Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-473

ECSMGE 24
XVIII EUROPEAN CONFERENCE ON SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Lisbon new circular Metro line: Buildings underpinning

Nouvelle ligne circulaire du métro de Lisbonne: Reprise en sous-œuvre des bâtiments

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ABSTRACT: The new Lisbon circular metro line will crosses a densely urbanized part of the city, connecting Rato Station located at one of the hills of the city and Cais do Sodré Station, at the Tagus River right bank. The underground excavation intersects a wide range of materials, from rock mass to soft soils. Where the construction of the tunnel section is closer to the river, with about 10 m of cover, a Cut&Cover method is used. In this metro the tunnel intersected a pile foundation of two reinforced concrete buildings with 9 upper floors and 1 basement, determining the need to underpin the structures and change permanently its foundation system. The geotechnical and geological conditions present in this metro, associated to highly limited access and working conditions, led to the execution of the retaining walls using jet-grouting technology. Those elements were also used as the building deep foundations, which consists of a reinforced concrete slab (length=50m, width=13m and thicknesses=1.4m and 1.8m), being also responsible for the structure underpinning. In this complex process is defined a controlled load transfer between the structure and the new slab, which was executed using hydraulic jacks, limiting the building differential settlements thought gradual jacks opening and according with monitoring. This paper presents an overall description of the solutions, how they were implemented and the buildings' behaviour during the underground works.

RÉSUMÉ: La nouvelle ligne de métro circulaire de Lisbonne traversera une zone densément urbanisée de la ville, reliant la Station Rato, située sur l'une des collines de la ville, et la Station Cais do Sodré, sur la rive droite du Tage. L'excavation souterraine couvre une large gamme de matériaux, depuis les masses rocheuses jusqu'aux sols meubles. Lorsque la construction du tronçon de tunnel est plus proche de la rivière, avec une profondeur de couverture d'environ 10 m, la méthode de tranchée couverte est utilisée. Dans cette section, la ligne a traversé une fondation sur pieux de deux bâtiments en béton armé de 9 étages supérieurs, ce qui a déterminé la nécessité de soutenir la structure et de modifier de manière permanente son système de fondation. Les conditions géotechniques et géologiques présentes dans ce section, associées à des conditions d'accès et de travail très limitées, ont conduit à la matérialisation de murs de soutènement grâce à la technologie du jet-grouting. Ces éléments ont également servi de nouveau fondations profondes des bâtiments, constitué d'une dalle en béton armé (longueur = 50 m, largeur = 13 m et épaisseurs = 1,4 m et 1,8 m), qui est également chargée de soutenir la structure. Dans ce solution complexe, un transfert de charge contrôlé est défini entre la structure et la nouvelle dalle, qui a été réalisé à l'aide de vérins hydrauliques, limitant les tassements différentiels du bâtiment grâce à l'ouverture progressive des vérins et au contrôle concomitant. Cet article présente une description générale des solutions, de la manière dont elles ont été mises en œuvre et du comportement des bâtiments lors des travaux souterrains.

Keywords: Metro; underpinning; reinforced concrete building; jet-grouting; excavation cut&cover.

1 INTRODUCTION

The new Lisbon circular metro line will cross a densely urbanized part of the city, connecting Rato Station, located at one of the hills of the city, and Cais do Sodré Station at the Tagus River right bank.

Where the construction of the tunnel section is closer to the river a Cut&Cover method is used. In this section the line path intersected a pile foundation of reinforced concrete buildings with 9 upper floors and 1 basement, determining the need to underpin these structures.

The geotechnical and geological conditions in this section, associated to highly limited access and working conditions, led to the execution of retaining walls using jet-grouting technology. Those elements were also used as deep foundations of an reinforced concrete slab with 1.4m and 1.8m tick, built for the structure underpinning.

In this complex process was defined a controlled load transfer between the structure and the new slab, which was executed using hydraulic jacks and specific monitoring to control the buildings differential settlements.

2 AFFECTED BUILDINGS

The metro line tunnel intersets buildings nº 42 and nº 44 at Avenida D. Carlos I. Both buildings were built in the XX century, presenting a reinforced concrete structure and pile foundations. The buildings have 9 elevated floors and 1 basement (see Figure 1).

Figure 1. Reinforced concrete buildings above de tunnel.

Building nº42 was recently subject to rehabilitation works for conversion into residential use. As a result of the changes needed, was designed a reinforcement of both the structure and foundations, the latter with micropiles. Building nº44, on the other hand, is in its original conditions, used for offices, and showing a good state of conservation. In Figure 2 is presented the buildings plan superimposed with the tunnel structure layout, showing the need to underpin several columns over intervention area.

