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Earthquake analysis on 12-story building in Ohrid - Macedonia with Plaxis software

Analyse séismique d'un immeuble de 12 étages situé à Ohrid, R. de Macedoine avec Plaxis software

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ABSTRACT
This paper deals with the problem of soil improvement using geosynthetics and substitution of the loose sand and soft clay with coarse gravel having good soil mechanics characteristics. High ground water at 1 m below the ground surface, the anticipated earthquake of 9 degrees MCS intensity scale, liquefaction potential and heavy weight of the structure are the reasons for this soil improvement technique to be analytically examined in relation to the soil-structure interaction. Analysis has been performed using Plaxis software under static as well as earthquake conditions. By using the stress-strain analysis, forces in the geogrid and settlements have also been calculated. Earthquake loading case and the results from the analysis are discussed in details and the use of the geosynthetics has been approved.

RÉSUMÉ
Cette oeuvre traite le problème de l'amélioration du sol à l'aide de l'utilisation du géosynthétiques et de la substitution du sable friable et de l'argile douce avec une couche intermédiaire ayant de bonne caractéristiques géomécaniques. Le haut niveau des eaux souterraines de 1 m. au-dessous de la surfaces, le mouvement éventuel du tremblement de terre de 9 degré MCS - échelle d'intensité, la liquéfaction potentielle, ainsi que le grand poids de la construction sont des raisons pour lesquelles cette technique de l'amélioration du sol doit être examinée d'une façon analytique concernant l'interaction de la structure du sol. On a fait une analyse à l'aide de l'utilisation du Plaxis software dans des conditions statiques et séismiques. A l'aide de l'analyse on a fait une calculation de la sollicitation du sol et les forces du géogrid, ainsi que des tassements du sol. Le cadre de chargement séismique et les résultats de l'analyse ont été discutés en détail et on a approuvé l'utilité des géosynthétiques.

1 INTRODUCTION

Ohrid Lake is the largest natural lake in Macedonia. Ohrid town is spread on the coast of the Lake of Ohrid. The soil near the lake comprises mostly lake quarter sediments of loose sand and gravel and soft clay of total depth more than 50 m above the limestone. The ground water is only 1 m below the ground surface. All these factors led to poor foundation conditions. Another input parameter is the heavy weight of the structure. The structure is 12-story building, and for Macedonian circumstances it is called "Tower Grashnica". The Ohrid region is also earthquake sensitive. The earthquake of 9 degrees MCS intensity scale can take place. Owing to such an earthquake, liquefaction potential is evident.

For these circumstances and loads, cost-effective solution has been devised. This satisfies the Client's requirements to get a cheap and functional solution regarding shallow foundations. The foundation is carried out on a RC grillage. Only this foundation system meets the requirement for a stiff foundation and smaller settlements. The soil improvement is achieved by means of two layers of geogrids. The first one, above the geotextile, is placed on the original loose soil, while the second one above the 30 cm of compacted base layer. The calculation of the required base layer and stress-strain analysis using static and earthquake loads has then been performed.

2 DETERMINATION OF THE BASE LAYER THICKNESS BY THE MYSLIVEC METHOD

For the foundation depth of 1.2 m by the Myslivec method, we employ a combination of the top compacted and stiff layer and a bottom loose and compressible layer. Material with angle of internal friction of $\varphi = 35°$ has been adopted for the base layer. Analyzed are three models with two loading combinations. The analyzed models are: strip foundation B = 1.5 m wide, superposition of more strip foundations, while in the third model analyzed is a slab under the stair well. The results from the analysis are shown in Table 1. Further on in the analysis, a 3 m thick base layer has been approved.

3 DETERMINATION OF STRESSES AND SETTLEMENTS BY THE STEINBRENNER METHOD

For the three previously defined models, the calculation of stresses and settlements have been performed for dead load and 1/2 of the live loads. The results of calculated settlements, depending on the model, are shown in Table 2.

