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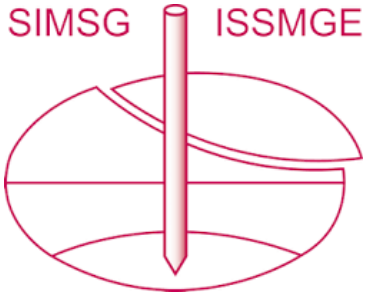

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Infinity Tower, high rise building in Lisbon: innovative solutions for a deep and complex excavation

Infinity Tower, bâtiment de grand hauteur à Lisbonne: solutions innovateurs pour une excavation profonde et complexe

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ABSTRACT: The Infinity Tower is a high-rise building, with 26 upper stories, being built in Lisbon. With 4 basement floors with about 4.600m^2 plan area, its construction comprises an approximately 18m maximum depth excavation, intersecting mainly heterogeneous fills and the Lisbon Volcanic Complex. The site is surrounded by vital infrastructures such as a 70 years old wastewater tunnel, with 8m width and a plain concrete structure (Alcântara wastewater tunnel), a viaduct abutment and a railway line. To reach the foundation level safely, minimizing the surrounding ground disturbance, a retaining wall solution with reinforced concrete bored piles wall was designed. Due to the close presence of the described infrastructures, the basement slabs were used as strips to brace the wall, cast against the ground during the excavation works, and bridging spans of about 50m. This paper describes the main design topics of this project, including the BIM approach.

RÉSUMÉ: L‘ Infinity Tower c‘est un bâtiment à grand hauteur, avec 26 étages, qui est en train de commencer à Lisbonne. Il aura 4 sous-sols avec une area de 4.600m2. Cette construction demande une excavation d’environ 18m of maximum profondeur, que va intersecter de remblais hétérogènes et le complexe volcanique de Lisbonne. L‘excavation sera entourné para des importantes infrastructures, comme le tunnel de drainage des eaux résiduelles avec une âge de 70 ans (Alcântara tunnel), un pont automobile et une ligne de chemin de fer. Pour prendre le niveau final d’excavation, minimisant la perturbation du sol, une paroi à pieux forés a été projeté. Tenant en compte la proximité des infrastructures invoques, des tronçons des dalles des sous-sols ont été utilisés pour contenir la paroi à pieux, bétonnes contre le sol et avec une portée d’environ 50m. L’article présent les principaux critères de dimensionnement, inclus les avantages de l’approche avec la technologie BIM.

Keywords: deep excavation; bored piles; BIM.

1 INTRODUCTION

The Infinity Tower will be an iconic building in the Lisbon skyline with an impressive modern architecture, being the tallest residential building in Lisbon with 26 upper stories and 4 basements, resting over an area of 4600m^2 and demanding a maximum excavation depth of 17.60m (Figure 1).

The main issues are related to the demanding conditions, mainly: the geological and geotechnical scenario, the topography as well as some vital neighbor infrastructures, such as the 70 years old wastewater sewage tunnel, with 8m width and plain concrete structure, (Alcântara WW tunnel), a roadway viaduct and a railway line (Figure 3).

This case study also approaches the use of the Building Information Modeling (BIM) for a complex geotechnical project. BIM helps to promote an early stage design collaboration with different project parties due to its capability to work as an information repository where the data is centralized in the BIM model (Azhar, 2011). This collaboration is important to tackle the uncertainty and reduce the reduplication of work, leading to an improved efficiency in the project delivery (Hardin, 2015). The centralized parametric elements in which the 3D/BIM models are based make possible that design changes are automatically assimilated in all drawings and views. The time spent in documentation can be shifted to the development and improvement of the design solutions.

In this project, the architecture model was used as a base for the geotechnical design and 3D modeling of the conceived solutions, allowing to achieve an accurate geometric coordination and efficiency gains in the structural design and project documentation.