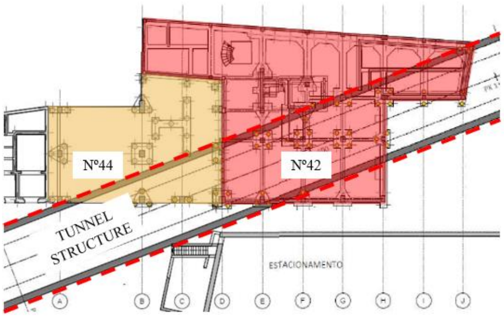

Figure 2. Buildings plan view and tunnel structure projection.

3 MAIN CONSTRAINS

3.1 Geological and geotechnical constrains

The geological investigation campaign included the execution of multiple boreholes that allowed the characterization of the ground units along the extension of the Cut&Cover trench over which the buildings to be underpinned are located (see Figure 3). It was possible to confirm that in the increasing direction of the mileage of the trench, there is a progressive increase in the thickness of recent materials (landfill and alluvium - essentially sandy type) in parallel with the decrease of the Miocene layer depth overlying the units of the Lisbon Volcanic Complex.

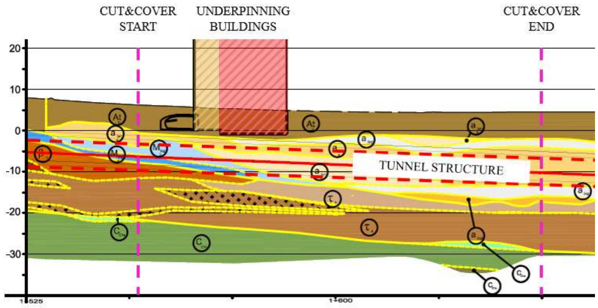

Figure 3. Geological and geotechnical scenario.

3.2 Constructive technologies constrains

The solutions had to respect the local constraints regarding the accessibility of equipment. Considering the need to work inside the building's basements, the solutions had to be compatible with equipment that can operate with a minimal ceiling height of about 3,0m.

3.3 Load transfer procedure

To minimize the occurrence of pathologies in the underpinning buildings, due to differential settlements, the solutions and construction phases had to be compatible with a procedure of controlled load transfer from the buildings to the new foundation system, which was carried out using hydraulic jacks accompanied by monitoring equipment to interpret the behaviour of the buildings and new foundation system.

4 SOLUTION DESCRIPTION

The solution consists of an underpinning system of the buildings columns and pile caps located above the tunnel alignment, which will allow the deactivation of the existing piles and the maintenance of the building's structure functionality and, simultaneously the construction and operation of the new metro tunnel.

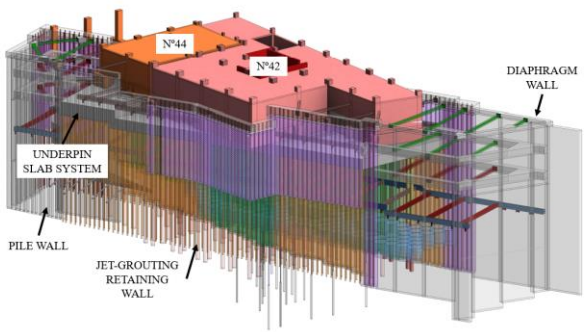

Figure 4. 3D view: Cut&Cover excavation and underpinning solution.

Once the underpinning system had been placed, which is composed of a reinforced concrete slab laterally supported by a double jet-grouting columns curtain wall, the excavation works done inside this curtain and below of the underpinned slab.

4.1 Cut&Cover excavation solution

Since the underpinning solution is connected with the Cut&Cover solution, a brief description is given of, although this is not the focus of this paper.

The Cut&Cover solution was generally composed of a double jet-grouting columns retaining wall with 1000mm diameter columns, spaced 700mm apart, and reinforced with tubular steel profiles, which have a dual function as a foundation of the underpinned slab, as well as retaining the soil and water to allow the excavation required to build the tunnel. In addition to this, and to reach the underpinned slab level, it was executed a third row of jet-grouting columns, also reinforced with steel profiles (Figure 5).

