The construction of the tunnel Lo Saldes in Santiago de Chile. A major challenge, a wide tunnel with an extremely low overburden

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ABSTRACT: Costanera Norte is an urban expressway concessionary in Santiago de Chile connecting its Western and Eastern sides. To enhance this connectivity several measures were necessary, including four new tunnels. One of these tunnels, is 'Tunnel Lo Saldes', a three-lane one that has a total length of 65 m, and an excavation rectangular section 14 x 7.2m. It has been excavated in anthropic materials, colluvial deposits, and hard tuffs. But the main singularity of the tunnel comes from its extremely low overburden, 2m to the surface, were an existing operative motorway is located. This low overburden has demanded a special construction method, based on two lateral side-drifts and a central one, a pre-grouting sequence and forepoling, and in some cases, a prior grouting of the ground and/or a face reinforcement with fibre-glass bolts. The support consists in wide flange steel ribs spaced 0.75m and 60 cm of shotcrete Sh35.

1 PROJECT DESCRIPTION

The tunnel is located in the NE of Santiago de Chile, close to the financial centre of the city. The tunnel provides a considerable improvement in the connection between Kennedy and Costanera axes. Figure 1 shows the location of the tunnel.

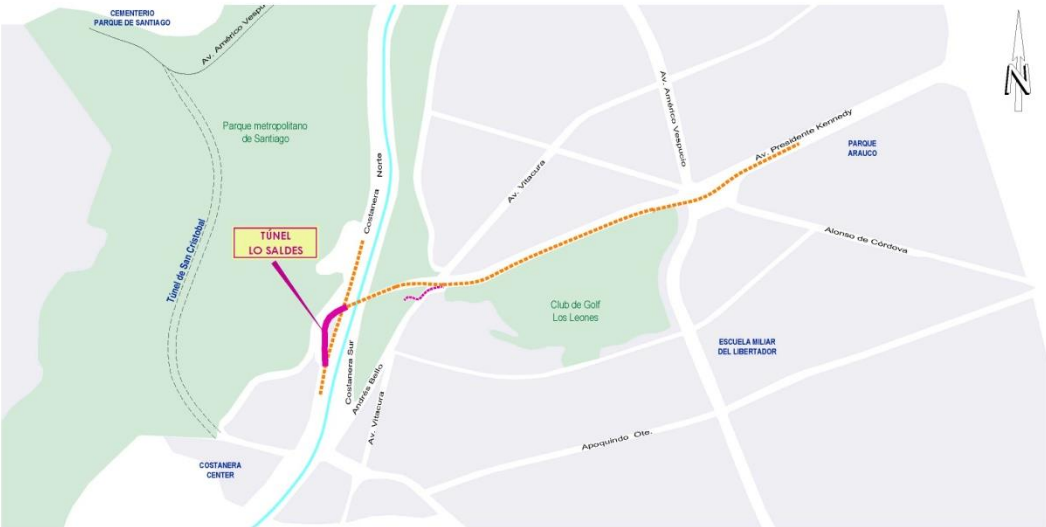

Figure 1. Location and layout. Lo Saldes Tunnel.

The access to the South portal is solved with a trench structure composed by piles and cross-beams. The access to the North portal is solved, in the construction phase, by mean of an oval shaft located in a very constrained emplacement which is surrounded by several roads. Finally this shaft was replaced by a trench structure and a cut and cover that crosses Costanera Highway.

The typical cross section of the tunnel provides three lanes, 3.5 m wide each one. The inner dimensions with respect to the lining are 14.0 m wide and 5.7 m height. Figure 3 shows the geometrical definition of the tunnel.

