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Bearing characteristics of clay reinforced by a sandwiched geogrid-sand system

H. Ghiassian & M. Jahannia
Civil Engineering Department, Iran University of Science and Technology, Iran

ABSTRACT: A study of the bearing capacity and compressibility characteristics of a cohesive soil, reinforced by a geogrid layer and supporting square footing loads, has been conducted. The lack of adequate frictional resistance between the clay and the reinforcing element was compensated by using a thin sand layer encapsulating the geogrid. In this way, the tensile force induced in the geogrid was transferred to the bulk clay medium through the sand particles and the soil reinforcement was accomplished. Experiments were conduced on specimens with 0.15 x 0.15 x 0.15 m dimension, the footing size of 3.7 x 3.7 cm, which was loaded under a strain controlled condition. All specimens were saturated and presumably loaded under an undrained condition. The results confirmed the effectiveness of the sand layer in improving the bearing capacity and settlement characteristics of the footing. A comparison was also made between the theoretical and experimental bearing capacity values for unreinforced cases, indicating that the experimental values are smaller than the theoretical predictions, in which Terzaghi's equation showed a closer prediction than that by the general bearing capacity equation.

1 INTRODUCTION

More advances in soil reinforcement techniques and applications, iterested researchers in examining the reinforced soil under footings and foundations. Binquet and Lee (1975) reported an early study on the bearing capacity of shallow foundations placed on a reinforced ground. They presented design charts for strip footings on underlying sandy layers reinforced by metal strips. Although this technique appeared economical compared to other improvement methods, the corrosion of metal reinforcing elements convinced researchers to use other materials such as geosynthetics which perform more satisfactorily.

The use of geosynthetics for the reinforced soil under footings is not as extensive as for other applications such as retaining walls, embankments, etc. More research have been conducted on the bearing sand as by Guido et al. (1985, 1986, 1987), Khing, et al. (1992, 1993), Takemura et al. (1992), Omar et al. (1993 a, b), Yetimoglo et al. (1994), and Adams and Collin (1997). Few studies on the bearing clay are also reported in the literature by Ingold and Miller (1982), Milligan and Love (1984), Sakti and Das (1987), Dawson and Lee (1988), Das (1989), Sab (1990), Mandal and Sah (1992), and Shin et al. (1993). The use of geogrids was mainly favored in these studies due to their relatively high modulus compared to geotextiles. According to these studies, the bearing capacity depends on the following parameters:

- Depth ratio of the first reinforcement layer (u/B)
- Vertical spacing between reinforcement layers (h/B)
- Number of reinforcement layers (N)
- Footing dimension (B, L)
- Geogrid layer dimension ratio (b/B, l/B)
- Geogrid modulus
- Relative density of sand.

The results of the above studies show that the bearing capacity of a footing for the case of reinforced soil is 1.8 to 4 times that of the footing for the unreinforced case.

Two studies for square and strip footings on clay, which was reinforced by geogrids, are reported by Mandal and Sah (1992), and Shin et al. (1993) respectively. These results show that the improvement of the bearing capacity for two reinforced and unreinforced cases is a ratio about 1.5, much smaller value than that obtained for sand. According to Shin's explanation for this difference, the bearing capacity increase is basically coming from two sources; the increase of soil modulus and pullout resistance of reinforcement. The pullout resistance is composed of two phenomena; first, the frictional resistance between the soil and the geogrid, and second, the passive resistance developed between the transversal strips of the geogrid and the soil. These mobilized resistances, particularly the passive resistance, depend on the friction angle of soil. Therefore, the pullout resistance of geogrid embedded in saturated clay at the undrained condition (ϕ=0 condition) is normally expected to be smaller than that in sand.

It appears that if the lack of sufficient pullout resistance in clay could somehow be resolved, more improvement in the bearing capacity from the reinforcement should be accomplished. A study by Sridharan et al. (1991) on the pullout resistance of metal bars, which were confined by a thin cylindrical layer of sand placed in a cohesive medium, showed that a 15 mm diameter sand layer was sufficient to increase the pullout resistance to the amount as if the whole medium were composed of sand. Similarly, it would be expected if a reinforcing element is sandwiched between a thin sand layer and used in a clay soil beneath a footing, the bearing capacity of the footing should increase due to the improvement of the pullout resistance of the element. The study presented here examines this hypothesis.

2 TEST MATERIALS

The type of soil used in this study was clay with 70% passing the No. 200 sieve. The Unified Classification of the soil was CL, and other properties were determined to be LL=26%, PI=8%, G_s=2.67. A clean sand was used to encapsulate the reinforcing element that was a layer of geogrid made by Huesker Synthetic Company and labeled Fortrac Geogrid 55/30-20. Its tensile strength was 55 kN/m at 12.5% strain, and with an aperture size of 20 x 20 mm.

