Dam in Barranco das Amoreiras

Preliminary project of zoned embankment dam type and of the appurtenant hydraulic structures

Luís Eugénio Lobo de Avilez, Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal, luis_avillez@hotmail.com

Abstract: This paper presents the main aspects followed in the preliminary design of a zoned earth dam and of the appurtenant hydraulic structures in Alentejo. The applicable Portuguese legislation was considered for the design.

1. Summary

The aim of this study was to apply the techniques and knowledge within the scope of Civil Engineering to make a preliminary design of a zoned embankment dam and of the appurtenant hydraulic structures. The dam is located in Barranco das Amoreiras, district of Beja, near the village of Orada. Table 1 shows the general features of the dam.

Table 1 - General features of the dam.

Type of Dam	Zoned embankment
Embakment volume (m^3)	784 000
Height above foundation (m)	28
Maximum crest level (m)	141.00
Minimum crest level (m)	140.50
Crest Lenght (m)	887.00
Minimum water level (m)	120.00
Normal water level (m)	137.50
Máximum water level (m)	139.00
Reservoir volume at NWL (m^3)	14 900

The schemes of the embankment dam and of the appurtenant hydraulic structures are presented in Figures 1 to 6.

2. Hydrological Study

The application of precipitation runoff models requires the knowledge of the characteristics of watershed. The time of concentration, t_c, is one factor that greatly influences the response of the basin to the precipitation. A value of 5 h has been adopted for this duration.

The series of maximum annual daily precipitations over the watershed was determined by the Thiessen interpolation method. Statistical laws were applied to determine the maximum daily precipitation with a return period of 1000 years. The law of Gumbel showed the best fit to the historical precipitation data. The application of this law resulted in a precipitation of 143 mm for that recurrence period.

Relations between sub-hourly precipitations were adopted in order to establish a function relating the precipitation and its duration. This relation was then used to establish precipitation hietograms for precipitations with duration of t_c, and $2t_c$.

A synthetic unit hydrograph of duration D, established by the Soil Conservation Service, was adopted in order to determine the relation between precipitation and runoff. The peak discharge, corresponding to a precipitation with the duration $2t_c$ and a return period of 1000 years was determined to be 615 m^3 /s. The peak inflow discharge, corresponding to a precipitation with duration t_c and a return period of 20 years, was determined to be 237 m^3/s.

3. Spillway

The spillway was implanted on the left river bank and includes an upstream control structure, a discharge channel and a terminal energy dissipation structure.

A labyrinth weir was adopted as control structure, because it adds crest length for a given channel width and this is an advantage when compared to other weir types. A procedure of flood routing was adopted in order to establish the crest length. For this procedure, the input data consisted on: inflow hydrograph (SCS unit hydrograph), reservoir storage capacity curve and weir discharge curve. The solution adopted consists of a 4 module labyrinth weir with 80 m crest length, designed to operate with a maximum head of 1.50 m and a peak discharge of 147 m^3/s.

The design of the channel and of the stilling basin was based on the hydraulic characteristics of the peak discharge. A BUREC (Bureau of Reclamation) type III stilling basin of was used in order to induce an hydraulic jump and return the discharge to the downstream river channel with acceptable velocity.

4. Embankment

A zoned profile was adopted, where the core was built with an impervious clayey material (CL) and the shoulders were built with a sandy clay (SC). The main properties of the materials are in Table 2.

Table 2 - Main features of the soils used to built the dam.

Material	γ_t (kN/m^3)	c' (kPa)	φ'(°)	k_h (m/s)	k_v (m/s)
Core	19	10	20	5,00 x10^{-8}	1,00 x10^{-8}
Embakment	20	0	33	5,00 x10^{-7}	1,00 x10^{-7}

The crest width was designed aiming to favor the compaction of the core material and also to provide minimum width for traffic. Variable crest elevation was adopted in order to compensate long term settlements of the embankment.

The general method of Morgenstern-Price, based on limit equilibrium of slices, was used in the stability calculation of the embankment slopes. Global safety factor was adopted and stability was ensured for the minimum value of 1.5 for this parameter, in accordance with the Portuguese legislation for small dams RSB (Prior to EC7).

