Experiences in the construction of the Interstation Tunnels of L-6 Santiago Subway (Chile).

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This work presents the experiences during the construction of 15 Km of the Interstation Tunnel of L-6 of Santiago Subway (Chile), where the Consortium Zañartu-Geocontrol proposed a new method for constructing this tunnel.

The proposed new method takes advantage of the excellent behaviour of the ground, called “ripio de Santiago”, to excavate the tunnel by full face.

The results obtained by the new method are more than three times higher than the obtained by the former methods.

1. Introduction

Line 6 of Santiago Subway (Chile) is 15.2 km long and has 10 stations. It starts in the southwest area of the city, crosses Line 2 (Franklin Station), Line 5 (Ñuble Station), Line 3 (Ñuñoa Station) and ends at Los Leones Station, which is a common station to Line 1. (Figure 1).

The Project for Detailed Engineering of Shafts & Galleries for the Line 6 was awarded to the Consortium Zañartu-Geocontrol in March 2012. Stations and interstation tunnel have been designed to be built by the NATM, method traditionally used in Santiago; and its construction began in September 2013.

2. Construction method proposed

Traditionally in Santiago de Chile the interstation tunnel is usually built performing the excavation with the help of a buttress in the face; which occupies a section of 15 m², within the 59 m² of the total section of the tunnel.

This buttress, which is maintained until 3.4 m from the face, limits significantly the access of the machinery; as illustrated in Figure 2 and Picture 1 and 2.
Under these conditions, when the interstation tunnel is built with the traditional method, the average advances were between 6 and 9 meters/week; working six days a week and with excavation steps up to 1.5 m long.

The Consortium Zañartu Geocontrol proposed, during the design of the L-6, a new construction method based on the full face excavation; which, as presented in the following sections has allowed to exceed largely the average week advance than the ones obtained with the traditional method.

2.1 Characteristics of the ground

The ground where the Santiago Subway is constructed is made of alluvial soils constituted by the bank of the Mapocho and Maipo river; but so far, most of the Santiago Subway lines have been constructed excavating the alluvial soils of the Mapocho river; known as "ripio de Santiago" and whose thickness exceeds 200 m.

These soils are constituted by granular conglomerates and in general, they have a water-filtering character; because water percolated through them without transport fine materials.

Although these conglomerates are not chemically cemented, they have a cohesion ranging from 30 to 50 kPa which, together with the friction angles between 45° and 50°, makes them have an excellent behaviour.
This good behaviour allows to excavate vertical slopes without support, with heights up to 20 m; as shown in Picture 3.

![Pic. 3 Typical excavation of the "ripio de Santiago"

In the soils of the Mapocho River three types of terrain are determined, with the average strength characteristics listed in Table I.

<table>
<thead>
<tr>
<th>GROUND</th>
<th>COHESION (KPa)</th>
<th>FRICTION (º)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Mapocho river deposition</td>
<td>35</td>
<td>47,5</td>
</tr>
<tr>
<td>Gravels</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>Deep Fine Soils</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

2.2 Fundamentals to adopt full face excavation

The main objective expected with the full face excavation was to have a larger space to work; which could imply to use more heavy machinery to get better performances.

To achieve this objective, the experiences transmitted by Carlos Mercado, Construction Manager of Santiago Subway, Mercado et alt (2004) were particularly interesting; which confirmed that in the gravels of the 1st Deposition no face instabilities occurred when the excavation steps up to 2 m length.

Based on these experiences a full analysis of the behaviour of the tunnel’s face was performed, excavating the complete section, in the most adverse ground conditions.

This analysis was performed using three-dimensional geomechanical models, solved with FLAC 3D software. Figure 3 shows the model performed to analyze the face stability.

To solve this model the properties listed in Table I have been employed and for the fillings a 10 KPa cohesion and a friction of 33° has been considered.

The results indicate that the failure in the surroundings of the face of the tunnel does not occur in the free side of the face but on its perimeter; exactly in the place of contact between the Fine Soils and the 1st Gravel Deposition, as illustrated in Figure 4.
Once the theoretical demonstration of the excavation faces of the L-6 Interstation Tunnel does not present problems of instability, under normal conditions, it was proceeded to design the excavation type sections and its supports.

2.3 Excavation type sections and support

Figures 4 and 5 show the excavation Type Sections and support to build the interstation tunnel excavated in 1st Deposition Gravels and Fine Soils; adopted for L-6, Metro SA 2013 and 2014.

The section for the Fine Soils is constructed with invert; therefore the excavated section is 76.5 m². In the gravels the section is excavated with a flat bottom and the excavated surface is 60.5 m²; 21% less than the one of the Fine Soils.

In the case of the mixed faces an intermediate section between the two above is used; when the bottom section consists of fine soils and invert is built and if it consists of gravels, it is not necessary.

