Determination of soil-geosynthetic interface parameters

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ABSTRACT: This paper presents results from a comprehensive investigation on shear strength parameters for soil-geosynthetic interfaces. A simple large dimension device was developed for testing multiple test configurations, such as direct shear, inclined shear and tilt tests. Details of the equipment and test procedures are reported herein. The experimental program included tests with sand and gravel in several interfaces with geogrid and geomembrane. The results show that the strength is dependent on the inclination angle of the imposed shearing surface. Conventional direct shear tests are shown to give unconservative results for geosynthetic applications on sloping surfaces.

1 INTRODUCTION

The use of reinforcing elements inserted in the soil for improving its geotechnical characteristics has become an attractive solution. Geosynthetic materials are also frequently used in several other applications, such as drainage systems, erosion control, separation, etc. Hence, the interaction mechanisms between soils and geosynthetic materials have become an essential issue in geotechnical design. Interaction parameters are dependent on the shear mechanisms and on the characteristics of specific soil and synthetic materials.

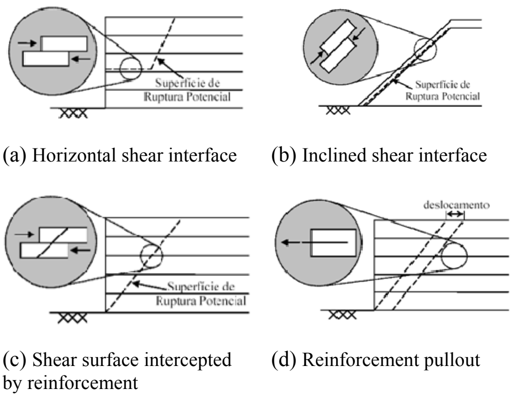
In terms of strength, the shear parameters are expressed by the adhesion (a) and interface friction angle (ϕ_{sg}). These parameters may be obtained from field or laboratory tests. Each type of test has its advantages and limitation. In the field, the difficulties in controlling loads and boundary conditions and the high cost are usually the main shortcomings. In the lab, the poor characterization of the soil mass due to sample dimensions and disturbance are usually the main issues.

The type of relative movement between the soil and the geosynthetic is also relevant when testing for interface shear parameters. Adequate selection of shear device and test procedures becomes therefore pertinent for obtaining design parameters.

This paper aims a review of laboratory test results of different soil-geosynthetic interfaces in large dimension devices.

2 INTERFACE PARAMETERS

Figure 1 shows diverse modes for mobilizing the interface shear strength: horizontal or inclined shear interfaces, reinforcement under tensile stress, and pullout. If the reinforcement remains fixed to half of the soil mass, while the other half is displaced, the direct shear device will be adequate (Fig. 1a). In situations where the interface is inclined, such as on upstream slopes covered by geomembranes, the tilt shear device (or inclined plane device) is recommended (Fig. 1.b).



(a) Horizontal shear interface (b) Inclined shear interface

(c) Shear surface intercepted by reinforcement (d) Reinforcement pullout

Figure 1. Interaction modes and relative movements at soil-geosynthetic interfaces (Aguiar, 2008).

In case the reinforcement intercepts the potential failure surface, the direct shear device shall be used with the reinforcement placed at the corresponding inclined position (Fig. 1c). Another situation is when the reinforcement is displaced and the soil mass is fixed. This case may be best duplicated in pullout test devices (Fig. 1d).

The shear strength envelope for soil-geosynthetic interfaces may be expressed as:

$$\tau_{sg} = a + \sigma . \tan \phi_{sg}$$

where: τ_{sg} = interface shear strength; σ = normal stress on the interface; a and ϕ_{sg} = interface parameters (adhesion and friction angle, respectively).

Values of a, ϕ_{sg} and σ may be interpreted in terms of effective or total stresses, depending on the soil characteristics. Interface parameters and interaction coefficients may be affected by several details, but test configuration is certainly one of the most important factors (Gourc *et al*., 1996; Sayão et al, 2009).

