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Plate Load Tests of Multi-Layered Geocell Reinforced Bed Considering Embedment Depth of Footing

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Abstract

This paper describes the effect of embedment depth on bearing capacity of footing supported by geocell-reinforced bed, using plate load test at a diameter of 300 mm. The embedment depth ratio of the footing was varied from zero to 0.75. The plate load tests were performed in an outdoor test pit dug in natural ground measuring 2000 x 2000 mm in plan and 1000 mm in depth. The geocell used in the tests was non-perforated with pocket size 110 x 110 mm2 and height 100 mm, fabricated from continuous polypropylene filaments as a nonwoven geotextile. The tests were conducted on geocell reinforced bed sand, which was compacted to 85% relative density. The test results demonstrate that the bearing pressure increases with increase in the embedment depth ratio and the number of geocell layers. The study also compares the embedment depth ratio of one layer geocell reinforcement with two and three layer geocell reinforcement bed with no embedment depth. These comparisons show that the performance of footing on single layer reinforced bed with the embedment depth ratio of 0.25 and 0.75 might be comparable to the performance of footing on geocell-reinforced bed with two and three reinforcement layers.

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Keywords: Bearing pressure, embedment depth, geocell reinforcement, plate load test.

1. Introduction

In recent decades, geosynthetic inclusions in the form of two-dimensional reinforcement (e.g., geotextile and geogrid) and three-dimensional reinforcement (e.g., geocell) have been widely utilized in geotechnical engineering applications for, e.g., road construction layers, stable embankments, slope and earth stabilization, and construction of footings over soft soil (e.g., Kim et al. 2006; Moghaddas Tafreshi and Dawson 2010; Moghaddas Tafreshi et al.

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2011; Chen et al., 2013). Although, in addition to planar reinforcements, several investigations have also highlighted the beneficial use of geocell reinforcement in the construction of embankments and footing over soft soil (e.g. Sireesh et al., 2009; Moghaddas Tafreshi and Dawson, 2012; Chen et al., 2013), but all of these studies on geocell reinforcement have been conducted for surface footings, despite the fact that embedded footings are more common in practice. At present, very limited experimental work is reported that assesses the effect of embedment depth of footing on planar reinforced footings (Patra et al., 2005; Sitharam and Sireesh, 2004, 2005). Since, the literature above indicates that there is a lack of studies into the behaviour of footing supported by geocell reinforcing layers with embedment depth, investigation of the beneficial means of geocell reinforcement and footing embedment depth is the main subject of this article.

2. Test Materials

The soil used in the testing program is a granular soil with grain sizes between 0.01 and 38 mm with a specific gravity of 2.65 (G_s=2.65). It has a Coefficient of uniformity, C_u, of 33.75, Coefficient of curvature, C_c, of 2.32, an effective grain size, D_{10}, of 0.18 mm, and mean grain size, D_{50}, of 3.04 which is classified as well graded sand with letter symbol "SW" in the unified soil classification system (ASTM D 2487-11). The maximum and minimum void ratio (e_{max} and e_{min}) of the sand were obtained as 0.74 and 0.26, respectively. According to ASTM D 1557-12, the maximum dry density was about 22.82 kN/m^3, which corresponds to an optimum moisture content of 6.7%. The angle of internal friction of soil, through triaxial compression tests at wet density of 19.35 kN/m^3 was obtained 39.5°. This soil was used to fill the geocell and to place between the geocell layers.

The geocell used were made of a type of a non-woven polymeric geotextile (see Moghaddas Tafreshi and Dawson (2012) for geotextile properties) and has the pocket size and height of 110×110 mm^2 and 100 mm, respectively. In the testing program, the ratio of the maximum geocell pocket size (*d=110 mm*) to diameter of loading plate (*D=300* mm) is, thus, 0.37 (*d/D*=0.37).

3. Tests Set-up

To investigate the bearing capacity and the settlement of shallow footings supported by layers of geocell, an experimental program was conducted using a standard plate load. All plate load tests were conducted in an outdoor test pit. The test pit, measuring 2000 mm × 2000 mm in plan, and 700 mm in depth, was excavated in natural ground to construct the geocell layers. The static load using a hydraulic jack was applied on the model footing monotonically at a rate of 1.5 kPa per second.

