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Influence of the number of reinforcement layers on the bearing capacity of strip foundation resting on sandy soil

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ABSTRACT

Reinforced soil technology is considered one of the most important methods of soil improvement due to its simplicity, easy implementation and saving cost. One of the known soil reinforcement methods is using geogrids to improve the bearing capacity of the soil and reduce the settlement of the soil beneath foundation. In this study, a strip foundation made of a rigid stainless steel with dimensions of 490 mm length, 135 mm width, and 40 mm thickness and reinforced with geogrid (called Tensar SS2) was tested in a laboratory model to investigate the effect of the number of reinforcement layers on the bearing capacity and settlement. The soil was reinforced with one, two, three, and four layers of geogrid (Tensar SS2). The obtained results showed that the reinforcement using geogrid system significantly improved the bearing capacity while reducing the settlement under the strip foundation compared with unreinforced soil. The test result also showed a good improvement in the bearing capacity when the number of reinforcement layers increased from one to four layers. The bearing capacity of the foundation increased when the soil reinforced by four layers of geogrid to about 2.5 times compared with the case of one layer of geogrid. In addition, the maximum settlement decreased to about 2.0 times compared with the case of one layer of geogrid.

1. Introduction

In order to achieve safe design of shallow foundation, it must be checked against two important characteristics. The first one is that the foundation should not exhibit exaggerated displacement or settlement, and the second is to ensure that the applied load does not yield shear failure Omar et al. [1]. In ancient times, the Sumerians used the soil in buildings using multiple methods. These methods vary depending on the nature of the building and its function. One of the important methods they considered was natural soil with other materials as a reinforcement such as straw to improve the soil. The ziggurat of Agar-Quf (3500 BC) is considered the first residual examples of a reinforced soil, as it was built using of the clay brick that were reinforced by utilizing of mats from woven reeds placed horizontally Aswad [2]. Many researchers have investigated the bearing capacity of geogrid reinforced foundation soils using experimental, analytical, and numerical methods. Binquet and Lee [3, 4] conducted the first parametric study that investigated the stability of soil layers mechanically to enhance the bearing capacity of shallow foundations [5, 6]. It was found from the previous experimental and numerical studies that the main factors affect the improvement of the bearing capacity are; the number of geogrid layers (N), depth of the upper layer (u), the type of geogrid, the soil properties, the vertical spacing of reinforcement (h), the maximum total depth of reinforced soil (d), and the effective length of reinforcements (b) [7-9]. It was also observed that the improvement in bearing capacity of reinforced soil by multi-layers of geogrid increased to about 7.0 times compared to the unreinforced soil Al-Sinaidi et al. [10]. In

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current study, the main experimental program included bearing capacity and settlement tests by using strip footing models resting on reinforced sand with one, two, three, and four layers of geogrid (Tensar SS2) in order to investigate the influence of the number of reinforcement layers.

2. Material Properties

2.1. Sand

Sandy soil of Al-Najaf City was used in the current experimental investigation. Physical, mechanical, and chemical tests were carried out to characterize the properties of this soil. These tests were the specific gravity, grain size analysis, maximum and minimum dry density, direct shear test and relative density. The chemical and physical features of the sand soil and the associated standards employed to do the tests are shown in the **Table 1**. The grain size distribution has been analyzed in accordance with the ASTM D422 [11]. The particle size distribution curve of the soil material is displayed in **Fig. 1**. The soil is classified as (poorly graded (SP) in accordance to the Unified Soil Classification System (USCS) [12].

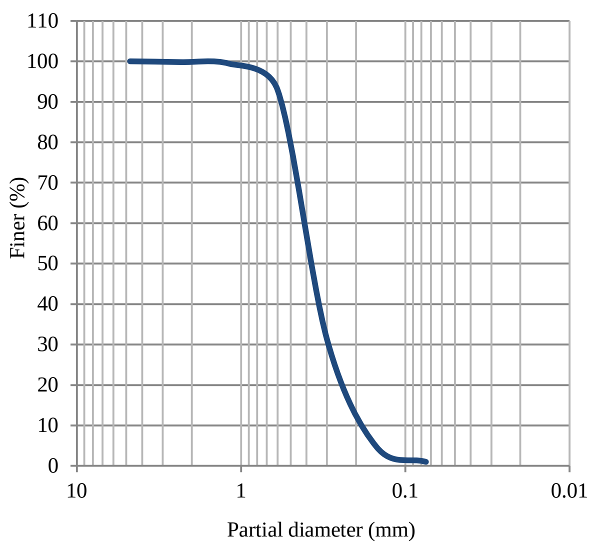

Figure 1 - Grain size distribution curve of the sand.