3 TEST APPARATUS

The model footing was a steel square plate with 3.7 cm width and 1 cm thickness loaded under the strain controlled condition in an unconfined compression test equipment. The load was applied at the rate of 1.5 mm/min on the plate. The soil specimen was prepared in a cubic metal box with the dimension of 15 cm. This box was made sufficiently rigid to prevent any important lateral deformation on its vertical sides under the footing loads. The total thickness (height) of the clay layer was 12 cm, a little more than three times the model footing width, therefore minimizing the boundary condition effects. All tests were performed on saturated clay specimens.

4 SPECIMEN PREPARATION

The dry clay was first mixed with 22% water (a water content between the plastic and liquid limits). The mix was then allowed to cure in a plastic bag for a week so that water could thoroughly be distributed in the clay, and a homogenous soil sample be made. The soil was then compacted in 2cm layers to a predetermined dry unit weight of 16.48 kN/m^3.

Table 1. Summary of tests (B = 3.7 cm, u/B= 0.4, b/B=4).

Test	Lens Thickness, (cm)	Reinforced (R), Unreinforced (U)
B-1	0	U
B-2	0.5	U
B-3	0	R
B-4	0.5	R
B-5	0	R
w = 22%, S_{ave} = 99%, $C_{u\,(ave)}$ = 12 kPa, γ_d = 16.48 kN/m^3		

All specimens were reinforced by one layer of the geogrid with the dimension of b=4B (B=3.7 cm) and the depth of u=0.4B measured from the bottom of the footing. These numbers were selected according to the study by Shin and et al. (1993). Table 1 shows the information about the performed tests. Each test was proceeded until a clear drop in the axial load occurred or the total settlement of the plate reached to 1.5 cm. In test B-5, instead of using the sand lens, the geogrid was nailed to the clay (see Fig. 2) in order to increase its pullout capacity and evaluate its effects on the bearing capacity of the footing. It should be noted that in all tests, the geogrid reached to its pullout capacity, far less than its tensile strength.

At the end of each test, three soil samples were taken by a 1.5 inch sampler from the section bellow the geogrid for determination of the unconfined compression strength, and the degree of saturation of the specimen.

5 DISCUSSION

The load-deformation characteristic and the type of instability were investigated in each test. Also, the type of failure in the geogrid layer was examined after removing the overlying soil layer; that appeared to be a pullout failure in all tests. As shown in Table 1, five tests were performed. Two dimensionless parameters; BCR_u (bearing capacity ratio at ultimate load), and PRS (percentage reduction in settlement), as introduced in previous studies, are used here for analyzing the results:

$$BCR_u = \frac{q_{u(R)}}{q_u} \qquad PRS = \frac{S_u - S_r}{S_u}(\%)$$

q_u = ultimate bearing capacity of footing on unreinforced soil
$q_{u(R)}$ = ultimate bearing capacity of footing on reinforced soil
S_u = settlement of footing on unreinforced soil at pressure of q_u
S_r = settlement of footing on reinforced soil at pressure of q_u.

Figure 1 presents the load-settlement plots of the tests. The ultimate bearing capacity value for each test was obtained based on the method proposed by Brand et al. (1972), which defines the ultimate load at a point where the plot of bearing load against the settlement becomes practically linear. According to these curves, the type of failure is expected to be the local shear or punching because there is no distinct

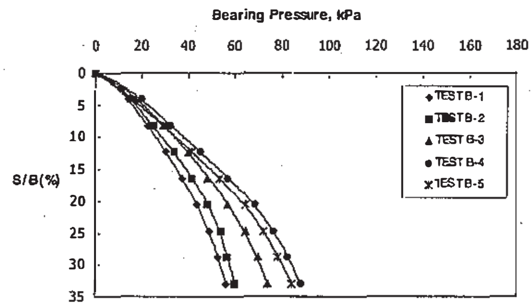

Figure 1. Load-settlement results of the footing on reinforced saturated clay.

Table 2. Summary of test results.

Test No.	Lens Thick-ness, (cm)	$q_{u(R)}$ (kPa)	BCR_u	S/B (%)	S_r/B (%)	PRS (%)
B-1	0	q_u=51	-	S_u/B=27	-	-
B-2	0.5	54	1.06	26	23	14.8
B-3	0	63.5	1.25	24.5	18	33.3
B-4	0.5	76	1.49	25	14.5	46.3
B-5	0	70	1.37	24	16	40.7

break on the curves. Observations also confirmed this failure mode as there was very slight soil swell around the footing, and the plate just penetrated into the underlying soil. Table 2 the results obtained from Fig. 1.

