Method of improvement of the subsoil under Adora facility – Ohrid, Republic Of Macedonia

Méthode d'amélioration du sous-sol sous le bâtiment Adora – Ohrid, République de Macédoine

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ABSTRACT: Adora residential building is a 6-storey structure, built nearby Ohrid Lake (Ohrid, Republic of Macedonia). The foundation depth of the building is approximately 1,5 m (foundation construction – foundation slab). The foundation soil consists of soil materials which have a poor strength properties and low bearing capacity. The ground water table (GWT) on the location is on 1,0 m bellow the ground surface. On such geotechnical conditions a big settlements are expected. Therefore, a project on soil improvement was prepared. Several preliminary solutions were considered, but most appropriated was the one which involves geosyntetic reinforcement as subsoil improvement measure. In order to evaluate the settlements, performance of the building, axial forces developed in the geogrids and stress-strain condition in the subsoil during static and dynamic loads, detailed analyses were conducted. The software models developed in Plaxis 2D clearly showed the effectiveness on the applied measures for soil improvement.

RÉSUMÉ : le bâtiment de résidence Adora est-une construction de 6 étages, bâti à coté du lac d'Ohrid (Ohrid, République de Macédoine). La profondeur des fondations du bâtiment est d'environ 1,5 m (construction de fondation – dalle de fondation). Le sol de fondation est composé de sols de mauvaise qualité et faible capacité portante. La nappe phréatique (NP) du site est située 1,0 m en dessous de la surface de sol. Avec ces conditions géotechniques des tassements du sol sont attendus. Un projet d'amélioration des sols a donc été préparé. Plusieurs solutions préliminaires ont été considérées, mais la plus appropriée est celle qui implique le renforcement par géosynthétiques, comme mesure d'amélioration du sous-sol. Des analyses détaillées ont été menées afin d'évaluer les tassements du sol, la construction du bâtiment, les forces axiales développées dans le géogrille et la relation contrainte-déformation dans le sous-sol sous chargements statique et dynamique. Les modèles logiciels développés dans Plaxis 2D montrent clairement l'efficacité des mesures appliquées pour l'amélioration des sols.

KEYWORDS:soil imporovement, geogrid, geotextile

1 INTRODUCTION

Adora residential building is foreseen to be built on a site which hasvery poor geomechanical properties or in other words the geotechnical conditions on the site are very unfavorable. In such casesalways major problems are low bearing capacity of the subsoil and large differential settlements. The city of Ohrid is located in active seismic area which is classified in the 9th seismic zone according to MCS. Moreover, on the site there are layers of loose uniform sand. Having in mind these two facts a liquefaction becomes also a serious danger for the structure. In order to adopt a solution for soil improvement and to check the liquefaction potential of the soil,comprehensive analyses were conducted.

Figure 1.Excavation pit on a site

2 GEOLOGICAL SITE PROPERTIES

According to the geological formations on the site, there are present sediments from the Quaternary period (Pleistocene epoch), i.e. lake and swamp sediments, represented with gravel, sand, sandy clays, silt, different types of clay and clayey-silty sediments, as well as occasional presence of peat. The sediments are well sorted, so that they have heterogenic particle size distribution and heterogenic mineralogy composition, i.e. they are fine to medium gravels and sands; fine silty sands, sandy clays and soft lake/swamp clays with low to medium plasticity. The thickness of these sediments varies between 50.0 – 80.0 m. According to the hydrogeological properties, they belong to the group of low permeability sediments with interparticle porosity. A closed type of springs with free level is present in the sediments, at depth to 20.0 m with GWT = 5.0 – 7.0 m, and with permeability $k = nx10^{-4} – nx10^{-5}$ m/s.

Also there is a closed type of springs under pressure (artesian springs) at depth from 20.0 – 60.0 m with discharge of Q = 1.0 – 5.0 l/sec.

From engineering geological point of view, these sediments belong to the group of weathered rocks, well placed and sorted with heterogenic particle size distribution, low compacted, with smooth surfaces, fully saturated with water. In other words they present materials with poor physical and mechanical properties that have different strength and deformability parameters.

