Improvement of the Soil under the Concrete Pavement of a Plant's Hall

Amélioration du terrain d'assise sous la dalle en béton d'une halle d'usine

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ABSTRACT: The geological profile of the ground for the construction of a hall of the "Stilmet" plant in Sofia includes soft saturated soils. The improvement is developed of the natural ground by constructing a geosynthetic reinforced pad of crushed stone. To determine the mechanical parameters of the improved soil ground, in situ tests have been performed and settlement/load relationships and E modulus values have been obtained. A numerical model is made of the ground by the finite element method. The undrained short term stability and the consolidation long term stress-strain process of the improved soil ground are investigated.

RÉSUMÉ : Le profil géologique du terrain d'assise, prévu pour la construction d'une halle de l'usine "Stilmet" à Sofia, contient des sols peu solides, imbibés d'eau. On a effectué une amélioration du terrain d'assise naturel par la mise en place d'une semelle en pierres concassées, armée de matériaux géosynthétiques. Pour définir les paramètres mécaniques de la fondation consolidée, on a exécuté des essais in situ et l'on a obtenu la relation affaissement-charge, ainsi que le module E. On a établi un modèle numérique suivant la méthode des éléments finis. La stabilité à court terme (non drainé) et l'évolution des contraintes et déformations (consolidation) des sols améliorés sont étudiés.

KEYWORDS: soft saturated soil, geosynthetics, reinforced foundation pad, FEM

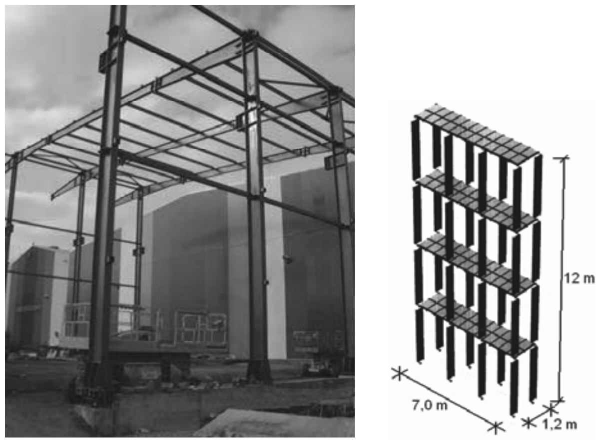
1 INTRODUCTION

The design of reinforced earth structures to replace natural soft soils is a modern practice in geotechnical engineering of improving the foundation ground. High bearing capacity and low ground deformation values are obtained by applying a foundation pad constructed of layers of hard soil, like compacted crushed stone, and of geosynthetic reinforcement. The required thickness of the reinforced pad is much smaller compared to unreinforced soil replacements. Some projects based on this way of soil improvement are realized in Bulgaria in the recent years (Mihov Y. and Mihova L. 2012, Kolev Ch. and Mihova L. 2012).

This paper presents some investigations of the improvement of soft saturated ground under the hall of the "Stilmet" plant in Sofia, which specializes in producing aluminum elements. The geological profile includes uncompacted non-homogeneous fillings at a depth of up to 4 m and soft clays at a depth of up to 10 m. The design of the ground improvement by the reinforced pad involves the following steps: (1) Choosing the thickness of the pad and the number of reinforced layers, based on FE analysis of various configurations of reinforced soil replacement; (2) Construction of an experimental improved ground area and realization of "in situ" settlement/load tests, using a circular steel plate with a diameter of 300 mm; (3) FE modeling using the actual mechanical parameters, and analyzing the stress-strain behavior and the stability of the improved ground; (4) Realization of the improvement of the hall's ground, and verifications of its deformation behavior using plate settlement/load tests.

2 GEOTECHNICAL CONSIDERATIONS

The "Stilmet" plant hall, whose area is 3000 m^2, is being constructed near halls of the same kind (Fig. 1). It has a frame steel structure with spread footings constructed after a 4-meter-deep strip excavation in three longitudinal axes. The pavement of the hall is made of fibre concrete with a thickness of 20 cm. The equipment of the hall is composed of steel shelves, each being supported at 8 points, and each being 12 m high and weighing 12 tons. Longitudinal beams on the concrete pavement of the hall transform the point loading into striped. The seismic loads on the pavement are obtained by performing a dynamic analysis of the shelf structures.



(a) (b)

Figure 1. Steel hall structure (a) and equipment shelf (b).

