Solutions for Excavation, Earth Retaining Structures and Columns Underpinning

Case Study – Av. Infante Santo – Building B – IS76

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1. Introduction

The construction market was one of the most affected by the various global financial crises that caused most markets to stop, but this sector is slowly starting to rise as the Portuguese economy grows.
As described above, most of the works currently underway are mostly made up of rehabilitation works, making space profitable, and not for large-scale public works as it has been in the past.
Taking this into account, the demand for real estate has grown exponentially mainly by the tourism sector in the biggest cities old centers.
Therefore, the solutions of excavation and earth retaining structures carried out in urban environments will have to meet this problem and this dissertation points out this subject.
This type of construction aims at a greater need for space, which is made possible by the creation of basements and buried structures, fundamental in this type of works, as can be seen in large urban centers, with Lisbon being a good example due to the increasing demand that has been verified.
In the present case study, a back analysis is carried out between the project and its execution, following the work in question, which will be described in detail.
The monitoring of the site works allowed to confirm the feasibility of the project in the production phase.
All the constructive processes as well as the observation and instrumentation plan allowed to better understand the solutions behavior.

2. Earth Retaining Structures – Flexible Earth Retaining Structures – King Post Walls

The earth retaining structures arise with the need to perform underground works and / or basements in depth, having as main function to retain the ground, structures and infrastructures located behind the excavation area.
These are essential to the profitability of the area (s) of the lot (s) taking into account the limitations of space and all the constraints arising. The execution of the most varied earth retaining structures solutions depends on selection criteria that are in agreement with the viability of each project.

The most critical factors to take into account are the construction deadlines, safety and budgets, as well as factors related to the neighborhood, water level or ground type. Table 1 depicts both technical and economic factors that influence the decision in the majority of cases [1]:

Table 1: Factors that condition the choice of an earth retaining solution.

Economic	Technical
➢ Deadlines; ➢ Budgets; ➢ Cost of equipment; ➢ Technical expertise; ➢ Labor; ➢ Materials.	➢ Surrounding area; ➢ Accessibility; ➢ Water depth; ➢ Area and space available for the execution of works; ➢ Excavation dimension; ➢ Local geological and geotechnical nature; ➢ Necessary resistance.

Taking into account the factors described above, it is necessary to carry out a follow-up of the recommended solution, taking into account the entire work area and the confirmation of all the estimates made by the project designer. The natural stress field of the executed ground changes with these actions; However, in the work in question, this only occurred from the second basement, the first basement maintained its natural properties, and the concrete was cast directly against the existing wall.

In the case study of this dissertation, the use of king post walls was the solution adopted for the peripheral earth retaining. It's a definitive solution that emerged in the 70's of the 20th century, being widely used today and presenting significant advantages over other solutions.

This technique characterized by the phased construction of reinforced concrete panels by levels, from top to bottom, in which the horizontal bracing is accomplished by the introduction of ground anchors [2]. Their vertical stability is ensured by steel micropiles fixed by steel brackets or embedded in the panel itself. They have the function of transmitting all loads coming not only from their own weight but also from the ground anchors vertical component. When the excavation final level is reached and all the panels are finished, then the micropiles are deactivated.

During the execution of the panels, this technique takes advantage of the loads redistribution between the executed ground and the adjacent berms. This relative movement, called the "arch effect", allows to reduce the stresses and displacements in the excavated zone.

3. Case Study – IS 76 – Building B

This dissertation is based on the works carried out at Avenida Infante Santo, nº 76, in Lisbon, with regard to peripheral earth retaining, reinforcement of columns and the excavation for two basement floors, plus the existing one (three levels in total) in order to build a car parking lot that will serve as support for a mixed building destined to housing and commerce adjacent to it.

The lot in question used to have commercial purposes and was in an advanced state of degradation. It is from this perspective that the opportunity arises of the real estate group REGRESSORBITAL, Lda to promote the project in order to value its investment.

This work is located at the intersection of Avenida Infante Santo and Rua de Sant'Ana à Lapa, as can be seen in Figure 1 (marked in red).

