Final design of Belesar III and Los Peares III Hydropower Projects. (Galicia, Spain).

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ABSTRACT: Belesar III and Los Peares III Hydropower Projects are reversible plants that require the construction of several underground excavations with different typologies. Belesar III Hydropower Project incorporates the construction of 2,100 m of principal conduction, a pressure shaft and two chambers in order to house the power and the transformer machinery. In addition, the project includes two gates shafts, a surge tunnel, a bus shaft to join the powerhouse with substation plant, an access tunnel and several construction tunnels. The underground works involved in Los Peares III are a 50 m length tunnel located at the intake area and a pressure tunnel of 440 m length. A 55 m depth shaft connects both tunnels. One more shaft will be constructed to contain the flow control gates. NATM was chosen to construct all the tunnels. Shafts have been designed as a raise-boring and enlarged up to final diameter using NATM.

1 INTRODUCTION

Belesar III and Los Peares III Hydropower Projects are reversible plants locate at Galicia, Spain, that require the construction of several underground excavations with different typologies. The owner is Gas Natural Fenosa. Figure 1 shows the location of the projects.

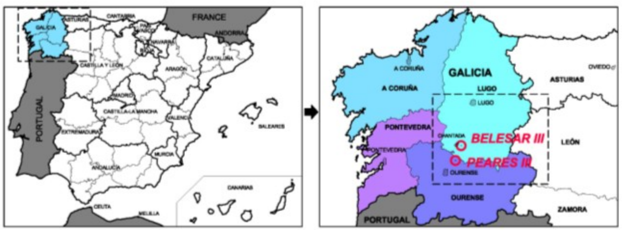

Figure 1.Location of the projects.

Belesar III Hydropower Project incorporates the construction of 2,100 m of principal conduction, a pressure shaft and two chambers in order to house the power and the transformer machinery. In addition, the project includes two gates shafts, a surge tunnel, a bus shaft to join the powerhouse with substation plant, an access tunnel and several construction tunnels. Figure 2 shows the scheme of Belesar III Hydropower Plant.

The underground works involved in Los Peares III are a intake tunnel and a pressure tunnel. A 55 m depth shaft connects both tunnels, while a second shaft will be constructed to contain the flow control gates

Figure 3 shows the scheme of Peares III Hydropower Plant.

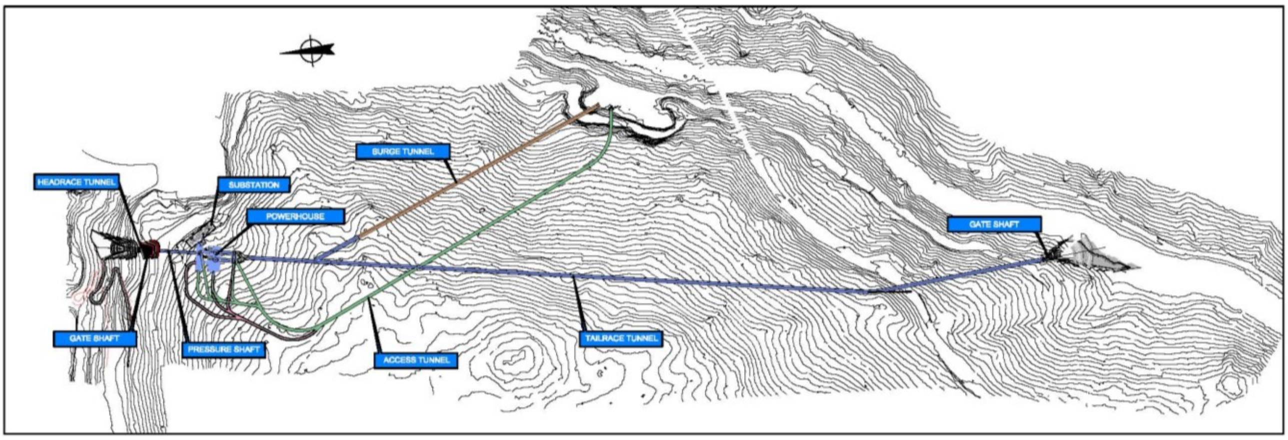

Figure 2.Scheme of Belesar III Hydropower Plant.

