Investigation of sand-geotextile interface behavior by laminated shear test

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ABSTRACT: In this study, large-scale laminated shear test apparatus was employed to investigate the mechanical behaviour of both the sand-sand and sand-geotextile interfaces. Influence of magnitude of normal stress was evaluated by conducting a series of shear tests on the pure sand and the reinforced sand. The dilation properties of the whole specimen as well as the local deformation near shear plane were investigated by analyzing the displacement obtained from each shear ring. Results shows that the value of normal stress had important influence on the deformation properties of sand. Although the peak shear strength for specimens with different interfaces was similar, the role of geotextile in restraining the deformation of sand was confirmed with the smaller dilation rate at the initial shearing period and the smaller horizontal displacement observed near the shear plane in the reinforced sand. Besides, the spatial distribution of the horizontal displacement in each shear ring was observed to be similar for both the pure sand and sand-geotextile specimen.

Keywords: geosynthetics; interface behavior; laminated shear test; shear band; dilatancy

1 INTRODUCTION

The interaction mechanism between soil and geosynthetics has always been the major concern among the researchers in geosynthetic properties, as it directly influences the internal stability and the behavior of reinforced soil structures. Up till now, extensive experimental investigation has been carried out by direct shear tests and pull-out tests, in which the effect of different factors on the properties of sand-geosynthetic interface were evaluated. The major focusses in these studies include the mechanical and geometric properties of geosynthetics, mechanical and physical properties of soil, and the loading condition (Lee and Manjunath, 2000; Xu et al., 2004; Palmeira E M., 2009; Anubhav and Basudhar, 2013; Hatami and Esmaili, 2015; Bathurst and Ezzein, 2016). Besides, the testing device also plays an important role in evaluating the interface behavior, with the sample size, the shear box and the stiffness of the loading plate involved. According to Lee and Manjunath (2000), due to differences in the boundary and testing condition of the testing apparatus, large variations are commonly observed in test results.

Recently, the laminated shear apparatus has gained more and more attention in the study of soil–geosynthetics interface behavior. It has a unique configuration which is composed by multiple layers of ring. Unlike the direct shear test, the failure plane of the test sample in laminated shear test is no longer fixed, which could better simulate the failure mechanism at the soil-geosynthetic interface. Most of the previous ring shear tests are commonly conducted to evaluate shear strength and failure mechanism at the soil-geosynthetic interface (Ding et al., 2006; Wang et al., 2008; Jiang et al., 2015). But limited studies have been carried out to understand the deformation mechanism of soil-geosynthetic interfaces, especially the local behavior, i.e., the shear banding development and particle crushing in large displacement.

This paper presents an experimental study on the interface behavior involving sand and geotextile using the large-scale laminated shear test apparatus. A series of experiments was conducted to study the shear behavior of sand-sand and sand-geotextile interface. Special attention is paid on the strength and volume change of the testing samples with the aim to obtain a better understanding of the shearing mechanism at sand-geosynthetic interfaces.

2 LARGE-SIZE STACKED RING SHEAR TEST

2.1 *Apparatus*

The large-size stacked ring shear apparatus in Yangtze River Scientific Research Institute was employed in this research. The size of test sample is L60cm*W60cm*H60cm. The apparatus mainly consists of the loading system, the upper laminar shear box with 7 pieces of vertically stacked metal rings, the lower shear box and the data acquisition system. Fig.1 shows the rectangular rigid rings, with a height of 30 mm for each ring. Rolling bearings are placed between the rings and the lateral braces to reduce the amount of friction. Seven pieces of 2 mm thick felt was inserted in between two rings, which is small enough to ensure the sand particle to be kept inside the rings.