Figure 1: Location of the work IS76 (Source: Google Earth).

The case study (Building B) is characterized by a building with one upper floor and one basement, and there is another one directly adjacent (Building A) with seven raised floors, which is also being object of a rehabilitation, not having been analyzed for the present dissertation (marked in green).

In a first phase, the building was partially demolished, with the framed structure and existing peripheral walls temporarily remaining, as well as some sections of the ground floor slab.

This decision was due not only to the enormous lack of space in the yard, but also to the awareness of the structural weaknesses and previous careless execution that led to a conservative approach. The building itself has a construction area of 351 m^2 with an implantation area of 300 m^2.

Figure 2: Remaining framed structure after the first demolition works.

3.1. Main Constructive Issues

The great challenge of this work was the lack of available space inside the perimeter of the excavation. It is a soil with rocky sedimentary characteristics of high mechanical resistance, where compact limestone was predominant, which made it difficult to carry out the work, especially in the type of equipment suitable for the excavation works.

At the same time, there was a need to minimize the impact on the normal functioning of neighboring buildings and infrastructures by adopting constructive methods that would induce non-excessive vibrations and noise. All the dimensions, as well as the characteristics of the foundations of all contiguous structures, mainly the columns of the main building, were confirmed prior to the beginning of the work.

3.2. Geological and Geotechnical Conditions

According to the Geological Chart of the Municipality of Lisbon, was possible to observe that in the zone where the work is taking place, the presence of a carbonate layer of marine sedimentary facies attributed to the Upper Cretaceous (Cenomanian), represented by the Formation of Bica (C^2_{B1}).

Three mechanical boreholes were performed during the exploration campaign carried out at the site in 2017, followed by dynamic penetration tests (SPT). Samples were collected for visual and laboratory identification of the intersected ground.

The boreholes allowed the identification of the lithostratigraphic units present as well as to calculate the degree of fracturing and weathering and the RQD (Rock Quality Designation) of the rock mass.

Subsequent to the geological-geotechnical site investigation and taking into account the local geology, it was possible to identify the following geotechnical zones [3]:

Table 2: Geotechnical parameters values for each geotechnical zone (adapted from [3]).

Geothechnical Zone	Geological Era	ϒ [kN/m^3]	Φ' [º]	c' [kPa]	E' [MPa]
GZ4	Landfills	18	28	0	0
GZ3	Cretaceous	21	30	20	40
GZ2		21	36	30	70
GZ1		22	40	150	150

During the same site investigation campaign, two piezometers were installed in the drilling holes of the S1 and S3 drills, where the solid mass was found to be hydrogeologically unproductive, presenting a water table at high depth not affecting the excavation works.

3.3. Adopted Solution

For the additional excavation of the two basement floors, the solution found for its execution was the adoption of the king post walls technique. Given the existing constraints, in particular the available space, this solution has a great advantage in allowing the final wall to be excavated during the excavation and redefining, at the construction stage, temporary bracings (ground anchors, soil nailing and shoring).
Due to the great shortage of work space, the stability of the earth retaining wall was assured by means of temporary ground anchors and soil nails during the excavation works and by the structure at the definite phase (slabs).

Figure 2: Execution of the formwork of one king post wall panel (on the left). Executed temporary ground anchors (on the right).

The execution of the peripheral earth retaining structures by the king post wall method consists of the staged and alternating construction of reinforced concrete panels from top to bottom, which constructive process can be described in the following stages:

1. Execution of the vertical micropiles to ensure the support of the panels;
2. Execution of the capping beam;
3. Execution of the primary panels;
4. Execution of the temporary ground anchors in the primary panels;
5. Execution of the secondary panels;
6. Execution of the of the temporary ground anchors in the secondary panels;
7. Execution of tertiary panels and the steel corner shoring;
8. This process repeats until it reaches the final excavation depth;
9. Execution of the super-structure and the deactivation of the temporary bracing elements.

