Rio de Janeiro Subway – Challenges of the Access Tunnel to the Cantagalo Station

Aluisio de Abreu Coutinho Jr.
Odebrecht Engenharia e Construção

Marco Antonio de Lima Rocha
Rio Trilhos

Luis Eduardo Sozio
Promon Engenharia

Werner Bilfinger
Vecttor Projetos Ltda.

ABSTRACT: The Rio de Janeiro Metro Line 1 was expanded recently in 1230 m, including the new Cantagalo Station. In this stretch, the tunnel and station were excavated mainly in sound gneiss. To connect the station to the highly populated Copacabana area, a 95 m long, main access tunnel connecting the station to the entrance area at Praça Eugênio Jardim, had to be built. This 9.1m wide and 11.6m high tunnel had to cross sharp and irregular transitions between the sound gneiss and a silty residual soil, underlying a sedimentary sand, below groundwater.

The access tunnel, additionally, crosses under a specially settlement sensitive building. The 11 story high, approx. 60 years old building, is founded on shallow footings. Few of the footings are bearing on rock and the remaining on sedimentary sand, which, is characterized by a loose to medium dense condition.

Sand compaction resulting from vibrations due to drill and blast excavation technique induced less than 15 mm additional settlements in the footings on sand, but lead to important structural damages.

To avoid further deterioration of the already critical structural condition, this building was underpinned with 84 root piles and 1.50 m thick reinforced concrete slab.

The main difficulties encountered during tunnel excavation under this building, the mitigating construction method adjustments, and building performance are detailed in the paper.

1 INTRODUCTION

Rio de Janeiro has a population of approx. 10 million inhabitants and is continuously growing. As so many other big cities, traffic is one of the main problems and, therefore, Line 2 of Rio de Janeiro Metro was recently expanded in another 1230 m, adding the new Cantagalo station. Excavation works are finished and delivery to operation is due in 11/2006.

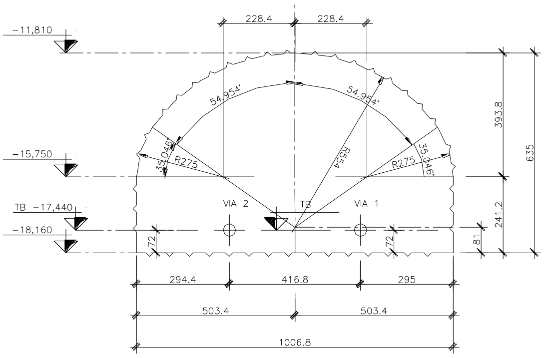
The south area of Rio de Janeiro is densely populated and, especially in Copacabana, where Cantagalo station is located, buildings are concentrated in a relatively narrow strip between the shoreline and steep mountains. These particular conditions oriented main design guidelines, which located the main subway line inside the rock massif, beneath mountains. Only access tunnels and relatively short crossings are constructed beneath buildings and roads.

During the construction of the access tunnel, significant damage to a specific building was detected. To avoid further deterioration, the building was underpinned with 84 root piles and a 1,5 m thick concrete slab.

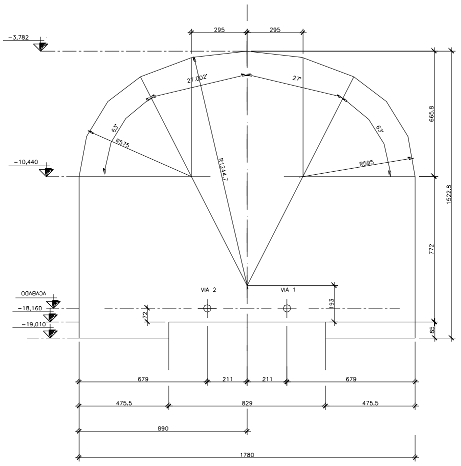
After completion of underpinning, excavation continued without further problems.

2 PROJECT DESCRIPTION

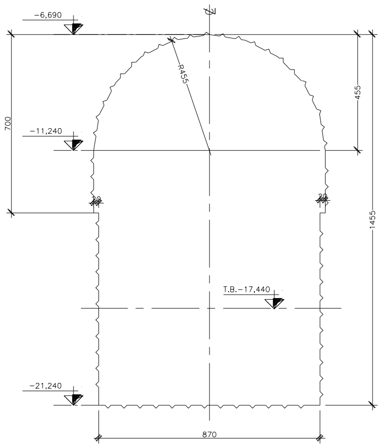
The recently built Metro stretch is 1230 m long, including approx. 1 km of a twin lane tunnel and a 180 m long cavern, where Cantagalo station is located. 3 short access and ventilation tunnels where also constructed. Figure 1 presents typical cross sections of the tunnels.



