Besondere Herausforderungen beim Vortrieb des 13,5km langen Triebwasserstollens Palomino (Dominikanische Republik)

Heading challenges of the 13.5 km long headrace tunnel Palomino (Dominican Republic)

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Kurzfassung

Im zentralen Bergland der Dominikanischen Republik wird das Wasserkraftwerk Palomino mit einer Nennleistung von 80 MW errichtet. Das Herzstück der Anlage ist ein 13,53 km langer Druckstollen welcher über eine Länge von etwa 12,4 km maschinell vorgetrieben wurde. Aufgrund der schwierigen Zugänglichkeit und der hohen Überlagerungen sowie der naturschutzbedingen Einschränkungen im Nationalpark José del Carmen Ramirez war die geologische Erkundung entlang des Druckstollens stark eingeschränkt. Um Störzonen oder das Antreffen druckhafter Gebirgswässer im Vortrieb vorab zu erkennen, wurde ein ausführliches Vorauserkundungsprogram konzipiert.
Das Kraftwerk wird voraussichtlich Ende Mai 2012 in Betrieb gehen.

Abstract

In the Central Mountains of the Dominican Republic the Palomino HPP with an installed capacity of 80 MW is under construction. The core of the scheme is a 13,53 km long headrace tunnel, whereas approximately 12.4km are excavated by a TBM. The geological investigations of the tunnel were highly restricted due to difficult access of the mountain areas, high tunnel overburden as well as precautionary environmental protections in the National Park José del Carmen Ramirez. As a consequence an exploration program was carried out during TBM excavation, to detect fractured zones as well as the presence of pressurized groundwater in advance.
The start of operation is predicted in the end of Mai 2012.

1. Introduction

In the Dominican Republic renewable energy offered by hydroelectric power became more and more accordance to cover the requirement of a comprehensive network on the energy market. One of the initial projects the Hydroelectric Power Plant Palomino, awarded to the Brazilian contractor C.N. Odebrecht as a D&B project, is in the final stage of construction. The scheme comprises a 60 m high and 145 m wide concrete dam, more than 18 km challenging tunnel works, a 360 m deep vertical shaft including surge tank, as well as a power house cavern with a total volume of approximately 20,000 m³ and installed capacity of net 80 MW. The paper on hand is dealing with the 12.4 km long headrace tunnel (HRT), driven by a hard-rock TBM. The installed drilling unit of the TBM and the concept of detection of fractured zones as well as of the presence of pressurized groundwater in advance are highlighted in the following paragraphs.

2. DS-TBM and Segmental Lining System

The mechanized drive was managed by a Herrenknecht Hardrock doubleshield TBM (fig. 1a/b) with a specified excavation diameter of 4,6 m. The heading unit including backup system amounts to a length of about 265m.

fig. 1a/b: Herrenknecht DS-TBM; TBM platform

The TBM-tunnel has an internal diameter of 3,96 m and is lined with a precast segmental lining (fig. 2a). The 20cm thick segments are designed to cover the predicted external loadings including external water head, TBM-thrust, grouting loads as well as loading during handling and transport. The final design of the lining foresees an unsealed, parallel ring system composed of an invert segment, two similar sidewall segments and a roof segment acting as a key stone. Thus the TBM backup system asks for a double track system to separate BU and rolling stock the invert segment was designed with a central located flat invert and fitted precast sleepers as well as two lateral consoles for rail support. After the excavation works the sleepers had been removed to offer optimized hydraulic conditions of the headrace tunnel (fig. 2b).
In principle the lining is designed for straight line application. To manage the curve characteristic of the alignment with a minimum radius of 600 m and to cope with slight deflections of the TBM excavation timber spacers are placed in the circumferential joints.

The bedding of the lining is provided by filling the annular gap with pea gravel and contact grouting in addition. Locally borehole grouting has been carried for rock-mass treatment and sealing, where required.

fig.2a: segmental linng / Tübbingauskleidung; 2b invert segment / Sohlsegment

3. Geology of the Headrace-Tunnel

Along the headrace tunnel three main geological formations are present (fig. 3): The Ventura Formation, the Tireo Formation and the Granodiorite del Rio Yaque del Sur. The rock cover of the 12.43 km long headrace tunnel is in the range of 100 – 500 m generally.

The first approximately 6,500 m were excavated in the sedimentary Ventura Formation of Eocene age, which mainly consists of siltstone with intercalated layers of sandstone and marl. The rock strength (UCS) does not exceed 60 MPa in general. The permeability of the rock mass is low, therefore the groundwater inflows to the tunnel have been restricted to small inflows. The rock mass has been classified mainly in RMC III and IV.

