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DAIVÕES DAM SPILLWAY: A NOVEL SOLUTION FOR THE STILLING BASIN

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Abstract. *The Upper Tâmega Hydroelectric Project is located in the Tâmega River, a tributary of Douro River, and includes, among other elements, the construction of three dams: Alto Tâmega, Daivões and Gouvães. Daivões Dam is a concrete arch gravity structure, 77 m high above foundation, with a gated controlled spillway, located in the center of the dam, and followed by stilling basin controlled by a tall end weir to force the hydraulic jump in a shorter distance. The hydraulic performance of the proposed spillway stilling basin was tested and optimized on a physical model at 1:50 scale. The paper presents the results of the physical models study and the final unconventional solution adopted for the spillway stilling basin.*

1 INTRODUCTION

The Upper Tâmega Hydroelectric Scheme is a project launched by the Portuguese Government, as a part of its National Program for Dams with High Hydroelectric Potential (PNBEPH) approved in 2007.

Iberdrola will develop the Upper Tâmega Hydroelectric Project in the Northern Region of Portugal, one of the largest projects of its kind in Europe in the last 25 years. The project includes, among other elements, the construction of three dams: Alto Tâmega and Daivões Dams, both located in the Tâmega River, and Gouvães Dam, located in the Torno River, a tributary of the Tâmega River on its left side.

The Portuguese National Laboratory of Civil Engineering (LNEC) was commissioned to study Daivões Dam and Alto Tâmega Dam spillways by means of physical modelling. This paper focus on the results of the Daivões spillway stilling basin study. Stilling basins are employed with the purpose of dissipating the excessive energy downstream hydraulic structures such as overflow spillways by means of a forced hydraulic jump. Due to site-specific arrangement, the Daivões stilling basin was designed with a tall end weir to control the hydraulic jump in a shorter distance. Some experiments of such stilling basins have been reported by Alikhani et al. (2010)[1] and Fathi-Moghadam et al. (2011)[2]. The proposed stilling basin project differs from standard basins, constituting an unconventional alternative whose hydraulic performance was validated and optimized through the physical model study.

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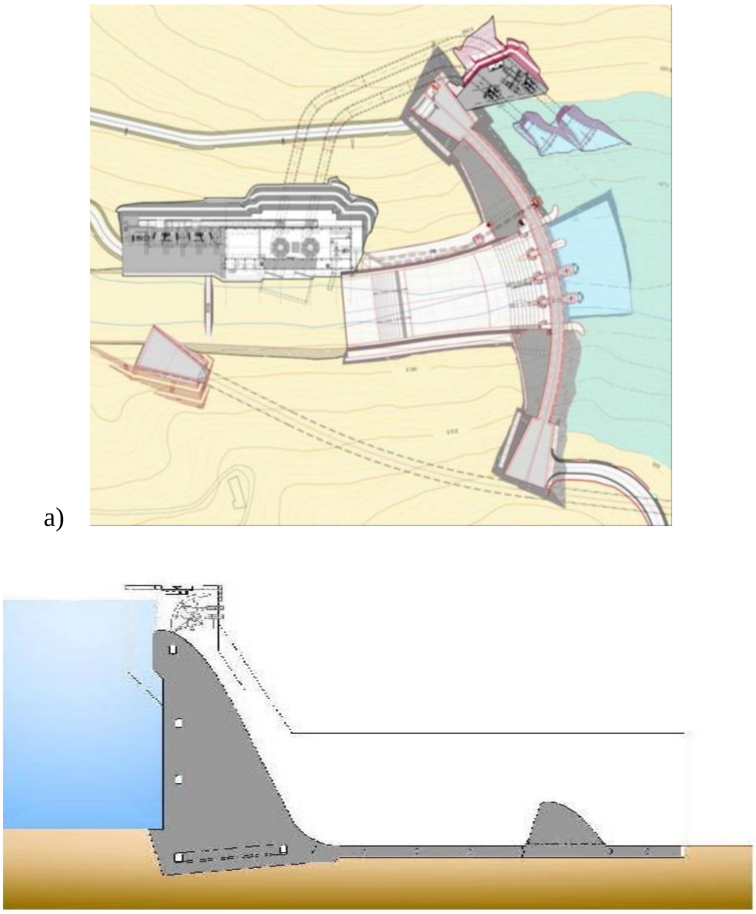
After this introduction, the main features of the Daivões project are presented in section 2 and the physical model is described in section 3. The main results of the physical model tests regarding the evaluation of the performance of the stilling basin in constraining the hydraulic jump inside the basin and on the restitutions flow conditions downstream the basin, including the proposed design solution, are presented in section 4. Finally, conclusions are drawn in section 5.