Line Tunnel



Station Tunnel



Access Tunnel

Figure 1 – Typical tunnel cross sections

The main line tunnel and the station were excavated mainly in sound gneiss, occasionally crossing faults and weathered zones.

To access the station, 2 relatively short tunnels, approximately perpendicular to the main line, were build, crossing from the sound gneiss, through weathered gneiss and sedimentary sands, beneath several relatively old, more than 10 story high buildings, founded on direct footings.

Figure 2 presents a schematic view of the lay-out of the project:

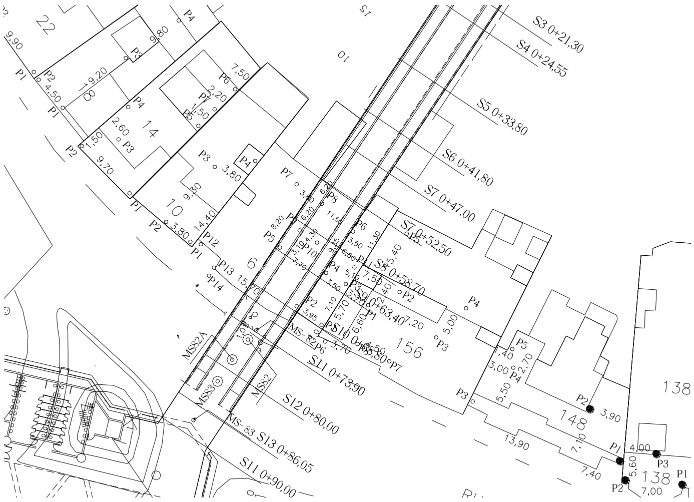


Figure 2 – plan view of the access tunnel. In the lower left corner, the cut & cover section

Aerial View of buildings above access tunnel

The access tunnel connects a cut & cover entrance structure , where the main public will enter the Metro, to the station. This excavation was built using 80 cm thick and 25 m deep diaphragm walls.

The emergency tunnel is connected to a 10 m diameter and 20 m deep circular shaft.

Excavation method in rock was conventional Drill & Blast, using a 3 boomer Jumbo .

Along the access tunnels, drill & blast method was used, where applicable, and conventional excavation with hydraulic excavators, front-loaders and hammers.

Along critical stretches, like fault zones, 62,5 mm tubular metallic forepolling was used, together with cement grout injections.

The access and emergency tunnel excavation was protected by horizontal and vertical Jet-Grouting, used together with 62,5 mm tubular metallic for pollings.

An extensive monitoring program was foreseen, mainly monitoring surface settlements of buildings and instrumented cross sections, as well as water level. Inside the tunnels, convergence and settlements were also measured. Additionally, periodic visual inspections of buildings located in the vicinities of excavations, to detect cracks and other signs of differential movements.

3 GEOLOGICAL BACKGROUND

The typical geological cross section along the line tunnel and station tunnel is a relatively thin silty residual soil cover, occasionally covered by colluvial soils, and its transitions to the sound gneiss.

Local gneisses are Kinzigitic, generally with three sets of discontinuities, one of then associated to the southward dipping xistosity. Rock quality index Q is in general between 15 and 35, and as low as 3 to 4 at faulted zones.

Along the 2 access tunnels (access tunnel and emergency tunnel) a transition from the conditions above, close to the station, to a cross section with the crown of the tunnels in saturated sedimentary sands, and side walls in residual soils and its transitions to the sound gneiss, occurs. The transition is sharp and irregular. Similar conditions where encountered in previous sections of Rio de Janeiro Metro (Nieble et al, 1998; Mello et al, 1998; Mello et al, 2001, Bilfinger et al, 2001).

Figure 3 below presents a typical longitudinal section along the access tunnel.

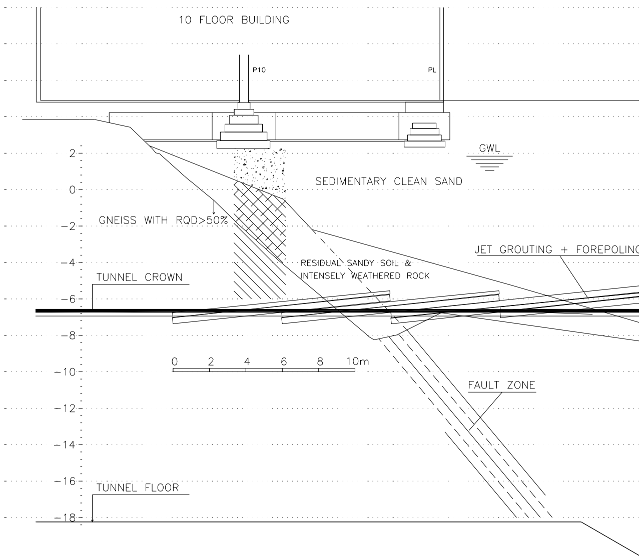


Figure 3 – geological cross section

The sedimentary sands are loose to medium dense, with and NSPT blow count between 5 and 20. Natural groundwater level is some 8m above tunnel crown.

