Research Article

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Geogrid reinforcement for improving bearing capacity and stability of square foundations

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Abstract: Shallow foundations are often the most economical option for building support, as they distribute structural weight to soil layers, require minimal earthwork, and do not necessitate specialized machinery. The most common type of soil in the city of Karbala is sandy soil. It is granular and loose by nature which has a relatively low bearing capacity. According to previous studies, the soil weakness is one of the problems with shallow foundation construction. Thus, the aim of this study is to improve the properties of the soil using geogrid reinforcement. Three critical parameters are examined, including depth, size, and number of geogrid layers in the soil reinforcement process to increase bearing capacity and decrease soil settling. The effect of geogrid depth (u) was studied by considering four depth ratios (u/B = 0.5, 1.0, 1.5, and 2.0) in order to determine the ideal depth of the geogrid layer, where (B) refers to the width of the footings. The results indicated that a decrease in depth ratio significantly increased the bearing capacity of footings built on reinforced soil layers compared to those built on natural soil, and the settlement reduction ratio (SRR) also increased. The size of the geogrid layer (*i.e.*, width of the geogrid layer (b) was evaluated by evaluating four size ratios (b/B = 1.5, 3.0, 4.5, and 6.0). With an increasing size ratio of the geogrid layer, the bearing capacity ratio (BRC) was significantly improved. Additionally, the study examined the optimal number of geogrid layers, focusing on single and multiple layers with N = 1, 2, 3, and 4. The results showed a higher BRC for footings on reinforced soil layers, as well as a significant rise in SRR with an increase in the number of geogrid layers. Finally, it was concluded that the optimal depth ratio was u/B = 0.5, the size ratio was b/B = 4.5, and reinforced with three geogrid layers, which provided the highest bearing capacity and SRR. The experimental test results were verified by comparing them with those calculated using theoretically developed models. The variation between the experimental and theoretical results is reasonable, confirming that the experimental testing results exhibit a high degree of accuracy.

Keywords: shallow footings, geogrid, bearing capacity, settlement reduction ratio, weak soils

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1 Introduction

Soil is the most typical building material utilized in practically all civil engineering projects. Weak soil is one of the most critical problems faced in the establishment of infrastructure facilities (*e.g.*, buildings, pavement infrastructure, bridge approaches, and retaining walls). Due to their significant heterogeneity, weak and erratic soils are considered troublesome. It has to be stabilized in order to improve its technical qualities and become a practical building material. Because geopolymers have a lower carbon footprint than traditional stabilizer materials like cement, their application as stabilizer materials for poor soils has increased recently [1–4]. The technique for enhancing the soil's engineering qualities is to decide whether to employ reinforcing materials in the soils. Gravel, sand, clay, and silt are the four main types of soils. These soil types typically exhibit poor tensile strength and are quite susceptible to environmental factors. The procedure of enhancing the mechanical characteristics of the soil, such as shear, compression, hydraulic conductivity, and density, is characterized as soil reinforcement [5,6].

A foundation that is built on the ground surface or at a shallow depth below the ground surface is considered a shallow foundation. Typically, a foundation is considered "shallow" if its depth is smaller than its width (B). This foundation serves the function of applying structural loads to the earth by dispersing them across a broader area. Based on the structural loads and the soil characteristics, an appropriate shallow foundation type will be chosen. The strength and stiffness of the soils beneath shallow foundations significantly influence their structural performance, and soil reinforcement is an effective method to improve the stability of poor soils. Estimating the behavior of shallow footings on weak soil layers augmented with a top replacement layer, both with and without a geo-grid, have been studied by several researchers [7,8]. Utilizing methods such as traditional geosynthetics, chemical stabilization, and fiber reinforcing aims to increase soil bearing capacity and decrease soil settlement. Geosynthetics function as soil stabilization through the following mechanisms: (a) shear strength improvements due to the soil-geosynthetic interface resistance; (b) anchorage or pull-out, when the geosynthetic resists being pulled from the soil; and (c) tensile membrane and lateral deflection restraint impacts when the geosynthetic supports apply load [9]. According to the findings from previous studies, it can be inferred that the kind of foundations, footing width, type of soil, texture, and unit weight or density of soil all affect the bearing capacity of soil [10–14].