2.2. Geogrid

In the present study, the geogrid Tensar SS2 is used as a reinforcement. The geogrid was made by the British Company Netlon Ltd. Properties of the geogrid include physical and chemical characteristics. Properties related to filtration, separation, drainage, and barrier applications are not including since the primary function of geogrids is reinforcement. **Table 2** shows the physical properties of the geogrid used in the present study, which tested by Al-Omari and Fekheraldin [13].

Table 1- Physical and Chemical Properties of the sand used

Soil property	Value	Standard
Effective size, D10	0.19 mm	ASTM D 422 [11]
D30	0.299 mm	
D50	0.39 mm	
D60	0.4 mm	
Coefficient of uniformity (C_u)	2.105	
Coefficient of curvature (C_c)	1.176	
Specific gravity (G_S)	2.61	ASTM D 854 [14]
Max. dry unit weight (γ_{dmax})	17.658 KN/m3	ASTM D 4253 [15]
Max. void Ratio,(e_{max})	0.754	
Min. dry unit weight(γ_{dmin})	14.59 KN/m3	ASTM D 4254 [16]
Min. Void Ratio, (e_{min})	0.45	
Water content, %	6.56	ASTM D 2216 [17]
Relative density (D_r) %	64	
friction Angle (φ Ø used)	35°	SATM D 3080 [18]
Dry unit weight used,(kN/m3)	16.4	-
Organic material	1.4	BS.1377(1967) [19]
Gypsum content, %		2.70
T.D.S., (mg/L)		1150

3. Experimental Setups

To assess the bearing capacity of the strip foundation models, an experimental investigation was performed using a physical model. **Fig. 2** shows the experimental setup used to carry out the tests, which consists of a container, strip foundation model, sand raining apparatus, and loading system. The strip footing model used in this study is made from a steel with a length of 490 mm, width of 135 mm, and thickness of 40 mm. The footing base model has been manufactured from a rigid stainless steel. The sand container has been made by Fakhraldin [20] and has been used previously in many geotechnical problems . The inner dimensions of the box container are 1.0 m length, 0.5 m width and 0.7 m depth. The loading system consists of a manual hydraulic jack that is used to apply the load. The manual hydraulic jack can apply a maximum load of about 16 tons, where a load cell of a tension/compression is utilized to measure the loads, and three-dial gauges of 0.01 mm sensitivity, one situated at the center of the footing and the other 2 at counter-side corners of the footing at both sides have been utilized to assess the vertical displacement of the footing.

Table 2 - The physical properties of geogrid by Al-Omari and Fekheraldin [13]

Properties	Unit	Data
Mesh type/color	-	Rectangle/black
Aperture size(MD/XMD)	Mm	28/40
Mass per unit area	Kg/m^2	0.3
Rib thickness	Mm	1.2/1.1
Junction thickness	Mm	3.9
Peak tensile resistance	kN/m	14.4/28.2
Elastic modulus	MPa	570/990
Tensile strength	MPa	24/30.7
Percentage elongation at max load	%	3.5/2.9

4. Sand Preparation

The sand raining technique is utilized to fill the box with sand to the required level. The sand is permitted to rain through the air at a controlled rate of discharge and a specific height of pour to obtain homogeneity of sand formation and reconstruct the sand at the specified relative density Turner et al.[21]. Before depositing the sand in the tank, the raining system was calibrated by carrying out loops of trials with various dropping heights (10 cm, 30 cm, 40 cm, 50 cm, and 70 cm). These trials carried out to check and control the uniformity of the sand bed. The proportional height of pouring for any density of the sand deposition is obtained and presented in **Fig. 3**. It is observed that the density of sand increases when the height of the pouring increases. From the graph in **Fig. 3**, the dropping height can be directly found for any desired relative density. The relative density selected in this study was 64% to study this phenomenon for medium sand, the required level proportional to achieve the desired density is 50 cm. The sand bed was prepared in six layers of 10 cm constant height of each layer to get the required height of 60 cm is measured from the bottom of the tank. The reinforcing material such as geogrid is put at the desired depth and the tank is filled up with sand with the assistance of the funnel. The sand surface at the depth is graded through of a straight edge before placing the geogrid (the reinforcing material).

