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The description of underground works evolution in Hospital Santo António station (Porto Metro)

Description de l'évolution des travaux souterrains de la station Hospital Santo António (Métro de Porto)

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ABSTRACT: Currently, the particular context of each underground work leads to the choice of different constructive methodologies in view of the wide variety of existing options and in this sense the article will focus on the description of underground works evolution, in an urban environment, on Porto Metro, specifically the Hospital Santo António station. Hospital Santo António station is part of the future circular line, section Liberdade / S. Bento - Boavista / Casa da Música, and its location is conditioned by: proximity to a road tunnel (Túnel de Ceuta); by an underground water line (Rio Frio); the need to preserve tree species in the existing garden (Jardim do Carregal) and to minimize disturbances to adjacent buildings and traffic during construction. These constraints led to a unique geometric solution and constructive methodology, consisting basically of two large-section tunnels (approximately 200 m^2), which intersect obliquely, two large-diameter shafts with an approximate area of 400 m^2 (for access, ventilation and emergency exit) and two inclined tunnels to arrive at distribution floor for access to the dock platform. The methodology adopted in the tunnels is the NATM "New Austrian Tunneling Method", while in the large diameter shafts the vertical sequential excavation method was chosen. These methodologies are an excavation procedure with minimal support, which depends on the geomechanical and hydrogeological properties of the terrain, because it considers that the tunnel surrounding terrain contributes to its own support.

RÉSUMÉ: Actuellement, le contexte particulier de chaque ouvrage souterrain conduit au choix de différentes méthodologies constructives compte tenu de la grande variété d'options existantes et, en ce sens, l'article se concentrera sur la description de l'évolution des travaux souterrains, en milieu urbain, dans le Métro de Porto, plus précisément la station Hospital Santo António. La station Hospital Santo António fait partie de la future ligne circulaire, section Liberdade / S. Bento - Boavista / Casa da Música, et son emplacement est conditionné par: la proximité d'un tunnel routier (Túnel de Ceuta); par une conduite d'eau souterraine (Rio Frio); la nécessité de préserver les espèces d'arbres dans le jardin existant (Jardim do Carregal) et de minimiser les perturbations des immeubles adjacents et de la circulation pendant la construction. Ces contraintes ont conduit à une solution géométrique et une méthodologie constructive uniques, constituées essentiellement de deux tunnels de grande section (environ 200 m^2), qui se croisent obliquement, de deux puits de grand diamètre et d'une superficie approximative de 400 m^2 (pour l'accès, la ventilation et la sortie de secours) et deux tunnels inclinés pour arriver au plancher de distribution pour accéder à la plateforme du quai. La méthodologie adoptée dans les tunnels est la méthode NATM "New Austrian Tunneling Method", tandis que dans les puits de grand diamètre, la méthode d'excavation séquentielle verticale a été choisie. Ces méthodologies sont une procédure d'excavation avec un soutènement minimal, qui dépend des propriétés géomécaniques et hydrogéologiques du terrain, car elle considère que le tunnel entourant le terrain contribue à son propre soutènement.

Keywords: Underground infrastructure; urban environment; large diameter shafts; tunneling; Porto Metro.

1 INTRODUCTION

The "Santo António Hospital's" station, which is currently under construction, belongs to the Porto Metro circular line project, also known as Pink Line. The circular line extends through the central axis of the city of Porto, with a length of approximately 3.1 kilometers, and it foresees the construction of four new stations: Liberdade/S.Bento, Hospital de Santo António, Galiza and Boavista/Casa da Musica (Sener/CJC/NSE, 2020).

The Hospital Santo António (HSA) station is located in the Carregal garden, in the center of Porto and in the vicinity of the hospital with the same name, and its construction is influenced by several

constraints (Figure 1). One of them is the Ceuta tunnel (road tunnel), which crosses over the tunnel of the future circular line, immediately before the station, requiring a special care during the station's implementation. Furthermore, once the construction takes place in one of the most emblematic and ancient gardens in the city, there's a need to preserve, as much as possible, the tree species in the Carregal garden and minimize the disturbances on the surrounding environment and traffic during the construction phase, to ensure the easy access to the hospital. These factors had a significant impact on the decision to locate accesses and shafts, on the surface, as well as on the construction solution and method (Pereira, 2023).

