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Deep Excavation Solution at Hill Base Using Tie Rods as Passive Ground Anchors

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ABSTRACT: The aim of this article is to describe a retaining wall deep excavation solution with a maximum height of 20 m, to allow the construction of several underground floors of a new building located at a hill base in Leiria, Portugal. Typically, retaining wall solutions in urban areas employ temporary bracing systems that are later replaced by underground building structure. In the present scenario, the retaining wall located at a hill base, required permanent support for earth pressures on the eastern side at the first two levels. Since the building had only three underground levels, the general horizontal bracing was achieved using temporary ground anchors, The horizontal bracing solution at the first two levels on the eastern side uses 50 mm diameter tie rods as passive ground anchors, with lengths up to 28 m, with double corrosion protection provided by enclosing the tie rod in a corrugated sheath and subsequently injecting cement grout inside. The 6 m sealing length, for both tie rods and pre-stressed ground anchors, was accomplished using a multi-valve system and an IRS injection procedure, respectively. The implemented solutions will be presented and the retaining wall behavior during the excavations works analyzed within the scope of the Monitoring and Survey Plan, which proved crucial for geotechnical risk management.

KEYWORDS: Deep excavation, retaining wall, bored piles, passive tie rods.

1 INTRODUCTION

This article aims to describe the excavation and earth retaining solutions implemented for the construction of the underground floors of a hospital building. The building is located at the base of a hill, requiring the excavation of five underground floors on the eastern side, adjacent to the hill and only two underground floors on the opposite western side (see Figure 1).

Figure 1. Building graphical representation.

In general, excavation and retaining solutions using pre-stressed ground anchors are temporary, with the horizontal equilibrium of soil pressures ensured by the structure slabs from the construction final stage. In this case, due to the presence of a hill at the rear of the building, East size, the retaining structure built during the construction phase must permanently withstand soil pressures equivalent to two floors.

To address this, and considering that permanent pre-stressed ground anchors require more demanding monitoring and maintenance, the first two bracing levels were designed with steel bar ground anchors that mobilize load passively and offer greater predictability. The three lower bracing levels were executed using temporary pre-stressed ground anchors, aligned with the underground slabs, which will provide the permanent horizontal support at the final construction stage.

During the excavation works, a Monitoring and Survey Plan was implemented to assess on time the structure behavior. As the excavation approached its final depth, anomalies were observed in the wedge plates of the first two levels of active temporary ground anchors, leading to increased deformations in the retaining structure and higher loads on the remaining ground anchors. Given that the alert thresholds defined in the Monitoring and Survey Plan were exceeded, mitigation measures were adopted to control the retaining wall deformation and modify the construction sequence to safely complete the excavation works.

2 GEOLOGICAL AND GEOTECHNICAL SCENARIO

Based on the Geological Map of Portugal at a 1:50,000 scale, the study area presents dolomitic limestones and marls of the Dagorda Formation (J1ab), dated from Jurassic period. To the West of the study area, near one of the branches of the Lis River, modern alluvial deposits (a) are found, which are distributed throughout the region along other streams. To the East, the geological map identifies outcrops of dolerites and related rocks (δ). Figure 2 shows the approximate location of the study area on an excerpt from the Portugal Geological Map at a 1:50,000 scale.

Figure 2. Excerpt from the Portugal Geological Map at 1:50,000 Scale.

To better understand the geological conditions at the site a site investigation campaign was conducted, including boreholes with Standard Penetration Tests (SPT) and laboratory tests.

The results of this campaign enabled the characterization of materials in terms of their geomechanical properties and developed geological-geotechnical profiles used at the project stage. The campaign identified the following soil layers, from top to bottom:

- ZG3 – Clayey, sandy, and silty-sandy fill with lithic elements ranging from small to coarse gravel, with SPT values between 13 and 47 blows and a thickness of about 2 to 3 m.
- ZG2 – Reddish clays with grayish streaks, identified as Dagorda marls, with sandier transitions, showing lower consistency near the surface (35 < SPT < 60 blows), and thickness varying between 4.5 m and 9 m.
- ZG1 – Reddish clays with grayish streaks, also Dagorda marls, with sandier transitions, showing high consistency (SPT > 60 blows).

The geological-geotechnical profile presented at Figure 3 shows that the excavation on the higher elevation side intersects all three identified geological-geotechnical units.

