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AR53 - Ground improvement and earth retaining solutions in Lisbon's downtown

AR53 - Solutions d'amélioration et de rétention des sols dans le centre-ville de Lisbonne

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ABSTRACT: The presented case study takes place in one of Lisbon's main avenues, Almirante Reis 53 (AR53). At the site area there was an old habitation building, which was previously demolished. The building to be built, has 7 raised floors and 2 basement floors, each with approximately 225m^2. Some of the most relevant restraints are the 60 years old tunnel of the Lisbon Metro, which is approximately 10m away from the excavation pit, the surrounding structures, as well as the geological conditions. In this scenario, it was decided to build a peripheral earth retaining structure, using a Berlin type wall, braced by steel props and slab bands. Prior to the excavation works and considering the characteristics of the surficial and very soft landfill deposits, these materials were treated with soil-cement columns. A monitoring plan was designed as a risk management tool, aiming to predict the behavior of all neighbor structures and infrastructures during the excavation works. The design was supported by a numerical analysis, using a Plaxis2D model, which aimed to predict deformations and stresses at the Berlin type wall and Lisbon Metro tunnel, for all the main construction phases. At last, a seismic analysis was developed, in order to guarantee the safety of the new building and its nearby constructions.

RÉSUMÉ: Le projet présenté se déroule dans l'une des principales avenues de Lisbonne, Almirante Reis 53 (AR53). Avant le projet il y avait un ancien bâtiment d'habitation, qui a été démoli avant le projet. Le bâtiment à construire sur comprend 7 étages surélevés et 2 sous-sols, chacun avec environ 225m^2. Les obstacles plus importants, sont le tunnel du Métro de Lisbonne, âgée de 60 ans, à environ 10 mètres de distance, les structures environnantes et les conditions géologiques. Dans ce scénario, il a été décidé de construire une paroi périphérique, utilisant la technologie d'exécution du type Berlin, soutenue par des buttons et des bandes de dalle. Avant les travaux d'excavation et en tenant compte des faibles caractéristiques des remblais à la surface, ces matériaux ont été traités avec des colonnes de sol-ciment. Un plan de surveillance a été élaboré comme un outil de gestion des risques visant à prévoir le comportement de toutes les structures pendant les travaux d'excavation. La conception a été calibrée par une analyse numérique utilisant un modèle Plaxis2D, qui visait à estimer les déformations et les contraintes au mur de Berlin et bien aussi à la galerie du Métro de Lisbonne à toutes les principales phases de construction. A la fin, une analyse sismique a été développée afin de garantir la sécurité du bâtiment et de ses constructions voisines.

Keywords: Berlin type wall; Soil-cement columns; Micropiles; Monitoring, Deformations.

1 INTRODUCTION

As a consequence to the rise of the construction and touristic market in Portugal, numerous new constructions and rehabilitations are being held for accommodation purpose. The presented project takes place in Almirante Reis (Figure 1), one of Lisbon's main avenues, located over an old water stream, in a dense urban area. The architectural design of the building to be built at the site, "Almirante Reis 53" (AR53), has 7 raised floors, intended for hotel purpose, and 2 basement floors, destined for restaurant and technical areas. The building provides an approximately square plan shape, with a total area of about 225m^2 per floor.

At the site, there was currently a three-raised floor habitation building, with an approximately square implantation area of about 15×15m^2, which was previously demolished. The geometry of the building, the topography of the site, the geotechnical and geological conditions, lead to an excavation with a maximum depth of 9m. In this scenario, it was decided to build a solution for the earth retaining structure, using a Berlin type wall, braced by steel props and slab bands, avoiding the use of temporary ground anchors.

2 MAIN RESTRAINTS

Some of the most relevant restraints of this project are the 60 years, plain concrete, Lisbon's Metro tunnel, which is approximately 10m away from the excavation pit, the surrounding structures and infrastructures, as well as the geological conditions, which are below described.

2.1 Geological and geotechnical conditions

A site investigation campaign was carried out in order to allow the geological and geotechnical characterization. Four boreholes, with SPT tests, were carried out, as well as two shafts, for confirmation of the neighbour buildings geometry and foundation levels, were executed.

