Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Direct shear behavior of sand geomembrane systems for various shear boxes

C. HSIEH, M-W HSIEH, J. CHEN,
Department of Civil Engineering, National Pingtung University of Science and Technology, Pingtung, Taiwan

ABSTRACT: ASTM D-5321 standard test method is adopted for measuring the shear strength of the interface of the test soils and geomembranes. In general, the shear strength for larger shear box is greater than that associated with smaller shear box. However, the shear strength associated with 300x300 mm and 400x400 mm shear boxes is almost identical to one another. Thus, a minimum dimension of 300 x 300 mm direct shear box is recommended to be used for determining the shear strength at the interface of a sand/geomembrane system. The shear strength parameters associated with flexible loading plate are less than those obtained from the test using a rigid load plate with few exception. In addition, the direct shear test performed using a flexible load plate showed a better reproducibility of test data than that using a rigid load plate.

1 INTRODUCTION

The interface friction angle and adhesion between a geosynthetic and soil are the primary variables used in the stability analysis and design of many applications including waste containment facilities. Geosynthetics are also used to improve the protection of existing foundation soils and groundwater supplies from leakage of hazardous solutions. Interface direct shear tests are performed to provide an engineer the friction angle and adhesion coefficient for the various interfaces within the design. The direct shear test, as a form of quality control, is also used to ensure product compliance to the values used in design.

Currently, ASTM D-5321 standard test method is commonly used for determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic system by the Direct Shear Method. The scale effect of shear box on frictional behavior of soil/geosynthetics system has been addressed by different researchers (Takasumi et all, 1991, Criley and Saint John, 1997, and Bemben and Schulze, 1998), and found to be different based upon different studies. In addition, a stiff load plate (typically 26 to 40 mm thick steel plate) is often used to transfer vertical load over the test area. However, the distribution and magnitude of the normal stress acting in the friction interface is unknown (Blumel and Stoewahse, 1998). Therefore, the objective of the study is to determine the test box scale effect and the influence of load plate rigidity on the shear strength of two types of test sands and HDPE geomembrane interfaces.

2 PRINCIPLES OF DIRECT SHEAR TEST AND TEST STANDARD

The direct shear test is used to measure a frictional behavior of soils. Recently, the test was modified for evaluating frictional behavior when shearing geosynthetics against soils. During tests with geomembranes, the soil is forced to slide along a geomembrane under a constant rate of displacement, while a constant load is applied normal to the plane of relative movement. The maximum shear stress is obtained and the test is conducted at different normal confining pressures. Shear stress/displacement curves for specimens tested under different normal pressures, as well as the Mohr-Coulomb envelope, the cohesion or adhesion, and friction angles of soils and soil/geosynthetics system can be determined. Using the obtained data, the efficiency on friction (Eφ) and the efficiency of cohesion (Ec) can be calculated based upon the following equations:

$$E\varphi = (\tan \delta)/(\tan \varphi) \quad (1)$$
$$Ec = Ca/C \quad (2)$$

Where φ = soil internal friction angle; δ = friction angle of geomembrane against soil; C = soil cohesion; Ca = adhesion.

The Geosynthetic Research Institute (GRI) in early 1986 developed and promoted a standard method, GS6 for conducting geosynthetic interface direct shear tests, and in 1991 the American Society for Testing and Materials (ASTM) adopted the currently used D-5321 standard test method for "Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method". The ASTM standard test method was used in the study.

The standard test method suggested both square and rectangular shear boxes could be used; they should have minimum dimension that is the greater of 300 mm, 15 times the d_{85} of the coarse soil used in the test, or a minimum of five times the maximum opening size (in plan) of the geosynthetic tested. These dimensions are guidelines based upon requirements for testing most combinations of geosynthetics and soils. However, smaller shear boxes could be used if it can be shown that data generated by the smaller devices contains no scale or edge effects when compared to the above mentioned minimum size devices. Details of the test method are shown in the standard.

3 TEST APPARATUS

A large-scale direct shear machine was employed in the study. The large-scale direct shear machine was fabricated according to ASTM D-5321 standard test method with some modifications. The shear container was designed to be able to fit various sizes of shear boxes. Server controlled hydraulic vertical loading system and DC motor drove shear devices were employed. A computerized data acquisition system was setup to collect the displacement and shear stress data. A convention direct shear machine with 100 x 100 mm shear box was also used in the study.

