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Load-settlement response of varying sand media reinforced by geogrids

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Abstract
A sequence of plate load tests (laboratory) were conducted to analyze the variations in load carrying capacity of geogrid-reinforced sand for different particle sizes (i.e –fine, medium and coarse sand). Geogrid sheets of circular shape and with diameter as 120 mm were provided in sand beds as reinforcement. All the sand beds were maintained at fixed relative density of 50%. The base plate (test plate) used as the surface foundation had a diameter of 60 mm. The effect of varying the number of geogrids and the varying the spacing between them on load-settlement characteristics was recorded and analyzed. The test results were used to interpret the improvement in load-settlement behaviour. The results showed that reinforcing sand beds with horizontal geogrid depicted improvement in the load carrying capacity of the sand beds. It was observed that by increasing the layers of geogrid, the load settlement behaviour improved further the bearing capacity improvement was observed by decreasing spacing between the geogrid layers.

Keywords: Geogrid reinforcement, plate load tests, relative density, bearing capacity, deformation.

1. Introduction

Soft clays are highly compressible and undergo large settlements. Among various techniques available for improving the load-settlement behaviour of soft clays, providing geosynthetic-reinforced sand bed as a cushion has been quite successful. Reinforced sand bed, developed after the reinforced earth concept (Vidal, 1966) [7], is a foundation system containing horizontally embedded geosynthetics. Laboratory and field scale tests were performed to analyze the performance of foundations supported by geogrid-reinforced soils. Binquet and Lee (1975) [1] studied the relationship of pressure intensity of isolated strip footings located on earth bed with reinforcement for a particular settlement value. Analytical and experimental results obtained by (Binquet and Lee, 1975) [1] complimented each other. Tests on strip foundations placed on loose sand bed reinforced and non-reinforced was conducted by Ramaswamy and Yong (1983) [4]

Multiple modal plate load tests were performed by Guido *et al.* (1985, 1986) [2, 3] on well graded sand beds in both un-reinforced as well as reinforced (with geotextiles of various types) conditions. Bearing capacity in reinforced sand beds varies with *u/b* ratio (ratio between the spacing of first reinforcement layer from bottom of footing to the width of the foundation), *s/b* (is the ratio of spacing between the reinforcement layers to the width of the foundation) and number of layers of geotextile reinforcement. Based on the plate load tests (model) on geogrid reinforcements (Yasufuku *et al*. 1996) [8], established a formula that improvement in bearing capacity was a function of width of loading normalize by the effective width in the supporting soil strata. Enhancement in the bearing capacity of footings resting on granular base layer laid over soft clay bed was studied by Shivashankar *et al.* (1993) [6], considering a punching shear failure occurrence in the base stratum. Ramu *et al.* (1999) [5] worked on a more diverse model to analyze the influence of granular strata laid over a soft clay deposit. Majority of the investigations conducted in laboratory so far were used to analyze the response of reinforced sands, pertain only to fine sand only. This paper represents the load-settlement response on various types of sands with geogrid reinforcements.

2. Experimental Investigation

Multiple plate load test were performed on sand beds prepared with various types of sand i.e - fine, medium and coarse. In all the sand beds relative density was maintained as 50%, which was randomly chosen. Tests were conducted on geogrid - reinforced and un-reinforced sand beds. The data obtained were compared to understand the load-settlement behaviour of sand beds in both reinforced and un-reinforced.

2.1 Test materials

2.1.1 Test sands

Sand beds were prepared by various types of sand for testing (i.e - fine, medium and coarse sand) The range of particle size variation was kept from 0.425 mm to 0.075 mm for fine sand, 0.425 mm to 2.36 mm for medium sand and 2.36 mm to 4.75 mm for coarse sand. All the sands were poorly graded (SP).

2.1.2 Geogrid reinforcement

The geogrid used as horizontal reinforcement for testing was Netlon CE 121. It is a polypropylene sheet with high tensile strength and 6mm aperture size.

2.2 Test Variables

A cylindrical test tank of 300mm height and 600mm diameter was used. All the sand layers were laid and compacted in 200mm thick layers inside the test tank. 50% relative density was maintained for all the sand beds, it was insured by keeping dry unit weight (γ_d) of sand layer equivalent to maintain the required relative density of respective sand beds as 50%. Plate load test was conducted. For conducting the plate load test the test plate of 60 mm (d_p) diameter was used. Plate load tests were conducted using test plate of diameter 60 mm. The diameter of geogrid reinforcement (d_g) was kept as120 mm for all the tests in order to keep ratio d_p/d_g = 2. The variation in number of geogrid layers (n) was varied as n = 1, 2, 3. Spacing between all the geogrid layers (s) were also varied as 20 mm and 10 mm. Spacing of bottom of base plate / test plate from top of geogrid (u) was kept as 10mm.

