SHALLOW FOUNDATIONS ON GEOGRID REINFORCED SOFT CLAY

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Abstract: Soft clay deposits can be found in most of the residential areas around the world. Shallow foundations, when built on soft clay deposit, have low load-bearing capacity and undergo large settlements. In this case, either deep foundations or ground improvement techniques should be applied before the construction. Deep foundations will only be applied if ground improving methods allowing for shallow foundations can not be financially justified. Reinforced soil is one of the soil improvement techniques that have gained attention in recent years. The soft clay behavior can be improved by totally or partially replacing inadequate soft soils with granular fill compacted in layers. It is also possible to further improve the bearing capacity by reinforcing the base course with geogrid.

In the present study, laboratory model tests were carried out to determine the improvement of bearing capacity of circular shallow foundations supported by a compacted granular fill with and without geogrid reinforcement over soft clay. This study has been initially directed to evaluate the beneficial effects of the granular fill on soft clay on the shallow foundation performance. Secondly, the effect of granular fill reinforced with geogrid over soft clay has been studied.

The results of the experimental study indicate that the thickness of the granular fills and the geogrid reinforcement have considerable effects on the bearing capacity of the circular shallow foundations. It is proved that the improvement depends also on the reinforcement geogrid arrangement. The use of geogrid reinforcement in a compacted granular fill over soft clay provides additional improvement of bearing capacity performance.

Keywords: soft soil, geogrid, bearing capacity.

INTRODUCTION

In many civil engineering applications, the need of soil reinforcement has been enormously raised in recent decades, due to economical and social development of the populations. Such development has also resulted in the necessity to use soils with problematic geotechnical characteristics as the foundation of many engineering projects. Soft soils characterised particularly by their low strength, high deformability and low permeability cause difficulties in geotechnical applications. Geogrid reinforcement of these problematic soils together with granular fill is a soil improvement technique which has gained attention.

Several experimental and numerical studies have been described regarding the reinforcement of a weak soft soil (Shin *et al.* 1993, Shukla and Chandra 1995, Ochiai *et al.* 1996, Adams and Collin 1997, Yin 1997, Otani *et al.* 1998, Alawaji 2001, Bergado *et al.* 2001, Borges and Cardoso 2001, Dash *et al.* 2003, Yetimoglu *et al.* 2005, Sitharam *et al.* 2005, Thome *et al*. 2005, El Sawwaf 2007, Deb *et al.* 2007). Ochiai (1996) summarized the theory and practice of geosynthetic reinforcement of fills over extremely soft ground in Japan. Adams and Collin (1997) conducted 34 large model load tests to evaluate the potential benefits of geosynthetic-reinforced spread foundations. It was concluded that the soil–geosynthetic system formed a composite material that inhibited development of the soil-failure wedge beneath shallow spread foundations. Otani *et al.* (1998) studied the behaviour of strip foundation constructed on reinforced clay. Settlement was found to be reduced with the increase in reinforcement size, stiffness and number of layers. The load carrying capacity of a foundation has been found to increase more on soil in which reinforcements are provided at closer spacing. Alawaji (2001) discussed the effects of reinforcing sand pad over collapsible soil and reported that successive reduction in collapse settlement up to 75% was obtained. Dash *et al.* (2003) performed model tests in the laboratory to study the response of reinforcing granular fill overlying soft clay beds and showed that substantial improvements in the load carrying capacity and reduction in surface heaving of the foundation bed were obtained. Yetimoglu *et al.* (2005) performed Laboratory CBR tests on sand fills reinforced with randomly distributed discrete fibres overlying soft clay and reported that adding fibre inclusions in sand fill resulted in an appreciable increase in the peak piston load. Although, these investigations have demonstrated that both the ultimate bearing capacity and the settlement characteristics of the foundation can be significantly improved using soil reinforcement, it should be mentioned that the aim of the reinforcement is not to eliminate the settlement, as this is not possible, but rather limiting the settlement to values that could be tolerated by the structure. Sitharam *et al.* (2005) studied the potential benefits of geocell reinforcement in soft clay foundations by a series of laboratory-scale static load tests on a rigid circular foundation placed on a fill surface. Parameters of the test program include depth of placement of the geocell layer, width and height of the geocell layer, and influence of an additional layer of planar geogrid at the base of the geocell mattress. With the provision of geocell reinforcement, the load carrying capacity of the soft clay foundation can be improved by a factor of up to 4.8 times that of the unreinforced soil. Thome *et al.* (2005) proposed a method for predicting the behaviour of shallow foundations bearing on an upper layer of processed cemented soil that overlies a lower layer of weakly bonded residual soil with a high void ratio. El Sawwaf (2007) studied the potential benefits of reinforcing a replaced layer of sand constructed on, or near, a slope crest. Model tests were carried out using model foundation of 75mm width and geogrids. Several parameters including the depth of replaced sand layer and the location of foundation relative to the slope crest were studied.

