THE BEHAVIOR OF FOUNDATION SOIL WITH AND WITHOUT GEOSYNTETHIC REINFORCEMENT

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ABSTRACT

This paper presents the computed diagrams showing the soil behavior in two alternative calculation hypotheses (with/without geogrid reinforcement) will be compared, so that the positive effect of two geogrid layers used for reinforcement is revealed. The diagrams show that the use of reinforcement layers contributes to a more uniform distribution of loads and to the decrease of the pressure, thus increasing the bearing capacity of the soil.

Keywords: geosynthetics, reinforced soil

REZUMAT [Style: "Abstract Title (RO)"]

În articol sunt prezentate, prin comparaţie, diagramele de comportare a terenului în două variante de calcul (cu/fără armare cu geogrile) şi este evidenţiat efectul pozitiv al dispunerii a două straturi de geogrile cu rol de armare. Diagramele arată că dispunerea straturilor de armătură duce la distribuire uniformă a eforturilor şi la scăderea solicitărilor în teren, ducând astfel la creşterea capacităţii portante a acestuia.

Cuvinte cheie: geosintetice, pământ armat

1. INTRODUCTION

Seismic motion is one of the main causes of buildings failure in case of earthquake; therefore, it is very important to understand correctly and accurately the phenomena that generate it, namely the parameters that characterize it and its effects on the buildings. For the seismic design of the entire system (i.e. superstructure - infrastructure - soil), it is important that the behavior of the foundation soil and of the foundation system used for buildings located in seismic areas is known, as the dynamic loads induced by seismic actions are transmitted through the soil and foundation to the structure above.

Geosynthetics are generally polymeric products used to solve geotechnical problems in civil engineering. This includes several product categories: geotextiles, geogrids, geonets, geomembranes, geocomposites, geocells, and combinations of the above-listed materials. Most geosynthetic products are made of synthetic polymers, such as polypropylene, polyester, polyethylene, polyamide, PVC etc. These materials have high resistance to chemical and biological degradation and can be processed to meet the requirements of resistance, tensile deformation, providing good adherence with the reinforced soil (NP075-2002).

1.1. Use of geosynthetic materials in construction works

Geosynthetic reinforcement of foundation soils that have lower bearing capacities than the loads resulting from the superstructure has emerged as an alternative solution to other ways of improving the bearing capacity of foundation soils. The use of geosynthetic material is effective, as it uniformly distributes the soil characteristics, which can largely vary at the construction site.

Many methodologies have been developed worldwide, using various specialized computer software, combining different types of soil (sand, clay, gravel) with various types of reinforcement materials (geogrids, geocells, geomembranes), which were or were not experimentally verified, either in the laboratory or during the construction works (Cicek et al., 2012; Axinte, 2010).

However, the use of geosynthetic materials as reinforcement of foundation soil for constructions located in seismic areas is not as widespread as the use of such materials for retaining walls, because their behavior at the construction site has not been fully understood.

For these reasons, the author considers that this study on the behavior of geosynthetics-reinforced foundation soil loaded with dynamic forces could prove useful, along with other studies presented in the literature, in order to guide the future development in Romania of guidelines/norms for the design of soil foundation reinforced with geosynthetic materials.

2. PRESENTATION OF THE RESEARCH PROGRAMME

To highlight the effect produced by the layout of reinforcement materials, a theoretical calculation of foundation soil was carried out, by using the finite element method (FEM) numerical technique. The calculation was performed by considering two possibilities, i.e. reinforced soil and unreinforced soil (Fig. 1), taking into account: the same properties and characteristics of foundation soil material, identical size of the foundation soil area, the same loading conditions (loads resulted from the superstructure and the foundation itself), the same conditions for dynamic (seismic) loads and the same dimensions of foundation area. In geotechnics, the calculation model closest to the natural soil behavior is considered the soil behavior according to the Mohr-Coulomb theory (elastic-perfectly plastic) (Axinte, 2010).

The studied foundation is part of a three-story framed structure. The building structure and foundation system were calculated beforehand. In order to determine the behavior of foundation soil with and without reinforcement, the foundation with the biggest load was selected, i.e. the central foundation. The designed foundation dimensions are 2.2 m x 2.2 m x 0.90 m.

Considering the stress resulting from the “special” combination (gravitational loads and seismic loads), the studied foundation, i.e. the foundation under the central pillar, bears the following loads:

- Axial load – N_x = 477 kN;
- Self weight of the reinforced concrete foundation – G_f =106 kN

Therefore, the calculated load on the foundation surface is: N_{total} = 583 kN.

