The new Upper Tâmega hydroelectric scheme: hydraulic design and physical model studies

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Abstract

The Upper Tâmega Hydroelectric Project, with a total installed capacity of 1154 MW, is located in the Tâmega River, a tributary of the Douro River on its right side (Portugal), and includes, among other elements, the construction of three dams: Alto Tâmega, Daivões and Gouvães. For two of them, namely Alto Tâmega and Daivões, physical models have been developed for validation and optimization purposes of the spillways designs.

Daivões Dam is a concrete arch gravity structure, 77 m high above foundation, with a gated controlled spillway, located in the centre of the dam, and followed by stilling basin. The design discharge capacity is 2944 m^3/s.

Alto Tâmega is a double curvature arch dam, 108 m high above foundation, with two tunnel spillways and ski jump structures. The main one is a tunnel with a discharge capacity of 1510 m^3/s. The auxiliary one has a discharge capacity of 300 m^3/s.

To evaluate the hydraulic performance of the proposed spillways designs, two physical models (scales around 1:50) were built at LNEC (Portuguese National Laboratory for Civil Engineering). In this paper, the main features of the proposed spillway designs, including the main technical challenges of energy dissipation, are described. Also, the paper presents the main results from the evaluation of the various design concepts in each of the physical models, and how these studies aided in the final design.

Keywords: Physical Model, Spillway, Stilling basin, Ski jump, Energy dissipation

1. Introduction

The Upper Tâmega Hydroelectric Scheme is a project launched by the Portuguese Government, through its Water National Institute (INAG-Instituto da Água, I.P.), as a part of a Portuguese 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.

In dam engineering, physical hydraulic models are commonly used during design stages to validate and optimize the hydraulic design, due to its ability to solve complex hydraulic problems which cannot be solved analytically or are still difficult to solve using computational models. They also have the advantage to study alternative designs, so that the most safe, economical and suitable design could be selected.

The Daivões dam and Alto Tâmega dam spillways and energy dissipation structures are currently under test in two physical models in the Portuguese National Laboratory of Civil Engineering (LNEC). The main objective of these studies is to analyse the performance of the hydraulic structures, to define alternative configurations, if necessary, in order to have technical solutions considered more favourable. In the following the results of physical model tests are presented.

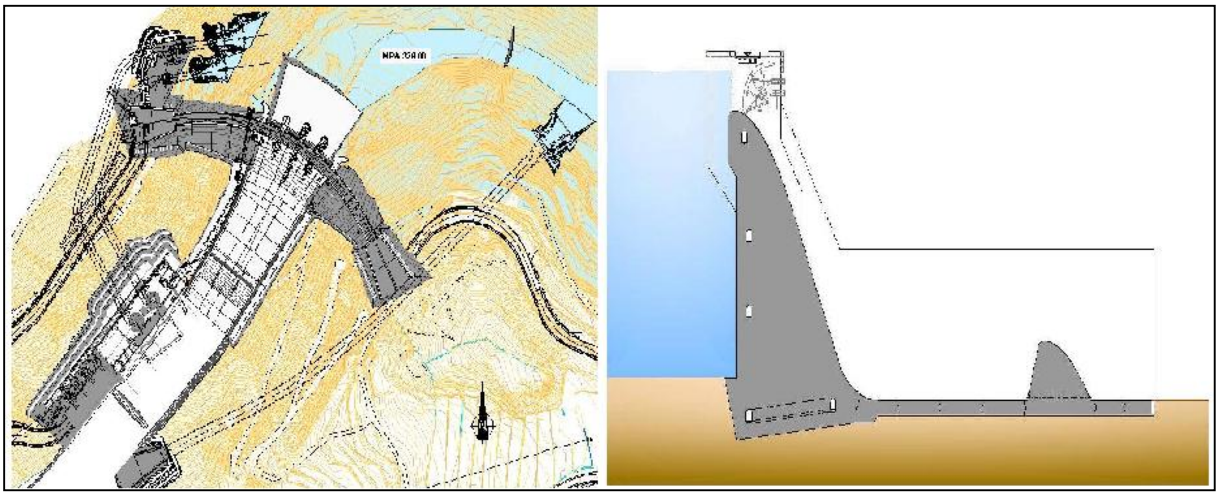
2. General Description

2.1. Daivões

The Daivões hydroelectric power plant, located in the right bank of the river, is equipped with two groups each with a discharge of 110 m^3/s, for a total installed capacity of 114 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.