3 GEOMECHANICAL SITE PROPERTIES

The site for construction of the new building is located approximately 200 m from the shore of Ohrid Lake, so, as it was mentioned before, the soils found on the site are with sediment nature. In order to get precise geotechnical profile of the ground, extensive geotechnical field investigations were conducted. On the other hand, soil samples were taken for laboratory testing. With such extensive scope of field investigations, clear view of the ground profile was obtained.

Based on the performed field investigation works, it was concluded that the site is composed of different layers of sedimentary soils. With foreseen depth of the boreholes, no bedrock was detected. On this site there is vast variety of soil materials, from gravels and sands to silts and clays. Because of the high heterogeneity of the ground profile, layers are grouped into two extinguishing layers. The surface layers are low plasticity clays and clayey sands, which are highly compressive and they are present up to approximately 2.0 m from the surface. While the next deeper layer is clayey sand with higher compaction than the previous layer, and they are present up to 10.0 m from the surface. It is supposed that this second layer continues up to depth for which loading stresses have impact on the settlements.

According to the conducted field and laboratory tests, present soil materials are loose and they have very poor strength properties. In addition, the level of ground water table is very high, approximately 1.0 m from the ground surface, because of the nearby Ohrid Lake.

Table 1. Geomechanical properties

Soil	*Fill Material*	*CL/SFc*	*SFc*
g (kN/m^3)	22.0	18.4	18.5
c(kN/m^2)	0.0	15.0	10.0
f (^{0})	35.0	10.0	20.0
Mv (kPa)	80000.0	5000.0	10000.0
SPT	/	4	13

Considering all these facts, it is obvious that ground improvement is necessary under the foundation of the new construction. Moreover, the problem with the settlements is inevitable, so the serviceability of the construction is also an important issue.

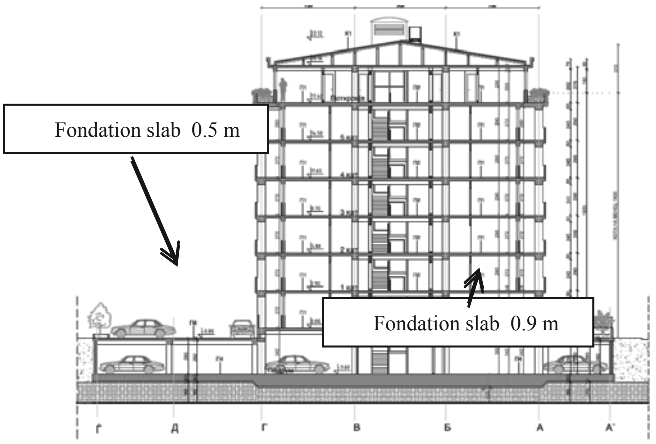

Figure 2.Adora building – cross section

4 CONSTRUCTION DETAILS

The Adorabuildingis built on the sitewhich is very close to the Ohrid Lake. The superstructure of the building has 5 floors and the substructure has 1 floor (see Figure 2). The substructure is extended out of the superstructure and it is actually a parking lot. The size of the superstructure in plan view is 52.0x22.0 m, and the total size of the building (including the extensions of the substructure) is 69.0x41.5 m. The foundation slab under the superstructure is 0.9 m thick and on the extension parts it is 0.5 m thick.The contact pressure transferred on the subsoil varies in range between 100 kPa (on cross-sectionsin the middle of the building) and 20 kPa (on cross-sections in the extensions).

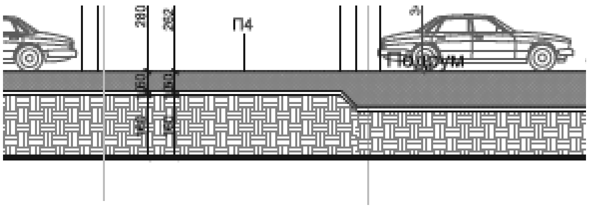

Figure 3. Cross section of the foundation structure

5 THE SOLUTION

As it was mentioned before, the improvement of the subsoil was done by means of soil replacement and usage of geosynthetic materials.