Loose, poorly graded sand soil is a predominant soil type in Kerbala City. This type of soil has a relatively low load-bearing capacity, resulting in stability issues (*i.e.*, excessive settlement) and potential footing failure under heavy structural loads. This challenge can be addressed by using geogrid reinforcement, which improves overall load distribution and enhances soil confinement, leading to the longevity and resilience of the foundation system. Therefore, the aim of the work is to assess the degree of improvement in the load-carrying capacity and stability of shallow foundations rested on sand soils reinforced using geogrid layers. To achieve this aim, three main geogrid parameters were studied, including size (b), depth (u), and the number of geogrid layers (N).

2 Materials used in the experimental work

2.1 Soil

The soil used in this investigation was collected near the Karbala-Najaf roadway (44°02'57" North and 10°34'32" East). Table 1 lists the main soil characteristics. The soil is classified as poorly graded sand soil as shown in Figure 1.

Table 1: Properties of the geogrid

Type of test	Soil parameter	Value
Physical tests	Water content	9%
	Dry density	1.85 g/cm^3
	Specific gravity	2.64
	Soil classification	SP
	Liquid limit	17%
	Plasticity index	2.45%
	Finer content	25%
	Sand friction	35%
Chemical tests	Sulfur trioxide	1.59%
	Granulated blast slag	3.44%
	Total soluble salts	6.9

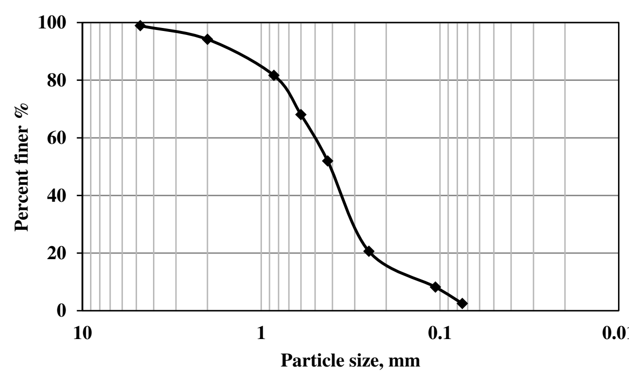

Figure 1: Particle size distribution of the soil used.

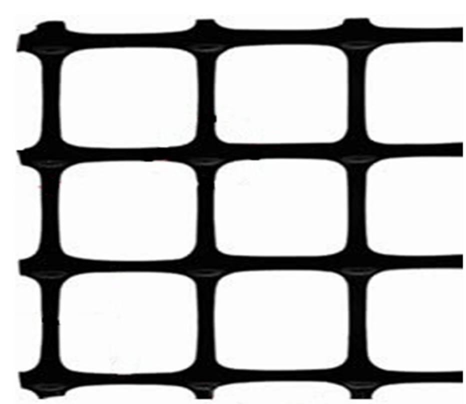

Figure 2: Geogrid material.

2.2 Biaxial geogrid

The type of geogrid used in this study was biaxial geogrid which meets with American Society for Testing and Materials ASTM D 6637 [15], biaxial geogrid has a tensile force of 100 kN/m both in the machine direction and the cross-machine direction. These geogrids were made of woven polyester fibers with a specific treatment that has a high molecular weight and durability, as shown in Figure 2. Table 2 lists the geogrid's characteristics.

Table 2: Properties of the geogrid type used

Property	Data
Longitudinal rib width (mm)	30
Transverse rib width (mm)	30
Material type	High-density polyethylene
Structure	Biaxial geogrid
Mass per unit area $\left(\frac{\mathrm{kg}}{\mathrm{m}^2}\right)$	0.3
Roll width (m)	4
Roll length (m)	50
Gross roll weight (kg)	84

3 Experimental works

3.1 Testing system

The experimental testing program was carried out in a large testing system consisting of a loading frame, a steel box, a hydraulic loading piston, and a data acquisition assembly. This system was utilized to simulate a shallow footing subjected to a concentric normal load. The soil sample was prepared in a steel box of 70 cm in length, 70 cm in width, and 60 cm in height. The experiment's model foundation was a strong steel plate with a 10 cm diameter (D) and 20 mm thickness. To apply the normal load to the footing, a hydraulic jack supported against the reaction frame was employed, as illustrated in Figure 3.