Before this work took place, demolition operations had already been done on non-structural divisions of building B and the removal or deviations of all the services affected by the intervention were performed. Hereupon, the micropiles were executed, functioned as indirect foundation elements, both for the capping beam (which ensured the structural integrity and the transmission of vertical loads throughout the first level panels). Micropiles with N80 steel (API 5A) tubes were placed inside the axis of the future retaining wall. It should be noted that the distance between these vertical elements was conditioned so that they were located at the ends of the primary panels, with spacings between 1.7m and 1.9m in the longest lengths.

Taking into account that it is a solution with good resistant characteristics to axial loads, the steel elements in "H" or "I" would resist less to bending in weak axis.

It should be noted that the stability of the hole through this drilling method was ensured by the high coesion of the soil, without the need for a coating tube. The sealing injection of the micropiles was performed using the IRS system.

Figure 3: Drilling with roto-percussion with rods and bit.

The various steel sections were placed and, in some cases, a steel bar could be inserted inside the micropile in order to increase the micropile stiffness, as well as the joints resistance.

In this retaining structure no steel bar was inserted for technical and economic reasons; However, for this case in particular, the micropiles with cross sections ∅101,6x10mm and ∅139,7x12mm were applied [4].

The primary or sealing injection (low pressure), assisted by a hose, was progressively introduced from bottom to top using cement grout filling between the hole diameter and the micropile.

After the hardening of the primary injection, injection of the sealing bulb was performed by the IRS injection technique (repetitive and selective injection) leading to a minimum sealing length between 2m and 3m for the four elevations, with the exception of the micropiles used in the column underpinning.

After the micropiles were executed, an underpinning beam was constructed in order to support the vertical elements and the panels constituting the peripheral earth retaining. The beam was coffered and cast against the existing wall.

Figure 4: Underpinned column in this case study.

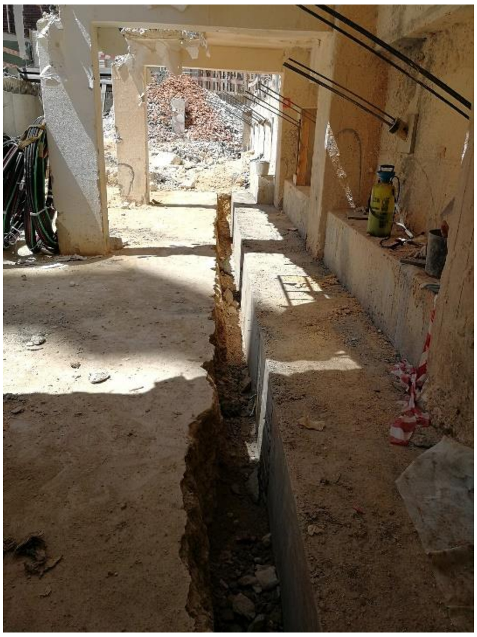

Figure 5: Executed underpinning beam.

The next process was the assembling of the reinforcement of the first level panels, duly prepared in the yard.

Then the works proceeded with the assembly of the reinforcement of both secondary and terciary panels, as well as those of the lower level.

After the panels were assembled, the formwork was made up of galvanized steel frames, which gave this system a high capacity to withstand the impulses of the concrete in the fresh state. The concrete casting was carried out from a trémie bucket, transported by the crane, and a plastic sleeve that allowed the correct placement of the fresh concrete inside the formwork, minimizing the segregation.

The secondary panels followed the same constructive process described above with respect to the primary panels. Tertiary panels were executed simultaneously with the secondary ones with the approval not only of the designer but also the supervisory staff, and they were complemented with steel struts with HEB profiles, as they are a more economical solution comparing with the ground anchors in terms of execution and specialized labor, and with the possibility of being reused in other jobs.

