THE CONSTRUCTION OF THE VIVACETA TUNNEL (SANTIAGO DE CHILE)

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ABSTRACT: The tunnel of Vivaceta is located at Santiago de Chile and has a total length of 525 m, involving also an intermediate shaft, and the crossing under the Mapocho River using a cut and cover tunnel. The tunnel is being excavating in the well-known gravels and pebbles of the second and first deposition of the Mapocho River. At the South side of the river fill materials cover these alluvial. The construction method follows the NATM, in top and benching sequence, using systematically micropile forepoles. The whole tunnel alignment has a very reduced overburden in an urban environment with several surface and subsurface structures, which have required a very strict control of the induced deformations and subsidence during construction.

1 Introduction

COSTANERA NORTE is the largest urban expressway concessionary in Santiago (Chile) that connects the city from East to West, with a total length of 35.26 km using an electronic toll collection system along the northern side of the Mapocho River. It was inaugurated on April 2005. The expressway connects Santiago's eastern districts with the downtown (where its connect with Central Panamericana Route) and with the airport and Ruta 68 at its western end. It also comprises Kennedy axis that has 7.4 km and Norteastern Motorway (Autopista Nororiente) with 21.5 km.

The concessionary has started the construction for MOP (Ministry of Public Works) of the first stage of the program called "Santiago Downtown - East" (Santiago Centro-Oriente), which aims to enhance the connectivity East-West in the city. The program includes, among others, the "Improvement of the connections between Costanera North and Central Panamericana Highway". The most singular work is the tunnel known as "Vivaceta" that has a total length of 525 m, involving also an intermediate shaft, and the crossing under the Mapocho River using a cut and cover tunnel.

The construction contract of these works was awarded to Sacyr Chile, S.A and started last February 2013 and its ends is envisage for the next August 2014. The total inversion is MUSD 30.

2 Project description

The new connection has a definitive length of 578 m between Costanera Norte (E-W) and Ruta Central (N-S) of which 490.2 m are in tunnel. This new infrastructure will allow the traffic from Costanera Norte to Ruta Central Sur. Figure 1 shows the alignment of the tunnel. As it can be observed the tunnel have five principal sections:

- Section 1 (0+057.5 to 0+230), from Costanera Norte portal to the Intermediate shaft,
- Section 2 (0+230 to 0+25.9), that corresponds to the Intermediate Technical shaft, in which the tunnel Control Room, Ventilation and the rest of electromechanical equipment will be installed,
- Section 3 (0+250.9 to 0+420), from the previous shaft to the Northern Mapocho portal.
- Section 4 (0+420 to 0+462.5), that corresponds to the cult box section that crosses under the Mapocho River.

- Section 5 (0+462.5 to 0+547.2), from the Southern Mapocho portal to the exit at the Central Motorway.

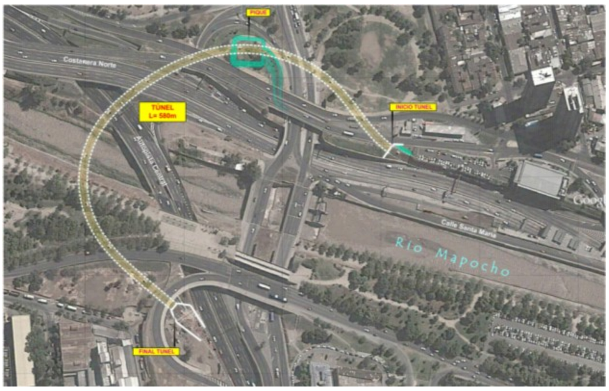

Figure 1. Connection Costanera Norte – Ruta Central (Tunnel of Vivaceta).

Figure 2 the longitudinal section has been included As it can be clearly observed from the above figures, the tunnel goes under a considerable amount of existing structures with an extremely low overburden that ranges between less than one and two diameters. The tunnel crosses under the following main elements (in brackets the overburden expressed in m): General Prieto (6.7 m) and Santa María (5.3 m) Streets, Fermín Vivaceta Street (7.4 m), Structures Central Motoroway (10.3 m), existing spill tunnel (6.2 m) Costanera Norte Motorway (15.9 m), and Central Motorway (8.7 m), including a duct of Metro.

Following the main project characteristics are described:

a) Geology: the tunnel is being excavating in the well-known alluvial materials composed by gravels and pebbles of the second and first deposition of the Mapocho River. At the South side of the river anthropic fill materials cover these alluvial. In the previous figure 3 the distribution of these deposits is detailed.

