Grouting of TBM Rock Tunnel for the Pinalito Hydroelectric Plant, Dominican Republic

Marcos Eduardo Hartwig

Abstract. The Pinalito main hydroelectric tunnel, with a length of 11 km, is located in Cordillera Central mountain range, Dominican Republic. This mountain tunnel has been mined through extremely fractured andesitic-basaltic and rhyolitic tuffs. These rocks are been subjected to shear and collisional displacements between Caribbean and North America plates since middle Eocene. As a result, geological and hydrogeological conditions along the tunnel alignment are rather complicated. This paper presents the main aspects and results employed in order to overcome an unexpected water bearing incompetent rock zone, approximately eleven meters wide, that cross the tunnel alignment at Sta. 5+237.40. Ground treatment was well succeeded and took six months to be concluded. Procedures adopted took into account three steps, respectively: (1) geological drilling; (2) drainage; and (3) spilling and grouting injections.

Key words: grouting, Pinalito Hydroelectric Tunnel, TBM, water bearing incompetent rock zone, Dominican Republic.

1. Introduction

The Pinalito main hydroelectric tunnel, nearly 11 km in length, link the Dam to the Power House. It is located in Cordillera Central mountain range, eastern Hispaniola, which is divided between the countries of the Dominican Republic and Haiti. This mountain tunnel has been mined with a Robbins Open TBM (*Tunnel Boring Machine*), 3.66 m of diameter, through extremely fractured andesitic-basaltic and rhyolitic tuffs (Fig. 1).

The Hispaniola Island is located on the strike-slip suture line between Caribbean and North America Plate. Due the complex orogenic processes, multiple brittle tectonic structures affected the Cordillera Central mountain range, which resulted in a very complicated and highly variable geological, structural and hydrogeological ground condition.

Due to the lack of geological investigation, probe drilling and under evaluation of previously mined fault zones along the Pinalito main hydroelectric tunnel, an unexpected water bearing incompetent rock zone was reached at Sta. 5+237.40 and caused the TBM entrapment for six months. This paper presents the main aspects and results of treatment of the rock mass employed at Sta. 5+237.40, in the Pinalito main hydroelectric tunnel, Dominican Republic.

2. Tectonic Settings

The Hispaniola Island is located in the north edge of the Caribbean tectonic plate, which since middle Eocene is displacing to east in relation to the American tectonic plates (Fig. 2). This limit represents a complex deformation zone, in which is recorded collisional and left-handed strike-slip displacements. The Hispaniola Island consists of a terrain agglomeration, bounded by main fault zones, consolidated between lower Cretaceous and Miocene. Much of these limits were reactivated and form morphotectonic provinces made of narrow and elongated mountain ranges and sedimentary basins limited by faults (Fig. 3, Dolan *et al.* 1998, DeMets *et al.* 2000, Mann *et al.* 1991, Mann *et al.* 2002).

The Cordillera Central mountain range with summits over 3.000 m a.s.l. and WNW-ESE-trending, represents a cretaceous magmatic arc composed mainly of volcano-sedimentary and igneous rocks with occasional intercalations of cretaceous sedimentary rocks, slightly metamorphosed (Bowin 1966, Mann *et al.* 1991). The Pinalito main hydroelectric tunnel has been mined through extremely fractured bedded to massif andesitic-basaltic and rhyolitic tuffs, with maximum coverage thickness up to 550 m.

3. Geotechnical Aspects

The rock mass geotechnical classification adopted in the Pinalito main hydroelectric tunnel was the Q index (Table 1, Barton *et al.* 1974). Most of the tunnel mined before the fault zone at Sta. 5+237.40 was in rock class III to IV/V, which means, regular to poor rock mechanic quality (Fig. 4).

Immediately before the fault zone at Sta. 5+237.40, any anomalous geotechnical feature was detected, with exception of somewhat increase in groundwater infiltration.

