PERFORMANCE OF SHALLOW FOOTING ON GEOCELL REINFORCED SAND BEDS USING 1-G MODEL TESTS

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ABSTRACT

This paper presents the results of the 1-g model tests performed on geocell reinforced sand bed supporting the square footing. Plate load tests were conducted in a square shaped tank with 600mm depth and 900mm width to understand the behavior of the geocell reinforcement. New commercially available PRS Neoweb geocells made up of polyethylene were used in the investigation; which is known for its high strength and durability. Test results of unreinforced, geogrid reinforced, geocell reinforced, and geocell with additional planar geogrid have been compared. Results show that the provision of geocell increases the ultimate bearing capacity of the sand bed by 4 times. Introduction of planar geogrid at the base of the geocell mattress further enhances the performance of the footing by increasing the load carrying capacity, arresting the surface heave and preventing the footing rotation.

*Keywords**:** Model tests, bearing pressure, geocell reinforcement, planar geogrid, square footing*

INTRODUCTION

Due to the rapid urbanization, construction in weak ground has become inevitable. Construction in weak ground requires treating large areas to a greater depth to ensure the safety of the superstructure. Traditionally available techniques for the improving the weak soils are generally deep foundation techniques. Deep foundations can transfer the heavy loads from superstructures to hard strata underneath the weak soils. But these techniques being very expensive, more economical solutions are constantly sought after. In recent years, ground improvement techniques such as vibro stone columns and prefabricated vertical drains have gained popularity for their wide range of application in soft soils. Ground improvement methods are relatively cheaper and faster compared to deep foundation techniques but suitable only for low loading applications. With a huge scope of infrastructure growth in the 21st century, engineers and scientists are constantly looking for new techniques which are much faster, easier, and cheaper to the ground improvement techniques. As a result of this, reinforcing the soil with 3D cellular mattress (geocell) is gaining the popularity.

Reinforcing the soil in the form of a cellular mattress has been showing its efficacy in construction field. The cell by virtue of its three dimensional nature, offers all round confinement to the encapsulated soil. The interconnected cells form a slab that behaves like a large pad that spreads the applied load over wider area and hence leads to the improved performance of the foundation beds. Several researchers have studied the beneficial use of geocell reinforcement in the construction of foundations. Broms and Massarch (1977) adopted the metallic grid mat consisting of rectangular and triangular cells for different offshore structure. Rea and Mitchell (1978) and Mitchell et al. (1979) carried out the study on footings supported on sand beds reinforced with square shaped paper grid cells through a series of small-scale laboratory tests and observed different modes of failure. Guido et al. (1989) studied the influence of number of layers of geoweb cells, the size of the geocell mat and the depth of placement of geocell on bearing capacity of sand bed using laboratory plate load tests. Similar studies in the sand bed were carried out using laboratory prepared geogrid cells by Dash et al. (2001a) on strip footing, Sitharam and Sireesh (2004) on circular footing and Madhavi Latha and Somwanshi (2009) on square footing. EI Sawwaf and Nazer (2005) used Unplasticized Polyvinyl Chloride (UPVC) cylinders of different diameters to study the soil confinement on circular footing. Tafreshi and Dawson (2010) used strips of thermo welded non-woven geotextiles as 3D cells to study the response of sand bed under static and dynamic loading.

The majority of the researchers used the laboratory prepared geogrid cells instead of commercially available geocells. However, commercially available geocells are the ones, which will be used directly in the field, the laboratory findings may not be correlated with the field situations. In the present investigation, new commercially available Neoweb geocells (PRS-330) is used; which is known for its strength and durability. The primary objective of this study is to evaluate the improvement in the overall performance of the square footing resting on reinforced sand beds through laboratory model tests for different forms and combination of reinforcements. Test results of unreinforced, geogrid reinforced, geocell reinforced, and geocell with additional basal geogrid (SS-20) cases have been reported in this paper.

LABORATORY MODEL TESTS

Experimental Set Up

The experiments were conducted in the test tank of size 900mm length x900mm width x 600mm height made up of cast iron. The tank was fitted to the loading frame which is connected to manually operated hydraulic jack. A square shaped steel plate with 20mm thickness and 150mm sides was used as the model footing. The bottom of the footing was made rough by a coating thin layer of sand with epoxy glue. The load was applied on the footing through the hand operated hydraulic jack and a pre-calibrated proving ring was placed between the footing and hydraulic jack to measure the imposed load. To avoid the eccentric application of the load, the ball bearing arrangement was used. Schematic representation of test setup is shown in Fig. 1.

