

Earth retaining solutions and façades underpinning, for the refurbishment of a historic building, in Lisbon

Inês Braz, Alexandre Pinto
JETsj Geotecnia Lda, Lisboa, Portugal, ibraz@jetsj.com

David Henriques, Rogério Santos, Eduardo Freitas
PPE – Planeamento e Projetos de Engenharia Lda, Lisboa, Portugal

ABSTRACT: This article presents the earth retaining and underpinning solutions implemented during the refurbishment of the 260-year-old Pedrosas Palace in Lisbon. To facilitate the construction of new basements beneath the original masonry building foundations, specialized solutions were developed to ensure compatibility with the existing structure. The project faced significant challenges due to the highly complex geological and geotechnical conditions, combined with the site's location in the historic city center at the base of a slope. The earth retaining solution involves a reinforced concrete wall constructed using the King Post Wall technique, temporarily supported by ground anchors and steel struts. Underpinning and the temporary foundation of the King Post Wall were achieved with tubular micropiles of different sections. This article outlines the primary design considerations, along with key monitoring and survey results, and explains the principal challenges faced during the site works.

KEYWORDS: earth retaining wall, underpinning, king post wall.

1 INTRODUCTION

As part of the rehabilitation works at Palácio das Pedrosas (CTT), located on Rua de São José in Lisbon, a geotechnical project was developed involving deep excavation and peripheral earth retention systems, including the underpinning of the existing façades. Figure 1 presents an aerial view of the intervention area, allowing the identification of the main site constraints and boundaries. The referenced area has boundaries with existing buildings that needs to be preserved.



Figure 1. Site location.

Figure 2 shows the areas to be excavated beneath the existing structure, identified in orange.



Figure 2. Areas to be excavated under the existing structure – orange areas

As an old building, the solution to be adopted was conditioned by various constraints, making this project quite challenging.

The most significant ones are described in the following sections.

2 MAIN CONSTRAINTS

2.1 Constraints related to the building's boundaries

In this intervention, 1 to 3 underground floors will be executed, being adjacent to neighbouring buildings and roads. The proposed solutions must, therefore, be compatible with preserving the integrity of all structures and infrastructure located outside the perimeter of the construction site, ensuring their functionality conditions. Figure 3 shows a 3D image of the construction site, taken from Google Earth.

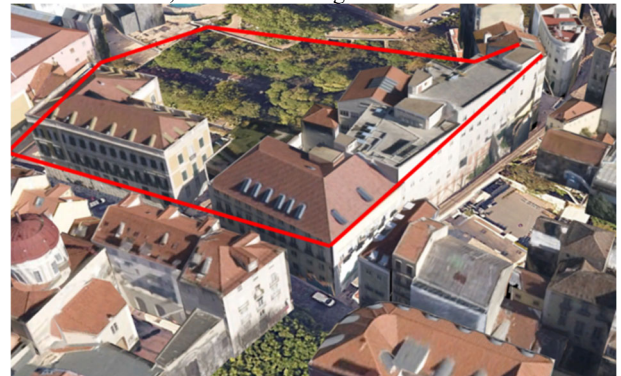


Figure 3. 3D view of neighbouring buildings and roads – Google earth image.

2.2 Constraints related to the need to preserve façades

Given the necessity to maintain the integrity of the majority of the main building façades, it is considered essential that the intervention be carried out in a way that minimizes its impact on their stability and appearance. Equally important was the adoption of construction solutions compatible with the use of equipment suitable for the available spaces and access, allowing the execution of the works while limiting the occurrence of vibrations and noise. In Figure 4 is visible the façades to be preserved, identified in grey, and the additional basements to be executed, identified in yellow.

