Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0230

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Retaining Wall Solutions for Underground Extension of Hospital da Luz in Lisbon - Portugal

Solutions de mur de soutènement pour l'extension souterraine de l'hôpital da Luz à Lisbonne – Portugal

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ABSTRACT: The paper addresses the solutions executed for the excavation and retaining walls of the four basements, included on the enlargement of Hospital da Luz, in Lisbon. The main existing conditions will be presented, namely the geological-geotechnical, the urban envelope and the presence of the Lisbon Metro tunnels, very close to the south area of the excavation plot. The working site, located between the existent hospital, Av. Condes de Carnide, Rua Aurélio Quintanilha and Av. Lusíada, comprises an area of approximately 9.800m2 and a maximum excavation depth of 16m. In order to maximize the economy-safety binomial, without forgetting the issues of functionality and simplicity of construction, it was necessary to develop different solutions, namely anchored bored pile curtains, bored pile curtains supported by reinforced concrete slab strips (area adjacent to the Metro tunnel) and temporary retaining walls "Berlin king post wall". The main criteria for the design of the implemented solutions, as well as the main results of the monitoring system will be presented and compared with the project predictions.

RÉSUMÉ: Le document traite des solutions mises en œuvre pour l'excavation et pour les murs de soutènement des quatre sous-sols, compris dans l'agrandissement de Hospital da Luz, à Lisbonne. Les principales conditions existantes seront présentées, à savoir la géologie et la géotechnique, l'enveloppe urbaine et la présence des tunnels du métro de Lisbonne, très proches de la zone sud de la parcelle d'excavation. Le chantier de travail, situé entre l'hôpital existant, la Av. Condes de Carnide, la Rua Aurélio Quintanilha et la Av. Lusíada, couvre une superficie de 9.800 m2 et une profondeur d'excavation maximale de 16 m. Afin de maximiser le binôme économie-sécurité, sans oublier les problèmes de fonctionnalité et de simplicité de construction, il était nécessaire de développer différentes solutions, à savoir des rideaux à pieu forés soutenus par ancrages ou par les dalles de béton armé (zone adjacente au tunnel du métro) et des murs de soutènement temporaires avec des profilés HEB e barres de bois. Les principaux critères de conception des solutions mises en œuvre, ainsi que les principaux résultats du système de levé topographique, seront présentés et comparés aux prévisions du projet.

Keywords: Retaining Walls; Bored Piles; Ground Anchors

1 INTRODUCTION

The enlargement of the “Hospital da Luz de Lisboa”, which will be described throughout the present article, is located in a plot, delimited by the building of the current hospital and by several streets and avenues, this plot was originally occupied by a Museum of Lisbon Firemen’s, as shown in Figure 1.

In order to ensure the consistency of the information, analyses and considerations presented throughout this article, recognizing that there are significantly different solutions corresponding to different areas of the work, determined by different constraints, it was decided to divide this article into three parts which correspond to three significantly different retaining solutions. Before the description of the three solutions and their design methods, the global existent conditions were explained. Aspects such as the geological-geotechnical and hydrogeological scenario, the architectural and functional needs of the building, the existence of important structures and infrastructures located in the vicinity were also detailed.

In order to materialize the excavation of the four underground floors, in a safe condition, in particular for the adjacent structures and infrastructures, three different peripheral retaining wall solutions were executed, and can be summarized as follows: curtain of bored piles , temporarily anchored, along the elevation adjacent to Av. Condes de Carnide; curtain of bored piles, horizontally supported with slab strips made according to the top-down methodology (Pinto et al., 2017 and 2015), along the elevation adjacent to the Av. Lusíada; and "Berlin king post wall" temporarily anchored, along the elevation adjacent to Rua Aurélio Quintanilha (Figure 1).

Figure 1. View of urban envelope and pre-existent structures

2 MAIN EXISTING CONDITIONS

2.1 Geology and hydrogeology

The geological-geotechnical and hydrogeological characterization of the formations interested in the work described was carried out through the execution of field tests and laboratory tests, namely: eleven boreholes with sampling and SPT test, installation of three piezometers, granulometric analysis, determination of the water content, determination of the limits of consistency, determination of chemical aggressiveness and determination of resistant parameters by direct shear tests.