Table 1: Required base layer according to models and load cases

models	foundation (effective) [m]	load cases	required base layer [m]
strip foundation	1.50	dead+live	2.02
		dead+live+ earthquake	2.17
superposition of more strip foundations	22.00	dead+live	2.26
		dead+live+ earthquake	2.76
slab foundation under the stairs core	4.30	dead+live	2.87
		dead+live+ earthquake	2.99

Table 2: Calculated settlements for anticipated loads

models	expected stresses [kN/m²]	calculated settlements [cm]
strip foundation	370.00	7.94
superposition of more strip foundations	300.00	24.63
slab foundation	220.00	30.00

4 STRESS-STRAIN ANALYSIS USING PLAXIS SOFTWARE

Besides the classical methods mentioned above, an analysis has also been performed using PLAXIS software with finite elements applied in geotechnics, employing plane strain approximations. The geometry and the strength characteristics of the soil and the structure have been modeled in the analysis. The plan of the building foundations and their layout are presented in Figure 1. Taking into consideration nearly square form of the foundation base, about 30% reduction of the input load is made to get the plane strain in PLAXIS analysis. The deformed model of the tower using PLAXIS software is shown in Figure 2. First of all the analysis is carried out for static loads acting on the structure. The maximal settlements of the structure, amounting to 24.6 cm, are calculated. The diagrams of settlements and stresses under the foundations are presented in Figure 3.

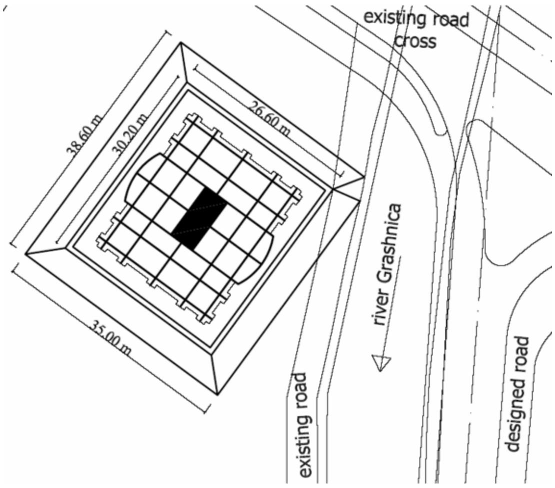

Figure 1. Layout of the foundation grid and pit.

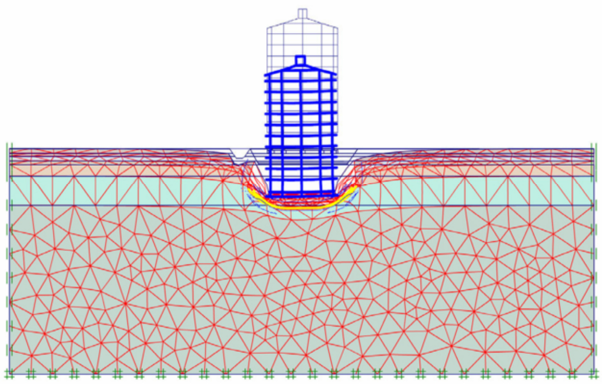

Figure 2. Model of the deformed PLAXIS mesh - static loads.

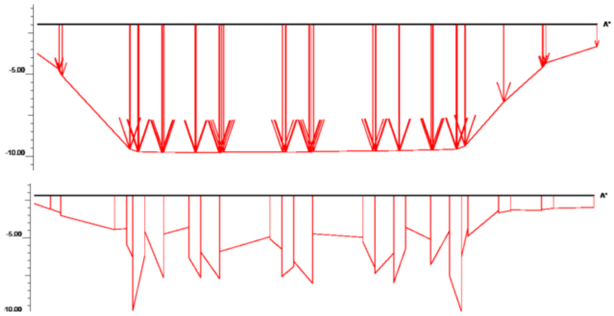

Figure 3. Settlements and stresses under the foundations - static loads.

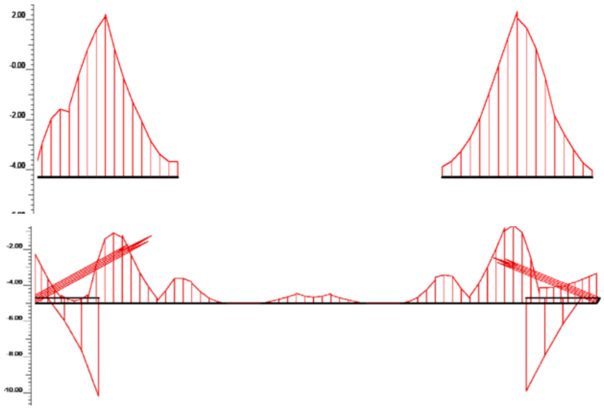

Figure 4. Axial force in the upper and lower geogrid - static loads.