4. General TBM Specifications

The Pinalito main hydroelectric tunnel has been mined by a Robbins open TBM built in 1981 and refurbished in 1983. It has 3.66 m of diameter and contains four electrical motors with 300 horse power each of it (Fig. 5A). The machine was not designed to operate through terrains with high groundwater flow, and does not present any pre-treatment capabilities inside, such as probe drilling and

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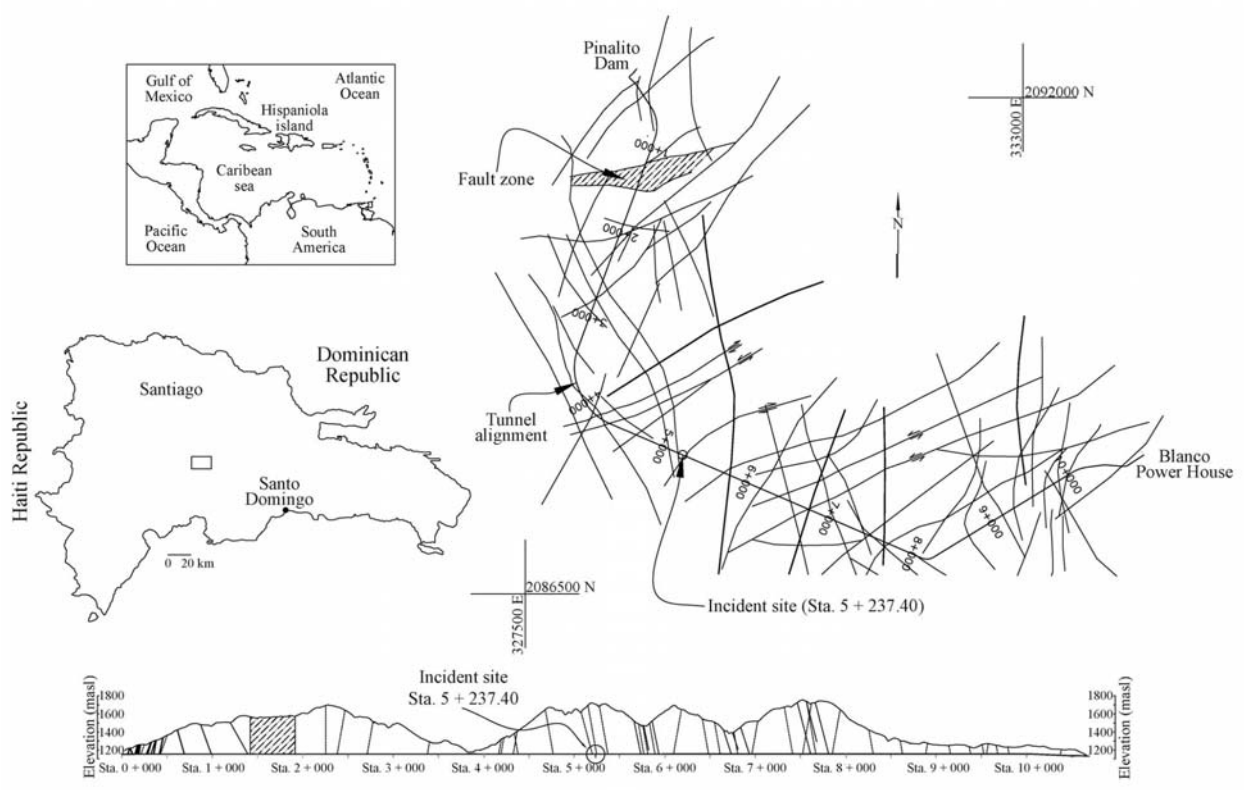

Figure 1 - Location of the Pinalito main hydroelectric tunnel. Geological profile and lineament map based on aerial photograph interpretation (scale 1:10.000) and field survey. Tunnel passes through cretaceous andesitic-basaltic and rhyolitic tuffs. UTM coordinate system, Zone 19Q, North Hemisphere.

