The construction of the hydroelectrical project Renace II (Alta Verapaz, Guatemala).

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ABSTRACT: The hydroelectrical project Renace II is located at Cahabón River, in the Alta Verapaz Department, Guatemala The owner is Recursos Naturales y Celulosas, S.A. (RENACE, S.A.) that is part of Corporación Multinversiones, and the construction contract was awarded to COBRA Infraestructuras Hidráulicas. Renace II will provide 112 MW using a gross head of 335 m and a flow of 40 m^3/s. This paper aims to summarize the main aspects of the design process that have been carried out for the underground works involved in the project. Also the main aspects of the construction phase are shown. The main difficulty has been the intersection of the tunnels with cavities originated by karstic processes in the limestones of the Coban Formation. The construction method and the equipment used are providing good advance rates and optimum safety condition in the excavation and support of a large underground project.

1 Introduction

The Renace II project is a hydropower project that is under construction by the company COBRA. The project is located at Cahabón River in the Alta Verapaz Department of Guatemala. Figure 1 shows the location of the project.

Figure 1. Location of the project.

Renace II is the second of three elements in the use of Cahabon River. The first stage, Renace I, has been already built and is operating since April 2004. It provides 13.6 MW using a gross head of 210 m. In this moment a regulating reservoir is projected whereby the production is envisaged to be increased to 60 MW.

The hydroelectric project Renace II is located immediately downstream of the Renace I powerhouse.

Renace II will provide 112 MW using a gross head of 335 m as its elevation varies from 974 m at the intake to 640 m at the powerhouse, with a flow of 40 m^3/s.

The underground works involved in this project basically consist of a low-pressure tunnel, a high-pressure tunnel and a small free flow mud tunnel. Their main characteristics are summarized in Table 1

Table 1. Characteristics of the tunnels.

Parameter	Tunnel 1	Tunnel 2	Tunnel 3
Pressure	Low	High	Free flow
Difference of heights	2 m	176.5	4.75
Cross section	29 m^2	15 m^2	3.8 m^2
Length	3.440 m	3.900 m	214.5 m

The construction of the tunnels started on October 2012. The whole pressure system is envisaged to be finished on May 2014.

1.1 *Hydroelectric concept of the project*

Renace II hydroelectric power plant makes use of the water of the Cahabón River.

The water is collected directly from the up-stream previous hydroelectric power Renace I.

The intake is located close to Renace I power house and it is composed by a 6 m high dam, a gated weir structure, a gravel sluice and an environmental flow gate.

From this intake the water is conveyed by an open channel to a reservoir first and afterwards by Tunnel 1 to the main desander.

This reservoir has the function of ensuring that the water is free of solid sediments before entering into the pressure circuit. The tunnel 3 or mud tunnel has been projected to allow the cleaning of the bottom of the reservoir.

From the reservoir the water is conveyed to the power house first by Tunnel 2 and finally, at the surface, by a steel pipe. The envisaged flow is 40 m^3/s.

2 Geology and geotechnics

Following, the main geological and geotechnical data of the tunnels are provided. Figure 2 shows a synthetic geological profile of tunnels 1 and 2.

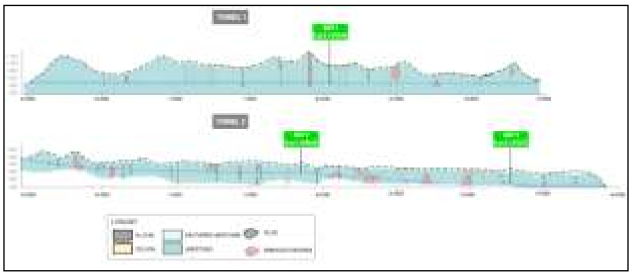

Figure 2.Geological synthetic profile of the principal tunnels.

2.1 *Geology*

The study area is located in the Central Mountain Range of Guatemala, which is one of the four biggest geologic provinces into which Guatemala is divided.