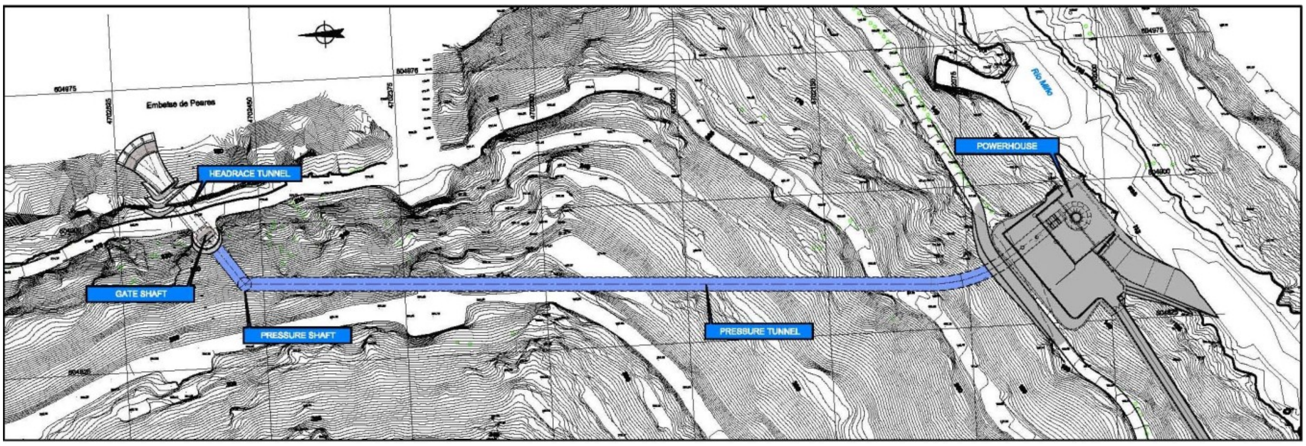

Figure 3.Scheme of Peares III Hydropower Plant.

2 GEOLOGICAL AND GEOTECHNICAL CONDITIONS

Both Belesar III and Peares III are located in Lugo, in the Northwest of Spain, in the Miño River, in crystalline and metamorphic rocks of the Hercynian belt that is constituted by Precambrian and Paleozoic materials folded during the Hercynian Orogeny.

An intense campaign for the rock mass characterization including the main joint sets was carried out.

For this purpose a site investigation including geophysical profiles, boreholes as well as in situ and laboratory tests were performed.

Rock mass has been intensively studied to make a realistic prediction of the stress-strain behavior including in the case of Belesar III cavern the execution of hydrofract tests at deep holes to determine the natural stress field.

Finally the main joint sets were obtained and also, by mean of statistical analyses, the scatter of discontinuities in terms of persistence, roughness, aperture and spacing.

The area in which Belesar III will be constructed belongs to “Ollo de Sapo” domain and Chantada-Taboada mass. These granitic plutons are constituted by porphiric biotite granitoids.

Different fault systems from hercynian and alpine ages modify the original fracture scheme and bring the chaotic model of the outcrops, which have a little lateral continuity.

The 2,100 m of tunnel crosses basically grey granodiorites composed by quartz, feldspar, biotite and sometimes muscovite crystals. Around powerhouse has been found an aplitic dyke which structural characteristics are similar to the granodiorites ones.

The mass rock has a massive and resistant structure and presents weathering grades II and III at the surface outcrops.

In order to characterize the mass rock, 2,658 m have been drilled distributed in 14 boreholes. In addition, 960 m of seismic profiles were performed in portal areas and two ERT Electrical Resistivity Tomographies (1,200 m length) were carried out.

Figure 4 shows the geological profile of Belesar III where different faults or fractured areas can be observed along the tunnels, as well as the presence of the main dykes.

In order to estimate the natural stress field, two hydro fracturing tests had been carried out in SB-1 and SB-2 (boreholes located around caverns).

The results obtain in those tests brought the following stress coefficient distribution:

- K_{0H}=1.4
- K_{0h}=0.8

with an orientation N-160º-E for the maximum horizontal stress.