Because of the foundation level of -1.5 m from the ground surface and the depth of soil replacement of 2.0 m, total of 3.5 m deep foundation pit was excavated. The excavation pit was done by constructing2:1 slopes. In addition, dry conditions for execution of the construction works in the excavation pit were ensured by dewatering the excavation by extraction wells. On the other hand the excavation pit had greater dimensions in plan view, 2.0 m greater than the contours of the foundation slab. Hence the loading stresses can be spread in the fill material by angle of max 45°.

Table 2. Properties of the geotextile

Raw material	PP multicolored/PET
Method of production	Mechanically bonded
Weight	≥ 300 gr/m^2
Thickness under 2 kPa load	≥ 3 mm
Ultimate tensile strength	Longitudinal ≥ 4.0 kN/m Transversal ≥ 7.5 kN/m
Strain at ultimate tensile strength	Longitudinal 120% (±40%) Transversal 80% (±40%)
CBR puncture resistance	≥ 1300 N (-300 N)
Opening size O90	0.10 mm (±0.02 mm)
Water permeability index normal to the plane	85 x 10-3 m/s (-15 x 10-3 m/s)

5.1 Geotextile

At the bottom of the excavation pit, geotextile was used to ensure separation of the fill material from the subsoil. By the separation, it is meant that the geotextile will prevent mixing of the different soils, but it will enable complete water permeability, so with this, complete preservation of the properties of the later placed fill materials will be ensured. Used geotextile has the physical and mechanical properties, listed in the Table 2.

The geotextile was placed all over the bottom of the excavation pit as well as on the excavation slopes. The overlap oftwo adjacent panels is 60 cm, and it completely wraps the fill material up. Used geotextile with the properties given in the Table 2 has the ability to withstand burst and puncture, and has enough tensile strength to serve a separation function, without being destroyed.

5.2 Geogrids and fill material

For increasing the bearing capacity of the subsoil under the foundation slab, geogrids are inserted as reinforcement. For reinforcement three layers of geogrids with different properties are placed in the fill material at different elevations.

The first layer of the geogrids was installed under the middle section of the building where the contact pressure has maximummean value up to P=100 kPa.The geogrids installed on this position give the geotextile anadditional tensile strength, as well as bursting and puncturing resistance.

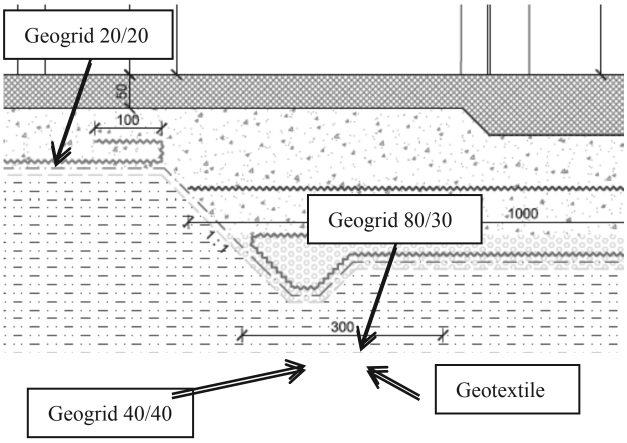

Figure 4. Cross section of the soil improvement measures

On other hand this first layer provides initial stiffness of the low lifts of the fill material. The overlap oftwo adjacent panels is 50 cm and anchoring length of 3.0 m. The properties of the first layer of geogrid are shown in the Table 3.

Table 3. Properties of the geogrid 40/40 (first layer of geogrids)

Raw material	PP
Coating	Polymer
Weight	~ 330 gr/m2
Ultimate tensile strength	Longitudinal ≥ 40 kN/m Transversal ≥ 40 kN/m
Tensile strength at 2% strain	Longitudinal ≥ 16 kN/m Transversal ≥ 16 kN/m
Tensile strength at 5% strain	Longitudinal ≥ 32 kN/m Transversal ≥ 32 kN/m
Strain at nominal tensile strength	Longitudinal < 7% Transversal < 7%
Mesh size	40 x 40 mm

Over this geogrid a layer of drainage fill material was placed with thickness of 50 cm. This material has particlessize from 16 to 32 mm.