In addition to the conventional rigid load plates (which were 26 to 40 mm thick steel plates), a flexible silicon membrane type water bladder attaching to the bottom of a conventional rigid load plate to form a flexible load plate is also used in the study.

A schematic view of the 300x300 mm flexible load plate is shown in Figure 1.

3.1 *Shear boxes*

In order to evaluate the scale effect of large-scale direct shear test of soil/geosynthetics systems, three different sizes of shear boxes were designed, fabricated and utilized in the study. To ensure a constant shearing area during the test, bottom shear boxes are commonly longer than the upper boxes. Upper shear boxes having 400x400 mm, 300x300 mm, and 200x200 mm shear areas were used in the study. The geosynthetics specimens were cut and glued to rigid supports within the lower boxes.

3.2 *Rigid load plate*

ASTM D-5321 standard specifies that load device should be capable of applying and maintaining a constant uniform normal stress on the specimen for the duration of the test. In general, the normal stress is applied to the top of the sample with weights, hydraulic jacks or hydraulic or pneumatic bellows. A rigid loading plate is often used for load distribution over the test area through a concentrated point load at the center (Fishman and Pal, 1994, and Blumel and Stoewahse, 1998). Theoretically, the concentrate point load requires a very stiff plate in order to uniformly transfer the applied load to the test specimen. However the distribution and magnitude of the normal stress acting in the friction interface during testing is unknown for the commonly used load plate. Therefore, the effect of load plate rigidity on the pressure distribution at the shearing plane is investigated in the study. To fit various sizes of upper shear boxes, three different rigid load plates were made, the dimension of the shear boxes are 200x200 mm, 300x300 mm, and 400x400 mm. For the 300x300 mm shear box, the dimension of the correspondence rigid load plate is 297x297 mm.

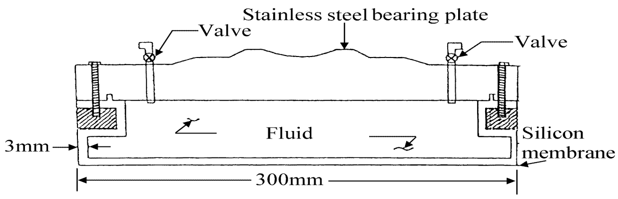

Fig 1. The assembly of the developed flexible load plate.

3.3 *Flexible load plate*

In order to investigate the effect of the rigidity of load plate on the normal pressure distribution at the shearing plane of direct shear test. A flexible silicon made membrane type water bladder attached at the bottom of the stiff load plate was designed. A schematic view of the assembly of the flexible silicon load plate is shown in Figure 1. As shown in the figure, the space between the flexible silicon bag and the rigid plate can be filled with water so that the applied normal force on the top of stiff load plate can be uniformly transferred to the test specimen. The developed flexible load plate can be used for any existing large-scale direct shear machine without a minor modification

3.4 *Data collection system*

A displacement transducer was used to measure the horizontal displacement. The normal applied force and the shearing force are measured by two 5-ton load cells with an accuracy of 0.5 kg. The data acquisition system is developed by the research group and written by Q-basic.

4 DESCRIPTION OF MATERIALS

4.1 *Geomembranes*

Two types high-density polyethylene (HDPE) geomembranes provided by a local manufacturer were used in the study; one smooth and one textured. The smooth geomembrane was manufactured by the standard blown film process. The average thickness is 1.862 mm. The textured sheet was a coextruded geomembrane manufactured using a blown film process having a textured outside layer fully integrated with the inside barrier layer. The asperities on the outside surface had an average height of 0.702 mm and the average core thickness of the textured geomembrane was 1.942 mm.

