New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-45775-0

Effect of soil dilation on performance of geocell reinforced sand beds

S.K. Dash
Department of Civil Engineering, Indian Institute of Technology Guwahati, India

ABSTRACT: This paper presents results of a series of laboratory model tests, designed to bring out the influence of dilation of the fill soil on the performance improvement due to the geocell reinforcement, in sand beds. The benefit due to geocell reinforcement in foundation soil is found to increase with increase in dilation of infill soil. With geocell reinforcement offering three dimensional confinement the dilation induced benefit is substantially high. Therefore, for effective utilisation of geocell reinforcement, the infill soil should be compacted well.

1 INTRODUCTION

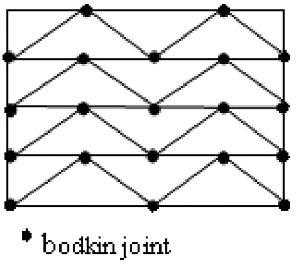
Soil reinforcement in the form of geocell has been utilised successfully in many areas of geotechnical engineering (e.g. Bathurst and Jarrett 1989, Bush et al. 1990, Dash et al. 2001). The geocell reinforcement arrests the lateral spreading of the infill soil and creates a stiffened mat to support the foundation, thereby, giving rise to higher load carrying capacity. This paper presents results of a series of laboratory model tests designed to bring out the influence of placement density of the fill soil, on the performance of geocell reinforced sand beds.

2 TEST DETAIL

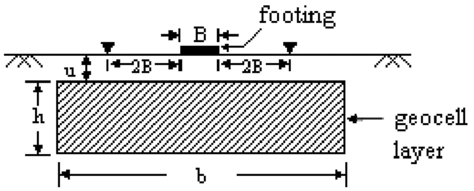
The model tests were conducted in a steel tank having a length of 1200 mm, width of 332 mm and a height of 700 mm. The model footing used was made of steel and measured 330 mm length × 100 mm width × 25 mm thickness. The bottom surface of this footing was made rough by cementing a thin layer of sand with epoxy glue. The footing was centered in the tank with the length of the footing parallel to the width of the tank. As the length of the footing is almost equal to the width of the tank, plane strain conditions prevailed in the tests. The soil used in this investigation is a poorly graded river sand. The maximum and minimum dry density of the soil are found to be 17.41 $\mathrm{kN/m^3}$ and 14.30 $\mathrm{kN/m^3}$ respectively.

The model tests were performed at relative densities of 30%, 40%, 50%, 60% and 70%. The friction angle of the sand at three relative densities, 30%, 50% and 70%, as determined from standard triaxial compression tests, are 39.2°, 41° and 42.2° respectively. The dilation angles of the sand were found to be 0°, 6°, 20°; at these relative densities respectively. The geocell layers were formed (Bush et al. 1990), using a biaxial geogrid of aperture opening size of 35 × 35 mm and ultimate tensile strength of 20 kN/m. The joints of the geocells were formed using 6 mm wide and 3 mm thick plastic strips cut from commercially available bodkins made of low-density polypropylene (Fig 1a). All the tests were performed with single layer of geocell reinforcement. To achieve uniform density of the fill soil in the test tank sand raining technique was used. The height of fall to achieve a desired relative density was determined through calibration tests a priori.

The load was applied through a hydraulic jack in small increments, in stress controlled fashion. The actual load transmitted to the footing was measured through a pre-calibrated proving ring placed between the hydraulic jack and the footing. The settlements (s) of the footing were measured using two dial gauges, placed diagonally on opposite sides of the footing centerline. The deformations on fill surface (settlement/heave, δ) were recorded through dial gauges placed at a distance of 2.5 B on either side of the footing (shown through ▼ in Fig. 1). The strains developed in the geocell were measured through electrical resistance type strain gauges fixed in horizontal direction on the geocell wall along its width at mid height. In many cases the strain gauges were damaged prematurely. However meaningful observations can be made from the available data. The load transferred to the footing, settlements of the footing, deformations on fill surface and strain in geocell wall, were recorded after stabilisation of settlement under each load increment. The geometry of the problem is shown in Fig. 1. In order to understand the influence of dilation of soil on the overall performance, in all the tests the geometry of the geocell layer was kept constant as, height, $h/B = 1.6$; width, $b/B = 8$; depth of placement, $u/B = 0.1$. The pocket size (d) that is considered as



(a) Plan



(b) Section

Figure 1. Geometry of geocell reinforced sand bed.

