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FOUNDATION SOLUTIONS FOR AN INDUSTRIAL PLATFORM BUILT ON CONTAMINATED SOFT SOIL

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Abstract

The paper presents the optimal solutions for the foundation of an industrial platform built on an old tailings pond consisting of drilling wells residues. The study of the foundation solutions was carried out based on the properties of the foundation soil from the site and based on pressures applied to the foundation soil by the industrial platform. Geotechnical properties were determined based on soil samples taken from 10 geotechnical boreholes with depths between 6 and 15 m. The paper analyzed the direct and indirect foundation solutions. In the hypothesis of direct foundation solution, the construction of the industrial platform was analyzed in the case of natural and improved foundation soil. Based on technical-economical point of view, two foundation solutions were detailed in the conclusions chapter.

Key words: *contaminated soft soil, industrial platform, drilling waste, foundation solution.*

INTRODUCTION

On contaminated sites, physical and mechanical properties of foundation soils suffer some changes that can lead to the loss of stability of embankments or significant settlements of the constructions. In this case, it is necessary to determine the geotechnical properties of the contaminated soils in order to estimate properly the effect of pollutant contamination on the constructions to be built (Dumitru et al., 2016; Olinic, 2016).
The paper presents the optimal solution for the foundation of an industrial platform built on an old tailings pond consisting of drilling wells residues. The study of the foundation solutions was carried out based on the properties of the soils from the site and based on the pressures applied to the foundation soil by the industrial platform.

MATERIALS AND METHODS

A preliminary geotechnical study was carried out on site and, according to this, the foundation soil consists in a filling layer (drilling wells residues) of 3.00-4.00 m thickness and a silty clay with stiff consistency.

In order to establish the foundation soil properties, a new geotechnical study was carried out, and were taken samples from 10 geotechnical boreholes with depths of 6.00-15.00 m. Due to the massive dimensions of the fillings of construction materials waste, several boreholes were blocked at depths between 2.50 and 4.00 m (Figure 1).

Figure 1. The position of the geotechnical boreholes (red points - existing boreholes, blue points - blocked boreholes) (Google Earth)

The groundwater level was identified as infiltrations in some of the boreholes conducted at depths between 2.60 and 6.30 m.

GEOTECHNICAL PROPERTIES

From the granulometric point of view, the filling layer is composed of predominantly cohesive or low cohesive materials in a clayey - silty clay matter, materials that have low - medium - high plasticity (I_P = 12.0 ÷ 33.2%) and are in a state of plastic to stiff consistency (I_C = 0.61 ÷ 1).

The natural foundation soil, beneath the soil fill, is composed of cohesive materials such as sandy clay, clay, fat clay, silty clay, clayey sand, with high and very high plasticity (I_P = 21.2 ÷ 58.6%) in a state of consistent plastic to stiff consistency (I_C = 0.48 ÷ 0.9). The stratification is complex, not a parallel and horizontal one.

In order to establish the optimal foundation solution, an essential geotechnical property is the compressibility of the foundation soil (Sridharan & Gurtug, 2005).

Figure 2 shows all the compressibility tests performed on samples from the filling or from the natural foundation soil. The oedometric deformation modules between the steps of 200 and 300 kPa ($E_{oed200-300}$) are grouped and divided on calculation layers, as follows:

- 0.00 ÷2.00 / Layer 1 - clayey sand - sandy clay, with high plasticity, in a state of consistent plastic to stiff consistency, with a high to very high compressibility ($E_{oed200-300}$ = 4695 ÷ 6211 kPa).
- 2.00 ÷ 4.00 / Layer 2 - clay, with high and very high plasticity, in a state of consistent - stiff consistency, with a medium to high compressibility ($E_{oed200-300}$ = 8850 ÷ 11236 kPa).
- 4.00 ÷ 6.00 / Layer 3 - clay, with a very high plasticity, in a state of consistent - stiff consistency, with a medium to high compressibility ($E_{oed200-300}$ = 8929 ÷ 13158 kPa).
- 6.00 ÷ 10.00 / Layer 4 - silty clay – clayey sand, with high and very high plasticity, in a state of consistent plastic to stiff consistency, with a high to very high compressibility ($E_{oed200-300}$ = 5848 ÷ 7042 kPa).

