In-Situ Stabilization of Soft Clay Using Geogrid

K. Premalatha, Assistant Professor, Department of Civil Engineering, Anna University Chennai, Chennai-25, India, kvprema@annauniv.edu
G. Manoj Kumar, Post Graduate Student, Department of Civil Engineering, Anna University Chennai, Chennai-25, India.
I. Ilavarasi, Post Graduate Student, Department of Civil Engineering, Anna University Chennai, Chennai-25, India.
A. Amala Raju Arul, Post Graduate Student, Department of Civil Engineering, Anna University Chennai, Chennai-25, India, amalarajuarul@gmail.com

ABSTRACT

Soil reinforcement is 50 years old technique and its use in clay soil was very limited. There is no established technique to improve the in-situ soft clay using geosynthetics. The objective of the present study is to establish an in-situ technique to improve the load carrying capacity of soft to medium consistency clay bed using geogrid. Cellular geogrid cages of different size and shape are fabricated and pushed into the soft clay bed. This cellular geogrid cage was also stiffened at every B, width of footing. Influence of width and depth of reinforcement in the load-settlement characteristics and improvement in the load carrying capacity were obtained. The increase in the load carrying capacity of reinforced soft clay is due to mobilization of adhesive shear resistance between the geogrid and the clay. Finally geogrid reinforced clay bed was consolidated by preloading technique with wick drain. Load test was conducted for the geogrid reinforced in-situ consolidated clay bed. The increment in load carrying capacity was measured and compared.

1. INTRODUCTION

Soil at a construction site is not always suitable for supporting structures such as buildings, bridges, highways and dams. In granular soil, the in situ deposits are loose and undergo large settlement. Soft saturated clay layers are often encountered at shallow depths. Depending on the structural load and the depth of the layers, large consolidation settlement occurs in these deposits. Different ground improvement techniques are being developed to improve the performance of the above deposits. Reinforcing the soil beneath the foundation is one of the accepted techniques in the field of geotechnical engineering. Reinforced soil refers to a soil which is strengthened by the placement of material in the form of strips, bars, sheets or grids. When load is applied to these reinforced mass, the reinforcement resist the tensile stresses developed within them.

Binquet and Lee (1975a, 1975b) investigated the mechanisms of using reinforced earth slabs to improve the bearing capacity of granular soils. They model tested strip footings on sand foundations reinforced with wide strips household aluminum foil. An analytical method for estimating the increased bearing capacity based on these tests was also presented. Fragaszy and Lawton (1984) also used aluminum reinforcing strips and model strip foundations to study the effects of density of the sand and length of reinforcing strips on bearing capacity. Several authors also studied strip foundations reinforced with different materials such as steel bars, steel grids, Geotextile and geogrids.

Mandal and Sah (1991) performed model tests on clay soil reinforced with geogrids placed horizontally. Introduction of geogrid reinforcement increased the bearing capacity and is 1.36 for the reinforcement layer placed at 0.175 B depths for a square foundation. The maximum percentage reduction in settlement with the use of geogrid reinforcement below the compacted and saturated clay was about 45% and is for reinforcement placed at 0.25B from the base of foundation. Khing et al (1993) conducted a number of small scale model tests to determine the ultimate and allowable bearing capacity of a surface strip foundation supported by a layer of strong sand underlain by saturated weak clay with a layer of geogrid reinforcement at the sand-clay interface. The maximum benefit from geogrid reinforcement in increasing the ultimate bearing capacity occurred when the thickness of the strong sand layer is about two-thirds the width of the foundation. For $H/B \geq 1.5$, the contribution of the geogrid reinforcement to the bearing capacity improvement was practically negligible. The optimum width of the geogrid layer required to mobilize the maximum possible bearing capacity for a given sand-geogrid-clay combination was about six times the width of the foundation. Das and Shin (1994) conducted laboratory model test to determine the permanent settlement of a surface strip foundation supported by geogrid-reinforced saturated clay and subjected to both static and low frequency cyclic load. The liquid limit and plastic limit of the soil used are 44% and 24% respectively. For a given intensity of static loading, the maximum permanent settlement increased with the increase in the amplitude of the cyclic load intensity. Full depth geogrid reinforcement reduced the permanent settlement of a foundation by about 20% to 30% compared to that of without reinforcement. For given amplitude of the cyclic load intensity, the maximum permanent settlement increased with the increase in the intensity of the static load. Sujit Kumar et al (2003) presented the effectiveness of geocell reinforcement placed in the granular fill overlying soft clay bed by small-scale model tests in the laboratory. Provision of geocell reinforcement in the overlying sand layer improved the load carrying capacity and reduced the surface heaving of the foundation bed substantially. Good improvements in the load carrying capacity of the foundation bed were obtained even with geocell mattress of width almost equal to the diameter of the footing. An additional layer of planar geogrid at the base of the geocell mattress further enhanced the performance both in terms of load carrying capacity and stiffness of the foundation bed. The beneficial effects of the basal geogrid layer decreased with increase in the height of the geocell mattress and become marginal at larger heights.