4.2 *Quartz sand and Li-kang sand*

A poorly graded rounded white quartz sand and a typical local river sand obtained from Li-kang river were used in the study. The gradation curves of the test sands are shown in Figure 2, D_{85} of the test sands are 1.0 mm and 0.9 mm, the uniform coefficient C_U are 1.0 and 3.0, respectively. The internal friction angles are 36 and 42 degrees and cohesion equals to zero for both test sands. Loose dry sands were used in the study. Dry unit weight was measured six times. The average dry unit weights of the quartz sand and Li-kang sand are 1.47 and 1.40 kg/cm^3, respectively. The variations of the dry unit weight are less than 0.5%. Therefore, the preparation of test specimen in the shear box is by placing method, and dry unit weight is used to control the sand layer thickness in the study. In each test, the sand was placed as reproducible as possible. For examples, a given constant quantity of sand was carefully placed in the box such that a known height was reached, but not exceeded. The authors assumed that the target density was reached in a constant manner.

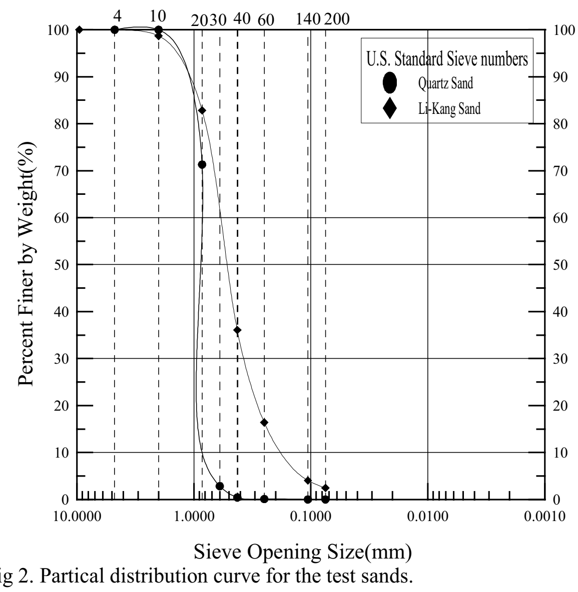

Fig 2. Partical distribution curve for the test sands.

5 RESULTS OF DIRECT SHEAR TESTS

A series of direct shear tests were performed to investigate the frictional behavior at the interface of sand/HDPE geomembrane systems. A smooth surface and a textured surface geomembranes provided by a local manufacturer were used in the study. The concentrated vertical loading was applied at center of loading plate, and the vertical loading is transferred through a rigid or a flexible loading plate to the shearing plane. Four different sizes of shear boxes were used in the study; the sizes are 100x100 mm, 200x200 mm, 300x300 mm, and 400x400 mm. The investigated conditions are summarized in Table 1.

5.1 *Scale effects on shear strength*

Typical shear stress versus normal stress curves at the quartz sand/smooth surface HDPE geomembrane interface for 100x100 mm, 200x200 mm, 300x300 mm, and 400x400 mm shear boxes under various normal pressures applied through a rigid load plate are shown in Figure 3. As shown in the figure, the stress-strain curves for 200x200 mm, 300x300 mm, and 400x400 mm shear boxes are quite similar to each other. However, the curves associated with 100x100 mm shear box are different from those for the other conditions. Since only 4.0 cm sand layer is placed in the 100x100 mm shear box, the difference among these stress-strain curves may induce by the edge effect and sand layer thickness effect. In general, the shear strength for larger shear box is greater than that associated with smaller shear box. However, the shear strength difference between that for 300x300 mm and 400x400 mm shear boxes is quite minimum.

Table 1 Summary of test conditions.

Geomembrane type	Loading Plate	Soil thickness	Box size	Quartz Sand	Li-Kang Sand
Smooth surface	Rigid	4cm	100×100mm	✓	NA
		9cm	200×200mm	✓	✓
			300×300mm	✓	✓
			400×400mm	✓	NA
	Flexible	9cm	200×200mm	✓	✓
			300×300mm	✓	✓
Textured surface	Rigid	4cm	100×100mm	✓	NA
		9cm	200×200mm	NA	✓
			300×300mm	✓	✓
	Flexible	9cm	200×200mm	NA	✓
			300×300mm	✓	✓