Several configurations of laboratory devices developed for studying the interaction mechanisms between soils and geosynthetic materials have been reported: Jewell & Wroth (1987); Palmeira & Milligan (1989); Girard *et al*. (1990); Athanasopoulos (1993); Sayão & Teixeira (1995); Lopes & Ladeira (1996); Lalaratokotoson *et al*. (1999); Nakamura *et al*. (1999); Lima Jr. (2000); Wasti & Özdüzgün (2001); Briançon *et al*. (2002); Palmeira *et al*. (2002); Sieira (2003); Najero (2003); Rezende (2005), Aguiar (2008).

These devices, however, are usually capable of imposing one shear condition only. A multiple use device, capable of testing different shear configurations is especially useful for investigating the soil-geosynthetic interface characteristics.

This paper reports on the development and use of a multiple shear device for testing soil-reinforcement interfaces in the laboratory. The apparatus is capable of carrying out direct shear, inclined direct shear and inclined plane shear tests on square or rectangular specimens of several sizes (from 0.25 to 1.0 m^2), under confining stresses up to 50 kPa.

3 INTERFACE SHEAR TEST DEVICE

The large dimension shear device has been developed for testing several configurations of interfaces between soil and reinforcement elements.

It consists of a metallic frame (Fig. 2), with a base which supports the confining boxes and loading systems. The frame holds the pulley for tilting the shear box (Aguiar, 2008).

Figure 2. Tilt shear device: frame and sample boxes

Hence, the different types of shear test may be carried out with this he same apparatus, provided a few accessories are changed or adapted in the main frame.

Experimental procedures and equipment details for performing tilt and direct shear tests in this interface shear device are reported by Aguiar (2008). Figure 3 shows three configurations of shear tests carried out with different specimen sizes.

3.1 Test specimens

Procedures for preparing the soil specimen and its interface with a geosynthetic sample are unique, regardless the test configuration (direct shear, tilt or pullout test). Geosynthetic sample dimensions must be compatible to the sizes of the test boxes: width shall be the same as the lower box, but geosynthetic length shall be 20 cm larger than the lower box length for allowing proper fixing at the extremities, whenever needed.

Preparation sand specimens starts by pluviating the exact amount (in weight) of soil inside the lower box in order to obtain the desired soil density (Fig.4). For dense specimens, vibration may be required. Careful leveling of soil surface is needed before installing the geosynthetic sample (Figures 5 and 6).

(a) Tilt test in progress with 1m^2 boxes

(b) Direct shear test with 0.5m^2 boxes

(c) Tilt test in progress with 0.25m^2 boxes

Figure 3. Configurations for the interface shear device

The upper box is then positioned and filled with soil (Figures 7 and 8). After careful leveling, the top plate and the confining load are placed (Fig. 9), and the instrumentation is adjusted (Fig. 10). Tell-tales are used for monitoring shear displacements and an analogical angular transducer gives the tilting angles during inclined shear or tilt tests. Finally, the shear loading system is set for performing direct shear tests. This system is simply made of dead weights and pulleys, as shown in Fig. 11.

Figure 4. Soil preparation in lower shear box

Figure 5. Proper leveling of sand surface

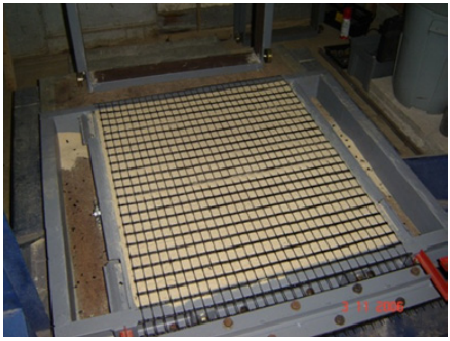


Figure 6. Installation of geosynthetic

Figure 7. Placement of upper shear box

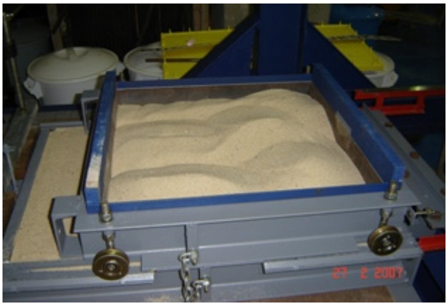


Figure 8. Soil preparation in upper shear box

Figure 9. Confining plate and load in position

Figure 10. Angular transducer during a tilt test

Figure 11. Shear loading system with pulleys

3.2 Tilt tests

The procedure for a tilt test consists on imposing a gradual inclination of the shear boxes, in 1º steps, while monitoring the corresponding relative displacements until failure is characterized by a sudden slide of the upper box over the fixed lower box.