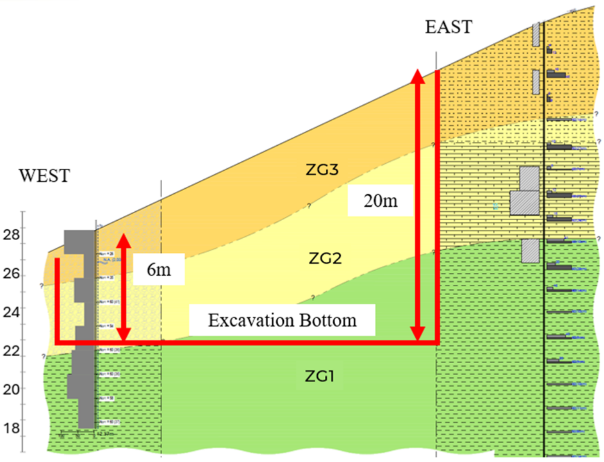

Figure 3. West – East geological and geotechnical profile, with excavation boundaries.

3 EXCAVATION AND RETAINING WALL SOLUTIONS

The excavation and retaining wall solutions included the construction of a reinforced concrete bored pile wall (600 mm diameter piles spaced 1.20 m apart) around the entire perimeter of the excavation pit. During the excavation works, the exposed soil between the piles was lined by a layer of reinforced shotcrete, into which geodrains were installed at specific points to mitigate the buildup of hydrostatic pressure behind the shotcrete, allowing water to inflow to the building's internal drainage system (Pinto et al. 2019).

The retaining structure was braced using distribution beams at the various underground floor levels and temporary pre-stressed ground anchors (six 0.60" pre-stressing strands). However, only at the first two bracing levels on the side with the greatest elevation, the support was provided by passive GEWI-type steel bar ground anchors with 50 mm diameter. Both types of ground anchors were sealed at the ZG1 layer over a 6m fixed length, implemented using a multi-valve tube and a repeatable injection process (see Figure 4 and Figure 5).

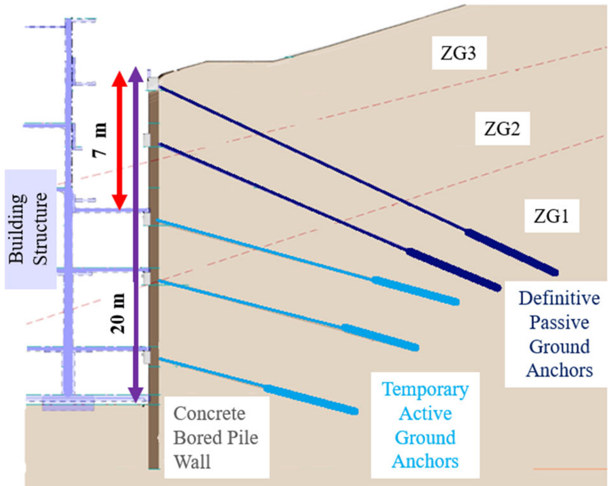

Figure 4. Cross-section in the area with the greatest elevation difference.

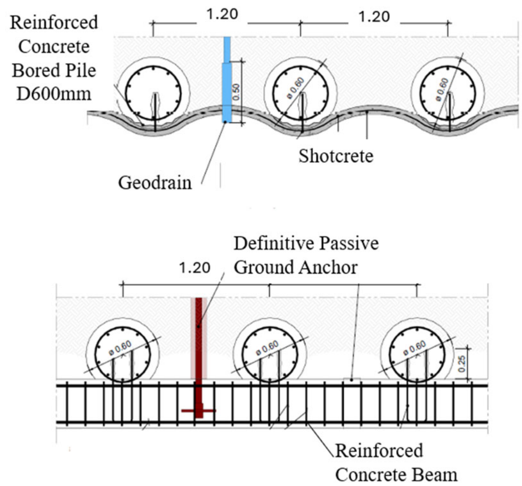

Figure 5. Cross-section of the retaining structure in the area between floors and at the distribution beam.

Certified systems with double corrosion protection were employed for the permanent passive ground anchors. Durability was ensured by installing a corrugated sheath along the anchor's entire length, allowing for pre-grouting with cement between the steel bar and the sheath before installation. A second smooth sheath was used to form the anchor free length ensuring that axial loads would only be transferred at the fixed length (see Figure 6).