2.3 Preparation of test beds

All the types of sand beds were laid in layers and compacted to maintain the respective relative density as 50% (50% relative density was chosen arbitrarily). As per the volume of test tank to be filled with sand, the weight of sand was calculated and the same was taken in order to attain the required relative density, then it was divided in 4 equal parts by weight. Each part was laid and compacted in layers of 50mm thickness in the test tank. For test sand beds reinforced with geogrids, the geogrids were placed at required depth from test plate ‘u’ and required spacing ‘s’ between them. After laying the final layer of sand bed the test plate of weight 3N and plate thickness 50mm was placed on the compacted sand bed of relative density of 50% positioned at the centre of the tank, then loading was done. Fig 1 shows the test set up.

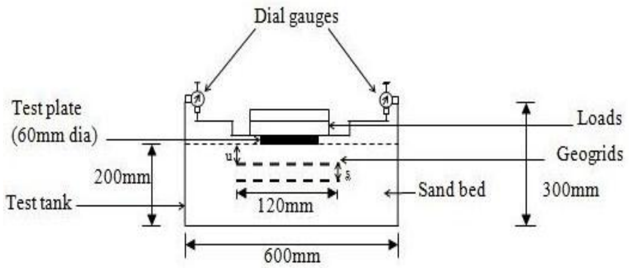

Fig 1: Experimental setup

2.4 Test procedure

For observing the settlement of test plate due to loading two numbers of dial gauges of 0.01 mm least count were positioned on the test plate for recording the settlement due to loading. The primary seating load was 10 N this included the load due to test plate (3 N). The succeeding load increments cumulative were 40 N, 70 N, 100 N, 130 N, 170 N and 210 N for sand beds without reinforcement and 40 N, 70 N, 100 N, 130 N and 170 N, 210 N, 250 N and 290 N for sand beds reinforced with geogrids. The loading was not conducted up to the failure. The load-settlement behaviour improved in case of geogrid-reinforced test sand beds subjected to the loading intensities as mentioned above was studied. All load addition was observed on the test sand bed for 1 hour (60 minutes). The deformation observed in both the dial gauges was recorded, the average of both the dial gauge readings was considered as the actual deformation.

3. Discussion on Test Results

3.1 Impact of geogrid reinforcement (n = 0, 1 and n > 1) on load - settlement behaviour

Fig 2 represents the load – settlement response of unreinforced test sand beds of various types (fine, medium and coarse) ($n = 0$) in comparison with that of the respective sand beds with single layer of geogrid reinforcement (n = 1) provided at u = 10 mm. All the sand beds reinforced by geogrid resulted in improved load-settlement behaviour compared to the unreinforced sand beds, indicating higher load carrying capacity of test sand beds due to geogrid reinforcement. Horizontal reinforcement of geogrid placed beneath the base plate caused smaller amount of settlement since the stress generated at a given plane (horizontal) of the sand bed got reduced. Further, geogrid resists tensile stresses caused in it due to possible bending under the applied compressive stresses; this resulted in improved load-settlement response. The vertical loads of compression recorded for settlement of 1 mm for sand beds i.e- fine sand, medium sand and coarse sand with geogrid reinforcement were 130 N, 70 N and 160 N respectively, whereas those for unreinforced sand beds i.e - fine, medium and coarse sand were 110 N, 65 N and 70 N respectively. This resulted in a % improvement of 18.13%, 7.69% and 128.55% respectively for fine, medium and coarse sand, indicating that coarse sand showed the best behaviour when reinforced with geogrids (n = 1).

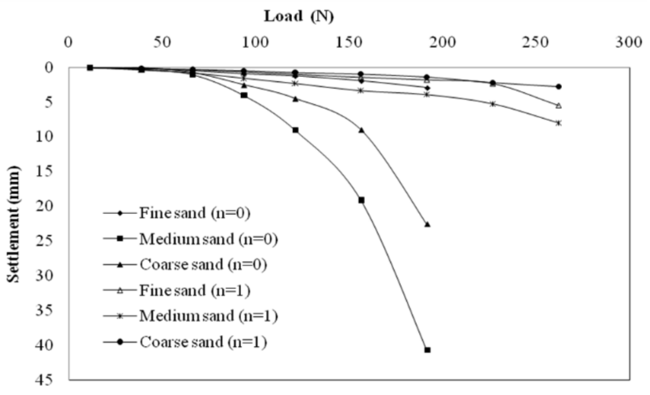

Fig 2: Load-settlement curves (u = 10 mm, s =10 mm)

