The Influence of the Geogrid Layers on the Bearing Capacity of Layered Soils

S. A. Naeini, H. R. Rahmani, M .Hossein Zade

***Abstract*—**Many classical bearing capacity theories assume that the natural soil's layers are homogenous for determining the bearing capacity of the soil. But, in many practical projects, we encounter multi-layer soils. Geosynthetic as reinforcement materials have been extensively used in the construction of various structures. In this paper, numerical analysis of the Plate Load Test (PLT) using of ABAQUS software in double-layered soils with different thicknesses of sandy and gravelly layers reinforced with geogrid was considered. The PLT is one of the common filed methods to calculate parameters such as soil bearing capacity, the evaluation of the compressibility and the determination of the Subgrade Reaction module. In fact, the influence of the geogrid layers on the bearing capacity of the layered soils is investigated. Finally, the most appropriate mode for the distance and number of reinforcement layers is determined. Results show that using three layers of geogrid with a distance of 0.3 times the width of the loading plate has the highest efficiency in bearing capacity of double-layer (sand and gravel) soils. Also, the significant increase in bearing capacity between unreinforced and reinforced soil with three layers of geogrid is caused by the condition that the upper layer (gravel) thickness is equal to the loading plate width.

***Keywords*—**Bearing capacity, reinforcement, geogrid, plate load test, layered soils.

I. Introduction

OFTEN there are assumptions such as homogeneous considerations in the classical relationships to determine the bearing capacity of shallow foundation, while these conditions for the soil profile do not exist in most practical projects. Soils in nature are usually layered and the shear strength parameters in these soils are different from homogeneous soils. But, Bowles [1] points out that if the thickness of the upper layer is large enough, the soil can be assumed to be homogeneous by using the usual classical relations. However, if the thickness of the upper layer is low, homogeneous assumption of soils is not corrected because each layer has different shear strength and affects the final bearing capacity.

Meyerhof and Hanna [2] point out that usually there are two main modes in layered soils: in the first state, the thickness of the upper layer is larger than the foundation's width and the bearing capacity is calculated based on the shear strength parameters of the upper layer, but if the thickness of the upper layer is low, classical methods are not suitable methods for the estimation of the bearing capacity.

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There are various methods for estimating bearing capacity in layered soils. The important approaches regarding this issue are the method of averaging of soil strength parameters [1], limited equilibrium method [2]-[4], semi- experimental methods based on Laboratory studies [2], [5], numerical methods [6] and exact analysis methods [7], [8].

The estimation of bearing capacity for shallow foundation in layered soils depends on the ratio of the thickness of the upper layer (H) to the width of the foundation (B). Therefore, in addition to the shear strength parameters of the soil layers, the H/B parameter is also important in determining the bearing capacity of layered soils. Sanjeev et al. [9] studied the bearing capacity of layered granular soils base on PLT data. According to the results, the ultimate bearing capacity of layered soils increases with the increase of the thickness of top layer if upper layer will be courser than the bottom layer.

Today, the use of geosynthetics has become very popular in many engineering projects. Abu-Farsakh et al. [10], using of PLT results, evaluated the performance of geosynthetic as reinforced material in unpaved roads. They found that geosynthetic reinforcement leads to increase of bearing capacity and reduction of surface deformation, and also, double geogrid layers yield the best improvement. Gabr and Hart [11] using the laboratory plate loading test evaluated the elastic modulus of sandy soil reinforced by two types of geogrids. They found that when sandy soil includes geogrid, an improvement in the plate load bearing capacity at relatively low displacement levels is achieved. Ibrahim et al. [12], to improve the pavement performance, investigated the influence of different depths of geogrids in the granular base layer. According the results, a significant reduction in the tensile strain in the reinforced pavement was observed compared to unreinforced pavement. When the geogrid layer was located directly below the asphalt concrete layer, the maximum reduction in the tensile strain happened at the bottom of the asphalt concrete layer. Kiptoo et al. [13] determined the advantage of using geotextile and geogrid as reinforcement in a pavement structure underlain by a soft subgrade soil with laboratory static and cyclic plate loading tests. They found that there was no significant difference between the performance of geogrid and geotextile reinforced pavement models, and the combination of geogrid within the base and geotextile at the interface led to the best result. Hufenus et al. [14], by numerical analysis, investigates the behavior of striped foundations on the sandy slopes reinforced with geotextile and effects of several parameters including geotextile layers, geotextile spacing, the distance between the first geotextile layers from below, the distance from the slope edge and the effect of the rotation angle of the geotextile layers were determined. The result showed that the optimum mode is obtained when using the three reinforcement layers at a distance of about 0.3 to 0.4 times the width of the foundation.