This unit is composed by calcareous rocks of the Cretaceous known as Coban Formation and it is structured by a successive serie of folds and thrusts.

All tunnels are located in the Upper Formation that consists basically in limestones with some interbedded dolomites affected by an intense karstic process.

Covering the rock formation, alluvial deposits associated with the Cahabón River can be found, formed by river stones in a poorly classified sand matrix. Also some thin coluvial deposits can be found resulting from the degradation of the rocky substrate.

With the aim of characterizing properly the materials affected by the tunnel excavations a geotechnical research campaign was carried out. It consisted in:

- Seven boreholes, four at Tunnel 1 and three at Tunnel 2. A total amount of 477.5 m have been drilled.
- Four electrical resistivity tomography profiles (ERT), two in each tunnel with a total length of 4.780 m.
- Twelve seismic refraction profiles with a total length of 1.240 m.
- Fifteen Lugeon tests and two Lefranc tests

One interesting aspect that should be noted is the development of a layout with the location extension and the likelihood of sinkhole presence, associated with the karstic process. This map was created on the basis of all the research previously mentioned and also a geological mapping carried out in the area. It has been very useful to define the final layout of the tunnels, which preferably should avoid those sinkholes. Figure 3 shows an extract of the sinkholes layout and the different outlines considered for the Tunnel 2

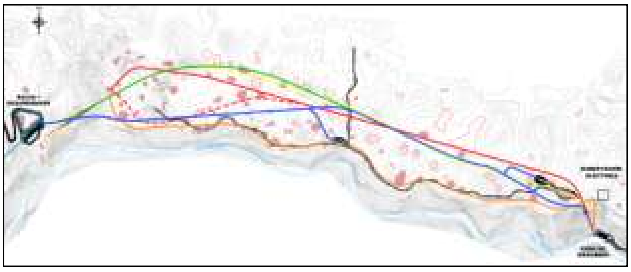

Figure 3.Karstic Sinkholes layout. Tunnel 2.

2.2 *Geotechnical characterization*

From all the information obtained in the site investigation, a geomechanical characterization of the rock mass has been done.

The geotechnical parameters have been calculated following the conventional methodology for rock masses Thereby the properties of the intact rock have been decreased depending on the rock mass rating (RMR).

The geotechnical parameters calculated for the limestone of the Cobán Formation are shown in Table 2

Table 2. Geotechnical Rock Mass parameters.

RMR	Overbunden	E_m (MPa)	c (MPa)	Ø (MPa)
65	50	13.238	0.67	52
65	100	13.238	0.81	48
65	150	13.238	0.95	45
55	50	10.028	0.42	50
55	100	10.028	0.56	45
55	150	10.028	0.68	42
45	50	7.596	0.29	47
45	100	7.596	0.42	42
45	150	7.596	0.53	39
35	50	4.110	0.18	41
35	100	4.110	0.28	36
35	150	4.110	0.36	33
25	50	1.868	0.17	41
25	100	1.868	0.26	36
25	150	1.868	0.33	33

A special attention was given to the study of the families of joints, their orientations, persistence, roughness, aperture, spacing and resistance, because they can conditioned the behavior of the excavation sections. The stereogram diagram was used and a statistic analysis of the parameters of the joints was carried out.

2.3 *Hydrogeology*

The groundwater level is below all the projected tunnels. Thereby the tunnel inflows will always be low and due to leakages from the surface.

2.4 *Seismicity and stress state*

According with the normative AGIES NR-2:2000, the Republic of Guatemala is divided into three seismic areas.

Renace II project is located in the Zone 3 where a seismic coefficient of 0.35g is recommended

Once analyzed the tectonics and orography context a stress state of 0.75 was considered both for $K_{0\ E\text{-}W}$ and $K_{0\ N\text{-}S}$.

3 Description of the underground works

The underground works involved in this project basically consists of:

- **Tunnel 1**, it is a low-pressure tunnel with shotcrete lining and 3.440 m of length. The tunnel excavation width is about 6.1 m and the useful cross section is 29 m^2. One adit has been envisaged in the construction plan.

