A Study on the Performance of Surface Footings on 3D Geogrid Reinforced Sand Beds

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***Abstract*: This research was carried out to study the performance of surface footing resting on 2D (Geogrid) and 3D (Geogrid-PVC pipe) reinforced sand bed of 20% relative density under static load. The parameters investigated in this study include number of reinforcement layers and vertical spacing of the reinforcement layer and also the performance of reinforced sand bed was studied by considering Bearing Capacity Ratio (BCR) and Settlement Ratio (SR) values. The result obtained was compared with the unreinforced, 2D and 3D reinforced sand bed. The result shows that the vertical spacing between the reinforcement was found to be 0.3 times the width of the footing. The BCR increases and SR value decreases with increase the number of reinforcement layer. Footing resting on 3D reinforcement performs better than the unreinforced and 2D (Geogrid) reinforced sand bed.**

Keywords*: *Reinforced sand bed, Geogrid-PVC pipe, relative density, Bearing Capacity Ratio and Settlement Ratio.

I. INTRODUCTION

Soils are the most common construction materials encountered almost in all civil engineering projects. Soil is strong in compression but week in shear and tension. In order to increase the shear strength and the overall bearing capacity of the soil, stabilization of the soil is necessary. Now a day reinforced soil techniques are widely used in order to stabilize the soil.

The concept of soil reinforcement was used since ancient times. One of the oldest methods of soil reinforcement is the inclusion of natural reinforcement material such as wood, bamboo and tree trunks. In 1960's Henry Vidal a French architect and engineer introduced the modern concept of soil reinforcement. In recent year major part of land that are available for construction of structure is found to have poor bearing capacity which needs to be improved, one of the methods that has recently gained more recognitions is soil reinforcement due to its cost effectiveness, ease of construction and it is less time consuming. The term Reinforced soil refers to soil that has been strengthened by placement of reinforcing material within the soil mass in the form of strips, bars, sheets or grids. When the load is applied to the soil mass this reinforcement materials resist the tensile stresses which is developed within the soil mass through friction, adhesion or bearing resistances. Now a day's wide varieties of geosynthetic materials are available in the market that is geotextile, geogrid, geonet, geo-composite and geocell. Today geogrids are used widely in the geotechnical field due to its cost effectiveness and ease of availability in markets. In geogrid reinforced soil, the strength is attained by the interaction between soil and the surface of geogrid ribs and interlocking between soil particles within the open of geogrid. Several laboratory tests are conducted using this geosynthetic reinforcement material to improve the stiffness and stability of the structure under static loading, which is published in the literatures Sujith Kumar Dash et al., (2001)[10], T. G. Sitharam et al.,(2005)[11], Mostafa A. El Sawwaf. (2006)[8], Arvind Kumar et al., (2006)[1], G. Madhavi Latha et al.,(2009)[5], Murad Abu-Farsakh et al.,(2013)[7], ElifCicek et al.,(2015)[2], S. Davarifard et al., (2015)[9], Femy M. Makkar et al.,(2017)[4], Emmanuel Baah-Frempong et al., (2019)[3], J. S. Dhanya et al., (2019)[6]. In the present investigation soil reinforcement system is formed from the combination of geogrid and PVC pipes. Geogrid act like reinforcement and supporting the PVC pipe to stand in proper vertical direction. In this system geogrid sheet reinforce the sand by increasing the shear resistance due to development of tensile strength and PVC pipe prevent the lateral movement of sand. Objectives of the present study is, to study and compare the performance of square footing on 2D(Geogrid) and 3D(Geogrid +2cm PVC pipe) reinforced sand beds.

II. MATERIALS AND METHODS

2.1 Materials

Poorly graded sand, biaxial geogrids and PVC pipes are used in the study. Properties of sand and Geogrid are shown in Table 1 and Table 2 respectively.