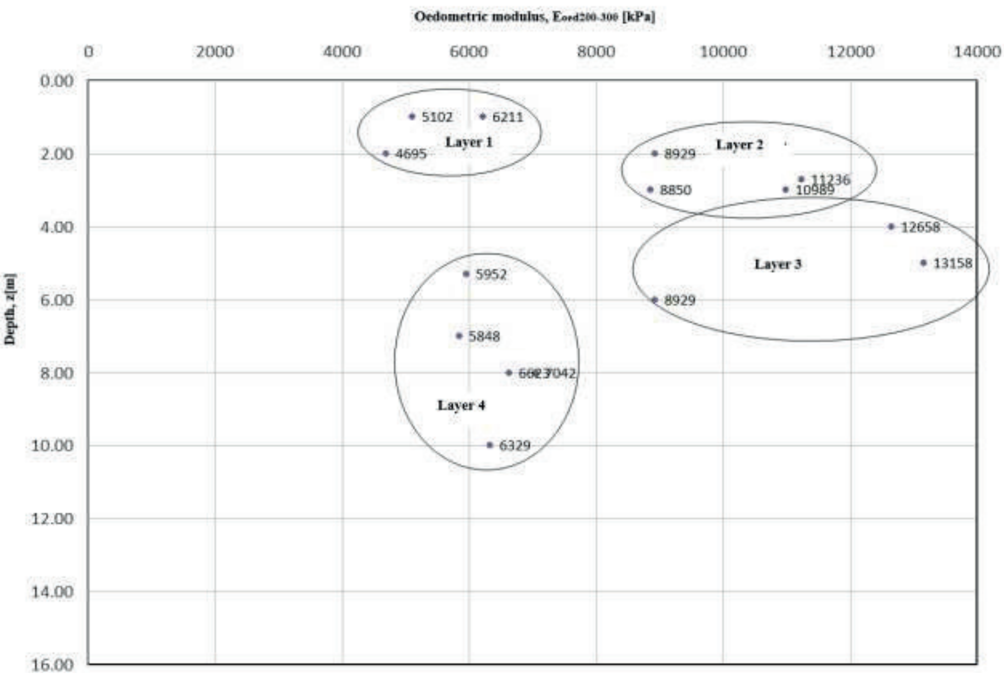

Figure 2. The variation of the oedometric deformation modules on depth

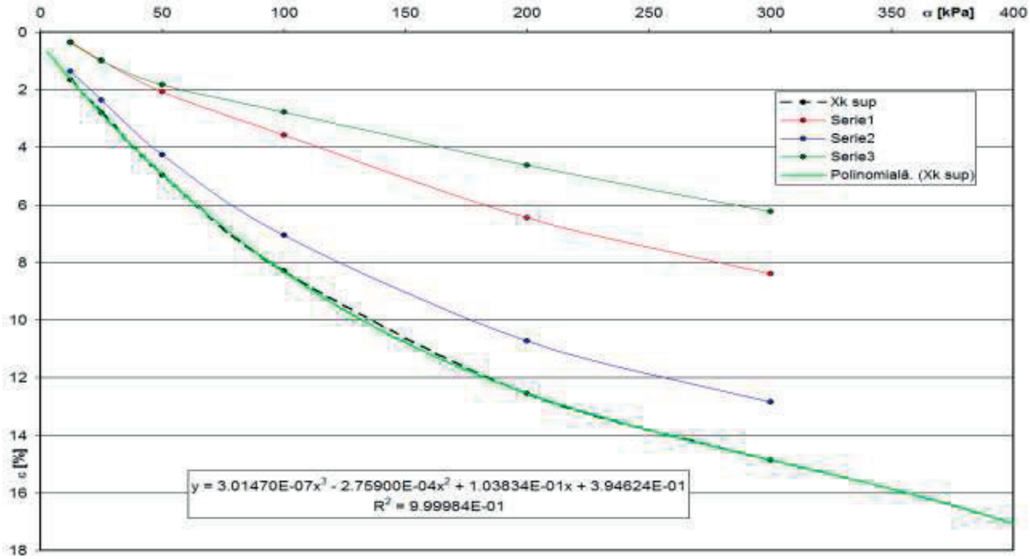

Figure 3. Layer 1 - Oedometric curves and stress - strain relationship of characteristic values

For each previously defined calculation layer, the specific characteristic settlements under each loading stage were calculated and, in a comprehensive way, the superior characteristic values were selected and the functions that best approximate the strain-strain relationship were identified (Figure 3) (NP 122:2010, NP 112:2014).