2 DAIVÕES PROJECT MAIN FEATURES

The Daivões hydroelectric power plant, located in the right bank of the River Tâmega, is equipped with two main groups each with a discharge of 110 m^3/s, for a total installed capacity of 118 MW. The hydraulic circuit includes two independent 210 m and 265 m long tunnels. The outlet works are located approximately 40 m downstream the stilling basin (Figure 1a).

Daivões Dam is a concrete arch gravity structure, 77 m high above foundation, with a crest length of around 265 m, and a gated controlled spillway, located in the centre of the dam, followed by stilling basin (Figure 1). The design discharge capacity is 2944 m^3/s (5000 year flood).



a)

b)

Figure 1: General view of the Daivões scheme (a) and section of the dam spillway and stilling basin (b)

The designed spillway of Daivões Dam, was defined as a Creager weir with crest at 220, equipped with four radial gates each 11.5 m wide and 9.0 m high. A rectangular stilling basin 65 m long and 40 m wide, with horizontal slope, was located downstream the spillway. Its bottom elevation was at level 161.5. At the downstream end of the stilling basin, a weir 12 m high was used to control the water levels and reduce the length of the basin (Figure 1b). The configuration of this weir was of Creager type.

3 PHYSICAL MODEL

3.1 Description

The 1:50 physical hydraulic model represents the whole spillway, the stilling basin, the power plant water intakes and restitution as shown in Figure 2. The model included the reservoir over a distance of 250 m upstream of the gated weir crest, and a 500 m long river reach downstream. To reproduce appropriate flow conditions in the reservoir, the water enters the physical model through a permeable screen made of perforated bricks. Tailwater settings were made with a movable weir, which allows the reproduction of the water level – discharge relation estimated in a specific river cross section in the project design.

Figure 2: Overview of the Daivões physical model. a) view looking upstream; b) view looking downstream at the reservoir; c) lateral view of the spillway and stilling basin; d) mobile bed used to study erosions

Water was supplied to the model through the laboratory supply system. Discharges rates were measured with an electromagnetic flowmeter, which measuring uncertainty is less than 1%. A control valve was used to set the flow in the physical model. Reservoir water surface elevations and tailwater elevations were measured by means of point gauge limnimeters which errors are considered to be inferior to ±0.2 mm. Average pressures on the spillway were measured using a piezometers board, which provided the referred to values in each pressure tap location. Flow velocities were measured with a micro-propeller and with an Acoustic Doppler Velocimeter (ADV Vectrino).

Initially, a fixed bed was considered (Figure 1a). In a second phase, for evaluating the erosive potential downstream the stilling basin, a mobile bed was considered (Figure 1d). The mean diameter of the gravel used in the physical model (D50 = 15 mm) correspond approximately to the joint intervals observed on the rocks characterized in the geological/geotechnical study.

The physical model was operated at prototype flows between 500 m^3/s and 2944 m^3/s. The design flow rate of 2944 m^3/s in the prototype scales to approximately 167 l/s in the physical model.

3.2 Purpose of the physical model study

The physical model study was performed to evaluate the hydraulic conditions of the spillway with particular regard to the performance of the stilling basin. The specific objectives of the physical model study were:

- Determination of the rating curve for the spillway (with and without the gate operation).
- Optimization of the hydraulic performance of the stilling basin in constraining the hydraulic jump inside and flow pattern downstream the stilling basin.
- Analysis of the simultaneously functioning of the spillway and the hydraulic circuit.
- Evaluation of the erosions downstream the stilling basin.

4 RESULTS AND DISCUSSION

4.1 Initial design tests

The initial design was tested to determine the discharge capacity of the spillway and to observe flow conditions in the stilling basin and downstream river channel. Discharge capacities (not shown here) were adequate to pass the required maximum flows and similar to those provided in the project.

