Los Bronces – Use of TBM Compact

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1. Location

Los Bronces mine is located in the Andean Mountains and lies in an area of steep relief along the upper reaches of the San Francisco Valley at an elevation ranging between 3400 m and 4100 above sea level. Access is by public road from Santiago.

The climate at Los Bronces is typical of the high Andes region that means annual snowfall of 764 cm, mostly concentrated in the winter period (from April to September). Temperatures reach -18°C in the winter and 19°C in the summer.

2. Geology

Based on a rough interpretation of the single lengths of the various rock types expected along the tunnel an approximate geological distribution can be resumed as per table 1 below.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Approximate chainage (m)</th>
<th>Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz monzonite</td>
<td>0 - 3150</td>
<td>3150</td>
</tr>
<tr>
<td>rhyodacite porphyry</td>
<td>2600 - 2675</td>
<td>75</td>
</tr>
<tr>
<td>andesite</td>
<td>3150 - 4450</td>
<td>1300</td>
</tr>
<tr>
<td>rhyodacite porphyry</td>
<td>4450 - 5300</td>
<td>850</td>
</tr>
<tr>
<td>tourmaline breccia</td>
<td>5300 - 6650</td>
<td>1350</td>
</tr>
<tr>
<td>chlorite breccia / biotitic breccia</td>
<td>6650 - 6700</td>
<td>50</td>
</tr>
<tr>
<td>rhyodacite porphyry</td>
<td>6700 - 6850</td>
<td>150</td>
</tr>
<tr>
<td>chlorite breccia / biotitic breccia</td>
<td>6850 - 6900</td>
<td>50</td>
</tr>
<tr>
<td>andesite</td>
<td>6900 - 7100</td>
<td>200</td>
</tr>
<tr>
<td>tourmaline breccia</td>
<td>7100 - 7400</td>
<td>300</td>
</tr>
<tr>
<td>andesite</td>
<td>7400 - 7700</td>
<td>300</td>
</tr>
<tr>
<td>rhyodacite porphyry</td>
<td>7700 - 7750</td>
<td>50</td>
</tr>
<tr>
<td>tourmaline breccia</td>
<td>7750 - 7950</td>
<td>200</td>
</tr>
<tr>
<td>rhyodacite porphyry</td>
<td>7950 - 8125</td>
<td>175</td>
</tr>
</tbody>
</table>

Table 1. Approximate simplified interpretation of geologic sections

If we collect data “by-rock-type”, rock distribution results simplified as per table 2 below.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>quartz monzonite</td>
<td>3150</td>
</tr>
<tr>
<td>andesite</td>
<td>1700</td>
</tr>
<tr>
<td>rhyodacite porphyry</td>
<td>1300</td>
</tr>
</tbody>
</table>
3. The equipment

Due to the scope of the tunnel, the forecast geology and the severe logistic situation, we decided - in strict agreement with the Main Contractor - to use a Double Shield machine, we specifically designed for this project. The employed machine is a Double Shield Universal (DSU) Compact TBM, an innovative system that we developed and improved during the past three years.

3.1 The DSU Compact TBM System

The DSU Compact TBM system was studied to:

- substitute Open Type TBMs in their typical fields of application;
- offer many of the same advantages of traditional Double Shield Universal TBM but at the same time a simpler and easier system to operate too.

The DSU Compact TBM system is not only a new type of TBM; for the first time in the TBM industrial market, we have the opportunity to employ a complete integrated system made of: the TBM, the back-up and the tunnel transport device.

DSU Compact TBM system design targets are:

- To improve safety and workers environment;
- To reduce transportation and installation time/costs;
- To reduce the operation and maintenance costs and crews;
- To improve performances in a wider range of rock conditions;
- To reduce the typical length of tunnels where TBM excavation becomes competitive with conventional heading.

3.2 Main design concepts and guidelines

In order to match the operational targets the design process requires to follow some basic concepts and guidelines; more specifically it has to:

- Minimise the total system length;

<table>
<thead>
<tr>
<th>Tourmaline Breccia</th>
<th>1850</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorite Breccia/Biotitic Breccia</td>
<td>100</td>
</tr>
<tr>
<td>Faults</td>
<td>25 (six cases)</td>
</tr>
</tbody>
</table>

Table 2. Simplified "collected-by-rock-type" distributions
Minimise the number of track/containers to transport the system to site;
Minimise the number of components the system is made of;
Make a robust design of all structures and components;
Simplify the hydraulic & electronic circuits and fast electric and hydraulic connections;
Mechanize fully NATM support installation;
Minimise the crew for operation and maintenance;
Allow to the TBM to thrust of the steel supports where the ground is too weak/unstable to resist to the gripper shoes pressure;
Increase the capacity to investigate and treat the ground ahead of the tunnel face;
Improve air quality in the working area;
Provide with working platforms and walkways to improve crew safety.

