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Research Article

A RESEARCH ON THE EFFECT OF THE REINFORCEMENT GEOMETRY ON THE SOIL BEARING CAPACITY UNDER THE STRIP FOOTING LOADS

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ABSTRACT

Increasing the bearing capacity in the soils could be rational and economical solution for the shallow foundations in the geotechnical design. When the soil is loose and incapable of carrying loads from foundation, soil improvement appears to be essential. For this reason, the usage of geogrids for reinforcement of foundation soils is one of the principal ways in soil improvement, which is used horizontally as the reinforcement to increase the soil strength. In this research, a geotextile layer with wraparound ends is accomplished on the granular soils because of increasing the load capacity. For this purpose, a modified form of the geogrid alongside the installation method was explored. In addition, PLAXIS (2D) finite element analysis software was employed to model and analyze the new design of the reinforcement. The acquired results demonstrated that the new geometrical form could improve the soil to a greater extent and reduced the settlements, compared to the horizontal reinforcement system.
Keywords: Geotextile, wraparound ends, strip footing, settlement, reinforced soil, PLAXIS.

Abbreviations

γ_d	Dry unit weight
φ	Friction angle
Ψ	Dilation angle
E	Young's modulus
c	Cohesion
υ	Poisson's ratio
R_{inter}	Interface strength
D	Depth of geotextile reinforcement from the base of the footing
d	Lap depth of reinforcement from the base of the footing
B	Width of footing
b	Width of reinforcement without wraparound ends
b'	Width of reinforcement with wraparound ends
l	Lap width of reinforcement (m)
EA	Axial stiffness
EI	Flexural rigidity

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1. INTRODUCTION

The reinforced soil is consists of a mixture of the reinforcement materials and the soil. The reinforcements from metals or synthetic fibers are resistance components against tensile forces, which are created in the form of bars, strips, network fabrics, layers, etc.[1,2]. The friction between the soil and the reinforcing element plays a remarkable role on the shear and pressure forces in the reinforced soils [3]. The reinforced soil may attain a superior behavior, as a consequence of the stress transfer from the soil to the reinforcement in the contact area [4]. Therefore, an appropriate interaction in the contact area of the reinforced soil is essential for sufficient soil resistance.

The advantage of the reinforced soil behavior, compared with the unreinforced soil, is often as the result of an increase in the shear strength. The shear strength of the soil reinforced with geosynthetics is due to the higher modulus of the soil, as well as the high tensile strength in the reinforcement. This is the result of the frictional resistance between the soil and the reinforcement and has been developed due to the passive resistance between the cross-reinforcement component [5,6].

The reinforcements are often used in parallel with each other because of the stress transfer between them and the soil. Up to now, a variety of researches have been carried out on the applicability and the beneficial effects of using the reinforced soil in various geotechnical works and in this domain, several methods have been appreciably extended for soil reinforcement [7-18]. Along with the other available options, they have been employed in most projects, as an economic approach. Many investigations have been accomplished on the behavior of the shallow foundation, based on the context of the reinforced soils, using a variety of reinforcements. One single result, which has been achieved by all these researchers, is the large increase in the soil bearing capacity, by using the reinforcement in the depth of the soil.

Kazi et al [19] conducted a laboratory study on a strip foundation, located on the bed of the geotextile-reinforced sand. They concluded that using a geotextile layer with wraparound ends can increase the load capacity, compared to the simple mode. Azzam and Nasr [20] performed a laboratory study on the bearing capacity of the strip footing, located on the geotextile-reinforced sand with different relative densities. Moreover, Al-Saeed et al. [21] completed several laboratory studies on the behavior of the circular foundation, located on the reinforced sand with side constraints. After the respective investigations and tests, they claimed that the maximum improvement happens, when the diameter of the cylinder is the same as the foundation diameter. Naderi and Hatef [22] worked on the interaction between the circular and ring-shaped foundations, placed on the reinforced sand. They stated that the bearing capacity of the reinforced soil was increased due to the effect of the overlap and the interference.