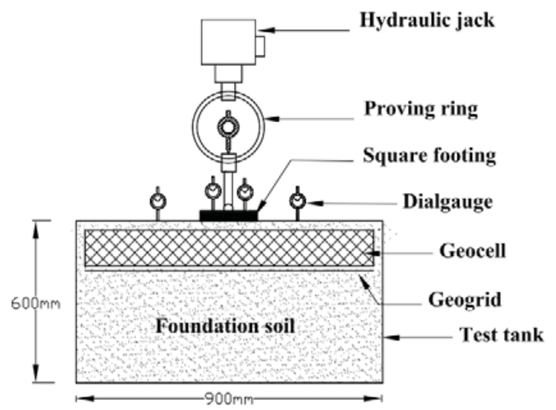


Fig. 1 Schematic representation of test set-up

Materials Used

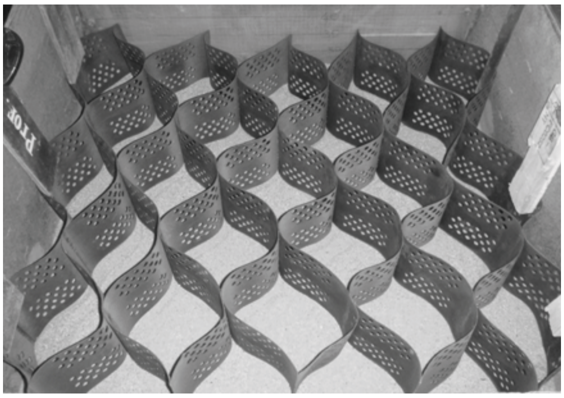
Sand used in the investigation was dry sand with specific gravity 2.64, effective particle seize (D_{10}) 0.26mm, coefficient of uniformity (C_u) 3.08, coefficient of uniformity (C_c) 1.05, maximum void ratio (e_{max}) 0.81 and minimum void ratio (e_{min}) of 0.51. According to Indian Standard Soil Classification System (ISSCS) the soil can be classified as poorly graded sand with symbol SP. The geocell used in the study is made of polyethylene. The density of the geocell is 0.95 g/cm^3. The cells are of 250mm length, 210mm width and 150mm in depth. 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 is 20 kN/m.

Preparation of Test Bed

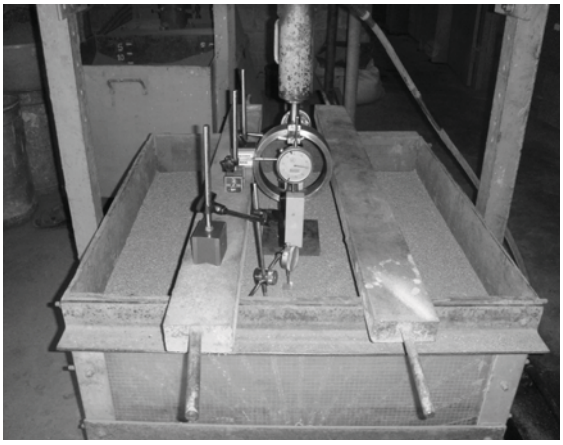
First, the sides of the tank were coated with Polythene sheets to avoid the side friction. Pluviation technique was used to prepare the sand bed of 500mm thickness. Before the start of the actual test, a series of trials were conducted to determine the height of fall required to achieve the desired relative density. In each trail, small aluminum cups with known volume were placed at the different locations of the tank. A calibration chart was prepared by knowing the maximum and minimum void ratios of the sand. All the tests were conducted at a constant relative density of 65%. The height of fall required to achieve 65% relative density was directly obtained from the chart.

Testing Procedure

Reinforcements were placed at the predetermined depth during the pluviation of sand into test tank. After preparing the sand bed of 500m thickness, the fill was leveled using a trowel without disturbing the density of the bed. Footing was placed at the pre-determined alignment at the surface of the sand bed. A recess was made on the top surface of the footing and a ball bearing arrangement was placed into it. Through this arrangement, the concentrated vertical load was applied on the footing. Through the precise measurements, the footing was placed exactly at the center of the test tank in order to avoid the eccentric loading. The load applied to sand bed was measured through the pre-calibrated proving placed between the footing and the hydraulic jack. Two dial gauges (D1 and D2) were placed on the either side of the center line of the footing to record the footing settlements. Another set of dial gauges (S1 and S2) were placed at the distance of 1.5B (B is the width of the footing) from the center line of the footing to measure the deformation underwent by the fill surface. Fig. 2a shows the photographs of the test set-up after the placement of the geocell while the Fig.2b represents the photographic view during the application of load.



