PERFORMANCE OF SHALLOW FOOTING ON GEOCELL REINFORCED CLAY BED USING EXPERIMENTAL AND NUMERICAL STUDIES

A. Hegde, Research Scholar, Deptt. of Civil Engg, Indian Institute of Science, Bangalore, amarnath@civil.iisc.ernet.in
T.G. Sitharam, Professor, Deptt. of Civil Engg., Indian Institute of Science, Bangalore, sitharam@civil.iisc.ernet.in

ABSTRACT: This paper summarizes the beneficial effect of geocell reinforcement in soft clay beds through 1-g model plate load tests and numerical simulations using FLAC^{2D}. New commercially available PRS Neoweb geocells are used in the investigation; which is known for its high strength and durability. Results show that provision of geocell increases the load carrying capacity of soft clay bed by 5 times. The overall performance of the clay bed improves further due to the provision of planar geogrid at the base of the geocell. Numerical results are also in the same line with the experimental findings.

INTRODUCTION

Construction in soft ground has always been a big challenge for the engineers. Construction in weak ground requires treating large areas to a greater depth to ensure the safety of the superstructure. Whenever the soft soil is encountered, the general tendency is to go for the deep foundation technique like plié foundations or the ground improvement technique like vibro stone columns. But in the situations involving the low to moderate loading condition, deep foundations become very costly and in such cases more economical solutions are constantly sought after. Reinforcing the soil with the geocell is emerging as the one of the most the cost effective as well as alternative solution to the deep foundation techniques in some cases.

It is well known fact from the past research is that the geocell reinforcement increases the load carrying capacity of the foundation bed. Since late 1970's, many researchers have studied the beneficial effect of the cellular reinforcement through laboratory model plate load tests such as Brooms and Massarach (1977) and Mitchell et al. (1979) . But the majority of the past studies carried out were using laboratory prepared 3D cells made up of paper, geogrids, PVC (Polyvinyl Chloride), geotextiles etc. (Dash et al. 2001; Sitharam and Sireesh, 2004; EI Sawwaf and Nazer, 2005; Madhavi Latha and Somwanshi, 2009; Tafreshi and Dawson , 2010). Very few researchers directly used the commercially available geocell in their studies (Guido et al. 1989; Kief and Rajgopal, 2008). Use of the commercial geocell in the laboratory study is more relevant because, those are the ones, which will be directly utilized in soft soil. In the present study, new commercially available Neoweb geocells (PRS-330) are used; which is known for its high strength and durability.

The primary objective of this study is to evaluate the improvement in the overall performance of the footing in the presence of commercially available Neoweb geocell. Results of the laboratory model tests and the numerical simulations on a square footing resting on reinforced clay beds are reported in this paper.

LABORATORY MODEL TESTS

Laboratory model plate load tests were conducted on test bed cum loading frame assembly. Foundation bed was prepared in a test tank having dimension of 900mm length, 900mm width and 600mm height. The footing used in the study was square in shape with 150mm sides, made up of rigid steel plate with 20mm thickness. The base of the footing was made rough by coating a thin layer of sand to it using epoxy glue. Footing was loaded with hand operated hydraulic jack supported against self-reacting frame. The load applied to the footing was measured through a pre-calibrated proving ring, which was placed between hydraulic jack and the footing with the ball bearing arrangement. Schematic representation of test setup is shown in Fig.1.

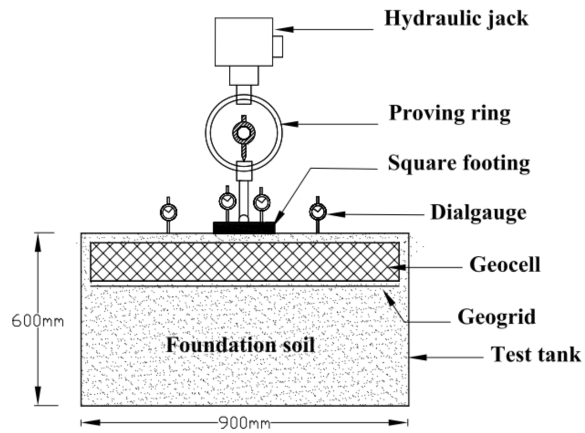

Fig. 1 Schematic representation of test set-up

Natural silty clay was used to prepare the foundation bed. The liquid limit, plastic limit and specific gravity of the soil were 40%, 19% and 2.66. As per Indian Standard Soil Classification System (ISSCS), soil can be classified as clay with medium compressibility (CI). The geocell used in the study was made up of polyethylene with a density of 0.95 g/cm^3. The each cell is 250mm long, 210mm wide and 150mm deep. The thickness of the strip is 1.53mm with cell to cell seam strength is 2150N. Biaxial geogrid made up Polypropylene with aperture size 35mm x 35mm was used.

