

Bearing Capacity Improvement of Sand Bed Reinforced with 3D Geogrids of Rectangular Pattern



Femy M. Makkar, S. Chandrakaran and N. Sankar

Abstract In this paper, the effect of three-dimensional geogrid as a reinforcing material in enhancing the bearing capacity and settlement behaviour of reinforced soil is investigated. Laboratory-scaled plate load tests have been conducted to study the performance of square footing resting on the sand bed reinforced with 3D geogrids of rectangular pattern. The results show that a single layer of 3D geogrid placed at a depth of $0.25B$ from the bottom of footing provides a threefold increase in bearing capacity compared to unreinforced soil. The optimum spacing between two consecutive layers of 3D geogrids was obtained as $0.75B$. Soil reinforced with two layers of 3D geogrid gives higher bearing capacity improvement (6 times) and a further increase in the number of layers does not show any significant improvement in bearing capacity. The results obtained from this study shows that 3D geogrids can be used as an effective reinforcing material in improving the mechanical properties of reinforced soil structures such as embankments, retaining walls, shallow foundations, stabilization of steep slopes, etc.

Keywords 3D geogrids · Bearing capacity · Footing settlement · Plate load test · Shallow foundation

1 Introduction

The provision of geosynthetics for improving the bearing capacity and settlement characteristics of the soil are well documented (Ghosh and Bera 2005; Latha and Somwanshi 2009a; Vinod et al. 2009; Abu-Farsakh et al. 2013). Generally, conventional horizontal or planar reinforcements such as geotextiles and geogrids are used in many areas of geotechnical engineering. Recently, a few studies have been reported on the performance of reinforcements in three-dimensional forms (Zhang et al. 2006; Khedkar and Mandal 2009; Sireesh et al. 2009; Harikumar et al. 2016; Mozellanezhad et al. 2016). The beneficial effect of geosynthetic reinforcement

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largely depends on the form in which it is used (Latha and Somwanshi 2009b). In the case of geotextiles-reinforced soil beds, the friction between the soil and surface of reinforcement enhances the strength of reinforced soil. In geogrid-reinforced soil, the friction between soil and surface of geogrid ribs, and the interlocking of soil particles within the apertures of geogrid contributes to the improvement in strength. Whereas, the 3D reinforcement forms provide additional confinement along with the advantages of conventional forms.

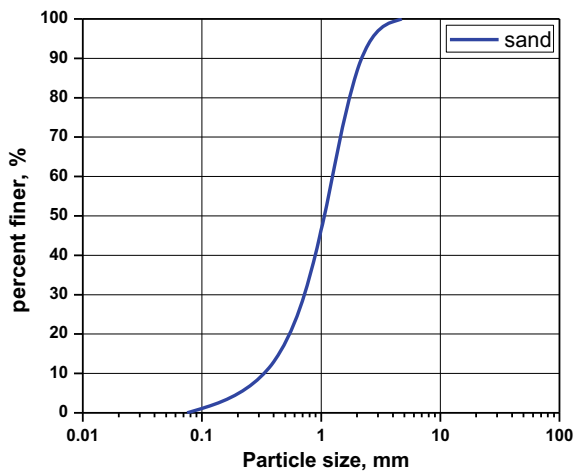
In this paper, geogrid in three-dimensional (3D) form is used to reinforce the soil. Laboratory-scaled plate load tests were conducted to study the performance of sand bed reinforced with 3D geogrids of the rectangular pattern. The results are expressed in terms of bearing capacity improvement and settlement reduction.

2 Materials

Locally available river sand with an effective particle size (D_{10}) of 0.33 mm was used as the sand bed. According to the unified soil classification system, the sand was classified as poorly graded sand (SP). The grain size distribution curve for sand is shown in Fig. 1. The sand bed was prepared under the medium dense condition with 50% relative density.

