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SPECIAL FOUNDATION SOLUTIONS FOR THE MAIN STAGE OF THE WORLD YOUTH DAY 2023, IN LISBON

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ABSTRACT

This paper presents the foundation solutions adopted for the main stage of the World Youth Day 2023 in Lisbon. The stage was built above the old municipal solid waste landfill, sealed at the top by a HDPE geomembrane. This geomembrane restricted the use of deep foundation methods with impact on the urban solid waste landfill. The waste deposit rests over an alluvial layer, with weak geomechanical properties and variable thickness ranging about 12m at the main stage area. To mitigate differential settlements that could harm the structure behaviour during its set up and further utilization, a temporary preload landfill was built to anticipate settlements before the stage's installation. During the preload phase, several monitoring campaigns were carried out with readings of topographic marks to calibrate the initial design assumptions. Based on the data obtained from the monitoring and on-site tests, the foundation solution for the stage was defined and designed. The foundation system for the main structure incorporates pre-cast hollow slabs, that can be reused after the event, and ductile iron driven micropiles. For the main stage cover, the foundations solution includes also ductile iron driven micropiles, reinforced with a central self-drilling bar, properly sealed into the Miocene layer at depth bigger than 30m, to accommodate tension loads.

Keywords: micropiles, self-drilling rod, foundation, preload landfill.

INTRODUCTION

For the World Youth Day 2023 event, a stage needed to be constructed at Parque Tejo, Lisbon. However, the chosen location was challenging, because it was situated on an urban solid waste landfill. Beneath the landfill, separating it from the competent Miocene substrate, lay a layer of sludgy materials characterized by low strength and high deformability. As a result, it became essential to develop a suitable foundation solution to ensure the structural stability of the installation.

To address this issue, a pre-loading embankment was installed at the location where the stage would be supported by direct foundations. Due to the increased load, some parts of the stage and its covering required the use of indirect foundations.



Figure 1 Location of the main stage

To confirm the feasibility of the proposed solution, tests were performed on self-drilling micropiles within the embankment. Figure 1 illustrates the location of the structure and its surroundings.

MAIN CONSTRAINTS

The target intervention area was situated in a low, flat region on the right bank of the Tejo estuary. The Main Stage was built on the Beírolas landfill, which comprises contaminated soil deposits and urban waste, forming a heterogeneous landfill layer with silty-clay materials mixed with sand and rubble of artificial origin. As the site nears the river, the thickness of this artificial landfill layer gradually decreases until it disappears within the tidal zone.

Beneath the artificial landfill, an alluvial formation emerges, consisting of compressible silty mud soils with highly variable thickness throughout the Beírolas landfill area. In the stage area, the depth of these silty mud soils increases from 2 meters to 25 meters as it moves toward the river, while remaining relatively constant in the north-south direction. Below the layer of clayey mud lies the Miocene formation, composed of sandstones, calcareous sandstones, and limestones, with occasional marly levels.

In addition to the geological and geotechnical constraints, there were also constraints related to environmental issues. When designing the foundation solutions for the stage, deep

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foundations were ruled out from the start because the geomembrane protecting the landfill made them unsuitable. Furthermore, the removal of contaminated soil was considered inadvisable. This premise applied to the entire intervention area, except for the rear section of the stage – the southern zone – where indirect foundations were deemed necessary to accommodate the significant loads to be transmitted to the foundation and the maximum allowable deformations.

Moreover, during the development of foundation solutions, the temporary nature of the stage structure was considered, as it would eventually be dismantled. Therefore, a solution was chosen that prioritized ease of disassembly, enabling the reuse of components in future projects.

ADOPTED SOLUTIONS

The solution involved constructing a pre-load embankment with a height of 3.20 m in the stage installation area. The embankment was built using material with a bulk density of approximately 20 kN/m³. The primary objective of this pre-load embankment was to reduce the settlements that could occur during the stage assembly and operation.

The embankment remained in place for 90 days, during which it experienced a maximum settlement of 25 cm. To verify the design assumptions and predict settlements during stage assembly, a total of 16 settlement markers and 2 extensometers were installed during the pre-load phase.

The results for markers are presented in Figure 2. Figure 3 shows the location of all settlement markers installed within the pre-load embankment area, highlighting 2 extensometers also installed.