3. Case histories

As it follows, two case histories are presented on the implementation of the new construction method of the L-6 Interstation Tunnel; one of them refers to the construction of a normal section of the Interstation Tunnel and the other one refers to the construction of the passage under the Melitren tracks.
3.1 Excavation from Mar del Plata shaft to Los Leones Station

The Interstation Tunnel section built between the Shaft of Mar del Plata and Los Leones Station has a length of 1615 m and it is the longest section of tunnel that was never built in Santiago, advancing only with one excavation face.

In mid-March 2015, already 894 m had been excavated and 721 m were still to construct; most of them with buildings very close to the tunnel alignment, as shown in Figure 7.

In the sections next to the buildings the excavation steps are reduced to 0.5 m and protection forepoles are placed, made with self-boring bolts type DIWIDAG 90-16 with lengths of 9 m and 4 m overlap.

The grounds are formed by 1st Deposition gravels, which have an excellent behaviour; allowing full section excavation with no problems, with excavation steps of 1.5 m.

The construction of this section has been performed by the Chilean-Spanish Consortium Echevarría Izquierdo-Obras Subterráneas; which has achieved, working six days a week, advances between 27 and 33 m/week. Such performance are three times higher than those achieved so far in Santiago.

The key factors which have allowed to obtain these outstanding performances are:

- The absence of instabilities in the advancing faces, as it had been forecasted.
- The excavation with much more powerful machines than the ones used so far; like the CAT315D as shown in Picture 4.
- The projection of shotcrete by robots, as shown in Picture 5.
- The extraction of the excavated grounds through a vertical conveyor belt, as shown in Picture 6.
In the sections next to the buildings the excavations were performed under the protection of forepoles and the performance ranged from 10 to 20 m/week; reflecting a decrease of 50% compared to the excavation without forepoles; but still doubled the performance obtained so far in Santiago.

In all the cases, the maximum subsidence which has been measured on the vertical axis of the tunnel has been less than 5 mm; which has not caused any problems in nearby buildings.

### 3.2 Passage under the Melitrén tracks

In the western section of the L-6, a one track tunnel parallel to the interstation tunnel was built to access the Suiza train sheds.

As shown in Figure 8 this access tunnel had to be built under the Melitrén tracks, crossing it over about 45 m; with a lining over the vault of the tunnel between 3,9 m and 6 m.
Fig. 8 Passage of the Tunnel to the sheds under the Melitrén tracks

The ground to be excavated consisted of the 2nd Deposition gravel intercalated with sand layers; therefore, given the small thickness of the overburden between the tunnel and the Melitrén tracks, the excavation was performed with forepoles constituted by self boring bolts, type DIWIDAG 73/16 with 9 m long and 4 m overlap. Picture 7 shows a view from the face, which includes the self boring bolts umbrella.

Pic. 7 Self boring bolts umbrella

Figure 9 shows the support of the tunnel access section to the Suiza train sheds, passing under the Melitrén tracks.
To verify the design of the proposed construction method a three-dimensional geomechanical model was performed, as shown in Figure 10.

This model has been solved with FLAC3D 5.00 software to design the support, calculate ground displacements and the Safety Factor prior to the collapse of the excavation face.
Figure 11 shows the distribution of the vertical displacements of the ground in the tunnel cross section, located at the midpoint of the section under the Melitrén tracks.

![Figure 11](image1)

**Fig. 11 Vertical displacements at the center of the section under the Melitrén**

Figure 12 shows the Safety Factor distribution of the calculated ground before collapsing; having a minimum value of 1.25, which was considered acceptable for a provisional situation.

![Figure 12](image2)

**Fig. 12 Distribution of the Safety Factor of the ground.**

The construction of the Access Tunnel to the Suiza sheds has been performed by the Chilean company CONpax and the excavation under the Melitrén tracks was held from September 2014 to February 2015.
The average performance obtained was 2,8 m/week, which is considered reasonable; given the difficulty of excavating and building the forepoles with an overlap of almost 50%.

The maximum subsidence measure has been 6.1 mm somewhat less than the 7.5 mm calculated and has not made any affection to the Melitrén tracks.

4. Conclusions

The Zañartu-Geocontrol Consortium has designed a new construction method for the L-6 Interstation Tunnel of the Subway of Santiago de Chile, which is based on the following aspects:

- Full face excavation.
- Using powerful machines for the excavation.
- Projection of shotcrete with a robot.
- Extraction of excavated grounds through a vertical conveyor belt.

The application of this method on the Interstation Tunnel sections, excavated in 1st Deposition Gravels, has led to advances of 27-33 m/week; more than three times higher than those obtained with the traditional method.

Employing this method in the passage under the Melitrén tracks has also been a success; since the construction of the Interstation Tunnel was completed with a subsidence of 6,1 mm; less than 7.5 mm forecasted.

5. References