The axial forces in the geosynthetics are also calculated. The force in the geogrids and its distribution is shown in Figure 4. The maximal tensile force in the top geogrid amounts to 8.56 kN/m, while in the bottom geogrid is 2.76 kN/m.

5 EARTHQUAKE ANALYSIS USING PLAXIS SOFTWARE

With PLAXIS software also the earthquake analysis was made. The input was from the real earthquake happened in 1971 year in San Fernando. This acceleration record taken as a sample, very much by the soil conditions and the magnitude of 6.6 corresponds with Ohrid region maximum expected earthquake.

The response of the structure and nearby soil condition was analyzed. The acceleration in the three points of interests was observed. The points of interest were in the level of the sub base, the foundation level and the top of the tower. The acceleration diagram is shown in Figure 5. Also the settlements in the level of first geosynthetic and the level of the foundation in three point's left-middle-right are observed. Results are presented in the diagram on Figure 6.

For the comparison with the static case the model of deformed mesh is shown on Figure 7. The vertical deformations and stresses under the foundations from the earthquake are shown in Figure 8. In the earthquake case peak up vertical deformations of 28.4 cm are expected. After the quake the middle settlement of 14 cm can occur, with differential settlements of 3 cm. Axial force in the geogrids are 27.97 kN/m for the top and 13.65 kN/m for the bottom geogrid. The distribution of the forces is shown on Figure 9.

The liquefaction potential is calculated by the Chinese regulations and the occurrence of liquefaction is possible in the middle coarse send layer of 3 to 5 m thickness settled 4 m under the foundations. Constructive measure is taken for reducing the liquefaction potential with horizontal drainage gravel layer above the first geogrid.

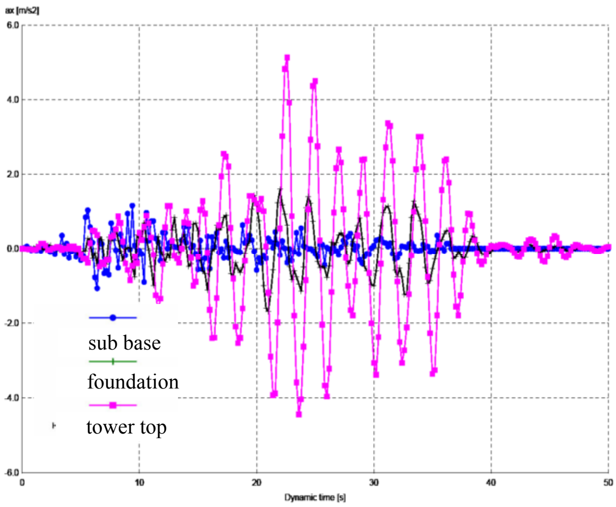

Figure 5. Acceleration diagram in the three levels.

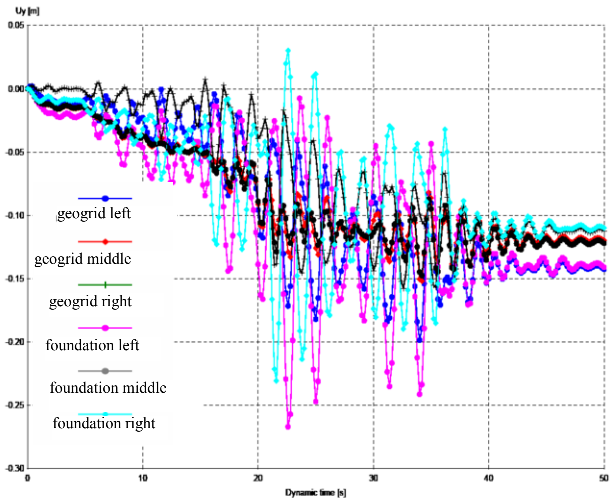

Figure 6. Settlements in the geogrid and foundation due to earthquake.