4 STRUCTURAL PROBLEMS – DESCRIPTION AND INTEPRETATION

Settlements, as mentioned, previously, were continuously monitored, including building no. 6 of “Praça Eugênio Jardim”. Settlements of some of the monitored columns started to increase with excavation still 15 m behind the buildings. Other columns showed no movements and, in some cases, slight heave. After visual inspections, severe cracking of walls and structural elements was detected (Photo 1). Calculated differential settlements were still only 1:480. Construction methodology was changed, reducing advance rates, but the settlements continued, with some columns not settling. Figure 4 presents the lay-out of the settlement gauges and Figure 5 the recorded settlements of these gauges.

PHOTO 1 – Cracks inside the building

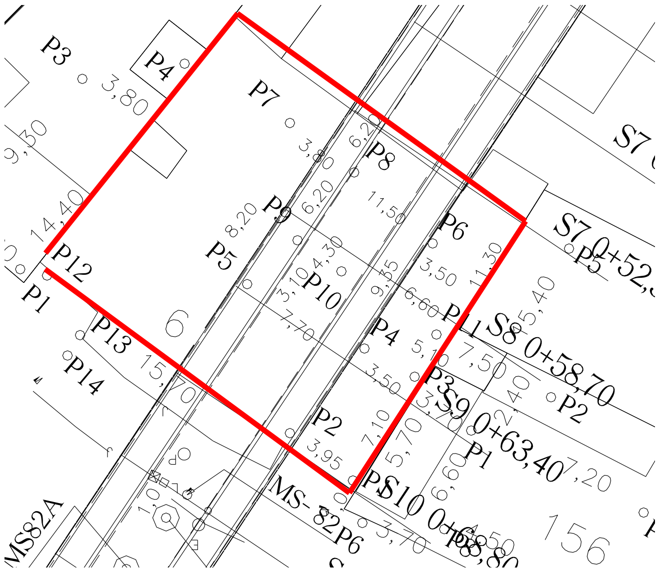


Figure 4 – plan view of building and settlement gauges location

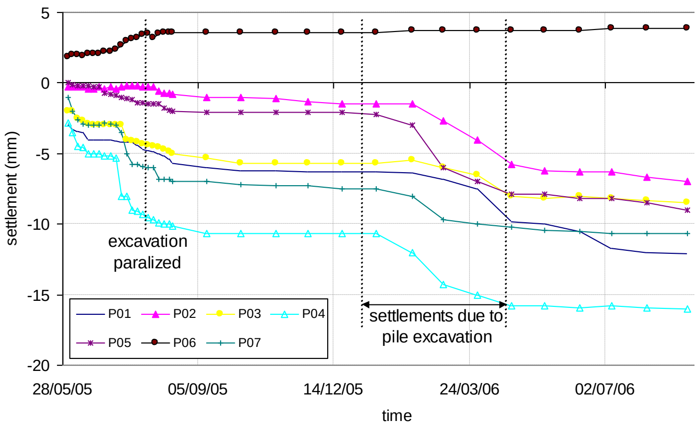


Figure 5 – building settlements

Analysis of available data showed that the direct footings beneath some of the building rear columns were founded on residual soil or rock, the remaining footings being founded on the typical Copacabana sand.

Analysis of the structure showed that average bearing pressures applied by the footings on the subsoil was around 350 KPa. And in opposition to a standard foundation design, there were no structural cantilever beams to balance the eccentric load at the peripheral footings.

Structural damage seemed to be excessive, when compared to differential settlements; however, probably, the building settled, during construction and 60 years of use, suffering considerable distortions and, when the settlements increased slightly due to tunnel construction, the effects were significant.

Interpretation of cause of the settlements was that the vibrations due to the blasting caused compaction of the loose to medium sand and the footings resting on it. On the other side, the foundations on rock / residual soil. did not settle; instead, some of the footings showed slight heave, interpreted as being associated to high horizontal / sub horizontal in situ stress relief due to the excavation. Similar results (heave) where observed on other stretches along the line.

Evaluations by the designer and an independent consultant showed that the risk of severe structural damage due to additional settlements was high and should be avoided. Considering that the excavation was still not beneath the building itself, the only solution that could be considered safe was underpinning, with the use of root piles. Figure 6 shows a schematic cross section of the tunnel, the building and the root piles.