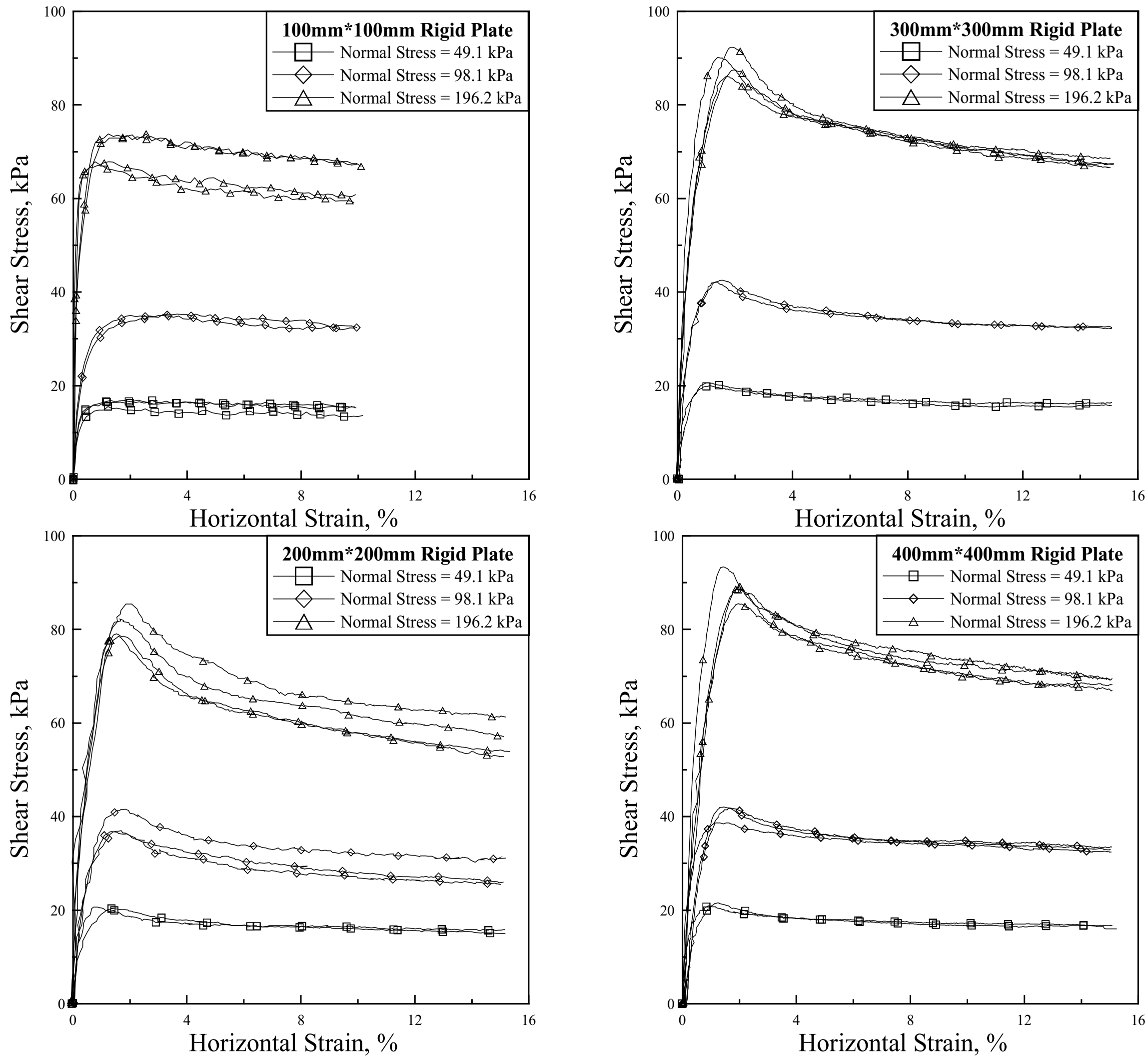

Fig 3 The stress-strain curves at the quartz sand/smooth HDPE geomembrane interfaces for various shear boxes with various loadings applied through a rigid load plate.

Based upon the stress-strain curves, the peak and residual shear strengths were used to determine the peak and residual strength parameters, respectively. The peak and residual envelopes at the quartz sand/smooth HDPE geomembrane interface for various sizes shear boxes are shown in Figure 4. The peak and residual frictional angles and their associated efficiencies are summarized in Table 2. As shown in the table, no cohesion was observed, and the friction angles for the quartz sand/smooth geomembrane interface would increase with increasing the box size. Moreover, the results obtained from 300x300 mm and 400x400 mm shear boxes are almost identical.