The slope of the clay core was established on the basis that its thickness would, at any elevation, be at least the necessary to ensure that the average hydraulic gradient, across the core, would be less than the unity. This criteria sought to reduce the gradients and consequently the seepage forces in the core. A cutoff trench was adopted in order to assure additional control of seepage.

Core filter and drainage blanket thickness were designed in accordance with the Darcy's law, so that they had sufficient capacity to drain the seepage flow from the embankment. Filter grading size distribution curves were established in order to meet filter requirements and also to provide adequate permeability and prevent segregation.

Table 3 shows the main features adopted for the embankment .

Table 3 - Embankment features.

Crest maximum elevation (m)	141
Crest width (m)	6.00
Upstream slope	(3H:1V)
Downstream slope	(2.5H:1V)
Core Slope	(1H:3V)
Core filter máximum thickness (m)	1.00
Drainage blanket thickness	1.50

Ultimate bearing capacity of the foundation was verified assuming as a simplification the bearing capacity law for soil shallow foundations. EC7 partial factors were used on this verification.

The grading size distribution curves and the profile of the highest section of the dam are presented in Figure 1.

5. Observation Plan

The definition of the observation plan relies on the calculation of overall level of risk parameter, EFR, established in the Portuguese legislation. The value of 7.15 was found for this risk parameter, for which the legislation requires the installation in the dam of the following instruments: a limnimetric scale, piezometers, an interstitial pressure cell, surface marks and a flow meter. All the instruments are shown in Figure 2.

Regarding piezometers, three open standpipe piezometers were adopted and deployed in the highest zone of dam, where they can provide information on seepage and hydrostatic pressure in order to evaluate the effectiveness of the overall drainage system. Two piezometers should be deployed in the core in order to establish the hydraulic gradient (Installation level: 120m and 115m respectively). The third piezometer, deployed in the downstream embankment (Installation level: 108m), is meant to collect seepage information above the drainage blanket.

Surface marks meant to control the long term settlements. They were deployed on the crest and on downstream slope, spaced apart by a range of 75m adopted in the higher zone of the dam, where higher settlements are expected. Additionally, two reference points should be deployed in each riverbank in order to run measurements.

6. River Diversion

A river diversion work must be considered in order to ensure working conditions during the construction period. Risk considerations have been made on establishing the return period of the design flow. A 20 years return period was been considered appropriate for this purpose.

A 3 phases solution was adopted. The first phase, meant to operate during the season of heavy rains, consists of a partial construction of the dam, leaving part of the valley opened for flow. The second and third phases, intended to operate during the dry season, consist on diverting the stream throughout a culvert. Low flow periods, during dry season, should therefore be used to the construction of the culvert structure and the closure of the valley.

Hydrometric data from a nearby watershed was used to determine the design discharge of the culvert structure (25 m^3/s). Table 4 shows the main features of the diversion culvert, wherein Z_1 is the culvert upstream level and Z_2 the downstream level.

Table 4 - Main features of the diversion culvert.

Diameter (mm)	2400
Slope	0.011
Z_1 elevation (m)	114.6
Z_2 elevation (m)	112.7
Lenght (m)	169

7. Water intake tower and bottom outlet discharge

The intake tower includes the bottom outlet and the inlet for the ecological and public water supplies. It is also the place where electromechanical control systems are installed. The overall system consists of a water intake tower, a culvert, previously used for river diversion and, afterwards used for the passage of the bottom outlet, ecological flow and water supply conduits.

The bottom outlet consists of a trashrack protected inlet located in the water intake tower (at 117.35 m level), a safety gate, a ø1000 mm conduit with 167 m length placed within the culvert, a transition to a ø800 mm conduit with 5 m length, and ultimately a ø800 mm Howell Bunger valve. A numerical model was set up in order to simulate the reservoir drawdown through the bottom discharge.The drawdown duration was of 33 days, with maximum and minimum discharges of 6.5 and 3 m^3/s, respectively.

The ecological and water supply outlets include trash racks (at 119.65m level), a flow control gate, a ø500mm conduit placed within the culvert ,a diversion for the ecological outlet consisting of a ø150mm conduit equipped with two sluice valves and a flow meter. The design criteria consisted of ensuring enough hydraulic head to establish the ecological flow of 0.10 m^3/s.