Based on the information collected with the tests described above, the following formations were identified, in agreement with the information available in the Lisbon Geological Chart:

Landfills – soils of a diverse nature, but with predominance of silt-clayey soils and sand-silty soils;

Prazeres clays and limestones – soils dating from the Miocene, constituted by the monotonic alternation of sedimentary layers of fine granulometry soils, constituted by more or less silty clays

Formation of Benfica – soils of Oligocene, characterized by purplish brown sediments, composed of sands with extensive granulometry and occasional fine pebbles (occurring at about 30m depth, ie not intersected by the present excavation).

The water table was observed at depths varying between 3m and 13m depth, seeming to follow the old topography of the site, with flow from NE to SW. However, the hydrogeological productivity of this site was very low considering the small permeability of the clay soils.

2.2 Adjacent Urban Infrastructures

As mentioned previously, the intervention area is located in a densely urbanized area, surrounded by important communication routes of the city of Lisbon (Figure 1). Such as streets and tunnels of the Lisbon Metro. Figure 2 shows in detail the different confrontations of the excavation site, where it is evident the Av. Condes de Carnide, (North), the Rua Aurélio Quintanilha (East), the Av. Lusíada and the tunnels of the ML (South) and the structure of the current Hospital.(West).

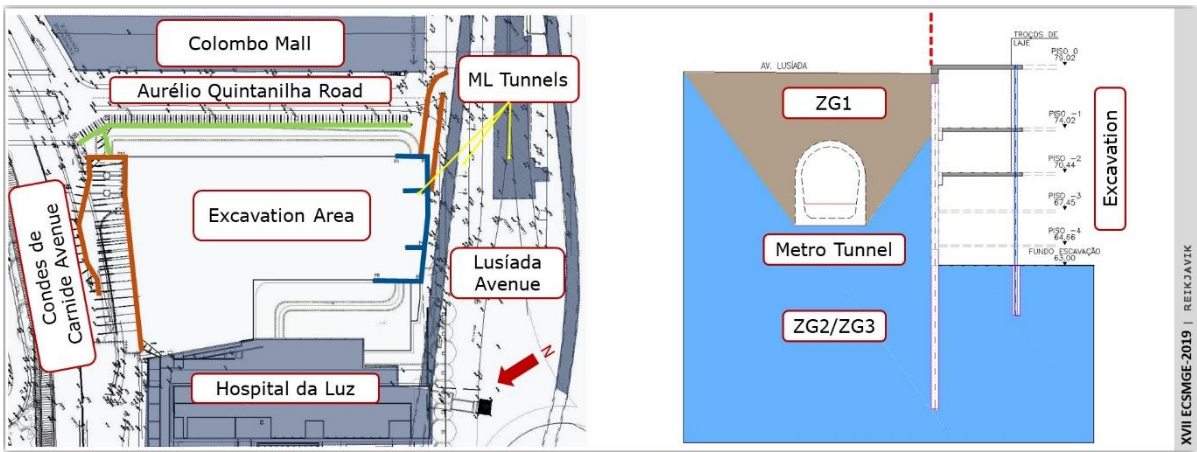

Figure 2. Aerial view of urban envelope

3 ADOPTED SOLUTIONS

3.1 North elevation – Adjacent to Av Condes de Carnide

Based on the existing conditions, in particular topographic, geological-geotechnical and occupation of the neighbourhood, a curtain of bored piles, reinforced concrete, Ø600mm apart ofeach 1.20m, with maximum total length of about 22m, in order to ensure an embedded length, below the final excavation level, of 5m. Considering the geological conditions of the site and the length of the piles, they were executed with kelly telescopic bar and only with temporary casing at the first meters of the drilling shaft, (landfill materials).

The exposed ground between piles was protected with a 10 cm thick sprayed concrete layer, applied in two phases and reinforced with metallic fibres and drained with sub-horizontal geodrains. To ensure the horizontal support during the final stage, whenever the underground slabs did not connect to the bored piles curtain, an additional reinforced concrete wall was connected to the piles.