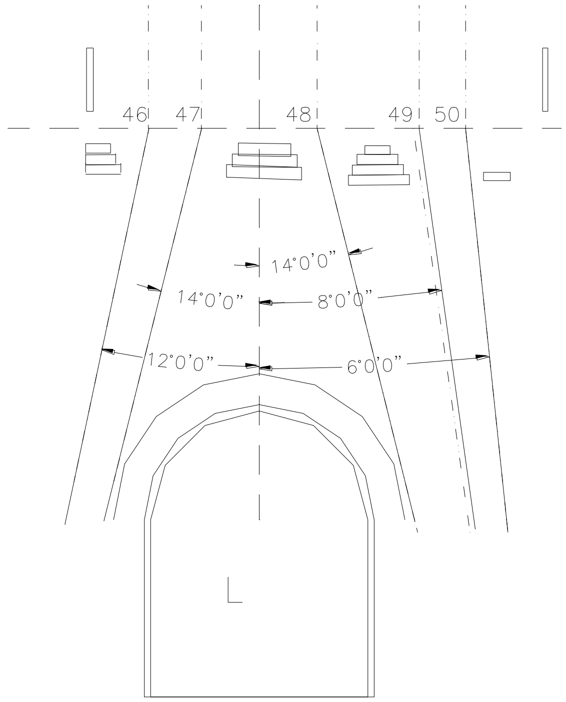


Figure 6 – Schematic cross section of the access tunnel and the root piles

5 SOLUTION

The solution conceived consisted of 84 root piles and a 1,5 m thick concrete slab. The root piles were concentrated in the region were the original footings were founded on the sedimentary sands.

The root piles were founded in the sound rock, avoiding direct loading of tunnel crown. Additionally to the underpinning, horizontal jet grounting and forepoling with 63,5mm dia. steel tubes were used to guarantee treatment of the interface between the rock, residual soils and sedimentary sands.

The existing footings were incorporated to the slab using pre-stressed Dywidag bars. Adequate concrete adherence was ensured along the 1.5m length where piles crossed the slab.

This enabled creation of a monolithic behavior that was confirmed by checking differential settlements between slab and columns, during subsequential tunnel excavation. .

6 PERFORMANCE

The building settled less than 1mm after the completion of the underpinning system and of tunnel conclusion.

During tunnel excavation it was noted that although the horizontal jet grouting system resulted in a moderately improved soil strength, it was not watertight, and therefore a risk of a progressive piping failure was high. Deep wells previously drilled from the building basement, and horizontal vacuum drains were activated in order to control groundwater pressure and mitigate this risk. Some minor settlement associated with groundwater lowering was induced to the neighbor buildings, however with no structural damage.

7 CONCLUDING REMARKS

The behaviour of the more than 60 year old building, suffering severe cracking with only limited settlements showed that the routine type of induced settlement analysis, where distortions are evaluated and compared to predetermined limit values, should be revisited. Previous settlements, not measured and technically documented, can reduce normally considered safety margins.

The underpinning solution showed adequate performance; after its construction, no additional significant settlements were measured and adverse behaviour detected.

Jet grouting soil treatment was not capable of creating an impervious barrier or reduction permeability significantly; this behaviour probably associated to the extremely variable rock-soil interface.

8 ACKNOWLEDGMENT

The authors want to thank the Owner, Rio Trilhos, the Contractor, Odebrecht Engenharia e Construção and the Designer, Promon Engenharia, for the opportunity of publishing and supporting this paper.

9 REFERENCES

Nieble, C. N., Mello, L. G., Melo, J. T. L. P., Camara, G. J. & Primo, C. N. P. 1998. Experiences in the excavation of tunnels and underground station in rock in Botafogo-Copacabana stretch of the subway in Rio de Janeiro, Brazil. In Negro Jr. & Ferreira (ed.s), *Tunnels and Metropolises*; *Proc. WTC, São Paulo, 25-30 April 1998*. Rotterdam: Balkema.

Mello, L. G., Bilfinger, W., Fialho, M. S. M., Rideg, P., Primo, C. N. P. & Rocha, M. A. L. 1998. Access tunnel to the Arcoverde Station of the Rio de Janeiro Subway: Design and Construction. In Negro Jr. & Ferreira (eds.), *Tunnels and Metropolises*; *Proc. WTC, São Paulo, 25-30 April 1998*. Rotterdam: Balkema.

Mello, L. G., Bilfinger, W., Primo, C. N. P., Carvalho, F. C. & Cortes, M. J.. 2001. Rio de Janeiro Subway System: Jet-Grouting Treatment Design and Control. In Teuschser P.. & Colombo, A.(eds.), *Progress In Tunneling after 2000*; *Proc. WTC., Milan, 10-13 June 2001*. Bologna: Patrone.

Bilfinger, W., Mello, L. G., Primo, C. N. P., Carvalho, F. C. & Cortes, M. J.. 2001. Rio de Janeiro Subway System: Settlements due to Horizontal Jet Grouting and their Control. In Teuschser P.. & Colombo, A.(eds.), *Progress In Tunneling after 2000*; *Proc. WTC., Milan, 10-13 June 2001*. Bologna: Patrone.