The ecological discharge of 0.10m^3/s was determined by the application of hydraulic methodologies in which changes in hydraulic variables were measured at a cross section of the streamflow in order to establish a regular flow regime and environmental protection.

8. Final remarks

The preparation of this project provided an opportunity to consolidate and apply the knowledge acquired during the MSc course and to get acquainted with new techniques and design procedures. The applicable Portuguese legislation was considered at design.

Benefits derived from consulting research papers and dam project reports should be highlighted as advantages. The differences found between the design that was carried out and a real project were recognized as valuable lessons for the future. At last, reference should be made about the assumptions taken in the preparation of this project, which were considered necessary in order to focus the study on the objectives defined by the supervisors.

Acknowledgements

The author acknowledge the comments provided by the supervisors Professor António Pinheiro and Professor Rafaela Cardoso to the work presented.

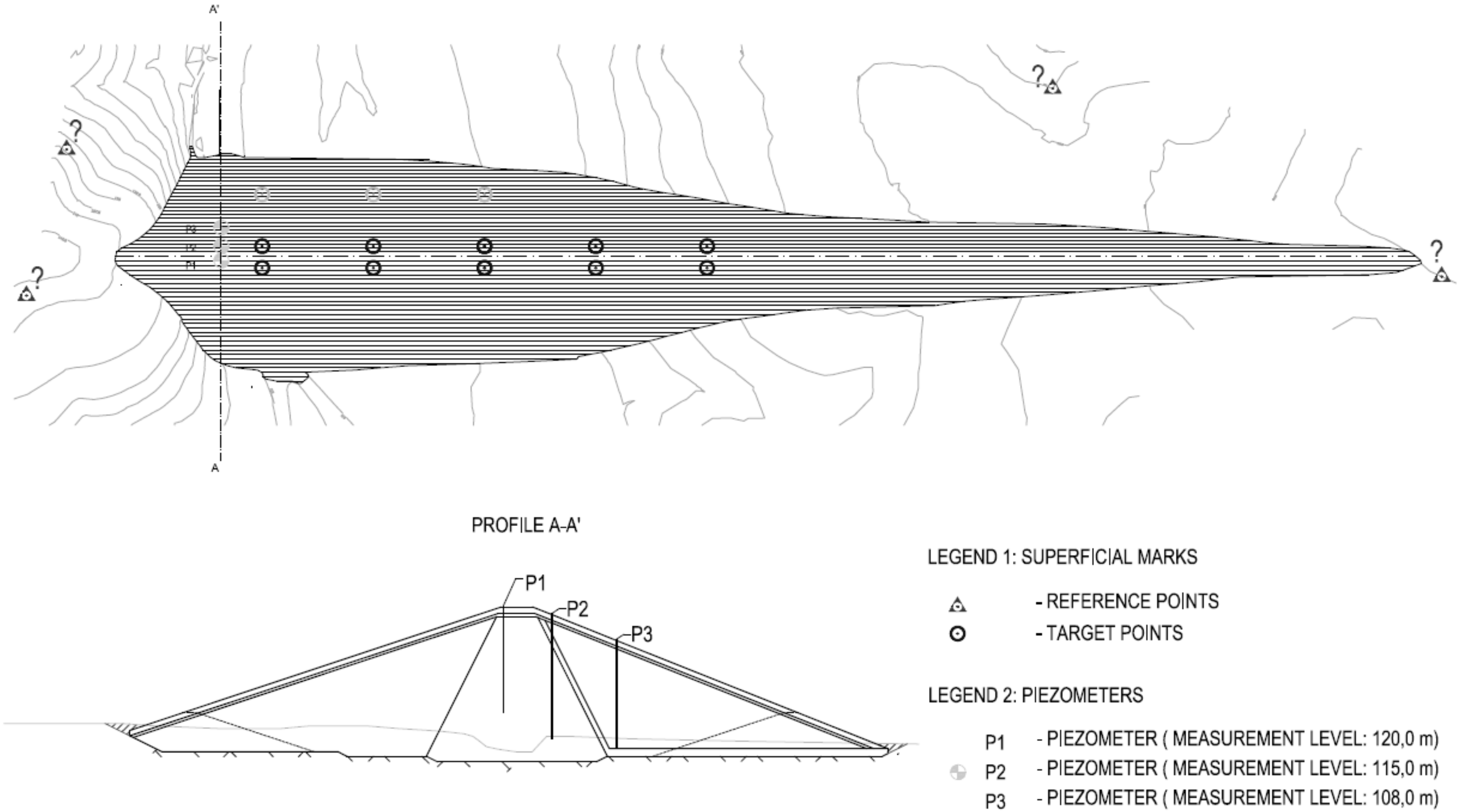

Figure 1 - Piezometers and superficial marks.

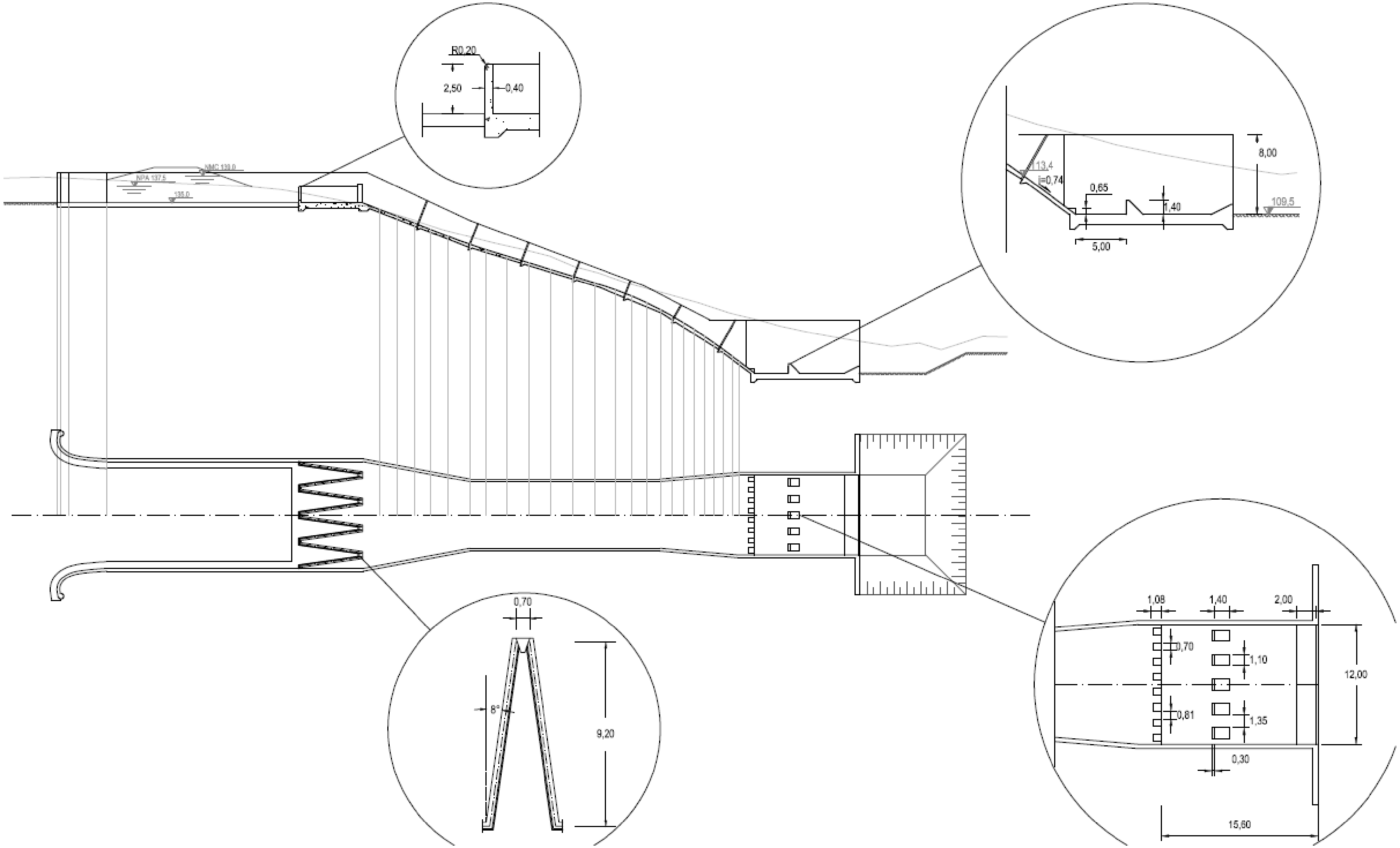

Figure 2 - Spillway structures.