Figure 1. Infinity Tower virtual image

2 MAIN RESTRAINTS

2.1 Geological and geotechnical conditions

The characterization of the underground conditions was made through 9 boreholes with SPT tests and sampling collected for visual classification and laboratory tests. The excavation area is located over the Lisbon Volcanic Complex materials, covered by a very heterogeneous landfill deposit layer, with a maximum thickness of about 12m. This area was divided into 4 geotechnical zones: ZG1, regarding the heterogeneous urban landfill layer; ZG2 for pyroclastic tufts and low-quality basalts; ZG3 and ZG4 for medium to high-quality basalts (Table 1 and Figure 2).

Table 1. Geotechnical zones and parameters

Geotechnical Zone	Description	γ (kN/m³)	Ø' (º)	c' (kPa)	Es (MPa)
ZG1	Landfill (5≤NSPT≤17)	18	30	0	15
ZG2	Pyroclastic tuffs and low-quality basalts W4 to W3-4; F5 to F4-5 with recovery ranging from 60% e 100% e RQD=0%	22	33	50	65
ZG3	Basalts W3 to W3-2, F4 to F4-5, with 90% recovery ranging and 20% ≤RQD≤75%, interbedded with basalts W3-2, F4-5 with 100% recover and 47%≤RQD≤74%	22	37	80	120
ZG4	Basalts W3-2 to F4-3, with 100% recovery and 56%≤RQD≤76%	22	45	100	150

It should be pointed out that the groundwater table was not observed above the final excavation level.

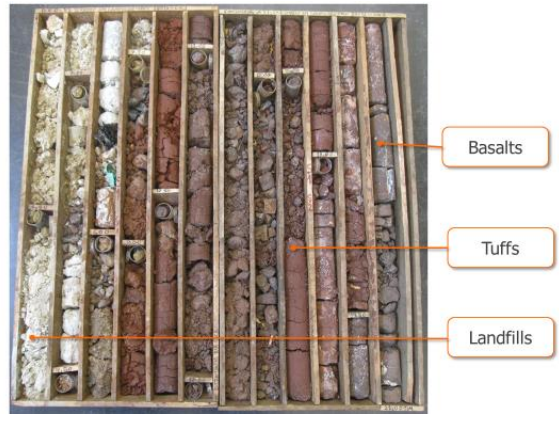

Figure 2. Boreholes cores samples

2.2 Topographic and urban restraints

The site is located over a 10m high hill, facing the railway line, consequently leading to an excavation depth ranging from 17.60m to 6.25m in opposed alignments: West (railway line) and East (WW tunnel and roads), as shown in Figures 1 and 3.

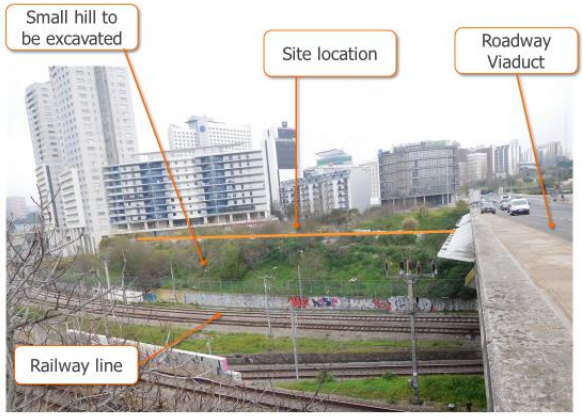

Figure 3. Topographic and urban restraints

2.3 Neighboring conditions

As already stated, the site is located on an urban area. In the West, it is limited by the Lisbon suburban railway line, at South side by a roadway viaduct, and at the North-East and East sides are limited by road traffic and pedestrian streets, over the old wastewater tunnel (Figure 4).

Figure 4. Site location and neighbor conditions

3 ADOPTED SOLUTIONS

The adopted earth retaining solutions were designed considering the existing restraints with the purpose to control the ground deformations and execute the excavation with the minimum interference with the surrounding infrastructures and services, taking in account the safety, constructability, schedule and economic factors.