This layer of drainage fill material is foreseen to reduce the possibility of liquefaction. So in case of earthquake, the building up of the pore water pressure will be reduced by draining the water from the subsoil layers into the drainage layer placed with the subsoil replacement works.

Over this drainage fill material, another geogrid was placed but this time with higher strength properties. The use of this geogrid is to reinforce the fill material as well as to ensure additional stiffness, which is gradually increasing from the bottom of the excavation pit up to the foundation slab. Furthermore, this geogrid will ensure reaching of the requested modulus of compressibility of the upperlayers of fill material. The properties of the second layer of geogrid are shown in the Table 4.

Table 4. Properties of the geogrid 80/30 (second layer of geogrids)

Raw material	PET
Coating	Polymer
Weight	~ 350 gr/m2
Ultimate tensile strength	Longitudinal ≥ 80 kN/m Transversal ≥ 30 kN/m
Ultimate tensile strength at 3% strain	Longitudinal ≥ 22 kN/m
Ultimate tensile strength at 5% strain	Longitudinal ≥ 40 kN/m
Strain at nominal tensile strength	Longitudinal < 8.5% Transversal < 8.5%
Mesh size	20 x 20 mm

On top of the second geogrid two lifts of fill material are done with thickness of 30 cm, total of 60 cm. The required modulus of compressibility on top of these two layers of fill material should be at least 100 MPa and minimum 98% compaction after Proctor. The fill material is crushed stone base aggregate.

On the extended parts of the building where the contact pressure has maximummean value up to P=20 kPa, also a geogrids is installed. This geogrid has an ultimate tensile strength of 20 kN/m in both directions. The overlap of two adjacent panels is 60 cm and the anchoring length is 1.0 m. After installation of this geogrid the fill material is placed and compacted in 30 cm thick lifts. The final layer of the fill material at the extended parts of the building should reach at least 80 kPa and minimum 98% compaction after Proctor.

After completion of the earth works ground improvement measures were completely finished. So the works for hydro insulation and constructing the structure commenced.

Table 5. Properties of the geogrid 40/40 (first layer of geogrids)

Raw material	PP
Coating	Polymer
Weight	~ 190 gr/m2
Ultimate tensile strength	Longitudinal ≥ 20 kN/m Transversal ≥ 20 kN/m
Tensile strength at 2% strain	Longitudinal ≥ 8 kN/m Transversal ≥ 8 kN/m
Tensile strength at 5% strain	Longitudinal ≥ 18 kN/m Transversal ≥ 18 kN/m
Strain at nominal tensile strength	Longitudinal < 7% Transversal < 7%
Mesh size	40 x 40 mm

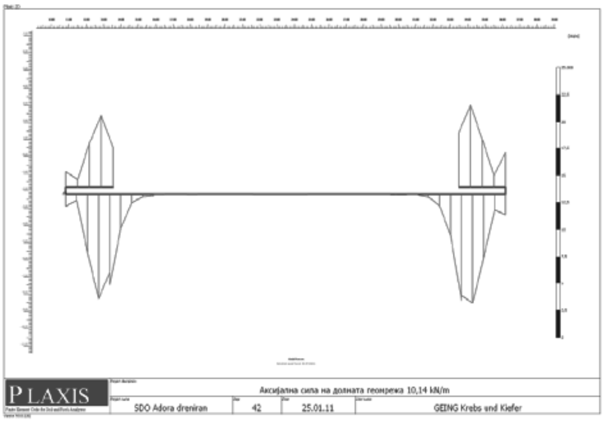

Figure 5. Axis forces in geogrid 80/30 (first layer of geogrids)

6 GEOTECHNICAL ANALYSES

In order to adopt the measures for improvement of the subsoil, detailed analyses were conducted. These analyses involve flow net analyses, analyses of soil-structure interaction due to geostatic and dynamic load as well as analyses of the liquefaction potential of the subsoil. The ground model was developed according to the adopted soil properties shown in the Table 1,and also the exact geometry of the structure was applied to the model. Most of the analyses were carried out in Plaxis 2D software suitusingfinite element method.