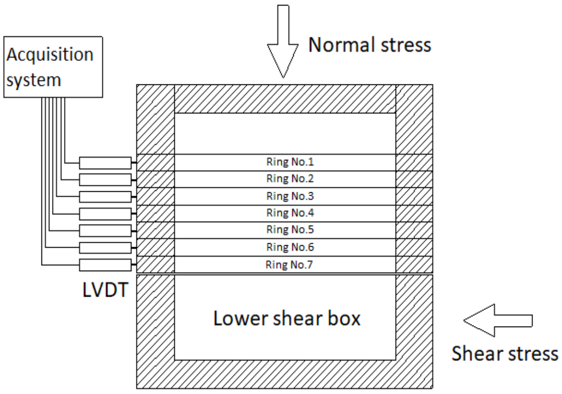

Figure 1. Schematic view of laminated shear apparatus.

2.2 *Material*

Table 1 shows the basic properties of the fine gravel soil used in the current study. Based on the consolidated undrained shear test, its strength indexes are $\varphi=36^{\circ}$, c=6.8kPa. Table 2 shows the mechanical properties of the polyester woven geotextile.

Table 1. Physical properties of soil samples

Grain distribution (%)				Cu	Cc	ρ_{dmax} (g/cm^3)	ρ_{dmin} (g/cm^3)
5~2mm	2~1mm	1~0.5mm	<0.5mm	2.22	0.91	1.886	1.585
20	20	40	20				

Table 2. Mechanical properties of polyester woven geotextile

Breaking strength (kN/m)	Breaking elongation (%)	Tensile strength at 2% Elongation (kN/m)	Tensile strength at 5% elongation (kN/m)
126.9	12.05	37.36	76.02

2.3 *Test procedures*

In most of the previous direct shear tests, geotextiles were usually glued onto the surface of the lower box, which was different from the state in site. In order to better represent the function of reinforcement in practice, the geotextile in the current study was changed to a wrapped-face arrangement, as is shown in Fig.2. In this way, the slippage or distortion of the geotextile during the shearing period could also be efficiently reduced. The sand was placed over the geotextile in the upper shear box and a relative density around 70% was achieved by tamping.

Two series of laminated shear tests were conducted. The first series of tests was on sands and the other series was on the soil-geotextile interface. In both series, four tests are performed under the normal stress of 25kPa, 50kPa, 100kPa and 150kPa respectively. The load was applied after completing the testing sample. Then a period of creep was allowed, followed by a monotonic shearing under the speed of 1mm/min by the application of load horizontally. The lateral displacement of each ring was then recorded through the Linear Variable Differential Transformer (LVDT). The normal stress and shear stress were also measured by load cells at the acquisition frequency of twice per second.

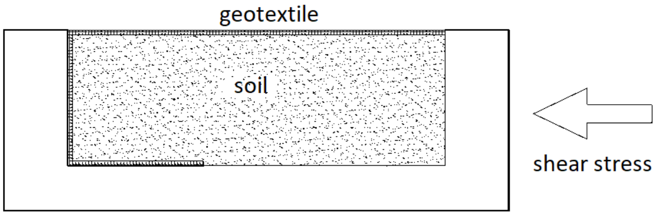

Figure 2. Sketch of wrapped geotextile.

3 RESULT AND DISCUSSION

3.1 *Strength and dilation properties for both interfaces under different normal stresses*

The stress-strain behavior of both the soil-soil interface and the soil-geotextile interface under different normal stress are shown in Fig.3. The solid symbol represents the sand-only sample and the circle one is the reinforced sand. It could be observed that the peak shear stress increased with an increase in normal stress, which was due to the larger frictional resistance on the plane of shear failure when the testing sample was subjected to a larger normal stress. For both interfaces, the peak shear stress did not show large difference and was attained at similar shear displacement. In comparison to the soil-soil interface, the soil-geotextile interface exhibited a distinct peak and post-peak shear stress behavior and a slight larger initial slope under the larger normal stress of 150 kPa, indicating a faster shear strength mobilization in sand-geotextile interface.