These stress-strain relationships, which were previously affected by the M_0 coefficient (which makes the transition from the oedometric strain modulus to the elastic modulus), were introduced in specific settlement calculations (M_0 = 1 for layer 1 and M_0 = 1.5 for layer. 2, 3 and 4) (SR EN 1997-1:2004).

Following the analysis of the loads and pressures at ground level transmitted by the equipment which will be positioned on the industrial platforms, the settlement calculations were performed for the hypothesis considered the most unfavourable, namely: metal jacks, contact surface 1.135 x 5.142 m and a field pressure of 243 kPa.

FOUNDATION SOLUTIONS

On the site, will be built a platform with an area of 6659 m^2, from which the northern area would be founded on natural soil and the southern area on the former tailings pond. Thus, the platform will be constructed on improved soils (STAS 2914-84) which cover an area of approx. 4360 m^2.

Considering the nature of the foundation soil and the type of request loads to the foundation soil, with significantly higher loads in the execution stage of the wells than in their exploitation stage, the following foundation solutions were distinguished:

- Direct foundation on natural soil - for comparison with engineering solutions that follows:
- Direct foundation on improved ground:
  - Improved on the entire soil fill thickness
  - Partially, improved on the surface (cushion of compacted granular material)
- Indirect foundation on piles.

Table 1. Analysis of foundation solutions

Foundation solution	Analysis/feasibility
Direct foundation on natural ground	Settlement, s = 16.7 cm Due to the very high value of settlement, this solution is not viable and, practically, argues the reason for the need to find an alternative foundation solution.
Direct foundation of controlled compacted cushion made from granular material	The solution was analyzed in two cases: **filling** over the current level of the natural land (after removing the topsoil) and **excavation** with return to the level of the natural land by controlled compacted fill. In each case were considered cushion thicknesses of compacted granular material of 1 and 2 m. **Filling** / **Excavation** H = 1 m, s = 11.7 cm / H = 1 m, s = 8.5 cm H = 2 m, s = 8.9 cm / **H = 2 m, s = 3.6 cm** The results of the settlement calculations shows that the most efficient solution is to remove a filling layer with a thickness of approx. 1.5 m to limit the settlement to about 5 cm.
Ground improved by dynamic compaction	This method is especially effective on non-cohesive soils in dry or wet state (degree of compaction, Sr <0.6). The existing foundation conditions are practically saturated cohesive soil, in which this technique has a low efficiency.
Improved ground with ballast/concrete columns (rigid elements)	The method is efficient in the given conditions of the location. Two variants were analyzed: columns of coarse granular material (ballast, broken stone) on the depth of the active area (approx. 7 m below the base of the foundation) considering: columns with a diameter of 65 cm, in a square network with a distance of 1.5 m. Thick cushion, H = 1 m **Filling** / **Excavation** s = 6.9 cm / **s = 5.1 cm** The optimal method would be to remove 1 m of the filling, return to the level with a compacted cushion realized by granular material and execution of columns with a length of 7 m, below the lower level of the compacted cushion.
Ground improved by deep mixing (deep chemical mixing)	The method is effective in cohesive soils with high water content (the case of this site). However, the presence of petroleum substances in the soil makes the chemical hydration reactions of the hydraulic binder not as strong as in the case of uncontaminated soil. The costs of this solution may be similar to columns of granular materials.
Ground improved by injections	The method is effective in non-cohesive or poorly cohesive, loose soils. In practically saturated cohesive soils (the case of the present location) the dispersion of the injected material in the soil mass is not achieved and practically some cement columns with insufficient diameter are obtained in order to improve the average compressibility characteristics of the soil mass.
Indirect foundation on piles	It is the simplest, but also the most expensive method; this method significantly limits settling. The piles must be embedded/supported in a good foundation layer, which was not intercepted to a depth of 15 m.

CONCLUSIONS

Considering the nature of the foundation ground (complex stratification, not a parallel and horizontal one), the rigid elements intercepted at different depths, the shape of the old tailing pond (identified after performing geotechnical investigations, Figure 4.a), the foundation on a compacted cushion made by granular materials could generate differentiated settlements. From the technical point of view, the optimal foundation solution becomes: foundation on columns of compacted granular material.