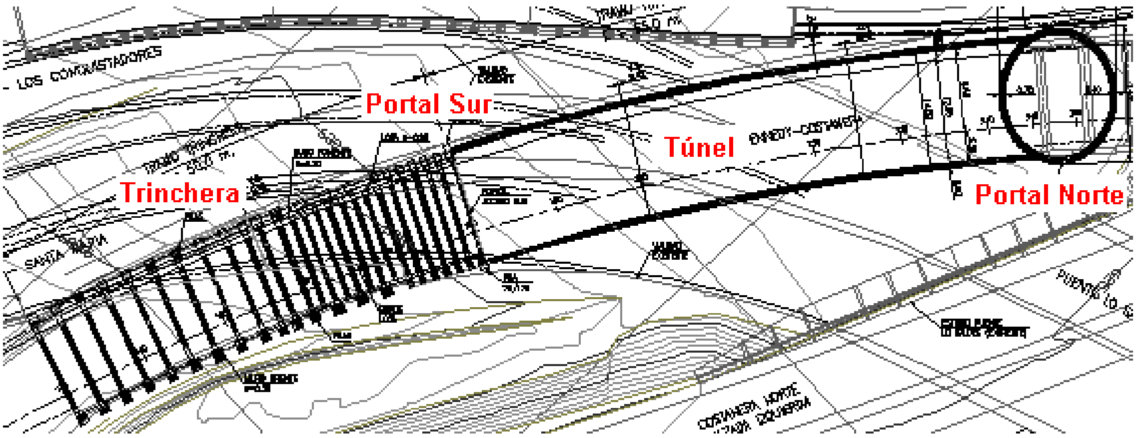

Figure 2. Layout. Lo Saldes Tunnel.

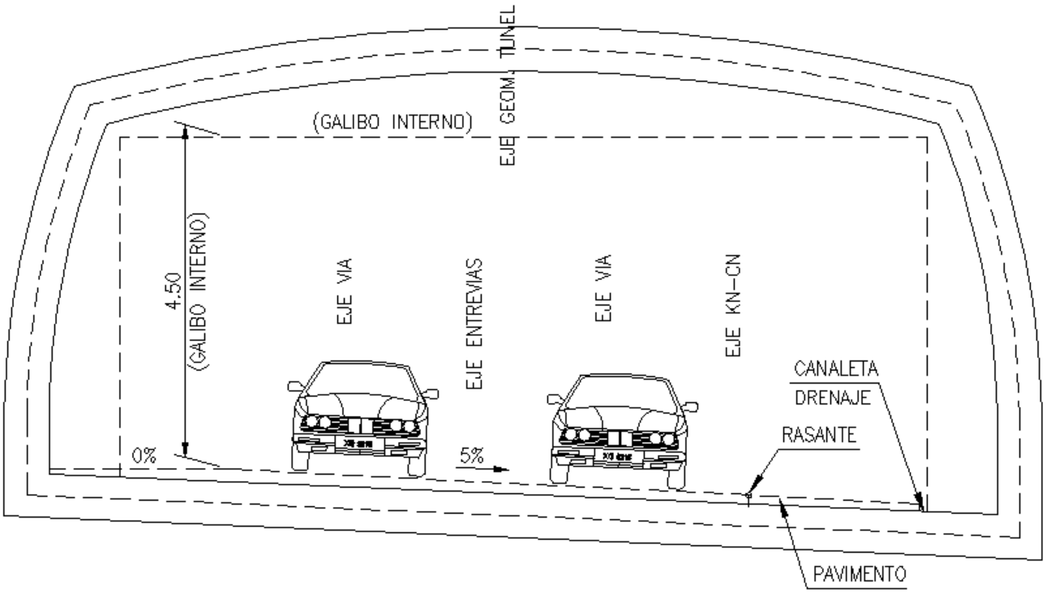

Figure 3. Functional section. Lo Saldes Tunnel.

The alignment crosses below Kennedy Street with an extremely low overburden that ranges between 4.7 m at North portal to reach a minimum of 1,60 m at South portal.

Following, the main project characteristics are described:

a) Geology: The tunnel has been excavated in weathered volcanic tuffs of Abanico Formation, alluvial materials composed by gravels, pebbles silt and clay. Covering these deposits, there was antrophic fill materials. In some extension of the tunnel alignment, the crown and walls are excavated in these fills. The water table was located below the level of the invert. Figure 4 includes a synthetic geological longitudinal section of the tunnel and Figure 5 shows the fills at the tunnel face.