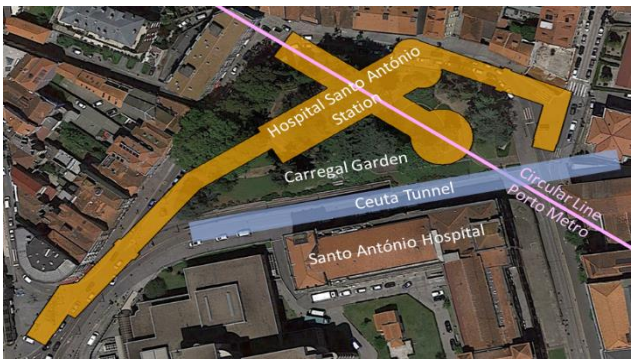

Figure 1. View of the Hospital Santo António station location.

2 CONSTRUCTION SOLUTION

The execution project, (Sener/CJC/NSE, 2019a), of the Hospital de Santo António station consists in the interconnection of two galleries with an angle of 66 degrees and a minimum cover of 11 meters.

The first gallery, named *Caverna Cais* (CC), extends for approximately 61 meters, covering an excavated area of approximately 172 m². In its cross section, the CC has a width of 18 meters and reaches a maximum excavation height of 12 meters. At the southeast end of the CC is the emergency exit shaft (EES). The EES has a circular configuration, with an average excavation diameter of around 24 meters (corresponding to an area of approximately 450 m²) and reaching a depth of approximately 27 meters.

The second gallery, named *Caverna Mezanino* (CM), extends approximately 62 meters, occupying an excavated area of around 260 m². In its cross section, the CM has a maximum excavation width of 20 meters and reaches a maximum excavation height of 17 meters. At the northeast end of the CM is the elevator shaft (ES). The ES has an elliptical shape, with an average excavation width of around 23 meters on the major axis and 18 meters on the minor axis (which corresponds to an approximate area of 325 m²) and has a depth of around 27.5 meters.

From the ES, there will be a connection with the surface through the construction of the east access tunnel (EAT). This tunnel will be approximately 25 meters long and its cross section will be variable. Initially, in the shaft-surface direction, the excavation section will be larger, covering around 130 m², with a height of 10.5 meters and a width of 15 meters. At the end of the tunnel, the excavation section will decrease to approximately 57 m², with a height of 8.3 meters and a width of 8.5 meters.

From the southwest end of the CM, a connection with the surface will be established through the construction of the western access tunnel (WAT). With an approximate length of 70 meters, this tunnel will feature a single excavation section, with an area of approximately 57 m², a height of 8.3 meters and a width of 8.5 meters and it will connect to the open ditch at its end. A three-dimensional modelling is presented in Figure 2.

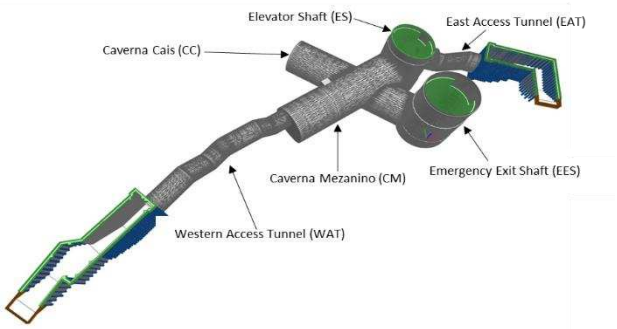

Figure 2. Three-dimensional modeling of the Hospital Santo António station (Pereira, 2023).

2.1 Construction methodology

The Hospital Santo António station will adopt three different methodologies: the underground station, composed of CM, CC, EAT and WAT, which will be carried out according to the NATM methodology; the connection of the east and west accesses to the surface, which will be executed through an open ditch and the two attack shafts to the station will be executed using a vertical sequential methodology (Sener/CJC/NSE, 2019a).

