1. INTRODUCTION

Sardinia, like many regions worldwide, is facing a decrease in average rainfall and runoff due to climate changes and an increase in water demand. The Italian government is aware of the importance of these problems and in particular of unpredictable variations of rainfall, both in time and in space, which have begun to affect Sardinia. Italy, with the financial support of the European Commu-
nity, is developing new strategies regarding the management of water resources in the area (EAF 2002).

The Island’s water supply depends essentially on surface runoff, which is stored temporarily in large reservoirs. There are about 57 dams in operation in Sardinia with a total storage capacity of more than 2'000 Mio. m³. A significant reduction of rainfall observed after 1975 has significantly reduced the runoff. In fact, over the last 25 years, an average runoff reduction of 50% has been observed in the region in comparison with the long term historical data.

Among others, the construction of new dams with new storage reservoirs and the heightening of existing dams are considered short-term solutions.

2. OVERVIEW OF THE PROJECT

The Maccheronis dam, built on the Posada River between 1956 and 1959, is located close to the town of Torpé in the North-East of Sardinia (Province of Nuoro). The 46 m high and 340 m long gravity dam impounds a reservoir with a live storage capacity of 25 Mio. m³ mainly used for irrigation and water supply. The 615 km² catchment area has an average annual runoff of 100 Mio. m³ (average referred to the period 1975-1992) with significant seasonal variations of the river discharge.

The dam foundation is mainly constituted of hard and sound granite. The dam is divided into 24 blocks with a total concrete volume of 96'000 m³. The slopes of the downstream and upstream dam faces are 1/0.70, respectively 1/0.04. Flood discharge is routed through an ungated spillway on the downstream wall. The control structure has a maximum capacity of 2'650 m³/s. A 10 m wide and 2.50 m high flap gate is located on the right abutment, whose purpose is the regulation of the water level. The dam is also equipped with a bottom outlet located on the left abutment, whose capacity is about 65 m³/s. Fig. 1 shows a downstream view of the Maccheronis dam.

The project of heightening the Maccheronis dam aims to increase the storage capacity by 10 Mio. m³ by plugging the overflow bays on the dam crest and by raising the normal water level by 3 m up to an elevation of 43 m a.s.l. The maximum water level will remain unchanged at an elevation of 46.50 m a.s.l. A new spillway will be excavated on the left bank, as shown in Fig. 2.
Fig. 1
Downstream view of the Maccheronis dam in the North-East of Sardinia
*Vue aval du barrage de Maccheronis au Nord-Est de la Sardaigne*

Fig. 2
General Layout of the Maccheronis dam and the new spillway
*Schéma du barrage de Maccheronis et du nouvel évacuateur de crue*

1. Maccheronis dam
2. New spillway
3. Regulation gate
4. Bottom outlet
5. Water intake
6. Control building
7. Public road
8. Preformed plunge pool
9. Posada River

1. Barrage de Maccheronis
2. Nouvel évacuateur de crue
3. Vanne de régulation
4. Vidange de fond
5. Prise d’eau
6. Local de commande
7. Route publique
8. Fosse d’erosion pré-excavée
9. Rivière Posada
The new spillway will consist of three gated overflow bays and a chute ending with a ski jump bucket diverting the flow into the preformed tailrace plunge pool. The excavation of the plunge pool will be carried out with the purpose to guide the erosion process and to reduce the formation of sediment deposits downstream. The Creager shaped sill will be fitted with three 15 m wide, 11 m high radial gates operated by an hydraulic hoisting equipment (Fig. 3). Each gate will be equipped with a completely independent hydraulic circuit and will be operated automatically or manually from the control buildings. Both a reserve electric pump and a manual pump will be installed on each hydraulic power unit in order to satisfy safety requirements.

![Fig. 3](image)

**Fig. 3**

General Layout of the Maccheronis dam and the new spillway

Schéma du barrage de Maccheronis et du nouvel évacuateur de crue

1. Weir axis  1. Axe du seuil
2. Radial gate  2. Vanne segment
3. Trunnion girder  3. Bloc d’ancrage des appuis de la vanne
5. Bridge  5. Pont
6. Drainage gallery  6. Galerie de drainage
7. Maximum water level  7. Niveau maximal

The overflow sill will divert the flows into a 40 m wide, 220 m long chute, whose longitudinal slope is 6%. The 60 cm thick slab will be equipped with 2
aerators located 60 m, respectively 145 m downstream from the sill. The chute will also be provided with an under-drainage system to reduce uplift pressures and with grouted anchor bars. The lateral 6.0 m high guide walls will also be drained and anchored to the rock. The ski jump will be divided into two 20 m wide elements to ensure good flow restitution conditions to the river. The downstream toe of the structure will be protected against retrogressive erosion by a concrete cut off.