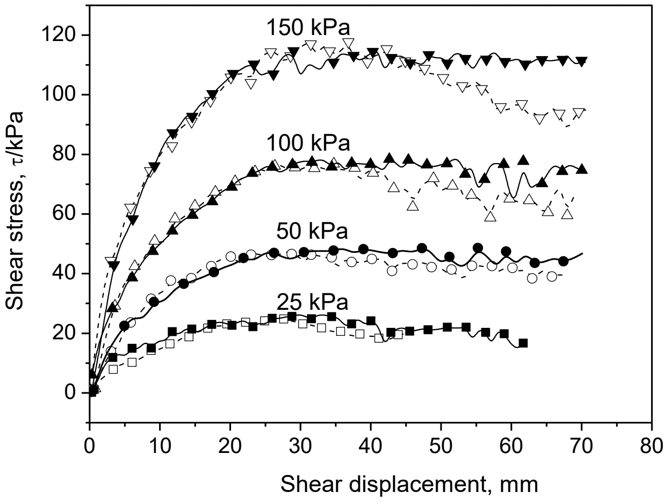

Figure 3. Relationship between shear displacement and shear stress for both interfaces under different normal stress.

One of the important characteristics in soil mechanics is the behavior of volumetric changes during shear deformation, so called stress-dilatancy relationships. This relationship is defined as the ratio between the changes of plastic volumetric strain over the changes of plastic shear strain with regards of the applied shear stress. Since the lateral deformation of the testing sample is not allowed during the test due to the rigid shear box and laminated shear rings, the variation in vertical displacement, in a way, could be taken as the volumetric change. Fig.4 represents the dilation property of the sample by plotting shear displacement against vertical displacement. From Fig.4 it was observed that in most cases, during the shearing process, the vertical deformation could be classified into three stages, which were the initial contraction, followed by an obvious dilation, and finally approached the constant volume (the residual state). In addition, the rate of the expansion due to dilatancy was obviously related with the magnitude of the normal stress. With a smaller normal stress, the vertical displacement became larger under the same value of shear displacement, i.e., the more volumetric increment. Particularly for the test case under 25kPa, a continuous dilation was observed until the end of the test. Comparison of tests shown in Fig.4 also indicated that dilation in sand-sand interface are larger than the corresponding values for sand-geotextile interface during the initial shearing period, indicating the effect of reinforcement in restraining the sand deformation.

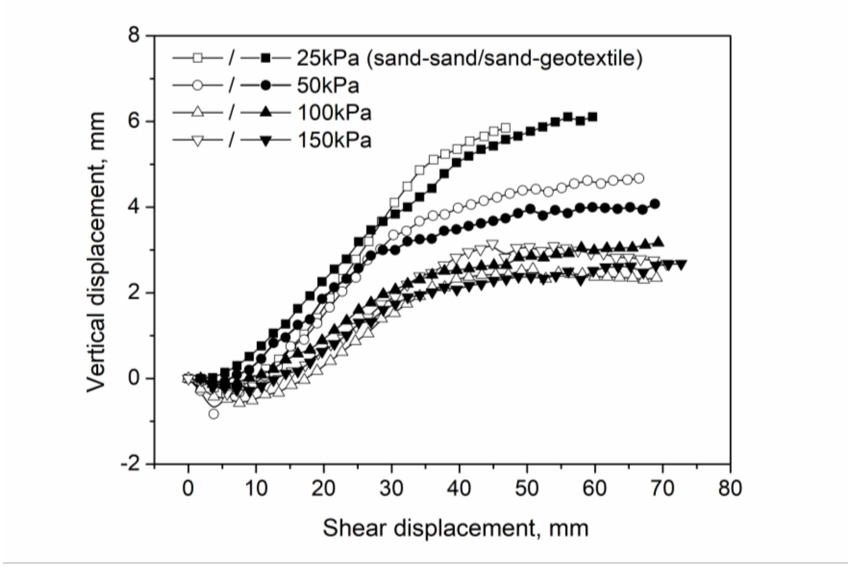

Figure 4. Relationship between shear displacement and vertical displacement for both interfaces under different normal stress.

