Specimen size effect in triaxial testing of geotextile reinforced sand

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ABSTRACT: Quantification of shear strength of soils is often done using small scale tests, results of which are influenced by the sample size and boundary effects. In the present study, realistic estimate of the shear strength of unreinforced and geotextile reinforced sand with varying quantity of reinforcement is presented through large scale triaxial tests and the effect of sample size on the strength is studied through triaxial tests on reinforced soil specimens of different sizes. Triaxial specimens were of diameter 38, 50, 70 and 300 mm with height to diameter ratio of 2 in the tests. Specimens were reinforced with layers of woven geotextile.From the experimental results it was observed that the reinforced specimens sustained more loads than unreinforced specimens, at all the strain levels. While the specimen size did not show considerable effect on the behavior of unreinforced sand, the effects are more pronounced in case of reinforced sand specimens. Results showed that the beneficial effect increased with increase in the quantity of reinforcement. However, the maximum strength improvement observed in 300 mm specimens is only about twice with the inclusion of six layers of geotextiles, whereas it was about four times for 38 mm test specimens. This study brought out the limitations of small scale testing on reinforced sand.

Keywords: large triaxial tests, shear strength, reinforced sand, geotextile, size effects

1 INTRODUCTION

Though the use of geosynthetics for soil reinforcement dates back to 60 years, laboratory studies available on the precise assessment of geosynthetic reinforced sand are limited. Most of the available studies are of small scale and there seems to be no accepted guidelines available on the minimum element sizes for such tests. Several earlier researchers have studied the stress-strain response and strength characteristics of reinforced soil using triaxial tests (e.g.Chandrasekaran et. al 1989, Gray and Al-Refeai 1986, El- Naggar et. al. 1997, Haeri et. al 2000, Latha and Murthy 2007, Zhang et. al., 2006 and Nguyen et. al., 2013). Previous studies of reinforced sand showed that the inclusions of reinforcements markedly increase peak shear strength, axial strain at failure, and reduced the loss of post peak strength. Previous research also reported that the responses of reinforced sand are greatly influenced by confining pressure, spacing of reinforcement, type and stiffness of reinforcement, and specimen size.

Not many researchers have attempted to use triaxial specimens of size greater than 100 mm diameter to estimate the shear strength of reinforced sands. Several researchers have investigated the specimen size effect of unreinforced sand using triaxial tests (Scott 1987, Jefferies et. al 1990, Omar and Sadrekarimi 2014, Hu et. al., 2010, Sung- Sik Park and Sueng Won Jeong 2015). Previous studies on unreinforced sand concluded that the peak behavior of smaller specimen was not affected by the specimen size, whereas the post peak behavior significantly depends on specimen size, larger specimen showing very rapid drop to a stable residual strength.

Until now, little attention was given to the specimen size effect on testing of reinforced soils. Haeri et. al., 2000 studied the effect of specimen size on the mechanical behavior of geotextile reinforced sand specimens. Triaxial compression tests were conducted on two sizes of specimens; 38 mm and 100 mm diameter.

Results from this study demonstrated that the size effect is negligible for unreinforced specimen. In contrary, size effects were found to be prominent in case of reinforced specimens. It was observed that the confinement enhancement due to inclusion of geotextile layers as reinforcement is much pronounced in smaller size specimens, which exhibited unduly high strength compared to larger specimens.

This paper studies the effect of specimen size on the stress- strain response of geosynthetic reinforced dry sand using triaxial compression tests. A series of triaxial compression tests were conducted on specimens of four different sizes by varying the number of geotextile layers. What makes this study unique and important is the triaxial testing undertaken on large diameter specimens of 300 mm along with the smaller specimen sizes 38, 50 and 70 mm.

2 MATERIALS USED FOR TESTING

2.1 *Sand*

Fine, sub- rounded sand was used in this study. Grain size distribution of the sand is shown in Fig. 1. Based on the Unified soil classification, the soil is classified as well graded sand with little fines (SW).Properties of sand are given in Table.1.

Table 1. Properties of test sand.