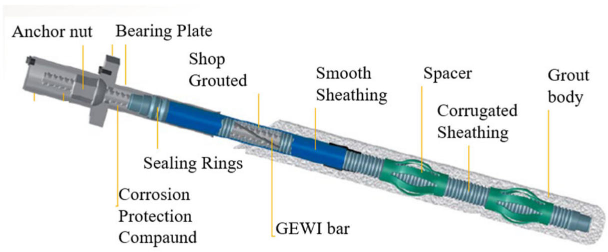

Figure 6. Certified system of permanent GEWI-type steel bar ground anchors (DYWIDAG-Systems International GmbH).

4 MONITORING AND SURVEY PLAN

The implementation of a Monitoring and Survey Plan, essential for a project of this complexity, was a fundamental tool to validate design assumptions in a timely manner and manage geotechnical risk. For this project, several monitoring devices were installed along the peripheral wall (see Figure 7), including:

- Piezometers: to measure the groundwater level.
- Inclinometers: to measure horizontal displacements at depth.
- Topographic targets: to measure planimetric and altimetric movements.
- Load cells: to measure the loads in both the pre-stressed and passive ground anchors.

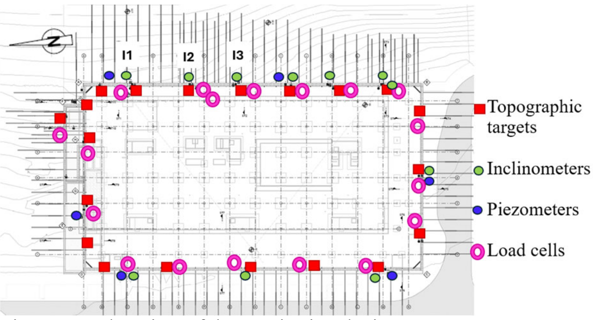

Figure 7. Plan view of the monitoring devices.

The monitoring plan defined weekly readings campaigns and established alert and alarm thresholds for each monitored parameter to assess geotechnical risk during construction.

During the excavation works, measurements gradually revealed an increase in monitored values, particularly at the East side retaining structure horizontal displacement with the greatest elevation. These deformations were expected as the upper two levels of ground anchors were passive and therefore require some deformation to mobilize (see Figure 8). However, near the final excavation stage, anomalies were detected in the wedge systems of the pre-stressed ground anchors installed at the lower levels. These anomalies were due to the use of materials with inadequate geometry, leading to load loss in several ground anchors and, consequently, increased deformation of the retaining structure. This poor performance of the temporary pre-stressed ground anchors was offset by the excellent performance of the passive permanent ground anchors.

At that point, since the recorded values had reached the alert thresholds defined in the design phase, as Figure 8 and Figure 9 presents, the associated geotechnical risk was reassessed, and reinforcement measures were implemented along with changes to the construction sequence.

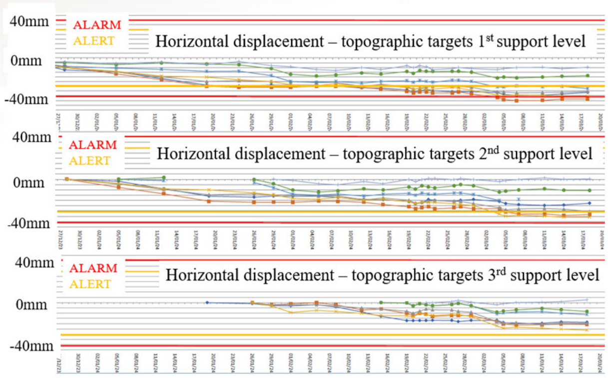

Figure 8. Horizontal movements toward the interior of the excavation measured by topographic targets.

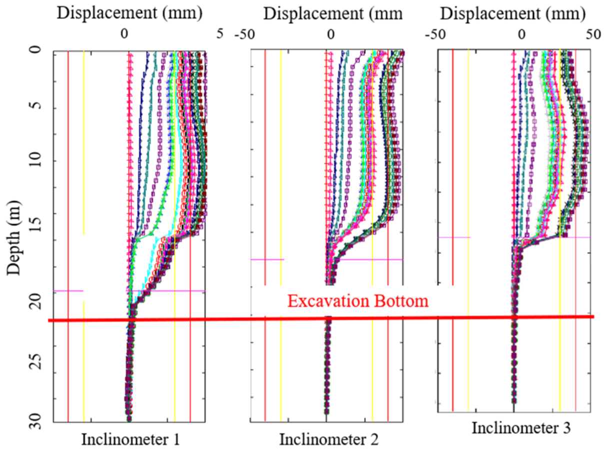

Figure 9. Horizontal displacements toward the interior of the excavation pit, measured by inclinometers.

