PRELIMINARY DESIGN OF THE HYDRAULIC STRUCTURES – DAM IN THE PISÃO RIVER

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SUMMARY

The purpose of this document is to study, in a preliminary level, different solutions for the design of the hydraulic structures appurtenant to the dam in the Pisão river, in order to find a viable technical solution.

A hydrological study was developed to obtain the flood hydrograph with a return period of 1000 years. For that purpose, precipitation-runoff models were used, such as the SCS’ HUD model and the rational formula. The hydrometric records of the area were also considered, scaled to the dam’s watershed through the Meyer’s formula.

For the design of the spillway, several of the most common types of weirs for earthfill dams were considered, such as the labyrinth, the WES and the circular. The analysis concluded that the labyrinth weir has more advantages in the present case. Additionally, the open channel on the left riverbank and a hydraulic jump stilling basin were designed.

The temporary diversion, designed for the return period of 20 years, was planned to be a gallery of concrete with circular cross section, also located on the left riverbank, below the dam embankment. This diversion includes the intake and restitution structures as well as two cofferdams. The restitution structure was planned as a SAF energy dissipation basin, suitable for the energy dissipation on the downstream end of a conduit.

The intake tower was placed above the intake structure of the temporary diversion and the metallic conduits of the bottom outlet and the water intake were embodied inside the diversion gallery.

The cross section of the bottom outlet and the Howell-Bunger valve were calculated to empty the reservoir within 20 days. The water intake conduit was intended to guarantee the discharge required for irrigation and maintain the ecological flow downstream.

A simplified structural design of one of the concrete elements of the hydraulic structures was made. The open channel of the spillway was the chosen structure.

Keywords: hydrological study, embankment dam, spillway, temporary diversion, bottom outlet, water intake.
1. INTRODUCTION

The thesis focuses on the preliminary design of an embankment dam in Pisão river, between the Breingel and Trigaches villages in the Beja district, defining a watershed with an area of 49 km².

The implantation of the dam’s axis was made based on the topographic characteristics of the construction area, with an established NWL at the elevation 159. The upstream and downstream slopes are 1:2.5 and 1:2.0, respectively. The dam has a maximum height of 16 m, 660 m of crest length and a total earthfill volume of 180 000 m³. In Figure 1 the general dam plant is presented.

![Figure 1 – General plant of the dam.](image-url)
2. OBJECTIVES

The purpose of this work is the hydraulic design of the appurtenant structures of the dam in the river Pisão. The designed works were: the spillway, the temporary diversion, the bottom outlet, the water intake for irrigation and the ecological discharge. For each one, several solutions were studied, according to the conditions of the area, in order to present a possible and viable solution.

3. HYDROLOGICAL STUDY

The main purpose of the hydrological study was to determine the peak discharge affluent to the dam for further hydraulic studies.

The design was made, according to the actual legislation, for the return period of 1000 years.

The peak discharge was determined through precipitation-runoff models and hydrometric records from hydrometric and meteorological stations near the watershed of the dam.

The maximum annual precipitation records were organized and statistically studied in order to estimate the precipitation with 1000 years of return period, from which were calculated the precipitations with duration of three times the concentration period do the dam’s watershed. Finally, the hyetographs were determined, according to the procedure presented by Portela (2006a and 2006b), taking into account the intensity-duration-frequency curve of the nearest meteorological station of those studied by Brandão et al. (2001).

The peak discharge affluent to the reservoir was estimated based on the hyetographs and on the unitary synthetic hydrograph (USH) of the Soil Conservation Service, SCS (Portela, 2000). Additionally, the rational formula was also used to determine the peak discharge, based on the precipitation with a duration equal to the concentration time.

The hydrometric records from a nearby station were also used, through a statistical analysis. The results of the discharge with the defined return period were transformed to the dam watershed by the Meyer formula.

In conclusion, the lowest peak discharge obtained was obtained by the Meyer formula (146 m$^3$/s), followed by the rational formula (229 m$^3$/s) and topped by the obtained through the USH model, considering hyetographs with alternate precipitation blocks ($Q_{\text{max}} = 270$ m$^3$/s).

A verification flood obtained, with the return period of 5000 years, was additionally considered. Applying the USH methodology, the peak discharge of this flood is 326 m$^3$/s.
4. SPILLWAY

The spillway was positioned in the left riverbank, due to the topographic conditions. The weir was designed to guarantee the passage in security of the design flow to downstream.

The study of the spillway included an analysis of several types of weir, the design of the open channel in concrete and the energy dissipation structure. The studied weirs were the labyrinth, the WES and the circular, and it was concluded that the labyrinth weir presents more advantages in the present case.

As presented in Figure 2, the characteristics of the adopted solutions are: $\alpha = 8^\circ$; depth, $p = 2.00$ m; two modules, with an effective length of 35.55 m and width of 7.10 m.

Downstream of the weir, there is a constriction along 7.70 m with a slope of 15% in which the width of the channel goes from 7.10 to 4.00 m. At the downstream edge of the constriction, the runoff is critical.

After the constriction, the channel has three straight reaches, connected by convex curves, completing a total of 187.90 m.

The energy dissipation at the downstream edge of the channel is accomplished with a type III hydraulic jump basin form USBR (cf. Figure 2).
Figure 2 – Spillway. Labyrinth weir, followed by a rectangular channel and a energy dissipation basin by hydraulic jump, type III of USBR.
5. TEMPORARY DIVERSION

The temporary diversion, designed for the return period of 20 years, was planned to be a gallery of concrete with circular cross section, also located on the left riverbank, below the dam embankment. This diversion includes the intake and restitution structures as well as two cofferdams.