LABORATORY MODEL TESTS

In this study, a series of small scale laboratory model tests were conducted. Three series of tests; without reinforcement, with granular fill, and granular fill with geogrid reinforcements, were undertaken. A total of 24 model tests were carried out using a special loading system, and two different foundation diameters.

Test Box

A cylindrical test box, 380mm diameter and 420mm high was used in the tests. This rigid test box is made of steel and has a wall thickness of 5mm. The inside walls of the test box are polished smooth to reduce friction with the soil fill and marked every 50mm to control fill level. A square steel plate with a width of 500mm is placed under this heavy model box and firmly clamped using two long pins.

Model Foundation

Model circular foundations made of mild steel with a hole at their top centres to accommodate ball bearings were used. Two model circular foundations with diameters of 60mm and 90mm, and with thickness of 20mm were used. The foundations were positioned at the centres of the top soil layers before the tests. The load transferred to the foundations through the balls bearing. Such an arrangement produced a hinge, which allowed the foundation to rotate freely as it approached failure and eliminated any potential moment transfer from the loading fixture (El Sawwaf 2007).

Test Material

Soft Clay

The soft clay used in this research was locally available soil from west part of Adana, Turkey. After conducting required conventional laboratory tests (sieve and hydrometer analysis, moisture content analysis, unit weight analysis, liquid and plastic limit analyses, unconfined compression test) the soil was prepared for model tests. The soil was identified as high plasticity inorganic clay, CH according to the unified soil classification system. For the model tests, soft clay soil was kept in an oven for 24h at the temperature of 105 ± 5 °C and sieved passing through B. S. sieve No 10 (2.00mm). After grinding the dry soil using a grinding machine, a specific quantity of water was added to the soil to obtain 23% water content (this was the value of moisture content of undisturbed in-situ soil samples). The soil was thoroughly mixed and placed by hand into the test box at the predetermined in-situ soil unit weight. Compaction of the soil in the test box was carried out using a special hammer at standard compaction energy. The test box was filled in similar way to get enough height for each test. The values of liquid limit, plastic limit and plasticity index of soft soil were obtained as 53%, 22% and 31%, respectively. The values of specific gravity and the undrained cohesion of clay soil were obtained as 2.60gr/cm^3 and 0.40kg/cm^2, respectively.

Granular Fill

The granular fill material used in the model test was obtained from the Kabasakal region situated northwest of Adana, Turkey. Some conventional tests (sieve analysis, moisture content analysis, unit weight analysis, direct shear test, proctor test) were conducted on this material. For the model tests, granular soil was kept in an oven for 24h at the temperature of 105 ± 5 °C and sieved passing through B. S. sieve No 4 (4.75mm). Granular soil was prepared at optimum moisture content of 7% and maximum dry unit weight of 2.17gr/cm^3 obtained from the standard proctor test. To maintain consistency of the in place density throughout the test box, the same compactive effort was applied to each layer. The values of internal friction angle and the cohesion of clay soil were obtained as 42° and 1.5kg/cm^2, respectively from direct shear tests. Specific gravity of the granular soil was obtained 2.64gr/cm^3. From the sieve analysis, granular soil was classified as well graded gravel-silty gravel, GW-GM according to the unified soil classification system. The results obtained from sieve analysis are shown in Figure 1.

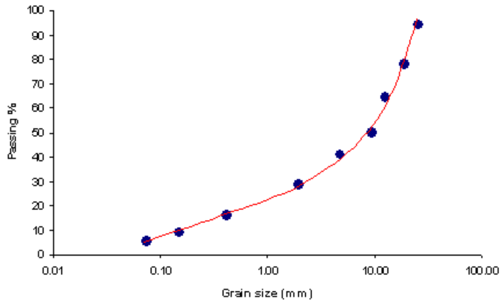

Figure 1. Grain size distribution of the granular fill material

Geogrid

A white coloured geogrid with maximum tensile strength of 60kN/m was used as reinforcing material in the model tests. The physical and mechanical properties of the geogrid, as listed by the manufacturer, are given in Table 1.