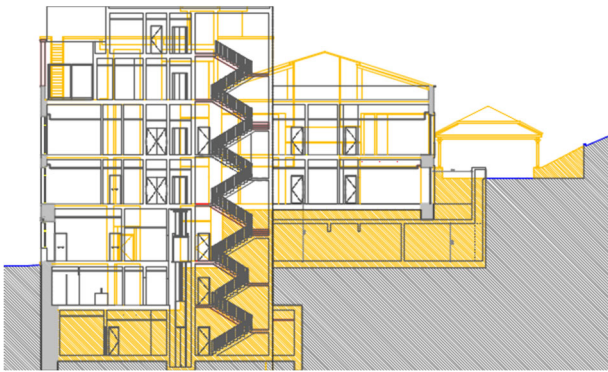


Figure 4. Additional basements to be built, identified in yellow.

2.3 Geological and geotechnical constraints

According to the data collected during the geotechnical characterization campaign and considering the geology described in the geological map, the following lithological strata were identified on-site:

Landfills: Detected in the superficial zone of all boreholes, with thickness ranging from approximately 0.20 to 1.50m. These are heterogeneous fills containing masonry fragments, primarily silty-clayey in composition and brownish in color – ZG3.

Prazeres Clays and Limestones: The Miocene levels are represented by alternating silty and clayey levels. The silty levels sometimes have transitions with fossil fragments and marly materials, with greenish to greyish tones. The more clayey levels often appear slightly micaceous and with darker tones - ZG1 and ZG2.

Figure 5 presents one of the geological profiles.

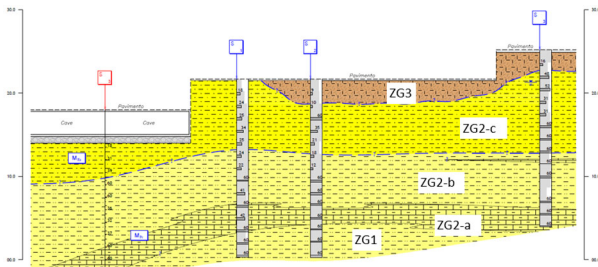


Figure 5. Geological profile.

Table 1. Geological and geotechnical parameters.

Geological formation/ Lithology	Geotechnical Zones	Unit weight	Internal friction angle	Cohesion (effective)	Drained deformation modulus, E'
Fill deposits		kN/m ³	degrees (°)	kPa	MPa
Clayey-silty sand and silty-sandy clay, with occasional small to medium gravel and scattered ceramic fragments. Silty sand and silty-sandy clay, with occasional small to medium gravel and scattered ceramic fragments.	ZG3	17	24	0	4
Miocene					
Silty sandy clay, with occasional dispersed small limestone gravel and shell fragments, hard to stiff.	ZG2-c	19	26	0-2	5
	ZG2-b	19	28	5	10
	ZG2-a	20	30	15	20
Limestone with shell fragments and calcareous-marl intercalations, stiff.	ZG1	21	32	30	40-50

Table 1 contains the identification of geotechnical zones and the geological parameters.

3 ADOPTED SOLUTIONS

For the construction of the additional basement levels, while ensuring the preservation of the existing façades, three solutions were required:

- Excavation and peripheral earth retaining: to be carried out using the king post wall technology.
- Underpinning solution: consisting of reinforced concrete beams anchored to the existing façades and supported on micropiles.
- Façade containing structure: The solution of the façade containing structure is beyond the scope of this article, although it was made with steel structure.

The proposed solutions were developed in coordination with the three types of interventions previously described.

Taking into account all the constraints previously mentioned, it was considered that the best solution would be to carry out the excavation using the king post wall methodology, which involves the phased execution, from top to bottom, of reinforced concrete panels supported by vertical micropiles. As in other projects executed with the same design team, a similar approach was successfully applied in Rosa Araújo Street, Lisbon (Pinto, A. and Pereira A., 2017).

Figure 6 shows the methodology of the execution for the primary panels for the first level of excavation.

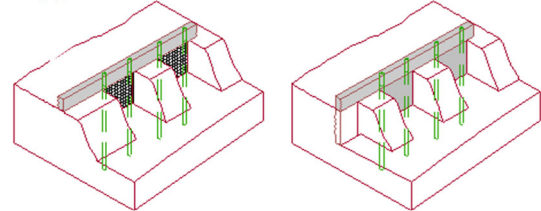


Figure 6. King post wall methodology- first level- primary panels.