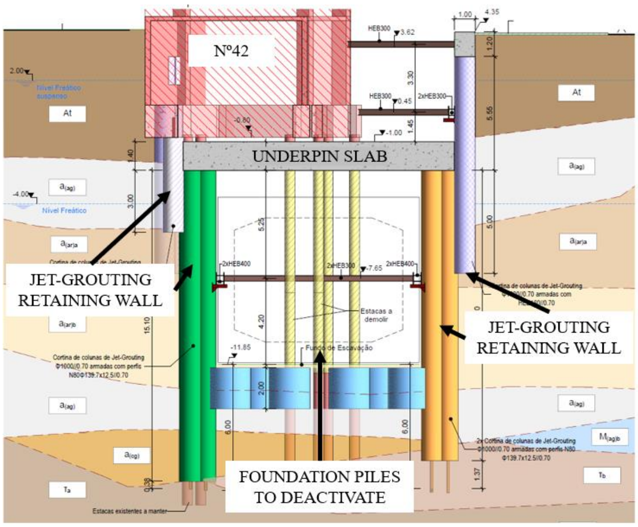

Figure 5. Section: Cut&Cover excavation and underpinning solution.

Finally, the retaining walls were temporary propped each other using four levels of steel struts, 5m apart, resting over steel and reinforced concrete distribution beams. However, in the underpinning area, reinforced concrete slab was used as the third strut level.

4.2 Underpinning solution

The underpinning solution consists of a reinforced concrete slab, not prestressed, supported indirectly on jet-grouting columns, reinforced with steel profiles in order to increase their ductility and stiffness, placed outside the tunnel. The underpinned slab was positioned below the existing pile caps and above the tunnel alignment, with geometry of approximately 50,0m by 13,0m and a variable thickness between 1.40m and 1.80m (see Figure 6).

Taken together, these elements make it possible to change the foundation system of the buildings, transferring the loads from the structural columns to the slab which, basically by cylindrical bending, transmits them to the two rows of jet-grouting columns, which finally transmit the reactions to the competent ground layers located below the bottom slab of the tunnel.

This solution makes it possible to deactivate the piles foundation of the buildings existing over the tunnel area, as well as to proceed with the excavation works to build the new tunnel.

4.3 Load transfer procedure

Hydraulic jacks were used in order to ensure a smoother transfer of loads between the buildings columns and the underpinned reinforced concrete slab, and thus allow for greater control of the settlements occurring in this process. Hydraulic jacks positioned between the underpinned slab and the pile caps, will be responsible for relieving the loads of the foundation piles, using the reaction provided by the slab.

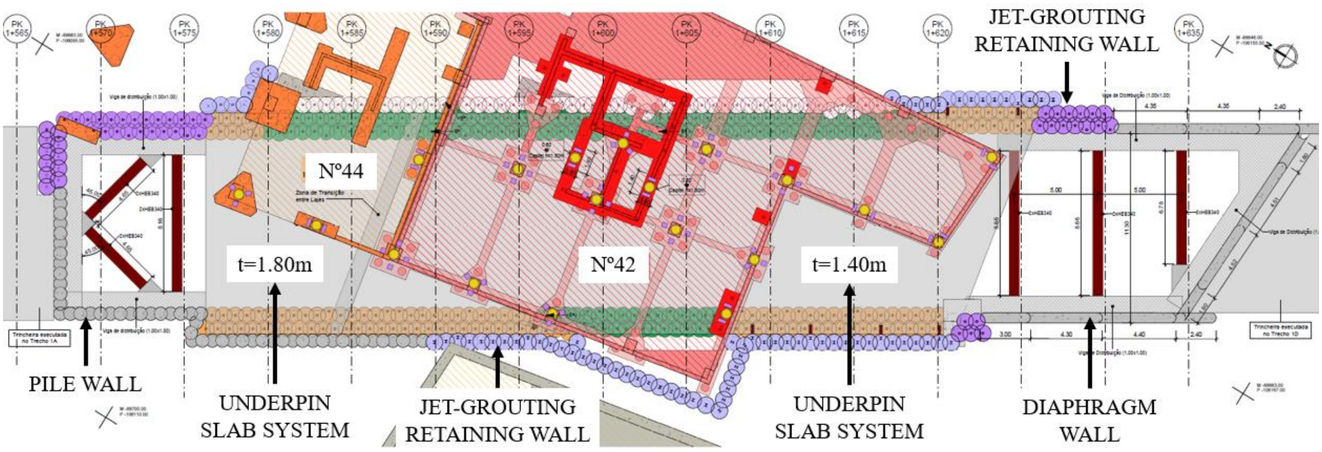

Figure 6. Plan view: Cut&Cover excavation and underpinning solution.

