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Lisbon new circular metro line: interconnection section between new line and existing terminus

Nouvelle ligne circulaire du métro de Lisbonne: section d'interconnexion entre la nouvelle ligne et le terminus existant

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ABSTRACT: The new Lisbon metro line will cross 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 Tagus River right bank. The interconnection between the new line and the existing terminus is located close to the Tagus River bank where the landfill and clayed soft soils rasting over the Miocene bedrock have more than 20m thickness. Given this geotechnical scenario and the constrains related to the densely urbanized area, the cut and cover excavation solutions have been designed to minimize the surrounding ground perturbance and surface settlements. Diaphragm walls braced by steel struts were used to hold a 20m depth excavation. The connection was materialized by the existing wall demolition and the simultaneous construction of a new structural system inside the terminus structure. This intervention included the construction of new reinforced concrete beams and columns with a meticulous construction phasing aligned with the demolition works using as well temporary support systems. The complexity of those works was increased by the constrains inside the terminus where the impact on Metro 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.

RÉSUMÉ: La nouvelle ligne de métro de Lisbonne traversera une partie densément urbanisée de la ville, reliant la station Rato située sur l'une des collines de la ville et la station Cais do Sodré sur la rive droite du Tage. L'interconnexion entre la nouvelle ligne et le terminus existant est située à proximité de la rive du Tage, où la décharge et les sols meubles argileux reposant sur le substratum rocheux du Miocène ont une épaisseur de plus de 20 mètres. Compte tenu de ce scénario géotechnique et des contraintes liées à la zone densément urbanisée, les solutions d'excavation en tranchée couverte ont été conçues pour minimiser les perturbations du sol environnant et les tassements de surface. Des parois diaphragmes contreventées par des étais en acier ont été utilisées pour maintenir une excavation de 20 m de profondeur. La connexion a été matérialisée par la démolition du mur existant et la construction simultanée d'un nouveau système structurel à l'intérieur de la structure du terminus. Cette intervention comprenait la construction de nouvelles poutres et colonnes en béton armé avec un phasage de construction méticuleux aligné sur les travaux de démolition en utilisant également des systèmes de support temporaires. La complexité de ces travaux a été accrue par les contraintes à l'intérieur du terminus où l'impact sur la circulation du métro devait être minimisé. Cet article présente une description générale des solutions adoptées, la manière dont elles ont été mises en œuvre ainsi que le plan de surveillance qui a permis la gestion des risques de ces travaux complexes.

Keywords: Metro; terminus; diaphragm walls; deep excavation.

1 INTRODUCTION

The new Lisbon circular metro line will cross 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 construction of the tunnel section is closer to the river a Cut&Cover method is used.

In the Cais Sodré area, the new metro line intersects the terminus of the existing metro line, and this is one of the points of intersection between the existing and new construction of the new Lisbon metro circular line. This type of connection, associated with geological and geotechnical constraints, existing infrastructures, a dense urban environment, the need for demolition and new construction, required the construction of a diaphragm wall, reinforced concrete framing structure, metal elements, micropile foundations and the use of hydraulic jacks and specific monitoring.

2 AFFECTED BUILDINGS

In the area intercepted by the connection of the new metro line to the existing terminus, the intervention essentially intersects one of Lisbon's busiest streets, Avenida 24 de Julho. Road and rail traffic will be affected, forcing the temporary and phased diversion of these infrastructures (see Figure 1).

Inevitably, this intervention, as already mentioned, intersects the structure at the terminus of the existing metro line. The structure of the existing terminus appeared to be in good condition, and parts of it could continue to be used in the new structural solution.

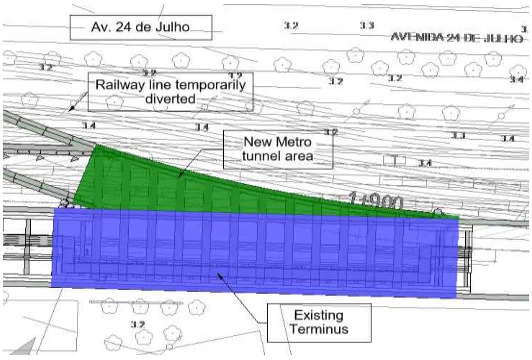

Figure 1. Plan: Layout of the new tunnel and the existing terminus.

