Settlement and Surface Heave characteristics of Geogrid Reinforced Cohesionless Soil

Femy M Makkar1
Chandarakaran S2
Sankar N3
1Research Scholar, 2, 3 Professors, Department of Civil Engineering, National Institute of Technology, Calicut-673601
Femy.makkar@gmail.com
Chandra@nitr.ac.in
sankar@nitr.ac.in

ABSTRACT: Reinforced soil has become one of the viable techniques in the field of geotechnical engineering for improving the performance of embankments, pavements, retaining structures and shallow foundations, etc. In most of the currently reinforced soil structures, geotextiles and geogrids are used as the reinforcing elements. In the present investigation, a laboratory scaled plate load test was conducted to study the bearing capacity and surface deformation characteristics of geogrid reinforced sand under shallow foundation. The test was performed on a steel tank of 750 mm x 750 mm x 750 mm size. The size of the model footing was 150 mm x 150 mm x 25 mm. The cohesionless soil used was locally available clean river sand at medium dense condition. Biaxial geogrid with a tensile strength of 100 kN/m was used as the reinforcement. The effect of depth of placement of the first layer of reinforcement, spacing between layers and number of layers were studied and the results are analyzed in terms of non-dimensional parameters Bearing Capacity Ratio (BCR), Settlement Reduction Factor (SRF) and Heave Reduction Factor (HRF). The optimum depth of the first layer of reinforcement and spacing between layers was obtained as 0.25 times the width of model footing. 85% increase in BCR value is observed with the inclusion of geogrid reinforcement. When the number of layers increases from 1 to 4, a substantial increase in BCR value (3.7 times) compared to unreinforced sand was observed. The inclusion of geogrid reduces the settlement by 82%, while the surface heave was reduced by 95% indicating the beneficial effect of soil reinforcement.

KEYWORDS: bearing capacity, geogrid reinforced sand, settlement, surface heave

1 INTRODUCTION

With the development of geosynthetics from strong and durable polymers, Reinforced Soil has become one of the viable and cost effective techniques for improving the bearing capacity and reducing the settlement of shallow foundation. Many experimental and analytical studies have been reported regarding the behavior of geosynthetic reinforced soil foundation in cohesive and cohesionless soil (Mandal and Shah, 1992; Kthing et al.,1993; Omar et al.,1993; Das and Omar,1994; Yetimoglu et al., 1994; Adams and Collin,1997; Dash et al., 2001; Boushehrian and Hataf, 2003;Ghosch et al., 2005; Latha et al., 2009; Sharma at al.,2009;Vinod et al.,2009; Tafreshi et al.,2010; Abufarsakh et al., 2013). Most of these studies mainly focused on the improvement in bearing capacity and settlement reduction by the provision of geosynthetic reinforcements, where as less attention is given to the surface heave characteristics of reinforced soil. Surface heave phenomena are also important because the settlement of footing causes the upheaval of surrounding soil, which may cause damage to the adjacent structures. So the present investigation is focused on the bearing capacity, settlement and surface heave behavior of a square model footing resting on geogrid reinforced cohesionless soil bed.

2 MATERIALS USED FOR THE STUDY

2.1 Cohesionless soil

The cohesionless soil used in the study was locally available river sand. The basic properties of sand are given in Table 1. The angle of internal friction of sand was measured by conducting direct shear test. The relative density of sand is taken as 50% corresponding to medium dense sand condition and the test was performed under normal stresses of 100 kPa, 200 kPa and 300 kPa. The dialatancy angle is measured as 10.4°. Fig.1 shows the particle size distribution of sand used in the study. According to USCS (Unified Soil Classification System), it is classified as Poorly Graded Sand (SP).

2.2 Reinforcing Material

The reinforcing material used in the investigation was strong biaxial geogrid with a tensile strength of 100kN/m in machine and cross-machine direction. The aperture size of the grid was 30 mm x 30 mm and the corresponding percent open area was 42.4%. The
width of the longitudinal rib was 10mm, and that of the transverse rib was 12mm