Figure 7 shows the underpinning and king post wall solution. It is also visible the façade containing structure.

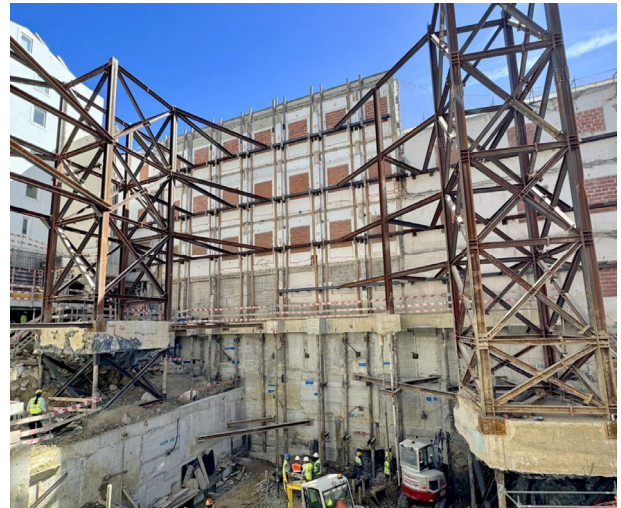


Figure 7. Execution of king post wall.

The micropiles are materialized by tubular profiles Ø88.9x9.0mm, Ø114.3x9.0mm and 177.8x12.5mm with external joints, made of high-strength steel (fsyd > 560MPa), this micropiles will also support the underpinning beams of the façade. These elements should be executed with the minimum possible distance from the façade, solidified with the king post wall through steel brackets.

Figure 8 shows one façade fully underpinned. In Figure 9 we can see a real image of the construction site and in Figure 10 we can see the 3D model from the same zone.

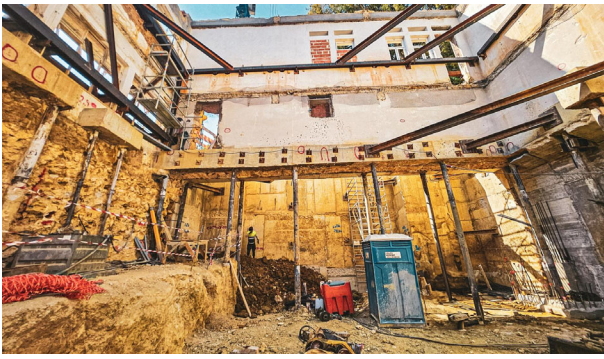


Figure 8. Excavation and underpinning.



Figure 9. Underpinning and earth retaining solution – Real image.

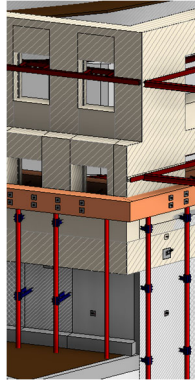


Figure 10. Underpinning and earth retaining solution – Project image.

The total micropile length varies according to elevation geometry. Minimum sealing lengths were calculated using the Bustamante method (Bustamante, M. and Doix, B. (1985)) considering the IRS system (repetitive and selective injection) for the bulbs that will be sealed in competent soils with strength and deformability characteristics compatible with NSPT greater than 35 blows and geologically stable concerning the excavation geometry.

This solution has the advantage of allowing the execution of the definitive wall during excavation. The number of temporary bracings (steel props and anchors) can be redefined during the construction phase based on the actual characteristics of the excavated soils and the results of the Instrumentation and Observation Plan.

In cases where underpinning the façade is necessary, a beam with the capacity to transmit loads from the façades is required to transmit the loads to the new foundations, materialized by the micropiles.