In this study, the results of the PLT in reinforced and non-reinforced layered soils are analyzed. The dimension of the plate was 30 * 30 cm. In fact, in order to investigate the effect of layered soils on the results of the PLT, various layers of soils with different combinations have been studied so that there is a layer of gravelly soil, and there is a sandy layer below it. The thickness of the gravelly layer is a coefficient of width of the loading plate (B) and four modes are considered for its thickness including: 0.5B, 1B, 1.5B and 2B. The distance between the reinforcement layers is 0.3 times the width of the plate.

II. Numerical Modeling

A. Model Geometry

The finite element program ABAQUS was used to model on the reinforced double-layered soil. The soil has two layers such that the upper layer is gravel with different thicknesses which depend on the width of the loading plate and below it is a sandy layer. For the rectangular plate, all of the numerical analyses were carried out in three-dimensional space. The horizontal displacement of four sides of boundary is restricted, while the boundaries of the bottom are restricted in all direction. Mesh was developed using linear brick elements for the rigid loading plate and soil. Analysis was performed under displacement controlled method. The model has dimensions of 2 meters in length and width and 1.5 meters in height. Fig. 1 shows the geometry of the model and the mesh network in the ABAQUS software.

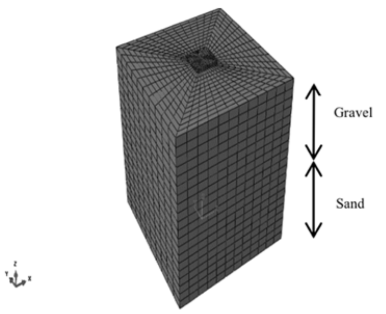

Fig. 1 Geometry and numerical modeling mesh grid

The influence of gravelly thickness has been studied in four different states including 0.5, 1, 1.5, and 2 times the width of the loading plate. The dimension of the square loading plate is 30 cm in length.

B. Material Properties

To determine the effect of the geogrid layers number, one to four layers of geogrid are used. The soil properties are presented in Table I, and Table II shows the geogrid characteristic used as the reinforcement. It should be noted that the reinforcement elements have a length and width of 1 meter.

TABLE I
Soil Properties Used in Numerical Modeling

soil type	E (kg/m^2)	υ	γ (kg/m^3)	ϕ (°)	C (kg/m^2)	Ψ (°)
Sand	5E5	0.35	1820	32	0	2
Gravel	1E6	0.30	1950	39	0	5

TABLE II
Geotextile Properties

Mesh thickness(mm)	3
Tensile strength(kN/m)	7.68
Extension at 1/2 peak load (%)	3.2
Extension at maximum load (%)	20.2
Tensile strength at 10% extension (kN/m)	6.8
Weight (g/m^2)	730

III. Numerical Simulations Result

In this research for modeling the yielding of frictional material (sand and gravel), the perfectly-elastic plastic Drucker-Prager Behavioral model was used. The results of the plate loading test obtained from numerical analyzes and the comparison of the effect of the number of geogrid layers for different soil conditions with the various thickness of the gravelly layer including the 0.5, 1, 1.5, and 2 times the width (B) of the loading plate are shown in Figs. 2-5, respectively.