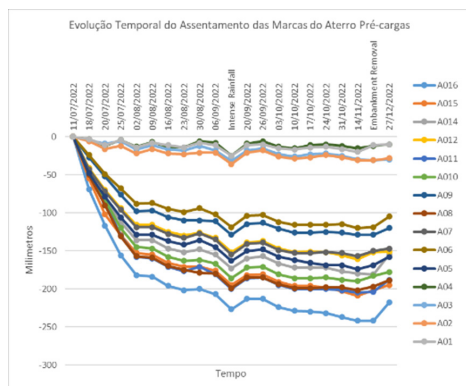


Figure 2 Time-Strain Graph. Instrumentation of the Pre-load Embankment Zone

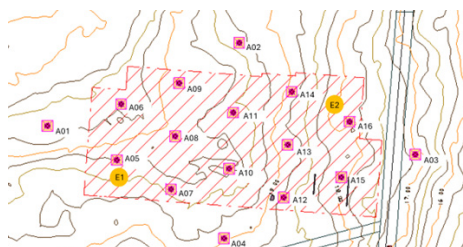


Figure 3 Location of the settlement markers and extensometers

Based on the results obtained after the removal of the preload embankment, a foundation solution was developed. To maximize the uniformity of load transmission to the ground, the recommended solution involves the construction of a foundation slab consisting of precast hollow-core slabs with a minimum thickness of 30 cm. Due to the increased magnitude of loads in certain alignments and the irregular geometry of the foundation masses of the stage's roof, it was necessary to recommend an in-situ concrete foundation solution in these areas. Thus, the solution is divided into 4 different types:

- Current area: Solution with hollow-core slabs simply supported on precast peripheral beams with an L-shaped or rectangular section, depending on the existing level difference.
- Periphery of the stage roof foundation: Solution consisting of an in-situ concrete slab with a thickness of 30cm.
- Rear alignments - East and West zones: Solution consisting of an in-situ concrete slab with a thickness of 25cm.
- Rear alignments - central zone:

Foundation beam with a section of 1.65x1.20 m² supported on ductile iron driven piles with a section of 170x7.5mm filled with C35/45 concrete and 3ø32mm bars inside. The foundation solution in this area was coordinated with the foundation solution of the stage roof, excluded from the scope of this article.

Figure 4 presents the 3D model of the entire foundation solution. Figure 5 was taken during the construction phase, where we can see the assembly of the hollow-core slabs.

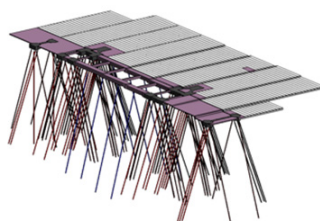


Figure 4 3D view of the stage and roof foundations



Figure 5 Precast hollow-core foundation slabs
DRIVEN MICRPILES FULL SCALE LOAD TESTS

Due to the uncertainty regarding the performance of micropiles installed in this type of material, very heterogeneous, it was essential to conduct load tests to confirm the design assumptions. Two full-scale tests were therefore carried out, one under compression and the other under tension. The tested micropiles were instrumented internally using strain gauges attached to a $\phi 16\text{mm}$ rod.

For the full scale tension test, the reaction structure was a reinforced concrete mass, approximately $2.5\text{m} \times 2.5\text{m} \times 1\text{m}$ in size, as shown in Figure 6. The tested micropile had a length of 30.50m , reaching the Miocene substrate, and the self-drilling interior micropile had a length of 41.5m with an approximately 10m grout bonding length in the Miocene layer (Bustamante and Doix, 1985). The planned test load was 850kN . The load test was conducted with four loading cycles up to the maximum load of 922kN . Additionally, a fifth loading cycle was performed up to 1598kN to test the load-bearing capacity of the sealing in the Miocene layer. Even after reaching the load of 1598kN , no failure was observed.



Figure 6 Full scale tension load test

For the 922kN test load, a strong response was observed in all loading cycles, with a plastic deformation of approximately 13mm and a maximum deformation of 33mm . In the 5th loading cycle, a total deformation of about 59mm was observed, with a residual deformation of 20mm . A set of strain gauges was installed at depths of 2.5m , 10m , 20m , 26m , 30m , and 38.5m , particularly at the transition between the embankment and the alluvial stratum.