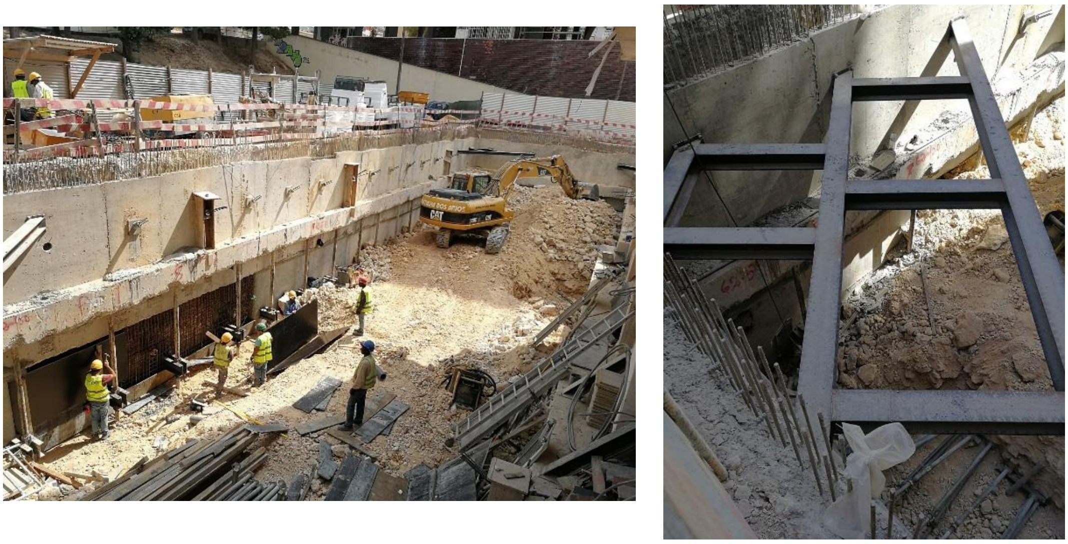

Figure 6: Execution of the formwork for the concreting and the HEB profiles used to shore the retaining wall corners.

3.4. Temporary Ground Anchors

Considering that the work in question was in a very busy urban area and the available space was scarce, this would be the most recommended solution taking into account the geological conditions, with the exception of shoring in the corners of the retaining wall.

The anchors were executed as soon as the concrete presented resistance. These bracing elements are spaced mostly at 1.85m, drilled through the negative PVC left on the panel of the retaining wall and, its process can be summarized in the following order:

- Drilling;
- Strands insertion;
- Cement grout filling (primary injection);
- Injection sealing;
- Strands Tensioning;
- Superstructure execution;
- Deactivation.

Depending on the elevation, the ground anchors total length varied between 12m to 14m with inclinations between 25º to 33º. It decreases with the depth of excavation, since they are closer to the bedrock, which reduces their cost and increases the effectiveness of the retaining wall.

The steel strands were constituted by 1860/1680 – Grande 270 k (ASTM A416) steel and they were wrapped in PVC sleeves along their free length, thus protecting them from corrosion and ensuring that they do not adhere to the cement grout.

At the sealing length they are totally free of any protection, in order to promote the mobilization of friction between the cables and the cement grout, thus giving rise to the "anchor" effect.

Spacers or centralizers were also used, spaced 1.5 meters in the sealing bulb and about 4 m in free length, in order to evenly distribute the strands in the cable contour and the load the strands cover.

The strands insertion was followed by the injection, which consists of two stages: the primary injection and the second.

The primary is intended to fill the voids between the anchorage and the borehole and provides some protection against corrosion, and the secondary injection or reinjection is responsible for creating the sealing bulb that ensures the pre-stress load transmission to the ground.

This process was performed through the IR injection system (repetitive injection), derived from the IRS system and the IGU system.

About one week after the injection procedures had elapsed, the prestress was applied using a hydraulic jack. It should be noted that the application of the tensioning must only be carried out with the guarantee that the cement grout is hard enough so as not to compromise the correct performance of the anchorage, and it is therefore fundamental to respect this curing period.

Some of these ground anchors were monitored with load cells in order to acess their load, with frequent readings. The anchors in this case study were progressively deactivated as the slabs were executed above the capping beam.

