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Connection between the New Lisbon Metro Line and the existent Terminus Station

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ABSTRACT: The aim of this paper is to describe the adopted main solutions for the new Lisbon Metro line, connecting Rato Station to Cais Sodré Terminus Station. Mainly the excavation and construction works to connect the new Metro line to the Cais Sodré Terminus Station, next to the Tagus River right bank in a very urbanized and busy area of the city, are described. As mentioned, the interconnection between the new line and the existing Terminus Station is located close to the Tagus right riverbank, where the landfill and clayed soft soils resting over the Miocene bedrock have more than 20m thickness. In addition, the excavation was located just 2m away from the Cascais railway line, which should continue under operation during the works. Given this geotechnical scenario, the small new tunnel cover and the constraints related to the densely urbanized area, cut and cover solutions were designed to minimize the surrounding ground disturbance and surface settlements. Bored piles wall braced by steel struts were used to support a 20m depth excavation. After excavation, the connection between the exterior and interior of the existing Terminus was possible by demolishing the existent diaphragm earth retaining wall and at the same time a new reinforced concrete structure was built. This intervention included the construction of foundation micropiles, new reinforced concrete beams and columns, with meticulous construction phasing compatibilized with the demolition works. The complexity of those works was increased by the constraints inside the Terminus where the impact on Metro line circulation should be minimized. This paper presents an overall description of the adopted solutions, how they were implemented as well as the monitoring plan that allowed the risk management of those complex works.

KEYWORDS: Lisbon Metro, Terminus Station, Bored Piles Wall, Excavation.

1 INTRODUCTION

The new Lisbon circular Metro line crosses a densely urbanized part of the city, connecting Rato Station, located at one of the hills of the city, and Cais do Sodré Station at the Tagus River right bank. Where the tunnel alignment approaches the river and its cover is small a Cut & Cover method is used.

As already stated at the Cais do Sodré area, the new Metro line intersects the Terminus Station, leading to the intersection between the existing and the new Lisbon Metro circular line.

This type of connection, associated with geological and geotechnical constraints, existing infrastructures, dense urban environment, required the construction of: i) bored piles wall; ii) reinforced concrete framing structure; iii) temporary steel elements; iv) micropiles foundations. It was also necessary to ensure that most of the infrastructure and surface access remained operational.

1.1 *Affected buildings*

In the area intercepted by the connection of the new Metro line to the existing Terminus Station, the excavation works intersected one of Lisbon's busiest area, 24 de Julho Avenue, a very busy and important road, parallel to the Cascais railway line, leading to the temporary and phased diversion of the infrastructures (see Figure 1).

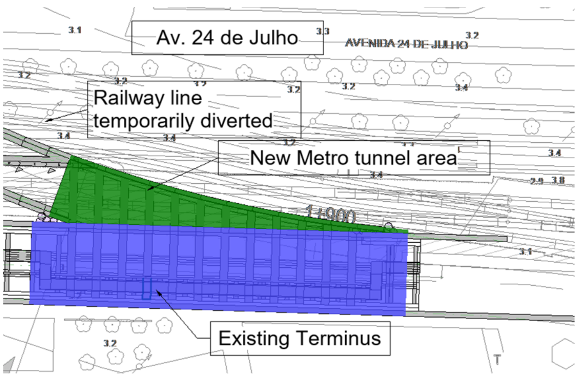

Figure 1. Plan: Layout of the new tunnel and the existing Terminus.

This intervention, as already mentioned, intersected the existent Terminus Station structure, built about 30 years ago with diaphragm walls and an interior reinforced concrete structure.

2 MAIN CONSTRAINTS

2.1 *Geological and geotechnical constraints*

The geological and geotechnical campaign included the execution of multiple boreholes that allowed the characterization of the ground units along the extension of the Cut & Cover alignment (see Figure 2). As the new Metro line approaches the Tagus River, it was possible to confirm a progressive increase in the thickness of the soft soils (landfill and alluvium - essentially sandy type), reaching a thickness of around 17m, in parallel with the sinking of the Miocene layer depth overlying the units of the Lisbon Volcanic Complex.

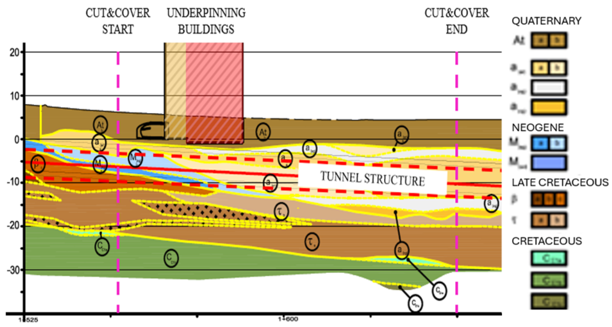

Figure 2. Longitudinal geological profile (Terminus station at right hand side).