3.2 *Deformation properties during shearing for specimens with sand-geotextile interfaces*

Except for the global behavior of sand, another focus of this study is the local behavior of sand nearby the sand-geotextile interface, which is the soil elements movement by observing the movements of each vertically arranged ring. During the shearing process, movement of the lower box would induce the deformation of the sand particles in the upper laminated shear box, and the deformation of each ring was measured by the LVDT connected to the shear box. As mentioned above, the volumetric variation in this study could be simply considered as the change of deformation in vertical direction due to the constant radial strain. Thus, the stress dilatancy relationships shown in Fig.5 describe the changes of volumetric strain during different stages of shear deformation.

Fig.5 shows the horizontal displacement of rings No.1, No.3. No.5 and No.7 for all test cases in sand-geotextile interface. It can be noticed that the horizontal displacement of each shear ring was derived from the misalignment of the beneath soil particles, and such effect turned to be less pronounced or diminished with the increase in the influencing distance. In addition, similar patterns of the variation in horizontal displacement and vertical displacement were observed excepted for the case under 25kPa of normal stress. That is, in the initial period, the rate of increase in both of the horizontal displacement and vertical displacement was rather large, and then the growth became slow down after the peak shear strength. Nevertheless, for test case under 25kPa in Fig.5(a), a continuous growth of vertical and horizontal displacement was observed, indicating a more significant dilation of soil under lower stress. This phenomenon could be explained by the fact that under large normal stress, indentation or plowing of geotextile surface by the sand particles could take place, which in turn required a larger amount of shear force to displace the sand particles.

3.3 *Local deformation in each shear ring for both interfaces*

Fig. 6 shows the movement of each ring along the vertical direction for both specimens with and without geotextile under normal stress of 100kPa, respectively. The horizontal displacements at height of 0 mm represented the shear displacement of the moveable pedestal box. An obvious reduction of the horizontal deformation of rings from bottom to top was noticed in both interfaces. Compared with the specimen without geotextile, smaller displacements were observed in specimen with geotextile for the most bottom ring (No.1), indicating a stronger restrain effect due to the existence of reinforcement. However, for rings above 60mm from the shear plane, a slight larger horizontal displacement was noticed in the sample with geotextile.

