Static and cyclic load response of reinforced sand through large triaxial tests

Madhavi Latha, G.i) and Nandhi Varman. A. M.ii)

i) Associate Professor, Department of Civil Engineering, Indian Institute of Science, Bangalore, 560012, India.
ii) Ph.D Student, Department of Civil Engineering, Indian Institute of Science, Bangalore, 560012, India.

ABSTRACT

This paper presents the response of unreinforced and geosynthetic reinforced dry sand under static and dynamic loading conditions. A large scale triaxial apparatus, capable of testing specimens having a maximum size of 300 mm in diameter and 600 mm in height was used for the study. Large specimen size used in this study allowed to overcome the boundary effects present in triaxial testing of reinforced sands. A series of triaxial compression tests were performed on unreinforced and reinforced sand specimens to investigate the effect of the quantity of geotextile reinforcement on the mechanical behavior of sand. A woven geotextile was used in layers to reinforce the sand. Number of reinforcing layers was varied from one to six in different tests. It was observed that under static conditions the peak shear strength, axial strain at failure and stiffness increased with the inclusion of geotextile layers. Reinforcement benefit ratio increased with the number of layers but decreased with the increase in confining pressure, indicating that the reinforcement layers are more effective at low confining pressures. Cyclic triaxial tests were carried out at 1 Hz frequency and 4 kN cyclic load. Reinforced specimens exhibited substantially higher dynamic moduli compared to the unreinforced sand.

Keywords: large triaxial tests, reinforced sand, geotextile, cyclic triaxial, dynamic modulus

1 INTRODUCTION

Understanding the mechanical behavior of reinforced sand has been dealt extensively by many researchers around the world. Most of the studies reported on the strength of reinforced sand used triaxial compression tests (Indraratna et al., 1991; Fabian and Fourie, 1986; Chen et al., 2014). Size of the specimen in triaxial testing plays a vital role in understanding the shear strength behavior because smaller sized specimens are subjected to boundary effects. Not many researchers have attempted to use triaxial specimens of size greater than 100 mm to estimate the shear strength of reinforced sands. Haeri et al. (2000) conducted 160 triaxial compression tests on geotextile-reinforced dry beach sand samples of 38 mm and 100 mm diameter to investigate the effects of reinforcement type, reinforcement layer, confining pressure and reinforcement arrangement. Comparing the tests with smaller and larger size specimens, it was concluded the sample size effects for reinforced sand as opposed to unreinforced sand was quite significant as the small-size samples demonstrated higher peak strength and increased failure strain and more reduction in the loss of post-peak strength compared to large-sized samples. Latha and Murthy (2007) performed a series triaxial compression tests on geosynthetic reinforced dry sand. Effect of reinforcement form on strength improvement of geosynthetic reinforced sand was studied by carrying out tests with geocell, horizontal layer and randomly distributed fibres as reinforcement.

Cyclic triaxial testing of reinforced sands was reported by very few researchers and the studies with larger triaxial specimens among them are very less (Tafreshi and Asakereh, A., 2007). Naeini and Gholampoor (2014) conducted a series of cyclic triaxial tests on specimens of 70 mm diameter to examine the cyclic behavior of dry silty sand reinforced with a geotextile. Factors affecting the cyclic behavior, such as the arrangement and number of geotextile layers, confining pressures and silt content were varied in the tests. It was observed that geotextile reinforcement causes significant increase in the cyclic axial modulus of dry sand and sand mixed with varying amounts of silt and the effect was more pronounced when the geotextile was placed near the surface of the sample. Considering the specimen size effects in triaxial testing and the lack of understanding towards the cyclic loading response of reinforced sand, large size static and triaxial tests were carried out in this study on unreinforced sand and sand reinforced with multiple layers of geotextile. The specimen size used in the tests is 300 mm diameter and 600 mm height, thus minimizing the boundary effects of triaxial tests.
2 MATERIALS

2.1 Sand
Fine sand with average grain size (D50) of 0.25 mm was used for the study. Grains of this sand were sub-rounded as observed from surface morphological studies. Grain size distribution of the sand is shown in Fig. 1. Coefficient of uniformity (Cu) and coefficient of curvature (Cc) obtained from the grain size distribution are 2.85 and 2.06 respectively. Based on the Unified soil classification, the soil belongs to poorly graded sand with little fines (SP). The maximum and minimum void ratios of this sand were determined as per ASTM D4253 and ASTM D4254 and were found to be 0.825 and 0.468 respectively.