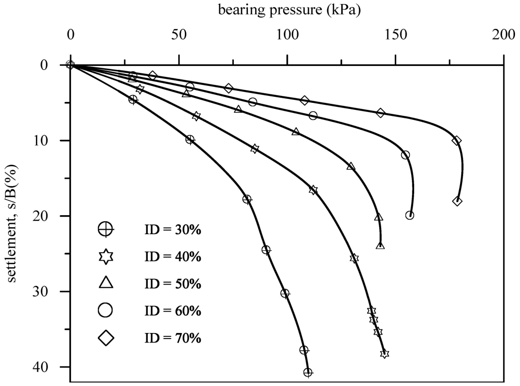


Figure 2. Pressure-settlement plots for unreinforced soil.

the equivalent circular diameter of the geocell pocket opening was kept equal to 1.2 B in all the tests.

3 RESULTS AND DISCUSSION

Bearing pressure versus settlement responses for unreinforced soil are shown in Fig. 2 and that for geocell-reinforced soil are shown in Fig. 3.

It could be observed that, while, the responses for unreinforced soil have a clear break point with reduction in slope indicating shear failure in soil, the geocell reinforced soil beds without showing any such failure continue to sustain increased footing loading till a settlement as high as 50% of the footing width.

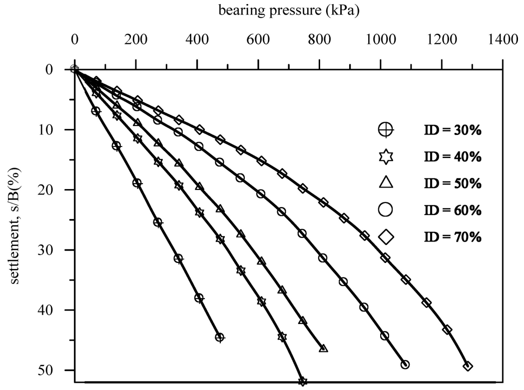


Figure 3. Pressure-settlement plots for geocell reinforced soil.

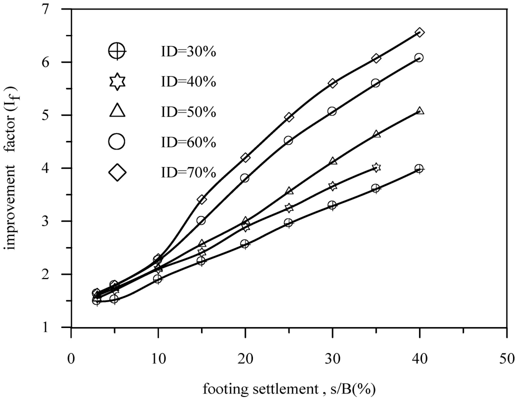


Figure 4. Improvement factor-settlement plots for different relative densities of soil.

The improvement due to the provision of geocell reinforcement is represented using a non-dimensional improvement factor (I_f) which is defined as the ratio of footing pressure (q) with geocell at a given settlement to the pressure on unreinforced soil (q_o) at the same settlement. If the footing has reached its ultimate capacity at a certain settlement, the bearing pressure q_o is assumed to remain constant at its ultimate value for higher settlements. The variation of improvement factors with footing settlement for different relative densities of soil are presented in Fig. 4.

From Fig. 4 it could be observed that the performance improvement due to the geocell reinforcement increases with increase in density of infill soil and footing settlement. The soil with higher relative density dilates more that induces higher frictional resistance at the geocell soil interface thereby increasing the

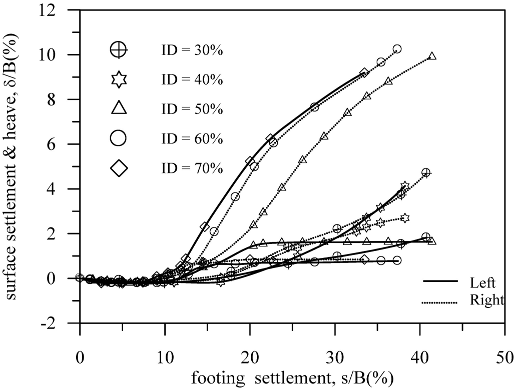


Figure 5. Surface deformation-footing settlement for unreinforced soil.