3 MAIN CONSTRAINS

3.1 Geological and geotechnical constrains

The geological investigation campaign included the execution of multiple boreholes that allowed the characterization of the ground units along the extension of the Cut&Cover trench on which the intervention is based (see Figure 2). As the line progressed approaching the Tagus River, based on prospecting and geotechnical and geological surveys, it was possible to confirm a progressive increase in the thickness of the materials of recent genesis (landfill and alluvium - essentially sandy type), reaching a thickness of around 17.0m, in parallel with the decrease of the Miocene layer depth overlying the units of the Lisbon Volcanic Complex.

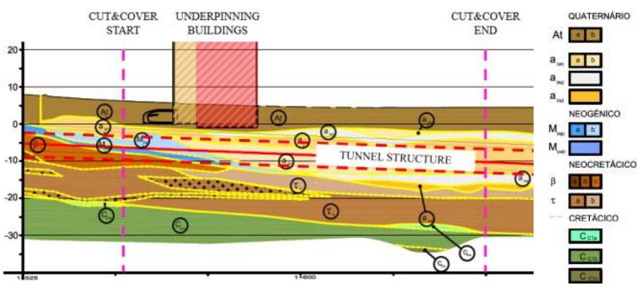

Figure 2. Longitudinal geological section.

It is also worth mentioning that, given the proximity of the Tagus River, the groundwater level was considered to be 1,0m below the surface.

3.2 Constructive technologies constrains

The solutions had to respect the local constraints regarding the accessibility of equipment and material, guarantee the partial operational continuity of the terminus throughout the intervention as well as its opening hours and the deadline for completion of the construction work. It should also be mentioned that the intervention ensured that the embankment over the existing terminus cover slab remained in place throughout the intervention, so as not to further restrict transport infrastructure in the area. Considering the need to work inside the existing terminus, the solutions had to be compatible with equipment and material that could initially be transported in an opening with a width of 2.0m and solutions that could be carried out in a short period of time.

3.3 Demolitions and load transfer procedure

The solution had to guarantee the safe partial demolition of elements of the existing terminus, while preserving the existing conditions 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 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 functioning were preserved, to minimize the occurrence of pathologies on the roof and surface, 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, which was carried out using hydraulic jacks accompanied by monitoring equipment to interpret the behaviour of the systems.

4 SOLUTION DESCRIPTION

The solution adopted consists of executing a diaphragm wall to carry out the excavation in the Cut&Cover trench, provisionally restrained by horizontal metal struts. This excavation solution allowed the demolition work to begin and equipment and materials to enter through the side wall of the existing terminus. Inside the terminus for the demolition phase, porticoed structures made of metal elements were defined, using hydraulic jacks and prestressed bars for provisional stability.

For the final phase of the terminus structure, the work generally consisted of building a new porticoed reinforced concrete structure. Locally, metal columns were used to support the concrete beams and the existing foundations were reinforced with micro-piles. The Figure 3 shows the Cut&Cover excavation solution adopted.

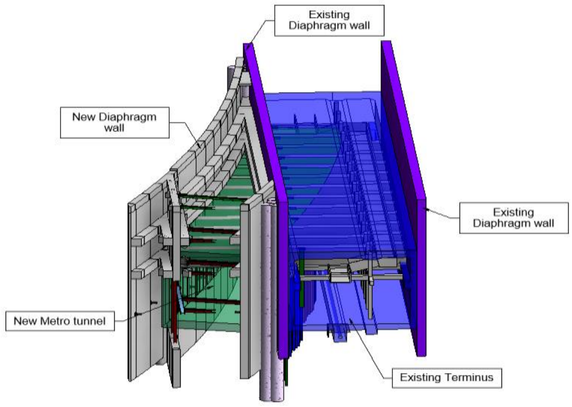

Figure 3. 3D View: Cut&Cover excavation and final structure of the terminus.