Variable groundwater level has been encountered so pore-pressure has been taken into account in the tunnel design. This pore-pressure has been considered 60 m ahead and afterwards the crossing of the Mapocho river as well as in the

b) Geotechnics: table I show the materials strength and deformational parameters that are well known in Santiago not only because the boreholes and lab tests carried out but also as it is a very homogeneous deposit in which several underground infrastructures have been constructed.

c) Seismicity: Santiago de Chile is located at a high seismicity area. According to the Chilenean standards the seismic acceleration to be considered are 0.3 g and 0.15 g respectively as horizontal and vertical acceleration.

d) Construction method: the construction method follows the NATM, in top and benching sequence, using systematically micropile forepoles and elephant foot. The excavation has been done using a backhoe loader and

e) Section and support: figure 3 shows the functional section prepared for two lanes that has 85.4 m2 (52.4/33.0 m^2 top/benching) of excavation with a width of 11 m.

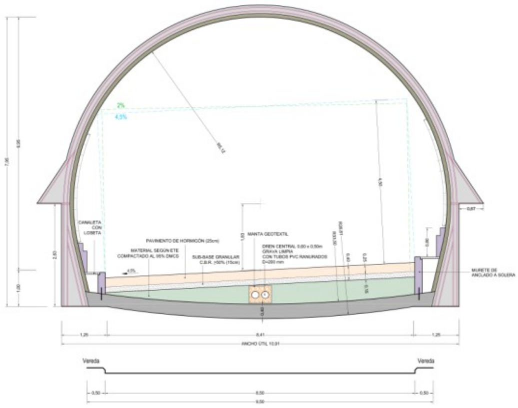

Figure 3. Functional section of the tunnel.

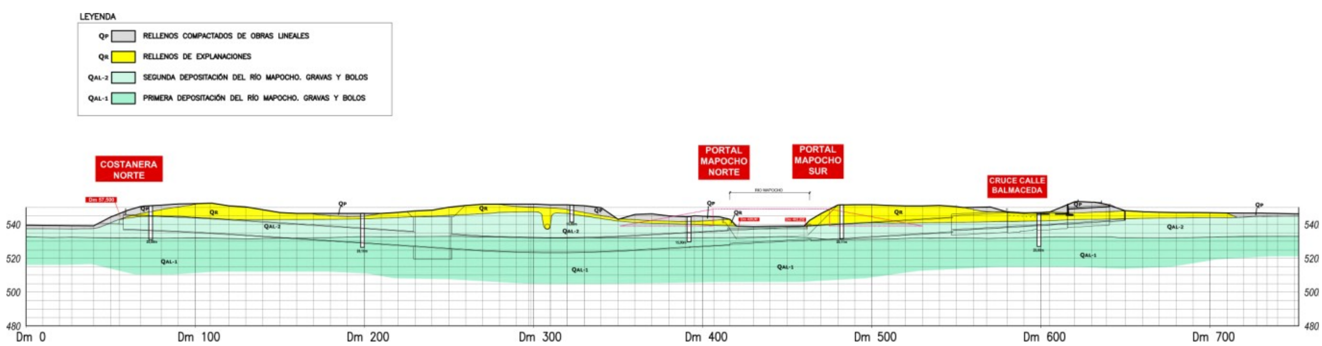

Figure 2. Longitudinal section of the tunnel of Vivaceta.

The support consist in 5 cm of shotcrete sealing, steel arches HEB 120 with elephant foot spaced 1.0 m, 20 cm shotcrete Sh35. Systematically buttress at the face and micropiles forepolling have been used in order to minimized the induced deformation at surface and to control possible instabilities at the face. The forepoles are composed of 25 micropiles (ϕ dril =101 mm, ϕ ext =88.9 mm, ϕ int =75.9 mm) spaced 0.4 m. The overlap between successive umbrellas is 3 m.

This support has been checked in the three critical parts of the tunnel: Dm 80 with minimum overburden (5.0 m above tunnel vault), Dm 322 under the existing structures of the Central Motorway (10 m overburden), and Dm 407 under Costanera Norte expressway (9 m overburden). Figures 4 and 5 show some results of the numerical models carried out for the mentioned purposes that have been solved using FLAC 3D code, in particular concerning the stresses acting on the support elements.