6 CONSTRUCTION TECHNOLOGY

Excavation of foundation pit has been performed to a depth of 4.65 m. Because of the high water table, the water in the pit has been pumped off all the time. Following excavation, the first layer of Huesker geosynthetic type Comtrac 30/30 B20 is unrolled in the foundation pit. This geocomposite consists of no woven geotextile as a separation layer and a geogrid for reinforcement of 30 kN/m tensile strength. Overlapping of the geosynthetic in the transverse direction is minimum 50 cm. A drainage layer of 30 cm thickness has been filled and compacted. The first geosynthetic layer is wrapped above this drainage layer. After that the first base layer 30 cm thick has been filled and compacted up to a compression module of 30 MPa. Next, the second geosynthetic of Huesker geogrid Fortrac 80/30-20 of axial strength 80 kN/m is installed. Then the base course has been filled and compacted, first with a compression module of 50 MPa and of 80 MPa afterwards. The cross section of the foundations and soil improvement underneath is shown in Figure 10.

Following the completion of soil improvement, foundations are constructed and the in-between space is filled and compacted. Compacted around the foundations is the base course material at a distance of minimum 7 m from the foundations. The considerable consolidation settlements are not expected.

The spots for settlements measurement are incorporated in eight exterior columns. Construction survey observation of the settlements will be performed during building execution and afterwards.

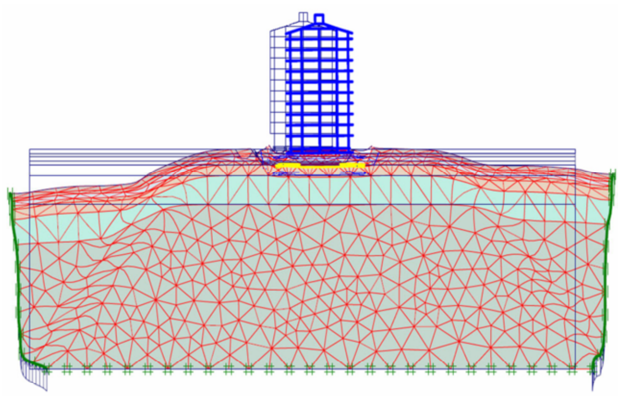

Figure 7. Model of the deformed PLAXIS mesh - earthquake.

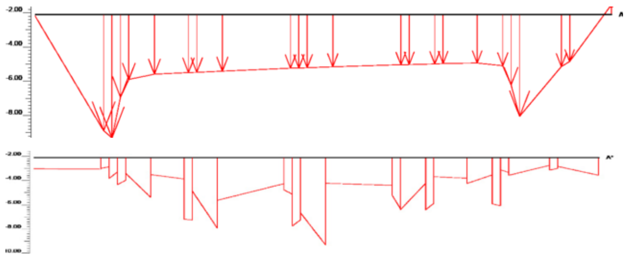

Figure 8. Settlements and stresses under the foundations - earthquake.

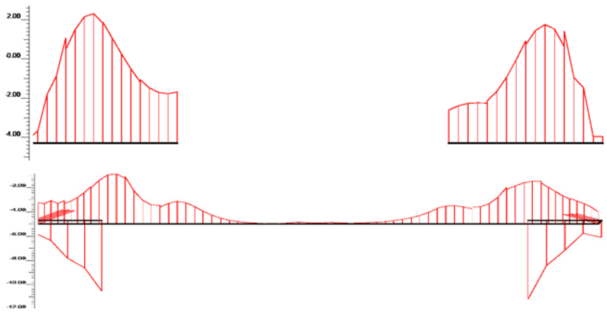

Figure 9. Axial force in the upper and lower geogrid - earthquake.

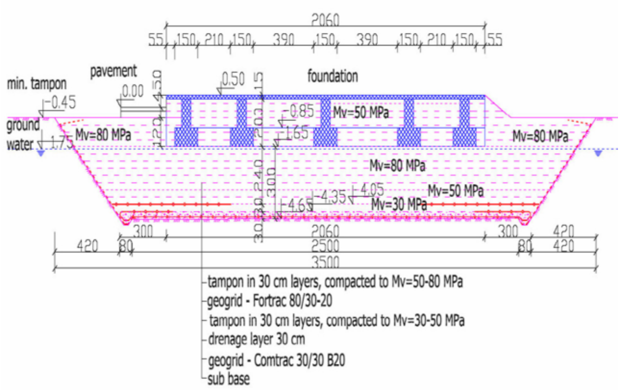

Figure 10. Cross-section of the foundation and soil improvement.

