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Brief report on the construction of the Liberdade/São Bento Station of circular line G (Pink Line) of the Porto Metro

Bref rapport sur la construction de la station Liberdade/São Bento de la ligne circulaire G (Ligne Rose) du métro de Porto

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ABSTRACT: Liberdade/São Bento station (L/SBS) is one of the four stations that are part of the new circular line, also known as "Line G" or "Pink Line". This new project will increment 3 km's to Oporto light rail system and will connect the existing stations of São Bento and Casa da Música. Once it is located in the heart of Oporto city centre, it was important to ensure the minimum impact at the surface and traffic disruption, which why Liberdade/São Bento station is being built using a mix of cut-and-cover and top-down construction methodologies. The station is formed by its main body, which develops longitudinally to the axis of the railway, and by its surface accesses, which develops perpendicularly to the railway axis at both ends and in the central area of the station body. Due to its location and dimension, the construction process has revealed himself as extremely challenging, once it combines the complexity of building in an high urban area, extremely affected by various services (water supply, wastewater network, rainwater, gas, electricity and all telecommunication services), but also historical (proximity to several monuments and the appearance of new archaeological monuments during excavations), along with the geological-geotechnical conditions considered in the design of excavations, retaining support and foundations (structural support and protection of buildings; high levels of groundwater; groundwater contamination). This paper aims to describe the main constraints that are being faced during the execution and explain how are they being managed and overcome.

RÉSUMÉ: La station Liberdade/São Bento (L/SBS) est l'une des quatre stations qui font partie de la nouvelle ligne circulaire, également connue sous le nom de "Ligne G" ou "Ligne rose". Ce nouveau projet ajoutera 3 km au système de métro léger de Porto et reliera les stations existantes de São Bento et Casa da Música. Une fois située au cœur du centre-ville de Porto, il était important de minimiser l'impact sur la surface et les perturbations du trafic. C'est pourquoi la station Liberdade/São Bento a été construite en utilisant un mélange de méthodologies de construction en tranchée couverte et de construction de haut en bas. La gare est formée par son corps principal, qui se développe longitudinalement à l'axe du chemin de fer, et par ses accès de surface, qui se développent perpendiculairement à l'axe du chemin de fer aux deux extrémités et dans la zone centrale du corps de la gare. En raison de son emplacement et de sa dimension, le processus de construction s'est révélé extrêmement difficile, une fois qu'il combine la complexité de la construction dans une zone urbaine élevée, extrêmement affectée par divers services (approvisionnement en eau, réseau d'eaux usées, eaux pluviales, gaz, électricité et tous les services de télécommunication), mais aussi historique (proximité de plusieurs monuments et apparition de nouveaux monuments archéologiques pendant les fouilles), ainsi que les conditions géologiques-géotechniques prises en compte dans la conception des fouilles, des confinements et des fondations (soutien structurel et protection des bâtiments; niveaux élevés des eaux souterraines; contamination des eaux souterraines). Ce document vise à décrire les principales contraintes rencontrées au cours de l'exécution et à expliquer comment elles sont gérées et surmontées.

Keywords: Metro; construction; cut-and-cover, top-down, granite.

1 INTRODUCTION / GENERAL FRAMEWORK OF THE WORK

Liberdade/São Bento station (L/SBS) integrates the new circular line (aka Line G, or Pink Line) of Metro do Porto light rail system, which will increment 3km's to the current network. It is located in a consolidated urban area of Oporto city centre, and it will connect the existing station of São Bento and Casa da Música.

Considered as a Unesco World Heritage area, the implementation of this new station demanded a careful and thorough study of the spatial, structural and planning constraints.

Figure 1. Plant insertion of Liberdade/S. Bento Station (L/SBS).

In order to enable the construction in such a narrow space (Figure 1) and ensure the safety of all the building and historical heritage on the surroundings, it was necessary for the design team to study and conceive new approaches and solutions, once the standard solutions (foundation piles, e.g.) were not possible to implement.

The density of utilities and services affected (namely wastewater, water supply, electricity, etc.) and the crossing of an ancient underground rainwater galleries (Rio da Vila), demanded a complex coordination between the several specialities projects, in order to achieve a feasible and integrated solution.