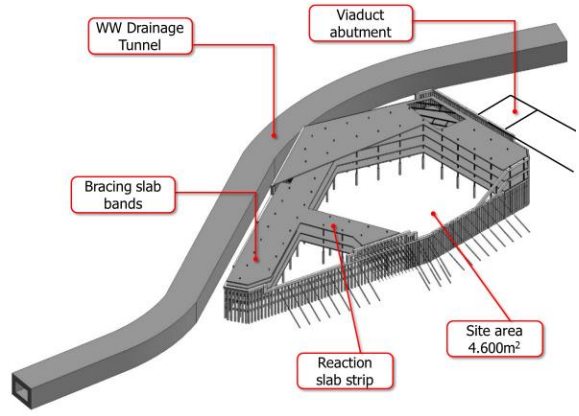

Figure 5. Virtual 3D perspective of the solution

The designed solution was a bored piled wall (BPW) with 600mm diameter piles spaced at centers from 0.80m to 1.20m, according to the geological and geotechnical conditions. The total pile's length ranges from about 22m to 10m, all with a minimum embedment length of 4m at the Lisbon Volcanic Complex materials.

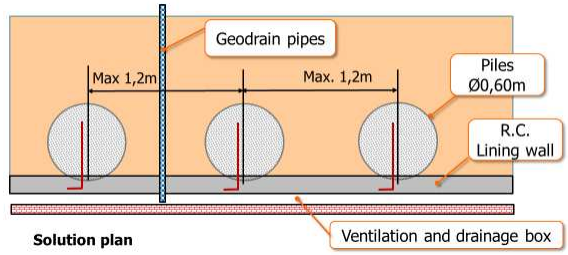

Figure 6. Plan of the adopted solution

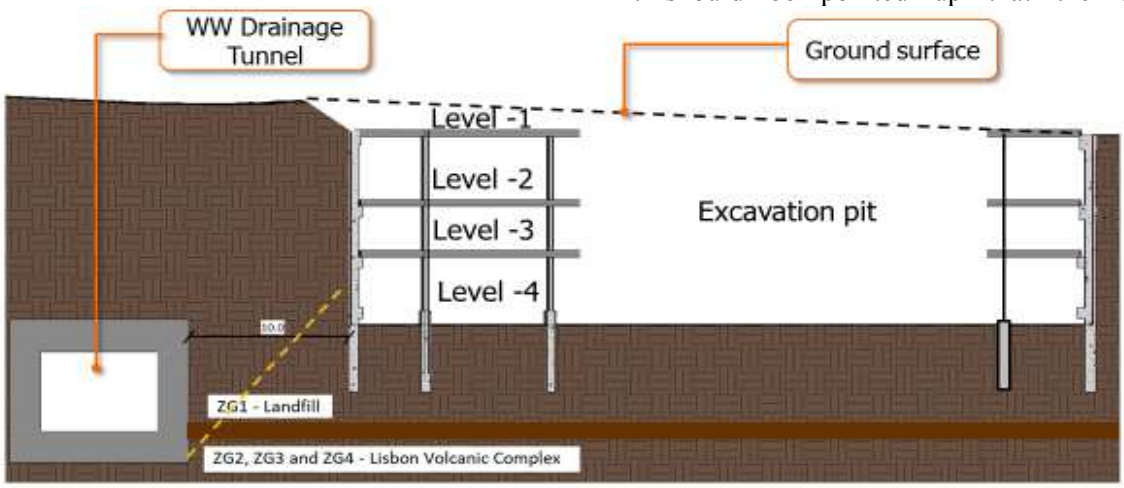

Figure 7. Cross section of the adopted solution at the North side

The BPW was braced, at each floor level, by reinforced concrete slab bands and temporary ground anchors (West side). The soil located between the pile faces will be lined by a shotcrete layer of 80mm minimum thickness. At each excavation phase, corresponding to about 3m depth, geodrains, with a minimum of 50mm diameter, will be installed with at least 3.60m plan distance to ensure the wall drainage (Figures 5, 6 and 7).