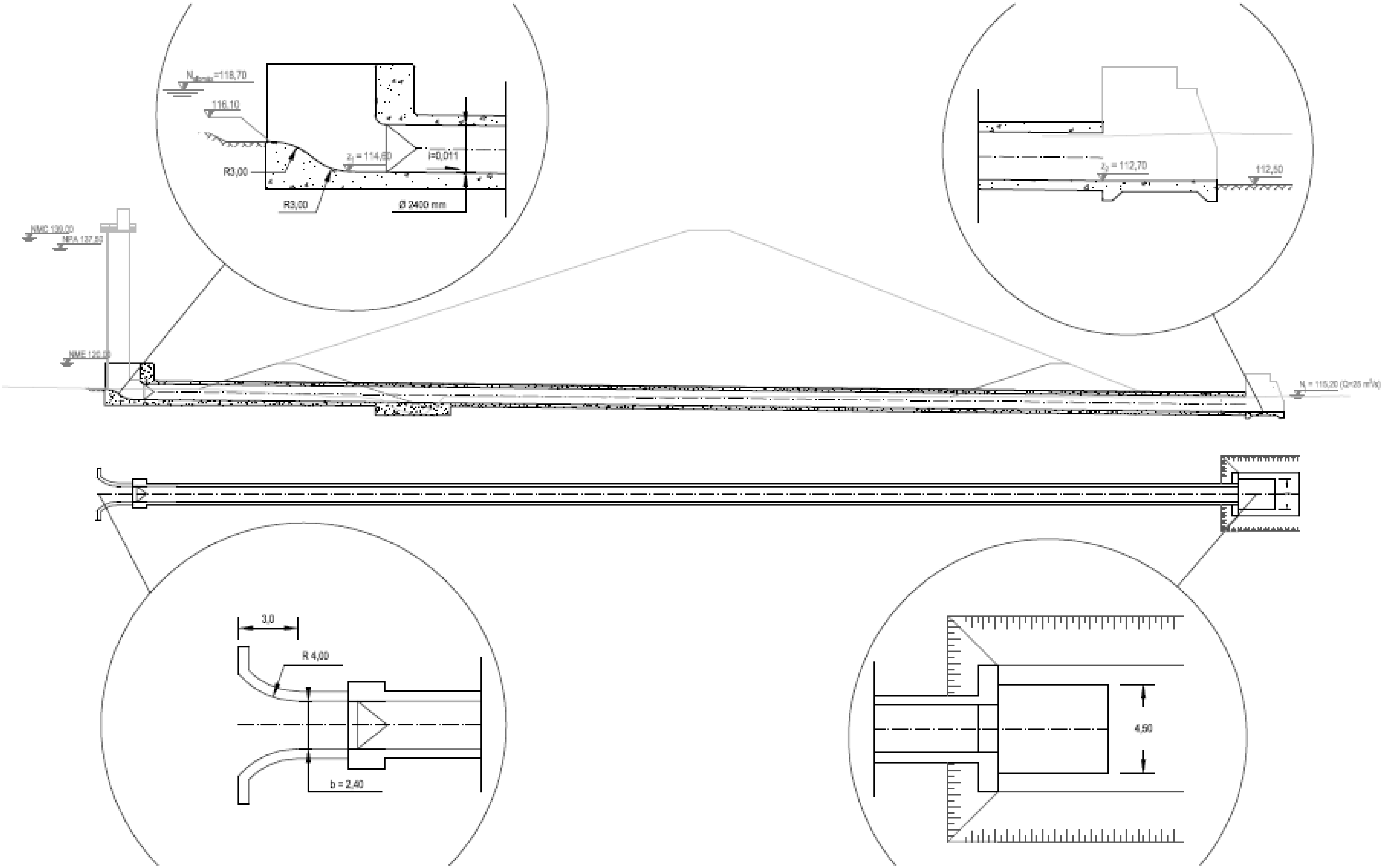

Figure 3 - Temporary diversion structures.