In order to point out the positive contribution of using geosynthetic-reinforcing materials for the foundation soil, the considered type of soil was one with low bearing capacity, i.e. sand, with the following characteristics:

- Density while compressed, γ_{sat} = 19.40 kN/m^3
- Horizontal permeability coefficient, k_x = 0.9 m/day
- Vertical permeability coefficient, k_y = 0.9 m/day
- Young's modulus, E_{ref} = 25000 kN/m^2
- Poisson's ratio, ν = 0.3
- Cohesion index – c_{ref} = 0
- Angle of friction, φ = 30
- Angle of dilation, ψ = 0
- Bearing capacity (according to STAS 3300/2-85 and NP 112-2004) p_{conv} = 200 kN/m^2

For the ease of calculation, the existence of groundwater was not taken into account.

After a detailed study of national and international literature, it was decided to reinforce the soil with biaxial geogrid (Cicek et al., 2012; Mahboubi and Keyghobadi, 2012; Zhang J. et al., 2012; Kleveko, 2012; Fraser et al, 2012; Moghaddas Tafreshi, 2012; Pokharel et al., 2010; Zhang et al., 2010; Boushehrian et al., 2010; Alamshahi and Hataf, 2009; Ghazavi and Lavasan, 2008; Latha and Murthy, 2007; Neven and Kavazanjian, 2006; Dash et al, 2004; Michalowski, 2004, McGown A., 2000; Vito A. et al., 1986; Lungu I. et al., 2002; Axinte, 2010.

The technical characteristics of the material were taken from the TENCATE product presentation catalogue and they are as follows: MIRAGRID GX BIAXIAL 55/55, with a longitudinal and transverse tensile strength of 58 kN / m (Fig. 3).

The following loads were considered for the calculation of the studied building:

- permanent loads: self weight of the structure, loads from superstructure elements;
- permanent loads from non-structural walls;
- live loads;
- loads resulting from seismic action.

The structure was analyzed by considering that the building is allegedly situated in the Banat region where, according to the seismic design code for buildings, P100-2006, in force in Romania, the design peak ground acceleration is a_g = 0.16 g and the control period of the design spectrum is T_C = 0.7 s.

In order to take into account the seismic load from the foundation soil (Fig. 2), the design acceleration value will be broken down as follows:

- a_g = 0.16 g horizontally;
- a_g = 0.08 g vertically.

In order to center the calculation model, given the distribution of stresses in the studied reinforced soil, a reference area for the foundation soil, related to the size of the foundation itself, will be considered, so that negligible deformations are recorded at the edges.

Considering the foundation length, marked with B = 2.2 m, used for calculation, the reference area will have the following dimensions (Fig. 1):

- horizontal length – 5B
=> 5 x 2.2 +2.2 m + 5 x2.2m = 24.2 m;
- vertical height – 8B
=> 8 x 2.2 m = 18 m.

Upon studying the literature, the following conclusions could be inferred:

- the presence of reinforcement elements leads to a higher bearing capacity of the foundation soil;
- when using more than one reinforcement layers, the first reinforcement layer needs to be positioned at an optimum depth estimated at 0.25 B from the foundations base (the loaded area), with the layers at a distance of 0.25 B;
- the reinforcement elements are efficient up to an estimated length of 3B ;
- the bearing capacity of the reinforced soil increases as the number of reinforcement layers increases;
- the use of reinforcing elements embedded in structures such as compacted cushions has a double effect: it reduces deformability and increases load bearing.

Using this information, but taking into account that an experimental stand to test the results obtained by numerical analysis is envisaged in the future, the following option was chosen (Fig. 1):

- the foundation soil is considered to be made up of sand;
- the reinforcement consists of 2 layers with geogrids laid out at 0,25 B = 0.25 x 2.2m = 0.4 m from the foundation base;
- the distance between the two reinforcement levels is 0.25 B = 0.25 x 2.2m = 0.4 m;
- the length of the reinforced layer (geogrid) is 3B = 3 x 2.2 m = 6.6 m.

3. RESULTS

The bearing diagrams obtained after performing the calculations for both conditions are presented in the following:

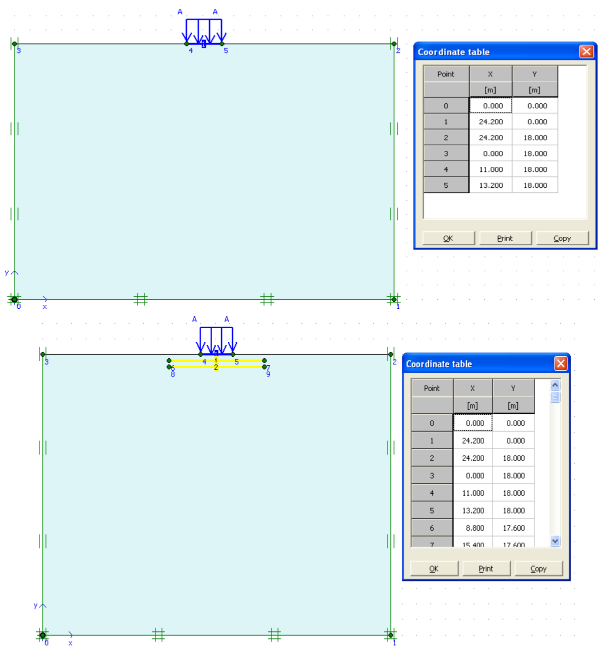


Fig. 1. Foundation - unreinforced / reinforced soil

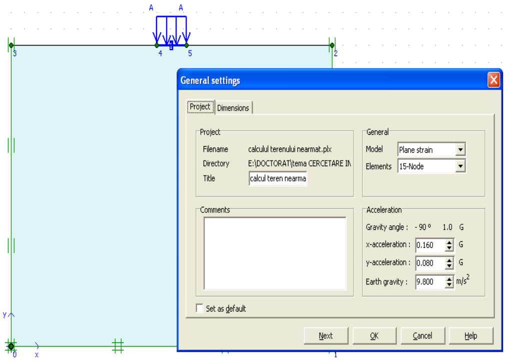


Fig. 2. Dynamic loads

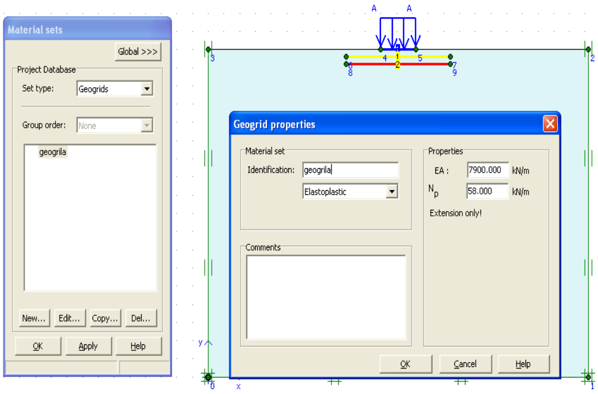


Fig. 3. Presentation of the geogrid characteristics

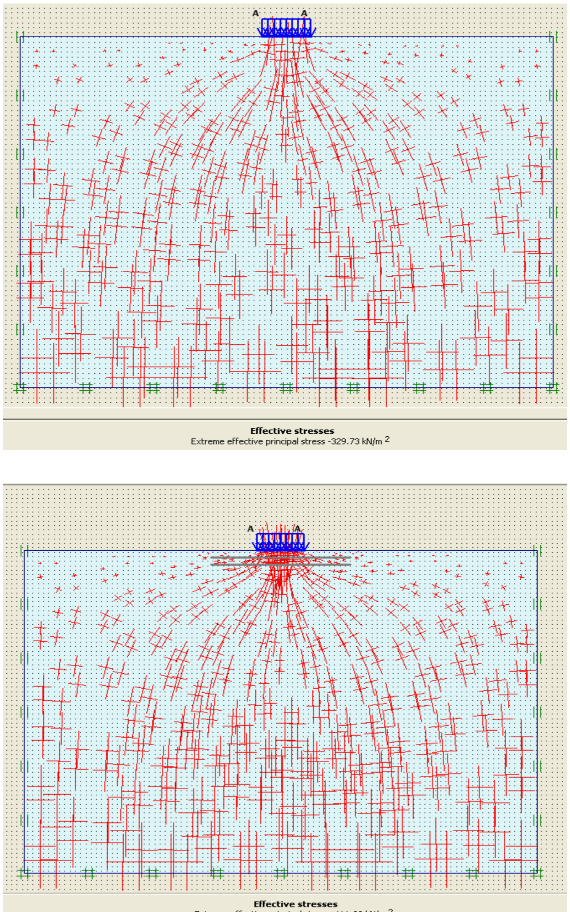


Fig. 4. Distribution of total stress - unreinforced / reinforced soil