In the cases of tests pertaining to *n* = 2, *s* = 10mm and 20mm respectively. Fig 3 depicts the load-settlement interactions of geogrid-reinforced sand beds for coarse and fine sand in multiple combinations of geogrids spacing (s = 10; *n* = 2 and *s* = 20; *n* = 2) for preset value of *u* as 10 mm. Comparable behaviour was recorded for sand with medium particle size also. When number of geogrid was increased to *n* = 2, improvement in the load carrying capacity was observed as that of *n* = 1 for all sand types. As the layers of geogrid increased (*n* = 2) and the spacing between the geogrids reduced, sand layers confinement increased, depicting better load response. The load-settlement curves for *n* = 2 at *s* = 20 mm lay below those for *n* = 2 at *s* = 10 mm. For *n* = 2, coarse sand showed best load-settlement behaviour. Higher interlocking effect between coarse sand and multiple numbers of geogrids has resulted in much higher load settlement behaviour. For a settlement of 1 mm the load needed to be applied on fine and coarse sand beds reinforced with geogrids (*n* = 2 at *s* = 10 mm) was respectively 155 N and 165 N, showing a % improvement of 15% and 17% in comparison to fine and coarse sand with reinforcement at *n* = 2 at *s* = 20 mm.

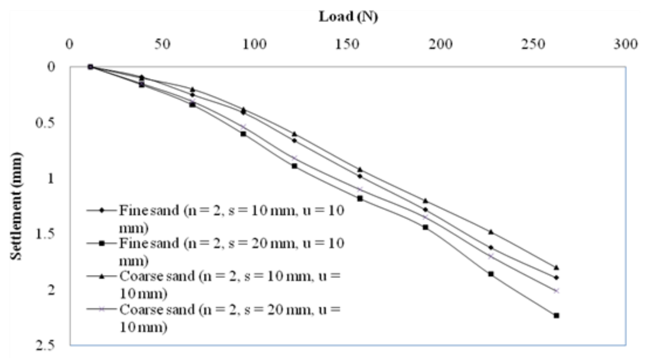

Fig 3: Effect of spacing on load-settlement behaviour (N=2, U= 10mm

Fig 4 summarises the test data on all the sand beds reinforced with geogrids at *n* = 1, 2 and 3 for *s* = 10 mm and *u* = 10 mm. With increase in the number of geogrids (*n*) layers, the load-settlement behaviour improved in all the sand beds. This can be endorsed to the increased confinement of the sand due to increase in geogrid layers. For three layers of geogrid *n* = 3 also the best load-settlement response was observed in coarse sand. Among the various cases of sand beds reinforced with geogrids, *n* = 3 depicted highest compressive load carrying capacity in all sand types. It was followed by *n* = 2 at *s* = 10 mm and *n* = 2 at *s* = 20 mm. As the number of geogrid layers (*n*) was increased from 1 to 3, percentage improvement was also observed in the corresponding load required for settlement of 1 mm in the cases of fine, medium and coarse sand by 61%, 26% and 70% respectively.

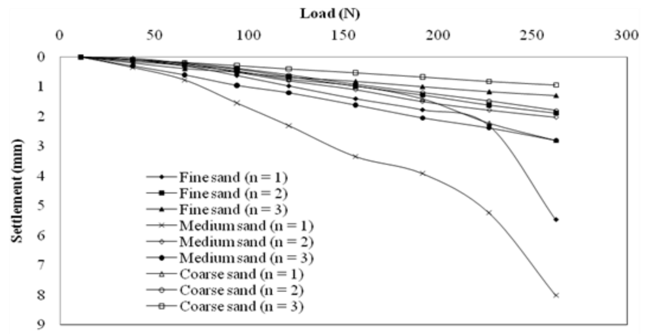

Fig 4: Relation of number (n) of geogrids and load-settlement behaviour (u = 10 mm, s =10 mm)

4. Conclusions

1. Improvement was observed in load settlement response of sand beds with geogrid reinforcements. For analyzing the data, corresponding compressive vertical loads required for a settlement of 1 mm for test sand beds of fine, medium and coarse sand reinforced with geogrids were recorded as 119 N, 71 N and 160 N respectively, where as those of fine sand, medium sand and coarse sand without geogrid reinforcement were recorded as 108 N, 65 N and 72 N respectively.
2. When number of geogrids were increased to (*n* = 2), improvement in load-settlement was observed in comparison to single geogrid reinforcement (*n* = 1) for all types of sands. Corresponding load required 1mm settlement in case of fine and coarse sand with geogrid reinforcement (*s = 10mm* for n = *2*) showed improvement of 15% and 17% as compared to fine and coarse sand with geogrid reinforcemment for *n* = 2 at *s* = 20 mm.
3. As the number of geogrids increased from *n* = 1 to *n* = 3, the percentage improvement in the load requirement corresponding to 1 mm settlement for fine, medium and coarse sand was 61%, 26% and 70% respectively.
4. For construction of structures in areas with loose sand beds, reinforcing the sand beds with geogrids can be much more efficient and easy to apply than other ground improvement techniques. Since we also have a choice of varying the particle size, number of geogrid layers and their spacing as per our requirement and economy of the project.

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