As can be realized from the comparison between the results of tests B-2 and B-1, the 0.5 cm sand lens without the geogrid has a negligible effect on the bearing capacity (BCR_u=1.06). Therefore, the main contribution of the sand lens on the bearing capacity can be attributed to the improvement of the pullout resistance of the geogrid, as can be seen from the comparison between the results of tests B-3 and B-4. In test B-3 in which only the geogrid is used, the bearing capacity has increased 25% and the settlement has decreased 33% (i.e., BCR_u=1.25, PRS=33). But, in test B-4, with a thin layer of sand placed around the geogrid, the results have improved to 49% increase in the bearing capacity and 46% decrease in the settlement (BCR_u=1.49, PRS=46.3). Consequently, the presence of the sand layer around the reinforcing element appears to have important effects on both the bearing capacity and settlement characteristics of the reinforced saturated clay.

In order to evaluate the effect of the frictional resistance of the geogrid and its anchorage in the clay, test B-5 was conducted. Clearly, if the ultimate tensile strength of the reinforcing element is mobilized, the maximum benefit will result. Otherwise, the amount of the increased bearing capacity will depend on the amount of the frictional strength mobilized at the soil-element interface. These forces, in turn, depend on the effective length and dimension of the element, as well as the interface friction angle

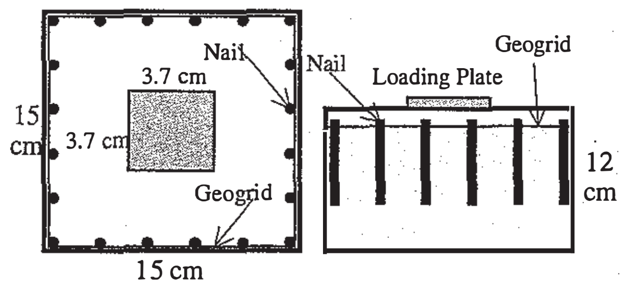

Figure 2. The use of nails for increasing the pullout resistance of geogrid.

and type of the element. In this test, an idea was examined to increase the pullout resistance of the element. Instead of using the sand layer around the geogrid, 20 nails with 8 cm length and 4 mm diameter were uniformly and vertically inserted through the openings at the perimeter of the geogrid, and embedded inside the soil specimen as shown in Fig. 2. The objective was to create some passive resistances against the geogrid displacement, and consequently, to increase the frictional resistance of the element. The inspection of the soil specimen and the geogrid at the end of the test revealed that the displacement of the geogrid did occur despite the nail resistance, and the bearing capacity increased 37% and the settlement decreased about 40%, indicating that the sand layer had performed more effectively than the nails. The results in Fig. 1 also show that the ratios of the ultimate settlement (S/B) in the reinforced and unreinforced cases are almost identical varying between 24% and 27%. This result is similar to those reported by Shin et al. (1993).

It should be noted that since the size of the square footing (3.7 cm) is fairly small compared to the grid aperture of the geogrid (2 cm), it would be expected that significant scale effects influence the results. Therefore, it is probably not possible to obtain quantitative information from these tests. However, the influence of the sand lens on the improved bearing capacity and settlement characteristics of the footing can be realized in the results.

The Mechanism of failure in all tests was the punching failure. This behavior was observed during the tests, and also reflected on the trend of the plots in Fig. 1. No distinctive swell was observed around the footing in any test, and the soil underneath the footing settled vertically downward along with the overlying plate.

6 BEARING CAPACITY PREDICTIONS

A comparison was made between the experimental results of the bearing capacity of the footing placed on an unreinforced soil with the theoretical predictions

Terzaghi's Equation

$$q_u = 1.3 * \frac{2}{3} * C_u * N_c , \qquad N_c = 5.7 \qquad \phi = 0$$

General Bearing Capacity Equation (Das, 1995)

$$q_u = 1.2 * C_u * N_c , \qquad N_c = 5.14 \qquad \phi = 0$$

q_u (Experiment, Test B-1) = 51 kPa
q_u (Terzaghi's equation) = 62 kPa
q_u(General equation) = 74 kPa.

The theoretical expressions predict more bearing capacities than the experimental value with the Terzaghi's equation being in a better agreement.

7 CONCLUSIONS

In order to increase the pullout resistance of geogrid layer embedded in a reinforced bearing saturated clay medium, an idea of placing a sandy soil around the reinforcing element (geogrid) was experimentally examined. The following conclusions can be made from this study:

The existence of the sand layer around the geogrid has pronounced effects on the increase of the bearing capacity and decrease of the settlement at the failure.

The presence of the sand layer itself (no geogrid) has a negligible effect on the bearing capacity.

The presence of the sand layer does not change the settlement at the failure considerably.

The failure mode is the punching failure with little if any surface heave.

The theoretical predictions of the bearing capacity overestimate the experimental values with Terzaghi's equation giving a closer answer.

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