2.2 Geological-geotechnical background

The city of Porto is closely linked to its impressive granite massif. This massif stands out in the outcrops along the coastline and on the city's cliffs. However, the geotechnical conditions are complex due to the tectonic setting of the granite massif and the hydrothermal changes and weathering that occurred after its formation.

This granite massif, called *Granito do Porto*, has two micas, with a predominance of muscovite, and has a medium grain, sometimes coarse. Fine-grained aplite-pegmatite transitions are also common.

The geology in the region, of the future circular line of the Porto Metro, is characterized by the granite massif covered by landfills and, frequently, by alluvial soils (Sener/CJC/NSE, 2019b).

The geological-geotechnical characterization of the region where the HSA station is located (Figure 3), defines that the upper lands, made up of landfills and alluvium whose development follows the morphology of the paleo valley represents, as a whole, the filling of the Rio Frio valley and are part of the geotechnical unit G7 which reaches 10 to 12 meters deep. The landfills are sandy and heterogeneous, including granite blocks, organic levels and debris remains. The lower alluvial soils are essentially made up of silty-clayey sands and sandy-clayey silts, brown or dark grey (Sener/CJC/NSE, 2019b).

The G6 and G5 units follow the G7 unit in depth. These geotechnical zones consist of very compact granite alteration soils and decomposed granite, respectively, characterized by a sub-horizontal development, with corrugated boundaries, which reaches a depth of 21 to 24 meters. In some areas of the station, the decomposed granite massif (G5) transitions to highly altered granite massifs (G4). The G3 geotechnical zone occurs below the G5 unit, occasionally appearing in the form of loosely continuous blocks within the G5 unit. The granite massif of unit G3 is classified as moderately altered, with closely spaced and moderately spaced, oxidized and open fractures. In the center of the station, the G3 granite massif quickly evolves into G2, characterized as little altered. Locally, there are intersections of sub-vertical fracture alignments, mainly without filling, which represent preferential zones of percolation and water storage in the rock mass. Before excavations began, the average water level was approximately 7 meters deep from the surface (Sener/CJC/NSE, 2019b).

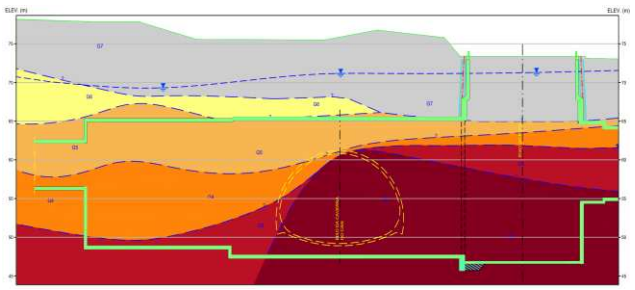

Figure 3. Geological-geotechnical longitudinal profile of the Hospital Santo António station.

3 EXECUTIVE SEQUENCE

Before the beginning of the excavation works, preparatory works were meticulously carried out in March 2021. These preparations were essential to enable the construction of the station and included the following tasks: alteration of local road traffic routes; execution of infrastructure diversion, including the diversion of the Rio Frio; carrying out an archaeological survey campaign and installation of the geotechnical instrumentation system in the massif and adjacent structures.

After the preparatory work are completed, the construction of the HSA station began. At this point, it is important to highlight that the construction process took place in a progressive and structured way. A concise summary of the activities that have been carried out up to the beginning of October 2023 will be now presented, as following.

The works on the HSA station began with the construction of the EES. Considering the presence of G7 surface terrain, it was necessary to implement a perimeter treatment into the massif surrounding the two attack shafts, which consisted in vertical drying jet-grouting columns with 0.8 meter in diameter. Once the jet-grouting columns were completed, the excavation works for the shafts started. The excavation works and application of the primary lining was carried out dividing the shaft into levels, with 1 meter high and panels 6 meters long, up to 27 meters deep, according to the execution project. From a depth of 9 meters, geodrains were installed to relieve hydrostatic pressure in the temporary lining, without causing a sharp lowering of the water level. The primary lining around the main tunnel and CC were reinforced to allow the excavation works to begin on both structures, dismissing the execution of the definitive lining of the shaft at this stage.