The gallery has a cross section with 4.00 m diameter and a length of 130.00 m. The base of the intake structure was placed at elevation 142.70 and the highest level reached in the reservoir for the design flow is 146.00, which means that the crest of the upstream cofferdam must be at elevation 147.00, considering a freeboard of 1.00 m.

In the present case, was considered necessary to design an energy dissipation device in the downstream edge of the gallery. The restitution structure was planned as a SAF energy dissipation basin, suitable for the energy dissipation downstream of a conduit. The stilling basin is 6.80 m long and 11.30 wide and it is presented in Figure 3.

The walls of the stilling basin have the top at elevation 147.80 and make a 45º angle with the axis of the basin.

Downstream from the basin, the channel has a trapezoidal section, covered with Reno mattresses and has a 15.00 m long constriction. The tailrace channel is 4.00 m wide and 70.00 m long.

The transition between the reservoir and the gallery is made through a constriction, in which the width changes from 7.00 to 4.00 m. The walls of the constriction must have an hydrodynamic geometry that guarantees a transition between the subcritical flow in the reservoir to the supercritical flow in the gallery without flow separation, as showed in Figure 3.

The upstream cofferdam will be embodied in the dam’s earthfill, which means that both upstream and downstream slopes are 1:2.5. The downstream cofferdam, with crest elevation 147, will be made in earthfill and with a 1:1.5 slope.
Figure 3 – Temporary diversion. Hydraulic jump stilling basin from SAF type.
6. BOTTOM OUTLET AND INTAKE

The bottom outlet and the water intake for irrigation are two parallel metallic conduits embodied in the gallery of the temporary diversion.

Upstream, the intake tower has two entrances, one for the bottom outlet and another for irrigation intake, both at elevation 146.20. The geometry of these entrances was adapted from the intake structure of the temporary diversion. The tower is accessible through a bridge 2.00 m wide and 46.00 m long.

The cross section of the bottom outlet and it is Howell-Bunger valve were calculated to empty the reservoir within 22 days. The maximum discharge of the outlet is 9 m$^3$/s, with a velocity of 4 m/s. The conduit has 1.50 m in diameter and a Howell-Bunger control valve with 1 m in diameter at the bottom edge.

The jet from the Howell-Bunger valve was directed to the SAF stilling basin built during the temporary diversion phase.

The water intake has the double function of assuring 4 m$^3$/s for irrigation and 20% of the modular flow ($Q_{mod} = 0.22$ m$^3$/s) for ecological discharge. The 1 m diameter conduit splits in two, one for irrigation and another for the ecological discharge.

Air conduits to place downstream of the floodgates to avoid the formation of vortexes were also designed.

Figure 4 contains the geometric definition of the intake tower and the bottom outlet.
Figure 4 – Bottom outlet and water intake. Upstream intake tower.
7. DAM AND APPURTEMENT CHARACTERISTICS

Location:
- Watershed ................................................................. Guadiana;
- River ................................................................. Pisão;
- District ................................................................. Beja;
- Villages ................................................................. Beringel, Trigaches;
- Military maps ............................................................. N. º 43.

Dam and appurtenants structures:

- Dam body and reservoir
  - Type ................................................................. earthfill;
  - Dam height ......................................................... 16.00 m;
  - Volume of dam ..................................................... 180 000 m³;
  - Crest length ......................................................... 660.00 m;
  - Crest width ......................................................... 10.50 m;
  - Crest elevation ..................................................... 161.10;
  - Maximum Flood Level, MFL .................................... 160.10;
  - Normal Water Level, NWL ...................................... 159.00;
  - Minimum Operating Level ...................................... 151.00;
  - Reservoir area .................................................... 49 km².

- Spillway
  - Location ............................................................. left riverbank;
  - Type ................................................................. labyrinth weir, followed by a rectangular channel and a stilling basin downstream;
  - Peak discharge (T=1000 years) ................................ 270 m³/s;
  - Weir elevation ..................................................... 159.00 m;
  - Weir width .......................................................... 7.10 m;
  - Weir high ............................................................. 2.00 m;
  - Constriction length ................................................ 7.70 m;
  - Channel length .................................................... 187.90 m;
  - Channel width ..................................................... 4.00 m;
  - Energy dissipation structure ................................... USBR type III hydraulic jump stilling basin.
- Temporary deviation
  - Location ................................................................. left riverbank;
  - Return period ............................................................ 20 years;
  - Peak discharge............................................................. 130 m³/s;
  - Type................................................................................. circular concrete gallery, with 4.00 m in diameter and 130.00 m long;
  - Energy dissipation structure........................................ SAF type hydraulic jump stilling basin;
  - Upstream cofferdam at elevation 152.00, embodied in the dam’s body;
  - Downstream cofferdam at elevation 147.00, to be removed.

- Bottom level:
  - Location ................................................................. left riverbank, embodied in the temporary deviation gallery;
  - Bottom outlet entrance 3.50 x 2.50 m² at elevation 146.20 m, protected by a metallic grid and controlled by a sluice gate 1.50 x 1.50 m²;
  - Conduit and accessories in steel, DN 1500, 110.00 m long;
  - Howell-Bunger valve DN 1000;
  - Energy dissipation structure........................................ SAF type hydraulic jump stilling basin.

- Water intake and ecological discharge:
  - Location ................................................................. left riverbank, embodied in the temporary deviation gallery;
  - Intake tower 20.00 m tall, with a rectangular section;
  - Intake entrance 3.00 x 1.50 m² at elevation 146.20, protected by a metallic grid and controlled by a sluice gate 1.00 x 1.00 m²;
  - Conduit and accessories in steel, DN 1000, 110.00 m long;
  - Deviation conduit for ecological discharge DN 100.