The implemented solution allowed an excavation depth of about 15m, necessary for the execution of the 4 underground floors. Throughout the present elevation, since there were no relevant restrictions and in order to guarantee a high excavation rate, the retaining wall was horizontally supported by means of several levels of temporary anchors. The supported earth pressures were determined by the terrain geotechnical parameters and the loads applied on the surface. In order to ensure a better distribution of the forces in the curtain and to avoid an excessive concentration of loads, around the ground anchors, several distribution beams were executed in front of the bored piles.

The ground anchors had 5 x 0.6 "strands to accommodate a maximum tension load of 600kN and were spaced of 3.6m. In order to avoid the possibility of intersections of these elements with existing installations and structures, as well as to allow the execution of the grouted length (minimum length of 7m) in terrain competent and geologically stable in relation to the excavation geometry, the anchors were drilled with variable inclinations and variable lengths.

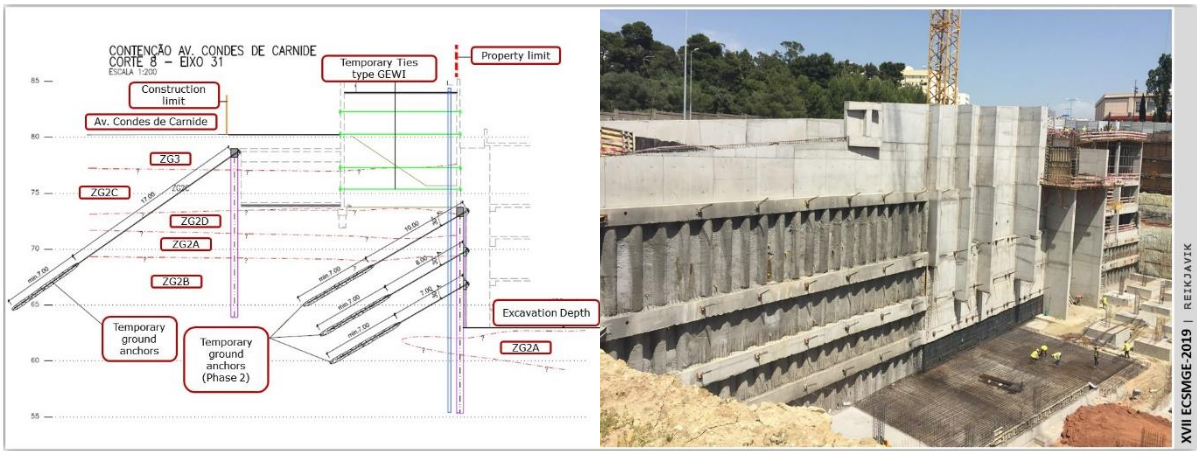

Figure 3. Section Cut and Construction Works

3.2 East elevation – Adjacent to Rua Aurélio Quintanilha

Considering the existing and previously described constraints, a temporary Berlin king post wall with a height varying between 5m and 10m, and temporarily anchored at 2, 3 or 4 levels, was executed along the edge adjacent to Rua Aurélio Quintanilha (Figure 4), which allowed the complete demolition of the existing building and the maintenance of traffic at Rua Aurélio Quintanilha.

The temporary Berlin king post wall technology consists of the pre-installation of vertical steel profiles, grouted in the ground, followed by the placement of wooden bars between them during the excavation and supported by ground anchors distributed along horizontal steel beams.

Considering the geotechnical characteristics of the existent soils, namely their cohesive nature, the vertical HEB 160 profiles, which reached maximum lengths of 22m and were planned to be installed using a small drilling diameter (250mm), were installed using CFA technology assembled on a bored pile rig, which allowed higher construction rates.

In the present case, HEB profiles were installed with distances of 1.2m and 1.5m, and the wooden bars placed between them had a thickness of 10cm. The temporary anchors, with variable spacings between 2.4m and 3.6m, were applied on distribution beams made of metallic laminated steel profiles, materialized by 2 x UPN 300 profiles, in order to accommodate the pressures determined by the terrain and the loads.

From bottom of the retaining wall, to allow the complete demolition of the existing building, was carried out an additional 12m excavation. The excavation slopes were an inclination of 2:3 (h:v), which allowed to reach the base of the excavation for the implantation of the foundations of the new building (Figure 4).