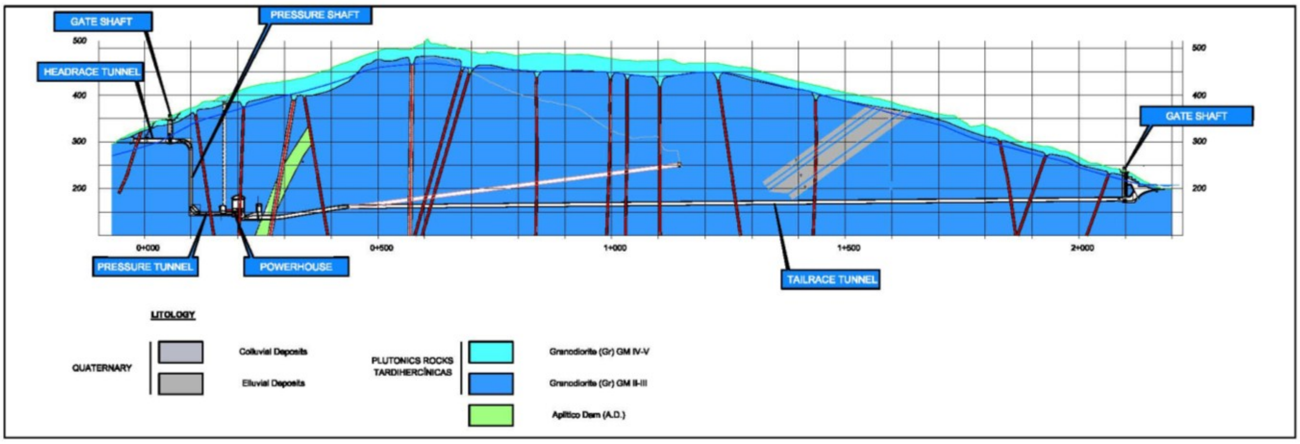

Figure 4.Geological profile. Belesar III.

The powerhouse area was deeply investigated through six boreholes that where very useful to defined the final location of the caverns.

Figure 5 shows, the geological plan at the cavern depth. It can be observed that the final location avoids almost totally, the faults affection.

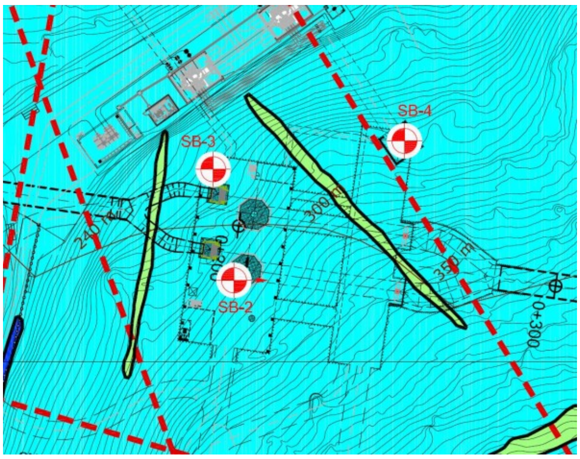

Figure 5.Geological plan at caverns level.

The orientation of the longitudinal axis of the caverns was chosen accordingly to the horizontal stresses.

The Hydroelectric Project Peares III is located at the existing dam of Los Peares also in the course of the river Miño, some kilometers downstream to Belesar III.

The geological units that will be affected by the underground works in Peares III hydropower project are composed by slates and schist with variable contain of mica and quartz. This schist locally changes to gneiss.

Figure 6 shows the longitudinal geology of the tunnel where it can be observed that most of the tunnels will be excavated in schist and gneiss. Besides five main faults have been detected along the tunnel alignment.