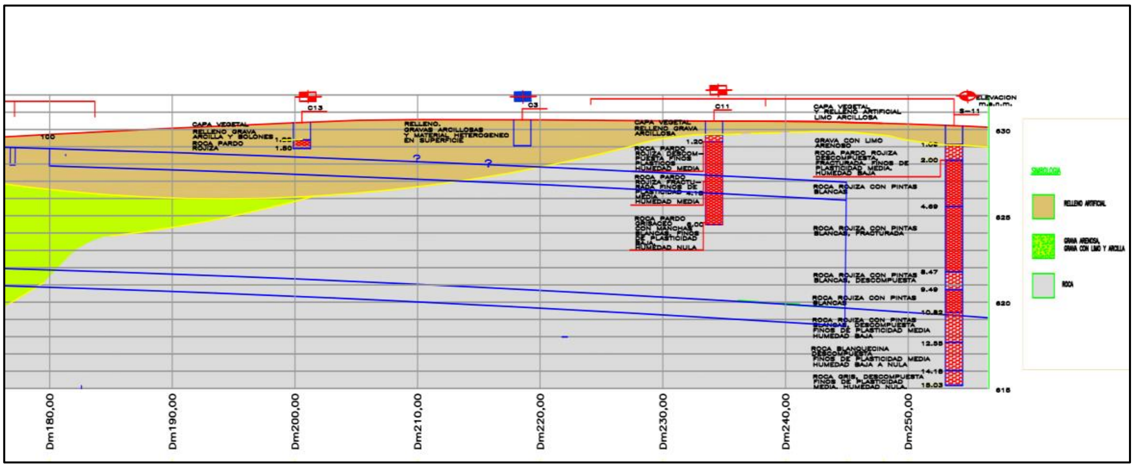

Figure 4. Geological section of the tunnel.

Figure 5 Antrophic fills materials on tunnel face.

b) Geotechnics: Table I shows the materials strength and deformational parameters considered in the design. A hardening soil model was considered for the fills and a Mohr-Couolomb one for the Abanico formation.
c) Seismicity: Santiago the Chile is located at a high seismicity area. According to the Chilean standards a ground shear distortion of 3.8·10-5 rad was considered.

Table 1 Strength and deformational parameters of the materials in the Lo Saldes Tunnel.

Suelo	Modelo	γ [kN/m^3]	c' [kN/m^3]	ϕ' [º]	E_{ref} [kN/m^2]	E_{50}^{ref} [kN/m^2]	E_{oed}^{ref} [kN/m^2]	E_{ur}^{ref} [kN/m^2]	ν	ko (1)
Fill	Hardening Soil	19,0	10	30	------	17.000	17.000	51.000	0,20	0,53
Rock	Mohr Coulomb	23,5	50	35	500.000	------	------	------	0,20	1,50

d) Construction method and support: The construction method has been a sequential excavation method, following NATM philosophy. The complete section has been excavated using three drifts. The advance spam in all of them was 70 cm. Figure 6 shows the three excavation sections.

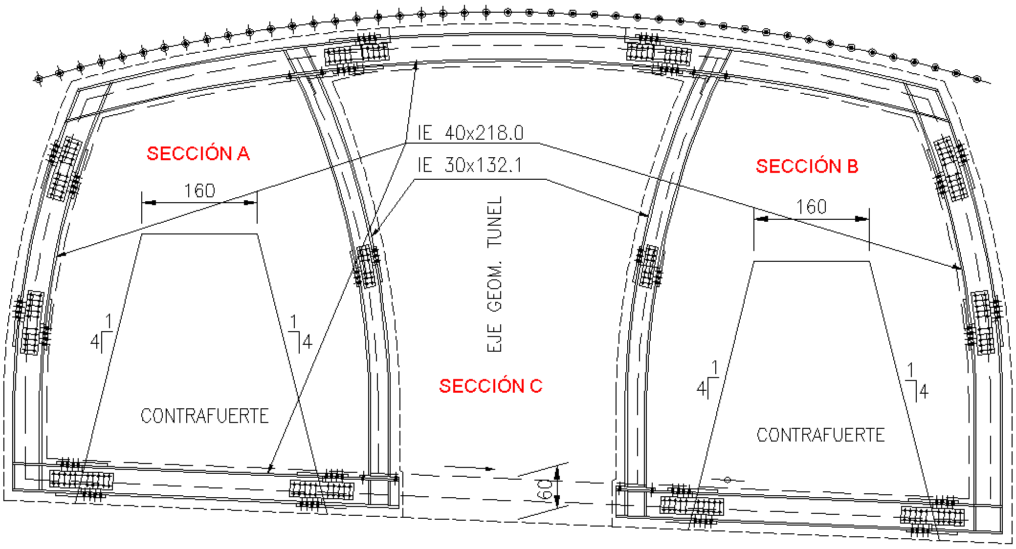

Figure 6. Excavation phases. Lo Saldes Tunnel.

First side-drift to be excavated was the left one (Section A). A distance of 20 m has been respected between excavation faces of section A and B. Same gap was respected between section B and C.

For the demolition of the temporary walls, the sequence was as follows. Demolition of 5 m of the temporary wall of section B. Installation of the secondary support in section B and C. The demolition of the wall continue when the concrete reached 60 % of the UCS. The demolition of the temporary wall in section A started when the process reached 20 m of distance in section B. The process ended with the execution of the whole secondary support in the tunnel section. Figure 7 shows the demolition of the temporary walls and the excavation face at sections B and C.