Property	**Value**
D_{10}	0.07 mm
D_{50}	0.24 mm
D_{30}	0.175 mm
D_{60}	0.29 mm
Coefficient of curvature C_c	1.5
Coefficient of uniformity C_u	4.14
Minimum void ratio e_{min}	0.457
Maximum void ratio e_{max}	0.832
Maximum dry unit weight γ_{max}	17.8 kN/ m^3
Minimum dry unit weight γ_{min}	14.1 kN/ m^3

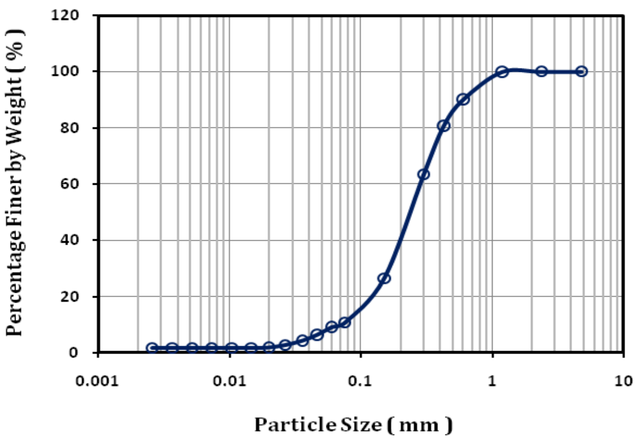


Figure 1. Grain size distribution curve for the sand

2.2 *Geotextile*

Woven geotextile, made of polypropylene was used to reinforce the sand specimen. The ultimate tensile strength of the geotextile was obtained as 55 kN/m from wide-width strip tension test as per ASTM D-4595. Thickness of the geotextile was 0.5 mm.

3 TRIAXIAL COMPRESSION TEST

To study the effect of specimen sizes on the mechanical behavior of unreinforced sand and reinforced sand specimen, four different sizes of specimens of 38 mm, 50 mm, 70 mm, and 300 mm diameter with an aspect ratio of 2 were used. All specimens were prepared by using dry sand at constant relative density of 70 %, which corresponds to a unit weight of 16.4 kN/m^3. A standard method for preparing dry sand specimen for testing in triaxial test apparatus was adopted as recommended by Bishop and Henkel (1969). The specimens were prepared by compacting in several layers using a tamper consisting of circular disc of diameter slightly less than the mold diameter. The unreinforced specimens (UR) were compacted in three layers for all sizes of specimens. For reinforced specimens, the compacting layers were selected based on the number of reinforcement layers. After compacting and leveling of the each layer of sand, geotextile disc of diameter slightly less than the specimen diameter was placed horizontally. The number of geotextile layers was varied from one layer to six layers in different test series GT1 to GT6, as shown in Fig. 2. Fig. 3 shows the triaxial test set-up used and the prepared specimen of 300 mm diameter and 600 mm height.