![Grain size distribution curve for sand.](image)

2.2 Geotextile
Woven geotextile used in this study was a polypropylene multifilament woven fabric. The ultimate tensile strength of the geotextile was obtained as 55 kN/m from wide-width strip tension test as per ASTM D4959. Thickness of the geotextile was 1 mm.

3 DESCRIPTION OF TESTS

3.1 Large triaxial setup
The large cyclic triaxial test setup used in this study is capable of testing specimens of sizes between 38 mm to 300 mm in diameter. Fig. 2 shows the custom built large triaxial apparatus with the test specimen. The maximum load carrying capacity of this triaxial apparatus is 100 kN and the maximum pneumatic confining pressure that can be applied on the specimen is 1 MPa. The load frame is fitted with servo hydraulic actuator which can apply a maximum cyclic loading frequency of 10 Hz. The submersible load cell is installed inside the triaxial cell in order to minimize the friction between the platens and to measure the load fairly accurately.

3.2 Specimen preparation
All specimens were prepared using dry sand to a size of 300 mm diameter and 600 mm height. Specimens were prepared to a relative density of 70%, which corresponds to a unit weight of 16.3 kN/m³. Target relative density was achieved by compacting the specimen in 6 layers. Metal disc of 6 kg, whose diameter was slightly less than the specimen diameter, was used for tamping the layers. The numbers of blows on layers were adjusted progressively, so as to achieve a specimen of uniform density. In case of reinforced specimens, spacing between the layers was kept the same and the numbers of sand layers were adjusted to match with the position of the reinforcing layers. Diameter of the geotextile layers was 3 mm less than the diameter of the specimen to avoid edge effects. Fig. 3 shows the stages of sample preparation and the prepared specimen.

![Triaxial setup](image)

![Stages of sample preparation.](image)

3.3 Test matrix
Total 21 static triaxial compression tests with reinforced and unreinforced specimens were carried out. Another set of 6 specimens were used for carrying out load controlled cyclic triaxial tests. Specimens were tested under three different confining pressures of 60 kPa, 110 kPa and 160 kPa. The static tests were displacement controlled and tested at a rate of 1 mm/min while the cyclic tests were performed with a cyclic load of ±4kN at 1 Hz frequency. Table 1 gives the details of the tests carried out in this study. In case of reinforced sand specimens, number of geotextile layers was varied as 1, 2, 3, 4, 5 and 6. Fig. 4 gives the schematic sketch showing the arrangement of reinforcing layers for these tests. Total height of the sample remained 600 mm for all the tests.
Table 1. Test matrix

| Specimen type         | Test ID | Tests performed |
|-----------------------|---------|-----------------|
| Unreinforced          | UR      | Static and cyclic |
| One layer reinforcement| GT1     | Static |
| Two layer reinforcement| GT2     | Static |
| Three layer reinforcement | GT3   | Static |
| Four layer reinforcement | GT4    | Static |
| Five layer reinforcement | GT5    | Static |
| Six layer reinforcement | GT6    | Static and cyclic |

Fig. 4. Arrangement of geotextile reinforcement in different tests

5 RESULTS AND DISCUSSION

5.1 Static triaxial tests

The stress-strain response of unreinforced sand at three different confining pressures of 60 kPa, 110 kPa and 160 kPa is shown in Fig. 5. Unreinforced sand specimens showed definite peak and post peak strain softening behavior at all confining pressures. From the p-q plot of unreinforced sand, the shear strength parameters were obtained as $\phi = 38^\circ$ and $c = 7$ kPa. Fig. 6 shows the failure patterns for unreinforced and five layer geotextile reinforced sand specimens. Clear shear plane was formed in unreinforced specimens during failure. In case of geotextile reinforced sand, the failure was by bulging between the layers, as observed from Fig. 6.

Fig. 5. Stress-strain response of unreinforced sand

Fig. 6. Failure patterns in sand specimens: (a) unreinforced sand (b) five layer reinforced sand.

Figs. 7, 8 and 9 show the comparison of stress-strain response of unreinforced and geotextile reinforced sands at confining pressures of 60 kPa, 110 kPa and 160 kPa respectively. As observed from the figure, reinforced specimens showed higher peak stress compared to unreinforced specimens at all confining pressure and the improvement in strength increased with the number of reinforcing layer.

Fig. 7. Comparison of stress-strain response of reinforced and unreinforced sand at confining pressure of 60 kPa.

Fig. 8. Comparison of stress-strain response of reinforced and unreinforced sand at confining pressure of 110 kPa.
Fig. 9. Comparison of stress-strain response of reinforced and unreinforced sand at confining pressure of 160 kPa.