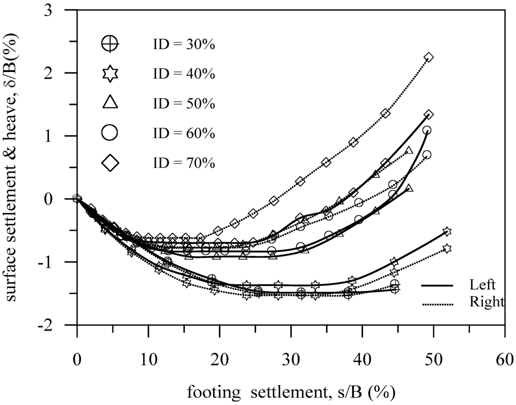


Figure 6. Surface deformation-footing settlement for geocell reinforced soil.

resistance to downward penetration of sand and hence a higher improvement in load carrying capacity. It is also believed that loose soil contracts under deformation therefore more strain is required before stress transfer to the geocell occurs. Whereas, soil with higher relative density dilates. This leads to a compact structure that mobilises higher strength in the geocell reinforcement. Therefore, the geocell reinforcement gives enhanced performance with higher relative density of fill soil.

In the case of soils with 30% and 40% relative density, the rate of increase of I_f at large settlements is the same as that at small settlements. On the other hand, the soils with higher relative density have exhibited higher rate of increase of I_f at higher settlements as compared to that at smaller settlements.

In Fig. 5 and Fig. 6, that depict the pattern of deformation on fill surface at left and right side of the footing, heave is shown through (+) sign and settlement through (−) sign. It could be observed that the unreinfiorced sand bed has undergone heaving equal to about 10% of footing width (Fig. 5), while with geocell reinforcement it is less than 2.5% (Fig. 6). Besides, the soils with higher relative density have undergone higher surface heaving, because of volumetric expansion. From Fig. 5 it can be observed that for dense soil (ID = 70% and 60%) heaving starts at a settlement equal to about 10% to 15% of footing width and it is at about 20% to 25% of footing width for loose soil (ID = 40 % and 30%). While in case with geocell reinforcement (Fig. 6) there occurs a zone where there is no surface deformation, indicated through a segment of horizontal line. In case of dense soil the no-surface-deformation zone starts at a footing settlement equal to about 10% to 15% of footing width. It may be the stage where the geocell by virtue of its confinement suppresses dilation in the soil, thereby, higher strength of geocell material is mobilised. This could be the reason for rapid increase in I_f values beyond settlement (s) of about 0.1B as compared to that at lower settlements (Fig. 4). However, in case of loose soil the improvement factor increases almost linearly with increase in footing settlement. This is because of non-dilative nature of the loose soil, which is reflected in the observation that in case of loose soil the surface deformation is completely in the settlement range (Fig. 6).

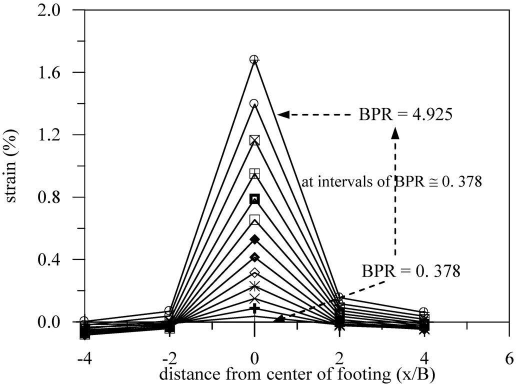


Figure 7. Strain in geocell wall for soil at 70% relative density.

Besides, the surface settlements are generally found to be lower for higher density of soil, which may be due to the increase in subgrade strength and end anchorage from soil that resists the downward deflection of the geocell mattress, giving rise to higher performance improvement. In the tests with loose soil fill, the two free ends of the geocell mattress were visible at the soil surface at large footing settlements. This result clearly shows that there was not enough anchorage at the two ends of the geocell mattress in the case of loose soil.

Fig. 7 and Fig. 8 depict the pattern of strain variation in geocell wall for dense soil (relative density 70%) and loose soil (relative density 30%) respectively.