From the above detailed literature review, it is understood that there is no study or no established technique to improve the in-situ strength of clay bed using geosynthetics. The main objective of the study presented in this paper is to establish a technique to improve the load carrying capacity of soft to medium clay bed using geogrids and to evaluate the efficiency of the reinforcement.

2. MATERIAL PROPERTIES

2.1 Soil

Locally available fine grained soil was selected for this study. The index properties of the soil are listed in Table 1. The undrained shear strength of the soil was determined using vane shear apparatus at different water content and is shown in Table 2.

Table .1 Index Properties of Soil

Property	Symbol/units	Values
Specific gravity	G	2.38
Coarse sand	%	2
Medium sand	%	11
Fine sand	%	16
Silt	%	43
Clay	%	27
Organic Content	%	6
Liquid Limit	%	53
Plastic Limit	%	33
Shrinkage Limit	%	22
Plasticity Index	%	20
I.S.Classification	MH	Silt of High Plasticity

Table .2 Undrained shear strength of clay at different W/C

Water content%	43	53	53	58	63
Undrained Shear Strength (kN/m^2)	23.54	16.05	10.70	7.49	6.41

2.2 Geogrid

A geogrid is defined as a geosynthetic material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow strike-through of surrounding soils, stones or other geotechnical material (Koerner 1998). Existing commercial geogrid products included extruded geogrids, woven geogrids, welded geogrids, and composites geogrids. Most of the geogrids are made from polymers, but some products have been manufactured from natural fibers, glass, and metal strips. The percentage of open area of geogrids lies between 40 to 90% of width of openings being typically 10 to 100mm. The rib thickness ranges from 5 to 15mm and mass per unit area lies between 200 to 1500gms. Geogrids are used because they have sufficient strength up to 200kN/m, low elongation failure of 5 to 25% and better soil-geogrid interfacial shearing resistance than other geosynthetics arising from interlocking of soil grains within the openings of the geogrid. For this laboratory investigation CE 121 type geogrids were used. The thickness of CE 121 geogrid was 3mm and the aperture size is 32mm. The ultimate tensile strength of the geogrid was determined by wide width method and is 7.68 kN/m.

2.3 Fabrication of Square Cellular Geogrid Cage

It is well known that, for an isolated footing the depth of influence for bearing capacity is B the width of footing and 2B for settlement. To study the influence of depth and width of reinforcement geogrid reinforcement cages of different size were fabricated and are listed in Table 3. The size of each geogrid cell is B x B. The line sketch of 3B x 3B square cellular geogrid cage is shown in Figure 1.

