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Ground improvement solutions at the plot 14 of the Northern Lisbon logistic platform

Solutions d'amélioration du sol sur le lot 14 de la Plateforme Logistique du Nord de Lisbonne

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ABSTRACT: The present work addresses the ground improvement solutions adopted for the soft soils as foundation of the future industrial warehouse, to be built at the plot 14 of the Northern Lisbon Logistic Platform, at Castanheira do Ribatejo, Vila Franca de Xira, Portugal, comprising an area of 49 813 m^2. A description of the existing conditions is made, particularly of the geological-geotechnical scenario, highlighting the existence of an alluvial layer, with clayed soft soils, with low characteristics of strength and stiffness as well as very low average permeability. The solution adopted consists in the execution of preload embankments associated with (i) stone columns, executed at the area of the warehouse indoor pavements, and (ii) vertical prefabricated geodrains, at the area of the outdoor pavements, in the places designed for car parking and circulation of light and heavy vehicles. This article describes the criteria and methods used at the design of the preload fills, seeking to reduce the hydrodynamic consolidation schedule. The Monitoring and Survey Plan and respective results are also presented.

RÉSUMÉ: Le présent travail traite des solutions d'amélioration du sol adoptées pour les sols meubles comme fondation du futur entrepôt industriel qui sera construit sur le lot 14 de la plate-forme logistique du nord de Lisbonne, à Castanheira do Ribatejo, Vila Franca de Xira, Portugal et qui comprend une superficie de 49 813 m^2. Une description des conditions existantes est faite, en particulier du scénario géologique-géotechnique mettant en évidence l'existence d'une couche alluviale et de sols meubles et argileux, aux faibles caractéristiques de résistance et de rigidité, ainsi qu'une très faible perméabilité moyenne. La solution adoptée consiste à l'exécution de remblais de pré chargement associés à (i) des colonnes ballastées exécutées dans la zone d'entrepôt des trottoirs intérieurs et (ii) des geodrains préfabriqués verticaux au niveau des trottoirs extérieurs aux endroits prévus pour le stationnement et la circulation des véhicules légers et lourds. Cet article décrit les critères et méthodes utilisés lors de la conception des remblais de pré chargement cherchant à réduire le temps de consolidation hydrodynamique. Le plan d'observation et de surveillance et les résultats respectifs sont également présentés.

Keywords: Ground improvement; soft soils; preloading embankments.

1 INTRODUCTION

The Northern Lisbon Logistic Platform (NLLP) is located at Vila Franca de Xira, Portugal, in an area of approximately 1 000 000 m^2. This platform was built with the intend of creating an interconnection point for international, national, and regional logistical flows within the Lisbon and Tagus Valley region.

On plot 14 of the stated platform, the construction of a new industrial building is expected, with an area of approximately 32 968 m^2. In the aerial view in Figure 1, it is possible to identify the target area for intervention, as well as the limits of the NLLP.

2 GEOLOGICAL AND GEOTECHNICAL CONDITIONS

The area is located on the right bank of the Tagus River, dominated by the alluvial soils of the Lower Tagus, ancient deposits of river terraces and, in depth, by soils dating from the Miocene.

Figure 1. Aerial view of the construction site (image taken from Google Earth).

According to the information obtained during the geotechnical investigations, it is confirmed that the local geological-geotechnical scenario is characterized, superficially, by a layer of landfills, developing to a depth variable between 1.1 m and 3.4 m. According to the available sampling, it is a heterogeneous layer made up of silts with calcareous gravel.

Immediately below the layer of landfills, to a maximum depth of 20,0 m, there are alluvial deposits, essentially made up of soft silts and very soft high plasticity clays, with a high content of organic matter and shell fragments.

Underlying the alluvial layer, colluvial formations can be identified, composed of sandy clays of medium consistency with rounded heterometric gravel of an essentially quartzite nature.

The position of the water table is dependent on the water level in the Tagus River, being influenced not only by seasonal variations, but also by the daily tidal cycles felt in the estuary. During the prospecting geotechnical works, the presence of the water table was detected at a depth varying between 1.3 m and 3.4 m, generally occurring at the level of the interface between the natural terrain and the overlying landfills.

3 GROUND IMPROVENT SOLUTIONS

Given the presence of soft clayey soils, with low strength and stiffness, as well as reduced support capacity, and considering the extended period available for the execution of the works, it was decided to implement ground improvement solutions with the aim of increasing the geomechanical characteristics of the foundation soils, thus providing favourable conditions to obtaining total and differentials settlements compatible with the good performance of the pavements during the service lifetime of the new industrial building.