To measure the settlement of the plate, throughout the tests, three linear dial gauges with an accuracy of 0.01% of full range (100 mm) were attached to a reference beam and their tips placed about 10 mm inwards from the edge of the. The schematic cross-section of the test set-up of the foundation bed containing geocell-reinforcement layers, the footing model and the geometry of the test configurations, is shown in Fig. 1. In order to compact the layers of foundation bed including the unreinforced soil and geocell-reinforced layers, a walk-behind vibrating plate compactor, 450 mm in width, was used. The soil in different layers was compacted at an optimum moisture content of 5.7% and wet density of 19.35 kN/m^3.

4. Test parameters and testing program

The details of all the test series done in this study are given in Table 1. The width of the geocell layers (*b*), the depth to the top of the first geocell layer below the footing (*u*) and the vertical spacing between the geocell layers are expressed in non-dimensional form with respect to footing diameter (*D=300 mm*) as, *b/D, u/D*, and *h/D*, whereas the height of geocell layers (h_g) is expressed in dimensional form equal to 100 mm (see Fig.1). The parameters of *b/D, u/D*, and *h/D* were held constant in all the tests at *b/D*=5 and *u/D= h/D=0.2* (Moghaddas Tafreshi and Dawson, 2012).

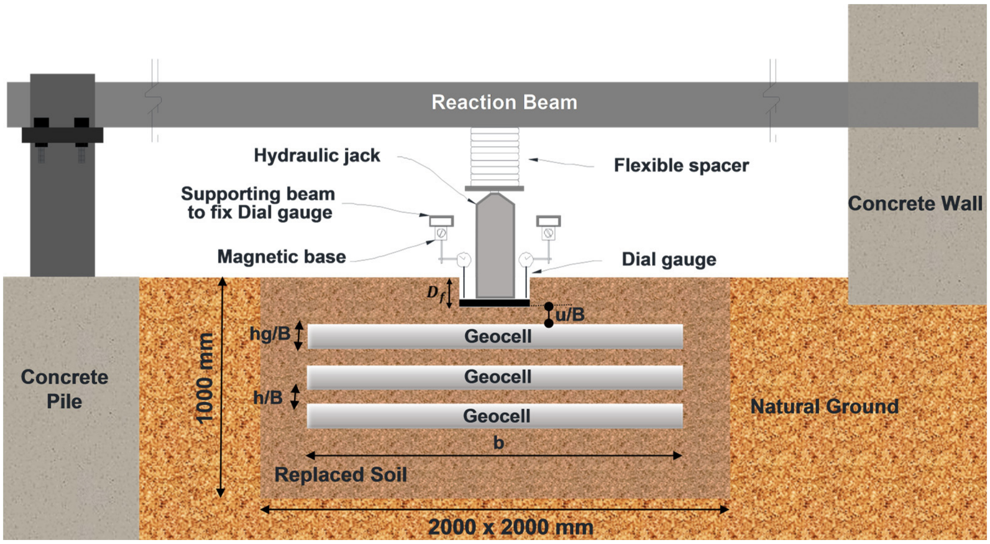


Fig. 1. Schematic cross-section of the test set-up (not to scale).

Table 1 Scheme of the plate load tests for footing on unreinforced and geocell-reinforced bed.

Test Series	Type of test	*N*	D_f/B	No. of Tests	Purpose of the tests
1	Unreinforced	0	0, 0.25, 0.75	1+2*	To investigate the effect of embedment depth
2	Geocell reinforced	1	0, 0.25, 0.75	7+4*	To investigate the effect of footing embedment depth and number of geocell layers
3		2, 3	0	5+2*	

*The tests which were performed two or three times to verify the repeatability of the test data (maximum differences in results of around 6-8%)