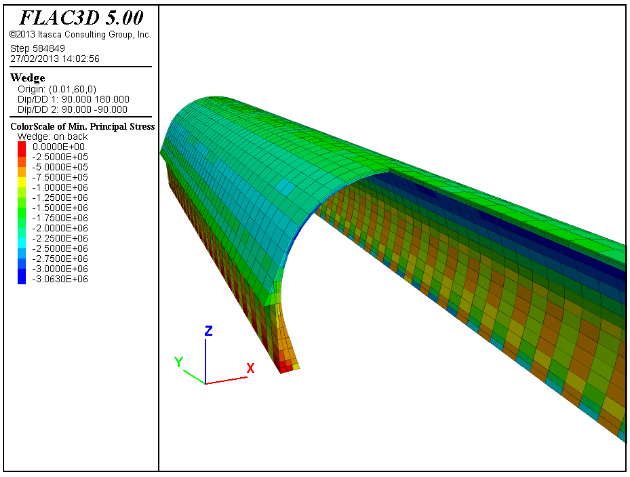

Figure 4. Principal stresses at the steel anches.

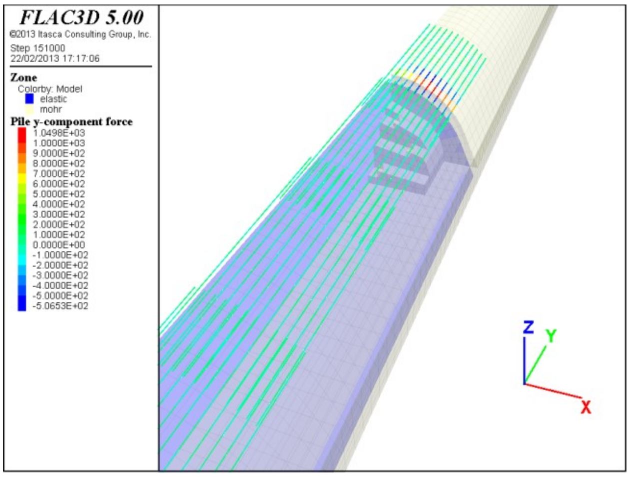

Figure 5. Shear forces at the micropiles.

As mentioned before, in the 60 m previous to the Mapocho River, pore pressure has been considered. For this reason in these 120 m a structural reinforced invert, as can be observed at Figure 6, was designed.

f) Waterproofing and lining: tunnel is foreseen to be waterproofed in order to reduce the maintenance costs derived from water pumping. This applies to the area under the water table that has a length of 80 m (Dm 337 to 417). The waterproof consists in a geomembrane, a waterproof sheet and a wire mesh. This is extended to the minimum place where a grouting curtain has been designed.

Above the waterproof layer a spayed concrete lining (SCL) of 10 cm with polypropylene fibers will be applied

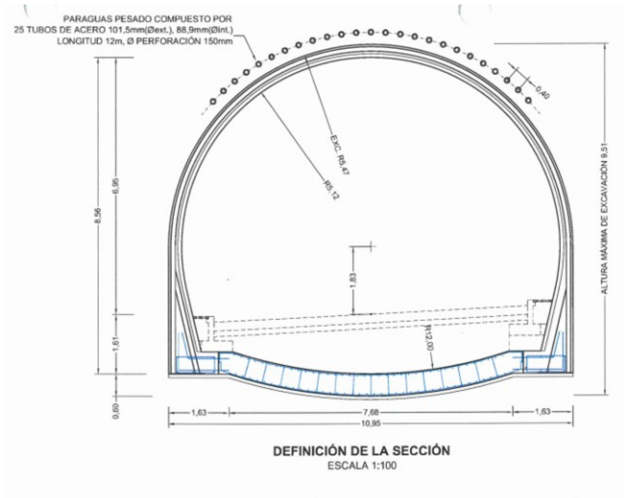

Figure 6. Section with invert for areas with pore pressure.

3 Key construction data

The construction method follows the NATM, in top and benching sequence, The excavation of the top part of the tunnel started in May 2013 and it is planned to be finished in November 2013, so it will last 5 months meaning an average monthly advance rate of 98 m/month or 3.2 m/day (two rounds per day).

As described before all the equipment used have been standard trucks and auxiliary machines, while an Atlas Copco 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 a backhoe loader and

The whole tunnel alignment has a very reduced overburden in an urban environment with several surface and subsurface structures, which have required a very strict control of the induced deformations and subsidence during construction. This control has been done with the following monitoring elements:

- extensometers installed from surface prior to the excavation of the tunnels at the most sensible areas
- convergence sections (one every 15 m) also measuring of the vault settlement
- settlement profiles at surface
- structure monitoring (jointmeters and settlement measurements)

The maximum settlement measure has been 35.1 mm at the Parque de los Reyes stretch, the maximum convergence was at Dm 229 were 5.92 mm was measured with a maximum convergence velocity of 1.76 mm/day. Under sensible areas (areas with structures at surface) the maximum deformation was 30.7 mm at Dm 69. Figure 7 shows the evolution of the settlement registered.