2 URBAN CONSTRAINTS

By way of background, it is important to highlight the existence of a combination of determining factors that led to an atypical metro station, especially in geometric and functional terms. These are summarised below: the small width of the urban roads for the insertion of a current metro station; intense road and pedestrian traffic on the surface as well as the presence of buildings next to the work, some of which are of heritage and historical importance; the convergence in "Praça da Liberdade" of a system of rain galleries (called Rio de Vila (RV)) that runs southwards towards the Douro river, which constitutes a barrier that is very difficult to overcome; the crossing of "Praça da Liberdade" through the tunnel of metro line C, heading north towards Aliados; the need for an underground pedestrian link between line C and the Circular line, connecting the new station to São Bento metro station.

Due to the above mentioned, a complex and dynamic coordination between design teams was needed, in order to ensure the feasibility of the technical solutions adopted.

3 THE STRUCTURAL SOLUTIONS ADOPTED

Due to the constraints presented, the L/SBS is being built, mostly, using the so-called top-down method, with peripheral retaining support in Diaphragm Walls (DW). Due to the proximity of the buildings and the need to drill through a relatively competent rock mas without percussion, an hydromill trench cutter was used, with specific dimension limitations.

This structural solution aims to ensure: structural continuity between the roof slab and the peripheral containment (first phase of the structure), labelled connections between diaphragm walls and the remaining station slabs (Mezzanine and Back Slab).

In order to simplify the work and enhance its durability, standard structural solutions were favoured, avoiding complex connections, mainly resulting from: intermediate vertical elements to be built in the first phase (top-down method), the support of the roof on walls to be built in the second phase (open excavation).

It should be noted, however, that it was necessary to use the support of the roof slab in an intermediate DW alignment in the body of the station, otherwise, considering the spans presented, it was necessary to increase significantly the thickness of the roof slab, what would have been unaffordable, because of the land cover intended.

Mainly due to the factors described and the need to minimize the traffic disruption, the construction had to be adapted to the several varied moments of diversions transition, with the execution of the station's structural elements being subdivided into 11 Phases (Figure 2).

Figure 2. Division of the Station for the execution of the structural elements.

The areas highlighted in red were executed entirely from the bottom up; the green area represents the top-down construction method.

4 GEOLOGICAL, GEOMORPHOLOGICAL AND TECTONIC SETTING

The route of the project is located in the Central Iberian Zone, where there is a characteristic granite massif with complex geotechnical conditions, marked by the tectonic framework of the granite massif and the hydrothermal and meteoric alteration that followed its installation (Santos et al, 2019).

According to Santos (2019), from a tectonic point of view, the influence of the Hercynian orogeny and the proximity of the Porto-Albergaria-a-Velha-Coimbra-Tomar Shear Belt, with a NNW-SSE orientation, which passes through the Foz do Douro and Nevogilde areas, stand out.

The granite massif of Porto is generally sandy and kaolinised, heterogeneous and geotechnically complex where granite soils and rock levels occur without a pattern. This is largely due to the proximity of an intense deformation zone which favoured a large fracture network and deep fluid circulation (hydrothermal alteration) which was intensified by meteoric alteration conditioned by the climate, surface water infiltration conditions and the relief in general.

From a geomorphological point of view, the route is located in a flattened region slightly inclined towards the sea, where low areas are followed by hills with flattened tops, intersecting the valleys of the tributary watercourses of the River Douro.

The L/SBS is built on several watercourses, which are currently channelled / diverted and substantially earthed, the main one being the RV, which means that the working levels reach minima close to 10m.

4.1 Geological-Geotechnical Zoning (GGZ)

In order to carry out the geological-geotechnical reconnaissance and elaborate the GGZ (Figure 3) of the massif, all the existing elements relevant to the project presented here were collected and analysed, two geotechnical prospecting campaigns were carried out and all the available data was subsequently analysed and systematised. Two prospecting campaigns were carried out with 48 geotechnical rotary boreholes, accompanied by the systematic execution of SPT tests and the complete collection of rock mass, with the installation of 24 open tube piezometers, 41 Lugeon tests and 43 Lefranc tests, plus 37 simple compressive strength tests.

The boreholes reached depths varying between 23.0 and 46.5 metres.