5. Results and discussions

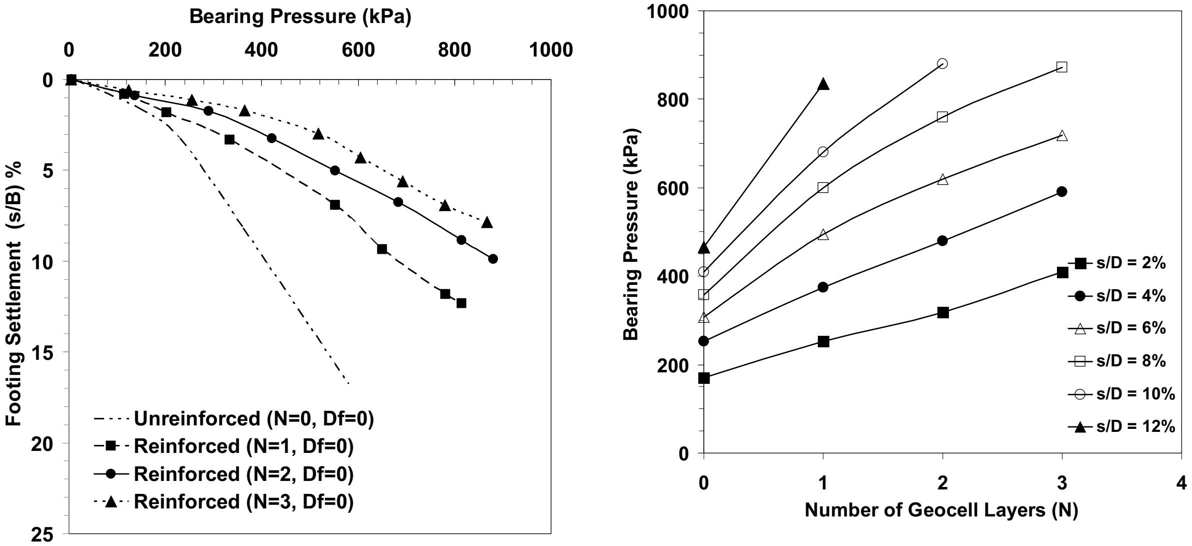
The results of tests are presented along with a discussion high lighting the effects of the embedment depth and number of geocell layers. The performance improvement of the footing is represented here by variations in the bearing pressure and settlement of the footings.

5.1. The effect of the number of geocell layers

Fig. 2a presents the bearing pressure-settlement of footing on unreinforced and geocell reinforced beds with no embedment depth ($D_f/B=0$). This figure clearly shows that, as the number of geocell layers increases (i.e., the increase in the depth of the reinforced zone), both stiffness and bearing pressure at a specified settlement increase substantially.

In order to have a direct comparison of the results for the unreinforced and geocell reinforced beds, the bearing pressure values corresponding to the settlement ratios of 2%, 4%, 6%, 8%, 10%, and 12% were extracted from Fig. 2a for different numbers of geocell layers. Fig. 2b plots this data against the number of geocell layers (N_g). It can be seen that as the number of geocell layers increases, the bearing pressure increases steadily, regardless of the settlement ratio. For example, at settlement ratio of s/B=4%, the bearing capacity values are about 253, 357, 490 and 592, and 688 kPa for unreinforced bed, and reinforced bed with one, two and three layers of geocell, respectively.

Fig. 2b also indicates that the benefits of geocell reinforcement increase as the footing settlement increases. This performance could be attributed to the internal confinement provided by geocell reinforcement. The confinement effect is dependent on the tensile strength of the reinforcement, the friction at the soil-reinforcement interface and the confining stress developed on the infilling soil inside the geocell pocket due to the passive resistance provided by the 3D structure of geocell (Sitharam and Sireesh 2005; Moghaddas Tafreshi and Dawson 2010, 2012). Obviously, the reinforced system must exhibit some settlement, and consequently, strain (elongation) must develop in the reinforcement layers to affect the geocell modulus, tensile and frictional strength and the passive resistance offered by the geocell layers. Additionally, this comparison indicates that it is necessary to consider the footing settlement level while investigating the effects of reinforcement on the bearing pressure of reinforced sand.