From chainage ~6+500 to chainage ~12+000 the tunnel was driven in the Tireo Formation of Upper Cretaceous age. The Tireo Formation comprises volcanic and vulcano-sedimentary rocks: andesitic and basaltic lava, pyroclastica, ignimbrite, volcanic tuffs and volcanic breccias. The values of the rock strength (UCS) are spread from 80 to 240 MPa. The permeability of the rock mass is low to medium, during excavation a number of moderate groundwater inflows have been encountered and at places higher inflows happened, especially in jointed zones and at the contact of Ventura Formation to Tireo Formation. The rock mass has been classified mainly in RMC II and III, in the fault zones mainly in RMC IV.

The last part of the tunnel at the upstream with a length of 480 m was excavated in the Granodiorite del Rio Yaque del Sur, which forms a big batholith of Palaeocene age. This granodiorite is a strong and abrasive rock, the rock strength (UCS) is in the range of 100 – 250 MPa, the quartz content amounts to 30 – 40 %. The permeability of the rock mass is low to medium in general.

Due to the difficult access to the mountainous areas and the overburden up to 500m the geological investigations have been limited, especially the number of core drillings. As some geological hazards were predicted, as there are faults, high external water head and squeezing potential within weak rock zones, the heading had to be prepared to react accordingly, facing critical conditions. As a consequence the TBM concept included methods of investigation during excavation, in order to identify critical zones in advance.

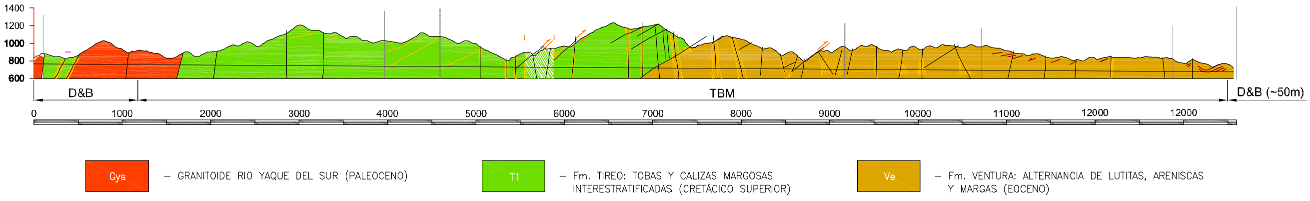

fig. 3: geological longitudinal section / Geologischer Längenschnitt

4. Specific specifications of the TBM

To cope with the predicted hazards additional specifications for the TBM drive have been defined. Facing some events of squeezing rock an increased TBM thrust of 24,000 kN, the possibility of adjustable over-excavation up to 62mm as well as the installed lubrication nozzles at the shield were considered, in order to minimize the risk of getting stuck. The opening of telescopic shield up to 800 mm offers a broad accessibility for any activities at the tunnel wall. Handling with pressurized groundwater, the machine was equipped to use polyurethane or silica foam for sealing measures. For systematical probing in advance a movable and rotatable drilling rig had been installed behind the erector (fig. 4a). The 25kW powered Atlas Copco percussion drill could manage bore holes up to a depth of 120 m in the Ventura respectively Tireo Formations. For effective drilling procedures rods with a length of 1.45 m and 32 mm in diameter could be handled on the drilling unit. A number of 10 regularly partitioned drilling lines with an opening of 3.5’’ (~89 mm) offer a broad exploration field in advance (fig. 4b). For any rock mass improvements in advance an injected canopy could be ordered if required.

As an additional measure to explore the geological conditions in advance, a sonic test device was installed. The test was carried out from chainage 5+000m to chainage 5+400m. The recording was compared with the results of the exploration drilling at chainage 5+100m. A comparison table of both seismic measurements and exploration drillings were elaborated, but without any useful results. Due to the fact that the recording of the sonic test device shows uncertain results of the geological conditions, especially in case of presence of water, this method was not used for further explorations during the further heading.

fig. 4a/b: drilling unit, drilling lines / Bohrvorrichtung, Bohrgassen

5. Probing in advance

With respect to the predicted geological conditions, derived from core drillings and field mapping, the exploration drillings on the TBM had been started before passing the first critical zones at chainage 5+100 for a first test. During the drilling procedure some modifications of the drilling unit were arranged to be well prepared for the systematical probing. One of the adjustments belongs to the well-known problematic of a controlled guiding of the drilling rods. Because of the small inclination of the drilling line of 9° only and the presence of in homogeneous rock mass especially in the Ventura Formation, a guiding device was needed, suitable for a variable annular gap width between gripper shield and tunnel wall. As a final solution a conical shaped steel wedge had been placed between shield and tunnel wall (fig. 5a/b). In addition an L-shaped clamping device fixed the guiding wedge in position. The accessibility to install the guiding system was given from the telescopic shield after opening.