Table 1. Basic Properties of Sand

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Specific Gravity</td>
<td>2.67</td>
</tr>
<tr>
<td>2.</td>
<td>(D_{10}) (mm)</td>
<td>0.33</td>
</tr>
<tr>
<td>3.</td>
<td>(D_{85}) (mm)</td>
<td>0.7</td>
</tr>
<tr>
<td>4.</td>
<td>(D_{60}) (mm)</td>
<td>1.4</td>
</tr>
<tr>
<td>5.</td>
<td>Uniformity coefficient, (C_u)</td>
<td>4.24</td>
</tr>
<tr>
<td>6.</td>
<td>Coefficient of curvature, (C_c)</td>
<td>1.06</td>
</tr>
<tr>
<td>7.</td>
<td>Maximum dry density, (\rho_{max}) (g/cc)</td>
<td>1.66</td>
</tr>
<tr>
<td>8.</td>
<td>Minimum dry density, (\rho_{min}) (g/cc)</td>
<td>1.40</td>
</tr>
<tr>
<td>9.</td>
<td>Dry density corresponding to 50% Dr</td>
<td>1.52</td>
</tr>
<tr>
<td>10.</td>
<td>Angle of internal friction</td>
<td>40.4</td>
</tr>
<tr>
<td>11.</td>
<td>IS Classification</td>
<td>SP</td>
</tr>
</tbody>
</table>

3 EXPERIMENTAL SETUP

The plate load test was conducted on a steel tank of 750 mm x 750 mm x 750 mm size. 25mm thick square steel plate of 150 mm x 150 mm size was used as the model footing. According to IS: 1988, the width of the test tank should be five times the width of the model footing to minimize the boundary effect. In this study, the width and the depth of the test tank is equal to five times the width of model footing, so that the boundary effects on the test results are considered to be small. The base of the footing was scratched and punched to make it rough. 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 and the surface heave was measured using dial gauges fixed at the left and right side of footing at a distance of 1.5 B (where B, is the width of model footing) from the centre of footing. The sand bed in test tank was prepared under medium dense condition. The relative density of sand was fixed as 50%. The sand was poured into the tank in layers of 50mm thickness. Each layer was compacted to attain the desired density. In the case of reinforced sand, the geogrids were placed at the predetermined locations in the sand bed. Fig. 2 shows the typical layout of multi-layered geogrid reinforced sand bed adopted in the study.

The reinforcement parameters considered in this study are listed in Table 2. The width of reinforcement (b) in all the tests was fixed as 4B, where B is the width of footing.

Table 2. Details of Testing Program

<table>
<thead>
<tr>
<th>Test Series</th>
<th>Constant parameters</th>
<th>Variable Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series A</td>
<td>b/B = 4, N=1</td>
<td>u/B = 0.1, 0.25, 0.5, 0.75</td>
</tr>
<tr>
<td>Series B</td>
<td>b/B = 4, u/B=0.25,  N=2</td>
<td>h/B = 0.1, 0.25, 0.5, 0.75</td>
</tr>
<tr>
<td>Series C</td>
<td>b/B = 4,</td>
<td>u/B=h/B=0.25,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N = 2,3,4</td>
</tr>
</tbody>
</table>

4 RESULTS AND DISCUSSIONS

The improvement in the performance of reinforced soil was quantified in terms of the non dimensional parameter, Bearing Capacity Ratio (BCR) which is defined as:

\[
BCR = \frac{q_{0(i)}}{q_0}
\]  

(1)

Where, \(q_{0(i)}\) is the bearing pressure of reinforced soil at a given settlement and \(q_0\) is the bearing pressure of unreinforced soil at the same settlement. According to IS 1888-1982, the plate load test shall continued till a settlement of 25mm under normal circumstances or 50mm in special cases such as dense gravel or gravel – sand mixture or till failer occurs , whichever is earlier. In the case of multilayered geogrid reinforced soil it was difficult to obtain a clear failure point. So, in the present study, the BCR value was calculated for a settlement 25mm. The reduction in footing settlement and surface deformation was quantified through parameters, settlement reduction factor (SRF) and heave reduction factor (HRF), which is defined as:

\[
SRF = \frac{(s_0-s_i)}{s_0}
\]  

(2)

\[
HRF = \frac{(h_0-h_i)}{h_0}
\]  

(3)
Where, \(s_0/h_0\) is the settlement or heave of unreinforced sand bed at a given pressure, and \(s/h\) is the settlement or heave of reinforced sand bed at the same pressure. SRF and HRF were calculated for bearing pressure corresponding to a normalized settlement of 30% of the unreinforced sand bed (Vinod et al., 2009).