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 (Drawing 1). The design discharge capacity is 2944 m^3/s (5.000 year flood).

The designed spillway of Daivões dam, previously to the model tests, 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. The configuration of this weir was of Creager type.



Drawing 1 – General view of the Daivões scheme

2.2. Alto Tâmega

The Alto Tâmega hydroelectric power plant, located at the bottom of the dam, is equipped with two groups each with a discharge of 100 m^3/s, for a total installed capacity of 160 MW.

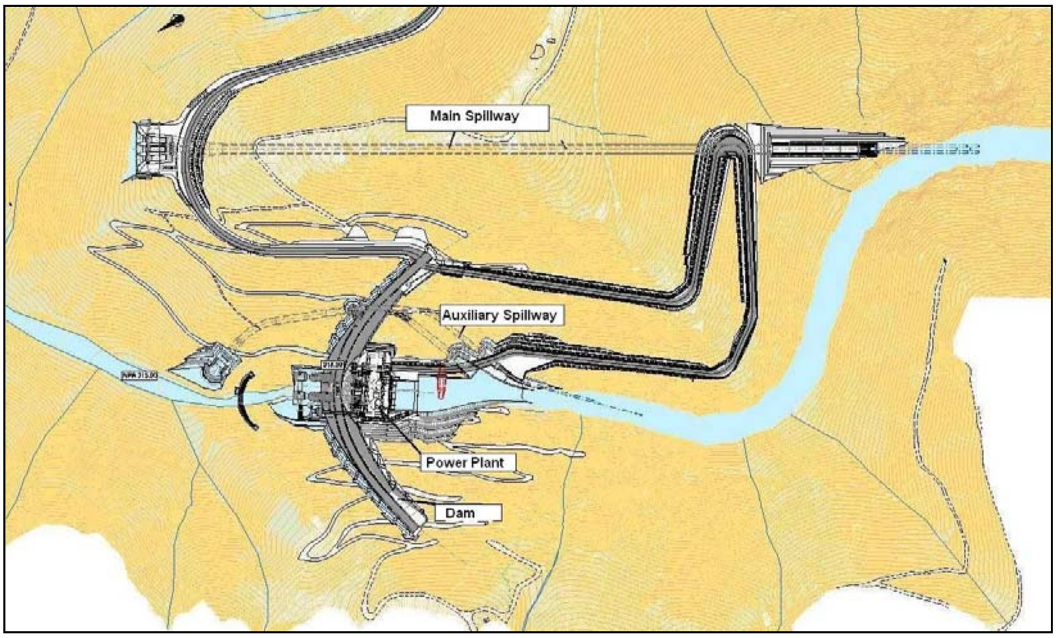
The Alto Tâmega dam (Drawing 2) is a double curvature arch dam, 108 m high above foundation and a crest length of around 330 m, and was designed with two tunnel spillways with the following characteristics:

- Main spillway with a discharge controlled by 3 gates, followed by a tunnel with 9 m diameter, with surface flow, and a final ski jump;
- Auxiliary spillway working as a bottom spillway in a pressure flow.

The main spillway have two alternative design solutions, one straight, another curved upstream. The entrance in main spillway is Creager type, with 3 span 5.5 m width, having radial gates with 12.55 m height. It follows a well with decreasing cross section, making the transition to the tunnel. This has a horseshoe shape and a 3.7% constant slope. The springboard output has the final edge 20 m above the river bed. The angle of the final teeth is 20º for central one and 30º for the lateral ones. The total length of the main spillway is 608.81 m in the straight alternative and 475.81 m in the curved one.

The design discharge is 1510 m^3/s (10.000 year flood), for the NWL 315.71, and for a jammed gate the discharge is 1290 m^3/s, for the MWL 317.44.

The auxiliary spillway has a tunnel with 6 m diameter, and an ascending 4 m diameter tunnel, shielded concrete, for the final part downstream the gates. The output is controlled by a radial gate. The design discharge for the auxiliary spillway is 300 m^3/s.