According to the result, the bearing capacity in the case of three layers of geogrid is equal to 5500 kg for a soil with a top layer thickness of 0.5B (the thickness of the gravelly layer is equivalent to half the width of the loading plate), 6300 kg for a soil with a top layer thickness of 1B (the thickness of the gravelly layer is equivalent to the width of the loading plate), 7800 kg for a soil with a top layer thickness of 1.5B (the thickness of the gravelly layer is equivalent to the 1.5 times the width of the loading plate) and 9500 kg for a soil with a top layer thickness of 2B (the thickness of the gravelly layer is equivalent to the twice the width of the loading plate). It should be noted that when the number of geogrid layers varies from three layers to four layers, the increase in ultimate load is less than 5%, but with increasing the number of geogrid layers into three layers from two layers, the ultimate bearing capacity increases by about 20%. Therefore, the use of three layers of geogrid is the optimal mode for all assumed layered soils.

As it is clear from the preceding diagrams, in all of the different layered soil, with increasing the geogrid layers, the bearing capacity of the plate loading test increases, but the results show that, if the number of reinforcement layers exceeds 3, there is no significant effect on increasing the bearing capacity. In Figs. 6-9, the contours of vertical stress formed below the loading plate related to using of three layers of geogrid are shown. As seen in these figures, the contour of vertical stress formed below the loading plate expands to the range of the third layer of the reinforcement.

In order to better compare the ultimate bearing capacity for different soil states, Fig. 10 shows the variations of this parameter with respect to the number of geogrid layers in all state of reinforced double-layer soils.

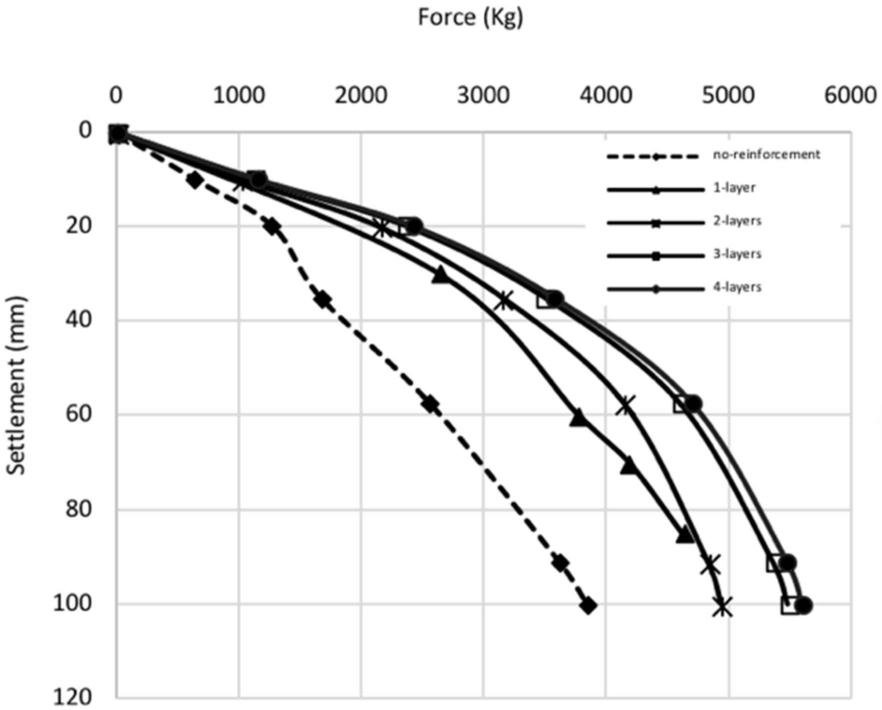

Fig. 2 The influence of number of geogrid layers on the bearing capacity obtained from the plate loading test in a double-layer soil with a top layer thickness (gravel) of 0.5B