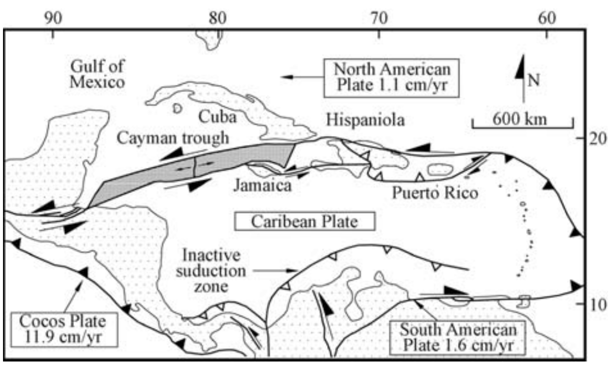

Figure 2 - Present-day plate structure of the Caribbean region. The island of Hispaniola straddles the active left-lateral strike-slip zone separating the North America and Caribbean plates. After Mann *et al.* (1991).

geophysics. For this reason, it was adapted an external rock drilling as showed in Fig. 5B.

5. Description of the Incident

Due to a combination of circumstances, such as lack of detailed geological investigation (overoptimism of geological underground conditions), probe drilling (related to operational difficulties) and production rates (and under evaluation of previously mined fault zone at Sta. 1+579 - due to its low water content), on march 26 of 2007, the excavation of the Pinalito main hydroelectric tunnel had to be stopped at Sta. 5+237.40, as it reached an unexpected water bearing incompetent rock zone, nearly eleven meters wide, which caused an extremely high pressurized groundwater influx into the tunnel (up to 460 L/s), followed by a rock collapse of the roof and face area over the TBM head.

6. Treatment Procedures

In order to overcome the extremely high groundwater influx into the tunnel related to this wide incompetent zone, three main steps were adopted, respectively: (1) geological drilling; (2) drainage; and (3) spilling and grouting injections.

6.1. Geological drilling

Horizontal geological drills were performed in order to investigate characteristics of the incompetent zone, like extent, direction and material contents. Basically it showed up a heterogeneous irregular-shaped incompetent zone of nearly N-S trending, with approximately eleven meters wide (Fig. 6). This zone cross the tunnel alignment at Sta.

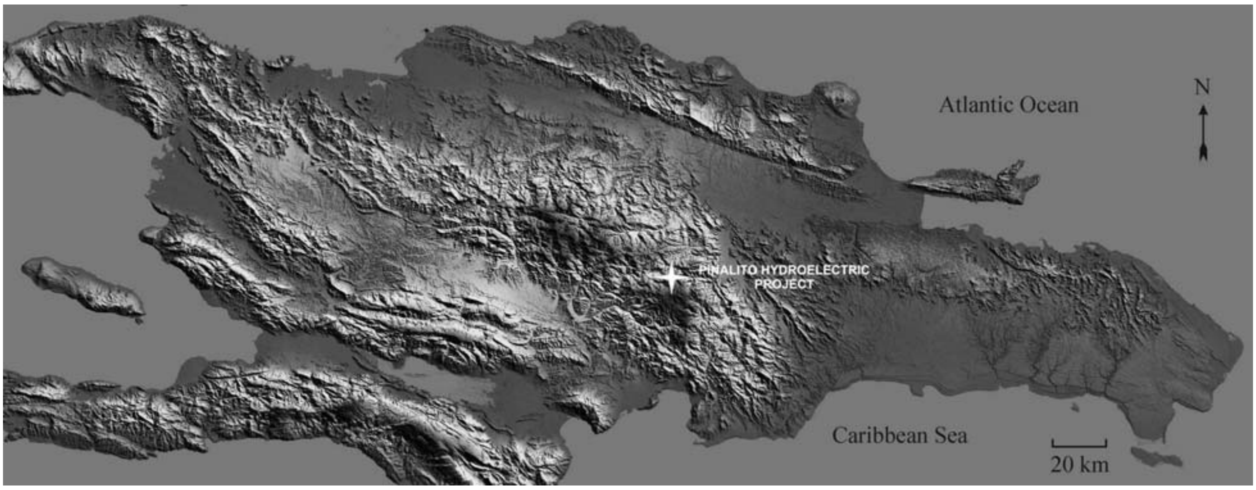

Figure 3 - Physiographic features of Hispaniola Island. Note markedly segmentation of landscape made of narrow and elongated mountain ranges and sedimentary basins limited by faults with WNW-ESE-trending. Source: Shuttle Radar Topography Mission (SRTM-90m).