Based on the information provided by the ground investigation campaign, geotechnical and geological zones and parameters were defined (Table 1). Regarding the site geology, landfill deposits, characterized by silt sand with fragments of variable dispersed nature, were intersected between 1.5 and 3m depth. Bellow the landfills, a layer of silty clay, occasionally sandy (N_{SPT} blows between 7 and 44), due to the old water stream, with an overall thickness ranging between 1.5 to 14.5m, was observed. At the boreholes base, the Miocene sandstones were observed, at a depth ranging from 12.5 to 14.5m.

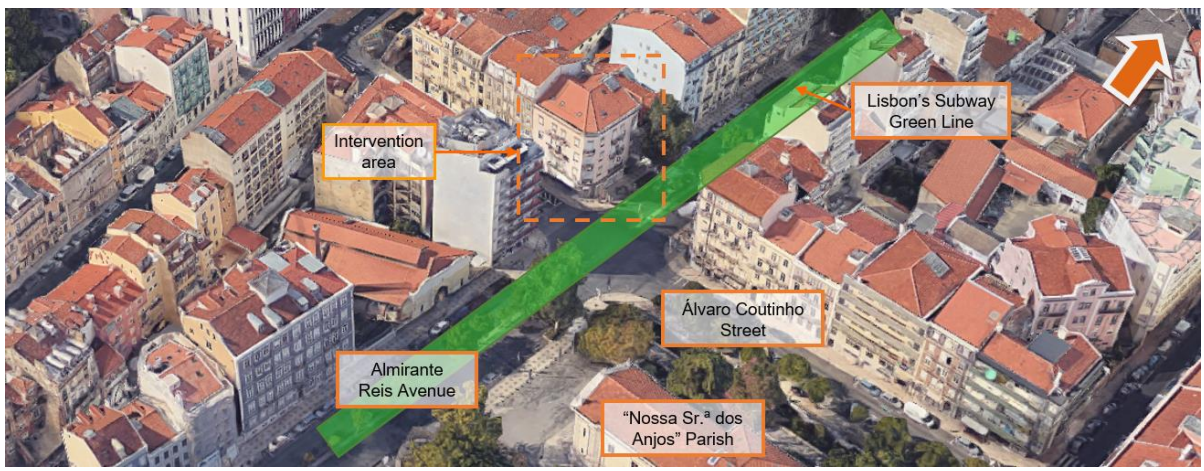

Figure 1 - Site location and conditioning (source: adapted from Google Maps)

It should be pointed out that the groundwater table was not observed above the final excavation level.

Table 1. Geotechnical parameters and zones

Geotechnical Zone	N_{SPT} [-]	ϕ' [°]	γ [kN/m³]	E [MPa]
ZG1 - Landfills, silt sands	<5	26	16	6
ZG2 - Silty clay, sometimes sandy	7-44	31	18	30
ZG3 - Miocene sandstones	>60	38	20	100

2.2 Demolition

Demolition in urban areas are always one of the most conditioning and dangerous part of the project. Given the age of the building, as well as the lack of information about the construction materials and its degradation status, additional prevention measures had to be considered in order to guarantee a controlled and safe demolition. In this case, the damaged structural status of a neighbour building at Álvaro Coutinho Street, demanded the need to install a façade retention structure, founded over micropiles, in order to allow the building stabilization during the future excavation works. In Figure 2, an example of a prevention measure can be observed.

Figure 2 - Shoring of the arches and installation of steel props (September 2018)

The shoring of the existent arches and the installation of steel props, in order to guarantee the execution of the façade retention structure and the micropiles foundation cap.

2.3 Neighbourhood conditions

The excavation enclosure is in an urbanized area, being delimited by buildings (to the north and west, with two and five raised floors), streets (Av. Almirante Reis at east, including the Lisbon Metro tunnel, and Álvaro Coutinho Street at south) and various infrastructures (Figure 1). As said, in order to control possible deformations due to decompression of the old and damaged building facing west, at Álvaro Coutinho street, previous to the demolition works, two facades retention towers were installed and founded over micropiles.