Drawing 2 – General view of the Alto Tâmega scheme

3. Daivões physical model tests

3.1. Physical model description

The physical model was constructed as an undistorted model with a scale factor 1:50 and operated with respect to Froude similarity, i.e. conserving the inertial and gravitational forces ratio. The model (Figures 1 and 2) represents the whole spillway, the stilling basin, the power plant water intakes and restitution. The model boundaries were selected to represent the reservoir over a distance of 250 m upstream of the gated weir crest, and a 500 m long reach downstream. In order to reproduce appropriate flow conditions in the reservoir, the water enters the physical model through a permeable screen made of perforated bricks. The control of the tailwater level is obtained by 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 1 – General view of the Daivões physical model: downstream view (left) and upstream view (right)

Figure 2 – Stilling basin with an end weir

The spillway, stilling basin, and the power plant water intakes and restitution structures were moulded with sand and cement mortar. In the first tests, a fixed bed was considered. In a second phase, a mobile bed was used for the river reach where there is the possibility of the flow to scour. The mean diameter of the gravel used ($D_{50} = 15$ mm) correspond approximately to the joint intervals observed on the rocks characterized in the geological/geotechnical study.

During the physical model tests 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. Average pressures on the spillway were measured using a piezometers board, which provided the referred to values in each pressure tap location. To measure the water levels in the reservoir and in the downstream section, gauge limnimeters were used which errors are considered to be inferior to ±0.2 mm.

The physical model has been tested with discharges ranging 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.

After the calibration of the physical model, several tests were conducted to analyse the following items: rating curve for the spillway (with and without the gate operation), approach channel flow patterns, stilling basin performance, energy dissipation and flow pattern downstream the stilling basin, simultaneously functioning of the spillway and the hydraulic circuit.

3.2. Stilling basin tests and modifications

Stilling basins are employed with the purpose of dissipating the excessive energy downstream hydraulic structures such as overflow spillways. In these basins forced hydraulic jumps are formed with the assistance of chute blocks, and/or baffles blocks and/or sills (or a combination of these accessories). The end sill plays an important role in the stilling basin design for allowing a reduction of its length and for improving the downstream flow conditions, in order to reduce the risk of bed scour. In the current engineering practice, stilling basins are designed in such a way that the elevation of the tail water depth at the downstream channel is approximately equal to the conjugated depth of the hydraulic jump.

In the Daivões spillway, due to constrain related with the proximity between the weir and outlet works of the hydraulic circuit (approximately 40 m), the stilling basin length was significantly reduced with the inclusion of a weir 12 m high (the reduction is about 50% of the free hydraulic jump length). This feature makes the stilling basin design rather different from the conventional one, i.e., the estimation of the stilling basin length rely on the definition of the height and position of an end weir (sill) without consideration of the tailwater level downstream. The experimental study of such stilling basins has been addressed by several authors, for instance, Alikhani et al. (2010) and Fathi-Moghadam et al. (2011).

One of the principal objectives of the physical model tests was to evaluate the performance of the stilling basin in constraining the hydraulic jump inside the basin and the restitutions flow conditions downstream the basin. These tests also serve to identify the need for modifications in the stilling basin.

As shown in Figure 3, for flood discharges lower than the design discharge an instable hydraulic jump is developed downstream the stilling basin end weir approaching the hydraulic circuit restitution area. This hydraulic jump results from the excess velocity downstream the weir and the insufficiency of the tail water level in the river channel. As it can been seen in Figure 3, the flow velocities are higher near the left bank of the river, since the dam orientation to the axis of the valley creates a non-symmetric flow pattern in the spillway due to its slightly curve configuration in plant.