Ultimate tensile strength of the geogrid was 20kN/m. The clayey soil was first pulverized and then mixed with a predetermined amount of water. The moist soil was placed in the airtight container for 3-4 days for allowing uniform distribution of moisture within the sample before kneading again. Soil was uniformly compacted in 25mm thick layers to achieve the desired height of the foundation bed. The sides of the tank were coated with Polythene sheets to avoid the side friction. By carefully controlling the compaction effort and the water content of the test bed, a uniform test condition was maintained in all the tests. In order to determine the degree of saturation, unit weight, moisture content and undrained shear strength of the soil mass, the undisturbed samples were collected at different location of the test bed. Table 1 represents the properties of the test bed maintained throughout the testing program.

Table 1 Properties of the soft clay bed

Parameters	Values
Moisture content	26%
Degree of saturation	91%
Unit weight	18.63 kN /m^3
Avg. dry density	14.81 kN/m^3
Undrained shear strength	5kPa

Above the foundation bed, geocell was placed to full width of the tank at the depth of 0.1B (where, B is the width of the footing) below the bottom of the footing. The geocell was filled up with the clean sand using pluviation technique to maintain the uniform density. Upon filling the geocell with the sand, the fill surface was leveled and footing was placed in a predetermined alignment in such a way that the load from the jack would act at the center on the footing. At the center of the footing plate a recess was made to accommodate the ball bearing arrangement through which vertical loads were applied onto the footing. The footing was placed carefully at the center of the loading jack supported against the reaction frame to avoid the eccentric loading. The load transferred to the footing was measured through the pre-calibrated proving ring placed between ball bearing and hydraulic jack. Footing settlements were measured through two dial gauges (D1 and D2) placed on either side of the center line of the footing. The deformations of the soil surface were measured by dial gauges (S1 and S2) placed at a distance 1.5B (B is the width of the footing) from the center line of the footing on either side. Photograph of the test setup is shown in Fig. 2.

RESULTS AND DISCUSSIONS

Fig. 3 presents the typical pressure settlement responses for different cases. Footing settlement (S) is expressed in non-dimensional form in terms of footing width as S/B (%). It can be observed that, for the unreinforced case, the slope of the pressure settlement curve becomes nearly perpendicular beyond a settlement about 20% of the footing width indicating the footing is unable to resist the additional pressure because the footing has already undergone the failure.