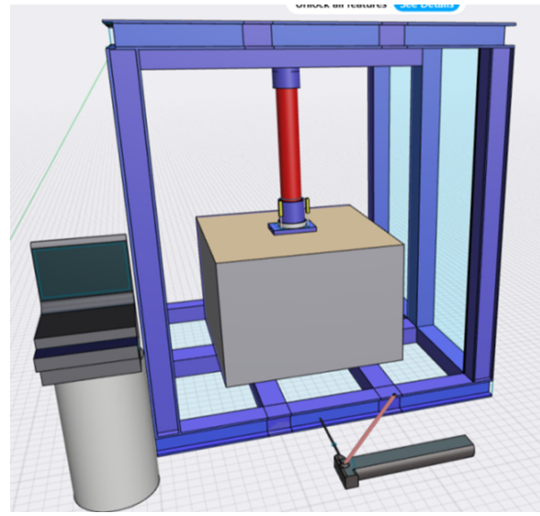

Figure 3: Three-dimensional testing system.

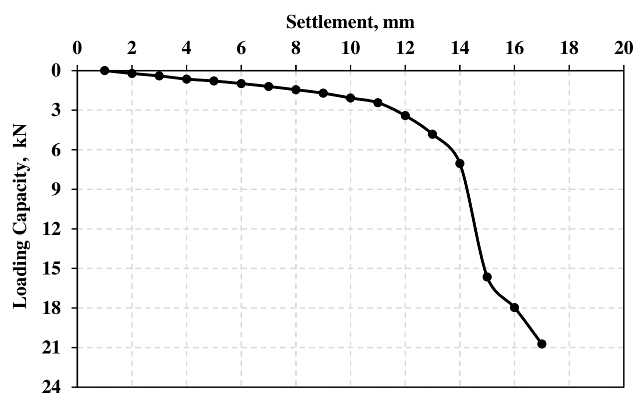

Figure 4: A typical load-settlement curve obtained from the plate loading test.

3.2 Soil preparation and testing procedure

The soil was mixed with water by a mixer in order to achieve the optimum moisture content of the soil which is equal to 9%. After that, the soil was placed in the steel box model as layers with a depth of 20 cm for each layer. The bulk soil placed in the box was then compacted using a metal plate compactor that can be held in the hand to achieve the ideal compaction properties of the soil.

After the completion of the soil preparation process, the installation of the equipment and setup of all dead loads (jacks, plates, *etc.*), two LVDTs (linear variable differential transformer) was conducted. Then, a fast load was applied to produce a displacement of at least 0.25 mm (0.01 in) and no more than 0.50 mm (0.01 in). The purpose of this loading stage is to make sure that the loading plate is seated properly. An increment load of, not exceeding 10% of the ultimate load capacity, was applied and the corresponding settlement was recorded when the settlement rate remains stationary for three consecutive minutes, or until each loading adjustment was given. The loading process continues until the soil begins to fail and the amount of settlement starts to increase. The testing procedure yielded a typical load settlement curve, as illustrated in Figure 4. The ultimate bearing and the corresponding settlement were determined using the two-tangent method.

3.3 Test geogrid variables

This study utilized the model footing test to evaluate the effects of reinforcing granular soils with geogrid, as shown in Figure 5. To evaluate the effects of geogrid on the bearing capacity and settlement characteristics of sand soil under a shallow footing, numerous model footing experiments were conducted while taking into account

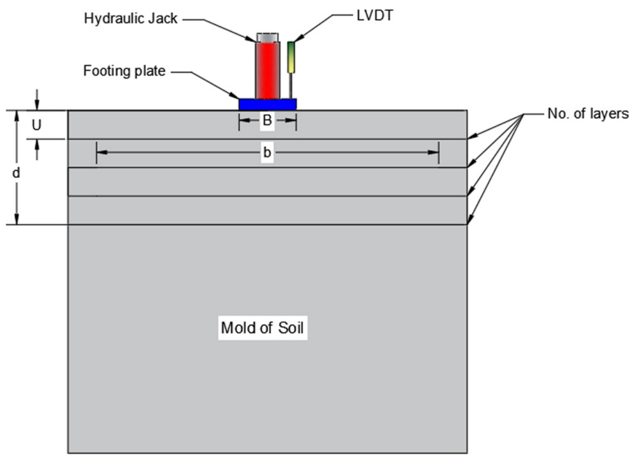

Figure 5: Parameters of laboratory model.