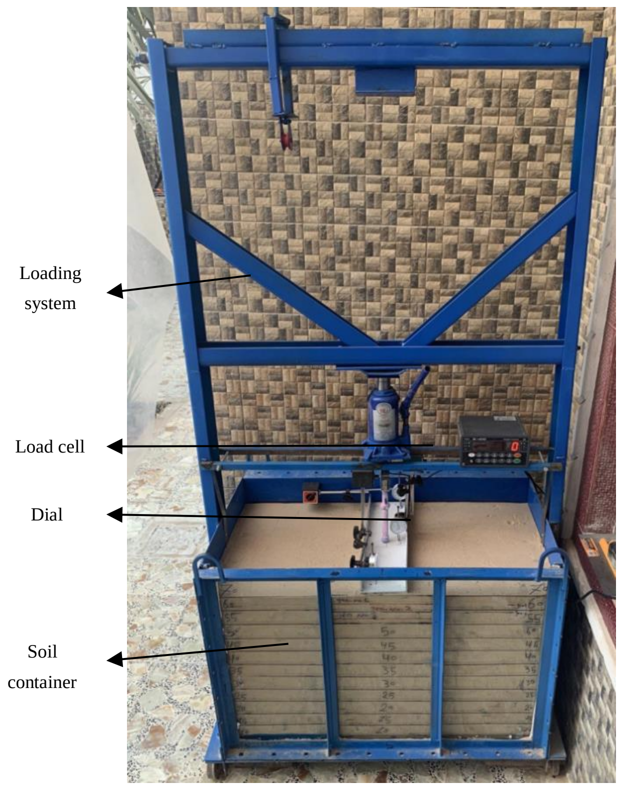

Figure 2 - Experimental set-up.

5. Geogrid Preparation

Fig. 4 illustrates the cross-sectional display of the model of the tank and the model of the footing with soil system having four layers of the Tensar SS2 reinforcement. A model strip footing with a width (B) is supported by the sand reinforced with (N) number of geogrid layers having a width "b". The vertical distance between successive layers of the geogrid Tensar SS2 is "h". The upper stratum of the geogrid is situated on a depth distance of "u" calculated from the footing model base. The following equation has been used to measure the reinforcement depth (d) beneath the foundation bottom: $d = u + (N - 1) * h$.

A value of u of 0.25 B is employed based on the findings of other researchers as being the best to give higher bearing capacity [1]. The distance between reinforcement layers (h) is considered equal to 0.1875 B as suggested by Fakhraldin [20]. By analyzing several test results and taking into account the prior results [1, 20], it is decided to take the following parameters in this research: u/B = 0.25; h/B = 0.1875; The geogrid stratum number (N): 1, 2, 3, and 4.

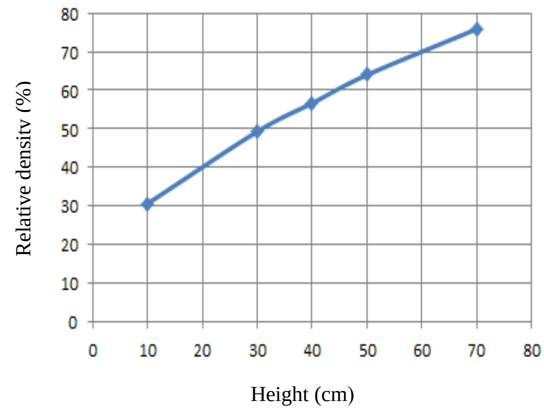

Figure 3 - Density calibration

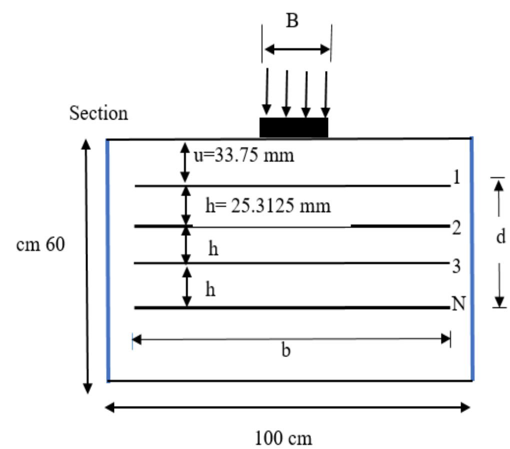

Figure 4 - Layout of geogrid spacing in cross section.

6. Testing Program

The inner face of the test tank was made smooth by the lubrication system to decrease the influence of the side friction on the load measurements Fakhraldin [20].

In every test, the foundation was loaded accumulatively until the failure occurred. The vertical load was transmitted axially to the foundation through the manual press. The load was viewed from the digital weighing indicator attached to the load cell; every load increase is maintained constant until the settlement is stabilized.

Initially, the soil reinforced by a single layer was tested. The first geogrid layer was positioned carefully on the distance equal to 0.25B from the surface of the sand.