Table 1: Property of sand

Property	Test Result
Grain Size Distribution:	-
Clay and Silt size (%)	0.2
Sand Size (%)	99.8
Gravel Size (%)	0
Coefficient of Uniformity, Cu	3.03
Coefficient of Curvature, Cc	1.65
Maximum dry density (kN/m³)	17.98
Minimum dry density (kN/m³)	14.17
Maximum Void ratio	0.85
Minimum Void ratio	0.46
Frictional angle (degrees)	34
Specific gravity, G	2.68

Table 2: Properties of Geogrid

Properties	Value
Thickness : Joint (mm) Rib (mm)	5 2.4
Structure	Bi axial, mesh type, Hexagonal aperture
Aperture size @ junction (mm)	26
Tensile Strength (kN/m)	7.74

The dimensions of PVC pipe, footing and steel tank are,

1. PVC pipe :
   Diameter = 20 mm
   Length = 20 mm
2. Mild steel footing :
   Size of square footing = 100mm ×100mm
   Thickness= 4mm
3. Mild steel tank:
   Diameter = 500mm
   Height = 390mm

2.2 Methods

2.2.1 Preparation of Test Sample

In unreinforced condition, sand was filled in to the tank up to a height of 360mm at a relative density of 20% in 6 equal layers of each 60mm thick. For reinforced condition, the geogrid reinforcement or geogrid pipe reinforcement are placed at predetermined intervals between the sand layers. Sand layers are compacted at a relative density of 20%. Reinforcements are provided in the form of circular disc with a clearance of 5mm to avoid the friction between reinforcement and the walls of the tank.

2.2.2 Procedure for Testing

After preparing the test bed, the top surface was leveled, and the footing was placed exactly at the center of the tank. The load is applied in vertical direction using static loading machine. The magnitudes of the applied loads were recorded using proving ring of 50kN capacity. Whereas the settlements values were measured through three different dial gaugse's placed orthogonal to each other.

2.2.3 Geogid – PVC Pipe System

Soil reinforcement system is formed from the combination of geogrid and PVC pipes, the length of 20mm PVC pipe was considered for the study. A layer of geogrid-PVC pipe as shown in Fig 1. Geogrid acting like reinforcement and supports the PVC pipes to stand in a proper vertical direction. In this system Geogrid sheet reinforce the sand by increasing the shearing resistance due to the development of tensile strength and PVC pipe prevents the lateral movement of the soil.

Fig 1: Layer of Geogrid-PVC Pipe

III. RESULTS AND DISCUSSIONS

In order to study the performance of square footing resting on 2D (Geogrid) and 3D (Geogrid-PVC Pipe) reinforced sand bed at a relative density of 20% under static loading, the factors taken into consideration for the experiments are (i) Depth of first layer of reinforcement(U) (ii) Spacing of the reinforcement layer i.e., S=0.3B, 0.4B and 0.5B, where B is breadth of footing. (iii)Number of reinforcement layers (N=0, 2 and 3). Tests are conducted for different U/B ratios in both 2D and 3D reinforced condition. The depth of first layer of reinforcement from the footing level is found to be effective at 0.3times the width of the footing i.e., U=0.3B for both 2D and 3D reinforced condition.

3.1 Performance of square footing on 2D reinforced sand bed

3.1.1 Effect of spacing of reinforcement layer(s) and number of reinforcement layer

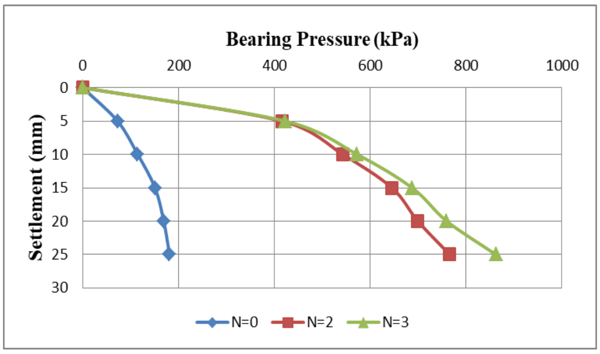

Fig 2: Effect of 2D geogrid on load settlement characteristic of square footing resting on reinforced sand bed at U=0.3B, S=0.3B

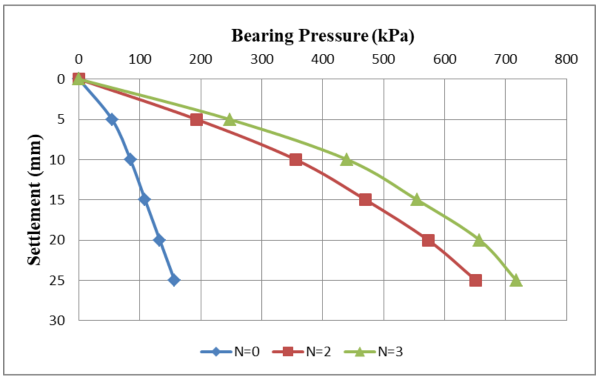

Fig 3: Effect of 2D geogrid on load settlement characteristic of square footing resting on reinforced sand bed at U=0.3B, S=0.4B