In this context, a consolidation ground improvement solution was adopted using preload embankments.

To accelerate the process of hydrodynamic consolidation of the compressible materials (soft clayey soils), the introduction of drainage elements was considered, namely, stone columns, at the area of the warehouse indoor pavements, and prefabricated vertical drains (PVD), at the area of the outdoor pavements, in the places designed for car parking and circulation of light and heavy vehicles. It should be noted that the stone columns were installed in a previous work in 2010, while the PVD were installed more recently in 2022.

Considering the magnitude of the predicted service load in the indoor and outdoor pavements (50 kN/m^2 and 20 kN/m^2, respectively), it was proposed to build 8.0 m and 4.0 m high embankments, with slopes H=1.5; V=1.0.

The stone columns were arranged in a square array with 3.0 m centre-to-centre spacing. The PVD were installed in a triangular arrangement with 1.2 m spacing. Both these elements were executed up to an estimated average depth of 20.0 m, in relation to the work platform elevation.

In Figure 2 the typical cross section of the consolidation ground improvement solution is presented.

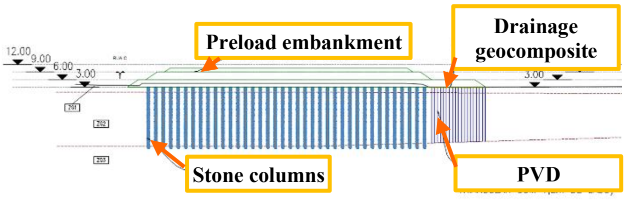

Figure 2. Typical cross section of the consolidation ground improvement solution (not to scale).

Given the presence of a surface layer of landfills, the execution of the PVD required pre-drilling works (Figure 3).

Figure 3. Installation of the prefabricated vertical drains.

After the installation of the PVD, and prior to the execution of the pre-load embankments, a drainage geocomposite responsible for directing the inflowing water to the vertical geodrains was applied (Figure 4).

Figure 4. Aerial photograph of the drainage geocomposite installation.

Figure 5 shows an aerial photograph of the preload embankments.

Figure 5. Aerial photograph of the preload embankments.

4 DESIGN

4.1 Settlements

The total settlement of the compressible soil as a result of the increase in vertical stresses can be calculated by adding the portions corresponding to (i) the immediate settlement, produced during construction in undrained conditions, therefore without volume variation; (ii) primary settlement, resulting from the expulsion of water due to the dissipation of excess pore pressure, during the development of the primary consolidation process; (iii) and secondary settlement, corresponding to the continuation of soil deformation after conclusion of primary consolidation, corresponding to secondary consolidation or creep.

For the problem under study, immediate and primary consolidation settlements were considered.

The value of immediate settlement was estimated, adopting, for the foundation soil, an isotropic linear elastic behaviour at constant volume and carefully choosing the deformability modulus in undrained conditions.

The methodology for calculating settlements by primary consolidation included the application of Terzaghi's theory of one-dimensional consolidation, associated with a two-dimensional distribution of loads transmitted to the ground.

For this purpose, the settlement by primary consolidation was estimated based on the parameters obtained in the oedometer laboratory tests, discretizing the compressible stratum into layers, and estimating the total settlement considering the variation in effective stresses in depth.

The stress increments for the stated calculation and, as such, for definition of the height of the preload embankments, were determined, considering the self-weight of the embankments (temporary and permanent), the self-weight of the pavement slab and the different service loads. It should be noted that in this estimate second-order effects associated with the expected settlement of landfills were considered.

The estimate of the duration of the primary consolidation process involved calculating the estimated vertical and horizontal consolidation times and subsequently the total value resulting from these two mechanisms.

Having knowledge of the total settlement value associated with a given embankment height, as well as the law that governs its evolution over time, it was possible to estimate the settlement evolution curves over time shown in Figure 6.

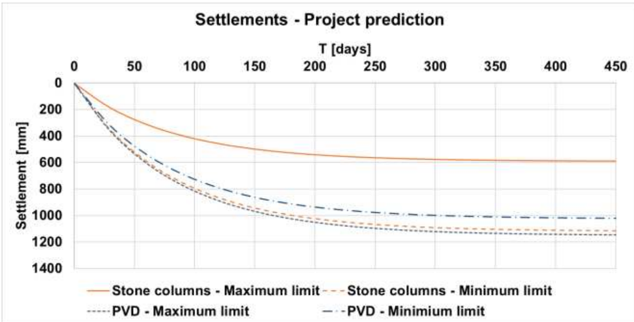

Figure 6. Primary consolidation settlements prediction at design stage.