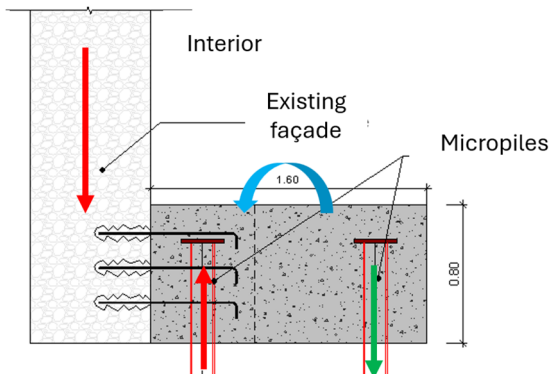


Figure 11. Asymmetric Underpinning solution.

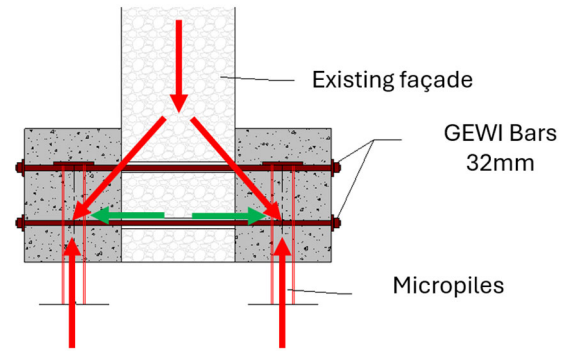


Figure 12. Symmetric Underpinning solution.

In this situation we have 2 cases: asymmetric and symmetric underpinning, represented in Figure 11 and Figure 12 respectively. In Figure 13 is visible the real case of the asymmetric underpinning and in Figure 14 the symmetrical one.



Figure 13. Asymmetric Underpinning solution - real image.



Figure 14. Symmetric Underpinning solution - real image.

In the permanent phase, the structure of the slabs and foundation elements will be responsible for the stability of the earth retaining wall, and the temporary props will be removed.

The 3D model is presented in Figure 15, where the existing façade elements to be preserved are represented in light blue, the underpinning beam in orange, and the earth retaining walls for excavation works are shown in grey.

After the construction of the permanent structure, the micropiles are cut off at the level of the final foundations and incorporated into the definitive footings.

Figure 16 shows an image of the deeper excavation site.

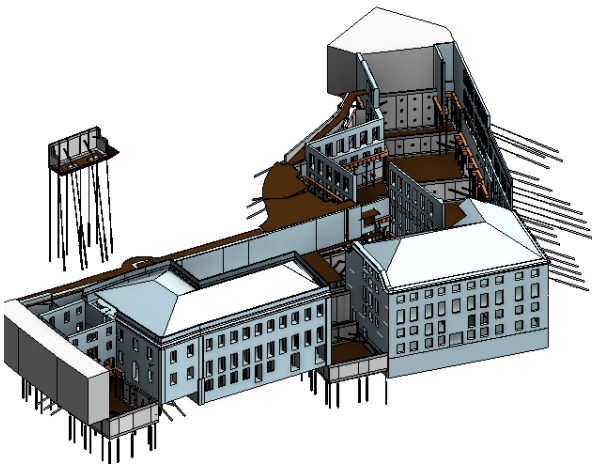


Figure 15. 3D view of solutions for excavation and peripheral earth retaining.

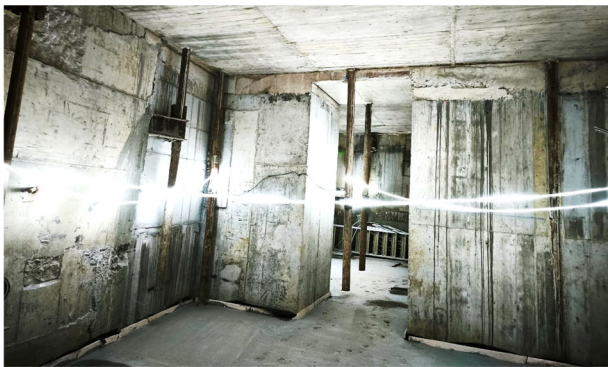


Figure 16. Final phase, before finishings.

4 DESIGN

The finite element program Plaxis 2D was used for the design of the peripheral earth retaining walls to be executed using the king post wall technology.