In the West front, the wall will be braced by one level of temporary ground anchors. at level -2, spaced in plan 3.60m. As mentioned, the remaining excavation sides will be braced by slab bands, with 12m width and 35cm minimum thickness, compatible with both the architectural and the structural solutions. The slab bands will ensure a stiff bracing to the solution and will be incorporated on the basements final structure (Pinto, 2017).

These slab bands will temporarily be supported by vertical steel profiles HEB260 embedded inside 600mm piles, with an embedment of about 4m below the excavation final level. The slab bands above level -2 will be braced by reaction slab strips, which will react against the BPW at the West side, where the volcanic complex is closest to the ground surface (Figure 8).

It should be pointed up that the very heterogeneous geological and geotechnical scenario, ranging from heterogeneous fills to basalts (W3 an F3), associated to the demanding neighbor conditions, mainly the wastewater tunnel and the roadway viaduct, lead to the adoption of a BPW solution, bracing at both the tunnel and the viaduct sides by slab bands, as main consequence eliminating the need for the use of temporary ground anchors.

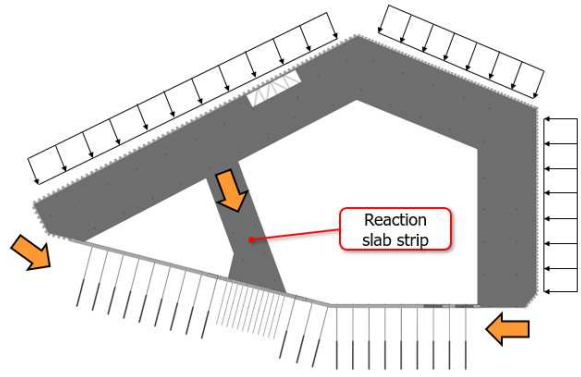

Figure 8. Plan view of the level -2.

4 DESIGN

The architecture project was available in a 3D BIM model and it was used as a base for the modeling and design of the retaining solution, allowing to explore some of the advantages of the BIM methodology (Figure 11). The existing topography was modeled in the BIM software Revit 2018 and then, the architecture model was linked to the file, allowing a geographic and geometric coordination (Figure 9).

Figure 9. Architecture and geotechnical coordinated 3D models

The designed solution was adjusted with the support of a finite element software (PLAXIS2D). The solution was analyzed in terms of stresses and displacements considering the geotechnical zones and its corresponding parameters (Table 1).

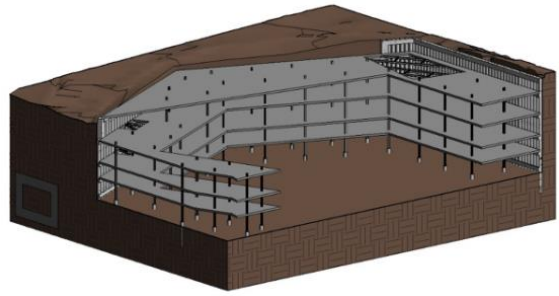

Figure 10. Perspective of the 3D BIM model

The geometry from the BIM model was exported to the structural analysis software (SAP2000) using the standard IFC file type and the stresses obtained from the PLAXIS2D were introduced in the model. The retaining solution was then iteratively optimized according to the stresses and displacements obtained from the analyses (Figures 12 and 13).