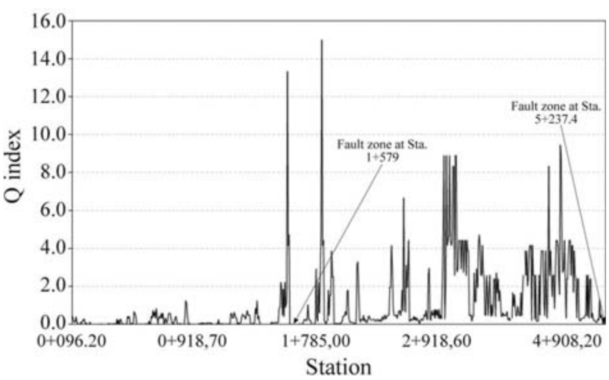

Figure 4 - Q index along Pinalito main hydroelectric tunnel, before the fault zone at Sta. 5+237.4.

5+237.40, and is mainly made of highly jointed andesitic tuff cut by minor clay and epidote-bearing faults.

6.2. Drainage

In order to relieve groundwater pressure, it was drilled fifty two drains at different locations comprising a half cone-like roof. The amount of it is concentrated in the hydraulic left sidewall of the tunnel alignment, a region where the incompetent zone seems to be wider according to geological drills (see Fig. 6). After a period of four months groundwater pressure decreased significantly, in contrast, groundwater influx was continuously growing until its highest value (~460 L/s) in the beginning of July (Fig. 7).

6.3. Spilling and grouting injections

Because of the extremely high groundwater influx into the tunnel and the rock collapse of the roof area over the TBM head two distinct resin grouting were injected. The polyurethane resin was firstly performed in order to water stopping while the urea-silicate resin was injected in order to fill unknown cavities, caused by the rapid groundwater leakage into the tunnel followed by a rock collapse. After controlling water and cavities, injections of cement and microcement (ultra-fine cement) slurries were performed in order to consolidate the fault zone. Pressures of injections varied from 0 to 200 bars.

Chemical resins were initially injected through thirty two spilling bars drilled approximately at four stations located in the back of the TBM, forming a half cone-like roof through the incompetent zone. The drill holes consumed 1.4 ton of both resins and its result couldn't still be evaluated.

Since the TBM went through the fault zone and was trapped by it, it was necessary to release and pull it back.

Table 1 - Relationship between TBM Push, Q index, rock class and rock support. Q index ranges derived exclusively from Pinalito Hydroelectric Project.

TBM Push (psi)	Q	Rock Class	Rock support
300	< 0.015	IV/V	Steel ribs
600	0.015-0.5	III	Systematic rock bolts and shotcrete
1.000	0.5-3	II	Rock bolts and shotcrete only localized
2.000	> 3	I	Unnecessary

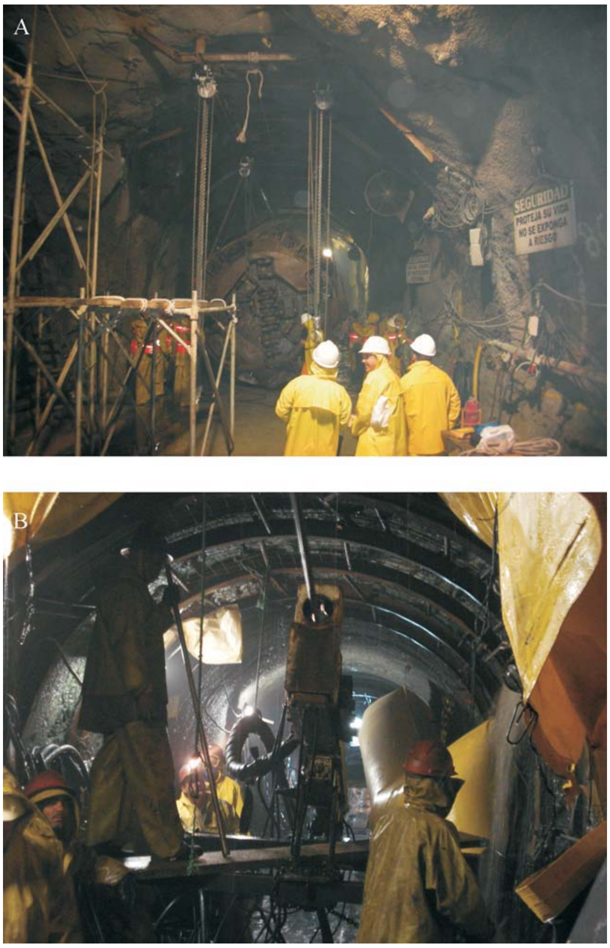

Figure 5 - A – TBM being disassembled (front view); B – External rock drilling adapted to operate during TBM entrapment.