The phases related to the load transfer are summarized below and illustrated in Figure 7:

1. Installation of the instrumentation system at the columns;
2. Excavation to the bottom level of the slab;
3. Sheathing of the piles followed by slab construction and hydraulic jacks installation;
4. Excavation under the slab, followed by hydraulic jacks activation and subsequent existing piles demolition, managed by monitoring data analysis.

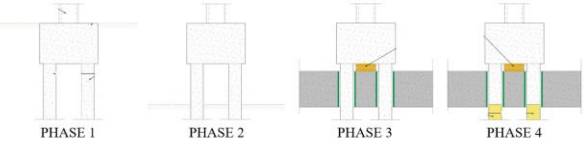

Figure 7. Underpinning solution – Load transfer beams.

5 SOLUTION DESIGN

The underpinning concrete slab was designed using structural models within the *SAP2000* software.

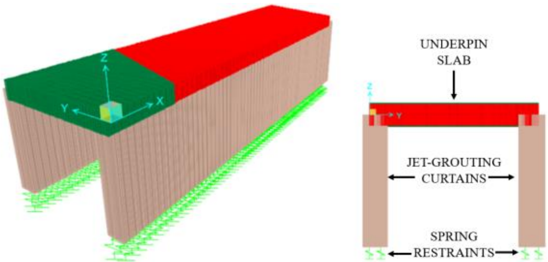

Figure 8. SAP2000 analysis model for underpin slab.

The underpinned slab, as well as the supporting jet-grouting columns, were modelled using shell type elements, and in the case of the latter, these were supported on springs type restraint. This model made it possible to estimate slab structural efforts (see, for example, bending moments in Figure 9) as well as its elastic deformation (see Figure 10).

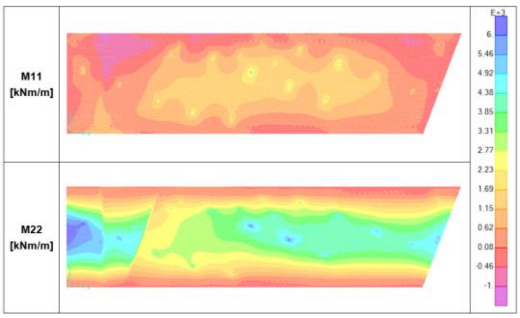

Figure 9. SAP2000 – Underpin slab bending moments.

Considering the support springs on the structural model, was estimated the maximum design axial load on each jet-grouting column, allowing, in parallel analysis with the geotechnical model for Cut&Cover solution, the safety validation of those elements.

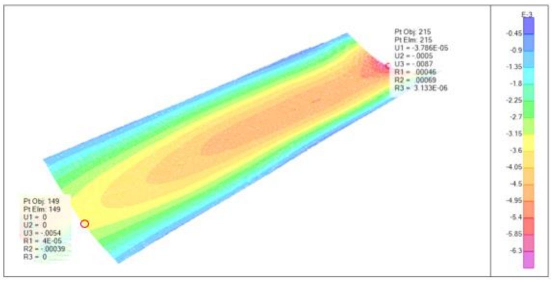

Figure 10. SAP2000 – Underpin slab displacements.

6 MONITORING PLAN

Complementarity, fort the Cut&Cover excavation, a monitoring plan using liquid level sensors and strain gages was installed to measure the settlement behaviour of the slab and columns, as well as the interaction between them (see Figure 11).

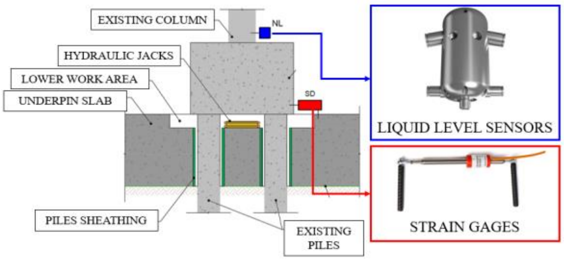

Figure 11. Monitoring devices: liquid level sensors and strain gages

The monitoring plan establishes threshold values for each device. The numerical analyses results were used to determine reference values for measured parameters that were used to set warning values, for 80% of the reference values, and alarm ones, for 120%.

7 FINAL REMARKS

The definition and implementation of a new metro line in a densely urbanized area may lead to interference with existing structures. For scenarios such as the one presented in this paper, an underpinning solution was the most appropriate way to maintain the integrity of the existing structures, although this type of solution often presents multiple restrictions regarding equipment access and operation.

An adequate monitoring and survey plan is essential to manage the load transfer to the underpinning system during the excavation works.

ACKNOWLEDGEMENTS

The authors are grateful to the Metropolitano de Lisboa for permission to present this paper.