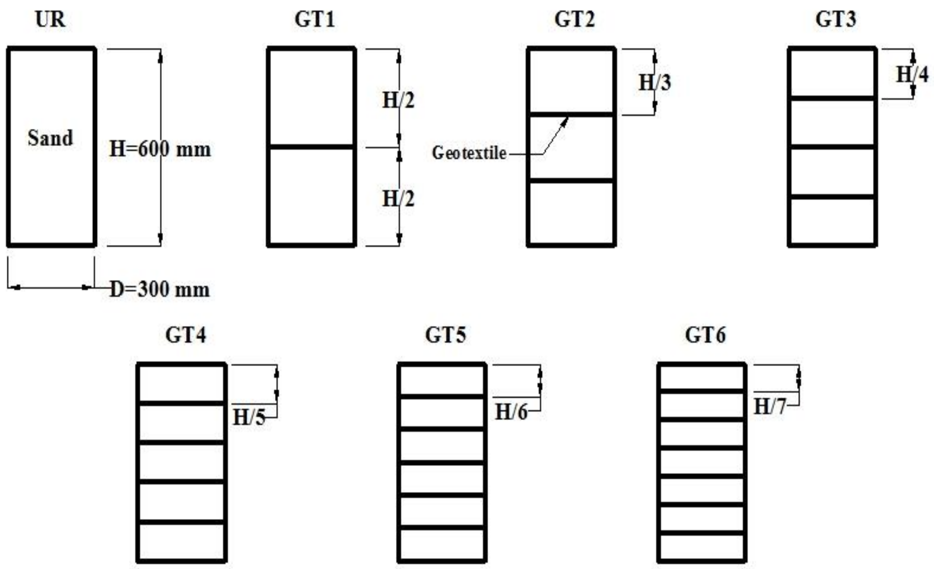


Figure 2. Arrangement of geotextile layers in at different test series

Figure3. Triaxial set-up and prepared 300 mm diameter unreinforced specimen

4 RESULTS AND DISCUSSION

4.1 *Unreinforced specimens*

Stress- strain response of unreinforced sand specimen of sizes of 38, 50, 70 and 300 mm of diameter tested at three different confining pressures of 60, 110 and 160 kPa are compared in Fig.4. The deviator stress mobilization throughout the test was consistently larger in the smaller specimens. Post peak strength drop is more in larger diameter specimens. Failure strain increased with increase in specimen size and confining pressure. By plotting normal stress vs, shear stress, cohesion (*c*) and angle of internal friction (ϕ) of unreinforced specimens of different sizes were calculated and presented in Table.2. From Table.2 it can observed that the friction angle decreased with increase in specimen size, the reduction of friction angle is about 4.4^{o} from diameter decrease from 38 mm to 300 mm diameter. Though there is no clear trend on the value of cohesion obtained, it can be seen that it is affected more compared to the friction angle. Considering the huge variation in sample size between 38 mm and 300 mm, the change in friction angle is less than 10% and can be considered to be insignificant. While the smaller sized specimens showed very less drop in strength after the peak, larger specimens showed clear drop in deviator stress beyond the peak. From Fig.4 it can be observed that the initial stiffness of the soil improved with decrease in specimen size. This observation is similar to the findings of Jefferies et. al.,(1990) and Hu et. al.,(2010).

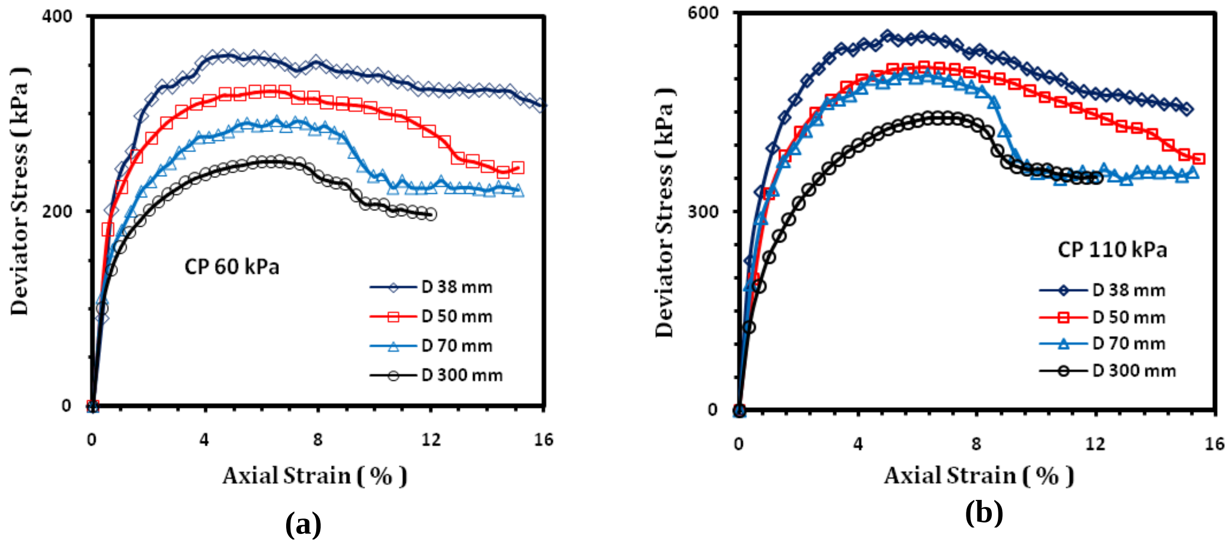


Figure 4. Comparison of stress- strain response of sand specimens of different diameters (a) confining pressure of 110 kPa (b) confining pressure of 160 kPa