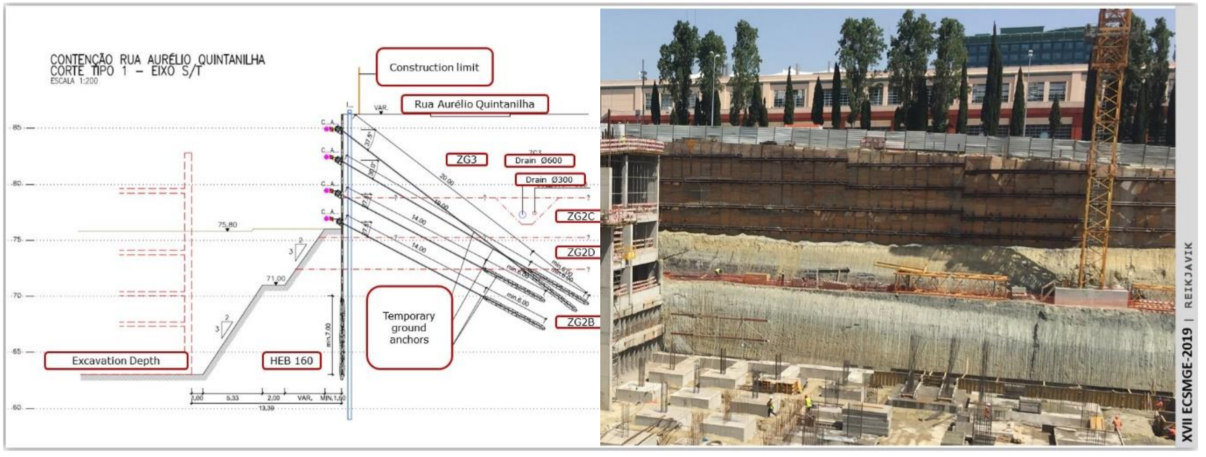

Figure 4. Section Cut and Construction Works

3.3 South elevation – Adjacent to Av. Lusíada and Metropolitan Tunnels

In the southern edge of the excavation area, a retaining wall solution similar to the one described for the North edge was implemented. However, considering the neighbourhood conditions present in this zone, particularly the ML Tunnels, the use of ground anchors to horizontal support the wall, was not geometrical viable. Thus, in this elevation, a retaining system consisting of partial slabs executed by top-down method was chosen, which consists of a set of horizontal beams (sections of slab of future underground floors). Considering high length of this elevation, two intermediate buttresses were executed to reduce the span of the slabs. With the exception of the two central buttresses and the steel profiles for temporary support of the slabs, all other structural elements were integrated into the final structure of the underground floors. This solution was inspired by previous works, where it proved to be very appropriate (Pinto et al., 2017 and 2015).

Due to the existing conditions, namely the subway tunnel, the slabs were executed at floors 0, -1 and -2, and the excavation between floor 3 and the foundations' depth was carried out only after the complete construction of the above underground floors, in order to better control the maximum displacements of ML tunnels (Figure 5).

The partial slabs had a variable width between 6.0m and 9.0m, a current thickness of 30cm, 2 lateral spans of 15.0m and a central span of 25.0m. The partial slabs were supported during the excavation phase in the bored piles curtain and in HEB240 profiles, spaced of 7.50m. These profiles had 2.0m of embedded length inside piles of Ø600, with a total length of 4m below the bottom of the excavation.