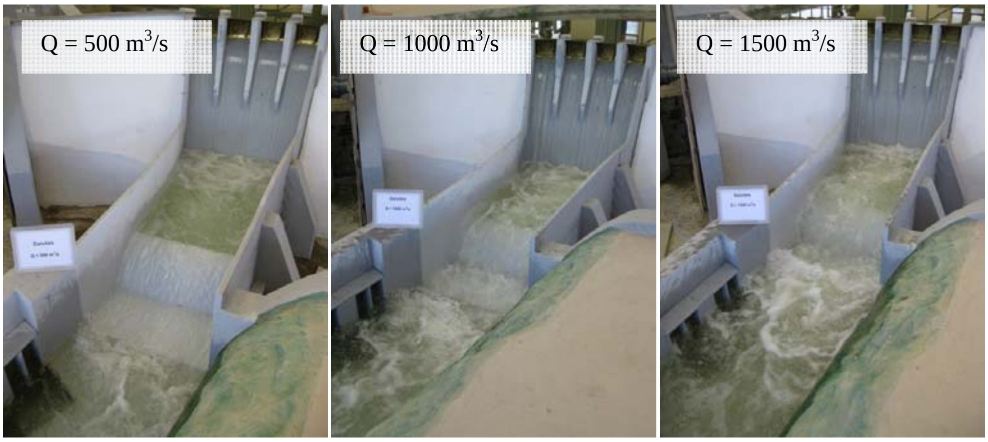


Figure 3 – Formation of a hydraulic jump downstream the end weir of the stilling basin flood discharges lower than the design discharge

To avoid the aforementioned problems, two modifications on the original design were considered: 1) reduction of the stilling basin end weir height, in order to decrease the flow velocity downstream the weir without compromising the formation of the forced hydraulic jump in the basin; 2) insertion of a dentate sill downstream the weir for the diffusing of a portion of the excess flow velocity that reaches the end of the basin.

A reduction of the weir height from 12 m to 11 m and to 10 m, were tested in the physical model. For the weir 10 m high, it was observed that the hydraulic jump had a tendency to partially sweep out of the basin for the design discharge. This solution was therefore rejected.

As the solution with the weir with 11 m high showed a good efficiency in constraining the hydraulic jump in the stilling basin, it was decided to test the insertion of a dentate sill downstream the weir. Furthermore, additional accessories as chute blocks and baffles blocks were introduce to improve the hydraulic jump control in the basin (Figure 4).

The pictures of Figure 4 show the improvement on the flow conditions downstream de stilling basin for a wide range of flood discharges. Moreover, the stilling basin with a weir 11 m high equipped with chute and baffles blocks seems to adequately control the hydraulic jump in the basin.

Although the flow conditions downstream the stilling basin showed less disturbances, in order to decrease the water level fluctuations and flow velocities near the outlet works, an additional element (deflector) was introduced immediately upstream the restitution area (Figure 5). The shape and dimensions of the deflector were defined in the physical model tests.

This figure illustrates the efficiency of the deflector on deviate the flow trajectories from the restitution area for flood discharges less than the design flood. For these discharges it is predicted the simultaneously functioning of the hydraulic circuit and the spillway.

It should be stressed that for the solutions referred to before, 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. The maximum scour depth was -4.5 m in relation to the original river bed. The depositional zone is located downstream the restitution.