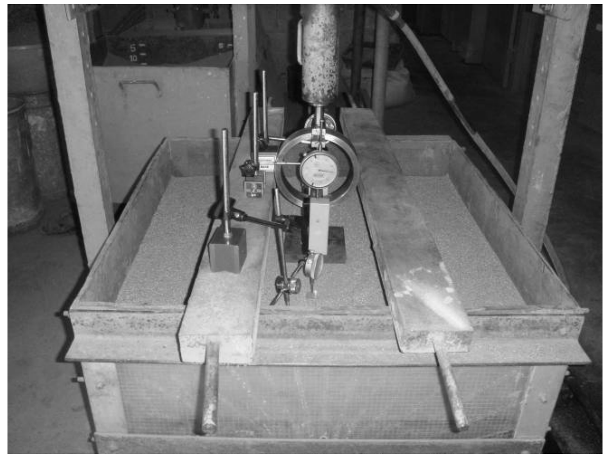

Fig. 2 Photograph of the test set-up

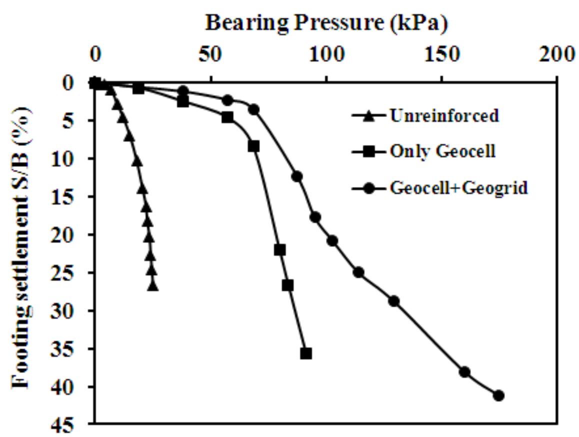

Fig. 3 Variation of bearing pressure with footing settlement

But in case of geocell reinforcement, there was a reduction in the slope about at settlement about 7% of the footing width and after which slope remains constant till 37% with continuous increase in the bearing pressure indicating that there is no clear bearing capacity failure. Interestingly at the same settlement of 7% of the footing width, where the reduction in slope was observed in pressure settlement behavior, the clay surface started heaving. Formation of the surface heaving indicates the occurrence of the local failure in the geocell soil composite around the footing. At this stage, due to mobilization of additional strength and stiffness in the clay bed due to presence of geocell reinforcement, it continues to take up the additional loading. Also the interconnected cells form a panel that acts like a large mat that transfers the imposed load to an extended area, leading to a better performance of the foundation beds.

A similar trend was observed in the pressure settlement behavior with additional planar geogrid at the base of the geocell. But at any particular settlement to footing width ratio, higher bearing pressure was observed as compared to only geocell reinforcement. Provision of the basal geogrid not only mobilizes the additional strength in the clay bed but also it resists the downward movement of soil due to the footing penetration.

The enhancement in the bearing capacity of the foundation bed, due to the inclusion of the reinforcement is measured through a non-dimensional parameter called bearing capacity improvement factor (If), which is defined as,

$$I_f = \frac{q_r}{q_o} \tag{1}$$

Where q_r is the bearing pressure of the reinforced soil at the given settlement and q_o is the bearing pressure of unreinforced soil at the same settlement. This improvement factor is similar to the bearing capacity ratio reported by Binquet and Lee (1975). When the ratio is beyond the ultimate bearing capacity of the unreinforced soil, the ultimate bearing capacity (q_{ult}) is used instead of $q_{0.}$ Variations of bearing capacity improvement factor for different tests are compared in the Fig. 4.

In case of geocell reinforcement, at initial settlement of 5% of the footing width, I_f value equal to 5 was observed. In other words, I_f =5 means the 5 time increments in the load carrying capacity of the foundation bed as compared to unreinforced bed. It can be observed from the figure that the If value decreases with the increase in the settlement in only geocell case. About 6 times increment in the load carrying capacity was observed with the additional planar geogrid at the initial settlements. In this case also, I_f values decrease with the increase in the settlement up to settlement value of 20% of the footing width and after which it again increases. I_f=5 observed at the settlement of 25%. Hence it is evident from the figure that the provision of the additional planar geogrid contributes to the strength at higher settlement. Hence it is always beneficial use planar geogrid layer at the base of the geocell mattress.

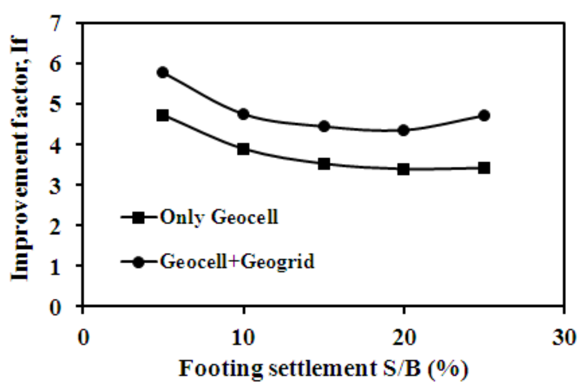

Fig.4 Bearing capacity improvement factor for different cases

NUMERICAL STUDY

Experimental set up was simulated numerically using the FLAC^{2D} (Fast Lagrangian Analysis of Continua in 2D) software. Elastic-perfectly plastic Mohr Coulomb model was used for modeling the behavior of soil. Analyses were carried out under controlled velocity loading of 2.5 x E-5 m/step. Only half portion of the test bed was modeled using symmetry to reduce the computational effort and the time. The FLAC^{2D} model with the details of loading and the boundary conditions are shown in Fig.5. The size of the mesh was as the same size of the test bed used in the experimental studies. The displacement along the bottom boundary was restricted in both horizontal as well as vertical direction. The side boundaries were restrained only in the horizontal direction, while the displacements were allowed in the vertical direction. Roughness of the footing was simulated by restraining the surface nodes representing the base of the footing in the horizontal direction.