The performance of the initial stilling basin is illustrated in Figure 3. As it can be seen, an instable hydraulic jump is formed downstream the stilling basin end weir, particularly for flow discharges lower than the design discharge. This hydraulic jump results from the excess velocity downstream the weir and the insufficiency of the tail water level in the river channel. It tends to approach the hydraulic circuit restitution area. There is also an asymmetry of the flow along the cross section of the river, with flow velocities higher near the left bank, since the dam spillway and stilling basin presents a slightly curve configuration in plant.

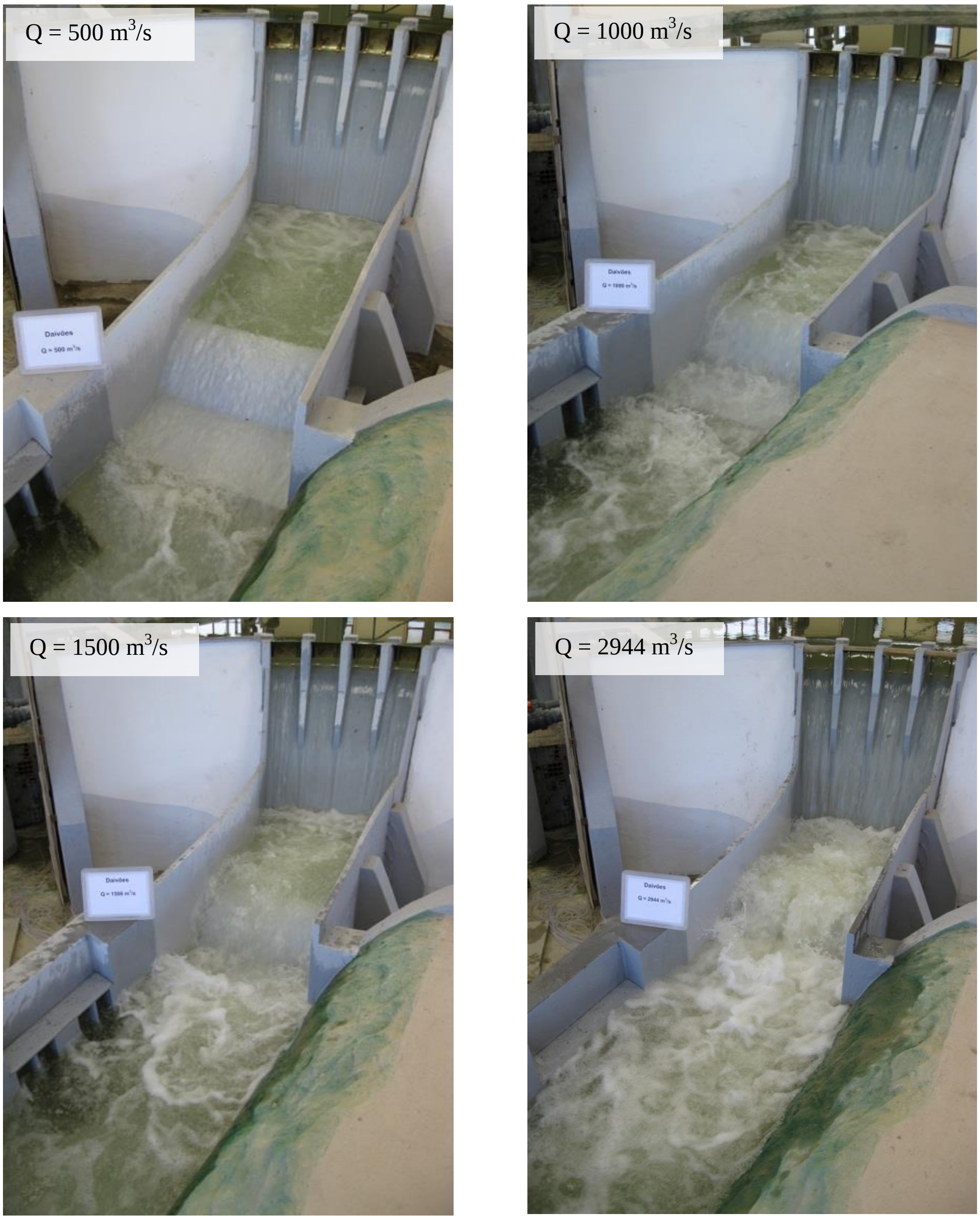


Figure 3: Initial design tests. Flow conditions in the stilling basin and downstream river channel for different discharges