For two layers of reinforcement, after filling the tank with sand to a defined position (i.e. height of the sand), the two layers of reinforcement were placed at a distance equal to 0.185B from one layer reinforced sand. After that, the raining of sand was continued to fill the tank. When the required level of sand was reached (at the base of the foundation model), the sand raining was stopped, and the raining box was removed. The procedure described above was also used for three and four layers of reinforcement. The third layer was put at a distance adjusted to 0.185B under the second layer of reinforcement and the fourth layer was put at a distance adjusted to 0.185B below the third layer. The strip foundation is placed with care in models to minimize the change in the relative density and to avoid disturbance to eventually ensure consistent density for all tests. The average vertical settlement was calculated utilizing three-dial gauges of 0.01 mm accuracy and 50 mm is the maximum capacity of dial gauge at three different locations on the surface of the foundation, one positioned on the center of the footing and the other two, at opposite corners of the footing at both sides. A magnetic holder was used to fix the dial gauge on the loading frame.

An experimental program was introduced to assess the influences of the relative density on the settlement and bearing pressure of the foundation subjected to vertical loads.

7. Discussions the results

The static loading tests were performed to determine the ultimate bearing capacity and load-settlement relationship for strip footing with one, two, three, and four reinforced layers by geogrid Tensar SS2 at 64% relative density. The load - settlement curves obtained from the tests are plotted in **Fig. 5** with multiple numbers (1, 2, 3, and 4) of geogrid layers.

From the load-settlement curve shown in **Fig. 5**, the ultimate load carrying capacity of sand at a relative density of 64% is calculated with varying number of geogrid layers. The ultimate bearing capacity for each model was determined by using Vesic method, which is the peak load obtained from the load - settlement curve of each model Vesic et al. [22]. The ultimate bearing capacity of sand reinforced by 1, 2, 3, and 4 layers of geogrid Tensar SS2 were 145.33 kPa, 167.57 kPa, 236.78 kPa, 358.86 kPa, respectively. From the above test results, it is observed that the bearing capacity of sand was increased after sand reinforced by four layers of geogrid to about 2.5 times the reinforced sand's bearing capacity by one layer of geogrid. The results obtained from the tests in reinforced sand by one, two, three, and four layers of geogrid Tensar SS2 are shown in **Fig. 6**. It is easy to observe that the bearing capacity increases when the number of reinforcement layers increases. The ultimate bearing capacity values obtained from the work tests and the maximum settlement are presented in **Table 3**.

Table 3 - The ultimate bearing capacity and maximum settlement.

Number of layers(N)	$(q_{ult})_R$ kPa	Max. settlement (mm)	Improvement in B.C (%)	Decrease in settlement (%)
1	145.33	20.52	-	-
2	167.57	25.54	1.153	1.0715
3	236.78	27.32	1.629	1.3689
4	358.86	27.02	2.469	2.083

$(q_{ult})_R$: The ultimate bearing capacity of reinforced sand
B.C : bearing capacity

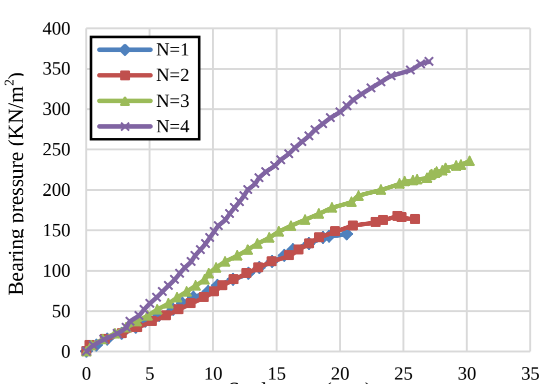

Figure 5 - Load –settlement curve

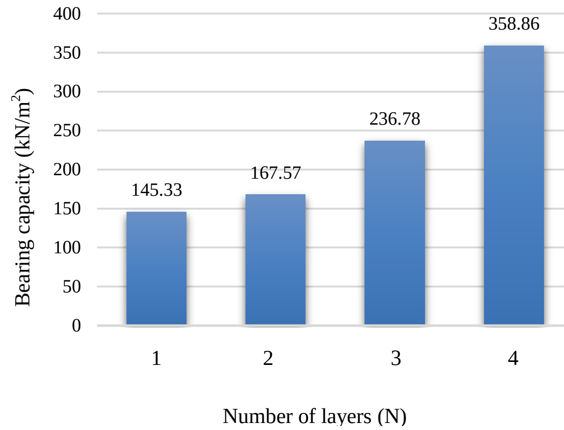

Figure 6 - Effective of number of layers on bearing capacity

8. Conclusions

In this study, a special experimental program was designed to study the influence of the number of reinforcement layers bearing capacity and settlement of strip footing models resting on sand reinforced by geogrid (Tensar SS2). Depending on the tests' results of this experimental study, the following conclusions can be deduced:

1. The bearing capacity of sand increased after sand reinforced by four layers of geogrid to about 2.5 times the case of one layer of geogrid.
2. The settlement is generally found to decrease when the number of reinforcement layers increased, the maximum settlement for forth layers of Tensar SS2 decreased to about 2.0 times the maximum settlement of one layer of geogrid.

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