Test results may be presented by plotting the inclination angle α against the upper box displacement δ, given by the tell-tales. Interface parameters (a e ϕ_{sg}) are obtained graphically from the strength envelopes obtained with tests at different confining stresses.

In tilt tests, both normal and shear stresses are related to the soil-box weight. Normal stress along the soil-geosynthetic interface plane has a trapezoidal distribution and varies continuously with the gradual change in inclination angle. Therefore, average values are considered when plotting the strength envelopes.

3.3 Conventional direct shear tests

For these tests, the procedure is similar to a load controlled direct shear in a standard soils laboratory. The only aspect which is different is the large dimensions of the device reported herein. The normal confining load is applied by steel plates acting as dead weight, as shown in Fig. 9, taking into account the weight of the top cap. The tangential load is imposed on the upper box by dead weights in a pulley system. The dead load is applied in increments The corresponding shear displacements are monitored by two tell-tales, one in each side of the box.

The results are presented in plots of shear load (or shear stress τ) against the average shear displacement δ .

3.4 Inclined direct shear test

The procedure for these tests consists of three main phases. First, the specimen is prepared and consolidated as usual, with the device in the horizontal position. Then, the platform is inclined to a specified angle with the upper box fixed to the lower one. Finally, the shearing phase is initiated by releasing the upper box and applying the dead load in incremental steps on the shear loading system.

It should be noted that, with this configuration, the shear load on the imposed failure plane is made of two components. One is the due to the projection of the weight of soil plus confining load, and the other is from the shear loading system.

The results are also presented in plots of shear load (or shear stress τ) against the average shear displacement δ .

4 MATERIALS

Two types of soil were selected for this investigation on interface shear parameters:

(i) Sand: uniform medium sand, taken from Ipanema beach, with quartz particles of 0.08 to 2.38 mm. Minimum and maximum specific gravity are 15.47 and 17.04 kN/m^3, respectively. All tests were carried out with loose specimens (Dr = 15%), corresponding to 15.69 kN/m^3 (Aguiar, 2008);

(ii) Gravel: uniform fine gravel, originated from gneissic rocks, with particles from 0.42 to 9.25 mm in diameter. Minimum and maximum specific gravity are 13.80 and 16.42 kN/m^3, respectively. All tests were carried out with loose specimens (Dr = 15%), corresponding to 14.14 kN/m^3 (Rezende, 2005 and Tavares, 2008).

The geosynthetic materials used in this investigation were:

(i) Geogrid: made of high tenacity polyester, covered by PVC (brand name: Fortrac), with main physical properties shown in Table 1;

(ii) Geomembrane: made of HDPE high-density polyethylene, with smooth sides (brand name: Polimanta). The main physical properties are shown in Table 2.

Table 1. Geogrid Characteristics (Huesker, 2003)

Properties	Values
Mass per unity area (g/m^2)	270
Grid opening (mm)	20 x 30
Open area ratio (%)	70
Tensile strength - longitudinal (kN/m)	35
Tensile strength - transversal (kN/m)	25
Elongation at failure – longitudinal (%)	4-6

Table 2. Geomembrane Characteristics (Engepol, 2007)

Properties	Values
Nominal thickness (mm)	1
Specific gravity (g/m^3)	≥ 0.94
Tensile strength at yielding (kN/m)	≥ 15
Tensile strength at failure (kN/m)	≥ 27
Elongation at yielding (%)	≥ 12
Elongation at failure (%)	≥ 700
Puncture resistance (N)	≥ 320

5 RESULTS

Results of tilt and direct shear tests at different inclinations are shown in terms of peak strength envelopes in Fig. 12.