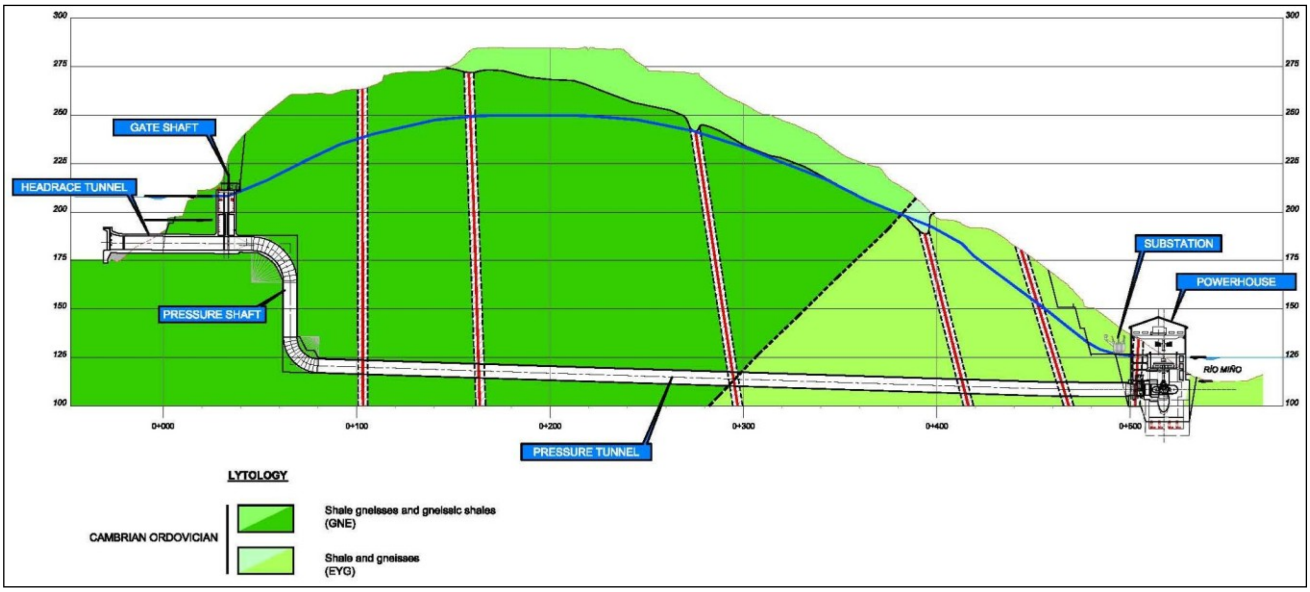

Figure 6.Geological section. Peares III.

In the case of Peares III, the following site investigation were done: 4 boreholes, 470 m of Electrical Resistivity Tomography profiles, 300 m of Seismic Refraction profiles. Also some in-situ tests have been carried out such as 4 pressure-dilatometers and 5 Lugeon permeability tests. Finally an intensive program lab test was performed.

From all the above information the geomechanical characterization of the rock mass was done.

The groundwater level affects in different magnitude the projected tunnels. For the intake tunnel the water level is associated with the maximum dam level which does not mean a high water pressure. However, for the pressure tunnel the water pressure associated with the groundwater level into the mountain have been foreseen to reach up to 130 m of height which should be considered at least in the faults intersections.

The natural stress field adopted corresponds to K_0 stress coefficient distribution of 0.75 in both directions, E-W and N-S

Concerning seismicity, according to Spanish normative (NCSR-02) the calculations in portals and superficial works have been done, in both projects, using a horizontal seismic acceleration of 0.032 g.

3 DESCRIPTION OF THE UNDERGROUND WORKS

Belesar III Hydropower Project consists of about 5,000 m of tunnel, shafts and caverns, distributed in the following elements:

- 80 m length of headrace tunnel that begins with a square internal section of 7.4 m to finish with a circular section (internal diameter Ø 7.4 m)
- A pressure shaft of 155 m depth and 6.5 m diameter
- A 60 m long pressure tunnel (internal diameter Ø 6.0 m)
- Power house which dimensions are 47 m high, 28.30 m width and 28.30 m large
- Transformer house (14.07 m high x 16 m width x 73.79 m large)
- A 1870 m length of tailrace tunnel which internal diameter is 7.4 m and its external diameter varies between 8.10 an 9.00 m depending on concrete final lining thickness.
- A 724 m length surge tunnel (internal diameter Ø 7.4 m)
- 1,153 m long access tunnel to power house. The cross section in order to allow the transport of turbines is 7.5 x 7.5 m.
- Caverns construction tunnels that allow the access to different levels in caverns

during construction. The cross sections are 6.5 x 6.5 m and 5.5 x 5.5 m. Total length of these tunnels is 485 m.

- Two gates shafts (Ø 8.8 m internal diameter and Ø 10.4 m external diameter), one upstream pressure shaft (L = 44 m) and another one downstream (L = 32 m)
- Bus shaft (225 m depth and Ø 5.5 m)

Figure 7 shows the cross section of the main underground structures.