From the technical-economical point of view, the costs for two foundation solutions were analyzed:

- compacted cushion made by granular materials after an excavation of 2.00 m depth (Figure 5) - estimated total cost of 321,323.28 EUR;
- ballast columns with a diameter of 65 cm, in a square network with a distance of 1.5 m and a compacted cushion made after an excavation of 1.00 m depth (Figure 6) - estimated total cost of 734,999.98 EUR.

a. 30.08.2011 b. 01.06.2018

Figure 4. Satellite images from the site (Google Earth)

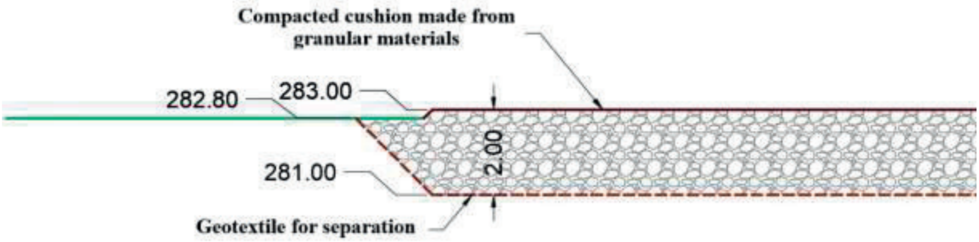

Figure 5. Cross section. Foundation solution 1: compacted cushion made by granular materials after an excavation of 2.00 m depth

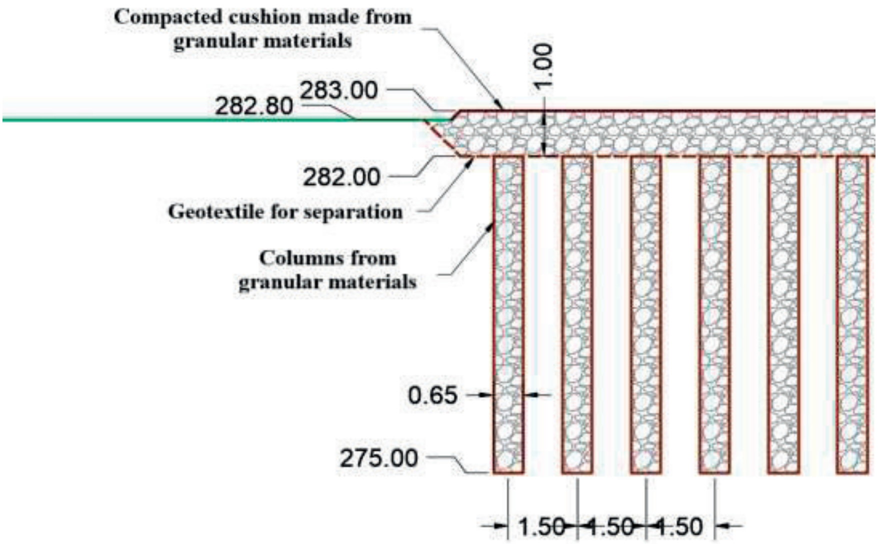

Figure 6. Cross section. Foundation solution 2: ballast columns with a diameter of 65 cm, in a square network with a distance of 1.5 m and a compacted cushion made after an excavation of 1.00 m depth

From the financial point of view, there are significant differences between these two foundation solutions; the solution with columns of granular material has at least a double price than the solution with a compacted cushion.

From the technical point of view, the optimal solution is to improve the soil with columns of granular material. The foundation solution to be chosen will be put into practice on the basis of a technical project.

REFERENCES

Dumitru, M., Carabis, D., Parvan, l., Sarbu, C. (2016). Environmental rehabilitation of mining dumps. *Agriculture and Agricultural Science Procedia*, vol.10, 3-9.

Olinic, T., Olinic, E. (2016). The variation of shear strenght parameters of contaminated soils. *16th International Multidisciplinary Scientific GeoConference SGEM 2016*, Book 1, Vol. 3, 333-338.

Sridharan, A., Gurtug, Y. (2005). Compressibility characteristics of soils. *Geotechnical and Geological Engineering 23.5*, 615-634

***NP 122:2010 - Normative regarding the determination of the characteristic and calculation values of the geotechnical parameters.

***NP 112:2014 - Normative regarding the design of surface foundations.

***SR EN 1997-1:2004. Eurocode 7. Geotechnical design. Part 1: General rules.

***SR EN 1997-1:2004. Eurocode 7. Geotechnical design. Part 2: Ground investigation and testing.

***STAS 2914-84 - Road works. Earthworks. General technical requirements for quality.