Figure 7. Mixed face and excavation of the tunnel face.

e) Support and lining: The support is emplacement in two layers. Primary support consists of 30 cm of shotcrete reinforced by mean of double T steel ribs. The arches were closed except for section C were a concrete slab was executed due to the difficulties of the joint between the steel beams. Secondary support consists of an additional layer of 30 cm of shotcrete reinforced by electrowelded mesh.

   In order to assure the face stability several actions were envisaged as systematic forepoles (marchiavanti), buttress and fiberglass bolts at the face.

2 KEY CONSTRUCTION DATA

The construction method has been a sequence Excavation Method, following NATM philosophy. The construction of the North portal and the excavation of 40,60 m of the left side drift were carried out by another contract. Then, as part of the SCO2 contract, the excavation and primary support of the tunnel was continued, it started in 20-10-2015 and finished in 11-10-2016. So the tunnel was constructed in 357days. But considering each excavation section of the tunnel, there was an average advance of 0.2 m / day. Table I shows the excavation dates by each section of the tunnel.

Table I. Excavation dates by section.

Section	PKi	Date	PKf	Date	Length (m)
B	241,65	20-10-2015	180,75	08-09-2016	60,9
C	241,65	19-11-2015	180,75	11-10-2016	60,9
A	201,05	25-06-2016	180,75	30-09-2016	20,3

All the equipment used have been standard trucks and auxiliary machines, while a jumbo has been used for the execution of the systematic forepoles and a robot for the sprayed concrete operations. The excavation has been done using hydraulic hammer and a backhoe loader.

The whole tunnel alignment has a very low overburden with a road crossing at surface, therefore a very strict control of the induced deformations and subsidences has been accomplished. This control has been done by mean of the following monitoring elements:

- 12 Convergence sections by reflex targets. Figures 8 shows the disposition of the convergence arrays in the tunnel section.
- 17 Settlement profiles at surface and structures. Figures 10 shows a settlement evolution of a control point.

The maximum settlement measure has been 10.6 mm at Dm 235 m. The maximum convergence was 11.89 mm at Dm 240 m. The deformation was related to the different phases of excavation and the demolition of the temporary support walls.

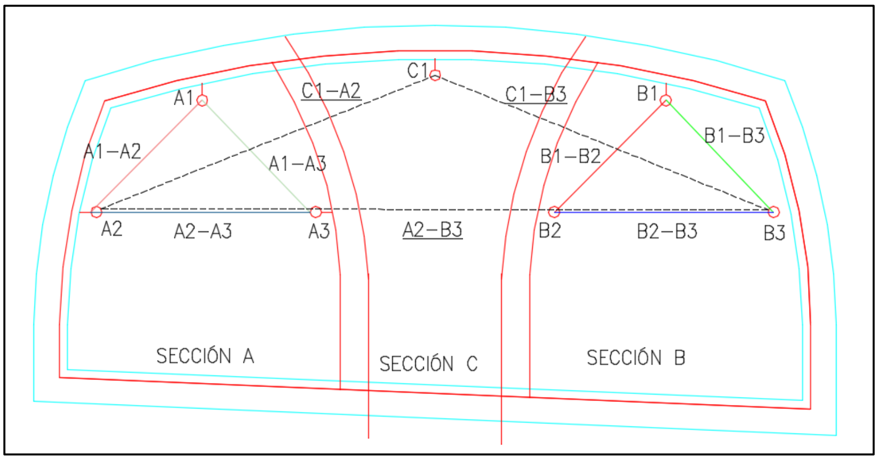

Figure 8. Convergence arrays disposition.

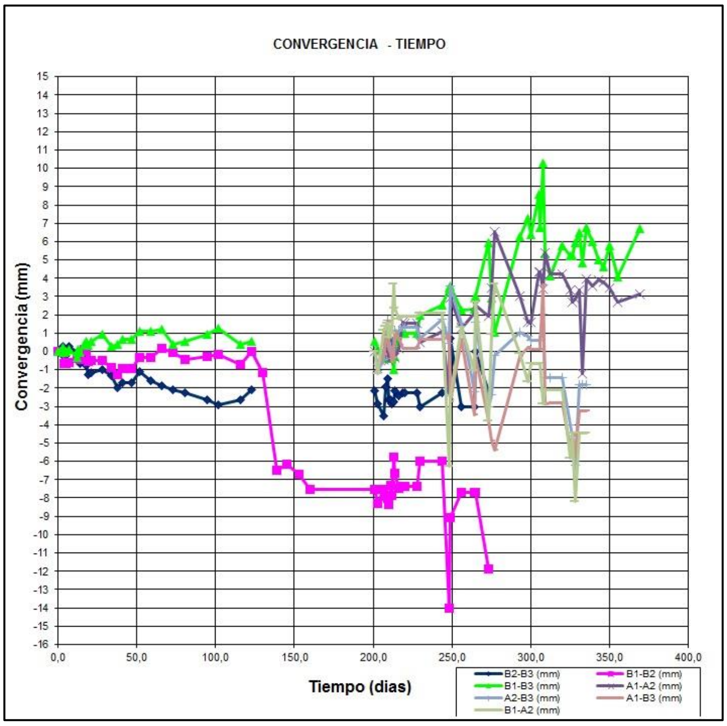

Figure 9. Convergence evolution.