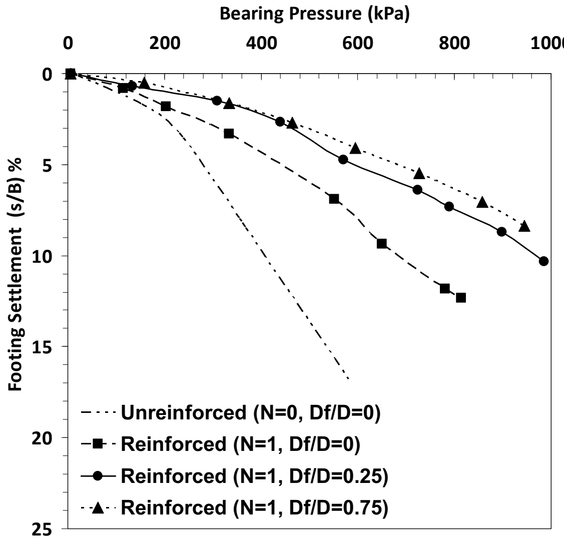


(a) (b)

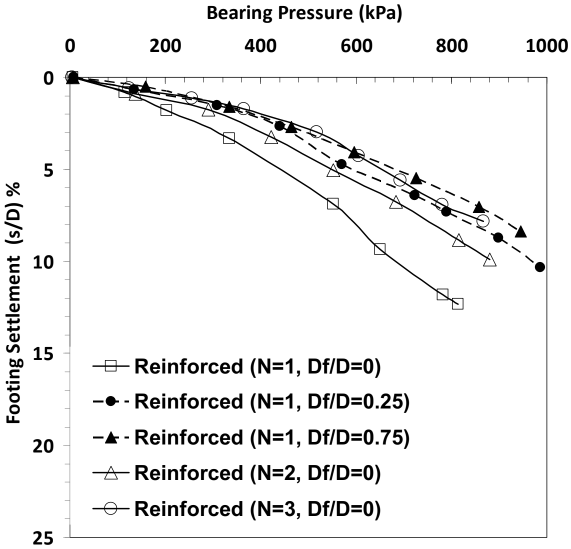
Fig. 2. Variation of bearing pressure with (a) settlement of footing, (b) number of geocell layers at different values of settlement.

5.2. The effect of embedment depth

The pressure–settlement responses observed from different series of tests are presented in Fig. 3. This figure shows as the embedment depth ratio of the footing (D_f/B) increases, a substantial improvement in terms of both the initial stiffness and the ultimate bearing capacity of the footing appear, irrespective of unreinforced and reinforced bases. This is believed to be due to the additional confinement induced in the foundation bed because of the increased overburden pressure with increase in the footing embedment depth. From Fig. 3a, at settlement ratio of s/B=4%, the bearing capacity values are about 250, 420, 520 and 595 kPa for unreinforced bed, and single geocell reinforced bed with embedment depth ratio 0, 0.25 and 0.75, respectively. Typical pressure-settlement responses that illustrate the effect of embedment depth and number of geocell reinforcement layers are shown in Fig. 3b. It could be observed that reinforced bed with or without embedment depth, both have no pronounced peak pressure. It is interesting to note that, one layer geocell reinforced bed with 0.75 embedment depth ratio (D_f/B=0.75), has more bearing pressure capacity as compared with three layers geocell reinforced bed with no embedment depth.. According to this figure the embedment depth helps to increase bearing capacity due to increasing the confinement effect compare with provision geocell (surface footing).



(a)



(b)

Fig. 3. Variation of bearing pressure with settlement for unreinforced and (a) single layer of geocell reinforced bed with embedment depth (b) one, two and three layers of geocell reinforced bed with embedment depth.

6. Conclusions

This paper presents large-scale model tests on a square embedded footing supported on geocell reinforced sand beds. Based on the results, the following conclusions are drawn:

- The bearing capacity increases and the settlement decreases with increase in the embedment ratio, D_f/B for both unreinforced and reinforced foundation bed.
- Footing supported on one layer geocell reinforced beds is almost linear up to a settlement range of 25-30% of the footing width, even at a settlement equal to about 50% of the footing width, clear signs of failure were not evident in the case of geocell-reinforced foundations.
- A comparison between number of layers and embedment depth ratio, under the same static load shows that, the bearing pressure values for the reinforced bed with two layers of geocell and for the reinforced bed with three layers of geocell, at settlement ratio range of 0% to 20%, are about equal with embedded rectangular footings resting on one layer geocell with embedment ratio (D_f/B) of 0.25 and 0.75.

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