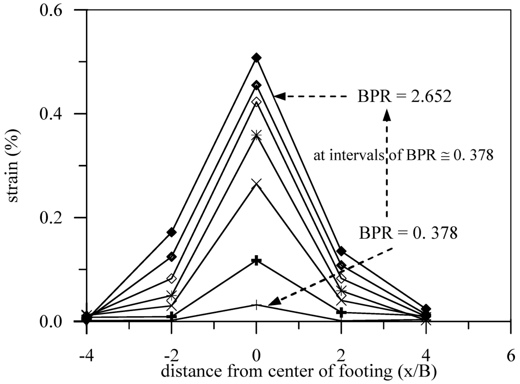


Figure 8. Strain in geocell wall for soil at 30% relative density.

The strain measurements are reported at various normalised footing load levels (BPR). The Bearing Pressure Ratio (BPR) is defined as the ratio between the footing pressure with geocell (q) and the ultimate footing pressure (q_{ult}) in tests on unreinforced soil. For uniformity in comparison of data from different tests, the q_{ult} is taken as the ultimate pressure on unreinforced soil at 70% relative density uniformly for all the tests. The compressive strains are shown with negative sign and the tensile strains with positive sign.

From Fig. 7 it could be observed that, in case of dense soil (ID = 70%) compressive strains are induced at (or near) two free ends of the geocell mattress. This compressive strain is found to be maximum at mid-height of the geocell. Due to dilation of soil in the regions of loading, there develops a volume expansion of sand, through aperture opening of geogrid walls. This expansion of soil is mostly in the transverse direction, in the vertical direction there is infinite zone of soil. This localised transverse expansion is restrained by the sand in the adjacent stable region. Such a restraint produces compression in the soil mass thereby giving rise to compression in the geocell wall. Fig. 8 shows that in the case of loose sand (ID = 30%), compressive strains have not developed anywhere in the mattress. This is because of the absence of dilation induced volume expansions in the loose soil. This observation once again reinforces the earlier conclusions regarding the infill soil dilation induced behaviour of geocell mattress.

The present observations in case with geocell reinforcement is in contrary to the findings of Fragaszy and Lawton (1984) in case of planar reinforcement that at 4% settlement (s = 0.04B) the values of BCR (which is same as I_f in the present study) for ID = 51%, 61%, 70%, 80%, 90% are 1.2, 1.2, 1.4, 1.5 and 1.5 respectively while at settlement close to failure (i.e. s = 10% of B) it is 1.6, 1.7, 1.7, 1.7 and 1.6 respectively. These results indicate that at relatively lower settlement range the performance improvement increases with increase in relative density of soil whereas at higher settlement range close to failure, the performance improvement is independent of soil density. In case of planar reinforcement system, the reinforcing effect is mostly due to interfacial frictional resistance mobilised through deformation and at settlement close to failure the soil shears away with the large strength of reinforcement remaining unmobilised. Whereas, the geocell system being an all-round confining system, restrains soil flow, thereby the encapsulated soil does not shear away. Hence, with increased density the dilation induced benefit is more at higher settlement.

4 CONCLUSIONS

From this study it could be said that the benefit due to geocell reinforcement in foundation soil increases with increase in dilation of soil. With geocell reinforcement offering three dimensional confinement the dilation induced benefit is substantially high compared to the case with planar reinforcement where the soil shears away easily. Therefore, for effective utilisation of geocell reinforcement, the infill soil should be compacted to higher density that it achieves higher dilation angle.

REFERENCES

Bathurst, R.J. and Jarrett, P.M. (1989) Large-scale tests of geo-composite mattresses over peat subgrades. *Transportation Research Record* 1188, pp. 28–36.

Bush, D.I., Jenner, C.G. and Basset, R.H. (1990) The design and construction of geocell foundation mattress supporting embankments over soft ground. *Geotextiles and Geomembranes*. Vol: 9, pp. 83–98.

Dash, S.K., Krishnaswamy, N.R. and Rajagopal, K. (2001) Bearing capacity of strip footings supported on geocell-reinforced sand. *Geotextiles and Geomembranes*, Vol:19, pp. 235–256.

Fragaszy, R.J. and Lawton, E. (1984) Bearing capacity of reinforced sand subgrades. *Journal of Geotechnical Engineering Division*, ASCE, Vol. 110, pp. 1500–1507.