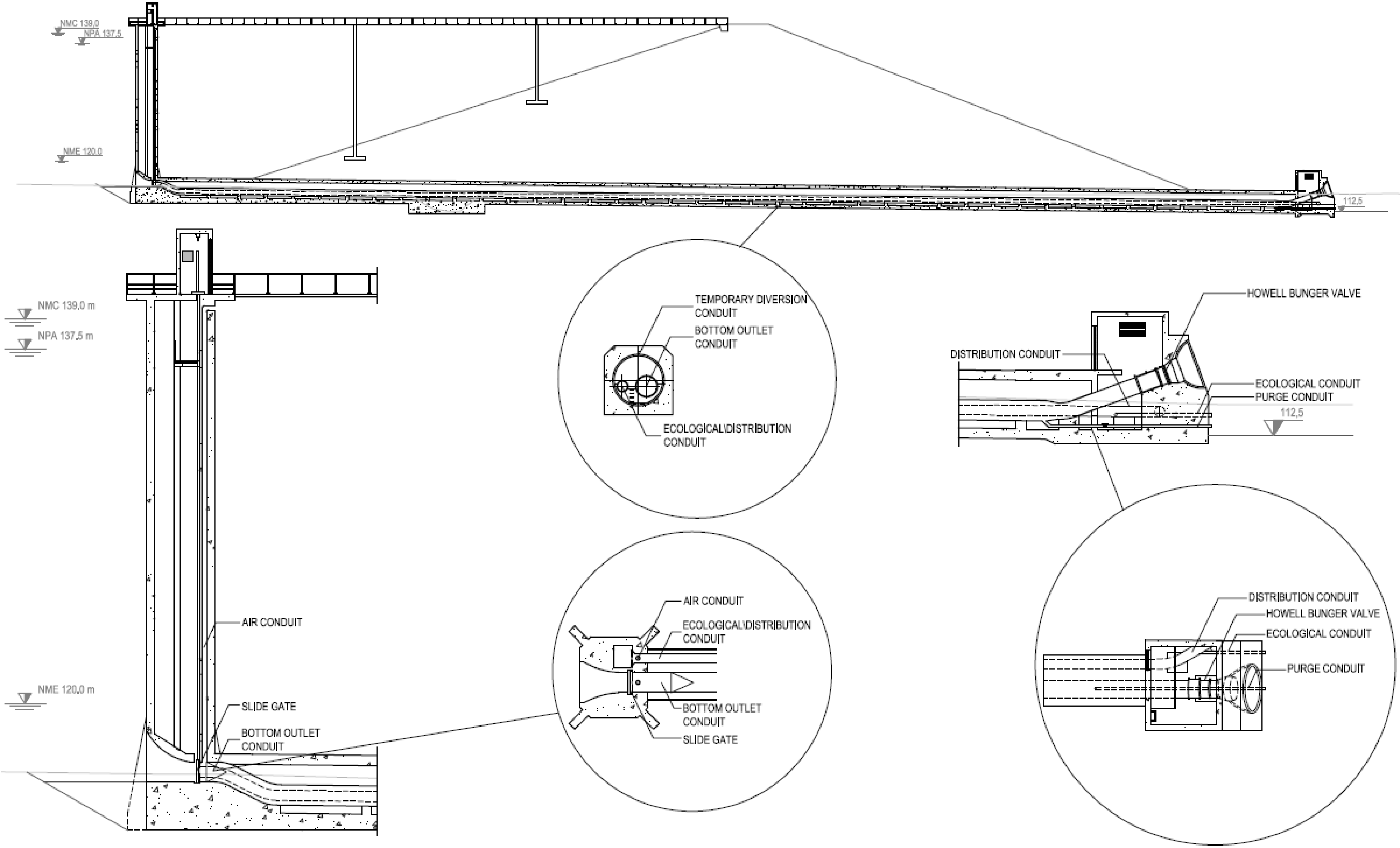

Figure 4 - Bottom outlet and intake structures.