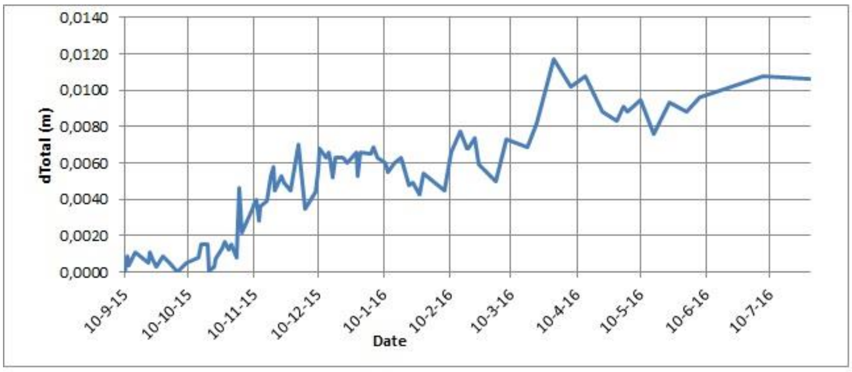

Figure 10. Settlement evolution.

The major issues of the construction were the beginning of the excavations at the portals and the dealing with the mixed face, with the presence of fills at the upper part.

The North Portal consists of a shaft with ovoid shape supported by mean of thicknesses of 20 and 30 cm of shotcrete. The shaft had three rings with more thickness (50 cm) in order to provide more stiffness at certain heights. One ring was at the surface, other immediately over the tunnel section and the last at the bottom. The support of the shaft has a reduction of its thickness up to 15 cm in the intersection with the tunnel.

At each portal micropile forepoles covering all the ceiling of the tunnel were executed. The tubes geometry was $Ø_{ext}$ 142 mm and $Ø_{int}$ 122 mm, spaced 0.30 m and 15.0 m of length. A double micropile forepole was executed at the corners of the section. Figure 11 shows a portal view.

From the inner section of the tunnel marchiavanti forepoles were executed ($Ø_{ext}$ 76 mm and $Ø_{in}$t 58 mm). The length of the marchiavanti were 7 m, spaced 0.30 m and the overlapping was 3.5 m. Furthermore, the tunnel face was reinforced with fiberglass bolts ($Ø_{ext}$ 22 mm), in a net of 1.0x1.0 m, with length of 9.0 m and overlapping of 4.5 m. The execution of the marchiavanti and the fiberglass bolts with that level of overlapping in these small space was very complicated.

Figure 11. Portal view. Sections A and B in excavation process.

In some length along the tunnel section, ground improvement injections were envisaged. Most cases they were developed from inside the tunnel (Figs. 12 and 13) but in some critical sections the injection had to be executed from the ground surface. In that cases the very different permeability of the fills and the Abanico Formation conditioned the leakage of the whole grout along the contact between these two layers. After several trials, a special procedure for the ground treatment was designed. The solution consisted of two pile mortar walls constructed at both sides of the tunnel in order to prevent the leakage and helping the confinement of the ground injections. That solution was a success. Figure 14 shows the problem before developing the solution, with all the grout injection in the contact between de fills and the Abanico Formation.

Figure 12. Ground injections from inside the tunnel.

Figure 13. Injection from the tunnel.

Figure 14. Leakage of the injection.

Figure 15. Demolition of the temporary support.

Figure 16. Execution of the secondary support.

Figure 17. Tunnel ready for its inauguration.

3 CONCLUSIONS

The excavation of the tunnel Lo Saldes started on October 20th, 2015 and finished on October 11th, 2016. The average advance rate for the construction was 0,2 m/day. Nevertheless the existing difficulties, basically due to the extremely low overburden and the mixed face, the excavation has been successfully accomplished without any affection to the traffic of the surrounding and crossing roads.

The construction method used in the construction, as the split of the excavation section, the ground improvement injections or the systematic forepoles, have been proved to be very useful and effective to minimize the subsidence induced and to assure the stability of the tunnel face.