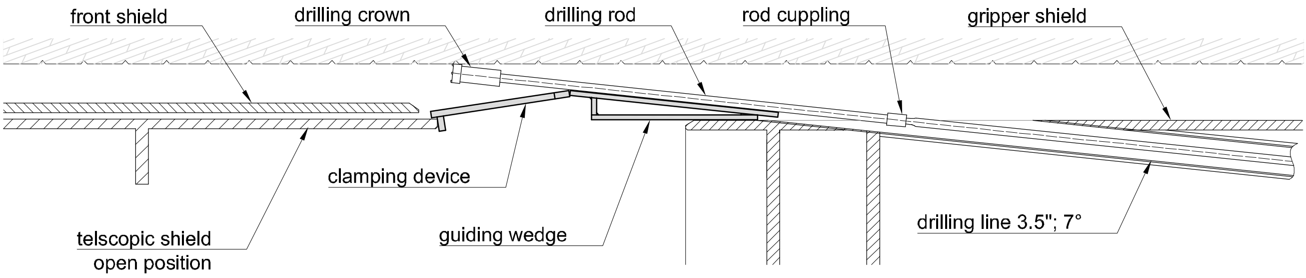

fig. 5a/b: guiding wedge, drilling crown / Führungskeil, Bohrkrone

After the adaption of the drilling unit and appropriate equipment the probing was carried out systematically, starting from chainage 5+660 m. The last exploration drilling had been ordered in the last tunnel section of Tireo Formation at chainage 11+650 m, where a fault zone was predicted. In the granodiorite section no probing was executed.

Generally the exploration drilling was scheduled during the daily maintenance shift of 4 hours, in order to have no interferences to the TBM heading. With respect to the drilling performance of 2 m/min in average and under consideration of an effective utilization factor of 30% (positioning of the drilling unit and removing, fitting the drilling rods, additional dead times) one exploration bore hole with a depth of approximately 110 m could be done within the maintenance shift. In case of special events, such as high water ingress or highly fractured zones, additional exploration drillings were carried out during the stoppage of the machine.

The drilling position was varied continuously (fig. 6), in order to cover a broad scope. As already mentioned a number of 10 drilling lines were available to explore the geological conditions in advance. Based on the advance rates the depth of the boreholes was adapted, to have an overlapping of the exploration drillings of minimum 10 m.

For the entire tunnel length a number of 151 exploration drillings was carried out, with an average length of 50 m, which is more than one and a half days of production.