The reinforcement used in the study was three-dimensional geogrid. The 3D geogrid was made from conventional biaxial geogrid of 100 kN/m tensile strength. It was made by placing two conventional geogrid sheets of required size, one above the other. The bottom layer was placed horizontally and the top geogrid layer was folded in a rectangular pattern and it was tied to the bottom layer at every junction using nylon thread. Figure 2 shows the 3D geogrid used in the study.

Fig. 1 Grain size distribution curve for sand



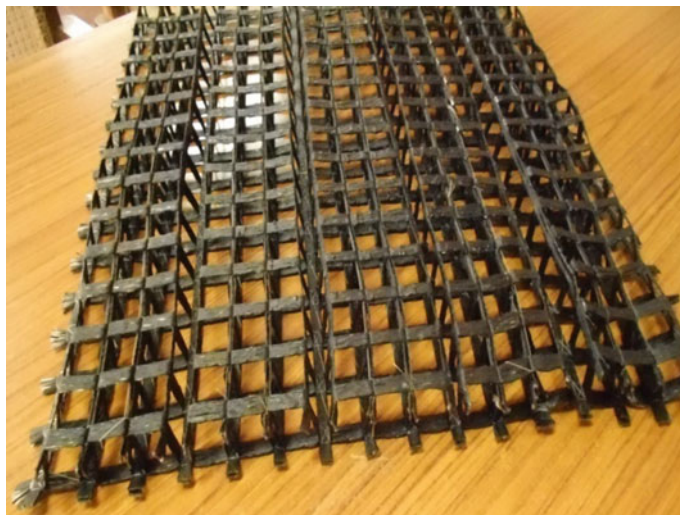


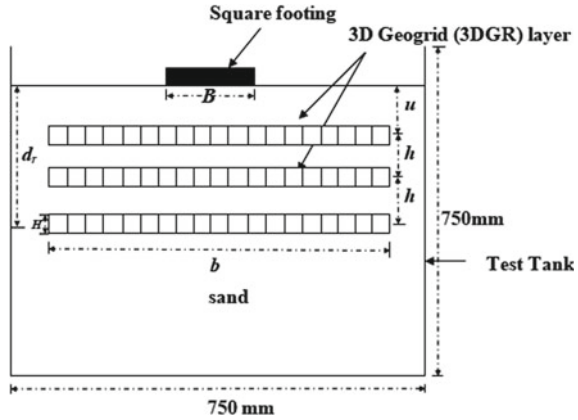
Fig. 2 3D geogrid of rectangular pattern (3DGR)

3 Experimental Setup

The plate load tests were conducted on a square steel tank of 750 mm side and 750 mm height. A square steel plate of 150 mm \times 150 mm size and 25 mm thickness was used as the model footing. The load was applied to the model footing with a manually operated hydraulic jack. The applied load was measured with a pressure gauge of 200 kg/cm² capacity. The settlement of footing was measured through dial gauges provided at two diagonally opposite points on the footing. In the case of the reinforced sand bed, the 3D geogrids were placed at predetermined locations with respect to its mid-height.

The typical layout of 3D geogrid-reinforced sand bed is shown in Fig. 3, where, B —width of footing, b —width of 3D geogrid, H —height of 3D geogrid, u —depth of first layer of reinforcement, h —spacing between two consecutive layers of 3D geogrid and d_r —depth of reinforcement. The study aims to find out the optimum depth of the first layer of reinforcement, spacing between two consecutive layers and optimum number of layers. In the present investigation, the width of reinforcement was $4B$ (600 mm) and height was 40 mm.

Fig. 3 Typical layout of 3D geogrid-reinforced sand bed



4 Results and Discussion

The improvement in bearing capacity and reduction in settlement due to the provision of 3D geogrid in sand bed was quantified in terms of non-dimensional parameters, improvement factor (I_f) and settlement reduction factor SR_f .

$$I_f = \frac{q_r}{q_u} \quad (1)$$

$$SR_f = \frac{(S_0 - S_r)}{S_0} \quad (2)$$

where q_r is the bearing pressure of reinforced sand at a given settlement and q_u is the bearing pressure of unreinforced sand at the same settlement. S_0 is the settlement of unreinforced sand bed at a given pressure and S_r is the settlement of reinforced sand bed at the same pressure. SR_f was calculated for a normalized settlement of 30% of the unreinforced sand bed.