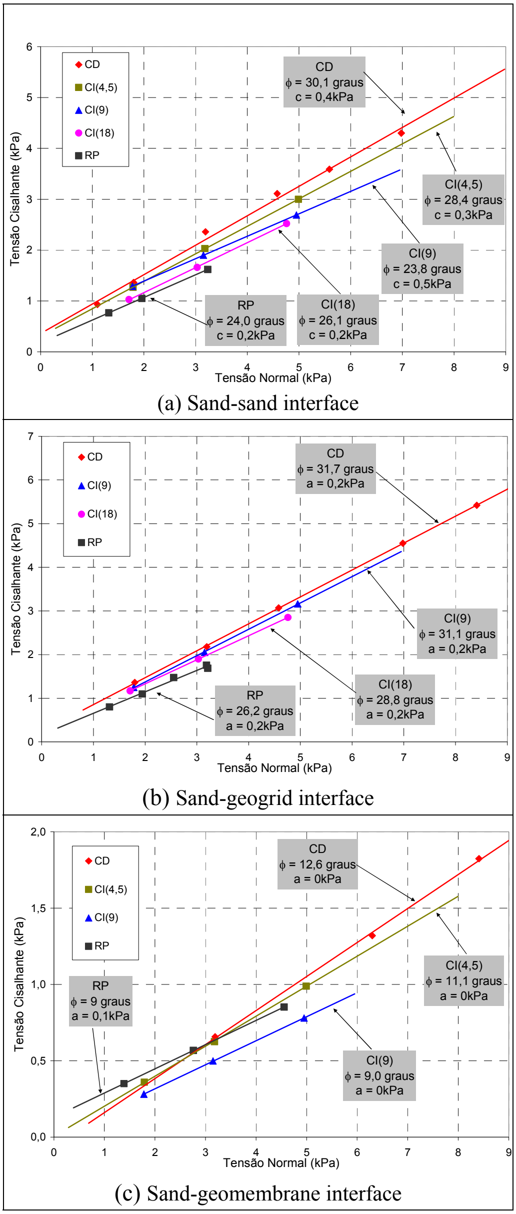


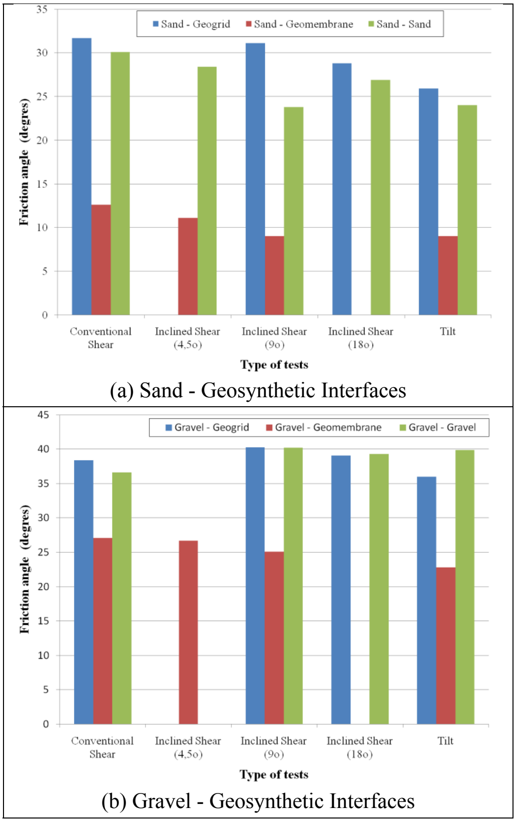
Figure 12. Shear strength envelopes (Aguiar, 2008)

For better comparisons, all tests reported were carried out on soil specimens at 15% relative density with square boxes of 0.25m^2. Direct shear tests were done at four different inclinations: 0^o, 4.5º, 9º and 18º. Six interface configurations are included in this report: sand-sand, gravel-gravel, sand-geomembrane, gravel-geomembrane, sand-geogrid and gravel-geogrid.

Figure 12 presents the strength envelopes from tests on all sand interfaces with sand, geogrid and geomembrane. Table 3 presents the strength parameters from all interface shear tests with sand and gravel. Figure 13 presents a comparison of friction angles from the various types of tests.