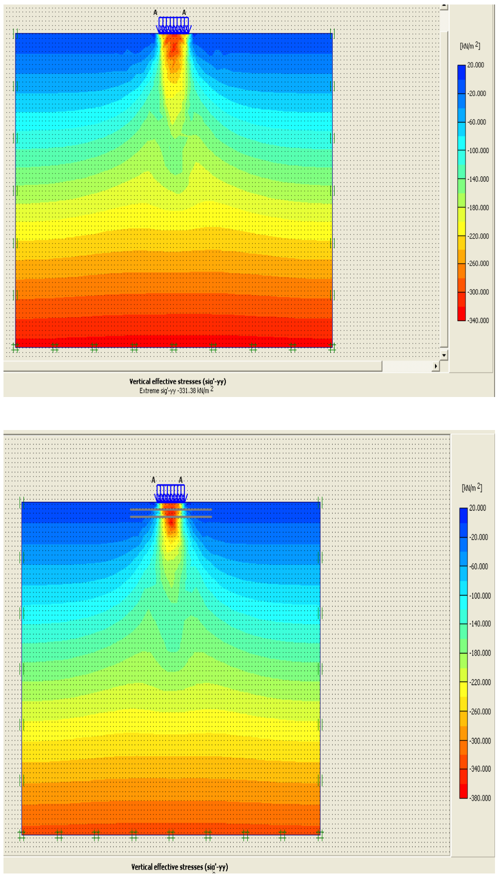


Fig. 5. Distribution of vertical stress, σ_y - unreinforced/reinforced soil

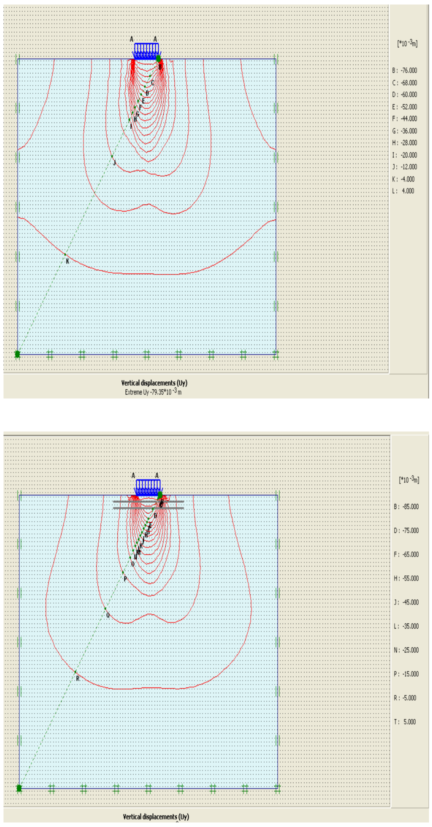


Fig. 6. Distribution of vertical U_y displacements - unreinforced / reinforced soil

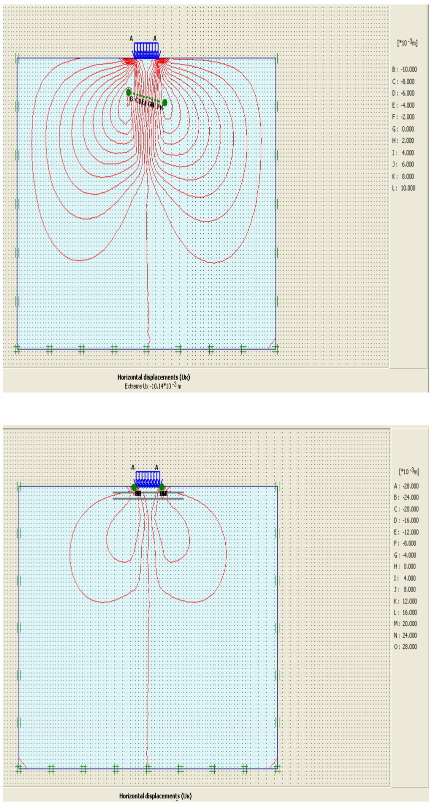


Fig. 7 Distribution of horizontal U_x displacements - unreinforced / reinforced soil