Table2. Shear strength parameters of unreinforced sand in triaxial test

Specimen diameter mm	Cohesion (*c*) kPa	Angle of internal friction (ϕ)Degrees
38	12	44.9
50	20.5	41.4
70	15.0	41.4
300	6.8	40.5

4.2 *Reinforced specimens*

The effect of specimen size on the stress strain response of reinforced sand is shown in Fig. 5. Figs. 5a to 5f show the stress strain response of reinforced specimens of four different sizes (38, 50, 70 and 300 mm diameter) reinforced with one, two, three, four five and six layer of geotextile respectively, tested at a confining pressure of 60 kPa. It can be observed from Fig.5 that the size effect for reinforced sand is very important. Small size specimens show significantly higher strength, even the specimen size effect is more pronounced between 38 mm and 50 mm diameter specimens, on contrary to unreinforced sand. The size effect more pronounced with higher number of geotextile layers tested at low confining pressure at 60 kPa. From this observation, it was concluded that the confinement enhancement provided by reinforcement is more pronounced in smaller size specimen. The stiffness of the reinforced specimen depends on the stiffness of the reinforcement. The reinforced specimens of all sizes have higher stiffness compared to that of unreinforced specimen. The increases in stiffness are well pronounced with increase in confining pressure and greater number of geotextile reinforcement layer. From Fig.5, 300 mm diameter reinforced specimen shows the lower stiffness compared to other sizes (38, 50, and 70 mm) of the specimens; the stiffness of reinforced specimen increases with decreases in sizes of the specimens.