In an effort to optimize the basin design several modifications were tested in the physical model. The most relevant modifications were:

1) reduction of the stilling basin end weir height
2) insertion of chute blocks and baffles blocks and a dentate sill downstream the weir
3) insertion of a deflector immediately upstream the restitution area
4) insertion of deflectors in the spillway piers
5) replacement of the continuous weir of the stilling basin with a dentate end weir

The performance of these modifications was evaluated and compared based on flow observations and velocity measurement downstream the stilling basin.

The hydraulic performance of the modifications 1) to 3) was reported in Alves et. al (2012)[3]. The solution of reduce the height of the weir from 12 m to 10 m proved to be inadequate as it was observed that the hydraulic jump had a tendency to partially sweep out of the basin for the design discharge (Figure 4). However, the combination of the reduction of the weir to 11 m high with the insertion of additional accessories (chute blocks and baffles blocks and a dentate sill downstream the weir) showed a good efficiency in constraining the hydraulic jump in the stilling basin (Figure 5).

Figure 4: Performance of the stilling basin for the design discharge considering the reduction of the height of the end weir (10 m)

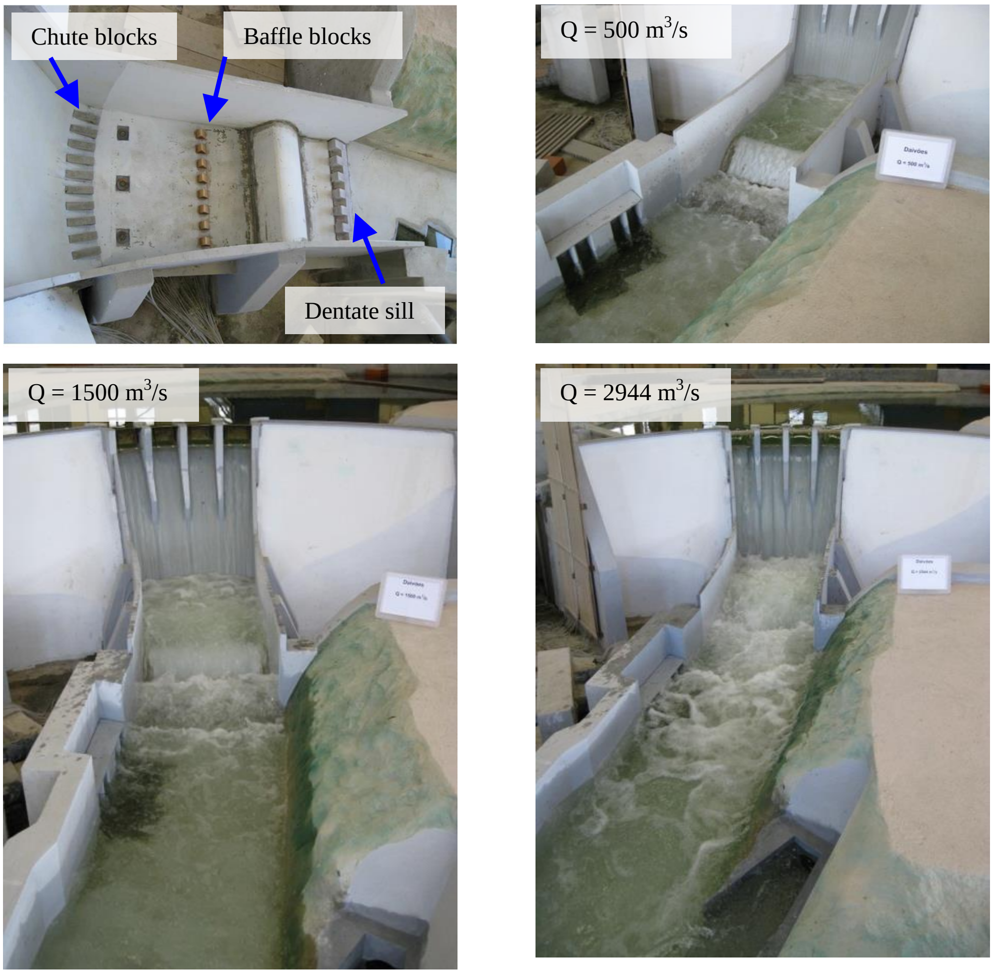


Figure 5: Performance of the stilling basin for different flood discharges considering the reduction of the height of the end weir (11 m) and the insertion of chute blocks and baffles blocks and a dentate sill downstream the weir