Flood safety assessment was carried out considering different methods to determine the flood frequency characteristics of the Posada River at the dam site. Finally the regional two-component extreme value distribution was applied. The control structure is designed to pass a 1’000 year return period flood of 3'600 m$^3$/s considering the contribution of the regulation gate located on the right bank of the dam (300 m$^3$/s). The latter consists of a new 9.90 m wide, 6.00 m high flap gate operated by two hydraulic cylinders.

3. PHYSICAL MODEL INVESTIGATION

The operation and capacity under various configurations of the new spillway as well as the erosion and energy dissipation at the toe of the chute were analysed and optimised by physical modelling at a scale of 1/50 (Fig. 4 and Fig. 5) in Froude similarity (LCH 2003). The physical scale model was built in the hydraulic laboratory of the Swiss Federal Institute of Technology EPFL. The model was split up into two basins: the upper one representing the reservoir topography in the vicinity of the new spillway with the water supply, and the lower one including the downstream Posada River with the plunge pool.

![Fig. 4](image)

View of the physical model of the new Maccheronis spillway
*Vue du modèle physique du nouvel évacuateur de crue de Maccheronis*
Both basins were connected with the spillway chute made in PVC. The reservoir topography as well as the downstream river reach, excluding the erodable plunge pool, were built using a rigid cover. The tailwater level was controlled by an adjustable weir. The automatic supply regulation of the laboratory equipped with electromagnetic flowmeters allows a precise discharge input to the model. Fig. 4 shows the physical model in operation.

The test program was divided into five major phases:

1. Preliminary overall test phase to validate the hydraulic behaviour of the initial project configuration taking into account in particular the flow conditions upstream of the sill, in the bays and directly downstream of the piers, along the lateral walls of the chute, over the aerators, through the ski jump bucket and in the downstream river section.

2. Test of the hydraulic capacity of the spillway.

3. Investigations on the approaching of the flow conditions upstream of the spillway.

4. Measurement of the flow profiles along the spillway chute.

5. Assessment of the ski jump, jet deflector behaviour and plunge pool erosion.

**Fig. 5**

Limits of the physical model of the new Maccheronis spillway

*Limites du modèle physique du nouvel l'évacuateur de crue de Maccheronis*

1. Upstream reservoir with embankment topography and water supply
2. Downstream basin with river topography and water restitution
3. Spillway chute in PVC
4. Three gated overflow bays
5. Ski jump bucket

1. Bassin amont avec la topographie du réservoir et l'alimentation en eau
2. Bassin aval avec la topographie de la rivière et la restitution de l'eau
3. Coursier en PVC
4. Trois passes munies de vannes segment
5. Saut de ski
The tests have been performed for prototype discharge values ranging from 1'000 m³/s to 3'500 m³/s. Each phase from 2 to 5 included the optimisation of the geometry in order to improve the flow behaviour.

The hydraulic capacity of the spillway was successfully tested and the theoretical discharge values were compared with the experimental values. The visual observation of the approach flow upstream of the spillway, influenced by the local topography and visualized by floating tracers, allowed optimising the approach flow conditions (Fig. 6). The hydraulic behaviour for various opening scenarios of the three gated overflow bays was validated, as well as the water level-discharge relation determined.

![Fig. 6](image)

Visualization of the approach flow currents using floating candles upstream of the three fully open gates weirs at the maximum reservoir operation level (46.0 m a.s.l.)

Visualisation des courants d’approche avec des bougies flottantes à l’amont du déversoir pour les trois pertuis complètement ouverts au niveau maximal d’exploitation (46.0 m s.m.)

The aeration behaviour of the flow on the chute with the two bottom aerationators could be qualitatively observed. Standing waves on the spillway chute were observed and measured for various opening conditions of the gates. The chosen height of the lateral walls was adequate.