5 REINFORCEMENT SOLUTIONS AT THE EAST SIDE

In the context described in the previous chapter, two main measures were implemented to mitigate the excessive deformation scenario observed in the East side retaining structure.

The first measure, implemented immediately, consisted of earth fill execution at the base of the retaining structure up to Floor 0 level (a fill height equivalent to two floors). This measure aimed to mobilize a higher passive pressure at the base of the retaining structure and to enable the implementation of the second geotechnical risk mitigation measure (see Figure 10).

The second measure involved modifying the construction sequence by implementing a partial top-down solution near the retaining wall. This included the construction of slab strips at the levels of the lower two floors, cast directly against the earth fill. These slabs could then transfer horizontal loads through temporary steel struts to the stairs and elevators structural boxes, which were also built in advance (see Figure 11, Figure 12 and Figure 13). This solution required the execution of micropiles, which were not initially planned, to act as temporary deep foundations for the slab strips, as well as for the stairs and elevators structural boxes, accommodating the loads resulting from their use as temporary support for the retaining structure.

Figure 10. View of the final stage of earth fill execution, implemented as the first reinforcement measure at East side wall.

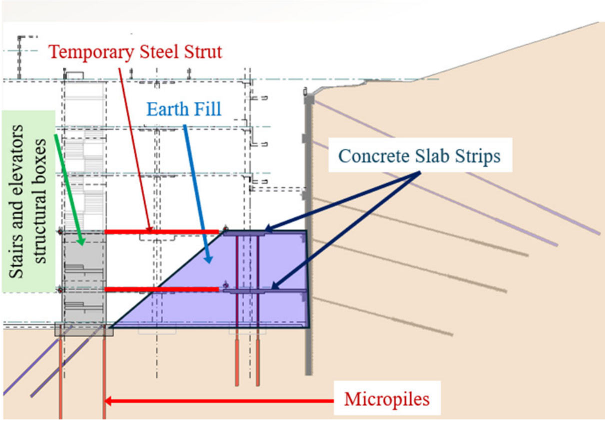

Figure 11. Cross section of the implemented reinforcement measures at the East side wall.

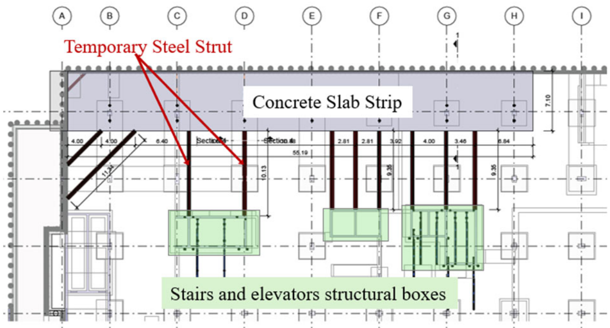

Figure 12. Plan of the implemented reinforcement measures.

Figure 13. Overall view of the implemented reinforcement measures.

6 FINAL REMARKS

This article aims to present the excavation and peripheral retaining solutions required for the excavation of two to five underground floors for the construction of a medium-sized building located at the base of a hill, using permanent passive ground anchors. The Monitoring and Survey Plan established at design phase to validate the considered assumptions and manage the associated geotechnical risk proved to be particularly effective, confirming the excellent performance of the passive permanent ground anchors and identifying on time a risk scenario related to the poor behavior of the wedge plates applied at the temporary pre-stressed ground anchors.

This project demonstrated that passive ground anchor solutions for permanent applications can be a viable alternative to conventional active anchor systems, especially in terms of reducing monitoring and maintenance requirements during the operational phase, provided the axial stiffness of the passive ground anchors is compatible with the mobilization of low deformations necessary to load the passive ground anchors.

The Monitoring and Survey Plan, which included weekly readings campaigns from the beginning of the earthworks, was adjusted to a higher frequency, daily, during the replacement of the temporary ground anchors wedge plates that showed inadequate performance. The Plan, adapted to the reinforcement measures and changes in the construction sequence, allowed for control of the retaining structure behavior until the end of the works (see Figure 14). Effective geotechnical risk management proved to be an indispensable tool in geotechnical projects particularly in deep excavation works (Pinto et al. 2017).

Figure 14. Overall view of the structure final works.

7 ACKNOWLEDGEMENTS

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