The comparison of the peak and residual friction angles for different box sizes with loading applied through flexible load plate is shown in Table 3. As shown in the table, scale effect is not significant factor for the tested conditions.

5.2 *Effect of load plate rigidity on shear strength*

The stress-strain curves at sand/smooth HDPE geomembrane interface for 300x300 mm shear box with various loadings applied through a rigid or a flexible load plate are shown in Figures 5 and 6 for the quartz sand and Li-kang sand. The stress-strain curves associated with rigid and flexible load plate are quite similar in shape, and the shear resistance associated with rigid loading plate is slightly greater than those associated with flexible load plate.

The comparison of the peak and residual friction angles for the tests performed using rigid or flexible load plate is shown in Tables 4 and 5 for the quartz sand and Li-kang sand, respectively. In general, the shear strength parameters associated with flexible loading plate are less than those obtained from the test using a rigid load plate with few exception.

5.3 *Effect of geomembrane surface texture on shear strength*

The stress-strain curves for smooth or textured surface HDPE geomembrane/sand interface with loading applied through a rigid load plate are shown in the Figures 7 and 8 for the quartz sand and Li-kang. It is clear that the shear resistance associated with the textured HDPE geomembrane is greater than that associated with smooth surface geomembrane. Please note that the shear strength associated with textured HDPE geomembrane increases with increasing the shear strain, no peak values were observed in the test.

Since the shear stress-strain curves associated with textured surface geomembrane loading through rigid load plate showed no peak values, only the residual friction angle was determined. The comparison of the shear resistance for smooth surface and textured surface geomembrane for difference box sizes is shown in Table 6. As shown in the table, the cohesion and internal friction angle associated with the textured geomembrane for larger shear box are greater than those for small shear box.

6 CONCLUSIONS AND DISCUSSIONS

This paper describes the study of the scale effect and the influence of load plate rigidity on the frictional behavior of sand/geomembrane systems. A flexible silicon membrane type bag is designed to attach at the bottom of conventional rigid load plate. From the results of the laboratory testing, the following conclusion can be drawn

The size of shear box has some effect on the shear strength at the interface of sand/geomembrane systems. In general, the shear strength for larger shear box is greater than that associated with smaller shear box. However, the shear strength behavior associated with 300x300 mm and 400x400 mm shear boxes is almost identical to each other. Thus, it is recommended that a minimum of 300 x 300 mm direct shear box should be used for determining the shear strength at the interface of sand/geomembrane systems.

The shear resistance associated with flexible and rigid load plates is quite similar to each other under same test conditions. However, the direct shear test performed using flexible load plate showed a better reproducibility of test data. Thus, it is recommended that a flexible loading mechanism should be used for large-scale direct shear test.

The shear resistance associated with textured HDPE geomembrane is greater than those associated with smooth surface geomembrane. The shear strength associated with textured HDPE geomembrane increases with increasing the shear strain, no peak values were observed. Stress-strain curve with peak value only occurs for sand/smooth geomembrane system under high normal stress condition. The friction angle for sand/textured geomembrane systems is about 12 to 19 degrees greater than that for sand/smooth geomembrane system.

7 A CKNOWLEDGEMENTS

The writers express their gratitude to Mr. Chia-hsing Wu, the Research Associate, who provided technical assistance for the study.

REFERENCES

– Bemben, S.M., and Schulze, D.A., 1998. The influence of equipment style and setup dimensions on sand/geomembrane direct shear test measurements. Proceedings of Sixth International Conference on Geosynthetics, pp. 453-458.
– Blumel, W., and Stoewashse, C., 1998. Geosynthetic Interface friction testing in Germany – effect of test setups. Proceedings of Sixth International Conference on Geosynthetics, pp. 439-442.
– Criley, K.R., and Saint John, D, 1997. Variability analysis of soil versus geosynthetic interface friction characteristics by multiple direct shear testing. Proceedings of Geosynthetics '97, IFAI, pp. 885-897.
– Fishman, K.L., and Pal, S., 1994. Further study of geomembrane/cohesive soil interface shear behavior. Geotextiles and Geomembranes, 13, pp. 571-590.
– Snow, M., Mansour, R., Swan, R.H., Kavazanjian, E., 1998. Variability of interface shear strengths. Sixth International Conference on Geosnthetic, pp. 439-442.
– Takasumi, D.L., Green, K.R., and Holtz, R.D., 1991. Soil-geosynthetics interface strength characteristics: a review of state-of-the-art testing procedures. Proceedings of Geosynthetics '91, IFAI, Atlanta, GA, pp. 87-100.