Chakraborty and Kumar [23] used numerical methods to evaluate the bearing capacity of the circular foundations, located on the reinforced granular soil. They declared that the optimum depth of the reinforcement was approximately between 0.15d and 0.43d (d: the diameter of the foundation). Lai et al. [24] carried out a numerical study to investigate the increase of the bearing capacity of shallow foundations using geosynthetics. They explored the effect of different parameters, including the depth of the buried length of the reinforcement material, and the number and arrangement of the reinforcement layers on the bearing capacity. Marandi et al. [25] carried out a numerical study on the behavior of the circular shallow foundations, located on the geogrid-reinforced sandy bed. They showed that the bearing capacity ratio of the geogrid-reinforced sand depends on several parameters, such as the location of the reinforcement, the number of the reinforcement layers, the reinforcement resistance, and the geometrical properties of the circular foundation. Moreover, they proposed new curves to estimate the bearing capacity of the circular foundation.

According to the expression of records, it can be witnessed that in all studies, the geosynthetic reinforcement is among the soil layers, and no investigation has been done on the geosynthetic reinforcement with wrapround ends. Therefore, this can prove the need for the investigation into this matter. In the current study, it has been tried to propose a new approach to increase the bearing capacity of the soil by changing the geometry of the reinforcement. In all previous studies, the researchers have used the reinforcement layers horizontally and flat layers (i.e., the normal mode), which is exhibited in Figure 1.

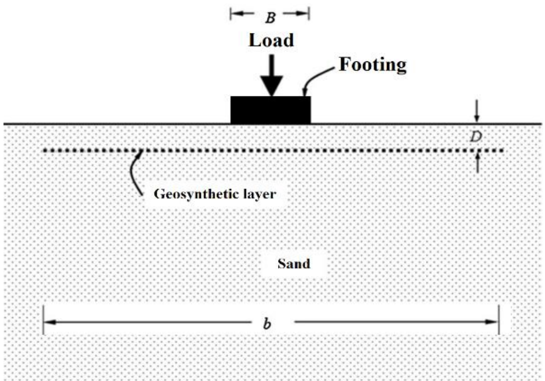


Figure 1. A schematic view of normal reinforced sand [19]

However, in this new idea, during the installation, the geometry of the reinforcement is changed and converted into the wraparound ends. For this purpose, the experimental results, presented by Kazi et al., [19] were exploited as the basis for managing the obtained results by the numerical method. They changed the reinforcement geometry into wraparound ends, when placed in the soil. The idea is portrayed in Figure 2.

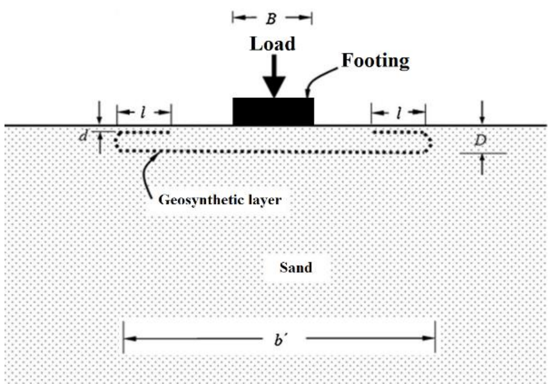


Figure 2. A schematic view of wraparound end reinforced sand [19]

2. THE GEOMETRY AND PROPERTIES OF MODEL

For the modeling phase, the data provided by Kazi et al. [19] were modeled in PLAXIS software, which is one of the the finite element analysis softwares, involved in the field of geotechnical engineering. Consequently, the results of the numerical and experimental models were compared. The finite element analysis was performed for the plane strain. In addition, the model boundary conditions were considered based on the true size of the models in the laboratory tests. Moreover, the soil behavior was modeled based on the Mohr-Coulomb condition. The studies were accomplished for different conditions, for the exposure of the reinforcement (3 conditions), the soil relative density (3 conditions), and the depth of the reinforcement (4 conditions). The parameters presented in Tables 1 to 3 were used to perform the numerical modeling. A sample of the model geometry and the modified model are shown in Figure 3.