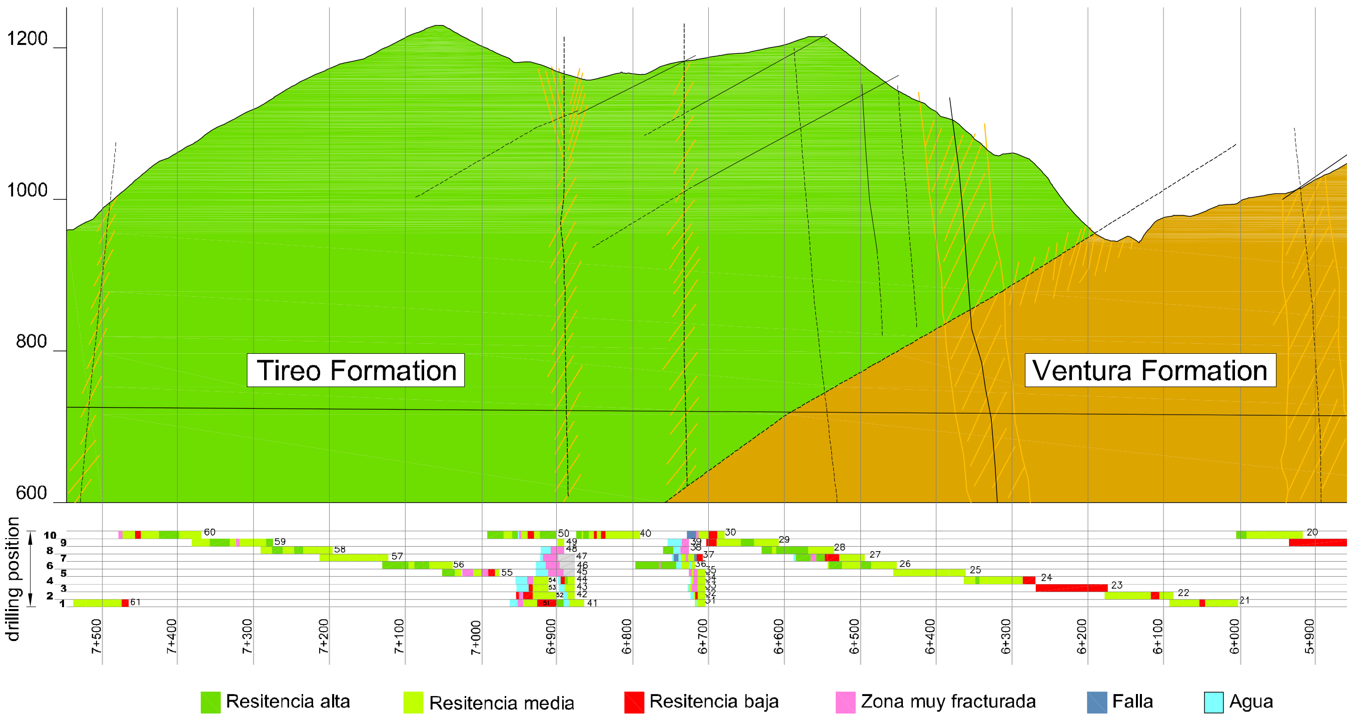

fig. 6: exploration drillings / Erkundungsbohrungen

Based on the drilling parameters the explored geological conditions were classified in 6 characteristic classes:

- high resistance (hard rock)
- medium resistance (fair rock)
- low resistance (weak rock)
- high fractured zone

- fault zone
- presence of high water ingress

The classified rock according to the exploration was compared to the geological mappings. For the TBM drive the geological mapping comprised the visual inspection of the tunnel face during the maintenance shift. In addition the tunnel wall could be inspected at the open telescopic shield and in the bottom area of the tail shield (open tail shield).

6. Special events

After the transition of the contact from Ventura Formation to Tireo Formation, at chainage ~6+700 pressurized groundwater of the jointed basalt was discovered during probing. The water was clear, without the presence of fines (fig 7a). As a consequence the decision was taken to drainage the rock mass by drilling in advance, without any pre-treatment of the rock. During drilling the water ingress increased with the number of drillings continuously. While the TBM was designed to manage a high amount of water up to 500 l/s temporarely, problems of lining bedding by washing out pea gravel through the grouting holes rose up. To keep the pea gravel in the annular gap, filter pipes were fitted into all penetrating holes. After stabilizing the rings the TBM heading could proceed.
At chainage 6+880 another zone of pressurized water ingress was encountered. After passing this zone a water inflow up to 280 l/s was measured at the portal area. Within a short time (~5 days) the amount of water decreased significantly and a steady state flow of about 70 l/s remained. With respect to the specific requirements of the HRT, contact grouting was carried out systematically for the entire tunnel lengths. Locally, where required, borehole grouting was done for rock mass consolidation. During grouting procedures the amount of water inflow could be reduced to a minimum. At some tunnel stretches drainage pipes were installed for pressure relief of the surrounding rock mass.
Besides the challenge of passing zones with high water ingress some critical zones with local rock mass disintegration were encountered. Instabilities of lining bedding and the occurrence of segment cracks (fig. 7b) had been urging the provision of anchorage to ensure stable conditions for

preliminary rock support. In a further step the contact grouting procedure as well as the final consolidation grouting were carried out, to stabilize the lining and to improve the bedding in long term view.

fig. 7a: water ingress / Wasserzutritt; 7b: segment cracks / Rissbilder

7. Review and site experience

Reviewing the TBM drive comprising a successful heading of 27 m daily performance as well as mastering a number of high challenging events the 12.43 km long TBM tunnel had celebrated the breakthrough on the 8th April 2011. Worth mentioning is the successful passing of the jointed basalt with the presence of high water ingress as well as the stabilization methods of the lining bedding and final improvement managed by a step by step grouting concept to cover the requirements of the headrace system. The well elaborated exploration concept provided a broad view of the geological conditions in advance and offered safe heading conditions during the excavation works.