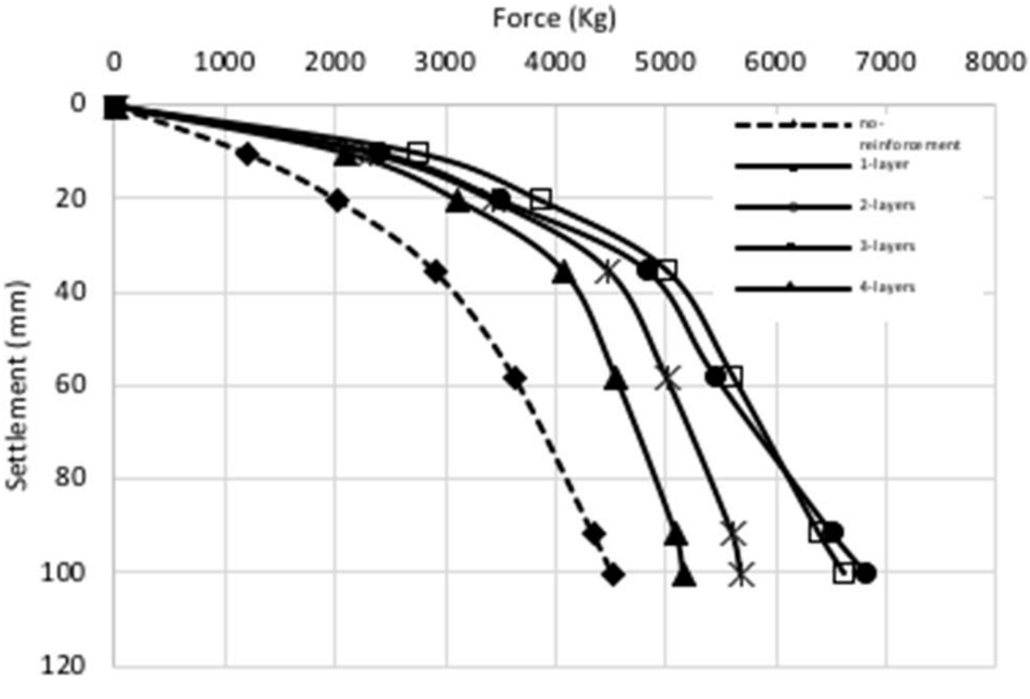

Fig. 3 The influence of number of geogrid layers on the bearing capacity obtained from the plate loading test in a double-layer soil with a top layer thickness (gravel) of 1.0B

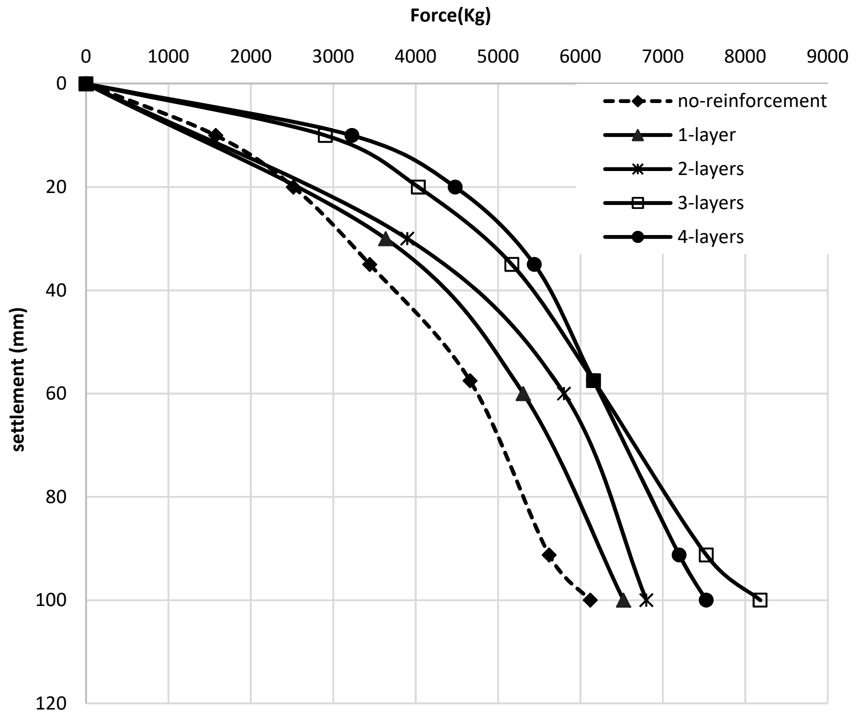

Fig. 4 The influence of number of geogrid layers on the bearing capacity obtained from the plate loading test in a double-layer soil with a top layer thickness (gravel) of 1.5B