- **Tunnel 2**, it is a high-pressure tunnel with 3,900 m of length lined with reinforcement concrete, except the last 100 meters where a steel lining will be used. The excavation width is about 5.3 m and the useful cross section is 15 m^2. Three adits were envisaged in the initial construction plan but finally only two have been necessary.

- **Tunnel 3** or mud tunnel, it has maintenance functions at the desander reservoir. It is a free flow tunnel with a total length of 210 m. The excavation width is about 2.5 m. Suitable machinery has been used in the excavation in order to deal properly with these small dimensions.

Figure 4 shows the sections of the main underground structures. It can be observed that an enlarged section was adopted for the adits, as they had to ensure the simultaneous excavation rates at two faces, upstream and downstream.

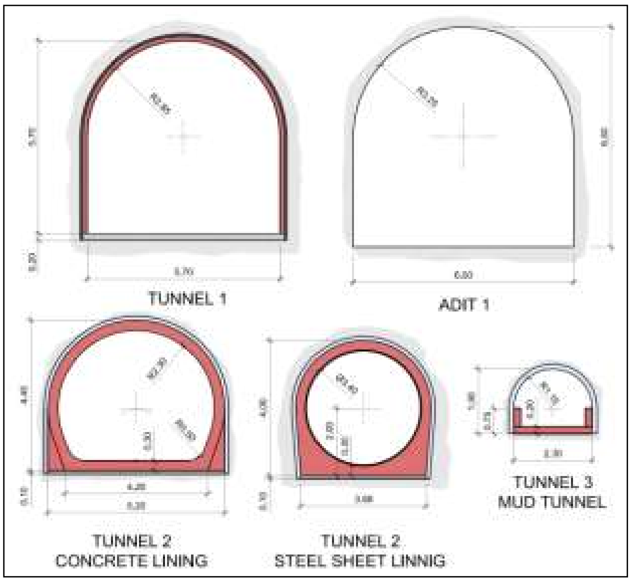

Figure 4.Sections of the main underground structures.

4 Support design

The tunnels have been excavated in full face by conventional drill&blast methods in almost all their length. Only in a few sections with a very poor quality of the rock some mechanical excavation was done.

Table 3 shows the support classes used in the tunnels. Five classes have been designed for tunnels 1 and 2, four for the adits and three for the mud tunnel. In the design of the support reinforcements a first approximation was done using Grinstand-Barton (1993) recommendations and considering the seismic context (Barton, 1984), so that a 50% reduction of the Q value was imposed.

Finally, all the supports were validated using stress-strain calculation solved with Flac 2D code and rock wedge calculation using Unwedge code.

Table 3.Support classes.

Tunnel	RMR	Fiber reinforced Shotcrete (cm)	Rock bolts	Steel ribs
1,2	>65	_	Friction bolts 160 kN length-1.8m Occasional	
1,2	55-65	_	2x2	
1,2	40-55	3	2x1.5	
1,2	30-40	10		Laticce girders @1.5
1,2	<30	12		@1.0
Adit	>65	_	Friction bolts 160 kN length-4m Occasional	
Adit	50-65	3	2x2.5	
Adit	35-50	5	1.5x2	
Adit	<35	15		@1.0
3	>50		Bars Ø31 length-1.2m 2 per m	
3	35-50	6	3 per m	
3	<35	12		@1.0

An additional design of support has been carried out for those sections where the tunnels cross karstic caves. In the case of Tunnel 2 this treatment has a very high importance because of the high pressures it will support, and therefore the structural collaboration of the surrounding contour of the lining is necessary.

This support has been designed differently for the caves than affect the void of the tunnel section and for cavities than affect the bottom of the section.

For the caves affecting the roof/walls the following procedure has been foreseen:

- Lattice girders with 1.0 m of distance lined with corrugated sheet
- Emplacement of 3 cm of shotcrete at the internal face
- Filled of the external face with concrete until 1 m of thickness.
- Filled the rest of the volume with cement and bentonite slurry.