3.3 DSU Compact TBM system description and specifications

The DSUC TBM system consists of an integrated set of equipment made of:

a. DSU Compact TBM

This machine is a Double Shield Universal TBM with some special general characteristics:

- Extremely short total shield length
- Robust 19" discs cutterhead design
- High main and auxiliary thrust capacity
- Variable Frequency Cutterhead drive
- Long life main components
- Simplified hydraulic and electric circuits
- Two roof drills mounting for rock bolting
- Probe drill mounting for 360° treatment/drainage holes
- Erector for prefabricated (steel) ring
- Guidance system for accurate steering
- Bolted structures to facilitate the dismounting and transport back inside the tunnel

Fig.2_ TBM Longitudinal section                                            Fig.3_ TBM schematic sections

Fig.4_Cutterhead
The TBM specifications are:

BORING DIAMETER- 4.500 mm
BORING STROKE- 1.400 mm
CUTTING PARURE- n°27 * 19” Cutters (300 kN/each)
MAXIMUM MAIN THRUST – 15.700 kN
MAXIMUM AUXILIARY THRUST - 14.300 kN
CUTTERHEAD POWER- 1575 kW
CUTTERHEAD RPM- 0-7.4 Rpm
CUTTERHEAD TORQUE - 2.612 kNm (3.395 kNm Unlocking)
CONVEYOR CAPACITY- 320 ton/h
MAXIMUM PENETRATION RATE - 120 mm/min

b. Back Up System

The Back-up system is extremely short (typical length ranges from 50 m to 65 m depending on muck transport system and optional components).

It is made of few decks, seven in all, (see fig. 5 below) and includes:

- TBM facilities (Control cabin, lube and hydraulic power packs, VFD units, Cabinets and Trafos)
- Muck conveyor
- Dust scrubber with capacity to treat the entire volume of air arriving in the tunnel pipeline
- Industrial water system
- HV cable reel
- Water and Compressed Air hose reels
- Ventilation Duct extension/storage unit (not used in this machine)
- Materials crane systems
- Safety walkways
- Tunnel conveyor extension station

The decks are pre-assembled units that allow to reduce time of system assembly and disassembly. A complete assembled deck fits into the container size.

![Fig. 5_Back-up layout](image-url)

c. Muck Transport system

The back-up conveyor discharges directly into the tunnel conveyor system. The extension of the tunnel conveyor structures is performed in the last 2 decks of the back-up contemporary with the TBM advance.
3.4 Quality and standard

The complete system is designed and manufactured according to the most rigorous CE norms and has mark CE.

All the main components are designed, developed and tested to have a working life of at least 10,000 hrs under the most severe work conditions.

3.5 DSU Operation Mode

There are three different operation modes for a DSU Compact TBM system:

i. Gripper telescope mode in hard rock
   The TBM advances by thrusting off the side grippers in the rear shield and extending the main thrust cylinders. Contemporary with the excavation rock bolts are installed as per requirement and design. At the end of a TBM stroke the stabilizers and auxiliary grippers placed in the front shield are expanded and the main thrust cylinders are used for pulling the rear shield forward.

ii. Auxiliary telescope mode in weak rock
   The TBM advances by thrusting off the side grippers in the rear shield and extending the main thrust cylinders. Contemporary with the excavation, prefabricated steel sets are installed within the tail fingers. At the end of TBM stroke the stabilizers and auxiliary grippers placed in the front shield are expanded and the rear shield is advanced thrusting off the steel sets using the auxiliary thrust.

iii. Single shield mode in fault area
   The TBM advances all together like an articulated single shield by thrusting off the auxiliary cylinders. At the end of excavation prefabricated steel sets will be installed within the tail fingers.