Table 1. Sand properties used in numerical analysis [19]

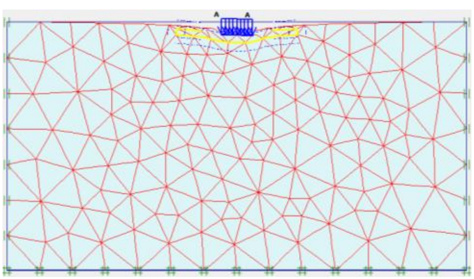
Parameter of soil	D_r=50%	D_r=70%	D_r=90%
γ_d (kN/m^3)	14.88	15.30	15.75
φ [˚]	36	37	38
ψ [˚]	6	7	8
E (kN/m^2)	672	10400	14400
c (kPa)	3.75	6.5	7.25
υ	0.25	0.25	0.25
R_{inter}	0.67	0.67	0.67

Table 2. Insertion depth of geotextile [19]

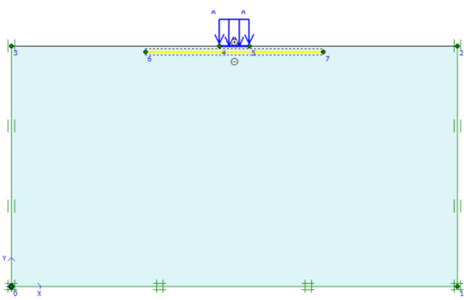
Geometric parameter	Size	Size	Size	Size
D (mm)	16	24	32	40
d (mm)	0	8	16	24

Table 3. Properties of geotextile and footing [19]

Parameter	Value
Axial stiffness (kN/m)	200
B (mm)	80
b (mm)	480
b’ (mm)	320
l (mm)	64
Thickness (m)	0.04
EA (kN/m)	64e4
EI (kNm^2/m)	85



(a)



(b)

Figure 3. (a) Typical geometry of model and (b) Typical deformed mesh of model

3. RESULTS AND DISCUSSION

In this study, two dimentional plane strain finite element analyses were done to calculate stresses and total settlements under the footing rested on poorly graded sand. PLAXIS version 8.5 is used to simulate the model.PLAXIS has been verified previously by comparing solutions achieved from it with measurements taken in actual case histories. PLAXIS is able to model different types of soils, footings [26], geogrid sheets [27], cavity and excavation [28], retaining walls [29] and dynamic analysis [30]. In current study, one example of the results of the laboratory and numerical methods are compared in Figure 4. As shown in the figure, the values obtained from the experimental and numerical methods are close to each other and they all fit well together. This verifies the accuracy and acceptability of the software outputs.

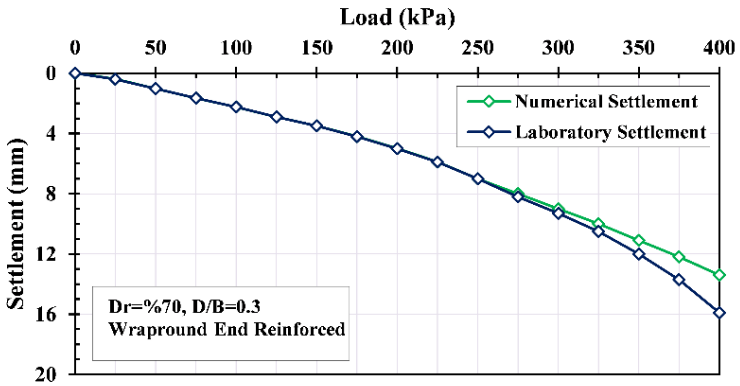


Figure 1. Load-Settlement curve for D_r=70% and wrapround reinforcement

The results of the numerical methods and laboratory tests demonstrated a better match after the increase in the relative density of the soil in the unreinforced soil, the normally reinforced soil, and the wrapround end reinforcement case. Also, the results of the numerical and laboratory experiments indicated that by using the wrapround reinforcement in different relative densities of soils, a better adaptation was observed, compared to the unreinforced and the normally reinforced situations.

3.1. The Effect Of The Reinforcement Geometry On The Soil Bearing Capacity

In this section, the effects and benefits, obtained in exchange for the wrapround reinforcement were compared with the unreinforced and the normally reinforced cases. For this purpose, the modeling was carried out in PLAXIS with different relative densities of 50%, 70%, 90%, and in different depths of the reinforcement (D/B = 0.2 to D/B = 0.5). The charts obtained from modeling in three different relative densities (for D/B = 0.3) are presented in Figures 5 to 7. As evident in Figures 5 to 7, the wrapround reinforcement has a large impact on reducing the surface settlement and improving the soil behavior.