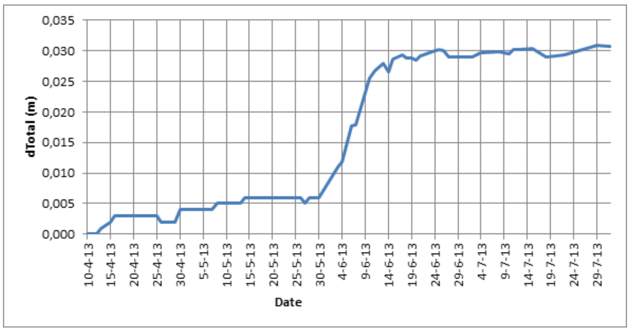

Figure 7. Settlement evolution of Santa María Street.

a. Costanera Portal

The Costanera portal presents special difficult conditions as the new alignment goes tangent to the actual motorway, and no affection to the existing traffic is desirable. For this reason the first meters of the tunnel have been excavated with half width of the section in advance in order to provide enough space for an access ramp, while afterwards this area will be filled and grouted for its complete excavation. The first 15 m have been excavated under a double micropile forepole.

Figure 8 includes a cross section showing the constructive elements.

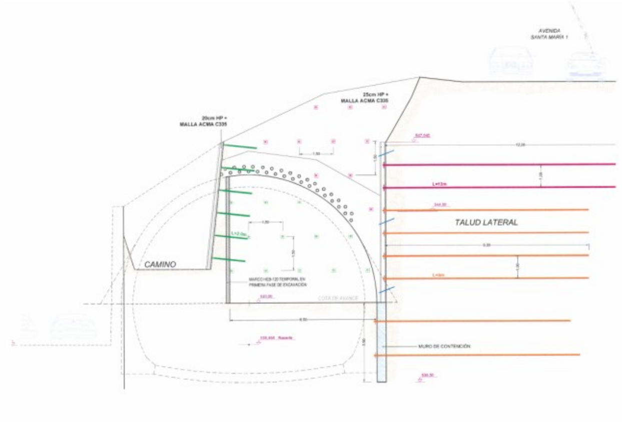

Figure 8. Detail of the solution used at Costanera Norte portal.

The lateral slope of the portal leaves only 3 m to Santa María street, making necessary the reinforcement of all the slopes with a dense “soil nailing”, with self boring fully 40/16 mm grouted bolts (l=9 m and 12 m), spaced 1 x 1.5 m, and 25 cm Sh30 with two wire mesh C-335.

Finally and in order to reduce the subsidence at General Prieto street all the area was grouted applying pressures of 0.5 and 1 kp/cm^2 with fluid cement slurry as the alluvial deposits are in these first meters covered by anthropic fills completely unconsolidated.

The constructive solution shown in Figure 9 was cheeked using FLAC code as well as SLIDE calculations for the soil nailing. The maximum deformation induced at surface has been 30.7 mm (25.5 mm in vertical).

Photos 1 and 2 show two aspects during the construction

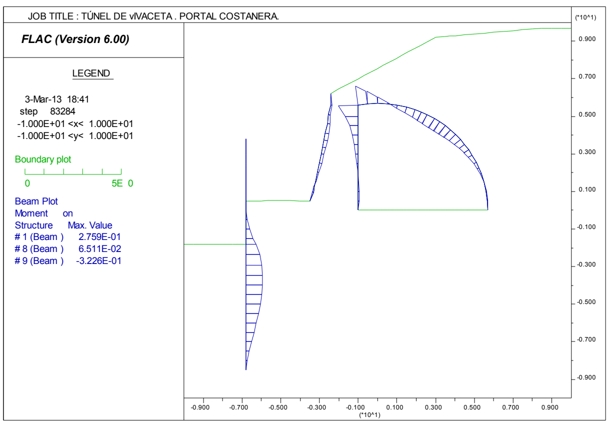

Figure 9. Bending moments at the structural elements at Costanera Portal.

Photo 1. Execution of double micropile forepole at Costanera Portal

Photo 2. First excavation al Costanera Portal.

b. Intermediate technical shaft

The shaft will be used as a technical one allowing to the installation of a Control Room, ventilators and other electromechanical equipment. Also it will be used as emergency exit and as pumping shaft.