3.5. Temporary Soil Nails

In the present case, the use of temporary passive soil nails injected with cement grout was used in A500NRSD steel rods with a diameter of 32mm. The soil nails were spaced between 2.5m to 3.2m and with lengths ranging from 6m to 8m and the constructive process is described below:

- Located excavation to the desired depth;
- Opening of the hole with a slope of 15º;
- Manual nail insertion inside the borehole;
- Injection of cement grout under low pressure;
- Clamp head fixing. Threaded surface plate, semi-spherical washer and hex nut;
- Excavation of the next level and installation of new row of soil nails by repetition of this method.

In comparison to the ground anchors, this technique has the great advantage that its application is simpler, more economical and with a lower level of vibration emission due to the use of light equipment. However, the use of this technique as a support system is limited in large urban centers, because it needs a deformation to load the nail.

3.6. Instrumentation and Observation Plan

This plan monitored the behavior of the earth retaining structure as well as all the excavation works and the follow-up of constructions and infrastructures contiguous to the execution pit, with appropriate instrumentation, defining allowable vibrations and displacements, as well as reinforcement measures in critical zones, if justifiable, such as:

- Horizontal and vertical displacements at the capping beam and the panels of the earth retaining structure;
- Horizontal and vertical displacements of the neighboring constructions;
- Horizontal displacements within the reinforced concrete column underpinning;
- Measurement of the load installed on the ground anchors.

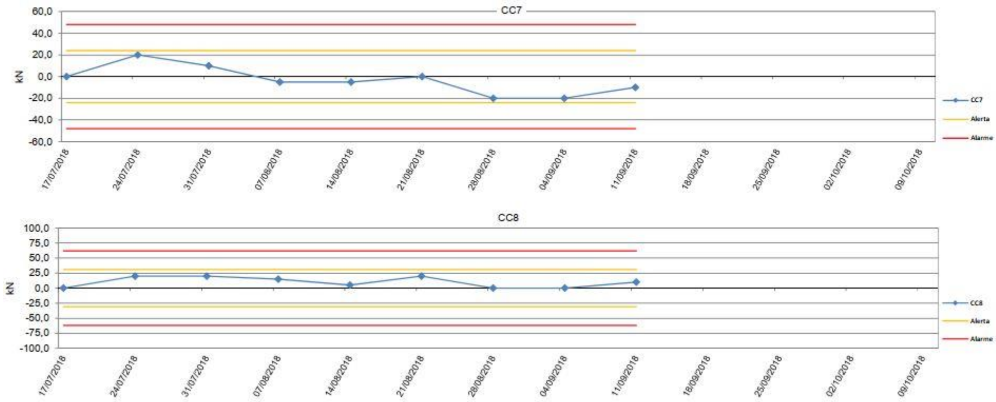

Figure 7: Readings of the load of two executed ground anchors.

4. Main Conclusions

The main purpose of this dissertation was the follow-up of the development of a work regarding the solutions of excavation, earth retaining and columns underpinning of a building located at Av. Infante Santo in Lisbon which made possible to know the various work stages. It should be printed out the conciliation between the solutions proposed in the project and those carried out on site. It was also possible to understand all the constraints, difficulties and solutions found by the contractor, with the objective to meeting the agreed deadlines. All the work involved in this endeavor would not have been possible without previous preparation, which minimized all risks and accomplished a safe and successful work.

References

[1] Slides of the discipline of Slopes and Support Structures, Instituto Superior Técnico, Lisbon, 2010 (in portuguese).

[2] Brito, J. de, King Post Walls, Document of support for the Building Construction discipline, Advanced Master Degree in Construction and Rehabilitation, Instituto Superior Técnico, Lisbon, March 2001 (in portuguese).

[3] Pinto, A., Pereira, A., Descriptive Report of the Excavation and Earth Retaining Structures Project of a housing and commercial building in Avenida Infante Santo nº 76, Lisbon, 2017 (in portuguese).

[4] Pinto, A., Pereira, A., Drawings of the Execution Project for the Excavation and Earth Retaining Structures Project of a housing and commercial Building in Av. Infante Santo nº 76, JETsj Geotecnia, Lda, Lisbon, January 2017 (in portuguese).