Table 3.Reinforcing cage details

Width of Reinforcement Cage (Br)	1B	1B	1B	3B	3B	3B	5B	5B	5B
Depth of Reinforcement Cage (Dr)	1B	2B	3B	1B	2B	3B	1B	2B	3B

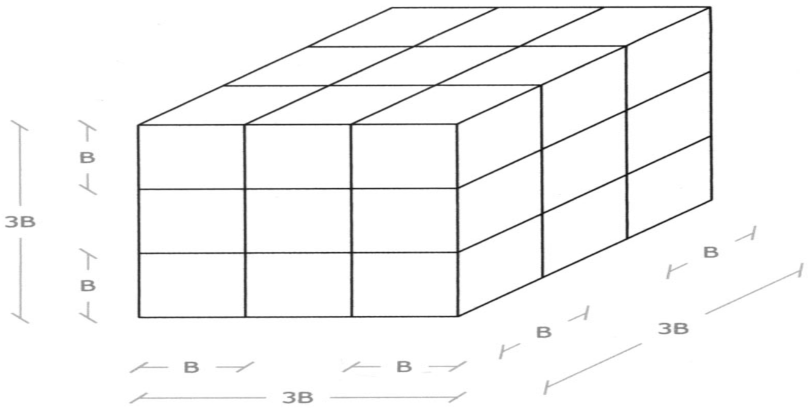

Figure 1. Line sketch of 3B x 3B x 3B square cellular geogrid cage

2.4 Preparation of Testing Media

The collected clay sample was air dried and pulverized to size of 4.75mm. The pulverized sample was soaked in water for a period of 30 days. The soaked process made the clay to form a good paste. Additional water content was added and bed was prepared at a water content of 55-58%. During the process of formation, the consistency of soil was maintained, by checking the water content and strength of clay periodically.

2.5 Sinking of Reinforcement

Sinking was done by keeping the cellular geogrid cage on the surface of prepared clay bed and a container was loaded by sand/iron dust which is placed over cellular geogrid cage. The test was conducted after 24hrs of sinking, so that the clay regains its strength due to the disturbance of installation. The view of loading and stiffening arrangement of cellular geogrid cage for sinking process is shown in Figure 2 and 3 respectively.

Figure 2. Cellular geogrid cage ready for pushing

Figure 3. After immersion of geogrid cage

The intensity of surcharge pressure used for sinking of different sized cellular geogrid reinforced cages are tabulated in Table 4. As the size of cellular geogrid cage increased the surcharge pressure required and time required for sinking also increased.

2.6 Model Footing and Tank

A square wooden plank of size 100 mm X 100 mm X 20 mm was used as a footing for conducting tests on reinforced clay bed. A circular tank of dimensions of 850mm diameter X 550mm depth has been used for conducting the experiments. The tank is made of concrete and has high stiffness. The diameter of the tank is sufficiently large to take care of the width of influence of footing.

Table 4.Surcharge and Time used for sinking

Size of reinforcing Cage	Surcharge Load (Kg)	Time Required for sinking (min)
B x B x B	7.264	60
B x B x 2B	9.944	120
B x Bx 3B	13.538	180
3B x 3B x B	35.578	180
3B x 3B x 2B	44.650	360
3B x 3B x 3B	51.550	480
5B x 5B x B	108.42	480
5B x 5B x 2B	124.39	600
5B x 5B x 3B	144.10	1440

3. EXPERIMENTAL PROCEDURE

The general test procedure for plate load tests as per IS 1888:1988 was adopted for all the tests. Footing was placed over the prepared Geogrid reinforced soil bed. The dial gauge was set in position and adjusted to read zero. The dial reading in the pre-Calibrated proving ring was also set to read zero. With the help of hydraulic jack desired load was applied and the settlement was measured at regular time intervals. Sufficient time was given for the settlement to stabilize. Figure 4 shows the overall view of the testing arrangement. The cellular geogrid cage was removed from the clay soil bed after testing.

Figure 5 shows one of the removed cages. It was observed that all the apertures were completely filled with clay soil. There was good bond between soil and the reinforcement.

1.1

Figure 4. Tank used for testing

Figure 5. View of removed geogrid after testing

Installation of square cellular geogrid cage of size greater than 2B was very difficult. Hence it was decided to make circular cellular geogrid cage of minimum diameter and height of B to 4B. The size of one circular cell is 40mm x 100mm. The minimum diameter of circular cellular geogrid cage fabricated was 40mm and placed at 50mm c/c for the selected width of reinforcement. A geogrid layer of width as equal to the width of reinforcement was placed over the circular cellular geogrid reinforced soil. The placement of circular cellular geogrid cage reinforcement is shown in Figure 6 and 7.