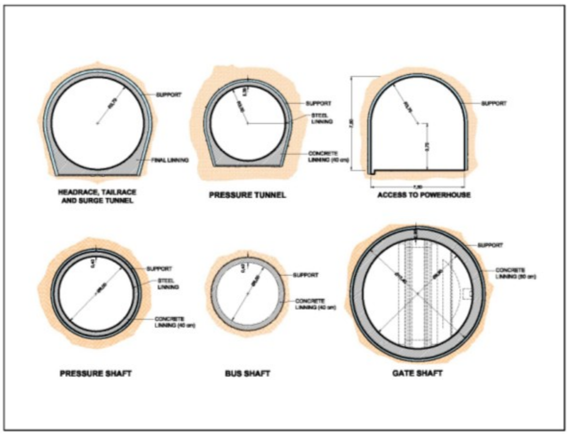

Figure 7.Sections of the main underground structures. Belesar III

The underground works involved in Peares III project basically consists of:

- 50 m length of headrace tunnel that begins with a square internal section of 7.0 m to finish with a circular section (internal diameter Ø 7.8 m)
- A pressure shaft of 55 m depth and 7.0 m diameter
- A 440 m length pressure tunnel (internal diameter Ø 7.0 m)
- A shaft of 25 m depth and 10.5 m that contain the flow gates

Figure 8 show the section of the main underground structures

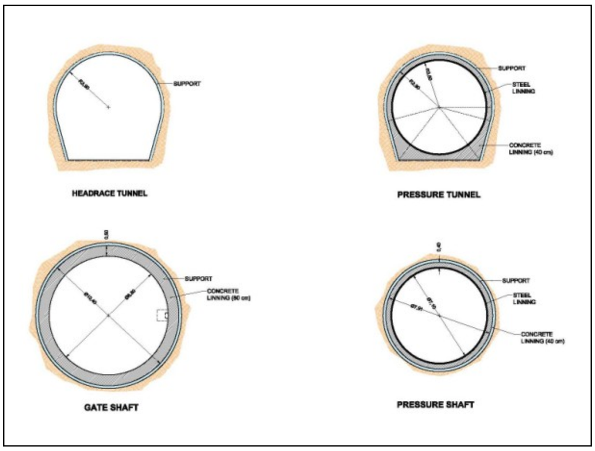

Figure 8.Sections of the main underground structures. Los Peares III

4 SUPPORT DESIGN

NATM was chosen to construct all the tunnels. Shafts were design as a raise-boring 2.8 m diameter and enlarged up to final diameter using NATM.

The excavation will be mainly made using drill and blast, while a few sections, affected by fault zones where de rock mass quality is lower, mechanical excavation will be used.

In order to cover all the quality rock mass, five sections have been design. For each support section, as it is showed in Table 1, has been defined shotcrete thickness, bolts grid, ribs spacing and round length needed in order to keep the safety factors during construction.

All the supports have been validated using stress-strain calculation solved with FLAC 2D code and rock wedge calculation using UDWEDGE code.

Table 1 shows the five support classes used in tunnel as well as the round lengths adopted and the ranges of rock mass quality of application for each class.

Table 1.Support Classes.

Excavation Class	RMR	Unsupported Span (m)	Fiber Reinforcement Shotcrete (cm)	Wire Mesh	Rock Bolt(1) Pattern (m x m)	Steel Ribs(2) Spacing (m)
ST-I	>70	5.0	-	Yes	2.5 x 2.5	-
ST-II	55-70	4.0	3+3	No	2.0 x 2.0	-
ST-III	45-55	3.0	3+7	No	1.5 x 1.5	-
ST-IV	35-45	1.5	3+12	No	-	1.5
ST-V	>35	1.0	3+20	No	-	1.0

(1) Swellex type (Mn 16). L = 2.4 m.

(2) TH-29

At the portals, in the beginning of the excavations a special support have been designed in order to prevent local instabilities in these sensible areas. The reinforcement consists of an umbrella of 9.0 m length micropiles and also the shotcrete and steel ribs corresponding with the heaviest support class. Figure 9 shows the reinforcement in the first few meters of the tunnels.