4.1 Cut&Cover excavation solution

The Cut&Cover solution was generally composed of an 800mm thick diaphragm wall that was horizontally braced by distribution beams and metal struts, materialised by HEB 400 to 600 profiles. It should also be noted that in this connection area, the existing diaphragm wall was used as a containment for excavation. This existing diaphragm wall had been used 25 years ago to build the structure of the terminus (see Figure 4).

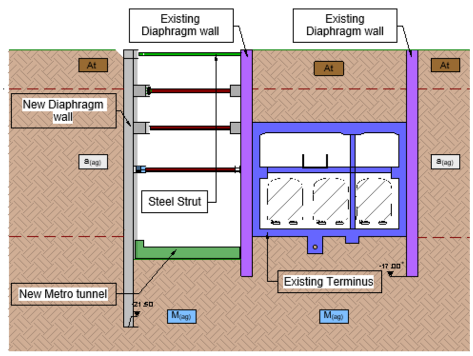

Figure 4. Section: Cut&Cover excavation solution.

4.2 Demolitions and load transfer procedure

For the demolition phase, it was initially decided to make an opening in the side wall of the existing terminus to bring in the equipment and materials needed to carry out the temporary reinforcement. Initially, the connection between the side wall of the existing terminus and the existing diaphragm wall was guaranteed by means of prestressed bars, and then a metal portal with hydraulic jacks at the top was installed along the entire length of the north side wall of the terminus to be demolished (see Figure 5).

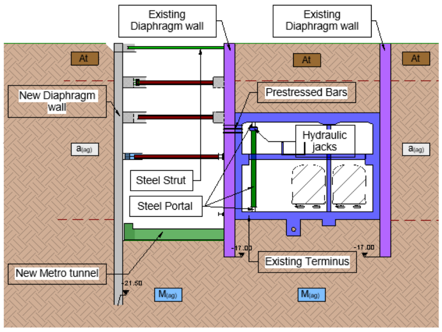

Figure 5. Section: Cut&Cover excavation, demolitions, and load transfer procedure solution.

After some secondary demolition, the existing diaphragm wall and the north side wall of the existing termination were demolished in 4.0 metre strips (see Figure 6).

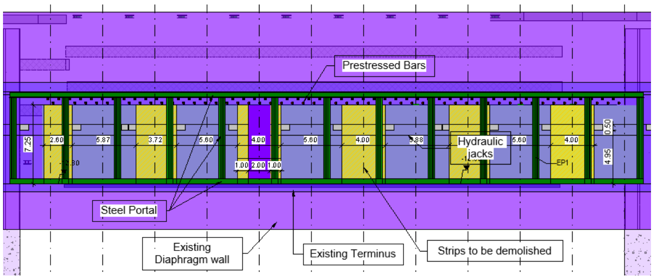

Figure 6. Elevated: Cut&Cover excavation, demolitions, and load transfer procedure solution.

The metal portal was materialised by HEB 500 vertical profiles and two HEB 500 horizontal beams.

Hydraulic jacks were used to ensure a smoother transfer of loads between the existing structure and the new structural solution.

4.3 Final structural solution for terminus

The final structural solution for the terminus consisted of making foundation micropiles on top of the existing floor slab to accommodate the localised load increase of the new solution. A wall beam (VPA) was built over these micropiles to distribute the loads from the new reinforced concrete columns (PB) (see Figure 7 and Figure 8).

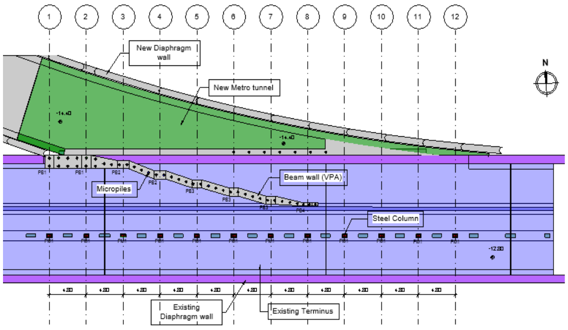

Figure 7. Plan: Foundation of the final solution to the terminus.