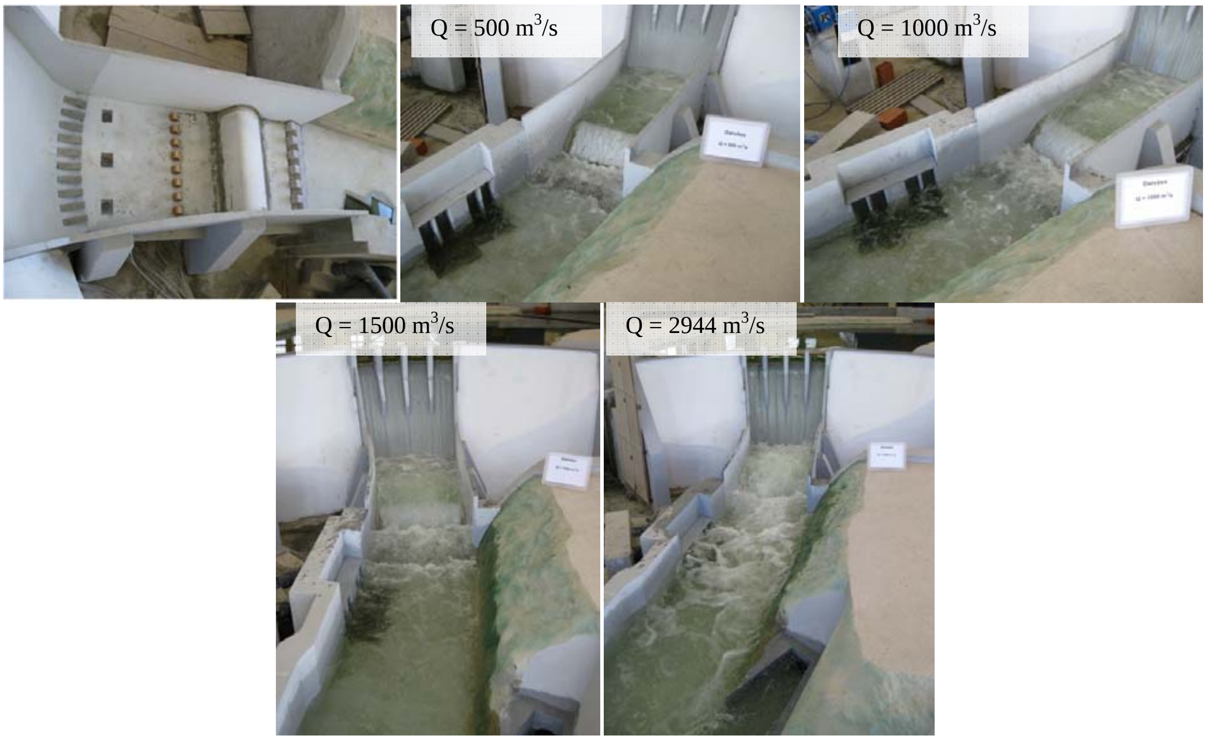


Figure 4 – Flow patterns for different flood discharges considering the reduction on the stilling basin end weir height (11 m) and the insertion of chute blocks and baffles blocks and a dentate sill downstream the weir

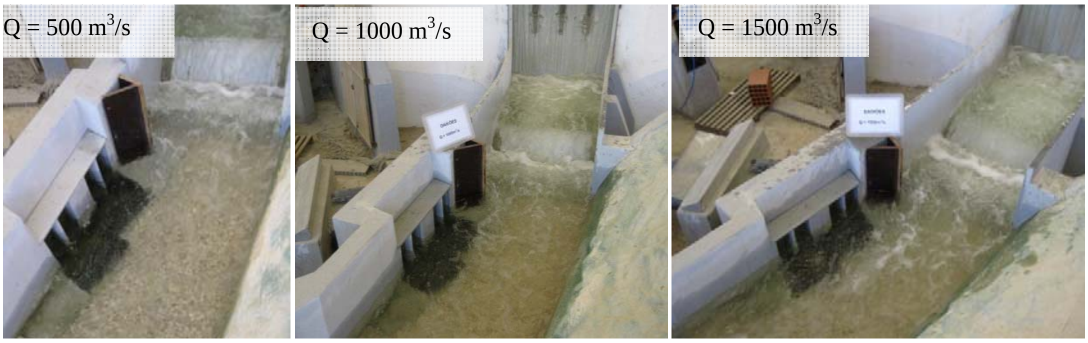


Figure 5 – Flow patterns for different flood discharges considering a deflector immediately upstream the restitution area

Currently, two additional alternatives are being studied in the physical model: 1) a dentate end weir in the stilling basin, to improve downstream flow conditions for lower discharges, and 2) the insertion of deflectors in the spillway to improve the energy dissipation in the stilling basin.

4. Alto Tâmega physical model tests

4.1. Physical model description

The physical model was built in order to optimize the hydraulic works components, such as the intake and approaching channel, maximizing the discharge; determine the discharge curve; measure the hydraulic pressures and flow heights, redefine geometry of the ski jump; evaluate the formation of the hydraulic jump upstream the ski jump and evaluate the erosion done by the falling jet in the river downstream both spillways. The model scale is 1/46.875.

The model (Figures 6) represents the two spillways, the power plant water intake and restitution. The model boundaries were selected to represent the reservoir and a long reach downstream both jets. In order to reproduce appropriate flow conditions in the reservoir, the water enters the physical model through a permeable screen made of perforated bricks. The control of the tailwater level is obtained by a movable weir, which allows the reproduction of the discharge curve in a specific river cross section in the project design.