4.2 Slope stability

As part of the verification of the global stability of the pre-load embankment slopes and the bearing capacity of the foundation, including the quantification of safety factors, an automatic calculation program designed for this purpose was used: SLIDE (V6.0) which allows carrying out analyses in a limit equilibrium regime. This software made it possible to carry out a stability analysis, using circular failure surfaces based on the Bishop-Simplified Method. Two-dimensional finite element analysis was also carried out in parallel using the PLAXIS 2D software.

5 MONITORING AND SURVEY PLAN

To guarantee the carrying out, in safe conditions, of the ground improvement works, mainly the stability of the embankments/foundation and the evolution of settlements/degree of consolidation, a Monitoring and Survey Plan was employed.

In this context, it was considered essential to monitor the following quantities:

a) Water levels installed on the ground, through the installation of 72 vibrating wire piezometers, arranged in a total of 18 locations, at 4 different depths.

b) Horizontal movements of the ground measured using 6 inclinometers, arranged on the periphery of the embankments.

c) Surface settlements of the natural terrain and embankments/platforms, through the measurement of topographic marks supported on 52 settlement plates.

Figures 7 and 8 show, respectively, the vertical displacements measured in the settlement plates, recorded until March 9, 2023, in the area where the stone columns and PVD were built.

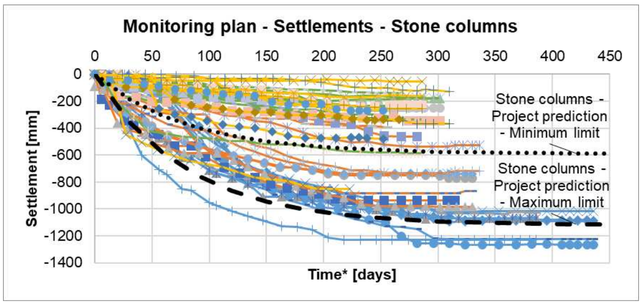

Figure 7. Observed settlements – stone columns.

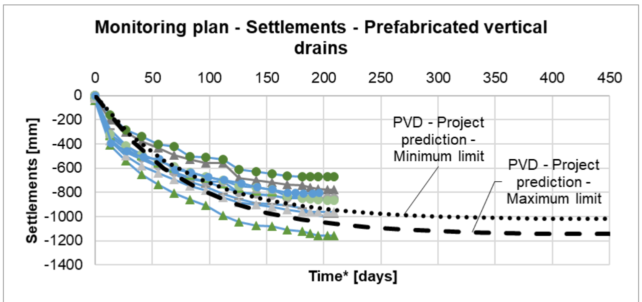

Figure 8. Observed settlements – prefabricated vertical drains.

Regarding measurements of water levels and horizontal displacements, it is important to note that the late installation of piezometers and inclinometers did not allow for a complete record of these quantities to be obtained from the beginning of the construction of the pre-load embankments. Nevertheless, the evolution recorded is in accordance with the project prediction, particularly regarding the reduction, over time, of pore water pressures tending towards values that are close to the hydrostatic distribution. Regarding the recording of horizontal displacements, the mobilization of displacements of greater magnitude was observed at the depths corresponding to the existence of the soft clayey stratum, with a higher rate of evolution during the construction period, which stabilized after the end of the construction of the embankments.

6 FINAL REMARKS

The framework of the work described, including the available time, determined the need to develop innovative ground improvement solutions aiming to provide favourable conditions for the future employment of economic foundation solutions, compatible with the structure serviceability, not only on plot 14, but also on adjacent plots, taking profit of both soil behaviour knowledge (from monitoring results) and existent preloading embankment.

In this context, it should be noted that the adopted solutions make it possible to mitigate, during the life of the future industrial structure, high magnitude settlements, resulting from the primary consolidation process, developed at the level of soft clayey alluvial layers.

The importance of the Monitoring and Survey Plan in managing the behaviour of the work is highlighted, allowing the interpretation of the observed settlements and the establishment, with greater accuracy, of the time necessary to obtain the specified degree of consolidation. As such, it is an indispensable tool in a geotechnical work, with the characteristics of this one.

It is noted that the magnitude of settlements estimated at the project stage, in general, was in line with the values measured on site. The exception to this statement were the settlements recorded in the NW area of the plot, where the stone columns were installed, and where settlements of a magnitude considerably lower than the values recorded and estimated for the SE area were observed. This difference is attributed to the effect of the prolonged presence of previously constructed pre-load embankments, as well as the effect of reinforcing the ground provided by the stone columns.

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