Table 1. Engineering properties of geogrid

Parameter	Value
Structure	biaxial
Aperture shape	squared
Aperture size	30mm x 30mm
Mass per unit area	360g/m^2
Unit weight	2.60 gr/cm^3
Raw material	polypropylene
Elongation at nominal strength	8 %
Tensile strength at 2% elongation	22 / 22 (md/cmd)
Tensile strength at 5% elongation	48 / 48 (md/cmd)

Experimental Procedure

The layout of the experimental setup is shown in Figure 2, where, D is the foundation diameter, H is the granular fill thickness and u is the location of the reinforcement.

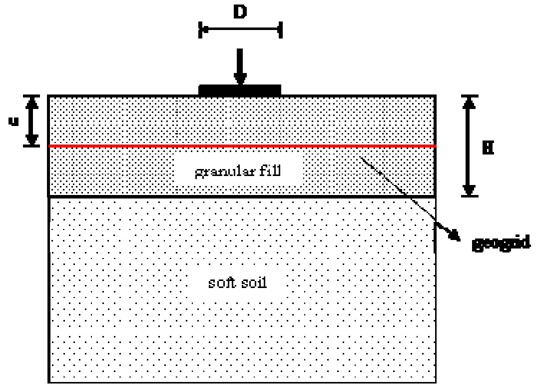

Figure 2. Geometric parameters used in the model test

Tests without Reinforcement

These tests were conducted using two different foundation diameters of 90mm and 60mm. The aims of carrying out these tests were to investigate the bearing capacity of soft soils with different foundation sizes, and to create a reference for the following tests with granular fills and geogrids. Constant load increment was automatically satisfied using special loading system during tests. Settlement of the foundation were measured using three dial gauges (model EL27-1689) placed on the foundation as shown in Figure 3. For each test, load-settlement readings were recorded by an eight channel data logger unit (EL27-1495 series data acquisition and monitoring system) and converted to produce values of settlement at ground level and load using DIALOG software on a PC (Laman and Yildiz 2003). The tests were continued until a considerable settlement of the foundation (20% of the foundation diameter) occured. The experimental setup and loading system are shown in Figure 3.

Figure 3. Experimental setup and loading system

Tests with Granular Fill

In this group, 8 model tests were conducted using two different foundation diameters (90mm and 60mm). The aim of carrying out these tests was to analyse the contribution of granular fill on the bearing capacity of soft soils. In the tests granular fill thickness was changed in relation to the foundation diameters (0.25D; 0.50D; 1.0D and 1.5D). The details of the tests are given in Table 2.

Table 2. Details of model tests with granular fill

Foundation Diameter (D)	**9cm**	**6cm**
Granular fill thickness depend on foundation diameter	0.25D	0.25D
	0.50D	0.50D
	1.00D	1.00D
	1.50D	1.50D
Number of test done	4	4

Tests with Geogrid

In this group, 14 model tests were conducted using two different foundation diameters (90mm and 60mm). The aim of carrying out these tests was to determine the contribution of geogrid on the bearing capacity of soft soils and granular fill reinforced soil. In the model tests, one layer of geogrid was used in predetermined level of the granular fill. In the tests, while the thickness of the granular fill was kept constant as 1.0D, 0.50D and 0.25D, the location of geogrid was changed in granular fill. The details of these tests are given in Table 3.

Table 3. Details of model tests with geogrids

Geogrid depth (u)	**u (D=9cm)**	**u (D=6cm)**
Granular fill thickness (1.0D)	0.25D	0.25D
	0.50D	0.50D
	1.00D	1.00D
Granular fill thickness (0.5D)	0.25D	0.25D
	0.375D	0.375D
	0.50D	0.50D
Granular fill thickness (0.25D)	0.25D	0.25D
Number of test done	7	7

RESULTS AND DISCUSSION

A total of 24 model tests were carried out on granular fill beds with and without geogrid overlying soft soil. After the tests were completed, bearing capacity / displacement curves for various arrangements were obtained and discussed. The bearing capacity was defined as the tangent intersection between the initial, stiff, straighter portion of the loading pressure – settlement curve and the following steeper, straight portion of the curve (Adams and Collin 1997). All the test results were interpreted using this approach.

The term “bearing capacity ratio” (BCR) is commonly used to express and compare the test data of the reinforced and unreinforced soils. The following well-established definition (Binquet and Lee 1975) is used for BCR:

$$BCR = q_R / q_0$$

Where q_R and q_0 are the bearing capacity for the reinforced and unreinforced soils, respectively. The parameters investigated, including the settlement of foundation plate, s, are normalised by the diameter of the foundation plate, D (Laman and Yildiz 2003).

Model Tests without Reinforcement

The relations of the bearing capacity to foundation settlement for two different foundation diameters are presented in Figure 4. It can be seen from the figure that the foundation diameter does not substantially affect bearing capacity characteristics.