Figure 6. Installation of circular geogrid cage

Figure 7. Tying of top surface the of circular geogrid cage

4. RESULTS AND DISCUSSIONS

4.1 Load Settlement Curve

The load verses settlement response for the selected Depth and Width of reinforcement using circular cellular geogrid reinforcement cage were obtained and are shown as figures 8, 9, 10 and 11.

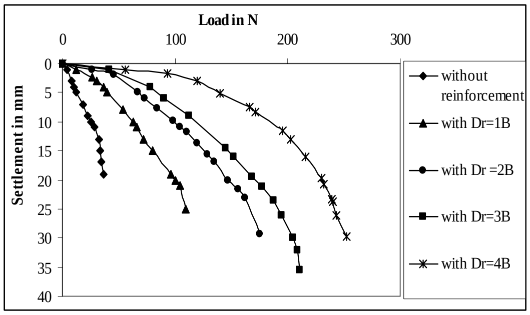

Figure 8. Effect of varying Dr for Br=B

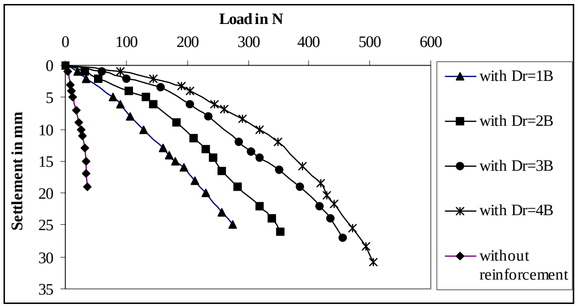

Figure 9. Effect of varying Dr for Br of 3B

For reinforcement of Br= B and Dr= B, 2B and 3B the failure was local shear failure mode. The increases in bearing loads are comparatively less. For Br=B and Dr=4B the pattern of load-settlement curve observed are as that of general shear failure mode. For reinforcement of Br=3B and Dr=B, 2B, 3B and 4B also there was a change in the pattern of load settlement behavior. It was observed that load settlement curve pattern was changed from local to that of general shear failure for the width of reinforcement of 5B and depth of reinforcement of 4B. The bearing load increased at the initial stage itself. No considerable increase due to increment in the depth of reinforcement for the width of reinforcement of 5B. For Dr=Br=3B, the observed load settlement curve is of general shear failure type.

4.2 Quantification of Increase in Bearing Load

To quantify the increase in the bearing load for the various depth and width of reinforcement the bearing load for settlements of 5mm, 10m, 15mm were observed and Increment ratio for 5mm settlement are listed in Tables 5. The increment ratio is higher for 5mm settlement than 15 mm settlement. The increment ratio decreases as the settlement increases. The maximum increment in ratio was 11.7 and was for Br=B and Dr= 4B.

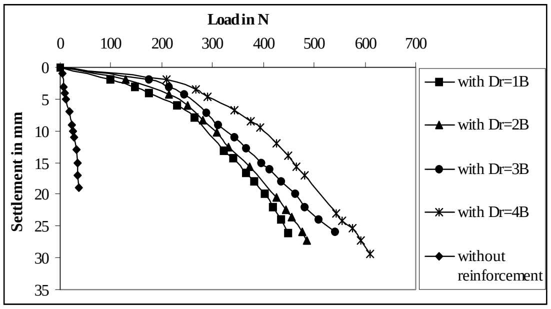

Figure 10. Effect of varying Dr for Br of 5B

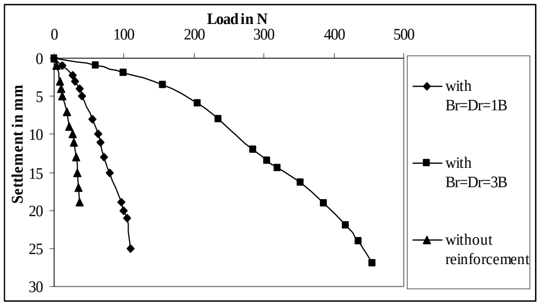

Figure 11. Effect of equal Br and Dr

For width of reinforcement of 3B also, the bearing load increased as the depth of reinforcement increased. The increment ratio is higher for 5mm settlement than 15mm settlement. The maximum increment ratio is 19.2 and is for Br=3B and Dr= 4B. For the breath of reinforcement of 5B, the bearing load increases as the depth of reinforcement increases. The increment ratio is higher for 5mm settlement than 15 mm settlement. The maximum increment ratio is 25.1 and is for Br=5B and Dr=4B.