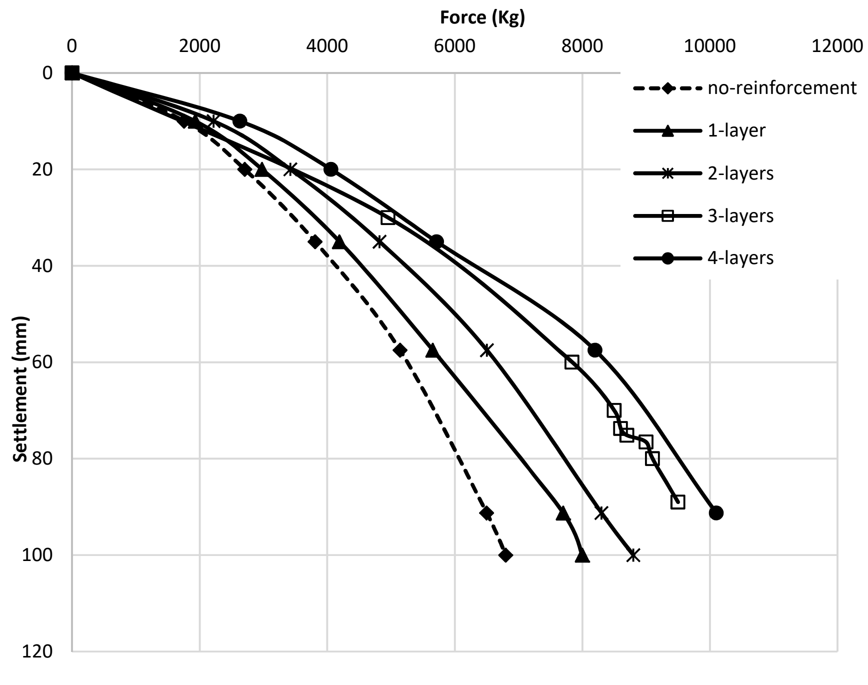

Fig. 5 The influence of number of geogrid layers on the bearing capacity obtained from the plate loading test in a double-layer soil with a top layer thickness (gravel) of 2.0B

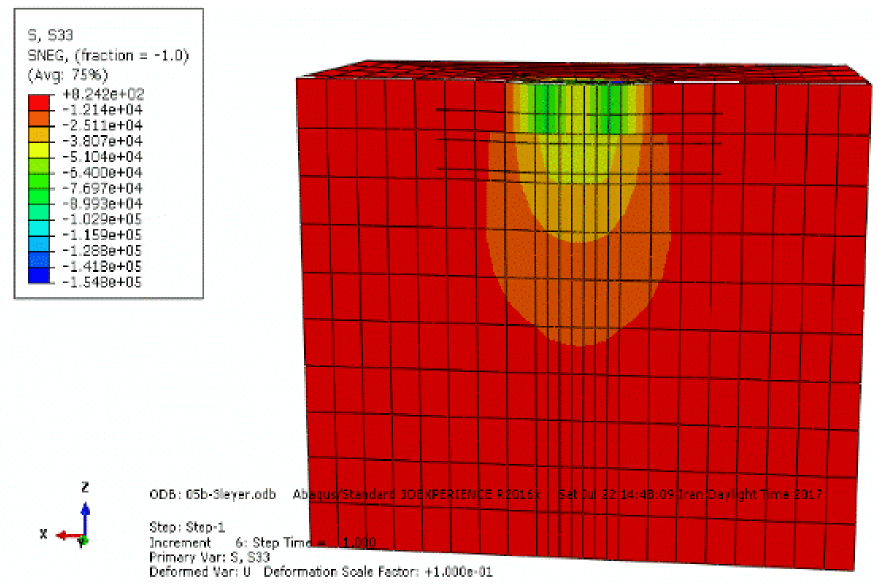

Fig. 6 The contour of vertical stress in a double-layer soil reinforced by three layers of geogrid with a top layer thickness (gravel) of 0.5B