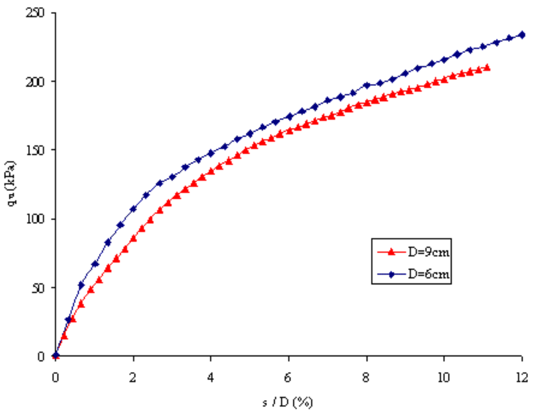

Figure 4. Curves of bearing capacity against settlement ratio for the tests without reinforcement

Effect of the Granular Fill

The test results were explained using bearing capacity ratios (BCR). It is shown from the Figure 5 that BCR increases with an increase in the granular fill thickness. In other words, bearing capacity increases with granular fill thickness. There is a similar tendency between the results obtained from the model tests of 90mm and 60mm. Also a sharp increase in bearing capacity was observed when the H/D ratio is greater than 0.50.

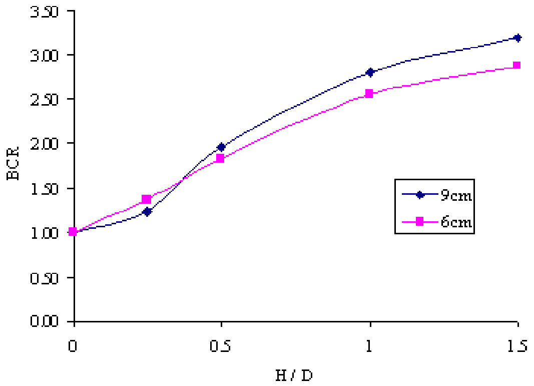

Figure 5. Relationship between BCR and H/D for the tests with granular fill

Effect of the Geogrid Depth

Tests with 90mm Foundation Diameter

In this group of the model tests, granular fill thickness was kept constant depending on foundation diameter such as 1.0D, 0.50D and 0.25D and the results obtained are shown in Figures 6, 7 and 8, respectively. It can be seen from the figures that, bearing capacities and also BCR values increase, when the geogrid depth gets smaller. The peak values in bearing capacities were obtained in the case of u=0.25D in all of the three arrangements. Maximum BCR values at the arrangements of u=0.25D and H=1.0D, u=0.25D and H=0.50D and u=0.25D and H=0.25D were calculated as 141%, 117% and 110%, respectively.

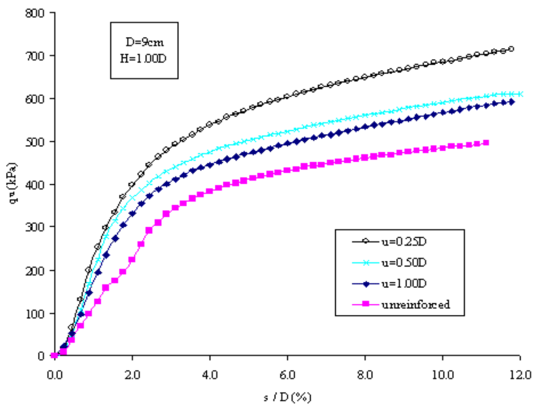

Figure 6. Curves of bearing capacity against settlement ratio (D=90mm and H=1.0D)

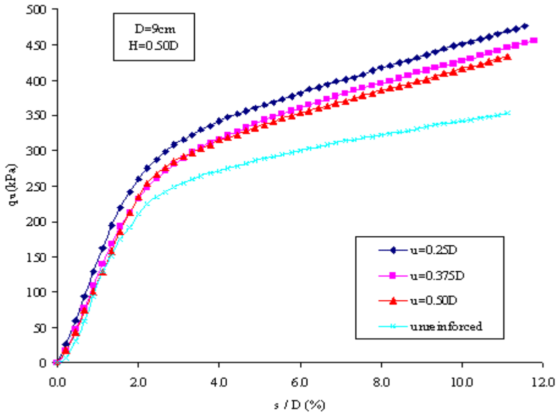

Figure 7. Curves of bearing capacity against settlement ratio (D=90mm and H=0.50D)