Table 2 The summary of the friction angles at the quartz sand/smooth geomembrane interfaces for various sizes of shearing boxes with loading applied through a rigid load plate.

Shear box size	Peak interface friction angle	Efficiency value ($E_{\psi p}$)	Residual interface friction angle	Efficiency value ($E_{\psi r}$)
100×100mm	19.7°	0.55	17.9°	0.50
200×200mm	22.4°	0.62	16.0°	0.44
300×300mm	24.2°	0.67	18.9°	0.52
400×400mm	24.1°	0.67	19.1°	0.53

Note Shear strength parameters for the test Quartz sand are C=0 and ψ=36.

Table 3 The summary of the friction angles at sand/smooth geomembrane interfaces for various sizes of shearing boxes with loading applied through a flexible load plate.

Sand Type	Shear box size	Peak interface friction angle	Efficiency value ($E_{\psi p}$)	Residual interface friction angle	Efficiency value ($E_{\psi r}$)
Quartz Sand	200×200mm	24.6°	0.68	18.2°	0.51
	300×300mm	23.4°	0.65	18.0°	0.50
Li-Kang Sand	200×200mm	26.1°	0.62	19.3°	0.46
	300×300mm	26.7°	0.65	20.8°	0.50

Table 4 The comparison of the results of direct shear tests of the quartz sand/geomembrane systems for different loading mechanisms and surface conditions (300x300 mm shear box).

Geomembrane type	Loading method	Peak interface friction angle	Efficiency value ($E_{\psi p}$)	Adhesion (kPa)	Residual interface friction angle	Efficiency value ($E_{\psi r}$)
Smooth surface	Rigid	24.2°	0.67	0	18.9°	0.52
	Flexible	23.4°	0.65	0	18.0°	0.50
Textured surface	Rigid	NA	NA	5.9	32.5°	0.90
	Flexible	NA	NA	1.4	33.6°	0.93

Table 5 The comparison of the results of direct shear tests of the Li-kang sand/geomembrane systems for different loading mechanisms and surface conditions (300x300 mm shear box).

Geomembrane type	Loading method	Peak interface friction angle	Efficiency value ($E_{\psi p}$)	Adhesion (kPa)	Residual interface friction angle	Efficiency value ($E_{\psi r}$)
Smooth surface	Rigid	28.1°	0.67	0	18.5°	0.44
	Flexible	27.7°	0.65	0	20.8°	0.50
Textured surface	Rigid	NA	NA	NA	37.4°	0.89
	Flexible	NA	NA	NA	35.5°	0.85

