IMPROVING LOAD-CARRYING CAPACITY OF GRANULAR PILES WITH HORIZONTAL GEOGRID REINFORCEMENT

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Abstract: Granular piles are an effective technique for improving the engineering behaviour of soft clays and loose sand deposits. The response of the composite ground (granular pile and soil) is assessed in terms of its load-carrying capacity and settlement. Reinforcing granular piles with geogrids increases load-carrying capacity. Improvement in load-carrying capacity depends upon the number of reinforcement layers, the spacing between them and the angle of shearing resistance of the granular medium. This paper presents the results of experiments conducted to investigate the effect of geogrid reinforcement on load-carrying capacity of granular piles in soft clay bed. Plate load tests were performed on granular piles (alone) in soft clay bed and on composite ground (both granular pile and clay bed together). The effect of the number of geogrid layers and the spacing between them on the load-carrying capacity of granular piles was investigated. The soil used in this study was clayey silt. Granular piles were formed using crushed stone aggregate with particle size varying from 4.75 mm to 2.36 mm, having a coefficient of uniformity (Cu) of 1.52 and a coefficient of curvature (Cc) of 0.96. This paper discusses the test results. The study revealed increases in the load-carrying capacity of geogrid-reinforced piles. The engineering behaviour improved with increasing number of geogrids and decreasing spacing between them.

Keywords: clay, HDPE geomembrane, geogrid, load test, granular pile, settlement

INTRODUCTION

Granular piles are an effective ground improvement technique to improve soft cohesive soils and also loose cohesionless deposits (Greenwood, 1970; Hughes and Withers, 1974; Priebe, 1976 and Ranjan, 1989). A single granular pile in a weak soil when loaded vertically on top, may fail with zero lateral strain (Madhav and Vitkar, 1978), by bulging (Hughes and Withers, 1974; Ranjan, 1988), by general shear failure mode (Greenwood, 1970) and by sliding (Aboshi et al, 1979). An end bearing granular pile of length greater than 3 diameters fails in bulging (Hughes and Withers, 1974). The length of the bulge is limited to 4-5 pile diameters. The phenomenon of bulging is connected with the amount of settlement of the composite ground also. The higher the settlement, the higher is the amount of bulge. Bearing capacity can be improved and bulging can be reduced by replacing the bulged portion of the pile by concrete plugs or cement grout, which is called skirting (Engelhardt and Kirsch, 1977; Floss, 1979). It can also be done by reinforcement with geogrids or by geomembrane encapsulation (Alamgir, 1989; Adayat and Hanna, 1991; Madhav et al. 1994). In bulging, the granular material in the top portion of the pile is displaced laterally into the soil while the composite ground settles under compressive load. Based on numerical analysis, Madhav et al. (1994) suggested that the greater the number of reinforcement layers and the closer the spacing, the lesser will be the bulging. However, there are few experimental validations of the proposals made by Madhav et al. This paper presents experimental work on load-settlement behaviour of geogrids-reinforced granular piles. The number of geogrids and the spacing between them were varied.

EXPERIMENTAL INVESTIGATION

The effect of number of geogrid layers and the spacing between them on the compressive load response of the geogrid-reinforced granular piles was studied. The soil used in the investigation was a clayey silt. Table 1 shows the index properties of the soil. Granular piles were prepared using crushed stone aggregate. The aggregate had its particle size varying from 4.75 mm to 2.36 mm. The maximum particle size of the granular material was less than the mesh aperture size. The stone aggregate had a coefficient of uniformity (C_u) of 1.52 and a coefficient of curvature (C_c) of 0.96. The granular material was compacted at 60% relative density. The angle of internal friction of the granular material, determined from the shear box tests, was 38^o at a relative density of 60%. Netlon geogrid was used for reinforcing the granular piles. The specifications of the geogrid are given in Table 2.

Tests performed and compaction procedure

Plate load tests were performed on plain granular piles (unreinforced) and granular piles reinforced with geogrids. The load-settlement behaviour of plain and geogrid reinforced granular piles was compared. Load tests were conducted on the granular pile alone using a bearing plate of 60mm diameter equal to that of the granular pile in both reinforced and unreinforced conditions (plain granular pile). Composite ground (both granular pile and clay bed) was also loaded using a plate of diameter 120 mm. The test set-up is shown in Figure 1. The parameters u_o is the depth of the uppermost geogrid from the top of the granular pile and s the spacing between two consecutive geogrid layers. The diameter of the granular pile (d) was fixed as 60 mm and the length (L) as 300 mm. The uppermost geogrid was placed at a depth (u_o) of 10 mm. The number of geogrid layers (n) was varied as 2, 3 and 5 in different tests. The spacing (s) between the geogrids was varied as 10, 15 and 20 mm. The clay bed was compacted at a dry unit weight of 13 kN/m^3 and a water content of 15%. The thickness of the clay bed was equal to the length of the granular pile (300