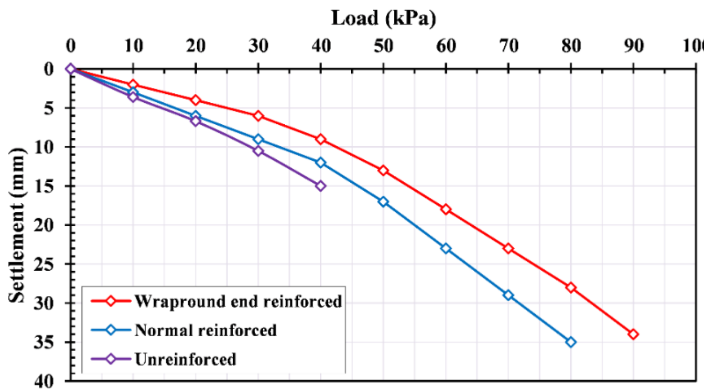


Figure 5. Load-Settlement curves for D_r=50% and D/B=0.3

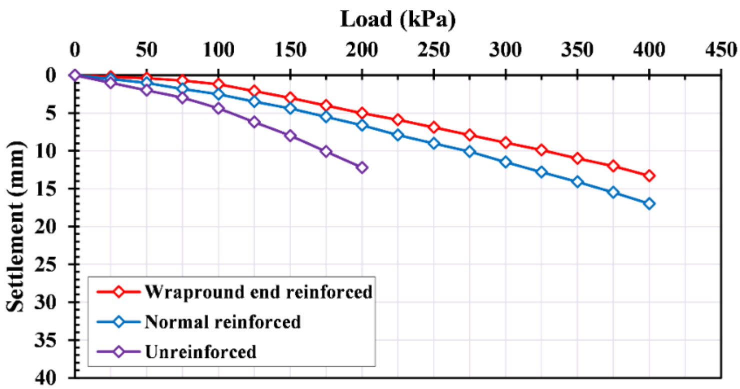


Figure 6. Load-Settlement curves for D_r=70% and D/B=0.3

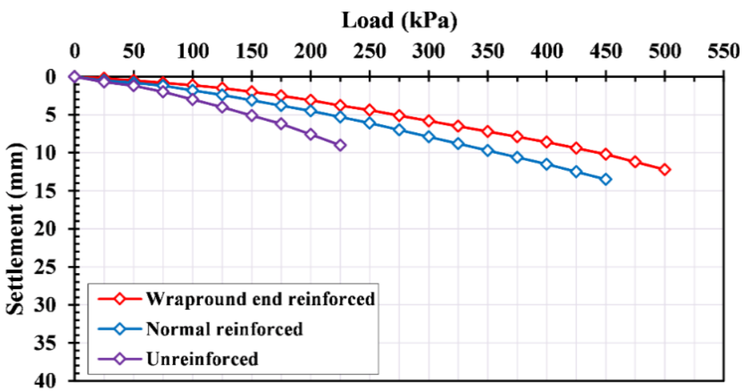


Figure 7. Load-Settlement curves for D_r=90% and D/B=0.3

The percentage of the surface settlement, caused by using wraparound reinforcement, and the comparison with the normal reinforcement are exhibited in Table 4 for different ratios of D/B. It can be seen that the surface settlement has been reduced from 4% to 42%, according to the different relative densities of the soil, when using the wraparound geogrid, instead of the normal geogrid. This indicates that the new idea can have profound effects on reducing the settlement of the soil and can support a new way of using the reinforcement.