Table 3: Geogrid parameters examined in this work

Depth of reinforcing layer, *u* (m)	Width of reinforcing layer, *b* (m)	Number of reinforcing layers, *N*
0.5	1.5	1
0.1	3.0	2
1.5	4.5	3
2.0	6.0	4

the following parameters: four depth ratios (u/B = 0.5, 1.0, 1.5, and 2.0), four size ratios (b/B = 1.5, 3.0, 4.5, and 6.0), and four layers as illustrated in Table 3.

4 Results and discussion

The data of load-settlement were analyzed using the two tangent methods to determine the ultimate bearing capacity (q_{ult}) and corresponding settlement ($S_{\mathrm{ult.}}$) for natural and reinforced soils beneath the footing. The ultimate bearing capacity and corresponding settlement were then utilized to identify the improvement in load-carrying capacity and stability of the footing by determining two parameters:

Bearing capacity ratio (BCR) represents the ratio of ultimate bearing capacity of reinforced soil (q_{ultR}) to the ultimate bearing capacity of unreinforced soil (q_{ultO}):

$$\mathrm{BCR} = \frac{q_{\mathrm{ultR}}}{q_{\mathrm{ultO}}}. \tag{1}$$

Settlement reduction ratio (SRR) is defined as the percent of decrease in settlement caused by a reinforced case compared to an unreinforced condition under a constant load:

$$\mathrm{SRR} = \left(\frac{S_{\mathrm{O}} - S_{\mathrm{R}}}{S_{\mathrm{O}}}\right) \times 100. \tag{2}$$

S_{O} and S_{R} are the settlements of unreinforced and reinforced soil, respectively at a specified load value. The Sections 4.1–4.4 present a detailed discussion about the effect of geogrid parameters on the performance of the square footing.

4.1 Depth of geogrid layer

The effect of geogrid layer depth (u) was examined by evaluating four depth ratios (u/B = 0.5, 1.0, 1.5, and 2.0), where (u) represents the depth of the first reinforcement layer above the foundation level and (B) represents the width of the footing. After reinforcing the soil layer beneath the square footing with geogrid layers at various depths, the footing's ability to bear loads is greatly enhanced. Figure 6 illustrates how the carrying capacity ratio of the soil increased with a decrease in depth ratio compared to the control case (*i.e.*, the unreinforced soil layer), this behavior agreed with the findings of previous literature [16,17]. As illustrated in Figure 6, the results showed the BCR values were 1.78, 1.60, 1.31, and 1.17 determined for depth ratios (u/B) of 0.5, 1.0, 1.5, and 2.0, respectively. The highest improvement was achieved at (u/B) of 0.5, while the lowest improvement was obtained at (u/B) of 2 beyond which no improvement was identified.

Additionally, the results exhibited that the settlement increases with the increase in the depth of geogrid reinforcement. As illustrated in Table 4, the maximum SRR was achieved at depth ratio (u/B) of 0.5.

4.2 Effect size of geogrid layer

The bearing capacity of the soil is clearly influenced by the size of the reinforcing layer (b), as illustrated in Figure 7. The capacity of the soil to withstand additional pressure beneath shallow foundations was found to rise when the ratio of the reinforcing layer's size (b/B) increases. This behavior is similar to previous research's finding [18]. As shown in Figure 7, the results showed that the BCR values were 1.79, 1.73, 1.20, and 1.16 determined for depth ratios (b/B) of 6.0, 4.5, 3.0, and 1.5, respectively. The optimal enhancement was achieved at (b/B) of 4.5, while the lowest improvement was obtained at (u/B) of 1.5 beyond which no improvement was identified.

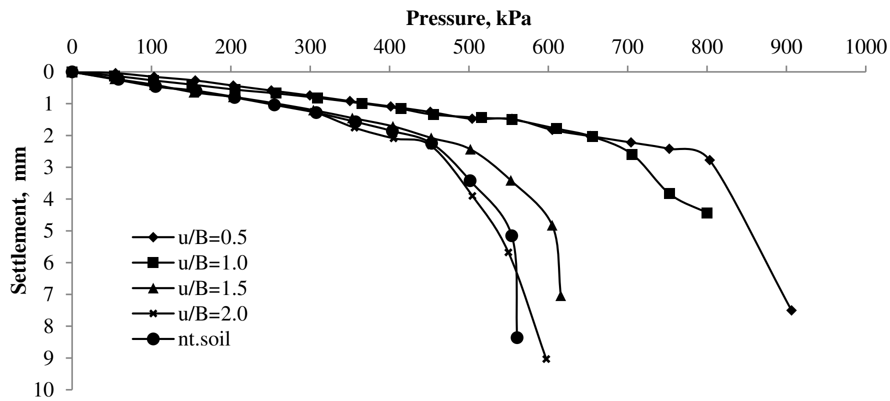

Figure 6: Variation in the bearing pressure at different depth ratios.