Table 1. Index properties of the soil

Specific Gravity	2.6
Gravel (%)	0.0
Sand (%)	22.5
Silt (%)	41.5
Clay (%)	36.0
Liquid limit (%)	50.0
Plastic limit (%)	22.0
Plasticity index	28.0
Classification based on plasticity characteristics	CI, clay of intermediate plasticity

Table 2. Properties of the geogrid as supplied by the manufacturers

Specification	Range
Mesh aperture size	6mm x 6mm
Mesh thickness	3.3 mm
Structural weight	730 g/m^2
Polymer	High-density polyethylene
Tensile strength	7.68 kN/m^2
Elongation at maximum load	20.2%

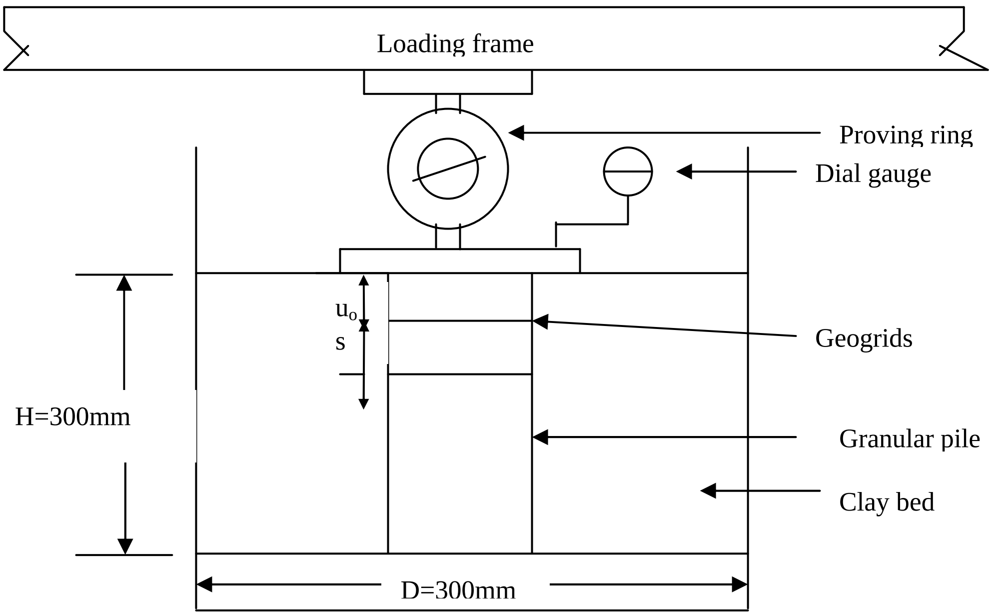

Figure 1. Experimental set up

mm) in all the tests. The granular material was compacted at a relative density of 60% throughout the test programme. A sand layer of thickness 50 mm was laid at the bottom of the tank. A casing pipe of internal diameter equal to that of the granular pile was kept vertically at the centre of the tank. The soil was compacted all round the casing in the test tank. After compacting the layer of clay bed to the predetermined thickness, granular material was poured into the casing pipe and compacted with a tamping rod to get the desired relative density. The required number of geogrid reinforcement layers was placed in the top portion of the granular pile at the required spacing. The foundation plate was seated centrally on the granular pile. Then the load test was performed and deformation measured.

Test procedure

Load tests were conducted in a test tank using a proving ring and a loading frame. Load was applied in increments of 45 N in all the tests. Each load was applied on the granular pile or the composite ground till the rate of settlement was less than or equal to 0.01 mm per hour, before the next load increment was applied. The tests were continued up to a maximum load of 275 N. The settlement under each load was measured with the help of a dial gauge of sensitivity 0.01 mm.

DISCUSSION OF TEST RESULTS

Figure 2 shows the stress-settlement behaviour of clay bed (unreinforced), plain granular pile and composite ground (clay bed and granular pile together). The load-carrying capacity of the clay improved on being reinforced with granular piles. The stress required to cause a given settlement increased when the clay bed was reinforced with granular pile. Granular material offers higher resistance applied loading and deformation by virtue of its frictional properties. Hence, the resistance to stress in the composite ground was higher than the clay bed alone and, further, the resistance to stress was still more in the case when pile alone was loaded (plate diameter = 60 mm) than when the composite ground was.

Figure 3 shows the stress-settlement curves for composite ground with a plain granular pile (n = 0) and with granular piles reinforced with geogrids (n = 3) placed at a spacing (s) of 10 mm and 20 mm. The stress required for producing any given settlement increased in the case of composite ground with geogrid-reinforced granular pile in comparison to that with a plain granular pile (n = 0). When the top portion of the granular pile was reinforced by geogrids, the granular particles were restricted by the geogrids from undergoing lateral displacement and hence, the reduction in the