In order to determine the aggressiveness of the groundwater to the concrete, 8 samples were taken from boreholes along the route and chemical analyses of the groundwater were carried out to obtain pH values, sulphate content, aggressive carbon dioxide, nitrogen and magnesium.

51 samples were also selected to be subjected to tests to determine density, porosity and resistance to uniaxial compression with determination of the modulus of deformability.

GEOTECHNICAL ZONING	LITHOLOGY	WEATHERING GRADE		FRACTURATION GRADE	JOINTING CONDITIONS	N_{SPT}	GSI
G1	γ	W1	FRESH GRANITIC	F1-F2	d1-d2	NA	65-85
G2	γ	W2	SLIGHTLY WEATHERED GRANITE	F2-F3	d2-d3	NA	45-65
G3	γ	W3	MODERATELY WEATHERED GRANITE	F3-F4	d3-d4	NA	30-45
G4	γ	W4	HIGHLY WEATHERED GRANITE	F4-F5	d4-d5	NA	15-30
G5	γ	W5	COMPLETELY WEATHERED GRANITE	NA	-	>50	-
G6	γ	W6	RESIDUAL SOIL GRANITE	NA	-	<50	-
G7	EMBANKMENT /ALLUVIUM	NOT APPLICABLE (NA)		NA	-	VARIABLE	-

Figure 3. Geotechnical zoning adopted and its reference parameters (adapted from Santos, 2019).

The GGZ of the L/SBS was defined on the basis of information from 5 geotechnical boreholes, with depths between 21 and 25m, complemented by information available from the 1st phase of the construction of the Metro do Porto when the line was built to the existing ESB (Santos, 2019).

Through GGZ, the station mostly intersects G7 and G5, to a lesser extent G4, and occasionally G3. Unit G7 is made up of embankments and alluvium that cover the underlying granite formation, reaching depths of between 2 and 9 metres (Figure 4).

Unit G5 is made up of very compact granitic soils (NSPT>60 strokes), with occasional rocky cores and is located between 2 and 19m deep, exceeding the

station's implantation level in the central zone (Santos, 2019).

According to Santos (2019), in the central area of the station, the rock mass only occurs below the station's base level (G4 and occasionally G3). To the east and west, the G4 and G3 massifs are already found between the top and base of the station. Circumscribed G3 rock cores can, however, be intercepted above the station's base level.

The G3 rock unit occurs at depth, with some continuity from 8-24m deep, and the G2 unit is punctual and not very continuous, usually between 18 and 25m.

According to Santos (2019), the high oxidation of the granite massif's fractures, some filled with organic soils, and the interception of a passage of monogranular rolled sands within the decomposed massif (G5), indicate the presence of an uncompressed granite massif, with open fractures and high underground percolation.

The water table is close to 5 metres deep (Santos, 2019).

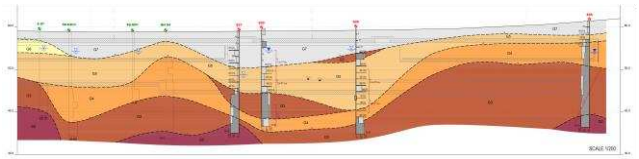

Figure 4. Longitudinal Geological-Geotechnical Profile of the L/SBS (excerpt from Drawing with code P-PR-LI-8000-GG-DS-SCN-000002-00), for legend of the GGZ see Figure 3.

5 CONCLUSIONS

Liberty/São Bento station represents a great example of the importance of exploring the underground space in urbanized cities. However, it also teaches us the importance of the existence of updated registrations and records for the underground services and utilities, which can compromise, severely, the construction process.

Location revelead itself as one of the major factors for the selection of the construction method, design and construction premisses: due to the proximity to residential, commercial and historical buildings, it was necessary to implement a solution which allowed to preserve the integrity of the built heritage, but also minimize the impact on the surface near the residents and population. Despite the careful and thorough coordination of the design teams for the several specialities during the design process, several question marks remained during the entire excavation, thus the importance of an high engagement of all the stakeholders involved (namely design teams, owner, constructor and municipality), such as a risk and expectation management.

An effective communication and engagement of the several competent authorities, are crutial to ensure the city dynamic, communication and disclosure of information near the population.

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