Although the flow conditions downstream the stilling basin showed less disturbances with the reduction of the height of the end weir (11 m) and the insertion of additional accessories, other modifications were considered necessary to improve the overall stilling basin performance. These modifications consisted in the insertion of deflectors in the spillway piers to improve the energy dissipation in the stilling basin, in the replacement of the continuous weir with a dentate end weir. Furthermore, an additional element (deflector) was introduced immediately upstream the restitution area in order to decrease the water level fluctuations and flow velocities near the outlet works. These modifications were previously identified, respectively, as 4), 5) and 3) formed the basis of the proposed solution for the stilling basin, which will be presented in the next section.

Thanks to the improvement in the performance of the modifications 3) to 5) chute blocks, baffles blocks and dentate sill downstream the weir were eliminated of the scheme with a successfully result.

4.2 The recommended design

The final recommended design consisted in a stilling basin with an end dentate weir (Figure 6a and b). Although the position of the weir inside the stilling basin and its height (12 m) remain the same as the initial design, a dentate configuration was defined to improve downstream flow conditions. Additionally, a deflector 7.5 m high and appropriate geometry (Figure 6c) was placed near the restitution. In Figure 7, it can be observed the insertion of deflectors in the spillway piers, which promote the diversion of the flow downstream the overflow weir.