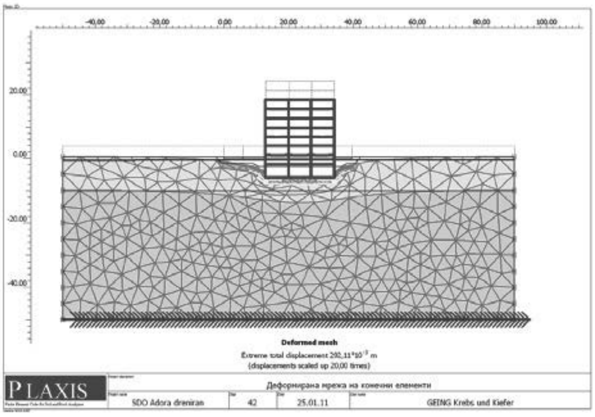

Figure 6. Plaxis model of the Adora building

The Plaxis model was subjected to several load cases which involves geostatic, hydrostatic and dynamic load. The analyses are conducted with and without applied geosyntetics under the construction. Comparing the results of analyses of both models it was obvious that improvement of the subsoil using geosyntetics is fully justified.

The maximum total settlements of the subsoil after the construction of the hotel are estimated at 30 cm. The estimated differential settlements during the seismic analyses were 0.1 cm. The maximum axial forces developed in the geogrids for geostatics load case are 13,86 kN/m in the middle geogrid and 10,14 kN/m in the lowest geogrids. When the model is subjected to dynamic loads (seismic activity) the axial force in the middle geogrid 35,17 kN/m and in the lowest geogrid the axial force is 19,12 kN/m.

Additional analyses were carried out in order to estimate a liquefaction potential of the subsoil. These analyses were necessary due to the presence of saturated, uniform sand in the subsoil which has a relative density in the range of Dr=15-40%. The results showed that the subsoil has a liquefaction potential.

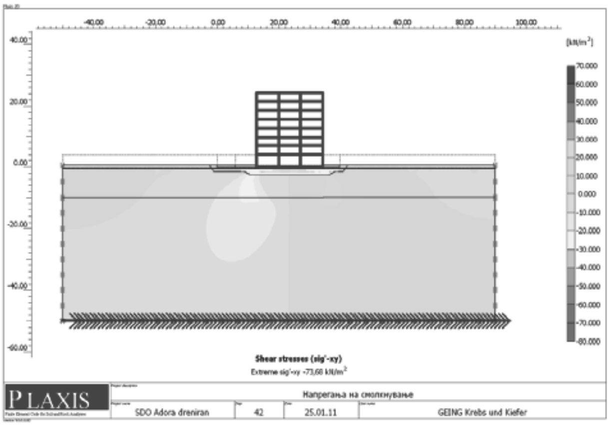

Figure 7. Shear stresses distribution

7 CONCLUSION

In the last 2,5 years this is the second bigger project of soil improvement using geosyntetics in the Ohrid area. The first, very similar, case was soil improvement under the new Hotel Park 2,5 years ago. The two buildings are approximately 2.0 km apart. On a basis of a obtain datafrom monitoring of the buildings settlements it can be concluded that the total settlements of bothbuildings are below the initially estimated settlements.

For example, for monitoring of the settlements of the Hotel Park 8 survey points were positioned. Those points initially were measured after placing them (during the fundaments constructing), later in the time of constructing the structure and after finishing of the whole construction. The first initial measurement of the elevation of the fixed points was undertaken on 11.07.2011, and the last one on 23.03.2012.

In both cases cost-benefit analyses conducted during the designing process showed that soil improvement using geosyntetics is most economical method in such geotechnical conditions. Regardless the economic aspect this method has a major advantage which is a very short period of installation.

8 REFFERENCES

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