The physical model test allowed optimising the initial configuration of the ski jump and the jet deflectors at the downstream end of the chute. Thus the jet emerging from the right side of the chute and falling on the left part of the ski jump could be avoided and the impact zone of the jet in the plunge pool controlled. Additionally, the aeration of the jet has been improved by moving the jet deflectors to the downstream extremity of the ski jump. The size and depth of the scour holes downstream of the ski jump were also measured for different scenarios. As previously mentioned, the downstream end of the spillway will be protected against retrogressive erosion by a concrete cut off.
The results of the physical modelling globally certified the suitable design of the new spillway.

4. WORK SCHEDULE AND COSTS

The heightening project of the Maccheronis dam was submitted for approval in October 2003 and was approved by the Italian Dam Authority at the end of August 2004. The bid for construction should be carried out in summer 2005 aiming works to start by the end of 2005. The duration of the works are estimated in 33 months and will start with excavation and construction of the new spillway on the left bank. During works drawdown of the reservoir will not be allowed because of the necessity to maintain water supply for irrigation. After the installation of the spillway gates, the dam will be heightened.

The costs for the heightening of the dam and the execution of the new spillway, including civil works, hydromechanical equipment and engineering services are approximately 10 Mio. Euro.

REFERENCES


SUMMARY

Sardinia is facing severe problems in relation with a decrease in average runoff attributable to climate changes and an increase in water demand. As an immediate response to these problems, hydraulic projects have been developed with the purpose to increase the storage capacity.

The Maccheronis dam, brought under operation in 1967 mainly for irrigation and water supply purpose, overlooks the valley of the Posada River in the North-East of Sardinia at a maximum height of 46 m.

The extension project aims to increase the storage capacity about 10 Mio. m$^3$ by raising the normal water level up by 3 m to elevation 46 m a.s.l. while the maximum flood level (46.50 m a.s.l.) remains unchanged.
In order to achieve this purpose, the project includes the construction of a new gated spillway on the left abutment of the dam. The existing ungated overflow bays on the dam will be plugged. The new spillway will be excavated in the rock and will be equipped with three 15 m wide, 11 m high radial gates over ogee weirs discharging into a long chute to flip buckets, which divert the flow into the tailrace plunge pool. The total capacity of the new completion will reach 3'250 m³/s.

The suitable operation and capacity of the new spillway as well as erosion and energy dissipation problems at the toe of the chute have been studied by physical modelling at a scale of 1/50. The experimental study allowed optimising the design of the spillway.

RÉSUMÉ

La Sardaigne est confrontée au problème de diminution de la disponibilité en eau attribuée aux changements climatiques d’une part et à l’accroissement des besoins en eau d’autre part. Comme réponse immédiate à cette problématique, des projets hydrauliques ont été développés en vue d’augmenter la capacité de stockage des retenues.

Le barrage de Maccheronis, mis en service en 1967 principalement pour l’irrigation et l’approvisionnement en eau, surplombe la vallée de la Posada au nord-est de la Sardaigne. L’ouvrage a une hauteur maximale sur fondation de 46.00 m.

Le projet de surélévation du barrage vise à augmenter d’environ 10 Mio. m³ le volume utile du réservoir en élevant le niveau normal d’exploitation de 3.00 m jusqu’à la cote 46.00 m s.m. tandis que le niveau maximal de la retenue (46.50 m s.m.) est maintenu inchangé.

Pour atteindre cet objectif, le projet prévoit essentiellement la réalisation en rive gauche d’un nouvel évacuateur de crue vanné en remplacement des seuils libres situés dans la partie centrale du barrage ; ces derniers seront obturés. Le nouvel évacuateur de crue, entièrement excavé dans le rocher, sera constitué d’un seuil fixe équipé de trois vannes segment de 15.00 m de largeur et 11.00 m de hauteur, d’un long coursier qui se termine par un saut de ski déversant dans un bassin amortisseur en aval du barrage. Cet évacuateur sera dimensionné pour un débit de 3’250 m³/s.

Le bon fonctionnement, la capacité dans différentes configurations du nouvel ouvrage ainsi que l’érosion et la dissipation d’énergie au pied de celui-ci ont été étudiés et optimisés sur modèle réduit à l’échelle 1/50.