It has an internal section of 20.4 x 25.3 m and has a depth of 20.4 m. The shaft has been excavated executing a concrete piles diaphragm wall (depth=19.2 m; ϕ=1.0 m; spacing = 2.0m) and prior to its execution an open excavation of 10 m depth was performed. The shaft has two crossbeams levels at 0.0 and -4.0 m depth and a temporay cable-anchored level at a depth -9.5 m. Figure 10 shows a longitudinal section of the shaft.

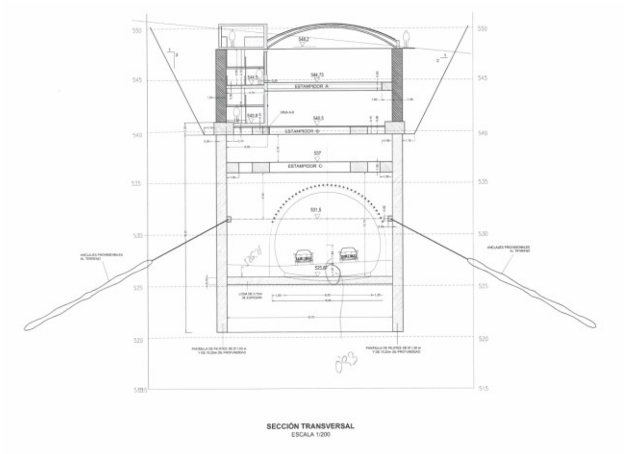

Figure 10. Longitudinal section of the shaft.

Figure 11 shows a longitudinal section of the shaft.

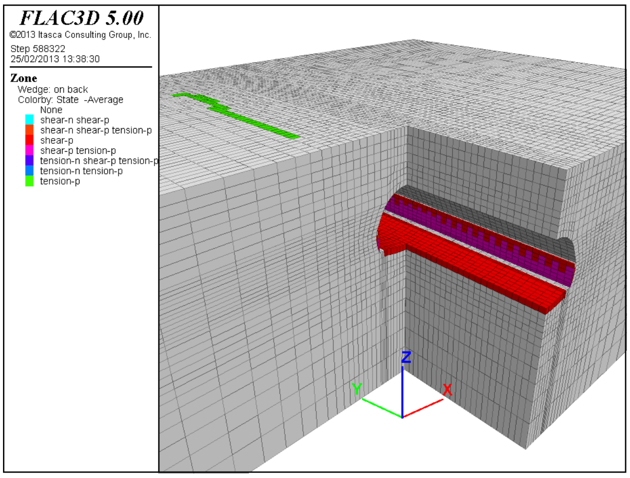

Figure 11. Plastified elements at Dm 407.

Photos 3 and 4 shows two views of the shaft after the end of its construction.

Photo 3. Open excavation at the shaft location. The concrete pile diaphragm can be observed.

Photo 4. Aspect of the shaft from the tunnel junction

c. Tunnel sensitive stretches

The most sensitive area of the tunnel is the section comprised between Dm 290 and 417. In this stretch the tunnel goes under two structures, with an overburden above the tunnel vault of 10 m, and it located just 100 m before the Mapocho River were between Dm 337 and 417 a water flow up to 500 m^3/day Mapocho River was measured.

As it has been described specific numerical analysis were done at those Dm to analyze the influence of the excavation above the existing underground structure and the aspect of this tunnel section, with several water flows. Photo 5 shows a typical aspect of the excavation.

d. Cut and Cover

This stretch corresponds to a “cut and cover” section just at the Mapocho River. Photo 6 show the cut and cover section of the tunnel. This cult box was constructed in two phases, deviating successively the river.

Photo 5. Typical aspect of the tunnel excavation face.

Photo 6. Cult box constructed for the crossing of the Mapocho River.

e. Parque de los Reyes

In this tunnel section between Mapocho Sur Portal and the exit to Central Motorway, the excavation is located under the Parque de los Reyes, that was an old railway used for years as a garbage dump and later landfilled to be used a park.

Photo 7 shows a steel box that was encountered at the tunnel face, creating a considerable overexcavation in a low overburden area.

Consequently in this area the surface subsidence has been considerable bigger than in other places reaching 3.5 cm.

Photo 7. Excavation face under Parque los Reyes, with evidences of anthropic fill.

4 Conclusions

At the date of writing this paper almost the top tunnel excavation of the Vivaceta Tunnel has been completed. Nevertheless the existing difficulties, basically due to the soil characteristics (alluvial deposit) and to the extremely low overburden, the excavation has been successfully with any affection to the surface.

The construction methods using systematically forepoles and an elephant foot at the top and at the bench excavation phases has been proved to be useful to control the induced deformations caused by the tunnel excavation.