Due to the proximity of the Tagus River, the maximum groundwater level was assumed to be 1m below ground surface and affected by Tagus River delta tides.

2.2 *Construction constraints*

The solutions adopted had to respect the local constraints regarding the equipment and material access, the Terminus Station operation during the excavation works. Considering the need to work inside the existing Terminus, the solutions had to be compatible with equipment and materials that could initially be transported through a 2m wide opening and executed within a short timeframe.

2.3 *Demolitions and load transfer procedure*

The adopted solution had to ensure a safe partial demolition of the existing Terminus structure, while preserving the existing infrastructures above the Terminus' roof slab. In this way, it was necessary to implement reinforcement solutions that would allow the demolition of one of the side earth retaining walls of the Terminus, duly reconciled with the other constraints described. Since the embankment over the roof slab of the existing structure and its partial operational were preserved, to minimize the risk of structural damage to the roof slab and surface infrastructure, due to differential settlements, the solutions and construction phases had to be compatible with a procedure of controlled load transfer from the existing structural solution to the new structural solution (see Figure 3).

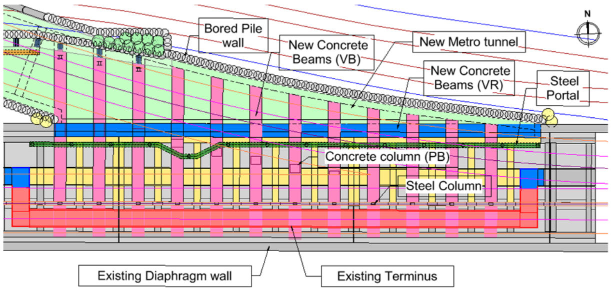

Figure 3. Plan: Demolitions and new structures to be built and preserved.

3 SOLUTION DESCRIPTION

The adopted solution was a bored piles wall to support the Cut & Cover excavation, temporally braced by horizontal steel struts. This excavation solution allowed the demolition works, as well as the equipment's and materials access. Inside the Terminus during the same demolition works, temporary steel portal structures were assembled, using prestressed bars for stability (see Figure 4).

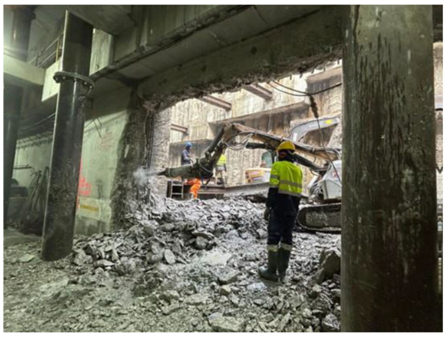

Figure 4. View of one opening at the existent diaphragm wall from the interior of the Terminus Station.

At the final phase of demolition works, a new reinforced concrete frame structure was built. Steel columns were used to temporarily support the reinforced concrete beams, and the existing foundations were reinforced with micropiles. Figure 5 shows the Cut & Cover excavation solution adopted.

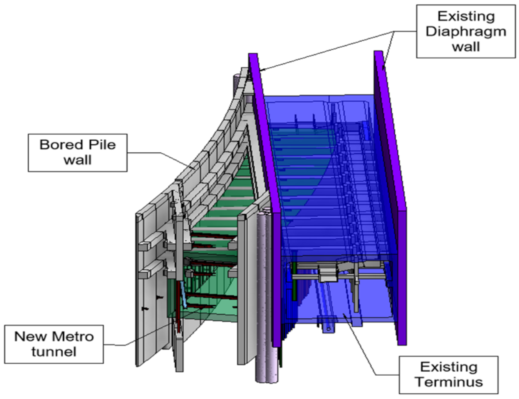

Figure 5. 3D View: Cut & Cover excavation and final structure of the Terminus.

3.1 *Cut & Cover excavation solution*

The Cut & Cover solution included a 1000 mm thickness bored piles wall (Pinto, A. Fartaria, C., Pisco, G., 2019) that was horizontally braced by distribution beams and steel struts, HEB 400 and HEB 600 steel profiles. It should also be pointed out that in this intersection area, the existing diaphragm wall was used as a retaining wall to protect the excavation (see Figure 6 and Figure 7).