Micropiles and walls were modelled as "Plate" elements, sealing bulbs were modelled as "Embedded beam row" elements, and pre-stressing tendons were modelled as "Node-to-node-anchor" elements. The struts were modeled as "Fixed end Anchors".

The forces were estimated considering the construction process, especially the excavation and construction phases of the peripheral earth retaining wall. Soil elements were modelled considering the previously presented geomechanical properties and following the "Hardening Soil Model" model.

One of the adopted models is presented in Figure 17.

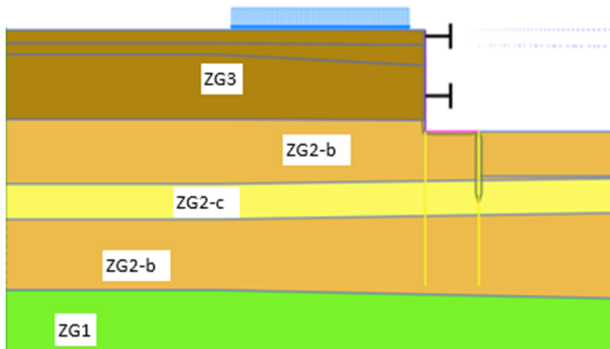


Figure 17. Plaxis 2D model.

After the execution of the interior structure of the building, in the permanent phase, the bracing of the earth retaining is guaranteed by the structure of the underground floors. For

locations where the micropile is located outside the earth retaining wall, it was necessary to verify safety against buckling. In areas where the micropile is used simultaneously to support the peripheral earth retaining and for façade underpinning, the additional load from it was considered.

The maximum horizontal estimated deformation for this solution was 1.15 cm. This value, obtained through numerical modelling, falls within acceptable limits for this type of geotechnical structure and confirms the effectiveness of the adopted design in controlling ground movements during excavation and construction phases.

5 MONITORING AND SURVEY PLAN

The proposed Monitoring and Survey Plan aims to ensure the safe and economical execution of demolition, excavation, and construction of earth retaining structures. It also involves the analysis of the behaviour of preserved façades and neighbouring structures and infrastructure during this construction phase. Thus, the proposed plan should allow the measurement, during excavation and construction of earth retaining structures and the underground floor, of the following parameters:

- Horizontal and vertical displacements of earth retaining structures and of neighbouring constructions.
- Measurement of tension/load at ground anchorages.
- Horizontal displacements in the earth retaining wall.

The parameters described above will be measured using the following:

- Topographic targets for measuring parameters mentioned in a).
- Load cells in anchorages for measuring the parameter mentioned in b).
- Inclinometers for measuring the parameter mentioned in c).

In Figure 19 it is visible the localization of the installed inclinometers (Inc) and load cells (CC).



Figure 18. Inclinometers (Inc) and load cells locations (CC).

Figure 20 shows that all walls have topographic targets, identified by red circles.

Based on the instrumentation results, several solutions were adjusted during construction. As an example, Inclinometer 3 began to show signs of deformation upon reaching the final excavation level, as we can see in Figure 20.

As a result, it was recommended that the final foundations be executed immediately (Figure 22), since the final excavation level had already been reached. From there, the construction of

the permanent structure could proceed upward to ground floor level.



Figure 19. Topographic targets locations.