Figure 5 shows this special section.

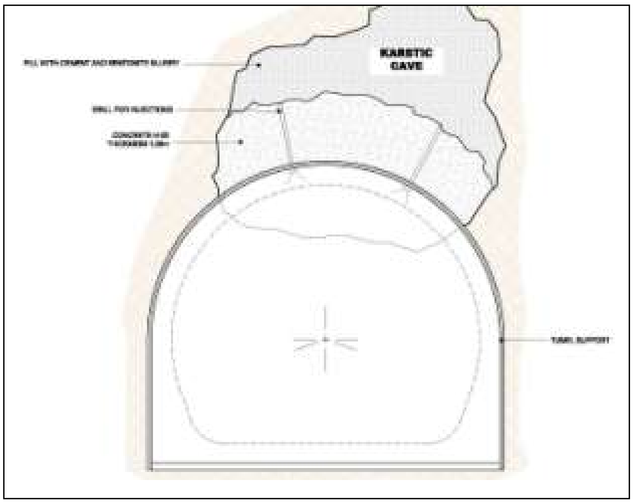

Figure 5. Section for caves intersection at the roof/walls.

For the caves located at the floor the following procedure has been foreseen:

- Filled of the cavity with concrete
- Execution of micropiles embedded two meters in the healthy rock
- Construction of a bottom slab reinforced concrete

Figure 6 shows this special section.

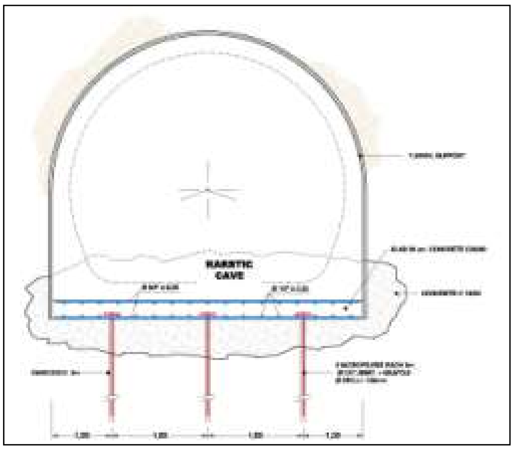

Figure 6. Section for caves intersection at the floor.

5 Tunnel construction

5.1 *Main data*

The construction of the tunnels started on October 2012. On the date in which this article is being written tunnel 1 and 2 are still under excavation. The whole pressure system is envisaged to be finished on May 2014.

Tunnel 1 is being excavated through four faces, F1 from up-stream intake, F2-3 from the adit and F4 from downstream at the reservoir.

Tunnel 2 is being excavated through five faces, F1 from upstream at the reservoir and F2-3-4-5 from the adits.

Tunnel 3 is being excavated using a single face.

From the beginning the number of simultaneous active faces has ranged between one and eight.

Figure 7 shows the advance reached at each face and month and Table 4 shows the advance rates achieved at each tunnel face.

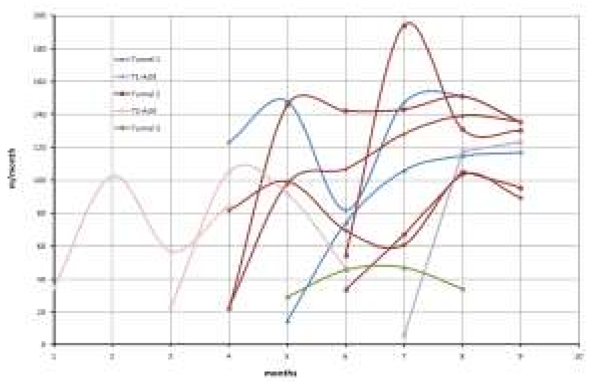

Figure 7. Evolution of the advances at all the tunnel faces.