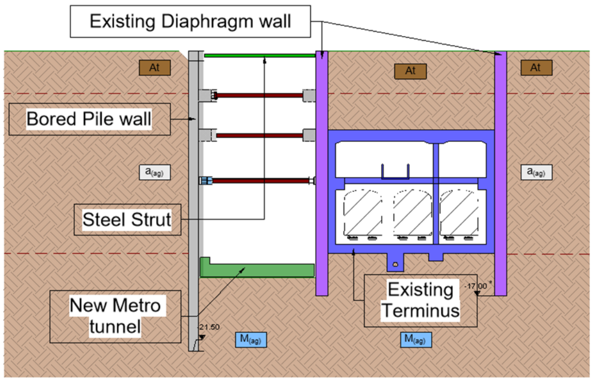

Figure 6. Cross section: Cut & Cover excavation solution.

Figure 7. View of the diaphragm wall solution.

3.2 *Demolitions and load transfer procedure*

As already stated, at the demolition phase, it was decided to build an opening at existing Terminus diaphragm wall to bring in equipment and materials. At the first stage, the connection between the existent diaphragm wall and the Terminus Station internal walls was assured by means of prestressed bars. At the second stage a temporary steel frame was installed along the entire length of the north side wall of the Terminus to be demolished (see Figure 8).

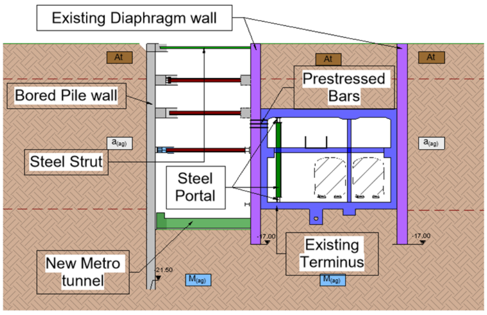

Figure 8. Section: Cut & Cover excavation, demolitions, and load transfer procedure solution.

After some secondary demolition, the existing diaphragm wall and the north side wall of the existing Terminus were demolished in 4m width strips (see Figure 9 and Figure 10).

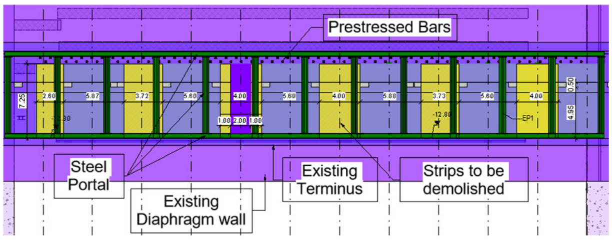

Figure 9. Elevated: Cut & Cover excavation, demolitions, and load transfer procedure solution.

The steel temporary portal was built using ROR 457x16mm vertical profiles supporting 2xHEB 500 horizontal beams.

Figure 10. View of one of the openings, prestressed bars (first stage) and the temporary steel portal (second stage).

3.3 *Final structural solution for Terminus*

The final structural solution for the connection included support micropiles (Bustamante, M. and Doix, B. (1985)) over the not demolished existent walls to accommodate the localized new solution loads (see Figure 11).

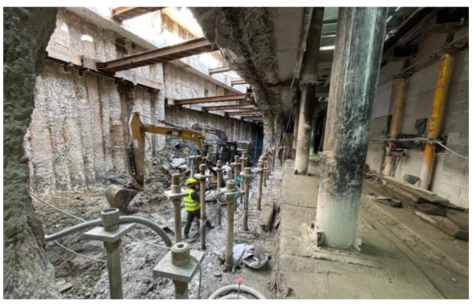

Figure 11. View of the micropiles tubes over the existing Terminus not demolished wall alignment.

The described structural system was able to allow the demolished north side Terminus wall replacement, ensuring the capacity to support the roof slab as well as the correct connection between the new tunnel structure and the existing structure (see Figure 12, Figure 13, Figure 14, Figure 15 and Figure 16).

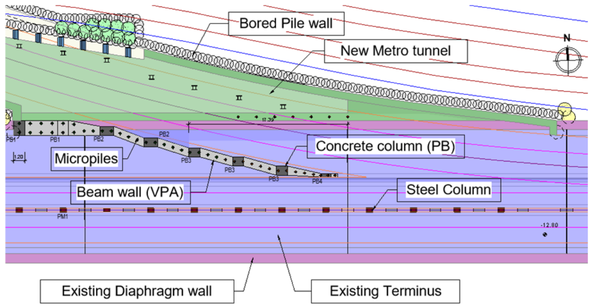

Figure 12. Plan: Foundation of the final solution to the Terminus.

A wall beam (VPA) was built over these micropiles to distribute the loads from the new reinforced concrete columns (PB) (see Figure 13 and Figure 14).