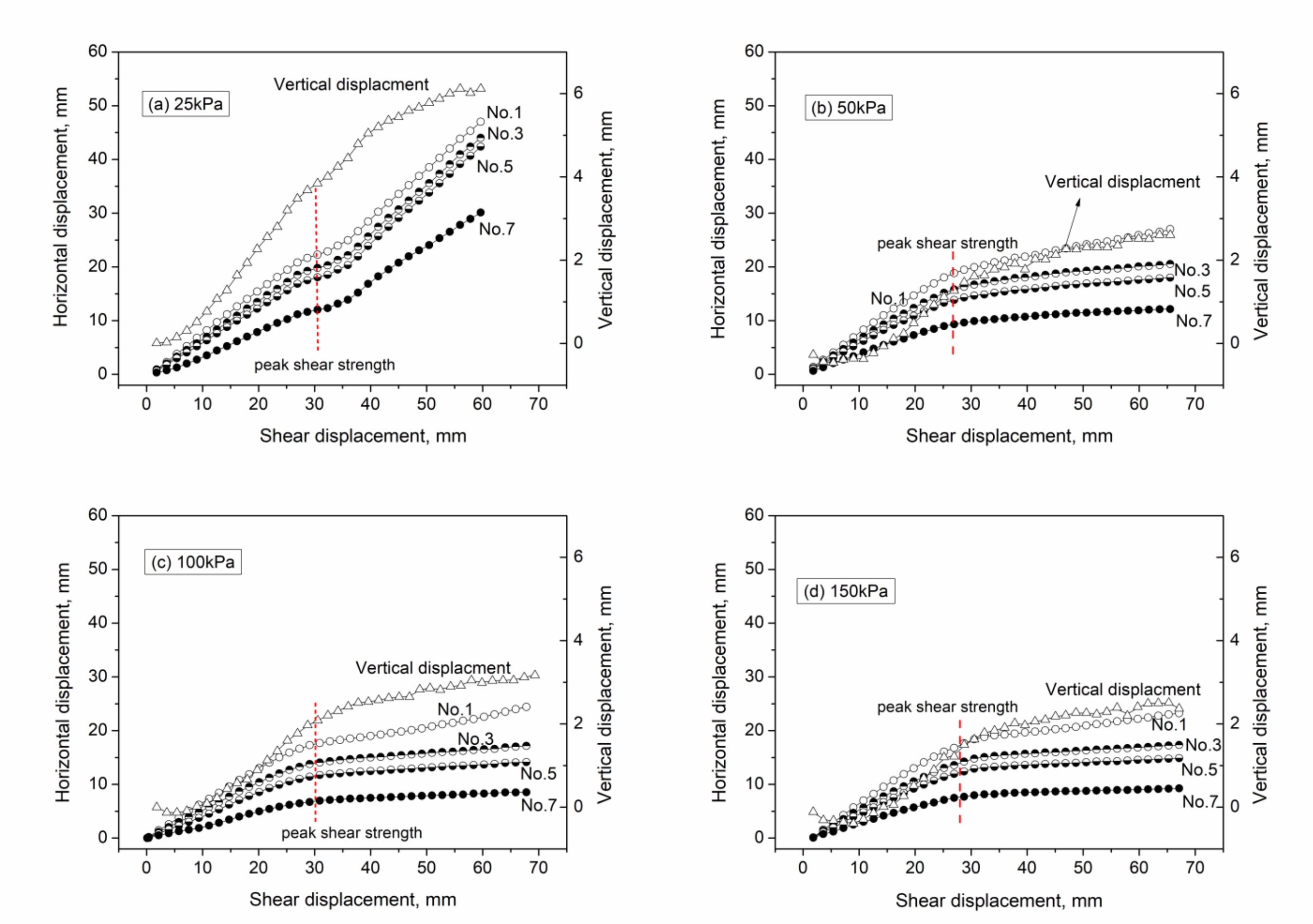

Figure 5. Relationship between shear displacement and horizontal/vertical displacement in different rings for sand-geotextile interface.

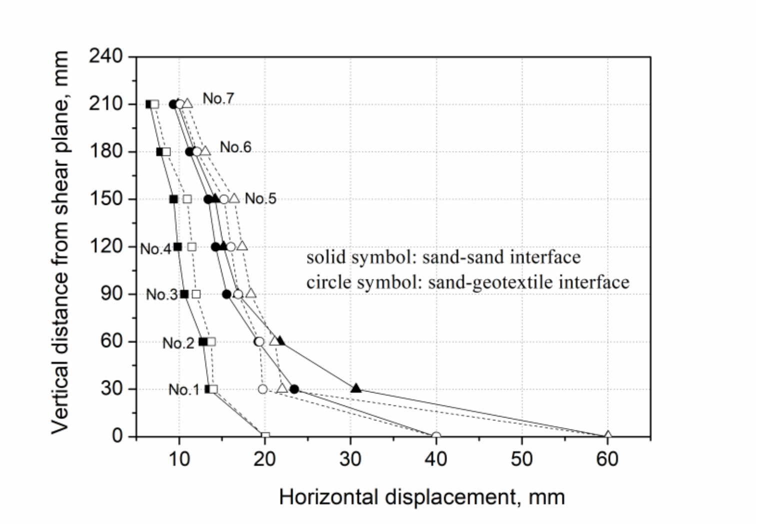

Figure 6. Horizontal displacement of rings under different shear displacement (100kPa).