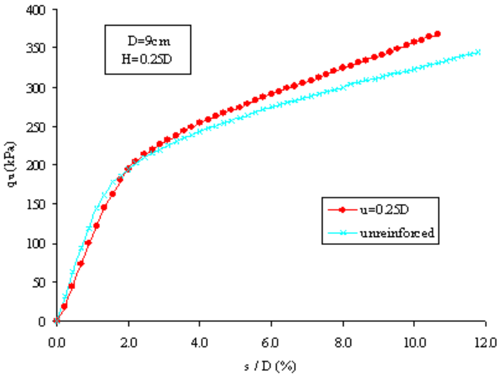

Figure 8. Curves of bearing capacity against settlement ratio (D=90mm and H=0.25D)

Tests with 60mm Foundation Diameter

Similar to models tests with 90mm foundation diameter, granular fill thickness was kept constant depending on foundation diameter as 1.0D, 0.50D and 0.25D and their results obtained are shown in Figures 9, 10 and 11, respectively. It was observed from the figures that there are inverse relationships between bearing capacities (as well as BCR values) and the geogrid depths. The peak values in bearing capacities were obtained in the case of u=0.25D in all of the three arrangements. Maximum BCR values at the arrangements of u=0.25D and H=1.0D, u=0.25D and H=0.50D and u=0.25D and H=0.25D were calculated as 146%, 161% and 110%, respectively.

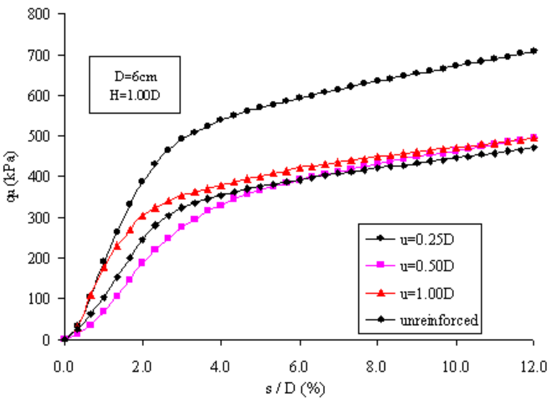

Figure 9. Curves of bearing capacity against settlement ratio (D=60mm and H=1.0D)

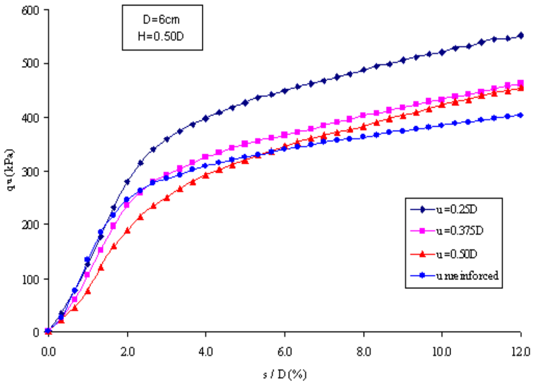

Figure 10. Curves of bearing capacity against settlement ratio (D=60mm and H=0.50D)

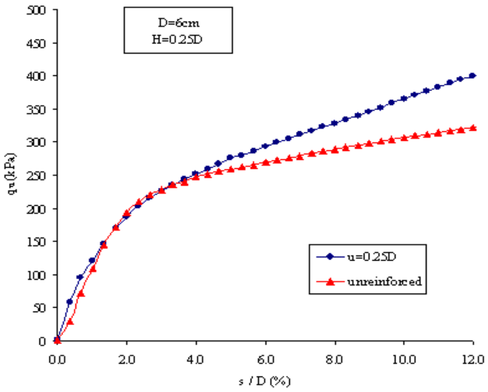

Figure 11. Curves of bearing capacity against settlement ratio (D=60mm and H=0.25D)

CONCLUSIONS

In this study, laboratory model tests were carried out to determine the improvement of bearing capacity and settlement behaviour of circular shallow foundations supported by a compacted granular fill with and without geogrid reinforcement over soft clay. Based on the results from this investigation, the following conclusions can be drawn:

- The foundation size doesn’t affect bearing capacity characteristics, significantly.
- Soil improvement of soft clay by partial replacement with granular fill increases the bearing capacity.
- A significant increase in bearing capacity begins especially when the granular fill thickness is greater than 0.50D.
- Geogrid inclusion in the granular fill / soft soil system has a significant effect on the bearing capacity.
- There is an inverse relationship between bearing capacity and geogrid depth.
- In the geogrid arrangement of u=0.25D, maximum BCR values and bearing capacity increases are obtained.
- The size and scale effects of model foundations have not been investigated here. Nevertheless the investigations are considered to have provided a useful basis for further research leading to an increased understanding of the application of soil reinforcement to bearing capacity problems.

Acknowledgements: The work presented in this paper was carried out with funding from TUBITAK (The Scientific and Technological Research Council of Turkey) grant number 106M496.

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