Efficacy of geogrid in improving the load carrying capacity of stone columns

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ABSTRACT: Granular piles are one of the most effective techniques for improving the load carrying capacity and reducing the settlements of soft clays. A granular pile subjected to compressive load from the top undergoes bulging, which is one of the chief modes of failure of granular piles. In most field situations, granular piles have been found to have failed by bulging. Granular piles which are longer than 4d-5d (where d is the diameter of the granular pile) have been found to undergo bulging failure. Bulging is a phenomenon in which the granular material flows laterally and radially into the surrounding clay. As granular pile settles under the applied load, bulge takes place to compensate volume changes. The extent to which bulging occurs depends upon the undrained strength of the surrounding clay, the density of the granular material and the l/d ratio of the granular pile. Other modes of failure recognized are general shear failure, local shear failure and sliding failure. Arresting bulging results in improved load-settlement behaviour of granular piles. Of various techniques employed for arresting bulging, applying surcharge, concrete skirting of individual granular piles and group of granular piles, geosynthetic reinforcement of granular piles and geosynthetic encapsulation of top portion of granular piles have been quite effective. This paper presents study on improvement of compressive load response and bulge response of laboratory scale granular piles reinforced with geogrids. The granular material with which granular piles was prepared was varied as fine sand, medium sand and coarse sand. However, the relative density of all the granular piles was kept constant at 60% irrespective of the granular material. The length and diameter of granular piles were kept constant at 250 mm and 60 mm respectively. Plate load tests were conducted on granular piles alone using a test plate of diameter 60mm. Horizontal geogrid reinforcement was provided in the top layers of the granular piles to arrest bulging and to improve load carrying capacity. The number of geogrid layers was varied. Geosynthetic encapsulation was also attempted with and without horizontal geogrid reinforcement. The type of geogrid used for encapsulation was varied with reference to its stiffness and aperture size.

1 INTRODUCTION

Granular piles are an effective ground improvement technique to improve soft cohesive soils and also loose cohesion less deposits (Greenwood, 1970; Hughes and Withers, 1974; Dayte and Raju, 1981 and Ranjan, 1988). 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), 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). 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 numbers of geogrids were varied. Moreover, geosynthetic encapsulation was also attempted by varying the type of geosynthetic.

2 EXPERIMENTAL INVESTIGATION

The effect of number of geogrid layers and type of geogrid used for encapsulation on the compressive load response of the granular piles was studied.

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 classified as highly plastic clay (CH) according to USCS classification. Table 1 shows the index properties of the soil. Granular piles were prepared using fine, medium and coarse sand. The particle size of fine, medium and coarse sand were 0.075-0.425 mm, 0.425-2.36 mm and 2.36-4.75 mm respectively. The Cu values for sands were 1.941, 3.33 and 1.476 and Cc values were 1.244, 0.625 and 0.96 respectively. The granular materials were compacted at 60% relative density. Netlon geogrid was used for reinforcing the granular piles. The specifications of the geogrids are given in Table 2.

Table 1. Index properties of soil

Specific gravity	2.68
Liquid limit (%)	60
Plastic limit (%)	26
Plasticity index (%)	34
Compaction properties	
OMC (%)	21
MDD (kN/m^3)	16.6
USCS classification	CH

Table 2. Properties of the geogrids as supplied by the manufacturer

Property	1	2	3
Aperture (mm)	6 * 6	1 * 1	1 * 1
Tensile strength (kN/m^2)	7.68	3.20	1.40
Elongation (%)	20.2	35	52
Polymer	HDPE	HDPE	HDPE

3 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). The test set-up is shown in Fig 1. The diameter of the granular pile (d) was fixed as 60 mm and the length (L) as 250 mm. The uppermost geogrid was placed at a depth of 120 mm. The number of geogrid layers (*n*) was varied as 2, 3 and 4 in different tests. The spacing (*s*) between the geogrids was kept constant as 20 mm. The clay bed was compacted at a dry unit weight of 13 kN/m^3 and at consistency index of 50%. The thickness of the clay bed was equal to the length of the granular pile (250 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 was measured.