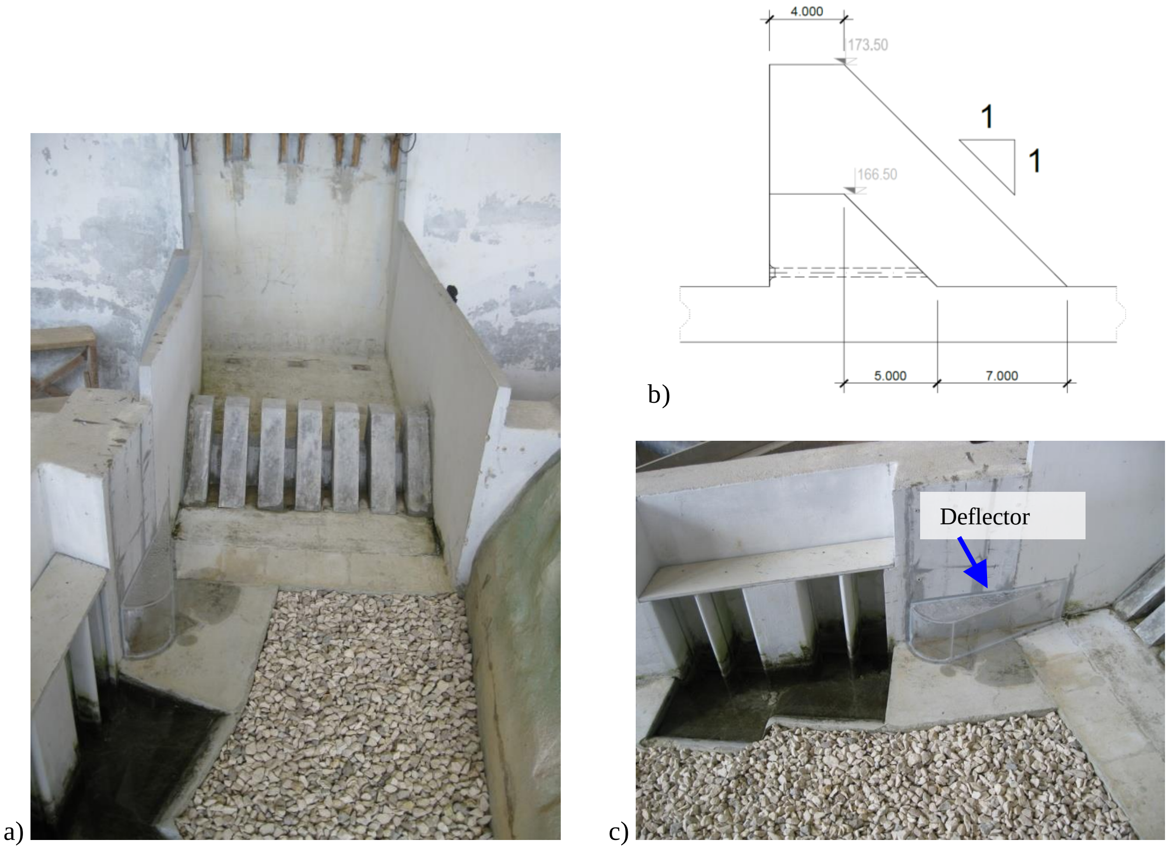


Figure 6: Recommended stilling basin with dentate end weir. a) general view, b) geometry of the dentate weir, c) geometry of the deflector near the outlet works

a)  b) 

Figure 7: Deflectors in the spillway piers. a) general view; b) detail of the lateral deflector

In Figures 8 to 10 the performance of the stilling basin is illustrated for different flow discharges. The dentate weir promotes a uniform distribution of the flow along the section improving considerably the flow conditions downstream of the stilling basin, particularly for low discharges. This aspect is very important in situations of simultaneous function of the power plant and spillway.

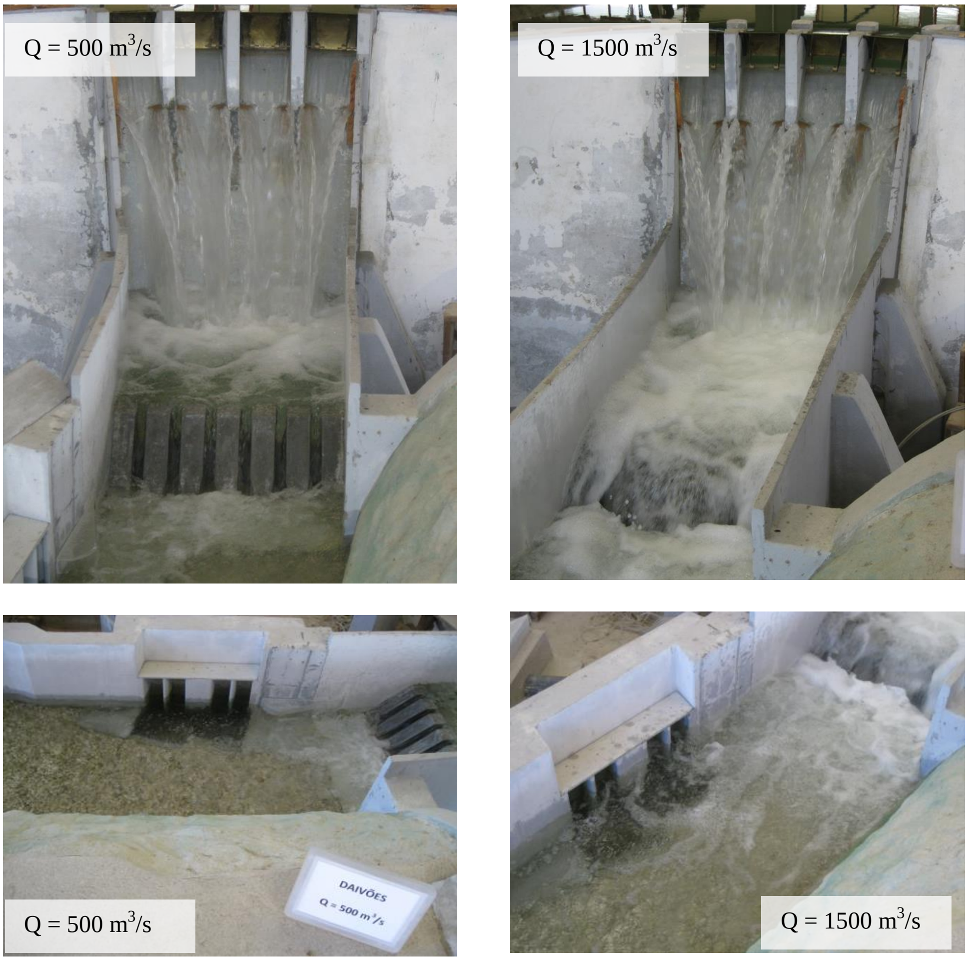


Figure 8: Recommended design tests. Flow conditions in the stilling basin and downstream river channel for 500 m^3/s and 1500 m^3/s