To understand the beneficial effect of reinforcement in a quantitative way, *Reinforcement Benefit Ratio* was estimated. Reinforcement benefit ratio is defined as the peak deviator stress obtained from a reinforced specimen to the peak deviator stress obtained from the unreinforced specimen at any specific strain level. To compute reinforcement benefit ratios for various reinforced specimens, 12% strain level was considered in this study. Fig. 10 shows the variation of reinforcement benefit ratio with the quantity of reinforcement represented by the number of layers at different confining pressures. Two important observations from this plot are: Reinforcement benefit ratio increased with the number of layers at all confining pressures; Increase in confining pressure resulted in the decrease in the benefit for any specific amount of reinforcement. These results are in agreement with the observations by Haeri et al. (2000). Increase in the benefit is nonlinear with the increase in quantity of reinforcement, the nonlinearity decreasing with the increase in confining pressure.

5.2 Cyclic triaxial tests

Cyclic triaxial tests were carried out on unreinforced and 6 layer reinforced sand specimens at a frequency of 1 Hz and cyclic load of 4 kN. Total 10000 load cycles were applied to the specimen. Typical hysteresis loop of deviator stress vs. axial strain obtained for unreinforced specimen at a confining pressure of 60 kPa is shown in Fig. 11. Equal deviator stress of about 50 kPa was achieved in both compression and tension sides of the loops. The loop got densified with the strain level, indicating that the stiffness of the specimen increased.

Dynamic modulus was estimated for the unreinforced and reinforced specimens at each cycle as the ratio of deviator stress and axial strain. The variation of dynamic modulus with the number of cycles for unreinforced and reinforced specimens at different confining pressures is shown in Fig. 12. Dynamic modulus degraded with the number of cycles for all specimens. Reinforced sand showed significantly higher dynamic modulus at higher confining pressures. At lower confining pressure of 60 kPa, unreinforced and reinforced specimens showed similar response.
6 CONCLUSIONS

The following conclusions are drawn from the large size static and cyclic triaxial tests carried out on unreinforced and geotextile-reinforced sand.

Failure patterns observed in static triaxial tests are different for unreinforced and reinforced sands. In case of unreinforced sand, clear shear plane was formed through the height of the specimen, whereas reinforced specimens showed bulging of sand between the layers.

Reinforcement benefit ratio increased nonlinearly with the increase in the quantity of reinforcement.

Reinforcement benefit ratio decreased with the increase in confining pressure under static loading conditions, indicating that the reinforcement is more beneficial at lower confining pressures.

Under cyclic loading conditions, dynamic modulus is not altered with the reinforcement at lower confining pressures but it increased significantly with the inclusion of reinforcing layers at higher confining pressures.

ACKNOWLEDGEMENT

Authors sincerely thank the Department of Science and Technology for funding the equipment through DST-FIST programme.

REFERENCES

1) Chen, X., Zhang, J. and Li, Z. (2014): Shear behaviour of a geogrid-reinforced coarse-grained soil based on large-scale triaxial tests, Geotextiles and Geomembranes, 42(4), 312-328, doi:10.1016/j.geotexmem.2014.05.004.
2) Fabian, K. and Fourie, A. (1986): Performance of geotextile-reinforced clay samples in undrained triaxial tests, Geotextiles and Geomembranes, 4(1), 53- 63, doi:10.1016/0266-1144(86)90036-1.
3) Haeri, S. M., Noorzad, R. and Oskoorouchi, A. M. (2000): Effect of geotextile reinforcement on the mechanical behavior of sand. Geotextiles and Geomembranes, 18, 385-402, 10.1016/S0266-1144(00)0005-4.
4) Indraratna, B., Satkunaseelan, K. S. and Rasul, M. G. (1991): Laboratory properties of a soft marine clay reinforced with woven and nonwoven geotextiles, Geotechnical Testing Journal, ASTM, 14(3), 288-295, 10.1520/GTJ10573J.
5) Latha, G.M. and Murthy, V.S. (2007): Effects of reinforcement form on the behavior of geosynthetic reinforced sand, Geotextiles and Geomembranes, 25(1), 23-32, doi:10.1016/j.geotexmem.2006.09.002.
6) Naeini, S.A. and Gholampoor, N. (2014): Cyclic behaviour of dry silty sand reinforced with a geotextile, Geotextiles and Geomembranes, 42(6), 611-619, doi:10.1016/j.geotexmem.2014.10.003.
7) Tafreshi, S.N.M. and Asakereh, A. (2007): Strength evaluation of wet reinforced silty sand by triaxial test, International Journal of Civil Engineering, 5(4), 274-283, doi:10.1016/j.geotexmem.2014.10.003.