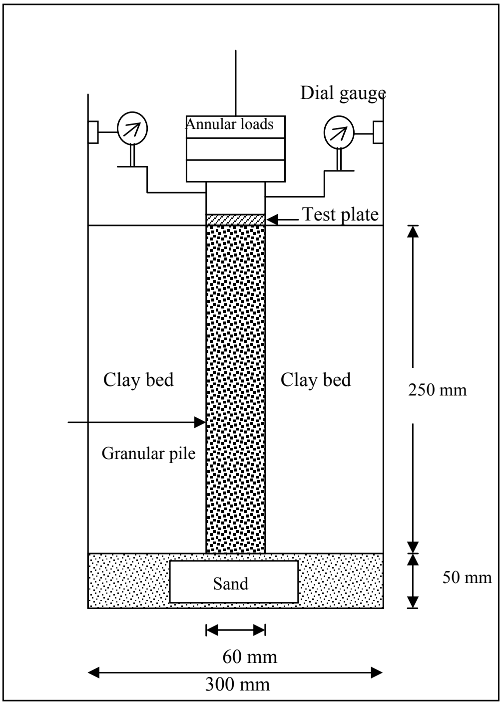

Figure 1. Experimental setup

4 TEST PROCEDURE

Load tests were conducted in a test tank using a proving ring and a loading frame. The first four loads were applied in increments of 36 N and the last two increments were equal to 72N each in all the tests. Each load was applied on the granular pile 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 288 N. The settlement under each load was measured with the help of a dial gauge of sensitivity 0.01 mm .At the end of each test bulge diameter and bulge length of the granular piles were measured.
The bulge diameter was measured carefully scrapping off clay, layer by layer, each of thickness 10 mm. The bulge length and diameter were measured till the diameter became equal to the original diameter (60 mm).

5 DISCUSSION OF TEST RESULTS

Figure 2 shows load-settlement behaviour of clay bed in comparison with that of clay beds reinforced with granular piles installed using varying sand media (fine sand, medium sand and coarse sand). As mentioned earlier, plate load tests were conducted only on granular piles using a test plate of diameter equal to that of granular pile (60 mm). The maximum settlement undergone by the clay bed at the maximum applied load of 288 N was 85 mm. When the clay beds were reinforced with granular piles, the load-settlement behaviour significantly improved. This can be attributed to the high angle of internal friction of granular piles by virtue of which the applied load was resisted effectively. The resistance offered to the applied load varied with varying sand medium in the granular pile. The load-settlement curve of granular pile of fine sand lay at the top, indicating the best load-settlement response. The load-settlement curves of granular piles of medium sand and coarse sand, in that order, lay below that of fine sand. For a relative density of 60%, fine sand resulted in the highest maximum dry density of 16.2 kN/m^3. The maximum dry densities of medium sand and coarse sand were respectively 15.7 kN/m^3 and 15.4 kN/m^3. By virtue of its highest maximum dry density, fine sand resisted the applied load most effectively. The applied compressive loads for a settlement of 5 mm for clay bed, and granular piles of coarse sand, medium sand, fine sand were respectively 60 N, 220 N, 216 N, and 288 N. With reference to unreinforced clay bed, granular pile of fine sand resulted in an improvement of 226% in the applied load. This establishes the efficacy of granular piles as a ground improvement technique.

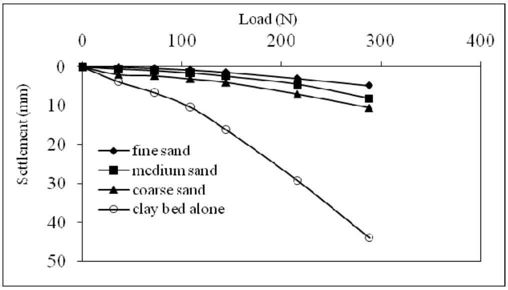

Figure 2. Load – settlement behaviour of granular piles (Ic= 60%)

Figure 3 shows load-settlement behaviour of plain granular pile (unreinforced granular pile) and of granular piles reinforced with horizontal geogrid layers of varying number (n = 2, 3 and 4). The load-settlement behaviour of geogrid-reinforced granular pile improved in comparison to that of plain granular pile. The behaviour further improved with increasing number of geogrid layers. When the top portion of granular pile is reinforced with geogrids, interlocking between geogrids and granular material prevents the granular pile material from bulging under the applied load. As bulging is restricted by geogrid reinforcement, settlement of granular piles decreases. Further, the stiffness of the top layers of granular piles reinforced with geogrids increases. Thus, geogrid-reinforced granular piles resist the compressive loads more effectively than the unreinforced granular piles. The stiffness increases with increasing number of geogrid layers, thus improving the load-settlement behaviour further.

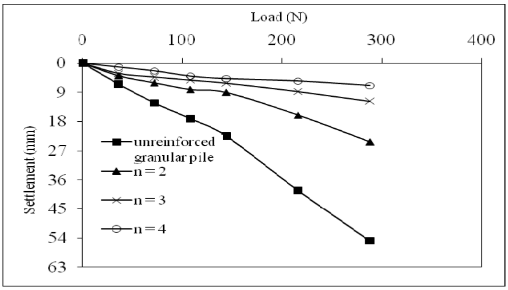

Figure 3. Effect of geogrid-reinforcement on load-settlement behaviour of granular piles

Figure 4 shows the influence of geogrid encapsulation of granular piles on their load-settlement behaviour. The load-settlement behaviour of granular piles improved when they were encapsulated with a geogrid up to a depth of 60 mm from the top of the granular pile. The data indicate load-settlement curves for a plain granular pile and granular piles encapsulated with three different types of geogrids of varying tensile strength, which are referred to as geogrid 1, geogrid 2, and geogrid 3. The tensile strengths of geogrid 1, geogrid 2 and geogrid 3 were

7.68 kN/m^2, 3.20 kN/m^2 and 1.40 kN/m^2 respectively. When a granular pile is encapsulated with geogrid, bulging is arrested. When bulging takes place, the radial stresses in the granular material generate hoop stresses in horizontal planes in geogrid encapsulation. Geogrid material resists tensile hoop stresses effectively and thus it is able to arrest bulging. This leads to an improved settlement response of the granular piles. The higher the tensile strength of the geogrid encapsulation, higher is the resistance to bulging and better the load-settlement response. Figure 4.13 shows that the load-settlement response of granular piles improved with geogrid encapsulation. The response further improved with increasing tensile strength of the encapsulating geogrid.