The consistency of results in the 4 loading cycles is noticeable, with pressure curves parallel to

each other. The top of the alluvial stratum is at 20m depth, which is consistent with the results of the boreholes conducted on-site. It is observed that 50% of the load is transmitted to the embankment, and 30% of the grout bonding length was not engaged. However, due to the significant heterogeneity of the embankment material, it was considered that the sealing length should not be less than 10m (Bustamante and Doix, 1985), to accommodate the entire tensile load.

The main results of the conducted test are shown in Figure 7.

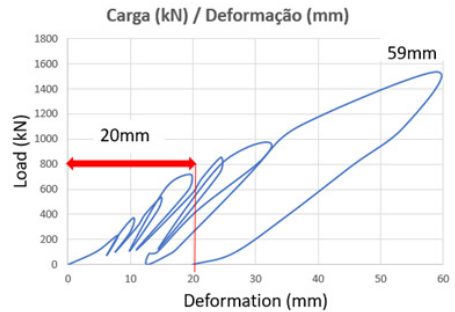


Figure 7 Load-displacement graph at the head.
Tension load test

For the compression load test, the reaction structure was constructed with steel profiles supported by 4 micropiles similar to the tested micropile in tension. The structure is illustrated in Figure 8. The tested micropile had a length of 34.00m , reaching the Miocene layer. The planned test load was 1820kN . Despite extreme care in aligning the jack with the axis of the micropile, instability of the micropile head mass was observed above a load of 1400kN with horizontal displacement of the mass to the west and north. Despite the rotation of the mass when the load exceeded approximately 1400kN , a continuous increase in load capacity of approximately 300kN was observed up to 1723kN .



Figure 8 Reaction structure for the compression full scale load test

The main results of the conducted test are shown in Figure 9.

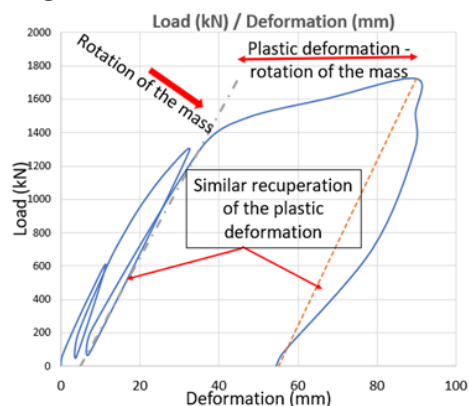


Figure 9 Load-displacement graph at the head.
Compression load test

A set of strain gauges was installed at depths of 2.5m, 11m, 20m, 23m, 28m, and 33m, particularly at the transition between the embankment and the alluvial stratum. There is consistency in the results in the 4 loading cycles with pressure curves parallel to each other. It is clearly observable that the top of the alluvial stratum is at an elevation of 23m, which is consistent with information from boreholes conducted on-site. There was a significant load transmission capacity to the embankment with a firm response between 2.5m and 11m and a very good response between 20m and 23m depth. Between the depths of 11m and 20m, the load transmission to the embankment was negligible. The mobilized tip load is estimated to be around 600kN for a load on the order of 1700kN. It is estimated that the compressive capacity of the pile formed by the ductile iron outer micropile and the self-drilling inner bar is above 1800kN, with a plastic displacement of about 20mm and 40mm when subjected to a load of 1800kN.

CONCLUSION

The purpose of this article is to present the foundation solution for the main stage of World Youth Day, highlighting the various constraints that guided the choices and decisions made.

Considering the constraints previously described, as well as the load tests results, the chosen solution consisted of a foundation slab with a minimum thickness of 30cm, designed to be removable after the event. In the areas subjected to higher loads, the solution transitions from direct to indirect foundations using ductile iron driven micropiles, topped with foundation beams measuring 1.65 x 1.20m, interconnected by perpendicular beams with cross-section of 0.40 x 0.80m.

To verify the design assumptions related to the foundation micropiles, two load tests were performed at the stage location, one in

compression and the other one in tension. The results obtained provided early validation of the primary design assumptions, confirming the adequacy of the solution in the local geological and geotechnical context. The suitability of the adopted solution was confirmed through the full scale load tests, continuous monitoring throughout the construction process, and detailed analysis of the micropile driving outcomes.

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