Table 4: Summary of SRR with different *u/B* ratios of the square footing

u/B	Settlement (mm)	SRR (%)
Control*	8.3	/
0.5	1.8	78.3
1.0	2.0	75.9
1.5	4.2	49.4
2.0	5.1	38.6

* Control represents the unreinforced soil condition.

Table 5: Summary of SRR with different *b/B* ratios of square footing

b/B	Settlement (mm)	SRR (%)
Control*	8.3	—
6.0	1.8	77.80
4.5	2.23	73.13
3.0	3.65	56.08
1.5	6.90	16.87

* Control represents the unreinforced soil condition.

The measured settlement of the soil that occurs beneath footings is directly influenced by the size of the reinforcing layer, as listed in Table 5. When the reinforcing layer's size increases, the quantity of soil settlement beneath the foundation reduces due to the increase in the contact between geogrid and soil particles, this is reported in "Table 5" and is in agreement with that reported by Yetimoglu *et al.* [19]. The maximum SRR was achieved at a size ratio (u/B) of 6.0, while the minimum SRR was identified at u/B of 1.5.

4.3 Effect number of geogrid layer

The effect of reinforced layers beneath the footing was examined by considering the number of reinforced layers. The number of layers (N) investigated were 1, 2, 3, and 4. The results indicated that the loading capacity of the reinforced soil increased with the number of geogrid layers (N) underneath the square footing. As shown in Figure 8, the BCR values were 1.73, 1.87, 2.44, and 2.67 for N equal to 1, 2,

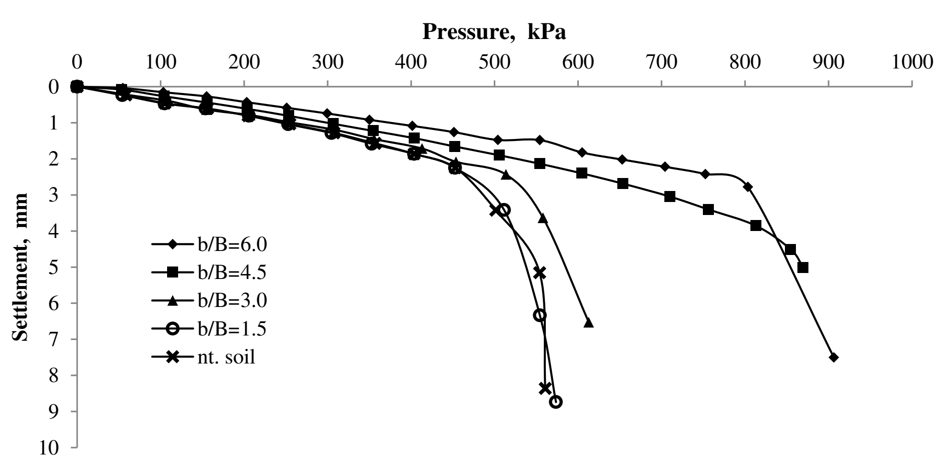

Figure 7: Variation in the bearing pressure at different size ratios.

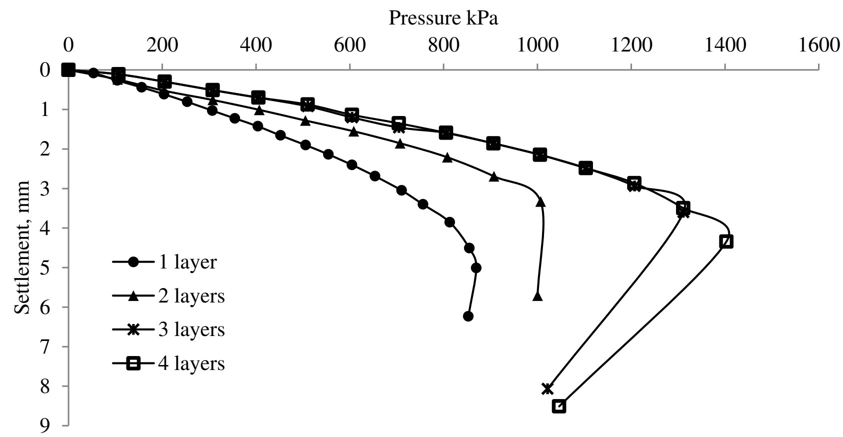

Figure 8: Variation in bearing pressure with different number of layers.