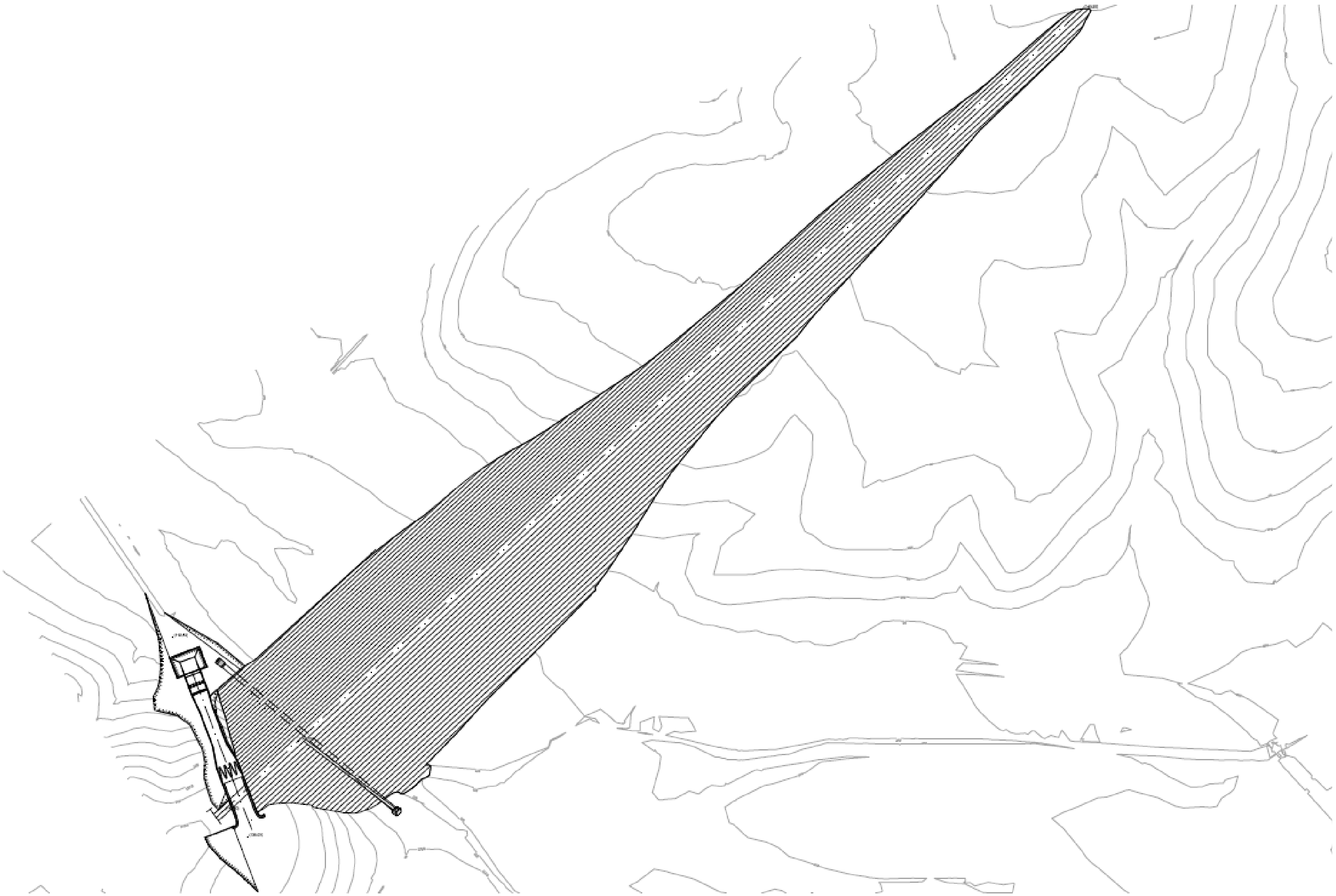

Figure 5 - General view of the dam.