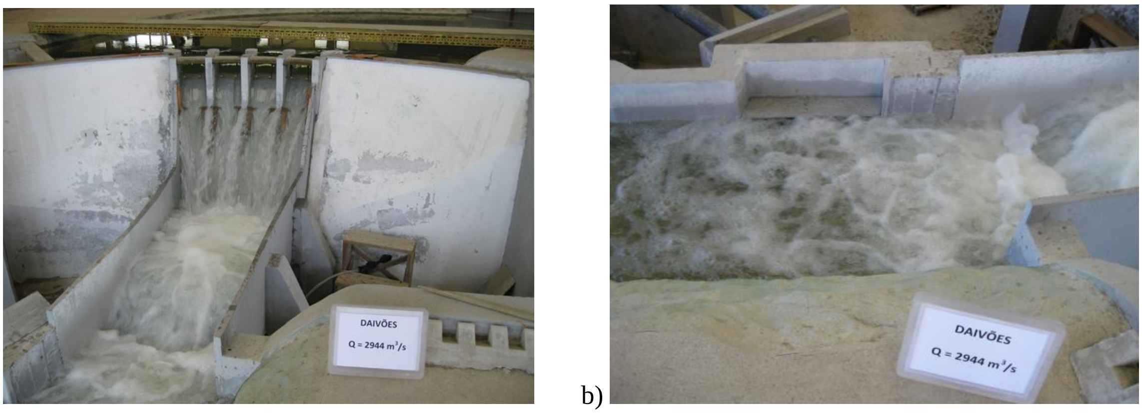


Figure 9: Recommended design tests. Flow conditions in the stilling basin and downstream river channel for the design discharge (2944 m^3/s): a) general view; b) lateral view

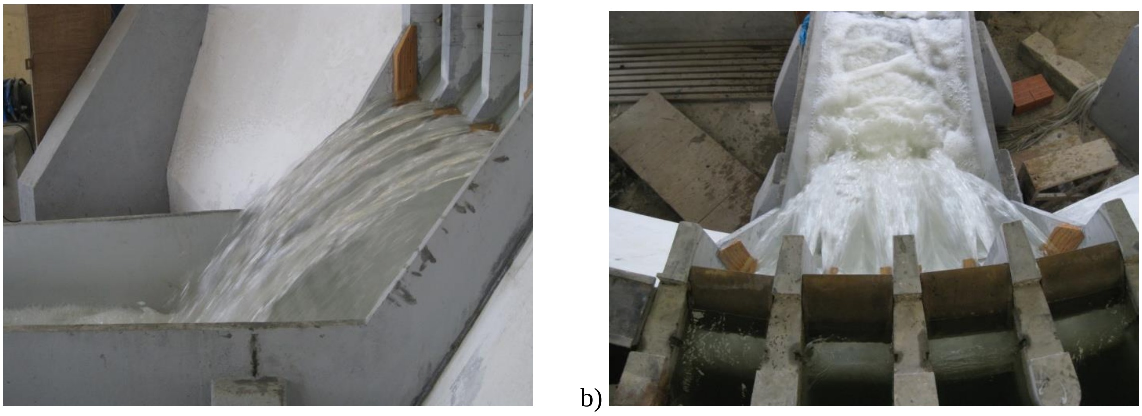


Figure 10: Recommended design tests. Jets trajectory for the discharge of 1500 m^3/s: a) lateral view; b) upstream view

As it can be seen in Figure 10, due to the insertion of deflectors in the spillway piers the flow is launched to the basin through different jets, which allows the improvement of the energy dissipation in the stilling basin.

For the design solution no local scour was observed in the mobile bed downstream the basin, except for the design discharge (2944 m^3/s). For this discharge, a scour hole was observed immediately downstream the basin and the depositional zone is located downstream the restitution.

Figure 11 illustrates the efficiency of the deflector inserted immediately upstream of the hydraulic circuit outlet works on deviate the flow trajectories and reducing flow velocities near the restitution area (point C1 on Figure 11), particularly for lower discharges, where simultaneously operation of the hydraulic circuit and the spillway will occurred.