Due to the location on a dense urban area, the risk of intersection of utilities networks, mainly: Lisbon Tunnel, rainwater collectors, gas network, telecommunications, electricity and water, lead to the design of earth retaining structures with the objective to avoid temporary ground anchors.

Other key restraint was the lack of space on site to use earth retaining solutions demanding big and heavy equipment's, as pile walls or diaphragm walls.

3 ADOPTED SOLUTIONS

In this scenario, it was decided to adopt a solution for the peripherical earth retaining structure, using a Berlin type wall, with reinforced concrete panels, braced by steel props and slab bands and vertically supported by micropiles. This type of solution has the advantage of allowing the final wall to be executed during excavation. The main design scopes were the following:

- Deformations control: ground and neighbour constructions and infrastructures;
- Minize possible interference with the Lisbon Metro tunnel;
- Guarantee ease, speed and safe execution.

Before the beginning of the excavation works and considering both the Berlin type wall and the

weak characteristics of the ZG1 and ZG2 materials, a ground improvement solution with soil-cement columns was executed.

3.1 Earth retaining solution

The architectural project includes two basement floors, which require, due to the above cited restraints, a vertical excavation, supported by an earth retaining wall. In this scenario, the Berlin-type wall (king post with reinforced concrete cast in situ panels) is one of the most suitable techniques, as it takes advantage of the staged construction, allowing to minimize walls thickness and back structures and infrastructures displacements. However, it is crucial that the design guidelines are respected, mainly, the excavation stages. This technique consists in phased retaining wall execution, from top to bottom, of 0.30m net thickness reinforced concrete panels, supported by steel vertical tubular micropiles. The panels are casted directly against the excavated soil face and braced by slab bands and temporary corner steel props at two levels.Temporary ground anchors were avoided given the proximity of the Lisbon Metro Tunnel and the neighbouring buildings shallow foundations. At the final stage, the new building basement slabs assure the stability of the retaining walls.

3.2 Ground improvement

Prior to the beginning of the excavation works and considering the weak characteristics of the soft landfill deposits, these materials were treated with soil-cement columns, in order to allow the execution of the Berlin wall solution (Figure 3).

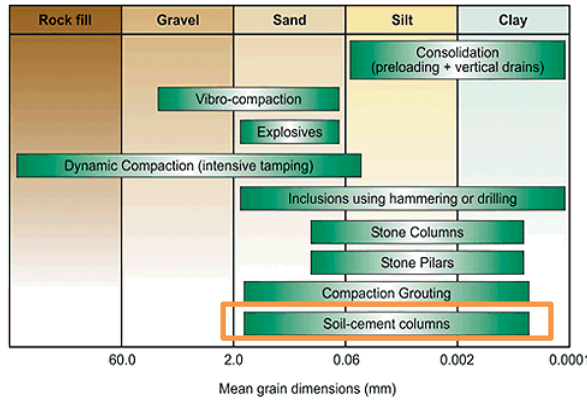

Figure 3 – Main ground improvement techniques (source: Soletanche Bachy)

4 DESIGN

4.1 Numerical Analysis

The design was supported by a numerical analysis using a Plaxis2D model. Geometry input, soil and interfaces properties were chosen to replicate, as best as possible, the local conditions. The main scope was to predict deformations and stresses at the Berlin type wall for all the main construction phases, as well as to calibrate the Monitoring and Survey Plan.

The most representative and conditioning sections were analysed, including the Lisbon Metro tunnel (Figure 4), in order to evaluate stresses and strains, as well as the stability of the retaining walls. The most important output of this analysis were the displacements of the retaining walls, the ground settlements, the forces at the temporary steel props and slab bands, as well as the micropiles axial loads.

Nonetheless, elements such as capping beams were analyzed considering simplified models, using concepts of the classical theory of elastic bars as well as strut and tie reinforced concrete models.