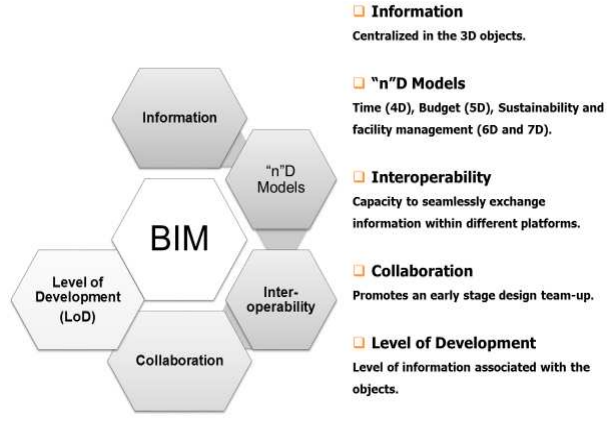

Figure 11. BIM concept

When the design and corresponding 3D model were completed, the earthwork quantities were readily available, the same for the structural elements. The length of each steel profile and volumes of concrete used for the bored piles, slab strips and beams could be accurately estimated. This is because the BIM methodology is based on parametric modeling which means that each design element can host relevant data that can be used through all the project lifecycle.

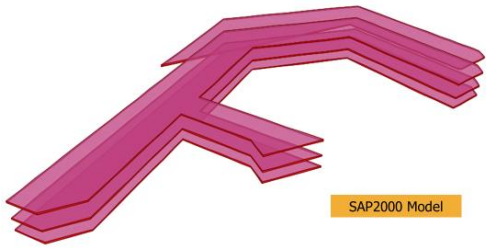

Figure 12. SAP2000 3D model for the slab bands

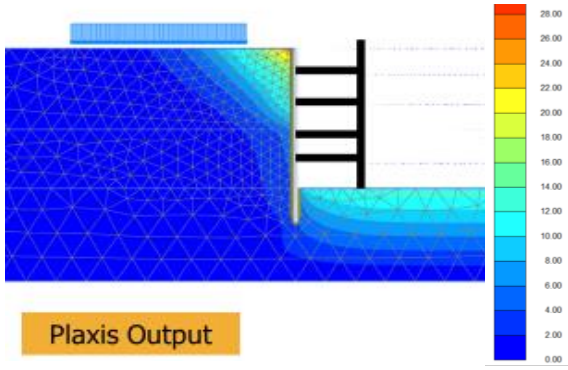

Figure 13. Plaxis 2D output: horizontal displacements for the South side cross section (x10^{-3} m)

5 MONITORING AND SURVEY PLAN

As usual in complex geotechnical works, the adopted solution should be confirmed, and the design geotechnical parameters will be calibrated considering the observation of the solution behavior on site. For this purpose, during the excavation works, a complete monitoring and survey plan will be implanted on both the BPW and neighbor structures and infrastructures, using mainly the following devices: inclinometers, topographic prisms and load cells.

Alert and alarm criteria will be accessed considering the predicted displacements at the design stage. If the criteria will be overpassed, reinforcement measures will be adopted.

6 FINAL REMARKS

In spite of the excavation works are predicted to start by the summer of 2019, the authors believe that the adopted solutions will have a good performance, from both technical and economic perspectives, and mainly the deformations control through the use of the bracing slabs bands concept, which is being used in Lisbon from about 15 years ago.

The presented case confirmed also that the use of the BIM methodology (Fig. 14) allowed an accurate coordination with the architecture project and promoted efficiency in terms of project documentation, especially when changes in the design were needed. The interoperability among software allowed that the geometry from the 3D BIM model could be exported, avoiding the remodeling and possible geometry inaccuracies. The 3D visualization of the project and the restrains helped to find and optimize the overall engineering solutions.

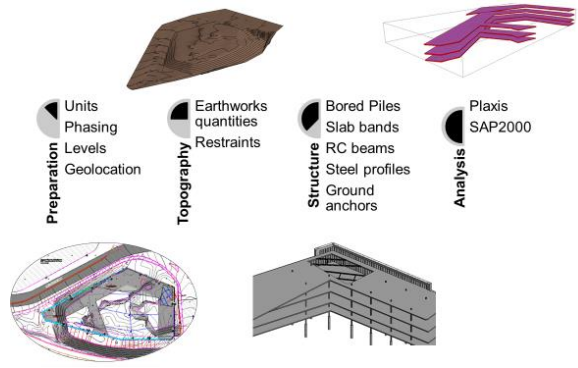

Figure 14. BIM methodology

7 ACKNOWLEDGEMENTS

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