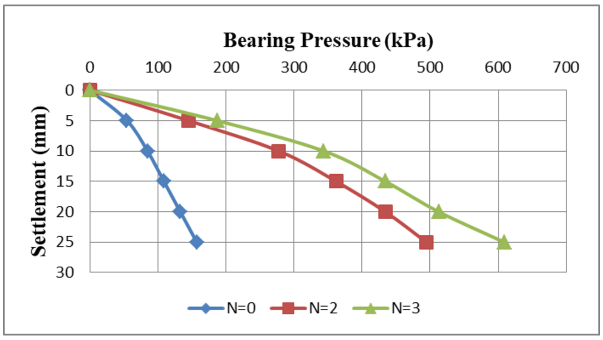

Fig 4: Effect of 2D geogrid on load settlement characteristic of square footing resting on reinforced sand bed at U=0.3B, S=0.5B

Fig 2 Fig 3 and Fig 4 shows the effect of number of reinforcement layers on the performance of square footings resting on unreinforced and geogrid reinforced sand bed (N=0, 2 and 3) with a vertical reinforcement spacing S=0.3B, 0.4B and 0.5B respectively. It can be seen from these figures that the footings resting on the three layer geogrid reinforced sand beds carries more bearing pressure compared to two layered and unreinforced condition. It is observed from the fig that for a bearing pressure of 157kPa, the footing on unreinforced sand bed exhibits a settlement of 25mm whereas footing resting 2 and 3 layer geogrid reinforced sand with a spacing 0.3B, 0.4B and 0.5B exhibits the settlement of 3, 4 & 5, 2.5 & 3.5, 3.5 mm respectively. This confirms the trend that with increase in the reinforcement layer in the sand bed, settlement of the footing decreases. Further the bearing pressure withstand by footing on unreinforced sand bed is only 157kPa for achieving the 25mm settlement whereas the footing on sand beds with reinforcement layers 2 and 3 takes 712kPa and 820kPa for S=0.3B, 651kPa and 718kPa for S=0.4B and 494 and 609 for S=0.5B respectively. This also shows the effectiveness of the inclusion of geogrid reinforcement in the performance of square footing on sand bed. With increase in number of layers of geogrid the contact area and the interlocking between geogrid and soil increases. From this it can be conclude that optimum of number of reinforcement layer is 3 and vertical spacing between the layers is 0.3 times

3.2 Performance of square footing on 3D reinforced sand bed

3.2.1 Effect of spacing of reinforcement layer(s) and number of reinforcement layer

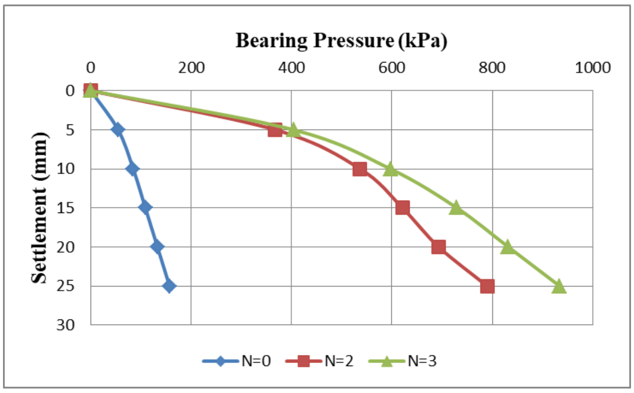

Fig 7: Effect of 3D geogrid on load settlement characteristic of square footing resting on reinforced sand bed at U=0.3B, S=0.3B

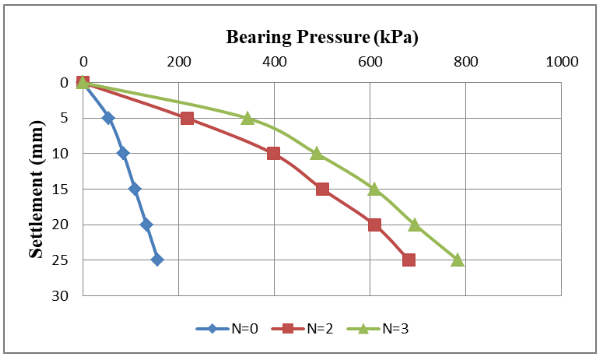

Fig 8: Effect of 3D geogrid on load settlement characteristic of square footing resting on reinforced sand bed at U=0.3B, S=0.4B