2.1 *Geological profile*

The geological profile is shown in figure 2, and the properties of the different layers are summarized in table 1. The water level is 1.5 m under the surface. The high water level requires analysis of both the undrained short-term stability and the consolidated long-term stress-strain behavior of the soil ground. The ground is being examined at a depth of up to 10 m, where solid clay lies.

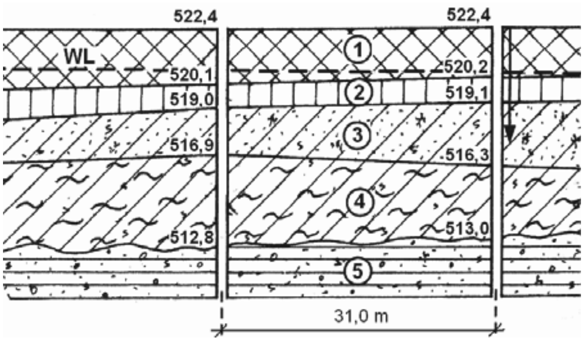


Figure 2. Geological profile

Table 1. Average values of the soil layers characteristics.

No.	Soil type	*e* -	*γ* kN/m^3	*c'* kPa	*φ'* deg	*E* MPa
1	Top soil	1,35	1,45	11,0	8,0	3,5
2	Black clay	1,30	1,62	15,0	5,0	3,5
3	Brown clay	0,95	1,86	32,5	7,0	8,5
4	Silty clay	1,41	1,70	11,0	5,0	6,0
5	Sandy clay	0,82	1,89	32,5	18,5	15,0

2.2 *Structure of the reinforced crushed stone pad*

Investigations about the stress-strain behavior of the improved soil ground with various thickness values of the crushed stone pad, various numbers and various stiffness values of the geosynthetic layers have been carried out in advance by FEM models. The optimal structure of reinforced pad with regard to mechanical behavior of improved soil is obtained (fig. 3).

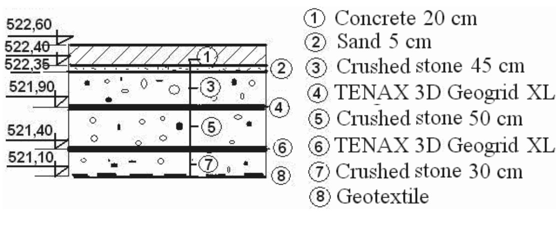


Figure 3. Structure of the reinforced crushed stone pad

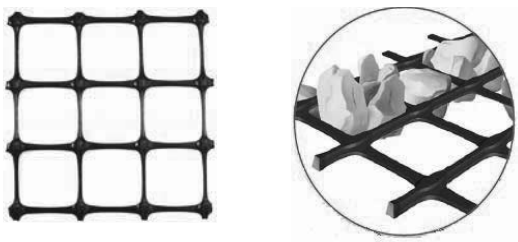


Figure 4. TENAX 3D Geogrid XL (www.tenax.net)

The pad should be built of stone particles sized 0–85 mm, and should be 1.3 m thick. The reinforcement is composed of two polypropylene TENAX 3D geogrid XL layers which have particularly large concaved shaped ribs that enhance the interaction mechanism between grids and stone particles by restricting the horizontal movement of particles (fig. 4). Technical characteristics of the geogrids are: bi-axial stiffness 900/600 kN/m at 0.5% strain and coefficient of friction soil/geogrid 1.2 (www.tenax.net).

3 FIELD TESTING PROCEDURE

To determine the E-modulus of the improved ground, a field test program is performed. It includes the construction of the reinforced pad of area 150 m^2 and an application of a static loading by rigid plate of dimension 30 cm at the following four stages of construction: (1) After compaction of the natural ground; (2) After building the first layer of crushed stone with a thickness of 30 cm; (3) After placing the first geogrid layer and building the second crushed stone layer with a thickness of 50 cm; (4) At the end of the pad construction. At each stage three loading/unloading cycles are applied by steps of 0.05 MPa and settlement/load curves are obtained. The *E*-modulus of total settlement and the E_e-modulus of their elastic part are estimated, and the results are shown in table 2. The settlement/load curves for the first and the last stage of pad construction are shown in figure 6. The moduli values increase more than five times after the soil ground improvement.

