematic rock bolts ϕ 30 mm have been applied with a mesh 2,5x2,5 m wide, completed with the application of a welded wire mesh.

The zone of the slope near “B” and “E” secondary faults was stabilized with a mesh of tendons with 4 and 5 strands, disposed with a regular mesh 2x2 m wide. Tendons length was variable from a minimum of 15 m to a maximum of 40 m.

Fig. 8
Gorge Susa Dam from upstream
Barrage de Gorge de Susa de l'amont

On the left abutment of the dam, the natural slope has a more regular morphology due to the locally favourable structural setting of the rock mass in relation with the slope orientation.

On this side it was then possible to limit remarkably the excavations depth into the slope and its reinforcing and protection with bolts and welded wire mesh.

The stability of both the slopes is monitored through a complex system of inclinometers, extensometers and topographic surveys.

6. ENVIRONMENTAL ISSUES

A particular attention in the lay-out of the works has been reserved to the environmental items. The Pont Ventoux-Susa Hydro Power Plant has been indeed the first in Italy to be subjected to the Environmental Impact Assessment procedure and to obtain the approval of the Environment Ministry in 1991 on the basis of the preliminary design.

Almost all the plant is located underground and the realization of a demodulation reservoir was considered essential in order to avoid frequent and sudden changes of the Dora Riparia River discharges, also due to the presence immediately downstream of Susa Town and of other important centres, Turin included.

The minimum vital flow has been warranted at any intake of the plant. At Susa Gorge Dam a pipe with regulating valve has been inserted in the structure to allow the continuous release of a 1.82 m^3/s discharge adapted to the minimum vital flow, directly on the chute of the spillway .

The position of the dam has been studied so that it is not visible from inhabited areas. Furthermore the arch-gravity typology better fits to the subvertical morphology of the slopes of the gorge.

The dimensions and the operation modalities of the bottom outlet on the left bank have been optimized, using also the addressing action of the cofferdam, to determine the solid transport transit during the frequent floods, avoiding the deposit by the dam and the erosion of the downstream river bed. In flood events the impound, kept prudentially empty, develops also a function of reduction of the peak discharges.

Fig. 9
Gorge Susa Dam from downstream
Barrage de Gorge de Susa de l'aval

7. ACKNOWLEDGMENTS

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ABSTRACT

Iride Energia S.p.A. (once A.E.M. of Turin S.p.A.) has planned in ’80s an important program of extraordinary maintenance and increase of its hydroelectric plants. As a part of this activity, the new 150 MW Pont Ventoux-Susa Plant on the Dora Riparia River has been designed and built in the Upper Susa Valley.

The production of energy and the pumping are developed in an underground power station located between two reservoirs of storage and modulation, Clarea and Susa Impounds.

The second one is about 1.100 m long and has a capacity of 470.000 m^3. It is formed by a dam on the Dora Riparia River, 1 km upstream of Susa Town, in a stretch of the valley named “Le Gorge”.

The geostructural conditions and the favourable deformability, strength and permeability of the local calcschists suggested to build an arch-gravity dam. It has a maximum height on the foundation plan of 57 m and on the river bed of about 30 m, as the alluvium material of the valley bottom was removed. The crest, at elevation 537.75 m a.s.l., is 4 m wide and has a length of 92 m.

The spillway is located in the central part of the dam and is able to discharge a flow of 1100 m^3/s, corresponding to a flood with return time of 1000 years. The main bottom outlet tunnel, designed for a maximum discharge of 142 m^3/s, is located on the left. A bottom outlet with maximum discharge of 49 m^3/s is present also in the dam body and its intake structure protected by the cofferdam makes it possible to empty the dead storage by the dam.

The daily water level range, due to the regulation of the discharged flows and the pumping, varies between 515.0 and 531.2 m a.s.l.

A particular attention in the lay-out of the works and in the operations of the plant has been reserved to the environmental aspects.

RESUME

Iride Energia S.p.A. (déjà A.E.M. de Turin S.p.A.) a établi dans les années ’80 un important programme d’entretien extraordinaire et de développement de ses aménagements hydroélectriques. Dans le cadre de cette activité, en Haute Vallée de Susa a été projeté et construit le nouveau Aménagement de Pont Ventoux-Susa de 150 MW sur le Fleuve Dora Riparia.

La production d’énergie et le pompage sont développés dans une usine souterraine localisée entre deux réservoirs de stockage et de modulation, les Bassins de Clarea et de Susa.

Le second est à peu près long 1.100 m et a une capacité de 470.000 m^3. Il est formé par un barrage sur le Fleuve Dora Riparia, 1 km amont de la Ville de Susa, dans une section de la vallée nommée “Le Gorge”.

Les conditions geostructurelles et la déformabilité, résistance et perméabilité favorables des calcschistes locaux ont déterminé le choix d’un barrage-poids voûte. Il a une hauteur maximale de 57 m sur le plan de fondation et de 30 m sur le lit du fleuve. La crête, à 537.75 m s.m., est large 4 m et a une longueur de 92 m.

Le déversoir est localisé dans la partie centrale du barrage et peut évacuer un débit de 1100 m^3/s, qui correspond à un temps de retour de 1000 ans. Le tunnel du vidange de fond principal, étudié pour un débit maximum de 142 m^3/s, est localisé à gauche. Un vidange de fond avec un débit maximum de 49 m^3/s est aussi présent dans le corps du barrage et son ouvrage de prise protégé par le batardeau rend possible l’évacuation de la réserve morte près du barrage.

En conséquence de la régulation des débits turbinés et pompés l’intervalle quotidien du niveau de l’eau varies entre 515.0 et 531.2 m s.m.

Une attention particulière dans la configuration des ouvrages et dans l’exercice de l’aménagement a été réservée aux aspects environnementaux.