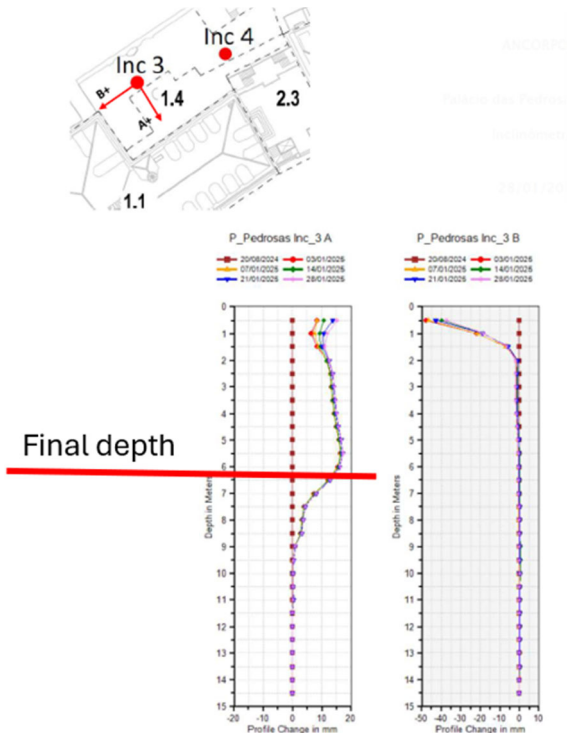


Figure 20. Inclinometer 3 (Inc3) results.

Two additional boreholes were executed in the context of a separate issue; however, the data collected proved relevant in understanding the cause of the observed deformations, since the information obtained from these investigations revealed a previously undetected soil layer. This layer exhibited significantly different geological and geotechnical characteristics, particularly low mechanical strength and high deformability. It became evident that this layer was the main contributor to the deformations observed during excavation



Figure 21. Execution of the definitive foundations as proposed for the stabilization of the deformations.

6 CONSTRUCTION ISSUES AND ADAPTATIONS

During the initial phases of construction, several unforeseen challenges emerged, requiring adaptations to the original design and execution strategy.

It is common in geotechnical projects to require adjustment during the construction phase. While thorough planning is essential, some conditions can only be fully understood once excavation begins. These on-site findings often lead to modifications that could not have been foreseen during the initial design stage.

In this chapter, a few examples are presented to illustrate how the construction process may deviate from the original plan. These cases reflect the broader reality of geotechnical engineering, where adaptability is often necessary as new information emerges during excavation.

6.1 Case 1

When excavation began along the perimeter of an existing wall, a local ground collapse occurred (Figure 22), revealing that the wall was partially unfooted as we can see at Figure 24 and 25. As a result, it was necessary to design an underpinning solution to ensure the wall's stability.



Figure 22. Floor collapse and unfooted Wall.

The proposed solution consisted of constructing a reinforced concrete wall anchored to the existing wall and supported by micropiles. The void identified beneath the existing wall was filled with concrete to ensure proper load transfer and structural stability. The 3D model of this solution is presented in Figure 26, identified in pink.

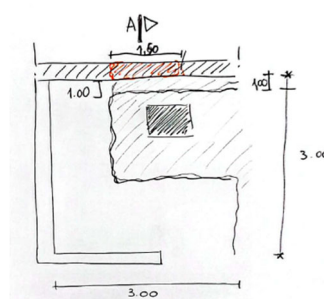


Figure 23. Received drawing showing the actual situation found on site - Plan.

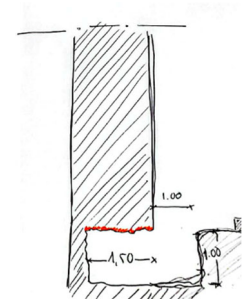


Figure 24. Section A - actual situation found on site- Cross section.

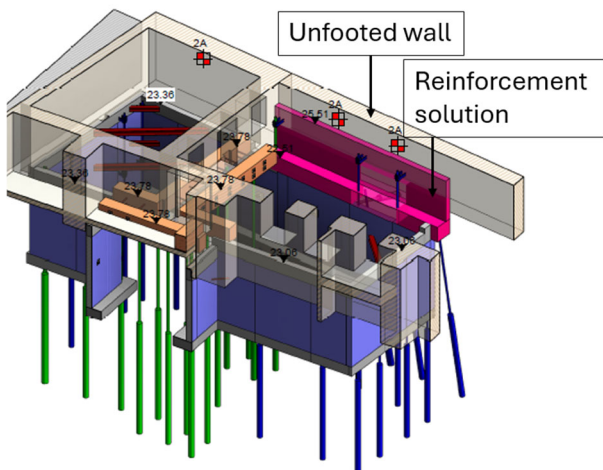


Figure 25. Proposed solution identified with pink color.