Figure 5. Construction of the experimental reinforced crushed stone pad

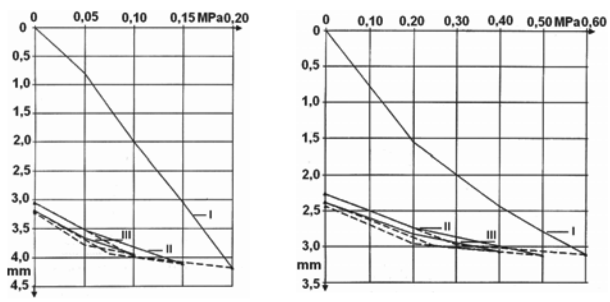


Figure 6. Settlement/load curves for the plate loading tests

Table 2. Values of the *E*-moduli of the soil ground at field testing

No.	Stage of the pad construction	*E* MPa	E_e MPa
1	Compaction of the natural ground	10,0	33,0
2	The first 30-cm-thick stone layer	25,7	60,0
3	The first geogrid layer and the second 50-cm-thick stone layer	44,3	121,0
4	The end of the pad construction	57,7	181,0

4 NUMERICAL ANALYSES

4.1 *Finite element model*

Plane-strain finite element model of the improved ground is made (fig. 7). The behavior of soil is modeled as Mohr-Coulomb material. Linear bar elements that only have tensile strength are used for the geogrids. The concrete pavement is modeled by using linear beam elements. Interface elements are included for modeling the interaction between the soil and the structure elements.

The loading of the pavement is assumed as uniformly distributed with a value of 30 kPa for combination of dead and live static loads and with a value of 45 kPa for seismic load combination. Before the pavement loading calculations, the initial condition of gravity loading is formed by the k_0-procedure. The construction stages of consecutive excavation and the replacement of the soil are simulated by means of phases of calculation with various FE meshes. An impermeable bottom boundary of the FE model is assumed in consolidation analysis.

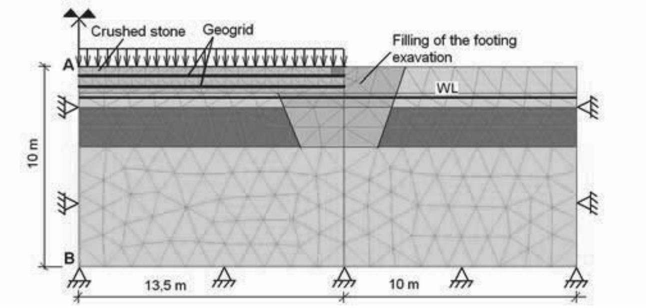


Figure 7. Finite element model

4.2 *Results from FE analyses*

4.2.1 *Consolidation of the ground at dead and live loads*
The consolidation process is investigated, and 3 years and 4 months is the time of the pore pressure dissipation. The maximum value of the pavement settlement is 2.62 cm at point A (fig. 7) and this value corresponds to the end of the consolidation process. The distribution of the vertical displacements is shown in figure 8.

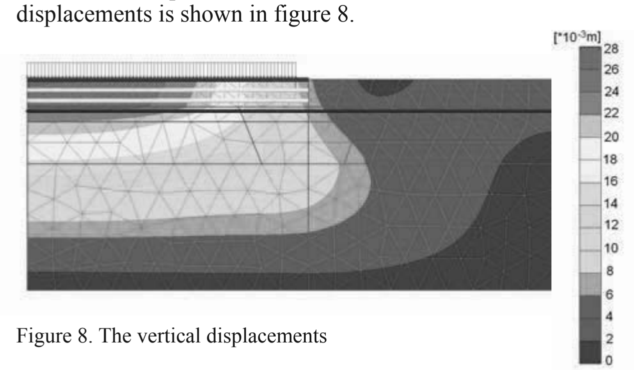


Figure 8. The vertical displacements

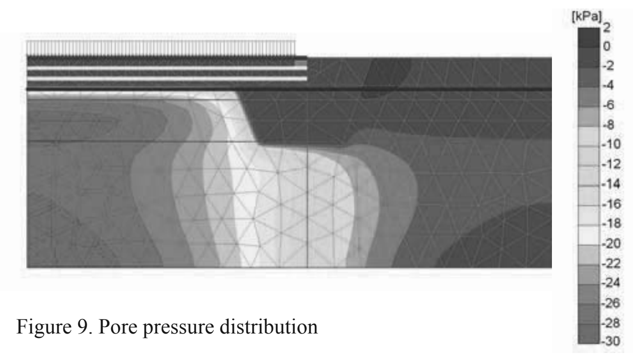


Figure 9. Pore pressure distribution

The maximum pore pressure values are obtained immediately after the load application, and its distribution is represented in figure 9. It is evident that in all clayed soils under the pavement the pore pressure increases up to the value of the applied load. The 29.6 kPa maximum value of pore pressure is calculated at point B situated at the bottom of the field. The consolidation curves pore pressure vs. distance at 18 time steps are shown in figure 10 for the cross section A – B. Step number 6 is related to the loading completion.