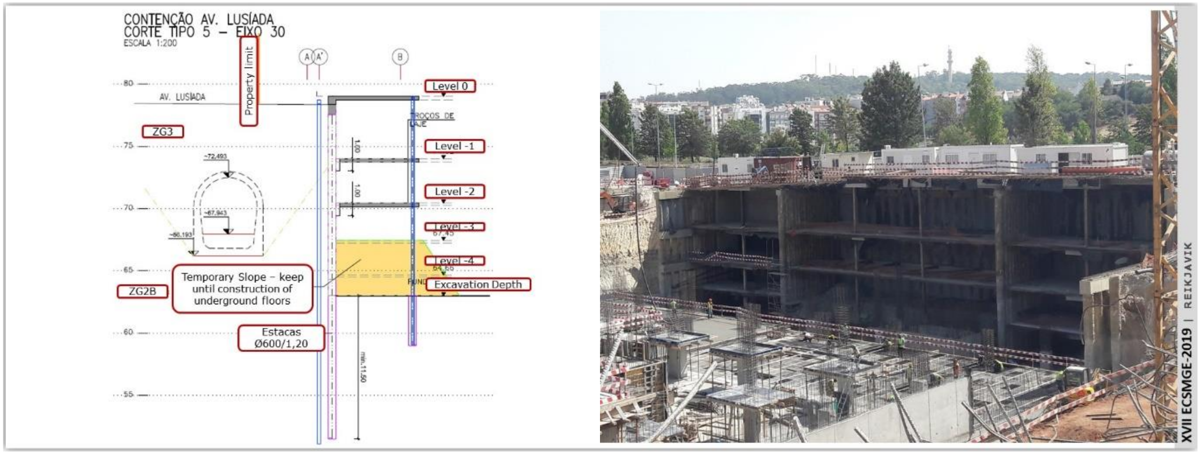

Figure 5. Section Cut and Construction Works

4 DESIGN METHODS

4.1 North elevation – Adjacent to Av Condes de Carnide

The design of the bored piles curtain was carried out using a nonlinear finite element model, in a flat state of deformation, using the software Plaxis 2D. The structural elements were modelled with linear elastic elements of the frame type, the ground anchors and their grout bodies with anchor type elements and geogrid type elements, respectively. The soil layers were modelled with non-linear finite elements of 15 nodes, using a constitutive law of Hardening Soil type and obeying the Mohr Coulomb rupture criteria.

4.2 East elevation – Adjacent to Rua Aurélio Quintanilha

For the design of the temporary Berlin-type king post wall executed along Rua Aurélio Quintanilha, the same software was used, as well as, the same type of simplified models. However, for this solution it was necessary to ensure the analyses of the safety against overall stability of the slopes between the base of the temporary retaining wall and the bottom of the excavation.

4.3 South elevation – Adjacent to Av. Lusíada and Metropolitan tunnels

Considering the complexity of the solution of the present elevation, namely the interference with ML tunnels and the difficulty of bi-dimensionally modelling a predominantly three-dimensional effect, a Plaxis 3D model was performed (Figure 6). Despite the 3D model did not ensure adequate results for the design of all the structural elements, due to high computational requirements (difficult to be compatible with the project development period), it allowed to obtain important information for the calibration of the 2D models and, in this way, to guarantee good estimations of stresses and realistic deformations, which were verified through an adequate system of monitoring.