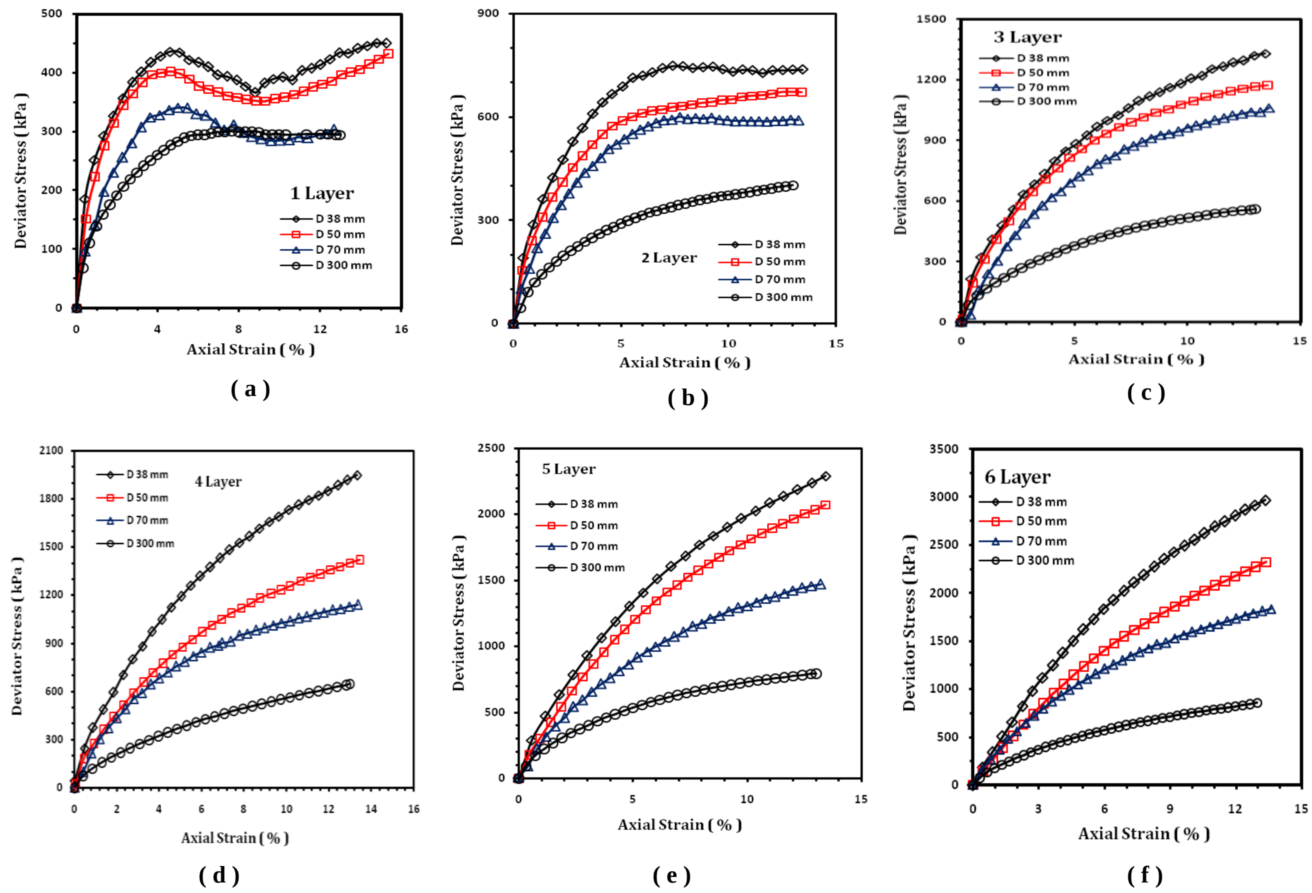


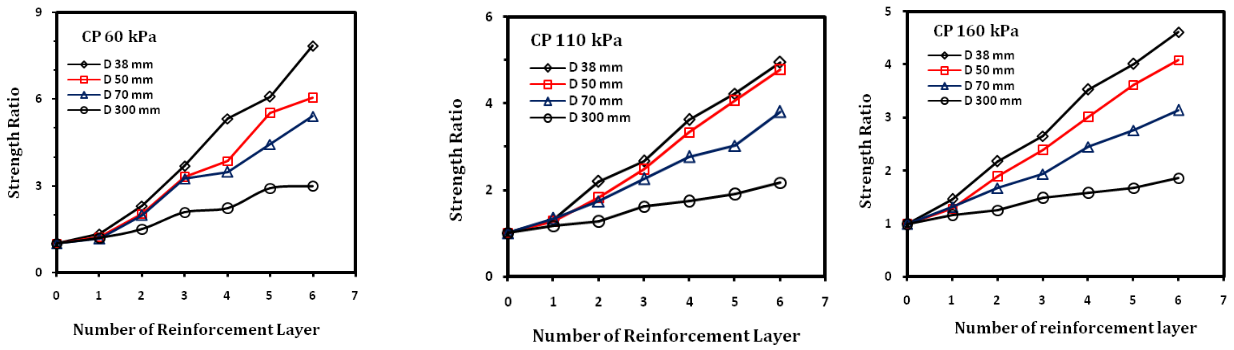
Figure 5. Stress-strain response of geotextile reinforced sand specimens of four different sizes tested at confining pressure of 60 kPa (a) one layer (b) two layer (c) three layer (d) four layer (e) five layer and (f) six layer

Shear strength properties calculated for different reinforced specimens is given in Table 3. It should be noted that some of the reinforced specimens, especially the ones with more number of reinforcing layers, did not fail within the test limits of the set-up. In such cases, the peak deviator stress for the calculation of shear strength parameters is extrapolated by fitting the stress-strain response to a hyperbola, as suggested by Janbu (1963). Not much information could be extracted from the comparison of cohesion and friction angles for reinforced specimens of different sizes, except that with the increase in specimen size, the shear strength parameters reduced to a great extent. To understand the effect of specimen size more clearly, strength ratios are plotted.