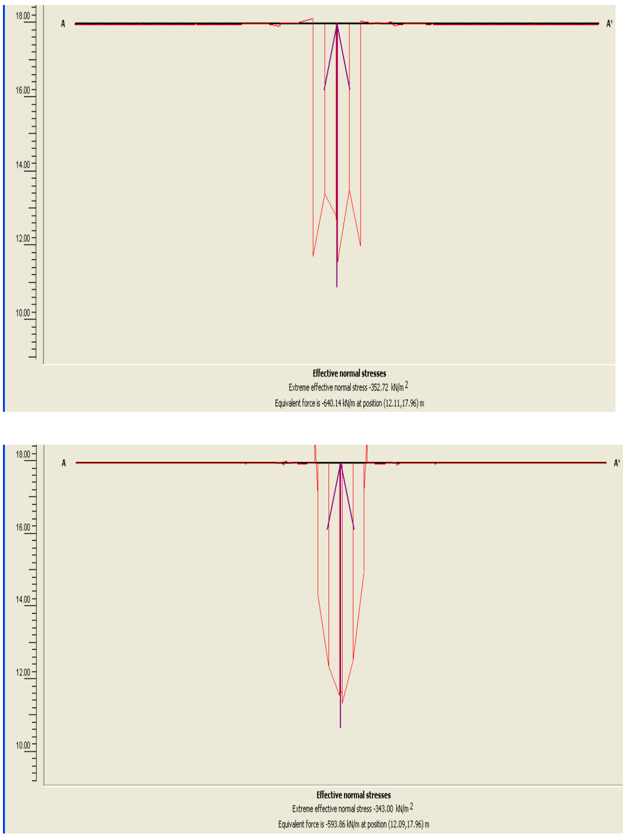


Fig. 8. Normal stress σ_y at 17.96m – just below the foundation base

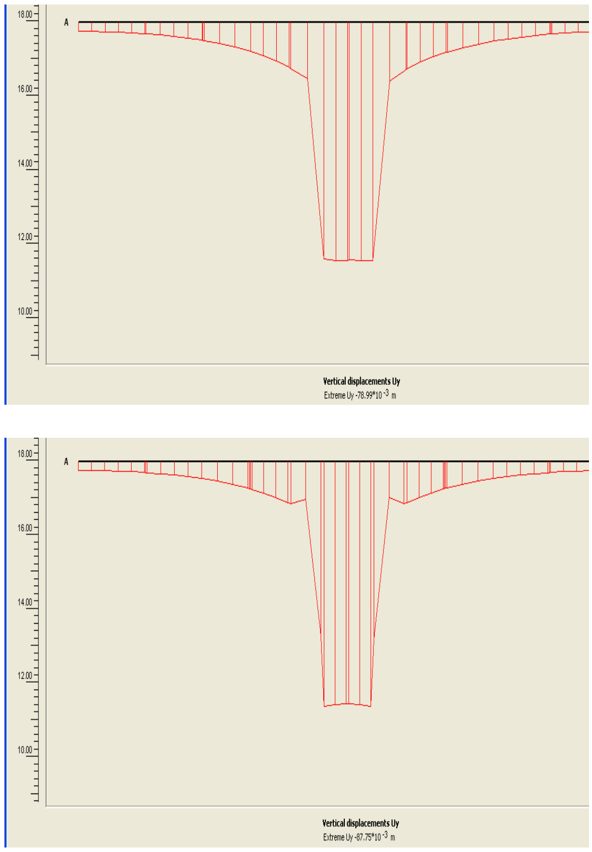


Fig. 9. Vertical displacements Uy at 17.96m – just below the foundation base

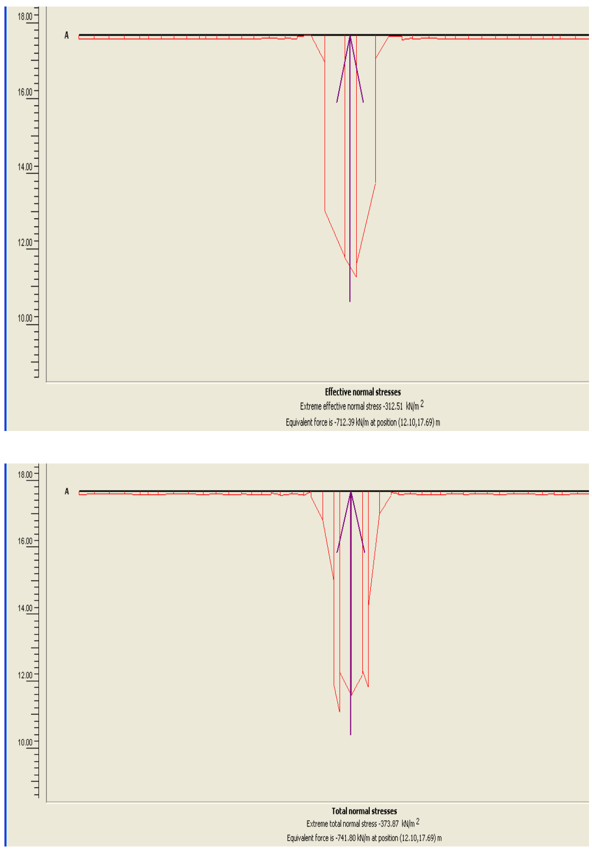


Fig. 10. Normal stress σy at 17.69m – just below the first reinforcement layer

Fig. 11. Vertical displacement Uy at 17.69m – just below the first reinforcement layer