Subsequently, the works on the CC proceeded, interspersed with the advancement of the main tunnel, using the NATM methodology and divided into two phases: top heading divided into side-drift and enlargement and undercut. After advancing 6 meters, a stoppage wall was created. This front is on hold until the CM definitive lining work is completed.

When the execution of the EES was 15 meters deep, the ES excavation work began, following the same sequential methodology for executing the EES. The ES excavation was temporarily halted at a depth of 17 meters, which is the depth coinciding with the height of the CM top heading, EAT and WAT invert. After the completion of the excavation work on the top heading and the first undercut of the CM, the excavation of the ES will be resumed.

The CM excavation is expected to be carried out in a sectional manner: in a top heading (divided into side-drift and enlargement), first and second undercut, respecting the NATM methodology (Figure 4).

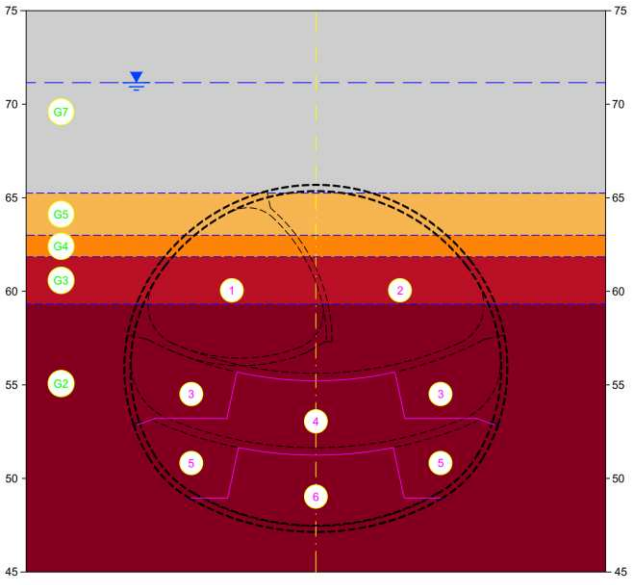

Figure 4. Executive phasing of Caverna Mezanino.

The excavation works, from the ES, began with the contour and front treatments of the CM and EAT portal. After the excavation of the CM side-drift was able to proceed. The enlargement of the CM's top heading began as soon as the side-drift was in the middle of the CM. After completion of the CM top heading, the stop wall and treatments of the WAT portal were carried out. The first undercut will begin once all the works for the WAT are concluded, from this work front.

While the CM was excavated, the excavation of the EAT also began, following the NATM construction sequence, up to approximately 12 meters in advance. Regarding WAT, underground excavation works advanced by around 12 meters. On the date of completion of this article, the EAT and WAT excavation fronts were being stopped, waiting the progress of the works being held from the surface, for the completion of the EAT and WAT excavation work.

At the same time and in order to guarantee the success of the project, a team of geologists and geotechnical engineers were designated to monitor the development of the works, on a daily basis. This group of professionals played a fundamental role in carrying out detailed cartography of the excavation fronts, carefully documenting the geological, geotechnical and hydrogeological characteristics found.

A geotechnical instrumentation plan was also implemented, during all the progress. This plan is based on a flexible project philosophy, providing a systematic control of the works and ensuring the project's assumptions. It also allows to adapt and adjust the project, if necessary, to ensure the compliance with deadlines and eases the management in case of geological-geotechnical and urban context unforeseen events, without underestimating safety.

4 CONCLUSIONS

The construction of the Santo António Hospital station, as part of the Porto Metro circular line, faced a series of constraints that required a careful designed constructive solution. This solution, with a bold and avant-garde approach, has proven to be suitable, even in an urban environment.

As the works approaches to the completion, it will be relevant to consider producing a scientific article addressing the geological complexities faced during construction, the performance of support structures over time and the impacts on the massif and structures adjacent. This will allow a critical assessment of what was predicted in the execution project compared to what was found during the construction phase.

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