Table .5 Increment ratios for 5mm settlement

SL No.	Width of Reinforcement	Dr=B	Dr=2B	Dr=3B	Dr=4B
1.	Br=1B	3.3	5.6	7	11.7
2.	Br=3B	6.5	11	15.3	19.2
3.	Br=5B	16.7	19.8	21.0	25.1

For the depth of reinforcement Dr=B, the increase in width of reinforcement from B and 5B increased the bearing load, the total increment ratio was 16.7 and it was for 5mm settlement. For depth of reinforcement of 2B, increase in width of reinforcement from B to 5B increased the bearing load by 2.0 times and the total increment ratio for 3B width of reinforcement is 19.8. For Dr=3B, increase in width of reinforcement from B to 5B, increases the bearing load by 3 times and the total increment ratio was 21 and it is for 5mm settlement. For Dr= 4B, increase in width of reinforcement from B to 5B increased the bearing load by 2.1 times and the total increment ratio was 25.1 and was for 5mm settlement. For equal width and depth of reinforcement the increment ratio was maximum for 5mm settlement and was 3.3 for Dr=Br=B and 15.3 for Dr=Br= 3B reinforcement.

4.3. Mobilization of Adhesive Resistance

There was an increase in the load carrying capacity of soil when it is reinforced with Geogrids. Adhesion between soil and Cellular Geogrid reinforcement was determined using shear box of size 30cm x 30cm x 10cm and is shown in Figure 12. The adhesion values for 53% and 58% water content were 7.85 and 7.46 kN/m^2 respectively. The increase in the load carrying capacity of reinforced soft clay was due to the mobilization of adhesive shear resistance. The maximum possible adhesive resistance i.e. to be mobilized based on the surface area and the laboratory determined adhesion resistance was calculated for different size of reinforcement. The relationship between the surface area, available adhesive resistance and mobilized adhesive resistance was obtained and is shown in Figure 13.

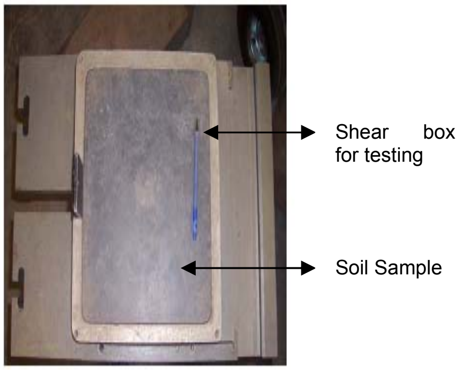

Figure 12. Large size Shear Box Testing

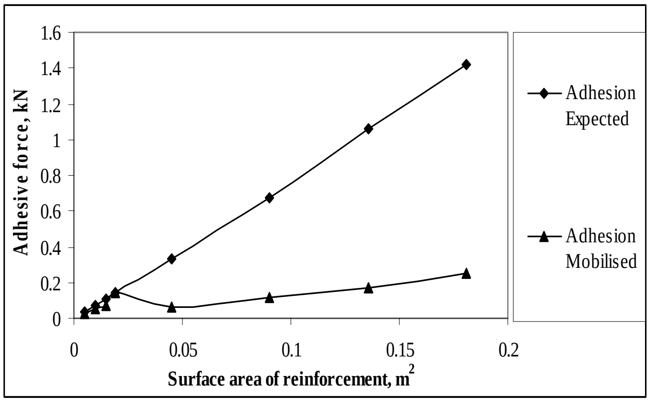

Figure 13. Adhesive Resistance of reinforced soil

The settlement was not sufficient to mobilize the maximum adhesive resistance for higher width and depth of reinforcement. It was observed that up to the surface area of 0.02 m^2, the mobilized and available shear strength was same. The size of the cellular geogrid cage for the particular surface area was B x 4B. From this, it was understood that this was the optimum size of reinforcement that could be used in the soft clay.