Table 4. Settlements reduction ratio

Ratio of insertion depth	Relative density		
	50%	70%	90%
D/B=0.2	10 - 17%	17 - 25%	17 - 25%
D/B=0.3	23 - 24%	21 - 32%	25 - 37%
D/B=0.4	11 - 15%	15 - 29%	15 - 27%
D/B=0.5	4 - 13%	18 - 25%	30 - 42%

3.2. The Optimum Depth Of The Reinforcement

In this section, the optimum depth for locating of the reinforcement was determined in order to achieve the maximum efficiency and the lowest surface settlement. In this regard, numerous modeling studies were conducted based on different relative densities of 50%, 70%, 90% and in different proportions of the depth exposure (D/B = 0.2 to D/B = 0.5). The acquired results from these models are revealed in Figures 8 to 10. It can be observed in the following figures that the best depth exposure reinforcement, which leads to the lowest surface settlement for the wraparound reinforcement, is in D/B = 0.3. This depth creates a meaningful reduction in the rate of subsidence.

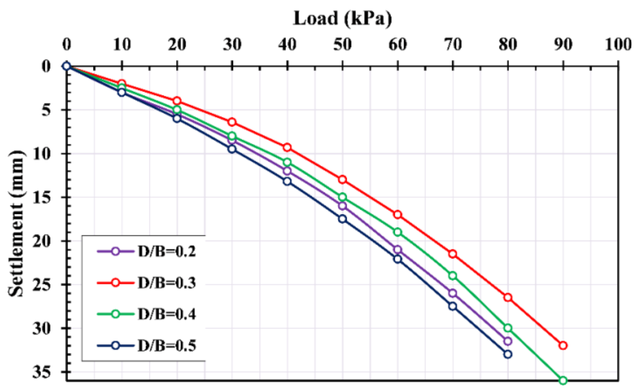


Figure 8. Load-Settlement curve, D_r=50%, wrapround end reinforcement

In Table 5, the decrease in the surface settlement percentage in the loading range, when the wraparound reinforcement was located in the depth of D/B = 0.3, was compared with the unreinforced condition. Also, in the above-stated depth, the increased percentage in the settlement of the wraparound reinforcement, in comparison with the normal reinforcement, is presented in Table 6.

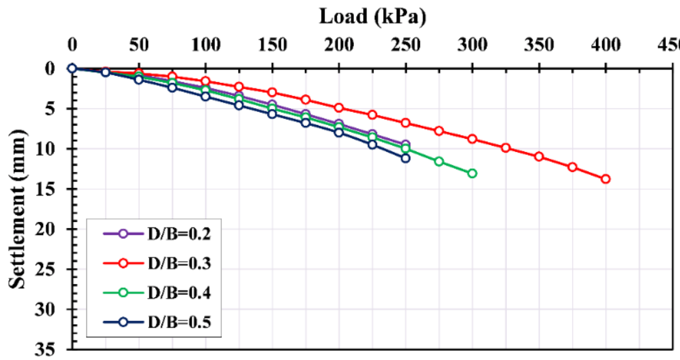


Figure 9. Load-Settlement curve, Dr=70%, wrapround end reinforcement

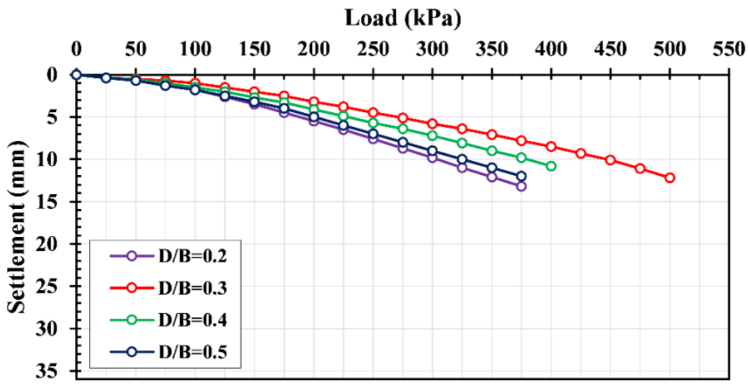


Figure 10. Load-Settlement curve, D_r=90%, wrapround end reinforcement

Table 5. Effect of wrapround reinforcement in settlement reduction against unreinforcement situation

Ratio of insertion depth	Relative density		
	50%	70%	90%
D/B=0.3	30 - 35%	56 - 61%	57 - 59%

Table 6. Effect of wrapround reinforcement in settlement reduction against normal reinforcement situation