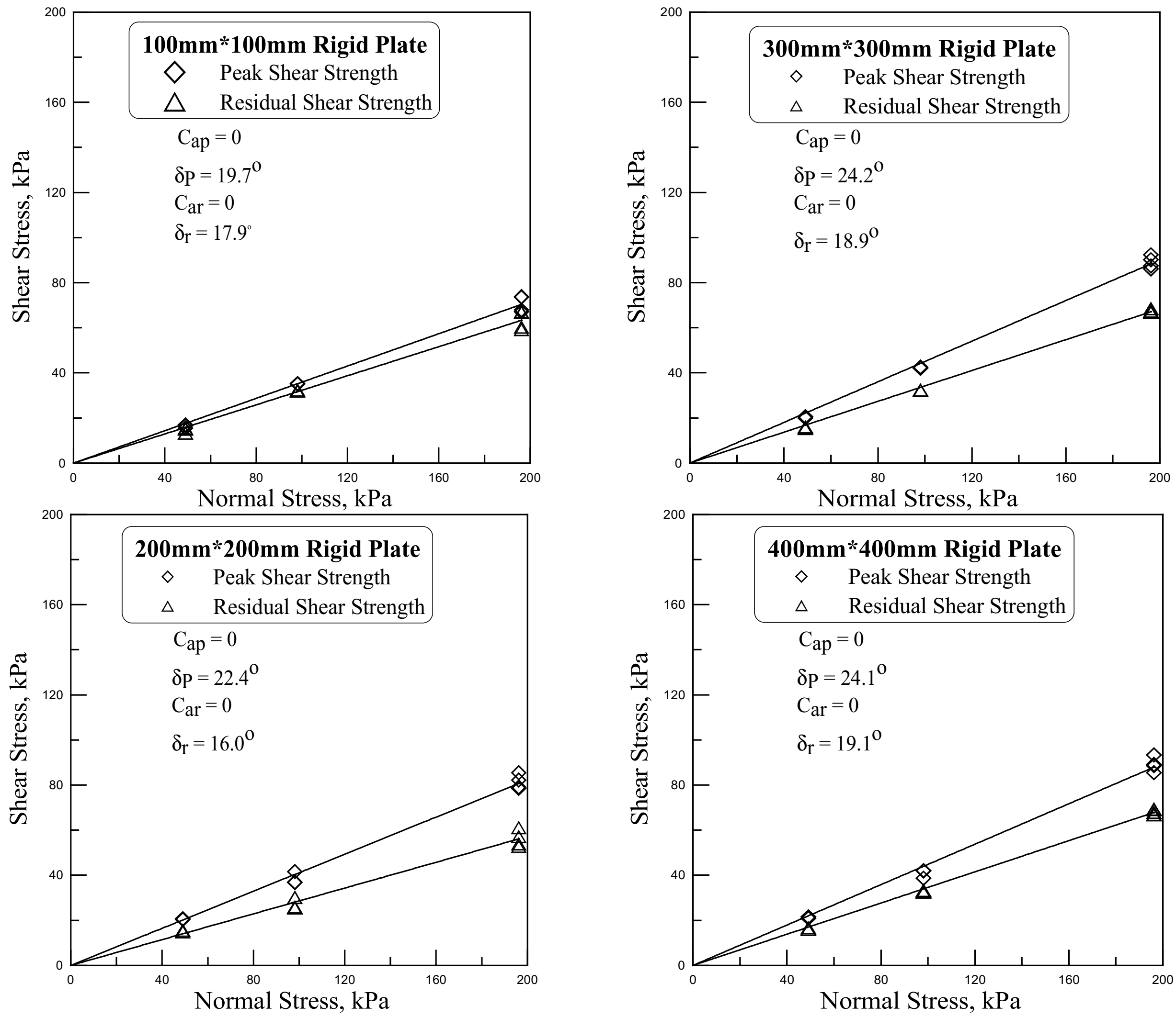

Fig 4. The failure envelopes at the quartz sand/smooth HDPE geomembrane interfaces for various shear boxes with various loadings applied through a rigid load plate.

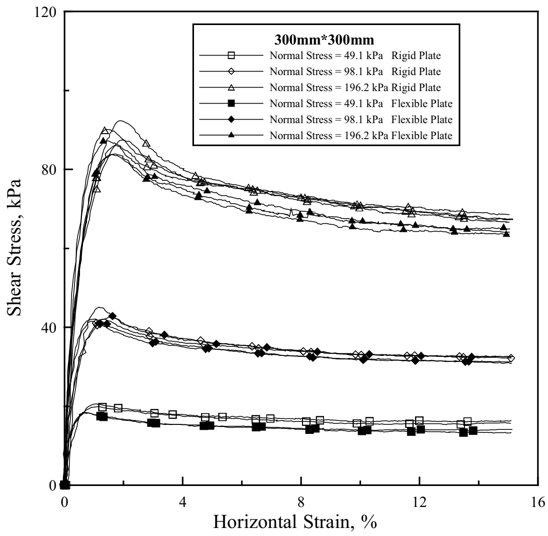

Fig 5. The stress-strain curves at the quartz sand/smooth HDPE geomembrane interfaces for 300x300 mm shear box with various loadings applied through a rigid or a flexible load plate.