4.4. Efficiency of Consolidation

To evaluate the efficiency of in situ consolidation of geogrid reinforced clay bed, tests were conducted for 3B width and 4B depth of reinforcement. Geogrid reinforced clay bed was prepared at soft consistency i.e., 53%, and consolidated by preloading with wick drains. With the results obtained from the one dimensional consolidation test results, the probable settlement caused by in-situ consolidation of the geogrid reinforced clay bed was determined. The settlements were also observed from the in-situ consolidation process at the every 24 hours of pressure increments. The results were compared. Figure 14 shows the installation of wick drains and Figure 15 shows the exhumed circular cellular geogrid cage after testing.

Figure 14. Installation of wick drains

Figure 15. View of removed geogrid after testing

4.4.1 Load-Settlement Relationship

Load settlement curve obtained after consolidation of clay bed along with other relevant results are presented in Figure 16.

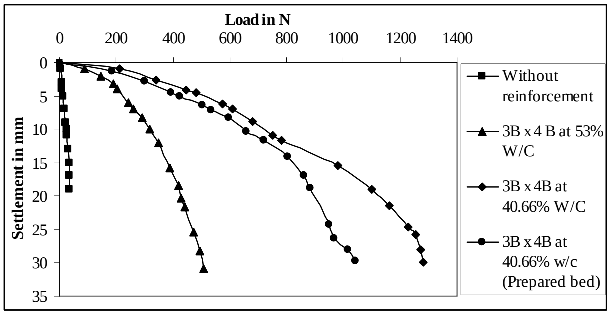

Figure 16. Effect of varying consistency of clay bed for 3B x 4B reinforcement

The improvement in bearing load due to in-situ consolidation of the clay bed was observed and the increment increased as the settlement increased. The increment in bearing load for all other case of reinforcement and clay bed prepared at soft consistency decreased as the settlement increased, but for the in-situ consolidated reinforced clay bed, this increment increased as the settlement increased. Quantification of these improvements requires further study.

5. CONCLUSIONS

An In-situ method of stabilization of soft clay using geogrid was attempted. Square cellular geogrid of cell size equal to width of the selected square footing was fabricated and pushed into the soft clay bed using loading arrangement. Sinking of large size square cellular geogrid cage was difficult and hence the system of reinforcement was changed. Circular cellular geogrid cage of cell size 40mm diameter and length of 100mm (width of footing) was fabricated and was sank at 50mm centre to centre and was tied by a geogrid of size equal to the width of reinforcement. The observations made from this study are listed below.

The above form of reinforcement in soft clay bed increased the bearing capacity. Increase in width and depth of reinforcement increased the bearing capacity. The increase in the bearing capacity is higher for Dr=4B. Increase in the width of reinforcement increased the bearing load due to increase in good bearing surface. Increase in depth of reinforcement increased the bearing load due to additional adhesive shearing resistance in the reinforcement. Introduction of reinforcement in the soft clay bed changed the type of failure from local shear to general shear.

Quantification of the increase in the bearing capacity was attempted for settlement of 5mm, 10mm and 15mm. The increment is higher for 5mm settlement. The maximum increment ratio is 25.1 and is for Br=5B and Dr=4B. To find the efficiency of reinforcement in the bearing load increment, the additional adhesive shearing resistance for all the area of reinforcement was calculated. The adhesive shearing resistance expected and mobilized was same upt0 0.02m^2 area of reinforcement and the corresponding size of the reinforcement is B x 4B.

The bearing capacity of selected MH type of clay at its soft consistency was improved by 25.1 times for 5B and 4B size of circular cellular reinforcement discussed in this paper. This type of reinforcement could be used to improve soft clay bearing capacity for lightly loaded temporary structures. Finally, it is also observed that the in-situ consolidation of this reinforced clay bed, further improved the load-settlement behaviour.

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