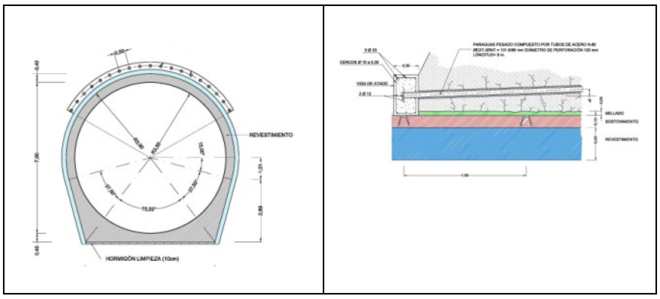

Figure 9. Tunnel support in the first meters at the portals

The analysis in the caverns was carried out using FLAC 3D due to the complexity of the model in order to analyze the interactions between the different excavations according to the defined geological model.

Support varies depending on different sidewalls or vault but all of them are composed by:

- Shotcrete fiber reinforcement (35 MPa): between 10 and 18 cm thickness
- Rockbolts of 9 m length: 25 or 32 mm diameter and between 2x2 and 1.5x1.5m spacing

Figure 10 shows the model used in calculation. In Figures 11 and 12 it can be observed the fault areas modeled.

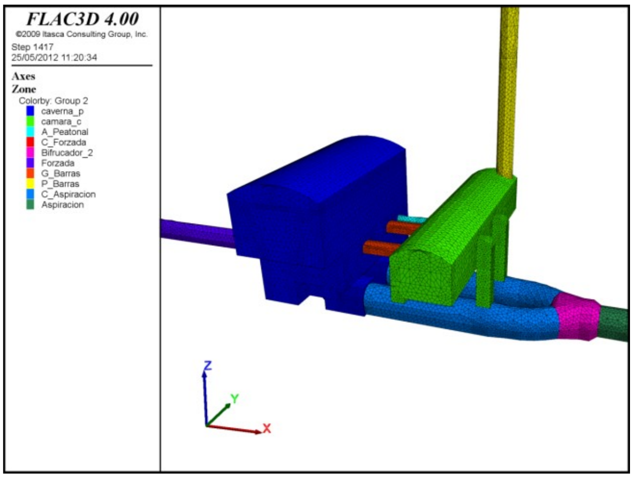

Figure 10. FLAC 3D model used in caverns analyses.

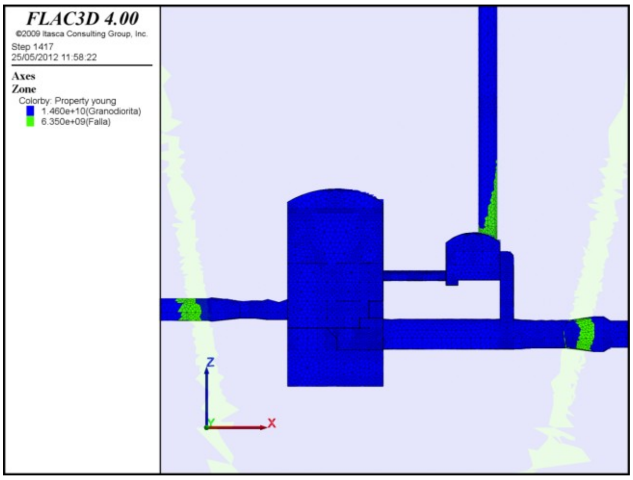

Figure 11. Powerhouse Caverns. Fault areas modeled. Profile.

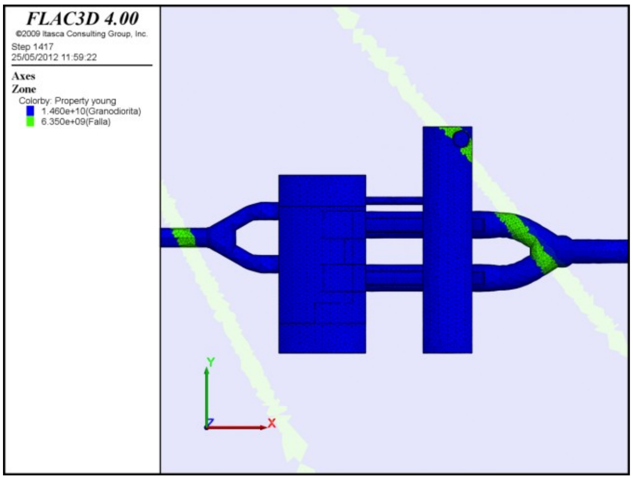

Figure 12. Powerhouse Caverns. Fault areas modeled. Plan.