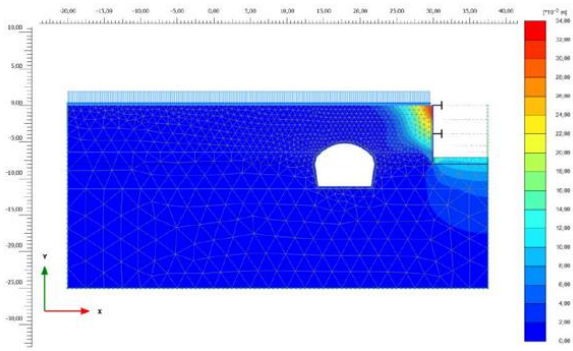

Figure 4- Plaxis 2D model of the Berlin wall and tunnel cross section (total estimated displacement of 33mm)

Taking into account the geological conditions as well as the location of the building foundations, a seismic analysis was developed, in order to guarantee the safety in terms of overall stability of the earth retaining structure, as well as the safety of the new building and its nearby constructions. Using the Plaxis2D software and considering the seismic action according to EC8 and the National Portuguese Annex, the following analysis were made:

- Loss of overall stability;
- Safety checking, ULS and SLS, for all the sections considered as conditioning and representative.

4.2 Micropiles

In this project, micropiles were used for several foundation purposes, namely the earth retaining structure, the new building foundations, the tower crane and the façade retention towers.

The micropiles were designed to transmit their loads to the Miocene layer mainly by lateral friction. The safety verification associated with the ground bearing capacity was carried out through the Bustamante method (Bustamante, 1985), which allows to quantify the sealing length. The credibility of this method is proven by its wide application, as well as the fact that it was developed based on a large number of experimental results, even at the Lisbon Miocene soils.

5 MONITORING PLAN

A monitoring plan was designed as a risk management important tool, in order to ensure the execution of the excavation works in safe and economic conditions. The plan aims to confirm, on time, the predicted behaviour of the earth retaining structure, as well as of neighbouring structures and infrastructures during and after the excavation works.

Regarding the Lisbon Metro tunnel, a specific monitoring plan had to be developed, given its proximity (about 10m) to the excavation pit area (Figure 5).

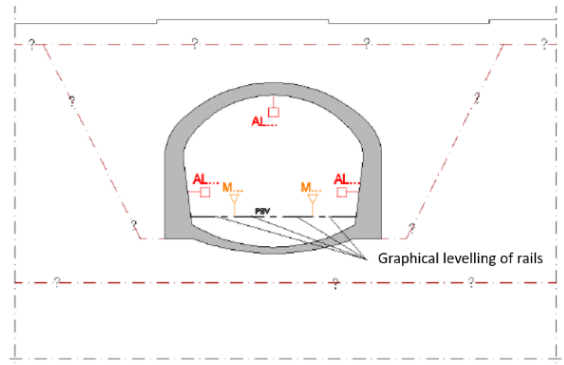

Figure 5 - Monitoring of the Lisbon Metro tunnel

The monitoring plan will be able to provide mainly the following data:

- Vertical and horizontal displacements of:
  - The retaining wall;
  - The neighbouring buildings;
  - The Lisbon Metro tunnel.
- Horizontal displacements of the retained ground;
- Ground water table depth.

In order to obtain the above data, the following main devices were installed: topographic targets, topographic levellings and inclinometers.

6 MAIN CONCLUSIONS

Considering the restraints faced, mainly the nearby constructions, such as Lisbon Metro tunnel, it was possible to overcome them by using a Berlin type wall solution, associated with the previous ground improvement, using soil-cement columns, braced by slab bands, which demonstrates the efficiency and versatility of this technique (Pinto, 2017 and Pinto, 2015).

In spite of at this stage just the demolition works have already been done (Figure 6), the adoption of the described earth retaining solutions has many advantages, mainly: the use of equipment with small dimensions and high versatility, the possibility to perform the final wall simultaneously with the excavation, as well as the possibility to apply ground improvement techniques with the same small equipment, when intersecting softer soils, as the soil-cement columns solution (Aleixo, 2018).

Figure 6 – Current phase of the site works: facade retention of the neighbour building and demolition (March 2019)

As usual in this kind of projects, the developed model will be calibrated and validated on time by the monitoring plan results, during the excavation works.

7 ACKNOWLEDGEMENTS

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