The strength ratio is defined as the ratio of peak deviator stress of reinforced sand specimen to that of peak deviator stress of unreinforced sand specimen, since, peak stress was not observed for the specimens reinforced above two layers of geotextile, deviator stress at 10 % of axial strain was taken as reference for comparisons. Fig. 6 shows the effect of specimen sizes on the strength ratio. It can be observed from the Fig. 6 that small sized specimens showed higher strength ratio and the strength ratio decreases with an increase in the specimen size. For example, the 38 mm diameter size specimen reinforced with six layers of geotextile tested at 60 kPa confining pressure showed the maximum strength ratio of 7.85 and the ratio decreased to about 4.61 at a confining pressure of 160 kPa, whereas the maximum strength ratio of 3 was obtained for 300 mm diameter specimen reinforced with six layers of geotextile, tested at confining pressure of 60 kPa and the strength ratio decreased to 1.86 at a confining pressure of 160 kPa. However the difference in the strength ratio was not observed between all four different sizes of specimens reinforced with one layer geotextile and these differences in the strength ratio between different sizes of specimens became more evident with an increase in the number of geotextile layers. These results are in agreement with the observations by Haeri et. al.,(2000). Increase in the strength ratio is nonlinear with the increase in quantity of reinforcement, the nonlinearity decreasing with the increase in confining pressure.

Table 3 Strength parameters of reinforced sand from triaxial test

Specimen diameter mm	**Number of reinforcing layers**	**Cohesion (*c*) kPa**	**Friction angle (ϕ) degree**
38	0	12	44.9
	1	13	49.5
	2	80	54.4
	3	149	56
	4	312	56.4
	5	310	59
	6	483	59.2
50	0	20.5	41.4
	1	21	45.8
	2	48	51
	3	116	55.7
	4	253	55.4
	5	352	55
	6	338	61
70	0	15	41.4
	1	27	45
	2	80	49
	3	160	50
	4	256	50.4
	5	497	40
	6	590	40
300	0	6.8	40.5
	1	10	42.8
	2	37	44
	3	93	44
	4	130	40
	5	177	40
	6	212	40



(a) (b) (c)

Figure 6. Variation of strength ratio with number of reinforcement layers for four different sizes of reinforced specimens: (a) confining pressure of 60 kPa; (b) confining pressure of 110 kPa and (c) confining pressure of 160 kPa.

It is evident from this study that the specimen size effects play major role on the stress-strain response and thus the shear strength of reinforced specimens in element tests. Reason for the decrease in strength with increase in size for unreinforced specimens is the extra stiffness acquired by the smaller sized specimens due to boundary effects. However, in case of reinforced sands, along with the boundary effects, the behavior of sand confined between layers becomes different with different specimen sizes. Increased volume of sand between reinforcing layers could provide more flexibility to movement, reduction in stiffness and also less confined atmosphere for bigger sized specimens, hence leading to lower strength in comparison to smaller sized specimens. It is possible that in a 300 mm diameter sample, sand in between the reinforcing layers also can reach a state of failure, unlike in case of 38 and 50 mm samples, where it is impossible for the sand layer to fail due to proximity of geotextile layers that are sandwiching the sand layer. To demonstrate these effects, further studies are in progress.

5 CONCLUSIONS

Conclusions and discussion points are summarized as follows.

- Specimen size effects are more pronounced in case of reinforced sand specimens compared to unreinforced specimens. In case of unreinforced specimens, the difference in behavior with change in specimen size is more pronounced in post peak drop of shear strength and initial stiffness of the specimens.
- In unreinforced specimen the failure stress was not affected between the specimen sizes; 38, 50, 70, mm diameter. Whereas the difference in failure stress was significant with 300 mm diameter specimen.The initial modulus and post peak behavior were greatly changed by the specimen size.
- The specimen size effect for reinforced sand is significant. Smaller sized specimens exhibited higher peak strength compared to that of large sized specimens.
- Effect of specimen size is more at higher number of reinforcing layers.
- Strength ratios decreased with increase in specimen size.

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