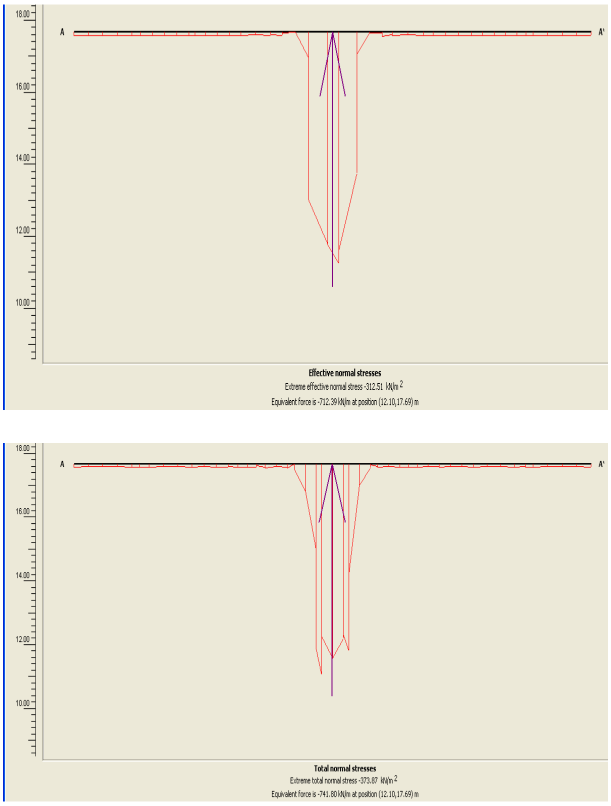


Fig. 12. Normal stress σy at 17.44m – between the two reinforcement layers

Fig. 13. Vertical displacement Uy at 17.44m – between the two reinforcement layers

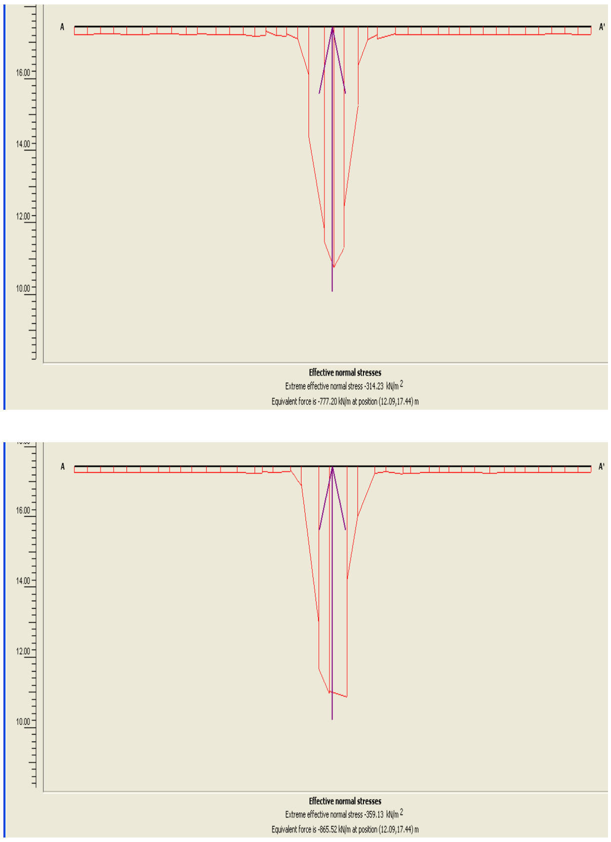


Fig. 14. Normal stress σy at 17 m – just below the two reinforcement layers

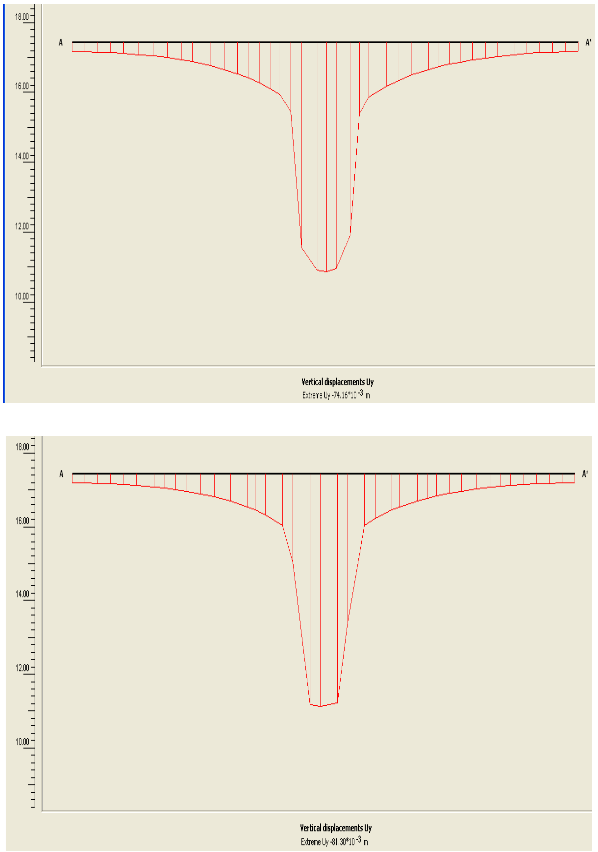


Fig. 15. Vertical displacement Uy at 17m – just below the two reinforcement layers