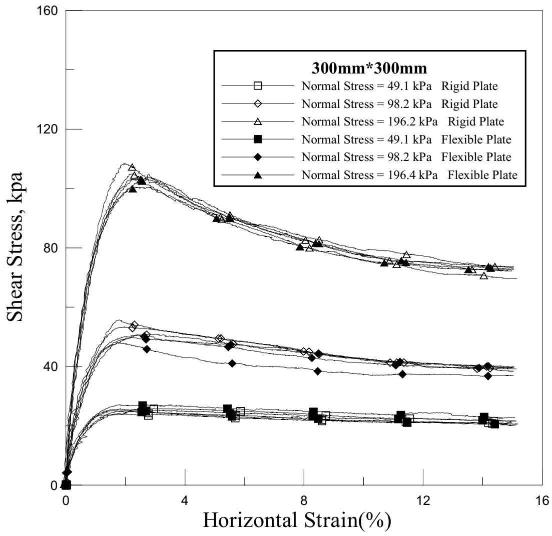

Fig 6. The stress-strain curves at the Li-kang sand/smooth HDPE geomembrane interfaces for 300x300 mm shear box with various loadings applied through a rigid or a flexible load plate

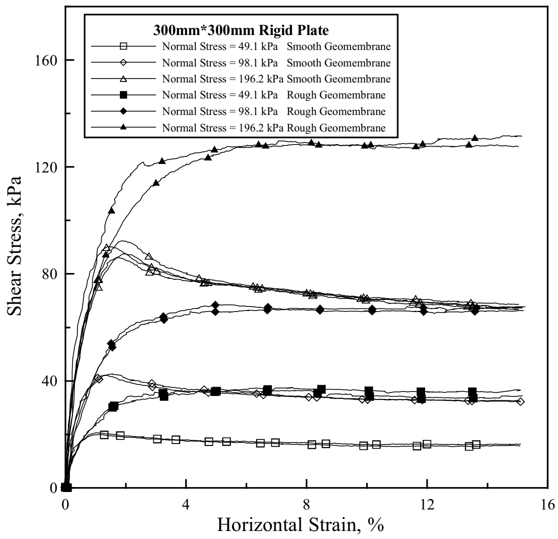

Fig 7. The stress-strain curves for smooth or textured surface HDPE geomembrane/ quartz sand interface with loading applied through a rigid load plate.

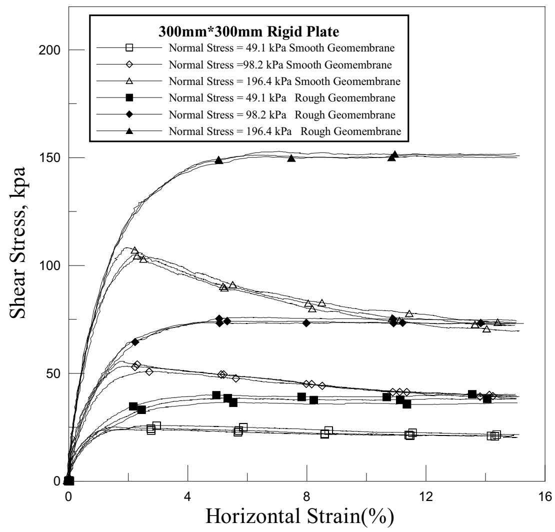

Fig. 8. The stress-strain curves for smooth or textured surface HDPE geomembrane/ Li-kang sand interface with loading applied through a rigid load plate.

Table 6 The comparison of the results of direct shear tests of sand/geomembrane systems for different shear box sizes and surface conditions.

Geomembrane type	Shear box size	Peak interface friction angle	Efficiency value ($E_{\psi p}$)	Adhesion (kPa)	Residual interface friction angle	Efficiency value ($E_{\psi r}$)
Smooth surface	100×100mm	19.7°	0.55	0	17.9°	0.50
	300×300mm	24.2°	0.67	0	18.9°	0.52
Textured surface	100×100mm	NA	NA	5.0	30.1°	0.84
	300×300mm	NA	NA	5.9	32.5°	0.90