Ratio of insertion depth	Relative density		
	50%	70%	90%
D/B=0.3	25 - 26%	22 - 34%	24 - 36%

4. CONCLUSION

In the present study, the numerical modeling with the finite element method was carried out using PLAXIS code in order to analyze the strip foundation, located on the sand bed, reinforced with geotextiles. In this work, the geometrical shape of the reinforcement was changed during the installation and was transformed into the wrapround form. The effects of the changes in the geometry were investigated and compared with the normally reinforced and unreinforced conditions. According to the mentioned cases and researches, the following results were acquired:

The obtained results in the unreinforced, normally reinforced, and wraparound reinforcement conditions, in the respective load ranges, disclosed that the results of the numerical and experimental tests have a better compliance, when the relative density of the soil was increased. The findings of both the numerical methods and the laboratory experiments confirmed a better compliance, at the relative densities of 50%, 70%, 90%, when using the wraparound reinforcement over the other two modes (i.e., the normally reinforced soil and the unreinforced soil). In fact, using the reinforcement in the wraparound form, instead of the normal reinforcement in different relative densities, led to reduce the settlement from 4% to 42%. This confirmed that the ideas can be introduced as a new way for using the reinforcements.

The ratio of the depth of insertion (D/B= 0.3) made a large reduction in the settlements. Therefore, in this depth, if the wraparound reinforcement is used, rather than the normal reinforcement, the percentage of the settlement for the relative densities of 50%, 70%, and 90%, was 25-26%, 22-34%, and 24-36%, respectively, which is remarkable. In the ratio of the depth of insertion (D/B= 0.3), if the wraparound reinforcement is used, compared to the unreinforced soil, the percentage of the settlement, for the relative densities of 50%, 70%, and 90%, was 29-37%, 58-62%, and 56-58%, respectively, which is significant.

REFERENCES

[1] Keskin M.S., (2009) Güçlendirilmiş Kumlu Şevlere Oturan Yüzeysel Temellerin Deneysel ve Teorik Analizi, PhD Thesis, *Graduate School of Natural and Applied Sciences, Çukurova University,* Adana, Turkey.

[2] Akbulut S, Pamukcu S, (2010) Evaluation of dynamic properties of geosynthetic reinforced clay samples for environmental impact practices. *Environmental Earth Sciences* 61, 1449- 1456.

[3] Abiera H.O., (1991) Mechanically stabilized earth using Tensar, bamboo and steel grid Reinforcements with weathered Bangkok clay as backfill, Msc Thesis, Asian Institute of technology, Bangkok, Thailand.

[4] Unnikrishnan K., Rajagopal N.R., Krishnaswamy., (2002) Behavior of reinforced clay under monotonic and cyclic loading. *Geotextiles and Geomembrances* 20, 117-133.

[5] Shin E.C., Das V.M., Pur V.K., Cook E.E., Yen S.C., (1993) Bearing capacity of a strip Foundation geogrid reinforced clay, *Geotechnical Testing Journal* 16, 534-541.

[6] Ghiassian H., (2004) Influence of Encapsulated Geogrod-Sand System on Bearing Capacity and Settlement Characteristics of Reinforced clay, *International Journal of Civil Engineering* 2, 45-53.

[7] Huang C.C., Tatsuoka F., (1990) Bearing Capacity of Reinforced Horizontal Sandy Ground, *Geotextile and Geomembranes* 9, 51-82.

[8] Mandal J.N., Sah H.S., (1992) Bearing Capacity Tests on Geogrid Reinforced Clay, *Geotextile and Geomembranes* 11, 327-333.

[9] Dixit R.K., Mandal J.N., (1993) Bearing Capacity of Geosynthetic Reinforced Soil Using Variational Method, *Geotextiles and Geomembranes* 12, 543-566.

[10] Khing K.H., Das B.M., Puri V.K., Cook E.E., Yen S.C. (1993) Bearing Capacity of a Strip Foundation on Geogrid-Reinforced Sand, *Geotextile and Geomembranes* 12, 351-361.

[11] Yetimoğlu T., Wu J.T.H., Saglamer A., (1994) Bearing Capacity of Rectangular Footings on Geogrid-Reinforced Sand, *Journal of Geotechnical Engineering* 120, 2083-2099.