(a)



(b)

Fig. 2a-b Photographs of the test set-up: (a) after the placement of geocell; (b) during the application of load

Testing Programme

In all the tests, footing was placed at the surface of the sand bed. The size of the footing (B=150mm) and relative density (D_r=65%) were maintained as constant parameters. In reinforced tests, the reinforcement was placed for the full width of the tank leaving the small distance between the tank wall and the reinforcement to avert the boundary effects. In other words, the width of the reinforcement is about the 6 times the width of the footing. Sitharam and Sireesh (2005) observed that the optimum depth of the geocell reinforcement is about 0.05D (where D is the diameter of circular footing) from the base of the footing. Dash et al. (2001b) reported the optimum depth of geocell placement as 0.1B (where, B is the width of footing) from the bottom of the footing. Similarly, many researchers reported the optimum depth of placement of the planar geogrid as 0.30B to 0.37B (e.g. Huang and Tatsuoka, 1990; Omar et al., 1993; Khing et al., 1993). Hence, in the present investigation, the geocell was placed at the depth of 0.1B (u) in tests C, D and the geogrid was placed at the depth 0.3B (u1) in test B. Details of the tests are summarized in Table 1. The geometry of the test configuration with reinforcement is shown in Fig. 3.

Table 1 Test details

Test	Type of tests
A	Unreinforced
B	Geogrid reinforced
C	Geocell reinforced
D	Geocell with additional basal geogrid

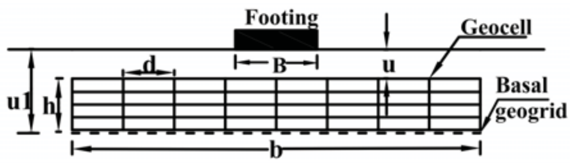


Fig. 3 Geometry of the test configuration

RESULTS AND DISCUSSIONS

Bearing Capacity Improvement Factors (I_f)

The increase in the bearing capacity due to the provision of the reinforcement can be measured through a non-dimensional parameter called bearing capacity improvement factor (I_f), which is defined as,

$$I_f = \frac{q_r}{q_o} \qquad (1)$$

where q_r is the bearing pressure of the reinforced soil at the given settlement and q_0 is the bearing pressure of unreinforced soil at the same settlement. Binquet and Lee (1975) reported the improvement factor is similar to the bearing capacity ratio. 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.

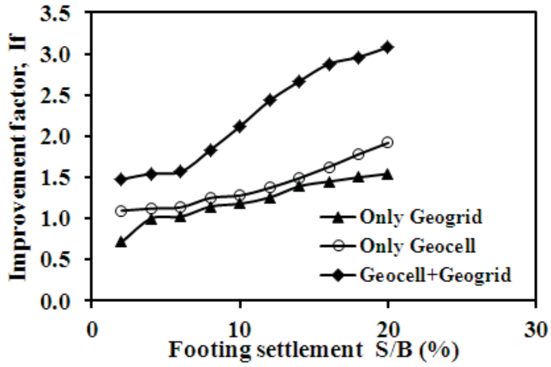


Fig. 4 Bearing capacity improvement factor for different case

The explanation of the same has been made later in the section pressure settlement behavior for the purpose of convenience. The footing settlement (S) and the surface deformation (δ) were normalized by footing width (B) to express them in non-dimensional form as S/B (%) and δ/B (%). In all the plots, settlements are reported with the negative sign and heave with the positive sign.