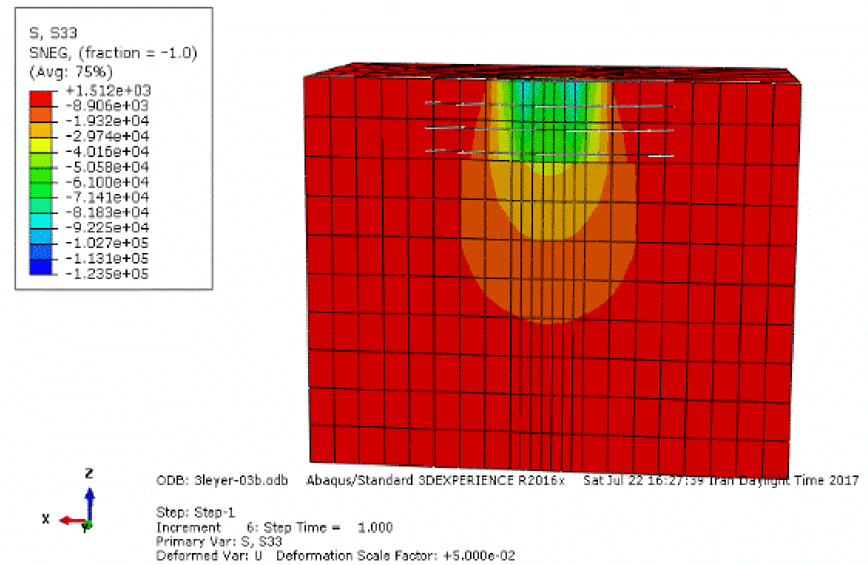

Fig. 7 The contour of vertical stress in a double-layer soil reinforced by three layers of geogrid with a top layer thickness (gravel) of 1.0B

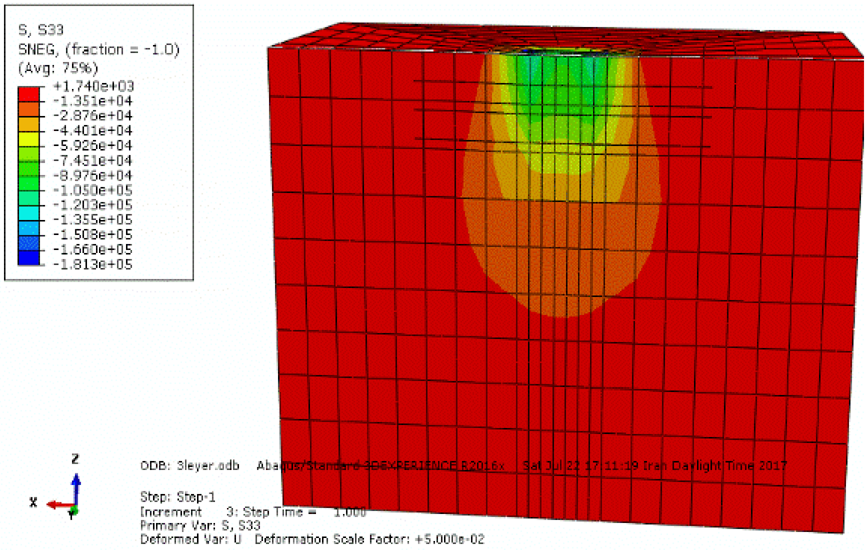

Fig. 8 The contour of vertical stress in a double-layer soil reinforced by three layers of geogrid with a top layer thickness (gravel) of 1.5B