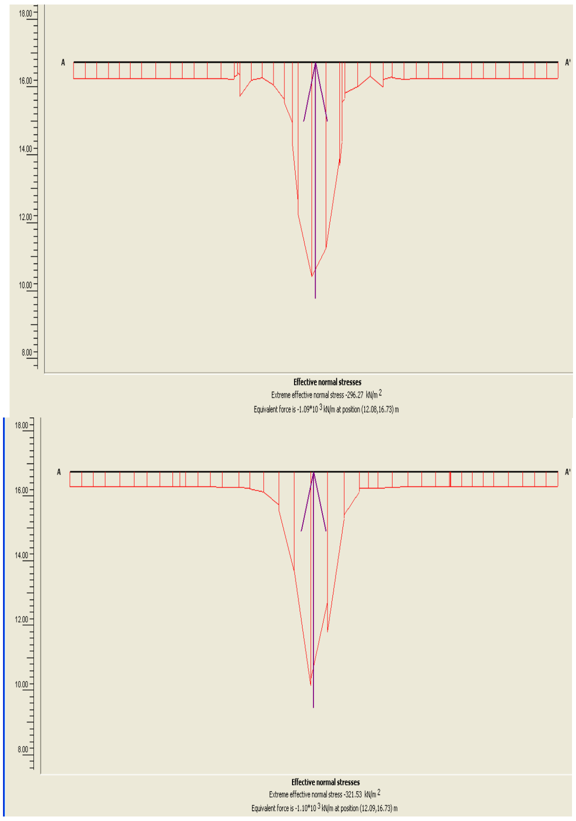


Fig. 16. Normal stress σy at 16.73 m – 45 cm below the two reinforcement layers

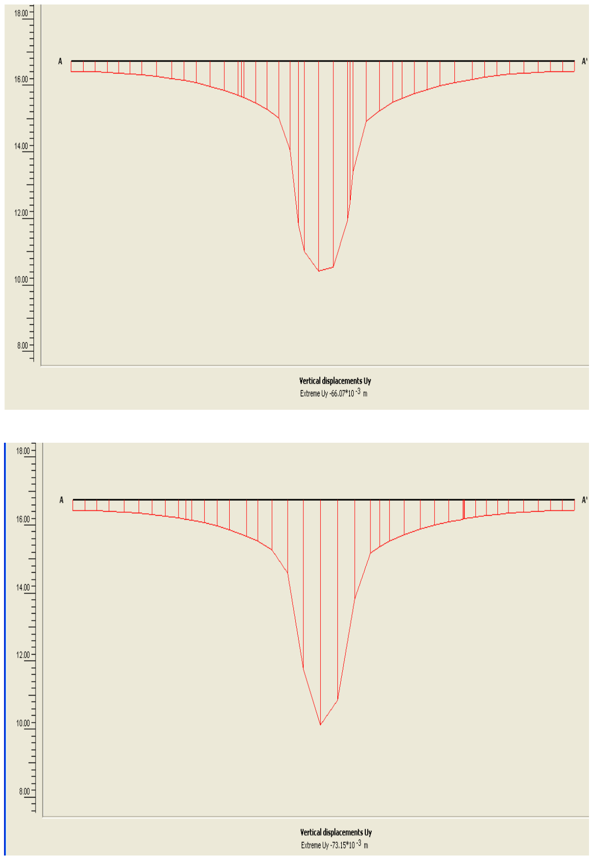


Fig. 17 Vertical displacement Uy at 16.73 m – at 45 cm below the two reinforcement layers

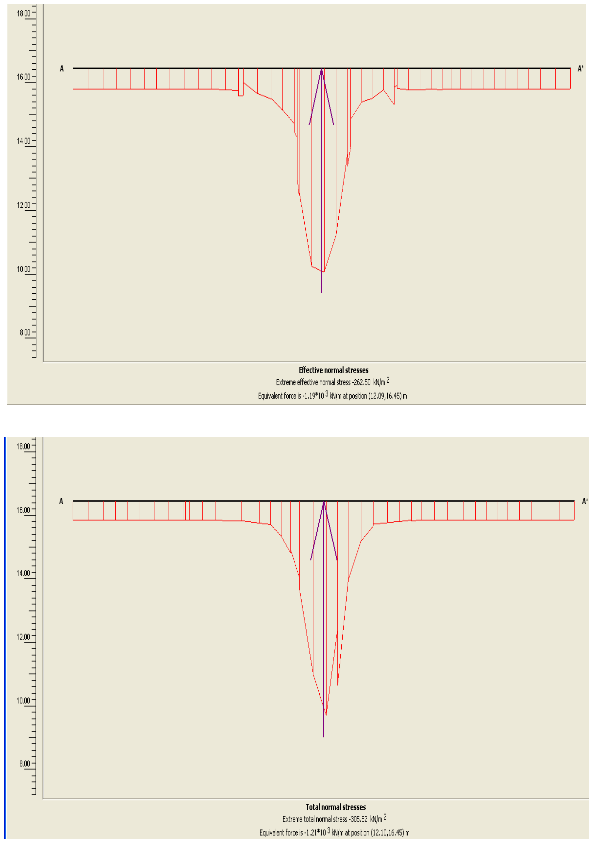
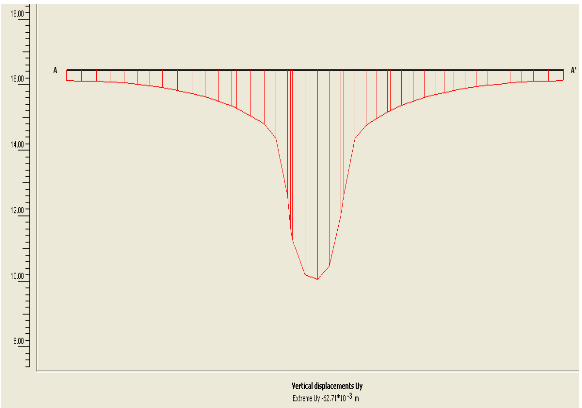