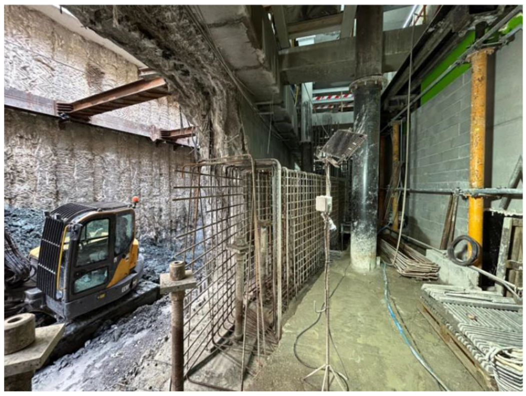

Figure 13. View of the new wall beam supported over micropiles.

Figure 14. View of the new wall beam, columns and temporary steel portal.

Beams (VB1) were built on top of the new columns, spanning the distance between the south side wall of the existing Terminus and the new north side wall of the new line's tunnel (see Figure 15).

Figure 15. View of the VB1 beams.

Once the entire new structure was built, demolition of the remaining existing north side wall was completed along the length of the connection between the structures, to allow the railway lines intersection and widths defined in the project.

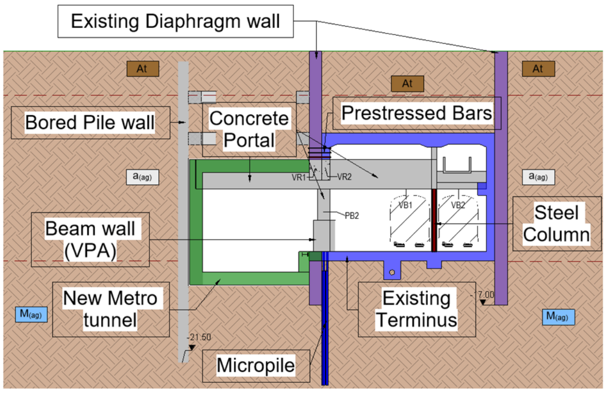

Figure 16. Cross section: Terminus final structural.

4 SOLUTION DESIGN

The temporary bored piles wall was designed using PLAXIS 2D software. In this model, the bored piles wall elements were modelled with plates, and the steel struts by anchor elements (see Figure 17).

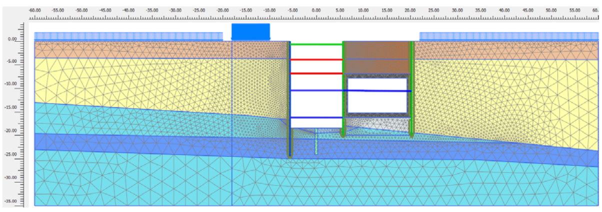

Figure 17. 3D View: Structural model developed in PLAXIS 2D.

The Terminus final structure was designed using 3D SAP2000 software. All the walls and slabs were modelled using shell elements, and the beams and columns using frames. The structural model was vertically braced using compression springs to simulate the soil structure vertical interaction, and horizontal compression springs to simulate the ground behavior (see Figure 18).

This model made it possible to estimate the design loads and displacements in the new and existing structural elements.

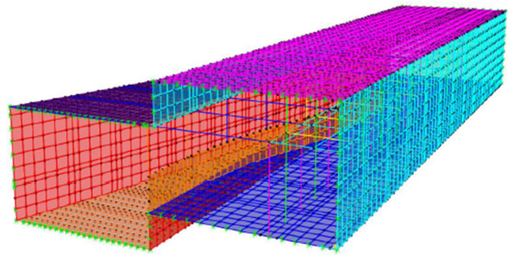

Figure 18. 3D View: Structural model developed in SAP2000

5 MONITORING AND SURVEY PLAN

For monitoring the excavation and demolition works, traditional devices such as topographic targets, inclinometers and piezometers were used.

In addition to the devices used in the Cut & Cover excavation, a monitoring and survey plan was installed using liquid level sensors and strain gauges to measure the settlement behaviour of the existing Terminus structure. The monitoring plan establishes alert and alarm criteria, based on the estimated deformations at the design stage.

6 FINAL REMARKS

The implementation of a new circular Metro line with low cover, in a densely urbanized area, intersecting soft soils with high groundwater level and partially using the existing Metro structures, lead to complex and staged solutions, requiring full compatible demolition and construction work. For scenarios such as the one presented in this work, based on experience in this type of construction work with similar geological-geotechnical conditions and other constraints, the solution for carrying out the excavation using a bored piles wall braced by steel struts, shown to be well appropriate to preserve the integrity of the existing structures and infrastructures.

A suitable monitoring and survey plan was essential to confirm, on time, the suitability of the adopted solutions.

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