Bearing Pressure-Settlement Curve

Pressure settlement behavior for different cases is shown in Fig. 5. This can be quantified in terms of bearing capacit y improvement factors as shown in Fig. 4. For unreinforced case, failure was occurred at footing settlement of 8% of footing width. In case of geogrid reinforced sand, failure was occurred at footing settlement of 10% of the footing width. Clearly defined failure was observed in geogrid reinforced sands as it was observed in unreinforced case. This is because, much of tensile strength of geogrid remains immobilized due to its downward movement when soil undergoes shear failure and instead initiating catastrophic failure in geogrid (Yetimoglu et al., 1994; Dash et al., 2001a). The ultimate bearing pressure of geogrid reinforced sand is about 1.4 times (I_f=1.4) the unreinforced case at the time of failure (see Fig. 4). In case of geocell reinforcement, no clear cut failure was observed in the pressure settlement behavior even up to the large settlement of 35% of footing width. There was a slight reduction in the slope of the pressure settlement curve at the settlement range of 22% to 24% of the footing width and after which again the slope has become constant. This nature of the curve can be attributed to the beam effect of the geocell mattress; due to its high bending and shear stiffness, geocell mattress can support the footing even after the failure of soil. The interconnected cells form a panel that acts like a large mat that spreads the applied load over an extended area, leading to an overall improvement in the performance of the foundation beds. Post test exhume of geocell has shown the deformation in the vertical and horizontal ribs (see Fig. 6). Reason for this could be, once the soil below footing underwent the shear failure, the footing might have rested directly on the ribs of the geocell. Also it was observed that the provision of the additional geogrid layer at the base of the geocell mattress further increase the load carrying capacity as well as the stiffness of the sand bed.(i.e. flattened pressure settlement curve). Figure 4 shows that the improvement due to basal geogrid is higher at larger settlements. Similar trends were observed by Dash et al. (2000b) on strip footing resting on sand bed reinforced with geocell and geogrid. Also the planar geogrid contributes in improving the overall performance of the foundation bed by resisting the downward movement of soil due to the footing penetration. Hence, it is always beneficial to use planar geogrid layer at the base of the geocell mattress.

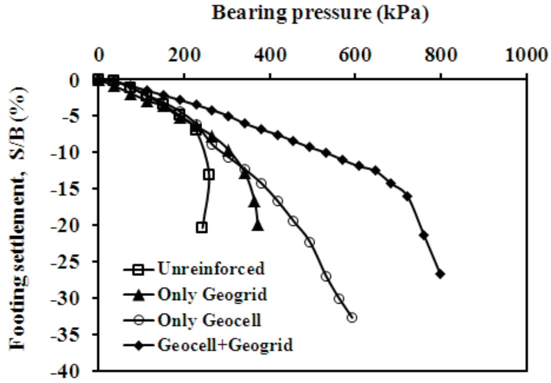


Fig. 5 Variation of bearing pressure with footing settlement

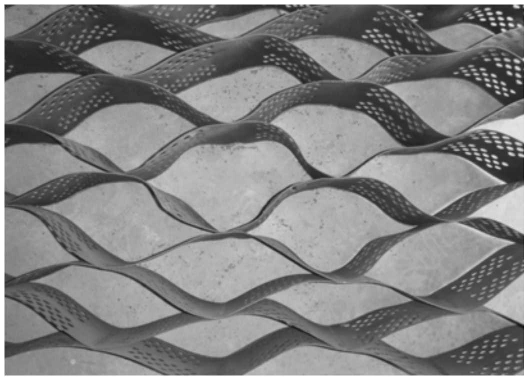


Fig. 6 Photograph showing the deformed geocell ribs after the test

Surface Deformation

Surface deformation (settlement/heave) profiles of sand bed reinforced with different forms of reinforcement are discussed in this section. Surface deformation measurements were made through the dial gauges placed at the distance of 1.5B from the centerline of the footing. Chummar (1972) observed that the surface heaving extends up to 2B from the centerline of the footing for unreinforced case and with maximum heaving at a distance of 1.5B. Generally, surface heaving can be attributed to the general shear failure of the soil mass. Figure 7 quantifies the maximum surface deformation for the different combination of reinforcements. The solid and dotted lines represent the deformation measured at the left and right side of the footing centerline. One can observe from the figure that the large difference between the solid and dotted lines. This difference is due to the rotational failure of the footing. The extent of rotation and amount of heaving got reduced in the case of the geocell reinforcement (Test-C) and further reduction in rotation was observed in the presence of the planar geogrid below the geocell. Interestingly, no surface heaving was observed in Test-D with additional basal geogrid. From the above observation it is evident that the combination of geocell and basal geogrid completely arrest the surface heaving and also reduces the footing rotation.