Fig. 18. Normal stress σy at 16.45m – under the two reinforcement layers



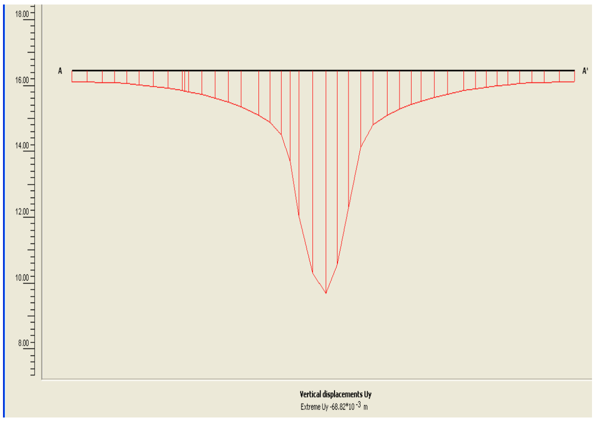


Fig. 19 Vertical displacement Uy at 16.45 m – under the two reinforcement layers

4. CONCLUSIONS

At 17.96 m depth, the change in the pressure and deformation diagram already starts immediately below the foundation base. A reduction in the width of the pressure bulb in the foundation soil immediately below the foundation base is noted (Figs. 6, 7, 8, 9).

At 17.69 m - situated above the first reinforcement layer, the pressure diagram narrows along with the increase in the maximum pressure value, which was also noted for vertical deformations (Figs. 6, 7, 10, 11).

At 17.44 m – at half distance between the two reinforcement layers, the pressure diagram narrowing is still present, accompanied by the increase in the extreme pressure and in the maximum vertical deformation values (Figs. 6, 7, 12, 13).

At 17.00 m - situated under the second reinforcement layer, the effect of the geogrid reinforcement is apparent (Figs. 6, 7, 14, 15):

- The pressure bulb reduces significantly;
- The deformation surface reduces, but the maximum vertical deformation value increases;
- The horizontal deformation diagram becomes uniform;

At 16.73 m and 16.45 m – situated 27 cm and 45 cm under the second reinforcement level, the reducing trend in the height of the pressure bulb is still present. Also, the deformation surface of the pressure bulb decreases horizontally with the increase of vertical deformation (Fig. 16, 17, 18, 19).

<u>General conclusions</u>

The use of various layers of geosynthetic reinforcement material, i.e. geogrids, results in the concentration of stresses on a smaller area under the foundation base, the same effect being noted for vertical deformations.

This concentration of stresses and deformations leads to the increase of maximum values. The reinforcement of foundation soil with natural bearing capacity smaller than the loads resulting from the superstructure could be improved by placing under the foundation a ballast/sand cushion, reinforced with geosynthetics.

As it results from the above analyses, the role of geosynthetic materials is to concentrate pressure stresses and vertical deformations, thus resulting in a smaller pressure bulb than the one occurring in unreinforced foundation soil. Even if the value of deformations and pressures is higher than the one for the same foundation made in unreinforced soil, the use of a reinforced ballast cushion will help these loads to will evenly distribute over this cushion, which has a higher bearing capacity than the natural soil around it.

The theoretical calculation of the foundation soil reinforced with geosynthetic materials is very important in the design stage because it allows establishing the pressure bulb and the deformations that will occur in the foundation soil. In this way, one can determine the size of the ballast/sand cushion in which the geosynthetic materials are inserted, so that the vertical pressure and deformations resulting inside the cushion would not exceed the bearing capacity of the natural foundation soil.

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