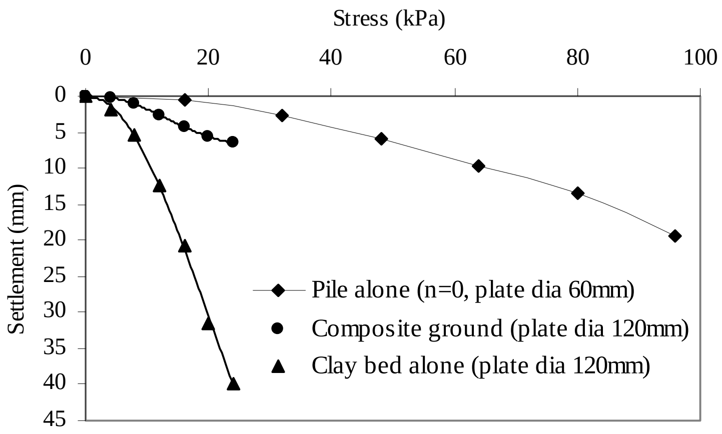

Figure 2. Stress-settlement curves

settlement. As the granular pile was subjected to loading, the geogrids were subjected to tensile stresses because of elongation. Geogrids, being a good tensile material, resisted these tensile stresses resulting in less settlement. The amount of settlement decreased with increasing number of geogrids and decreasing spacing between them. When the spacing was decreased for a given number of geogrids, the stress-settlement behaviour further improved. When the spacing decreases for a given number of geogrids, there will be more confining effect on the granular material. Hence, the settlement for a given stress was reduced in the case of the composite ground with a granular pile reinforced by geogrids (n = 3) placed at a lesser spacing (Figure 3). The same trend was observed when the granular pile was reinforced with 2 layers of geogrids also (see Figure 4).

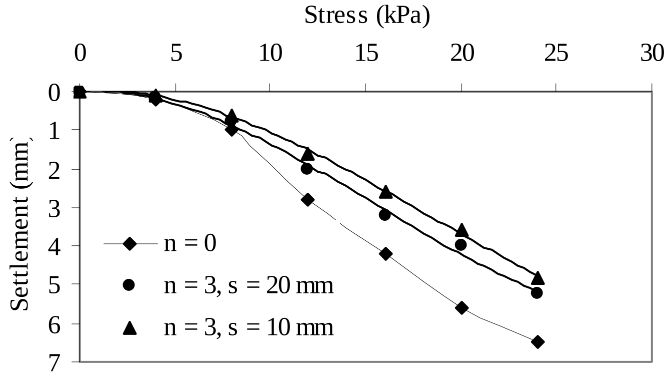

Figure 3. Stress-settlement curves

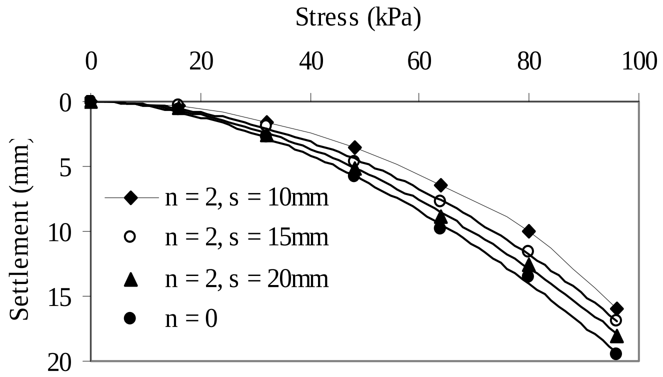

Figure 4. Stress-settlement curves

Figure 5 shows the stress-settlement curves for composite ground with granular piles reinforced with varying number of geogrids (n = 2, 3 & 5) at equal spacing (s = 10 mm). Increasing the number of geogrid reinforcement layers improved the compressive load response of the composite ground significantly. When the number of layers of geogrids increased for a given spacing, the stress-settlement behaviour of the composite ground was improved.

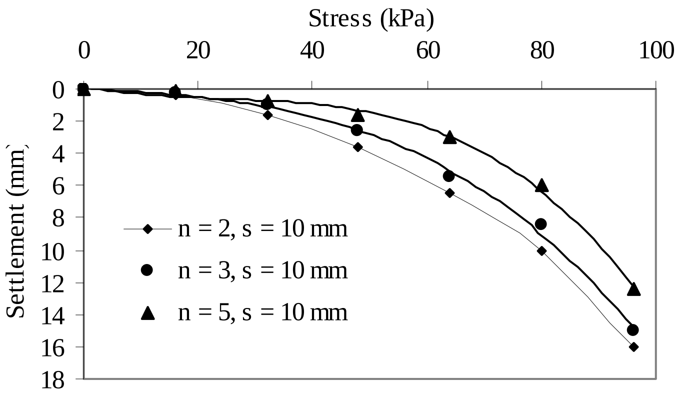

Figure 5. Stress-settlement curves

CONCLUSION

The stress required to cause a given settlement increased when the clay bed was reinforced with granular pile. The resistance to applied stress was still more when the pile alone was loaded (plate dia = 60 mm) than when the composite ground was loaded. When the top portion of the granular pile was reinforced by geogrids, the load-carrying capacity of the granular pile-reinforced clay bed improved significantly. Load-carrying capacity of theTclay bed further improved with increasing number of geogrids and decreasing spacing between them.

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