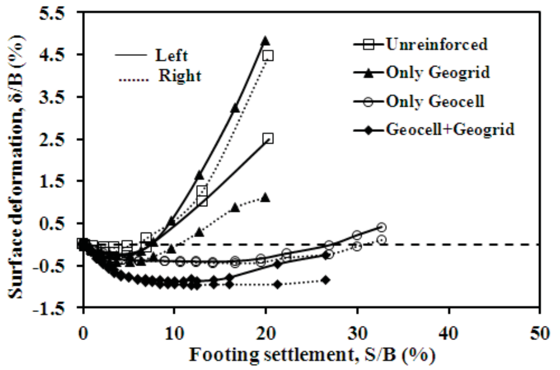
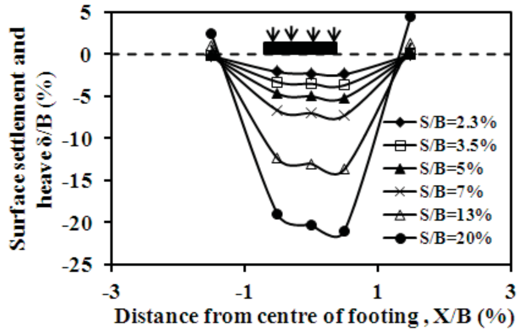
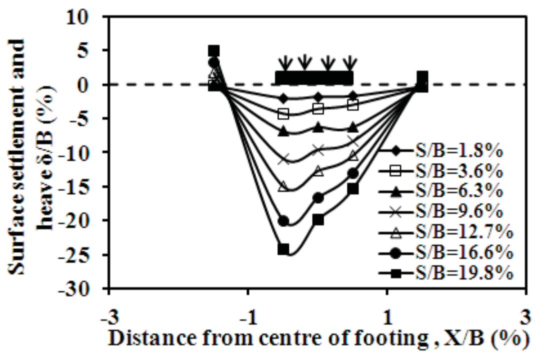


Fig. 7 Variation surface deformation with footing settlement

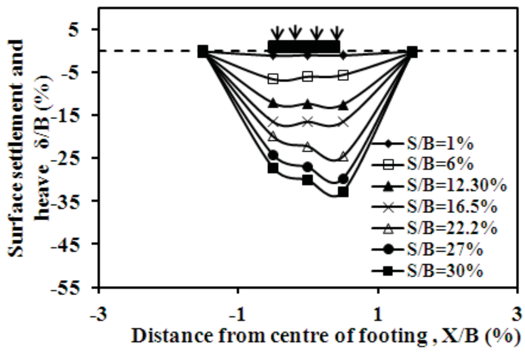
Figure 8a-d, represents the surface deformation profile observed at a particular ratio of footing settlement to the width of the footing (S/B) for different tests. Using these plots, progression of the surface heave and the rotation of the footing under each loading increment can be captured. One can utilize these figures to calculate the differential settlement underwent by the footing for different load increment till the failure and also the extent of rotation in terms of angle of rotation.



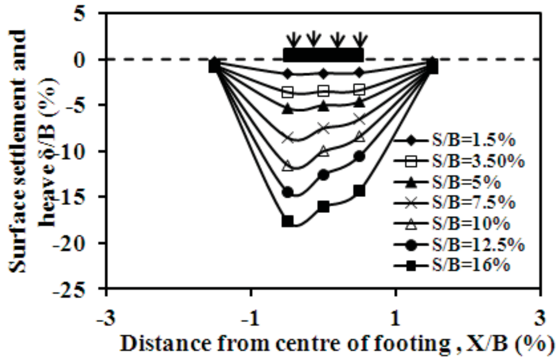
(a)



(b)



(c)



(d)

Fig. 8a-d Surface deformation profiles: (a) unreinforced; (b) geogrid reinforced; (c) geocell reinforced; (d) geocell with basal geogrid

CONCLUSIONS

Provision of geocell increases the ultimate bearing capacity of the sand bed by 4 times. Due to its high bending and shear stiffness, geocell mattress can support the footing at larger settlements and even after the failure of soil. Provision of the additional planar geogrid at the base of the geocell arrests the surface heaving and prevents the footing from undergoing the rotation failure. Hence, it is always beneficial to use planar geogrid layer at the base of the geocell mattress. Thus, the combinations of geocell and geogrid can be recommended as the foundation system for liquid storage tanks, parking areas and low cost unpaved roads as an alternative to the ground improvement technique like vibro compaction. However further studies are necessary to understand the behavior of geocells under repeated loading to comment about its suitability in highways and expressways.

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