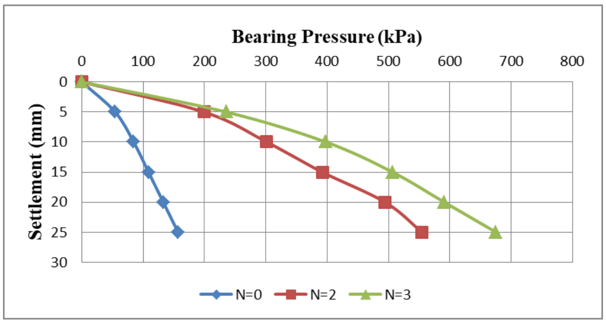

Fig 9: Effect of 3D geogrid on load settlement characteristic of square footing resting on reinforced sand bed at U=0.3B, S=0.5B

Fig 7 Fig 8 and Fig 9 shows the effect of number of 3D geogrid reinforcement layers on the performance of square footing on reinforced sand beds (2 and 3 layers) with spacing of S=0.3B,0.4B and 0.5B. It can be seen from the figure that the footing resting on reinforced sand bed experience less settlement compared to their unreinforced counterpart. The footing resting on three layer 3D geogrid reinforced sand bed resisted 1.14 and 5.96 times more bearing pressure compared to its 2D geogrid and unreinforced sand bed at a settlement level of 25mm at S=0.3B. But the increase in vertical spacing decreases the load carrying capacity. It is observed from the figure 7 that, at a bearing pressure of 157kPa, footing on the unreinforced sand bed experienced a settlement of 25mm whereas footing on grid-pipe reinforced sand beds with two and three layers experiences settlement of 2.6&2.4mm respectively. This confirms the trend that with the increase in number of grid-pipe reinforcement layers in the sand bed, the settlement of the footing decreases. From the Fig.7 it can also be seen that footing resting on three layered 3D geogrid reinforced sand bed carried a bearing pressure of 935kPa at a settlement level of 25mm. Whereas the footing resting on 2layered 3D geogrid reinforced sand bed carried a bearing pressure of 820kPa. Thus the footing on 3layered 3D reinforced sand bed showed on improvement of about 1.18times compared to the counterpart resting on 2layered 3D reinforced sand bed. From this it can be prove the fact that the optimum number of reinforcement layer for maximum efficiency is 3 for all the studied condition with a vertical spacing of 0.3B.

3.3 Comparisons of performaance of square footing between 2D and 3D reinforced sand bed

3.3.1 Effect of spacing of reinforcement layer(s) and number of reinforcement layer

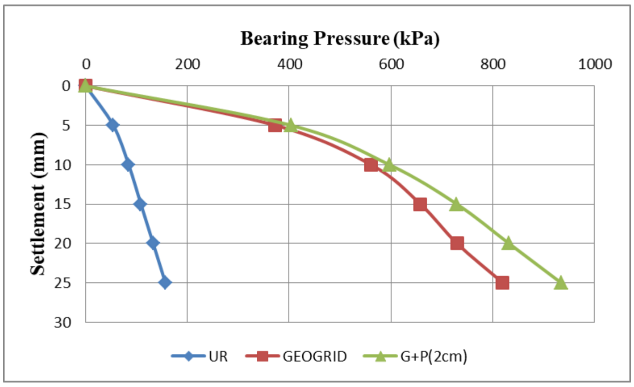

Fig.10. Load settlement curve for 2D and 3D reinforced sand bed at U=0.3B and S=0.3B N=3

Fig 10 shows the load settlement curve for 2D and 3D reinforced sand bed at the optimum reinforcement configuration i.e, U=0.3B, S=0.3B & N=3. It is observed from the figure 10 that, the 3D geogrid reinforcement carried a bearing pressure of 935kPa at 25mm settlement. Whereas for the same settlement value the 2D and unreinforced sand bed carry the bearing pressure of 820kPa and 157kPa respectively. The 3D reinforced sand bed carried bearing pressure of 1.14 & 5.96 times more than the 2D and unreinforced sand bed.