6.2 Case 2

Initially, the design included the use of ground anchors in a specific area. However, once drilling began, it was found that competent soil was only encountered at a depth of approximately 35 meters. This unexpected condition required a complete revision of the solution for this local.



Figure 26. First trying for the execution of the ground anchors.

The final approach involved the execution of the definitive structure applying the top-down method. Both the construction sequence and the structural solution had to be adjusted to allow the top-down execution method.

The initial bracing solution consisted of three levels of steel structure, as shown at Figure 27. However, due to changes in the construction sequence and the need for faster execution, an alternative solution was designed, consisting of only two levels of bracing, executed in reinforced concrete.

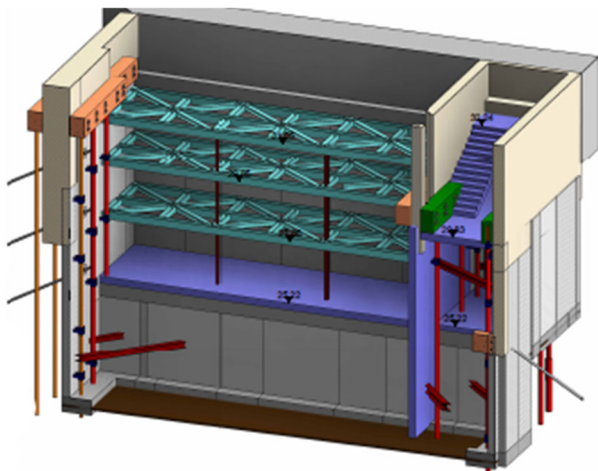


Figure 27. Initial solution.

The second and final solution is presented in Figure 28.

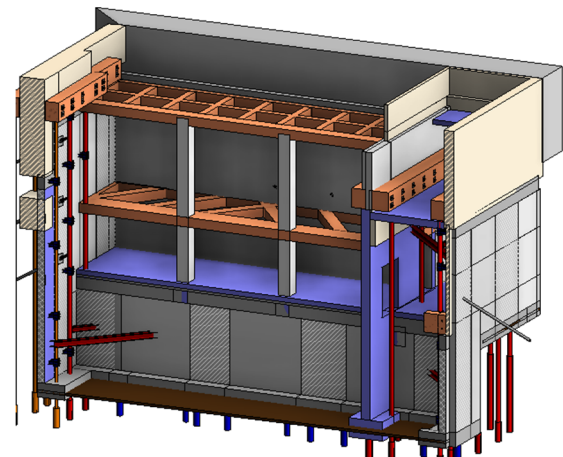


Figure 28. 3D model - Final bracing solution: two levels in reinforced concrete.

7 FINAL REMARKS

The rehabilitation project at Palácio das Pedrosas (CTT) presented a complex set of geotechnical, structural, and logistical challenges, particularly due to the need to preserve existing structures while executing deep excavations in a highly constrained urban environment. The adopted solutions, namely the king post wall system and micropile-supported underpinning beams, were carefully developed to ensure safety, compatibility with existing conditions, and construction feasibility.

Throughout the construction process, it became evident that adaptability was essential. Unforeseen ground conditions and structural inconsistencies, such as the discovery of a previously undetected weak soil layer and partially unfooted walls, required real-time analysis and redesign. These challenges were addressed through additional site investigations, structural adjustments, and close coordination between design and site execution teams.

The integration of the monitoring and survey plan was fundamental in identifying emerging issues at early stages, allowing corrective measures to be implemented effectively and in a timely manner. Instrumentation results not only validated the design assumptions but also guided key decisions during the excavation works.

Overall, this case demonstrated the importance of flexible geotechnical design, continuous monitoring, and collaborative on-site problem-solving. The success of the intervention relied on the ability to adapt standard methodologies to unique on-site conditions, which is a hallmark of complex geotechnical engineering projects in historic urban areas.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

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