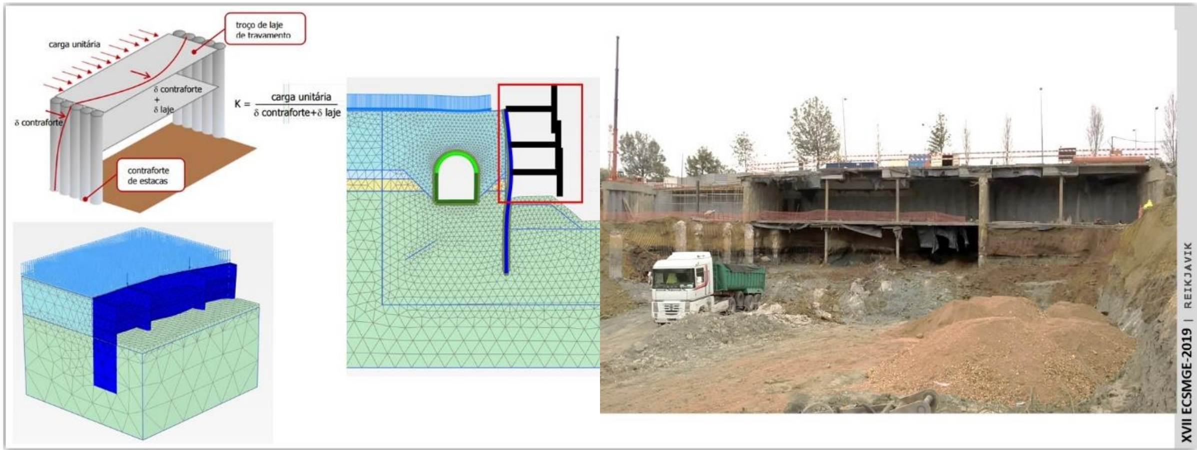

Figure 6. Models outputs and Construction Works

5 MONITORING

Regarding the size and complexity of the work described, it was necessary to implement a demanding monitoring system for the retaining walls and ML tunnels, which included the installation of topographic targets, inclinometers, piezometers, load cells and levelling marks (Figure 7). Based on the weekly readings of all the devices listed above, including the targets and marks installed on the rails and ML tunnels, it was possible to validate the design assumptions and, when and where necessary, to adapt the constructive phases to minimize excessive deformations.

To understand the significant load increase in the anchors shown in Figure 7, it should be noted that the same was already foreseen at the design stage and results from the increase in the level of the terrain located at the top of the piles, several meter above the capping beam.

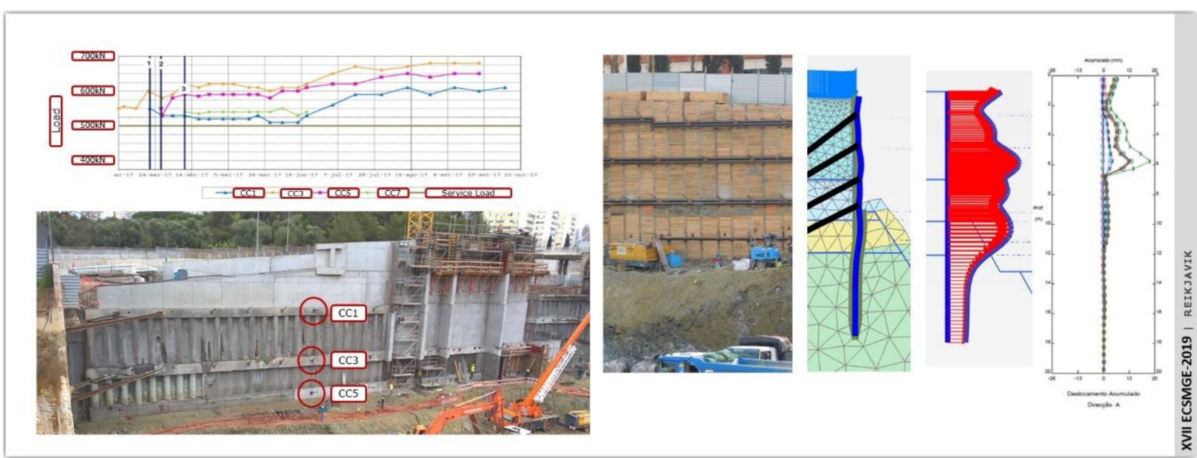

Figure 7. Monitoring results and Construction Works

6 FINAL REMARKS

Throughout the present article it was tried to demonstrate the importance of adopting different and adjusted solutions to the constraints of each zone of a complex worksite, in order to meet the client's expectations. The choice of proposed solutions was based on the main constraints in the worksite described, in particular the geological and geotechnical conditions, as well as the neighbourhood conditions. The main geotechnical solutions used consist of bored piles curtains, supported by ground anchors and partial slab and temporary Berlin king post wall, in order to maximize the suitability of the solutions to the described constraints.

It should be noted that, at the present moment, the entire excavation has already been carried out and all the underground floors have already been executed, with real measured deformations generally lower than those estimated at the design stage. The exception to this situation occurred in only on four monitoring sections in one of the three ML tunnels, in which the alert criteria were slightly exceeded and, consequently, some construction procedures and stages were adjusted in a timely manner. Namely, the excavation of the last berm was delayed to the end of the works, after all the underground slabs were executed.

7 ACKNOWLEDGEMENTS

The authors acknowledge to the Owner of the Work presented, the authorization for the writing and presentation of this article, as well as the excellent collaboration with all the actors of the work, inspection, other designers and contractors.

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