3.3.2 Bearing Capacity Ratio

$$BCR = \frac{\text{Bearing pressure of a reinforced soil at a given settlement}}{\text{Bearing pressure of unreinforced soil at the same settlement}}$$

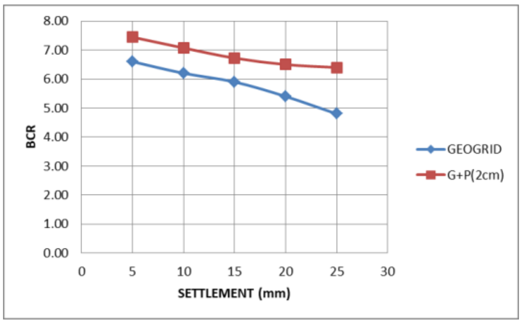

Fig.11. Variation of BCR with settlement value for 2D and 3D reinforced sand bed at u=0.3B, N=3 & S=0.3B

Fig.11. Variation of BCR with settlement value of 3layers of 2D and 3D reinforced sand bed at vertical spacing S=0.3B. The footing on 3D reinforced sand bed exhibits higher value of bearing capacity ratio compared with 2D reinforced sand bed. However, the bearing capacity ratio of 3layers of 3D reinforced sand bed at S=0.3B is observed to be 1.33 times higher than the bearing capacity ratio of 3layered 2D geogrid reinforced sand bed at settlement value of 25mm. The 3D reinforcement performs better due to the additional confinement to the soil in both the direction. That is the geogrid provides on horizontal confinement whereas pipe provides on lateral confinement. Hence it can be concluded that the provision of 3D (geogrid-pipe) reinforced sand bed performed better than 2D reinforced sand bed. Also 3D reinforcement is very effective in reducing the settlement of surface footing and in increasing the bearing capacity ratio.

3.3.3 Settlement Ratio

$$SR = \frac{\text{Settlement of reinforced sand bed at a given pressure}}{\text{Settlement of unreinforced sand bed at same pressure}}$$

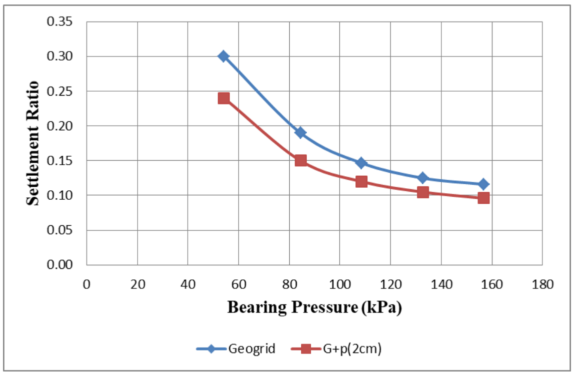

Fig.12. Variation of settlement ratio with bearing pressure for 2D and 3D reinforced sand bed at u=0.3B, N=3 & S=0.3B

Fig 12 shows variation of settlement ratio with bearing pressure for the square footing resting on 3layers of 2D and 3D reinforced sand bed with a vertical spacing of S=0.3B. It can be seen form the Fig.12 that the settlement ratio of 3layes of 3D geogrid reinforced sand bed at S=0.3B is observed to be 0.83 times lower than the settlement ratio of 3layered 2D geogrid reinforced sand bed. Hence it can be concluded that the provision of 3D geogrid (geogrid-pipe) reinforced sand bed performed better than 2D geogrid and unreinforced sand bed. This observation clearly indicates that the provision of 3D geogrid system is very effective in reducing the settlement of surface footing and resisting the applied loads.

IV. CONCLUSIONS

1. In general, the reinforced sand beds perform better than the unreinforced sand beds regard less of the number of reinforcement layers and spacing of the reinforcement under static load.
2. In the present experimental investigation, the following reinforcement configuration provided the best result.
   - ✓ For 2D reinforced sand bed: N=3 and S/B=0.3
   - ✓ For 3D reinforced sand bed: N=3 and S/B=0.3
3. The three layers of reinforcement shows better increase in BCR value and decrease in SR value both in 2D and 3D reinforced sand bed.
4. Performance of footing on 3D (geogrid-PVC pipe) system is better than the footing on 2D (plain geogrid) reinforced sand bed. This exhibits better improvement in increasing the resistance against loading and also reduces the settlement of the footing

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