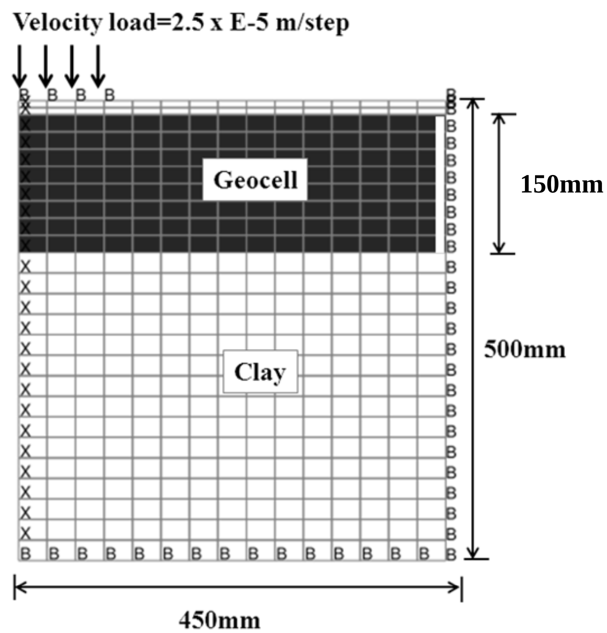

Fig.5 FLAC^{2D} model with details of loading and boundary condition

FLAC^{2D} is two dimensional explicit finite-difference program, which does not facilitate the user to model the 3-dimensional nature of the geocell. Therefore, the geocell layer in filled with sand was modeled as an equivalent composite layer with improved strength and stiffness parameters. A similar approach was also adopted by Madhavi Latha and Somwanshi (2009). The elastic properties are obtained from the experimental pressure settlement behavior using the method proposed in the Appendix D of the Engineering Manual: 1110-1-1904, U.S Army Corps of Engineers (1990). Table 2 presents the details of the elastic properties used in the analysis.

Table 2 Elastic properties used for modeling

	Unreinforced	Only Geocell	Geocell +Geogrid
Shear modulus, G (MPa)	0.1	15	25
Bulk modulus, K (MPa)	0.2	30	50
Poison's ratio	0.3	0.3	0.3

In the simulation of the unreinforced soil behavior, shear strength parameters were obtained from the actual clay bed itself. But in reinforced case, suitable value of the apparent cohesion was assumed. Comparisons of the pressure settlement behavior of experimental and numerical studies are presented in the Fig. 6. It can be observed from the figure that, there is a good agreement between the experimental and the numerical results. However in the case of the clay bed reinforced with additional planar geogrid, FLAC^{2D} overestimated the bearing pressure values by about 15%.

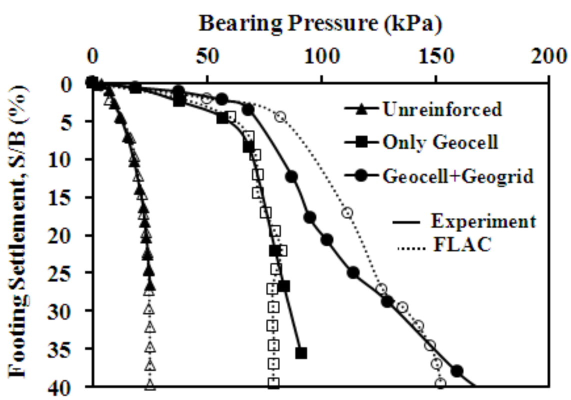

Fig. 6 Comparison of experimental and numerical results of pressure settlement behavior

CONCLUSIONS

Provision of Neoweb geocell increases the load carrying capacity of soft clay bed by 5 times. Load carrying capacity further increases (about 6 times of the unreinforced bed) due to the provision planar geogrid at the base of the geocell. Hence it is always beneficial to use the combination of the geocell and the planar geogrid in soft soils. Besides increasing the load carrying capacity, provision of the reinforcement also reduces the settlement and the surface heaving. Moreover, pressure settlement behavior obtained from the FLAC^{2D} also is in good agreement with the experimental findings. Hence combinations of geocell and geogrid can be recommended to use in pavement sectors as an alternative to the ground improvement technique like vibro stone columns to improve the strength of soft subgrade. However further studies are necessary to understand the behavior of geocells under repeated loading.

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