Fig.7 shows the horizontal displacement of each ring at the peak shear stress state. For the test case of sand-only specimen (Fig.7a), good positive correlations were found between the normal stress and the horizontal deformation of shear rings. However, the differences in horizontal displacements of sand-geotextile specimens were rather small under different normal stresses. This phenomenon implied the predominant function of geotextiles in evaluating the strength of testing samples. By analyzing the localized horizontal displacement of each ring in Fig.7, it is worth noting that similar deformation appeared among certain rings along the vertical direction for all the tests. That is bottom rings (No.1~No.2) close to the shear plane, middle rings (No.3~No.5) and top rings (No.6~No.7) which were influenced by the loading plate. Such small relative displacement among certain adjacent rings was observed regardless of the normal stress and the existence of geotextile. Similar conclusion was also mentioned by Feng et al. (2012).

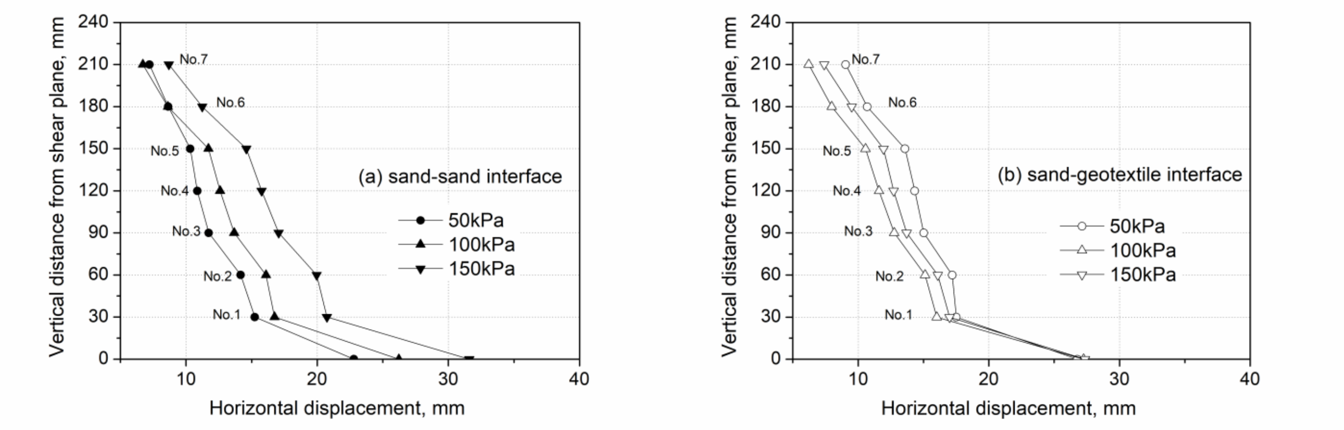

Figure 7. Horizontal displacement of seven shear rings under the peak shear stress in both interfaces.

4 CONCLUSIONS

In this paper, large-scale laminated shear test was performed to observe the interface behavior of soil-soil and soil-geotextile. With aid of different shear rings, the local deformation near the shear plane was obtained and the role of geotextile was investigated in governing the shear behavior of the reinforced testing samples. Based on the experimental results, the following conclusions could be drawn:

(1) No significant difference was observed in the peak shear strength between reinforced and unreinforced sands. However, during the initial shearing period with small shear strain, the dilation in sand-sand interface are more obvious than the corresponding values for sand-geotextile interface.

(2) For samples of both interfaces, the vertical deformation during shearing was influenced by the value of normal stress, with largest vertical deformation observed in specimen under smallest normal stress.

(3) Along with shearing process in reinforced sand, the change in the vertical displacement of the whole specimen and horizontal displacement of different shear rings showed similar patterns.

(4) Smaller horizontal displacement was found at the lower rings near the shear plane in sand with geotextile. For both interfaces, same distribution properties of horizontal deformation along the vertical direction was found regardless of the normal stress and the existence of geotextile.

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