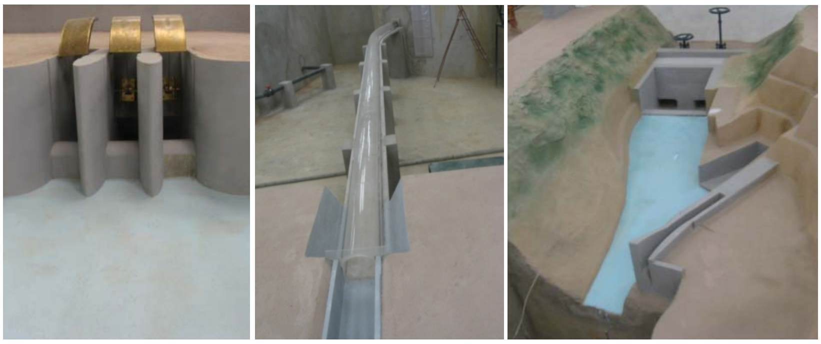


Figure 6 – Main spillway (intake and curved tunnel), auxiliary spillway and power station restitution

The hydraulic structures were moulded with sand and cement mortar. Major part of river downstream dam and main spillway has a fixed bed. For the erosion observation in the impact zone, there is a mobile bed. The mean diameter of the gravel used (D_{50} = 45 mm) tries to represent the rocks in the zone of the impact of two jets.

4.2. Running tests and modifications

The first series of tests were done on the curved tunnel spillway. The flow conditions along the tunnel are deeply conditioned by the two 90º curves, first a vertical followed by a horizontal one. The two curves generate significant water elevations in outside faces, inducing at the beginning of the tunnel a strong winding until the ceiling, Figure 7.

Figure 7 – Upstream part of tunnel with a strong winding flow

The analysis of the tests done in the curved tunnel has shown the need to split this alternative and to consider the straight tunnel alternative. The running tests for the second alternative have shown a much better behaviour of the flow in the tunnel. Until now it is not considered to modify the intake and the tunnel cross section.

There are not yet tests to observe the erosion on the river bed in the impact zone of the jets. However, being the end of the spillway defined by parallel walls, the jet opens in plant view, Figure 8. It will be necessary to redefine this end, with a mild convergence and probably changing the angle of the teeth.

Figure 8 – Jet behaviour in the main spillway

By hydraulic behaviour reasons the auxiliary spillway has changed from the left to right bank. This alternative is not yet built in the model, but it will be tested soon after the major part of tests for the main spillway is concluded.

5. Conclusions

Two physical model studies are currently being conducted in LNEC to evaluate the hydraulic performance of the spillways and energy dissipaters of Daivões and Alto Tâmega dams, which are part of the Upper Tâmega Hydroelectric Scheme, developed by Iberdrola.

In case of Daivões stilling basin, the paper focus on the dimensions of the end weir (sill) of the stilling basin. The physical model tests confirmed the considerable effect of the end weir height on the control of the hydraulic jump in a shorter distance and on the downstream flow conditions. Based on the physical model tests, proper definition of the weir height and the inclusion of additional accessories (chute and baffle blocks, dentate sill and deflector) have significant contribution to improve the original design where limitations associated with dam arrangement have imposed a significant reduction in the stilling basin available length. Other improvements are being currently studied in the physical model, namely, a dentate end weir in the stilling basin and the insertion of deflectors in the spillway.

In case of Alto Tâmega alternative hydraulic structures, the paper focuses on the first evaluation of the set of alternatives. The physical model tests rejected the curved alternative. The straight alternative has a much better performance. The tests have not been completed yet, but up to now they have concluded that the intake and the tunnel cross sections are accepted as designed. In near future the following recommendations will be developed: 1) minor modifications on the guide walls downstream the intake, 2) modification in the outlet of the ski jump in order to concentrate the jet impact on the right places of the river bed. The last suggestion will be based on the erosion evolution in the mobile river bed. Similarly, the outlet of the auxiliary spillway jet may eventually be optimized to minimize the erosion downstream the hydroelectric power station.

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