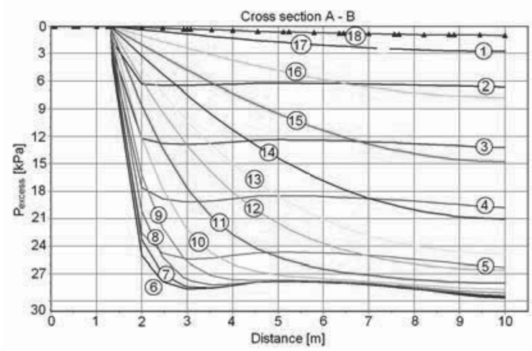


Figure 10. The curves pore pressure vs. distance

The membrane forces of geogrids, caused by vertical loading, reduce the normal stresses under it. The maximum value of the normal stresses on the soft subsoil at the bottom of the crushed pad is 52.3 kPa. Figure 11 presents the tensile forces in geogrids.

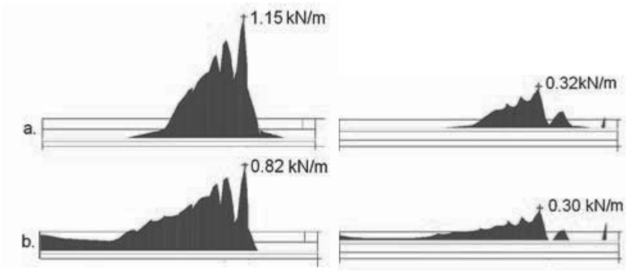


Figure 11. The forces in geogrids at time moments: (a) at a pavement loading; (b) at the end of consolidation

4.2.2 *Stability of the ground at seismic load combination*
The undrained analysis is performed and the lateral displacements are estimated. The vectors of the total displacements are shown in figure 12. The maximum horizontal displacement is 1.4 cm and it occurs at depth of 4 m under the crushed stone filling of the foundation excavation. The zones of lateral displacements are located, as shown in figure 13, and the stability of the ground is provided.

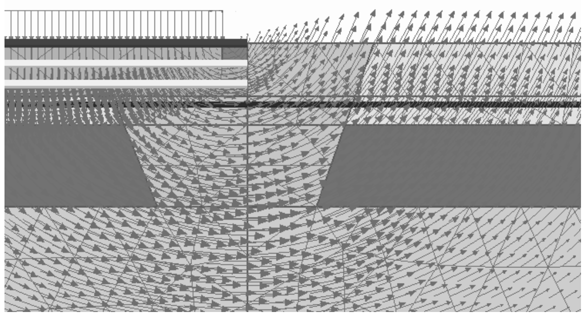


Figure 12. The vectors of the total displacements

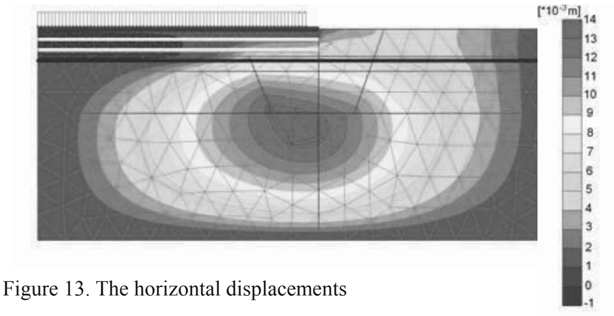


Figure 13. The horizontal displacements

The stability of the ground has been estimated using the φ, c-reduction method. The coefficient of stability has a value Fs = 3.42 for deep slide surface.

5 CONCLUSION

The required thickness of reinforced crushed stone pad is about two times smaller compared to the unreinforced pad. The improvement of the ground by replacing of the soft foundation soil by the reinforced crushed stone pad is an effective modern technology which decreases excavation works and increases the heartedness of the foundation soil.

6 REFERENCES

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TENAX 3D Geogrid XL, www.tenax.net.