4.1 Effect of Depth to First Layer of 3D Geogrid

Figure 4 shows the bearing pressure versus normalized settlement curve for unreinforced and 3D geogrid-reinforced sand bed for various depths of the first layer of reinforcement (u). It can be seen that the bearing pressure increases with the provision of 3D geogrid compared to unreinforced sand. When the 3D geogrid was placed at a depth of $0.25B$ from the base of the footing, the maximum improvement in bearing pressure was observed. The frictional resistance mobilized by the overburden pressure along with the confinement of soil particles within the cells of 3D

Fig. 4 Variation of settlement with bearing pressure for different u/B values

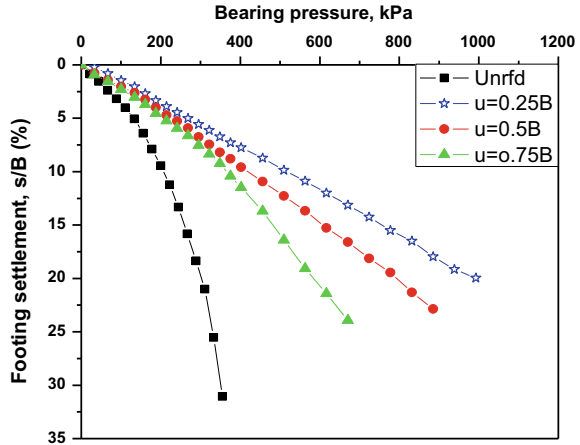
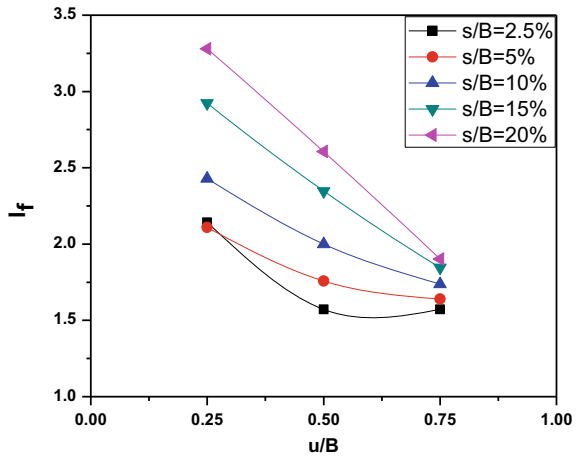


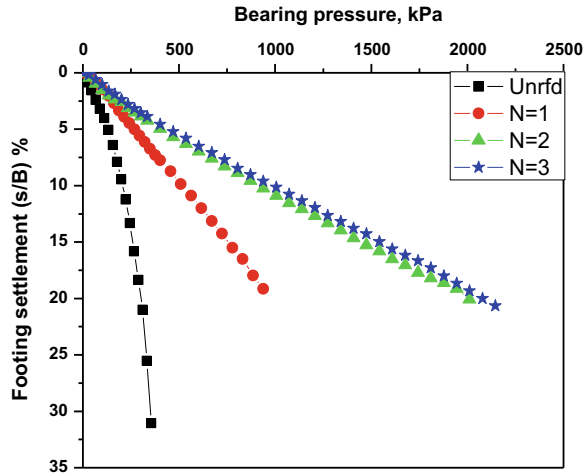
Fig. 5 Variation of improvement factor with u/B ratios for different normalized settlements



geogrid improves the performance of 3D geogrid-reinforced soil. 79% reduction in the settlement was observed with single-layer 3D geogrid-reinforced sand.