[12] Adams M.T., Collin J.G., (1997) Large Model Spread Footing Load Tests on Geosyntetic Reinforced Soil Foundation, *Journal of Geotech and Geoenvir Engineering* 123, 66-72.

[13] Kumar A., Saran S., (2003) Closely Spaced Footings on Geogrid Reinforced Sand, *Journal of Geotechnical and Geoenvironmental Engineering* 129, 660-664.

[14] Michalowski R.L., (2004) Limit Loads on Reinforced Foundation Soils, *Journal of Geotechnical and Geoenvironmental Engineering* 130, 381-390.

[15] Koerner R.M., (2005) Designing with geosynthetics, 5th ed. Prentice Hall, New Jersey.

[16] Kumar A., Walia B.S., (2006) Bearing Capacity of Square Footings on Reinforced Layered Soil. *J. Geotechnical and Geological Engineering* 24, 1001-1008.

[17] Shukla S.K., Yin J.H., (2006) Fundamentals of geosynthetic engineering. Taylor and Francis, London.

[18] Shukla S.K., (2012) Handbook of geosynthetic engineering. ICE, London.

[19] Kazi M., Shukla S. K., Habibi D., (2015) An Improved Method to Increase the Load-Bearing Capacity of Strip Footing Resting on Geotextile-Reinforced Sand Bed, *Indian Geotechnical Journal* 45, 98-109.

[20] Azzam W.R., Nasr A.M., (2014) Bearing capacity of shell strip footing on reinforced sand, *Journal of Advanced Research* 6, 727-737.

[21] Al-Saied A.E., Saleh N.M., Elmashad M.E., (2014) Behavior of circular footing resting on laterally confined granular reinforced soil, *HBRC Journal* 11, 240-245.

[22] Naderi E., Hataf N., (2014) Model testing and numerical investigation of interference effect of closely spaced ring and circular footings on reinforced sand, *Geotextiles and Geomembranes* 42, 191-200.

[23] Chakraborty D., Kumar J., (2014) Bearing Capacity of Circular Footings on Reinforced Soils, *International Journal of Geomechanics* 15, 1-9.

[24] Lai J., Chung S. Y., Yang B. H., Wu S., (2014) Numerical Study on Enhancing the Bearing Capacity of Shallow Foundation Using Geosynthetics, *Innovative and Sustainable Use of Geomaterials and Geosystems, Geo-Hubei 2014 International Conference on Sustainable Civil Infrastructure*, July 20-22, 2014, Yichang, Hubei, China, 64-70.

[25] Marandi S. M., Bagheripour M. H., Rahgozar R., Ghirian A. R., (2008) Numerical Investigation Into The Behavior of Circular Pad Shallow Foundations Supported By Geogrid Reinforced Sand , *American Journal of Applied Sciences* 5, 355-368.

[26] Krabbenhøft S., Damkilde L., Krabbenhøft K., (2016) Effect of slope height and horizontal forces on the bearing capacity of strip footings near slopes in cohesionless soil, *Insights and Innovations in Structural Engineering, Mechanics and Computation: Proceedings of the Sixth International Conference on Structural Engineering, Mechanics and Computation*, Cape Town, South Africa, 739-740.

[27] Yang S., Leshchinsky B., Zhang F., GaoY., (2016) Required strength of geosynthetic in reinforced soil structures supporting spread footings in three dimensions, *Computers and Geotechnics* 78, 72-87.

[28] Keawsawasvong S., Ukritchon B., (2017) Stability of unsupported conical excavations in non-homogeneous clays. *Computers and Geotechnics* 81, 125-136.

[29] Yu Y., Damians I. P., Bathurst R. J., (2015) Influence of choice of FLAC and PLAXIS interface models on reinforced soil-structure interactions, *Computers and Geotechnics* 65, 164-174.

[30] Melnikov R., Zazulya J., Stepanov M., Ashikhmin O., Maltseva T., (2016) OCR and POP parameters in Plaxis-based numerical analysis of loaded over consolidated soils, *Procedia Engineering* 165, 845-852.