3.6 DSU field of application

DSU Compact TBM system has been specifically designed for the following applications:

- Hydraulic tunnels and/or sequence of short hydraulic tunnels that do not require a systematic concrete pre-cast lining
- Mines exploratory and access tunnels
- Road and railway tunnels that do not require systematic concrete pre-cast lining
- Pilot and services tunnels

4. Equipment assembly

4.1 Transportation

TBM and Back-up were pre-assembled and tested at SELI workshop in Aprilia, Italy. After that, equipment was disassembled and loaded for transportation following standard transportation rules, whether it’s possible. Therefore, the whole transportation included:

- 8 open top 20’ containers
- 9 open top 40’ containers
• 2 box 40’ containers
• 10 flat racks
• 1 special bulk

The logic behind this so complicated plan of transportation was simply to facilitate as much as possible the future assembly at Los Bronces mine, mainly for two relevant reasons:

• The extremely severe weather conditions (3,600 m above sea level)
• The mandatory assembly into a pre-excavated large cavern

To be noted that this type of TBM had been designed and developed to be disassembled into the same excavated circular tunnel without further enlargement.

4.2 Site facilities

A large number of site facilities were implemented by the consortium before the arrival of TBM and Back-up.

The portal area did not allow storage of pieces and therefore containers had been unloaded close to the workshop area and pieces were delivered by trucks to the portal area.

Two mobile cranes were used:

• One at the workshop area to unload 40 tons
• One at the portal area to unload at least 50 tons at 10 m radius (bracing).

At the portal the trucks entered the underground by reverse movement (photo 1).

4.3 Underground facilities

SELI together with the Main Contractor studied and developed the best arrangement to assembly TBM and Back-up into a pre-excavated cavern by drill and blast method. Cavern size is limited due to the rock mass quality and therefore, sequence and timing of assembly are strictly related to the geometrical constraints. Figure 6 below shows a final cavern layout developed for both situations, assembly of the TBM and excavation with TBM.

Fig.6_Underground facilities, plan view and sections

Underground drill & blast excavation consists of:

• A 100 m long access tunnel (section AA in figure 6);
• A 68 m long assembly cavern (section EE)
• A 12 m long launching tunnel (section HH)

The execution of the last 20 m (right side) of the cavern floor + the launching tunnel has been completed with a concrete cradle, before the TBM arrival; the cradle, poured at a proper height,
supports TBM shields during assembly and allows the correct alignment when excavation starts.
Rails or steel profiles were embedded into the concrete cradle to support the TBM and to make easier the sliding towards the tunnel face.

Lifting capability was granted by means of three fixed monorail bolted to the crown of the cavern, providing a point load capacity of minimum 30 tons as well as a clearance of approximately 1.5 m between each line (see fig. 7 and 8 below). Each monorail is equipped with 2 movable chain hoists (pneumatic) of 20 ton capacity each one.

Fig. 7_TBM assembly under chain hoists
Fig. 8_TMB into the launching tunnel

The two gripper contrast sidewalls was concreted before starting the TBM’s assembly in the launching tunnel.

4.4 TBM assembly

Firstly, the two cutter head sectors were moved in the assembly chamber. Secondly, the forward shield (lower part) was positioned behind the cutterhead pieces. Thereafter, the cutter head support with the main bearing was placed upon the lower part of the forward shield.

Later, right and left segments of the front shield were assembled and bolted together with the lower section. The shield segments are bolted in order to allow future machine disassembly into the bored tunnel with no disassembly chamber (photo 2).

The outer and inner telescopic shield lower sections were assembled as well as the gripper shield behind the front shield (photo 3).

The two lower main thrust cylinders were installed to connect the gripper and front shield lower sections.

The main drive electric motors, the lower gripper cylinders then were mounted on the front shield and on the cutter head support.

The TBM conveyor structure was assembled in its final position and temporary supported in the rear part by the use of special beams (until the first Back-up deck was connected to the TBM). Thus, all main thrust cylinders could be installed between the front and the gripper shields. The assembly of the telescopic shield was completed.

At the same time the two sectors of the CH were assembled on the main bearing. Therefore, TBM stood and Back-up decks were introduced into the remaining available space of the cavern.
4.5 BU assembly

Contemporary with the TBM assembly, Back-up decks assembly was made in the portal area, in a yard placed at 500 m outside the tunnel (photo 4). Due to the easy transportation way, decks have been shifted inside the tunnel one by one as per their final order and pushed by a loco. Temporary structure holding the TBM conveyor rear part was removed and the conveyor itself was secured in its final location.

5 TBM Launching

In early August 2009, after 5 weeks of assembly, TBM started excavation and bored 22 m in 8 working days (1 shift) in rock class from 3 to 4 (according to Q system classification). After that rock mass quality dramatically and unexpectedly changed up to reach class 5 (and over) with continuous face collapses and cutterhead blockages. This situation, which is still going on, is successfully faced with means of foam injection, short length advances (less than half stoke) and steel rings as primary support (fig. 9 and 10 below).