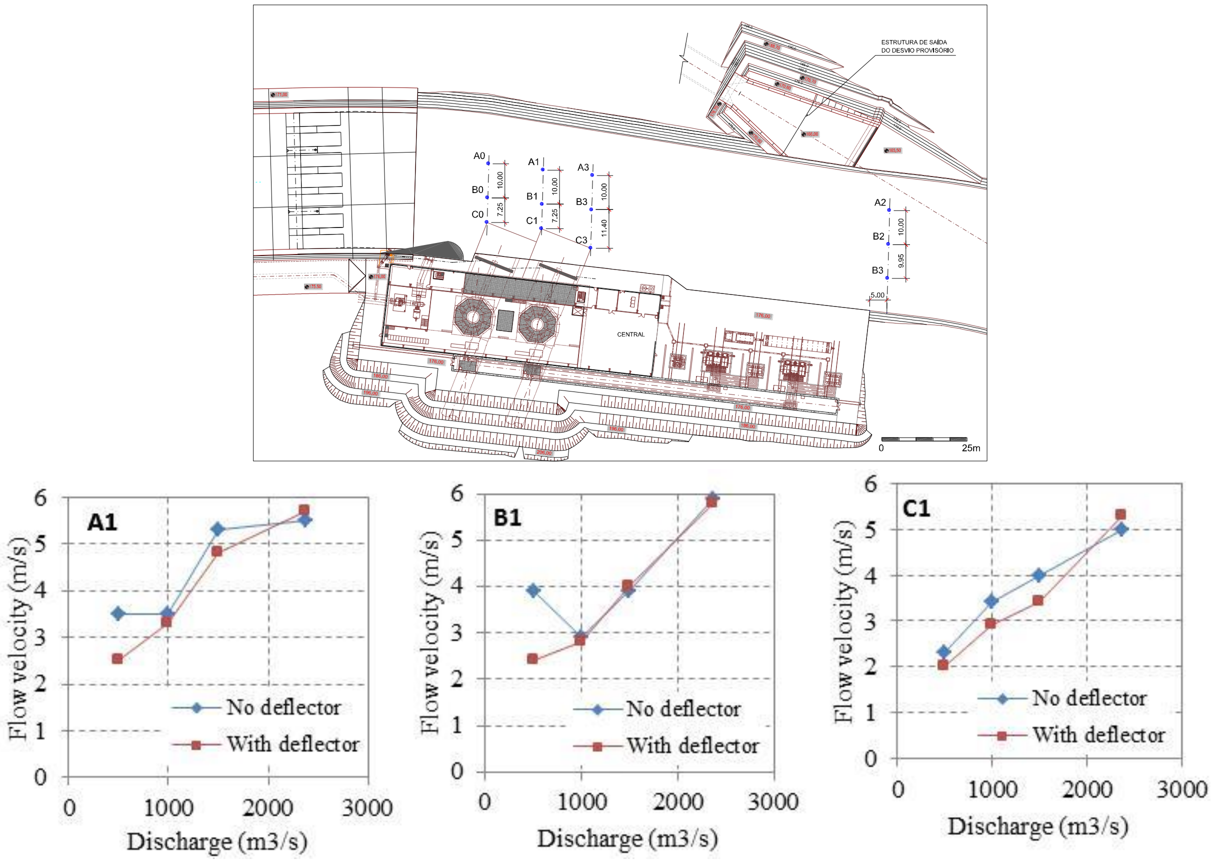


Figure 11: Comparison of the flow velocity near the hydraulic circuit restitution area

5 CONCLUSIONS

Daivões Dam is part of the Upper Tâmega Hydroelectric Project, one of the largest projects of its kind in Europe in the last 25 years. Due to site-specific arrangement, the Daivões spillway stilling basin was designed with a tall end weir to control the hydraulic jump in a shorter distance. Based on physical model tests a series of modifications were introduced to improve the energy dissipation in the stilling basin, ensuring adequately flow conditions downstream, particularly in the vicinity of the hydraulic circuit restitution area. The proposed solution consists in a spillway equipped with deflectors and a stilling basin with an end tall dentate weir resulting in a compact structure that meets the site-specific conditions with a satisfactory hydraulic performance for a wide variety of flow conditions.

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