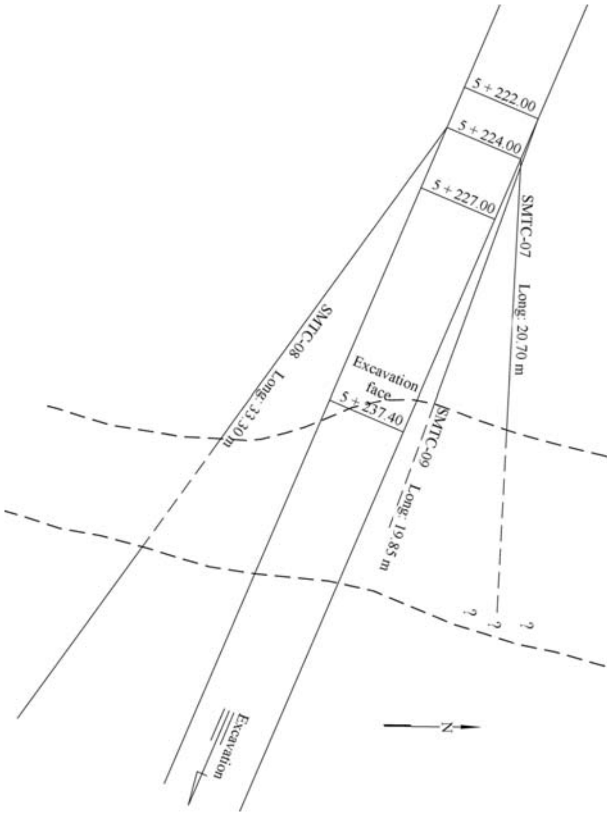

Figure 6 - Plain view of geological drills performed through the water fault zone (dash dot lines), Sta. 5+237.40 m. RQD = Rock Quality Designation.

Once the machine was free, it was observed a meaningful change of the groundwater flux in the excavation face, subsequently, was observed a sudden rock collapse that filled almost 70% of the released area ahead of the TBM (Fig. 8). In order to overcome it and carry on the excavation, collapsed material must be treated before consolidating the fault zone. The method found in order to stabilize the collapsed material was to set thirty one pipes of 1/2 and 2” of diameter straight into the collapsed material. All pipes were previously pierced with small holes in order to permit resin and cement slurries get into the collapsed material. Initially, it was made an attempt to injected 5.1 ton of cement/microcement slurries with different mixtures (water/cement) combined to additives; however, all of it ran away under the TBM, showing that groundwater was still present. Consequently, was performed the injection of 5.1 ton of polyurethane resin through the pipes until the absolute refuse of the rock mass by high pressure or inflow

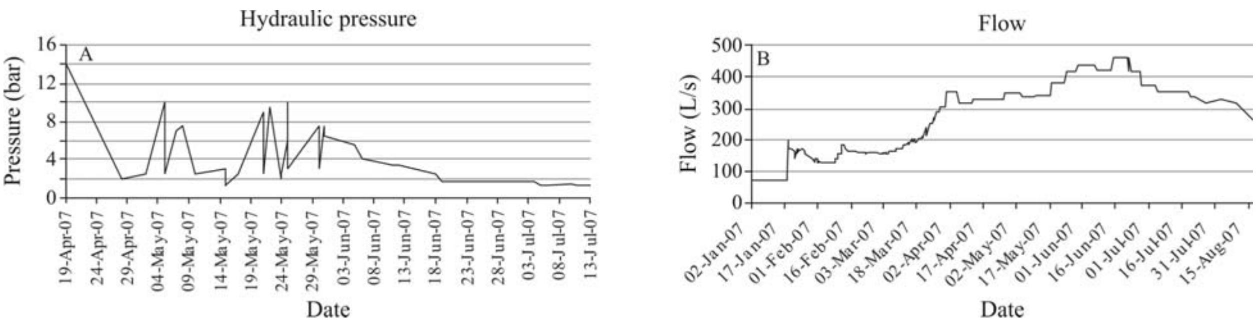

Figure 7 - Groundwater parameters: (A) hydraulic pressure (in bars); and (B) total groundwater flow (L/s). Parameters show opposite trend with time.