5 LINING DESIGN

The primary support ensures the stability of the excavations in the short term and with no additional surcharges apart from the stress field of the surrounding rock.

A secondary support or reinforcement concrete lining have been designed in order to endure the additional surcharges associated with the functionality of the tunnels.

Thus for the pressure tunnel the lining have been checked under two hypothesis:

- Empty tunnel and maximum ground water level; in this situation the stresses in the lining are predominantly compressions.

- Tunnel full water at the hammer pressure the groundwater level below the section of the tunnel; in this situation the stresses in the lining are predominantly tractions.

Figure 13 shows the model of calculus under internal pressure.

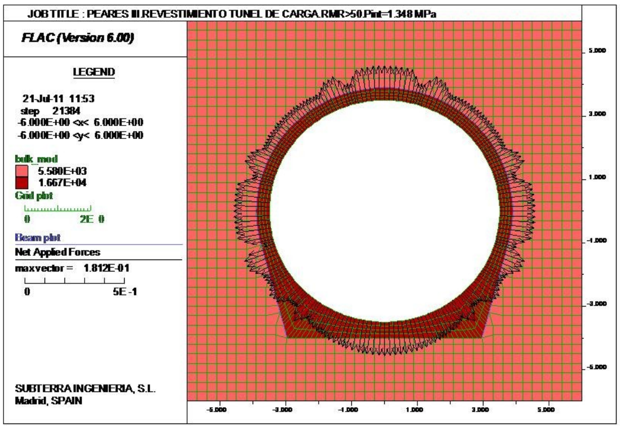

Figure 13. Model of calculus in the lining design.

In both situations the characteristic of the surrounding rock have a very high influence over the final resultant stresses in the lining. Therefore both checks have been done for two sections of the tunnel one considering good or fair resistance properties (RMR >50) and the other for lower properties of the surrounding rock.

Besides, a steel sheet has been envisaged for the last 100 m of the tunnel where the water pressure is so high that this typology of solution is required. Also the curved connections between the tunnels and the shaft are lined by a steel sheet in order to avoid the weathering of the rock by the water flow.

Tailrace and surge tunnels in Belesar III have been split in three stretches depending on the overburden in order to optimize the concrete thickness along the tunnel.

6 WORKING PLAN

For both projects a work plan have been developed with the aim to optimize the period of execution of the works and the resources to be implemented.

The expected performances of the main works to be executed have been analyzed, the critical paths have been found, and finally the work plans have been defined.

In order to estimate the construction times, the following excavation rates have been considered for principal tunnels:

- ST-I and ST-II: 6.5 m/day
- ST-III: 4.0 m/day
- ST-IV: 2.0 m/day
- ST-V: 1.0 m/day

In shafts constructed using raise boring method, the following drilling rates have been considered:

- Pilot drilling: 10 m/day
- Reamer head: 5 m/day
- Enlarged up: 3 m/day

Finally, the excavation rates in shafts constructed using conventional methods have been considered between 1.0 and 0.5 m/day depending on quality rock mass.

The construction estimated period in Belesar III has been 33 months using four different work teams.

Two of them will start the excavation of access tunnel and surge tunnel respectively, and will continue excavation the power house. The third one, that will start 4 months later, will excavate the shafts.

Finally, the last one will excavate the transformer cavern and some of the construction tunnels.

In the case of Peares III two alternatives have been purposed:

- The headrace and pressure tunnels carried out by conventional methods (drill&blast) and the shafts by raise-boring
- All tunnels carried out by conventional methods

In the two alternatives the estimated construction period has been 13 months.

7 CONCLUSION

From the design of the hydroelectrical projects of Belesar III and Peares III the following conclusions can be derived:

A deep and good geotechnical characterization is fundamental for the design of the underground structures. In the case of Belesar III the field stress characterization was very useful to decide the orientation of the powerhouse.

The modelization of the problems by mean of the commercial programs is a very useful tool to evaluate the stress states of support and rock under the different hypothesis of calculus that represent the different states in the time of service of the tunnels.

In the project phase the construction method and work plan must be considered in order to provide the properly supports for each case.