Figure 5 shows the bulge profiles of unreinforced granular pile and granular piles reinforced with geogrids at n = 2, 3 and 4. Bulge diameter was the highest at 8.7 cm in the case unreinforced granular pile. Bulge diameter decreased when the granular pile was reinforced with geogrids. Bulge diameter further decreased with increasing number of geogrid (n). The profiles indicate that bulge was effectively controlled by geogrid reinforcement. Bulge, which occurs through lateral movement of granular particles, was controlled through interlocking between geogrids and granular particles. The maximum bulge diameter (d_{bmax}) was 7.7 cm, 6.8 cm and 6.5 cm when n = 2, 3 and 4 respectively (see Table 4.4). It is of significance that bulge was arrested effectively within the reinforced length of granular pile. Bulge diameter increased to d_{bmax} beneath the reinforced length of the granular pile. The reduction in the bulge length with increasing number of geogrids is also evident from the bulge profiles. Further, the settlement of the granular piles also decreased with increase in number of geogrids as indicated by the initial points of the profile

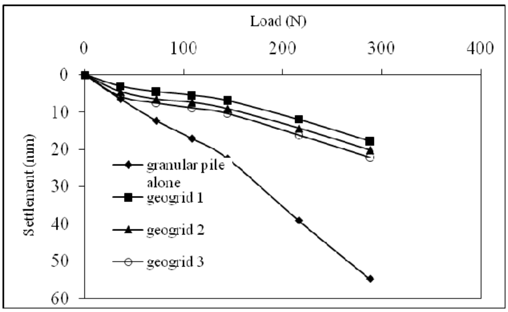

Figure 4. Load–settlement behaviour for geogrid–encapsulated granular pile

Figure 6 shows the bulge profiles of unreinforced granular pile and granular pile provided with geogrid encapsulation alone (geogrid 1, geogrid 2 and geogrid 3). As bulge was arrested through geogrid encapsulation, bulge diameter and bulge length decreased. Bulge further decreased with increasing tensile strength of the encapsulating geogrid. When granular pile bulges, radial stresses causes hoop stresses in the geogrid encapsulation. The tensile geogrid encapsulation resists hoop stresses and thus arrests bulging. The maximum bulge diameter (d_{bmax}) was 7.4 cm, 7.2 cm and 6.95 cm respectively for granular pile encapsulated by geogrid 3, geogrid 2 and geogrid 1.

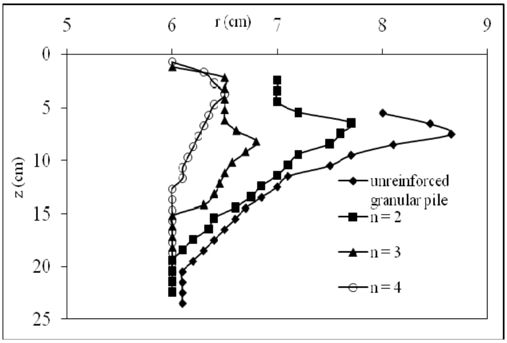

Figure 5. Bulge profiles of geogrid-reinforced granular piles

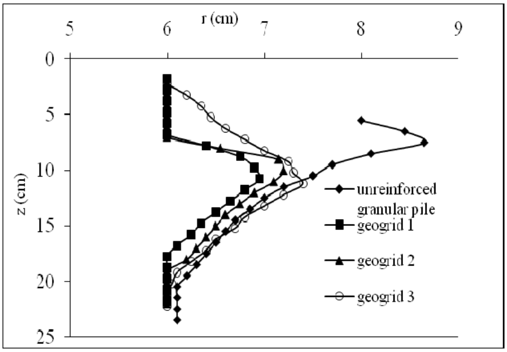

Figure 6. Bulge profiles of geogrid-encapsulated granular piles

5 CONCLUSIONS

When the clay beds were reinforced with granular piles, the load-settlement behavior significantly improved. Fine sand gave the best load-settlement response. The applied compressive loads for a settlement of 5 mm for clay bed, and granular piles of coarse sand, medium sand, fine sand were respectively 60 N, 220 N, 216 N, and 288 N. The percentage improvement in load was significant when D_{10} was the least or when the granular pile was installed with fine sand medium.

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