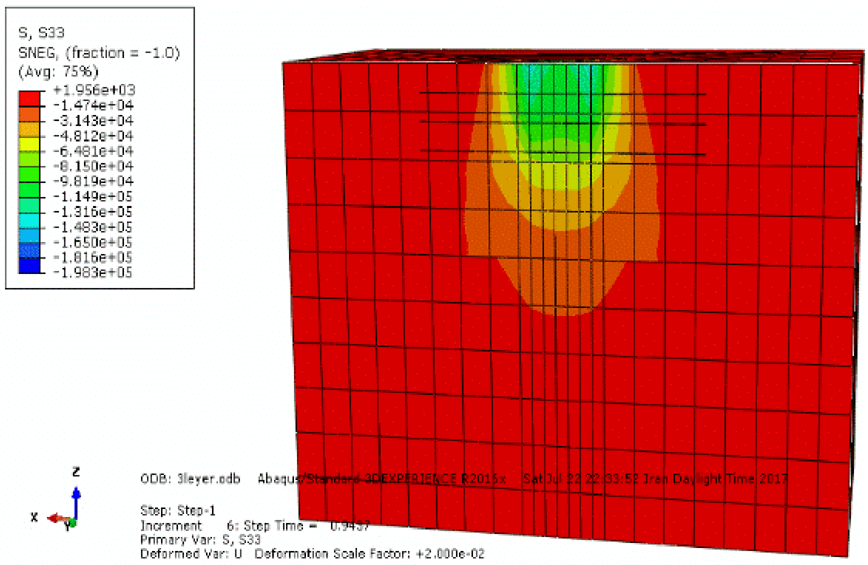

Fig. 9 The contour of vertical stress in a double-layer soil reinforced by three layers of geogrid with a top layer thickness (gravel) of 2.0B

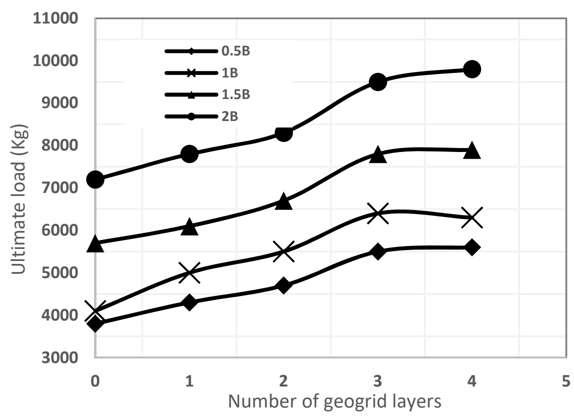

Fig. 10 The ultimate bearing capacity versus the number of geogrid layers for different double-layer soils

According to Fig. 10, the most variation in the bearing capacity between unreinforced and reinforced soil with three layers of geogrid is related to the condition that the top soil layer thickness is equal to the width of the loading plate, which is about 40%, and the least variation on the bearing capacity is related to the condition that the upper soil thickness is 2 times the width of the loading plate, in which an increase of about 15% is observed. It should be noted that in a double-layered soil with a top layer thickness of 2 times the width of the loading plate, due to the fact that there is a sufficient thickness of dense soil below the loading plate, the influence of the reinforcement layers is lesser and this means that most of the bearing capacity is provided by the soil under the loading plate and the reinforcement elements have a lower role.

IV. Conclusions

In this study, using the ABAQUS software, the results of the plate loading test in various double-layer soils (sand and gravel) reinforced by geogrid were analyzed. In order to determine the influence of gravelly layer, four different thicknesses of gravel layers including 0.5, 1, 1.5, and 2 times the width of the loading plate considered. In all cases, the bearing capacity of layered soils increased with increasing the number of geogrid layers up to three layers, and after reaching the three layers, increasing the number of reinforcement layers has little effect on increasing the bearing capacity, so that when the number of geogrid layers varies from three layers to four layers, the increase in ultimate bearing capacity is less than 5%. But with increasing the number of geogrid layers into three layers from two layers, the ultimate bearing capacity increases by about 20%.

The results also show that, for a soil with three layers of geogrid, in the case where the upper layer (gravel) thickness is equal to the width of the loading plate, the greatest increase in the bearing capacity occurs compared to the unreinforced soil, which is about 40% and the least variation in bearing capacity is related to the condition that the upper layer thickness of the soil is 2 times the width of the loading plate, in which a 15% increase in bearing capacity is observed.

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