Figure 8 - Photo taken from the upper portion of the TBM head. It shows the ground condition ahead of the TBM after sudden rock collapse. Note fault content occupying almost 70% of the released area and a hanged spilling bar previously drilled through the fault zone.

Figure 9 - Wall of injection built at Sta. 5+237.40 m, in the Pinalito rock Tunnel. Note in the roof area, part of tubes/spilling bars previously drilled and remnants of polyurethane foam.

into the tunnel. Additionally, was drilled more twenty five spilling bars before consolidation of the fault zone get started. These consumed 3.4 ton of polyurethane resin and 1.6 ton of cement/microcement slurries.

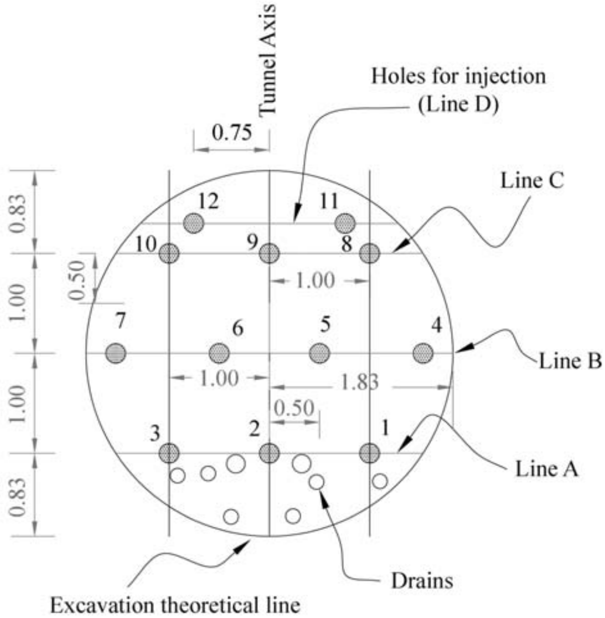

Figure 10 - Vertical section of the wall of injection at Sta. 5+237.40 m, Pinalito rock Tunnel. Note parallel lines of injection, from A to D, and drains placed in the base in order to release groundwater pressure.

Once the collapsed material was stabilized, the TBM was pulled back nearly three and a half meters and treatment of the fault zone could proceed. In order to increase efficiency of consolidation treatment, was opted to build two walls through the fault zone, not exactly the same, separated approximately of five meters, comprising 3.66 m of diameter and 1.0 m of wide, made of cement bags and shotcrete (Fig. 9). The walls comprise horizontal and parallel lines with holes of injection through the fault zone and drains in its base, in order to relieve groundwater pressure (Fig. 10). Because of the fault zone showed to be wider in the left sidewall of the tunnel alignment, special attention was given to holes placed in there. The injections started from the foot to the top of the wall and from the right to the left sidewall of the tunnel. It was consumed a total of 23.3 ton of cement/microcement and 1.1 ton of polyurethane.

7. Conclusions

The TBM re-started to work regularly in the middle of September of 2007. Ground treatment was successful and took six months to be concluded.

The sequence of procedures adopted to overcome the fault zone – (1) geological drilling; (2) drainage; and (3) spilling and grouting injections – showed to be very efficient, nevertheless slow and laborious.

The fault zone, with approximately eleven meters wide, consumed 11 ton of chemical resins and 30 ton of cement slurries. Pressure of resin injections varied from 20 to 200 bars while cement injections from 0 to 30 bars.

Geological, structural and hydrogeological investigations are indispensable procedures for rock tunnels projects, particularly adjoining plate tectonic boundaries, which combined with systematic probe drills and geophysics, can prevent many geological unfavorable situations, saving money and time.

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