Beams (VB1) were built on top of the new columns, running between the south side wall of the existing terminus and the new north side wall of the new line's tunnel. 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, in order to guarantee the track areas and widths defined in the project.

The structural system described has the capacity to replace the demolished north side wall of the terminus, leaving it with the capacity to support the roof slab and guarantee the correct connection between the new tunnel structure and the existing structure (see Figure 7 and Figure 8).

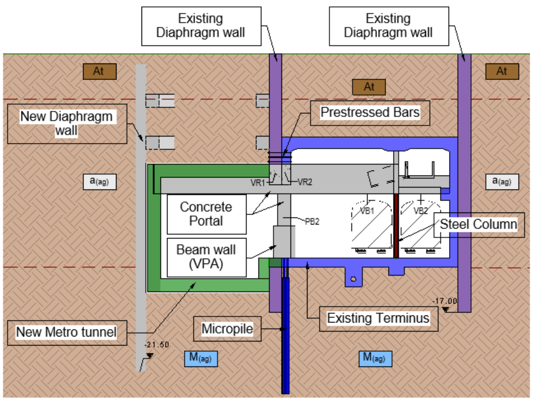

Figure 8. Section: final structural solution for terminus.

5 SOLUTION DESIGN

The temporary diaphragm wall containment was dimensioned using a two-dimensional model in *Plaxis 2D* software. In this model, the diaphragm wall elements were modelled with plates, and the metal struts by anchor elements.

The final structure of the terminus was designed using a three-dimensional model in SAP2000 software. All the walls and slabs were modelled using shell elements, and the beams and columns were modelled using frames. The structural model was vertically braced using compression springs to simulate the foundation soil of the floor slab, and horizontal compression springs to simulate the resistance of the ground (see Figure 9).

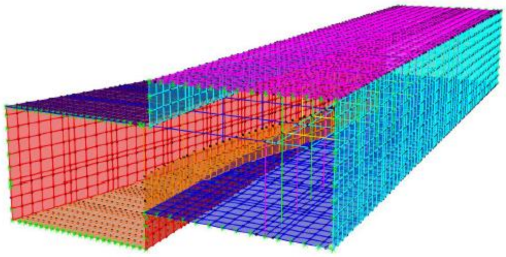

Figure 9. 3D View: Structural model developed in SAP 2000.

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

The model also made it possible to estimate the deformations in the various structural elements of the terminus, considering the new structural solution.

6 MONITORING PLAN

For monitoring the Cut&Cover excavation, traditional elements such as topographic targets, inclinometers and piezometers were used.

In addition to the instruments used in the Cut&Cover excavation, a monitoring plan was installed using liquid level sensors and strain gauges to measure the settlement behaviour of the existing terminus cover slab during the demolition phase.

The monitoring plan establishes alert and alarm values for the limits of each device. With the aim of guaranteeing safety and compliance with the values estimated in the project.

7 FINAL REMARKS

The definition and implementation of a new metro line in a densely urbanised area, on recent soil, with a high water level, with a circular shape and using the structures of the existing metro, leads to areas of connection between new and existing structures, requiring demolition and construction work. For scenarios such as the one presented in this work, based on experience in this type of construction work with these geological-geotechnical conditions and the other constraints mentioned, the solution for carrying out the excavation using a diaphragm wall restrained by metal struts seemed to be the most appropriate for maintaining the integrity of the existing structures and infrastructures. The remaining solution adopted for connecting the new structure to the existing one also proved to be adequate, guaranteeing all the regulatory safety criteria.

An adequate monitoring and survey plan was essential to confirm the suitability of the solution during excavation work, and also to manage the transfer of loads between the new structural system and the new structural system. the shoring system during excavation work.

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