3, and 4, respectively. These layers may prevent the soil from mobilizing under the foundation during overloading stages, as supported by the research of Zidan [20].

As summarized in Table 6, the additional layers of geogrid under the footing significantly reduce the amount of soil settlement beneath the square footing, as measured by the soil SRR, as agreed with findings listed in previous studies [21].

4.4 Comparison between experimental and theoretical results

The results obtained from the experimental work were compared with those obtained from a theoretical analysis in order to verify their accuracy and reliability. The theoretical analysis was carried out using a mathematical formula developed for isolated footings placed on a strengthen soil foundation having a horizontal reinforcement [22].

$$q_{\mathrm{u(R)}} = q_{\mathrm{u(b)}} + \frac{4c_{\mathrm{a}}d}{B} + \gamma_{\mathrm{t}}d^2\left(1 + \frac{2D_{\mathrm{f}}}{d}\right)\frac{K_{\mathrm{s}}\tan\phi_{\mathrm{t}}}{B} + \frac{4\sum_{\mathrm{i}=1}^{N}T_{\mathrm{i}}\tan\delta}{B} - \gamma_{\mathrm{t}}d, \tag{3}$$

where $q_{\mathrm{u(R)}}$ is the ultimate bearing capacity of reinforced soil (kPa), $q_{\mathrm{u(b)}}$ is the ultimate bearing capacity of the underlying unreinforced soil (kPa), c_{a} is the unit adhesion of soil along two sides, γ_{t} is the unit weight of soil in reinforced, D_{f} is the embedment depth of the footing, K_{s} is the punching shear coefficient depends on the friction angle of soil, ϕ is the friction angle of soil, T_{i} is the tensile force in the *ith* layer of reinforcement equal, δ is the mobilized friction angle along two sides, B is the width of footing equal, d is the thickness of reinforced layer, and N is the number of layers.

Using Equation (3), the bearing capacity for different reinforced soil cases (*i.e.*, reinforced by geogrid layers 1, 2, 3, and 4) were calculated. The results were close to those obtained from the experimental work, as listed in Table 7.

The experimental results for the square footing constructed on geogrid-reinforced soil layers were slightly higher than the predicted values. The percentage difference between the measured and predicted values ranged from 2.0 to 19.1%. This difference may be attributed to several theoretical assumptions that were not considered in the experimental tests.

Table 6: Summary of SRR with different number of layers for square footing

No. of layers	Settlement (mm)	SRR (%)
Control*	8.3	—
4	1.8	77.80
3	2.23	73.13
2	3.65	56.08
1	6.90	16.87

* Control represents the unreinforced soil condition.

Table 7: Summary of measured and predicted results of bearing capacity of soil

Type of footing	No. of layers	$q_{\mathrm{u(R)}}$ (calculated)[a] (kPa)	$q_{\mathrm{u(R)}}$ (measured) (kPa)	Error (%)
Square	1	795.9	780	2.0
	2	837.5	840	0.2
	3	884.3	1,100	19.1
	4	1143.5	1,200	4.7

[a]Calculated using Equation (3).

5 Conclusion

According to the laboratory test results obtained, the following conclusion can be listed:

1) It was found that employing a geogrid layer at a depth (u/B = 0.5) below the footing (where B is equal to the footing's width) allows square footings to have better bearing capacity and less settlement.
2) The findings showed that a larger geogrid layer beneath the square footings increases bearing capacity and reduces settling. It was discovered that a ratio of b/B equal to 4.5 is ideal for the size of the reinforcing geogrid.
3) It has been shown that increasing the number of geogrid layers decreases settling while increasing bearing capacity. It was concluded that the ideal number of layers (N) for geogrid layers with little settlement is three.
4) The experimental test results were validated by comparing them with calculations performed with theoretically generated models. The calculated and measured results exhibit a reasonable degree of acceptance, proving the experimental testing results' high degree of accuracy.

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Conflicts of interest: The authors state no conflict of interest.

Data availability statement: The datasets generated during the current research entitled "Geogrid reinforcement for improving bearing capacity and stability of square foundations" are available from the corresponding author on reasonable request.

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