### 4.1 Effect of Depth of First Layer of Geogrid

From the pressure-settlement curve shown in Fig.3, it is clear that the optimum value of \(u/B\) is 0.25, at which maximum benefit of geogrid reinforcement was obtained. Fig.4 shows the variation of BCR with different \(u/B\) ratios. The BCR value increases up to 0.25B for all levels of normalized settlement and thereafter it decreases. The reason is that, in order to develop the maximum frictional resistance at the interface of geogrid and sand, sufficient overburden pressure is required which was attained at 0.25B. (Ghosh 2005, Vinod et al. 2009). Further increase in depth of first layer of reinforcement, the increase in overburden pressure does not result in any increase in BCR, whereas the greater thickness of sand above reinforcement layer results in increased settlement (Vinod et al. 2009). The BCR value increased 1.85 times when the reinforcement was placed at 0.25B from the bottom of the footing. The result obtained was in good agreement with the results reported in literature. Mandal and Shah (1992) reported that the improvement factors improve significantly in the range of 0-0.25B from the base of square foundation. Yetimoglu (1994) reported that the optimum embedment depth for single layer reinforcement was 0.3B and that for multilayer was 0.25B. Adams et al. (1997) also reported that the maximum improvement in bearing capacity at low strains occurs when \(u/B\) is equal to 0.25.

![Fig.3 Pressure- Settlement Curve for Different u/B Ratios](image1)

Fig. 3 shows the pressure-heave curve for various \(u/B\) ratios. A settlement reduction factor of 0.64 and heave reduction factor of 0.6 was observed when geogrid was placed at a depth of 0.25B from the bottom of the footing compared to non reinforced sand bed.

![Fig.4. Variation of BCR with u/B Ratios](image2)

The BCR value increases up to 0.25B for all levels of normalized settlement and thereafter it decreases. The reason is that, in order to develop the maximum frictional resistance at the interface of geogrid and sand, sufficient overburden pressure is required which was attained at 0.25B. (Ghosh 2005, Vinod et al. 2009).

![Fig.5 Pressure- Heave Curve for Different u/B Ratios](image3)

### 4.2 Effect of Spacing Curve between Layers

To study the effect of spacing between two consecutive layers, the \(h/B\) ratio was varied from 0.1 to 0.75B. From Fig.6, it can be seen that BCR is maximum when \(h/B\) is 0.25. As seen in the case of \(u/B\) ratio, sufficient over burden pressure is required in between two consecutive layers to mobilize the maximum interfacial frictional resistance, which is attained at a spacing of 0.25B. Yetimoglu et al. (1994) reported that the optimum spacing for reinforced sand is in between 0.2-0.4B.

![Fig.6. Variation of BCR with h/B Ratios](image4)

SRF value of 0.72 was observed with two layers of reinforcement at optimum spacing. Also the heave reduction factor, HRF is maximum (0.81), when the spacing between two layers was of 0.25B.
4.3 Effect of Number of Layers

To study the effect of number of layers, the depth of first layer and spacing between layers kept constant as 0.25B. Table 3 shows the variation of BCR, SRF and HRF with increase in number if layers. It can be seen that BCR increases significantly with increase in number of layers up to N=4. Several researchers have observed that increasing no. of layers beyond a certain level does not increase the BCR significantly. Yetimoglu et al. (1994) reported that optimum performance of geogrid reinforcement was observed when first layer was provided at 0.25B, with total number of layers as four at an optimum spacing of 0.2B.

When number of layers increases to 4, 82% reduction in Settlement and 95% reduction in heave was observed compared to unreinforced soil.

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>No.of layers</th>
<th>BCR</th>
<th>SRF</th>
<th>HRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N=1</td>
<td>1.85</td>
<td>0.64</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>N=2</td>
<td>2.51</td>
<td>0.72</td>
<td>0.81</td>
</tr>
<tr>
<td>3</td>
<td>N=3</td>
<td>3.23</td>
<td>0.8</td>
<td>0.93</td>
</tr>
<tr>
<td>4</td>
<td>N=4</td>
<td>3.7</td>
<td>0.82</td>
<td>0.95</td>
</tr>
</tbody>
</table>

5 CONCLUSION

- The maximum benefit of geogrid reinforcement was obtained when the first layer of reinforcement was placed at a distance of 0.25B (1.85 times increase in BCR) from the bottom of footing.
- The optimum spacing between two consecutive layers was obtained as 0.25 times width of the footing.
- The present study suggests that the optimum number of reinforcement layers in order to get maximum improvement is four. When 4 layers of reinforcement was provided, 3.7 times increase in BCR compared to unreinforced sand was observed.
- Settlement and heave was considerably reduced by the provision of geogrid reinforcement. 82% reduction in settlement and 95% reduction in heave were observed with the inclusion of four layers of reinforcement.

6 REFERENCES

7. IS:1888 (1982), Method of load test on Soils, Bureau of Indian Standards, New Delhi, India