As the figure show, the advances are above 100 m/month as the average rate until the last month registered is 120 m. A peak advance of 194 m/month has been achieved.

For the mud tunnel, the average rate is rather lower (39 m/month), due to the reduced size of the tunnel section (Figure 2 and Photo 8) that does not allow the use of standard equipments.

Table 4. Rates of advance.

Tunnel	Face	Length (m)	Excavation rate (m/month)
1	1	426.1	85.2
1	2	–	–
1	3	–	–
1	4	786	131
1	Adit	247	82.2
2	1	505	84
2	2	738	123
2	3	630.5	105
2	4	509.3	127.3
2	5	301.7	75.4
2	Adit	279.5	70
2	Adit	267	67
3	–	155.5	39

The tunnels are being excavated in the limestones of the Coban Formation, presenting good and fair geomechanical quality, with RMR values usually higher than 50. No major faults have been crossed but in several sections loose materials, residual soils and fractured zones, have been found and, as well as previously mentioned, several cavities. Table 5 shows the percentage distribution of each support class in the tunnels. As it can be checked in most sections the support has consisted in bolts and shotcrete and heavy support has hardly ever been necessary.

Table 5. Support class distribution at each tunnel.

Tunnel	Support class (RMR)	Length (m)	Percentage (%)
1	>65	720	49.2%
1	55-65	370.5	25.3%
1	40-55	300.5	20.5%
1	30-40	23.5	1.6%
1	<30	50	3.4%
1-Adits	>65	167	49.1%
1-Adits	50-65	148	43.5%
1-Adits	35-50	17.5	5.1%
1-Adits	<35	7.7	2.3%
2	>65	1077.5	35.2%
2	55-65	1328	43.3%
2	40-55	370.5	12.1%
2	30-40	112	3.6%
2	<30	176.5	5.8%
2-Adits	>65	140	25.6%
2-Adits	50-65	142.5	26%
2-Adits	35-50	128.5	23.5%
2-Adits	<35	136	24.9%
3	>50	180.5	84.1%
3	35-50	9.0	4.2%
3	<35	25.0	11.7%

Photos 1 to 9 show different aspects of the construction of the main tunnel structures.

Photo 1. Desander-Reservoir. Tunnel 2, Face 1 Portal.

Photo 2. Tunnel 2, Adit 2 portal.

Photo 3. Tunnel 1, Adit portal in residual soils.

Photo 4. Charging the explosives at tunnel face T1.

Photo 5. Drilling at tunnel face T2.

Photo 6. Installation of LG at a cave in T1.

Photo 7. Treatment of a cave located at the roof in T1.

Photo 8. Drilling at the tunnel face in T1.

Photo 9. Tunnel 3 ending.

5.2 *Main incidents*

Following, the main incidents registered are described.

5.2.1 Caverns

According with the karstic context of the emplacement, several caverns have been crossed during the construction of the tunnels. The bigger caves have affected over 10 m of the length of the tunnels and 25 m above the roof.

Frequently they are associated with low quality rocks and minor water flows.

In all cases the special supports designed were used.

5.2.2 Portal Slides

The portals of one adit of the tunnel 2 and the adit of the tunnel 1 were located in residual soils and weathered rocks (Photo 3). In both cases slope failures took place during the excavation of those portals. In order to solve those incidents a new design of the slopes and their reinforcement by mean of bolts and shotcrete, was done. In the case of the adit of the tunnel 1, the beginning of the tunnel was relocated in order to achieve a better quality for its initial stretch.

5.2.3 Convergences

During the construction of the tunnels several sections have been monitorized with convergence sections. In all the cases the deformation measured have been rather low, reaching 6 mm, which is around 0.1% of the tunnel diameter.

5.2.4 Water

In some cavities minor water flows were registered. In all cases the flows were low and due to leakages from the surface.

6 Conclusion

The construction method and the equipment used have provided excellent advance rates and optimum safety condition in the excavation and support of this large underground project.