7 ADDITIONAL PLAXIS ANALYSIS WITH AND WITHOUT GEOSYNTHETICS

Additional analysis with and without geogrid reinforcement has been performed for earthquake loading. Deformations and stresses have been compared. Small differences in total deformations and stresses have been observed. The main difference in the result is in shear strains in the critical zone where the geogrids have been installed. The reduction in strains has been about 35%. In static case this reduction has been about 20% lower. The reduction of the peak strains indicates that the shear resistance in the critical areas has been improved. The state of strains without geogrid reinforcement is shown in Figure 11 while Figure 12 indicates the state with geogrid reinforcement.

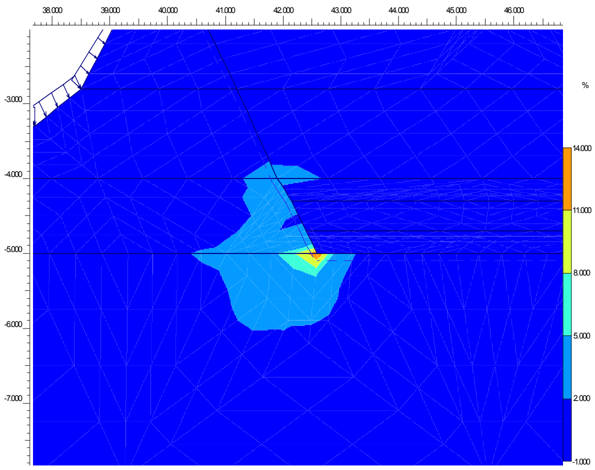

Figure 11. Shear strains in the critical part without geogrids.

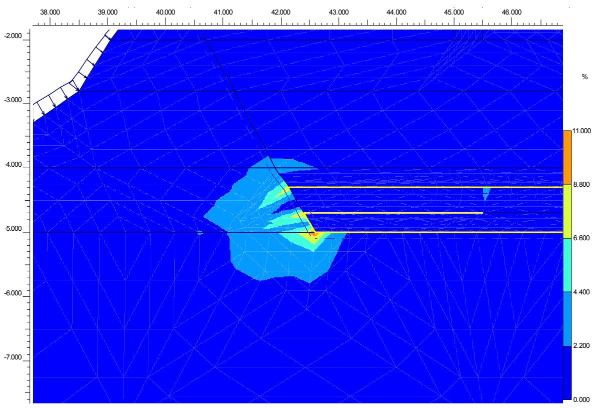

Figure 12. Shear strains in the critical part with geogrids.

8 SUMMARY AND CONCLUSIONS

According to the aforementioned statements, stresses and settlements in the soil increased rapidly during an earthquake. Geogrids take on considerable part of the tension forces in the soil. This can be observed through the increase of the axial tension force for the top geogrid by 320% and for the bottom geogrid by 495%. The geogrid pattern must be adjusted to the regions where extreme strains are anticipated and where the coefficient of their exploitation will be maximum; for shallow foundations this is the region at the edge of the foundations.

By stressing the geogrid, the soil can lose one part of the strains. This leads directly to reduction of shear stresses in the soil. Soil and geogrid reinforcement form a complex material, like reinforced concrete so-called reinforced earth.

Further investigations concern laboratory modeling for static and dynamic conditions and in-situ installation stress, strain and deformation measuring equipment in the soil and in the geogrids, can be beneficial for verification of the models. Other more sophisticated 3D models should be developed and results compared with the measured quantities.

Placing geogrids under the shallow foundations is a useful solution when soft and loose soil is underneath. Additional safety is achieved in seismically active areas of the world where additional soil strength and resistance are needed. Soil-structure interaction should be attained whenever large settlements are expected, especially during earthquakes. The use of geogrids is particularly useful during the earthquakes where the soil is influenced by not precisely defined additional stresses and deformations.

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