Figure 5 shows the variation of improvement factor (I_f) with u/B ratios for different normalized footing settlements. It can be seen that the bearing capacity improvement is maximum, when the 3D geogrid was placed at $0.25B$ at all levels of footing settlement. The ultimate bearing capacity of unreinforced and reinforced case was calculated corresponding to a settlement of 25 mm. About three times improvement in ultimate bearing capacity was observed with a single layer of 3D geogrid at an optimum depth of $0.25B$.

Fig. 6 Bearing pressure versus footing settlement curve for different number of layers



4.2 Effect of Spacing Between Two Layers

In order to study the effect of spacing between two consecutive layers, the first layer was placed at an optimum depth of $0.25B$ and second layer was placed at $0.5B$ and $0.75B$ spacing. At these spacing ratios, the improvement factor was 5.36 and 6, respectively. Therefore, the optimum spacing between two consecutive layers is taken as $0.75B$.

4.3 Effect of Number of Layers

Figure 6 shows the bearing pressure versus footing settlement curve for different number of layers. The maximum improvement in bearing pressure (6.4 times) was observed with three layers of 3D geogrids. When the number of 3D geogrid layers increases from 1 to 2, the bearing capacity improvement was 97%, and from 2 to 3, the improvement was only 6%.

Further increase in the number of layers will not show any significant improvement, since the maximum depth of influence of vertical load is governed by the depth of the pressure bulb, which is equal to $2B$. Also, second and third layers of 3D geogrid give 87% settlement reduction. Considering the percentage improvement in bearing capacity and settlement reduction, the optimum number of 3D geogrid layers was taken as two. Figure 7 shows the variation of improvement factor with the number of layers. Table 1 shows the settlement reduction factors for various parameters.

Fig. 7 Variation of improvement factor with number of layers

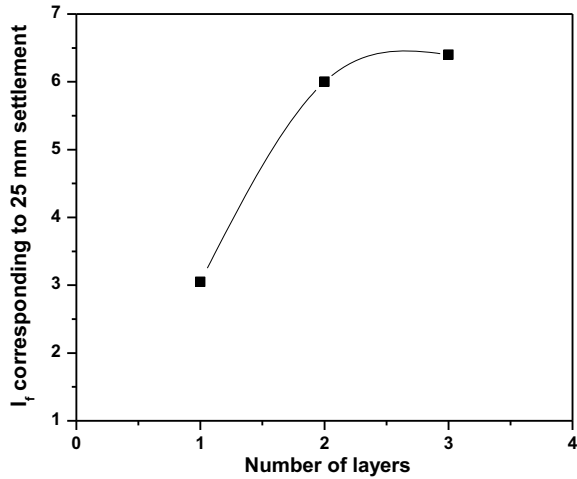


Table 1 Settlement reduction factor for various parameters

Parameters		SR_f
u/B	0.25	0.79
	0.5	0.73
	0.75	0.72
h/B	0.5	0.86
	0.75	0.87
N	1	0.79
	2	0.87
	3	0.87

5 Conclusions

In this study, a series of plate load tests were conducted to understand the bearing capacity and settlement characteristics of a model square footing resting on 3D geogrid-reinforced sand bed. The major conclusions from the study are the following:

- 3D geogrid-reinforced sand bed performs far better than an unreinforced sand bed in improving the bearing capacity and reducing the settlement.
- The optimum depth of the first layer of reinforcement was obtained as $0.25B$ from the base of the footing, where B is the width of footing.
- A single layer of 3D geogrid at the optimum depth improves the bearing capacity by three times and the settlement of footing was reduced by 79% compared to unreinforced sand.
- The optimum spacing between two consecutive layers was $0.75B$.

- The optimum number of 3D geogrid layers was taken as 2 with an improvement factor of 6, and a further increase in the number of layers does not show any significant improvement.
- The settlement of the footing was reduced by 87% by the provision of two layers of 3D geogrid.

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