Table 3. Strength parameters for different interfaces

Interface	Sand - Sand	
Test type	Adhesion (kPa)	Friction Angle(°)
Direct shear 0°	0.4	30.1
Direct shear 4.5°	0.3	28.4
Direct shear 9°	0.5	23.8
Direct shear 18°	0.2	26.9
Tilt shear	0.2	24.0
Interface	Sand - Geogrid	
Test type	Adhesion (kPa)	Friction Angle(°)
Direct shear 0°	0.2	31.7
Direct shear 4.5°	-	-
Direct shear 9°	0.2	31.1
Direct shear 18°	0.2	28.8
Tilt shear	0.2	25.9
Interface	Sand - Geomembrane	
Test type	Adhesion (kPa)	Friction Angle(°)
Direct shear 0°	0.0	12.6
Direct shear 4.5°	0.0	11.1
Direct shear 9°	0.0	9.0
Direct shear 18°	-	-
Tilt shear	0.1	9.0
Interface	Gravel - Gravel	
Test type	Adhesion (kPa)	Friction Angle(°)
Direct shear 0°	0.0	36.6
Direct shear 4.5°	-	-
Direct shear 9°	0.1	38.8
Direct shear 18°	0.0	39.3
Tilt shear	0.2	39.9
Interface	Gravel - Geogrid	
Test type	Adhesion (kPa)	Friction Angle(°)
Direct shear 0°	0.1	35.7
Direct shear 4.5°	-	-
Direct shear 9°	0.0	40.3
Direct shear 18°	0.3	33.9
Tilt shear	0.2	36.0
Interface	Gravel - Geomembrane	
Test type	Adhesion (kPa)	Friction Angle(°)
Direct shear 0°	0.1	24.7
Direct shear 4.5°	0.1	24.8
Direct shear 9°	0.1	22.9
Direct shear 18°	-	-
Tilt shear	0.0	22.8



(a) Sand - Geosynthetic Interfaces

(b) Gravel - Geosynthetic Interfaces

Figure 13. Friction angles for different interfaces

Results from Figures 12 and 13 and Table 3 indicate that the interface friction angle decreases with increasing inclination of the direct shear platform direction. With all tests being on cohesionless materials, no specific relation is noted for adhesion values, which were all very small.

In general, it may be concluded that tilt tests give the lowest values of friction angles, with the highest values coming from conventional direct shear (horizontal plane).

A possible explanation may be seen in s in Fig. 14, which shows schematically the stress paths typical for has a tilt tests (RP), conventional direct shear (CC) e inclined direct shear (CI). This Figure also shows comparatively the strength envelopes from these three tests.

For a given initial normal confining stress σ_3, the tilt test procedure consists in a gradual increase in inclination of the platform until failure is achieved by a relative slide of the upper box along the lower box.

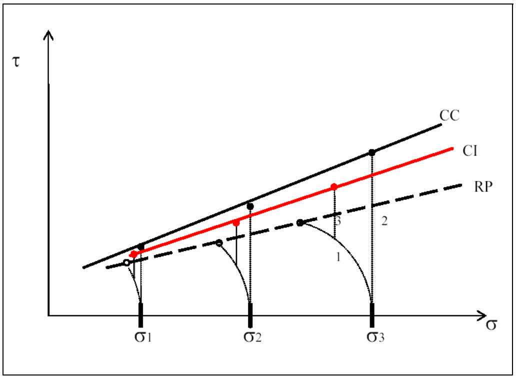


Figure 14. Stress paths and envelopes in tilt tests (RP), conventional direct shear (CC) e inclined shear (CI).

During the tilt tests, both the normal and the shear stress gradually change. While the shear stress increases, the normal stress decreases. Both changes are contributing to directing the stress path towards the failure envelope. Corresponding stress paths are curved, as suggested by curve 1.

In conventional direct shear tests, only the shear stress increases gradually until failure is reached. The normal stress remains constant. Hence, the stress path may be represented by the vertical line 2 in Figure 14.

In inclined direct shear tests, the two situations above occur in a sequence. First, while the platform is inclined to the prescribed angle, the stress path follows the initial portion of curve 1 in Fig. 14. Then, when the shear loading system is activated, the platform inclination remains constant.

As a consequence, the normal confining stress also remains unchanged while the shear stress increases towards failure. Hence, the stress path follows the vertical line 3 in the same figure.

Therefore, the stress path is highly affected by the tests procedures, and the observed variations in strength may be explained.

6 CONCLUSIONS

The main conclusions from the investigation herein reported may be pointed out:

- The multiple interface shear device was developed for conducting several types of tests, with simple configurations. This paper presents results from direct shear at different inclinations and from tilt tests.
- The large dimensions of the new device allows tests using geogrids and gravel.
- The instrumentation was kept simple, with one angular transducer, 2 dial gages and two tell-tales. Although no provision was made for digital or automatic data acquisition, the results were very satisfactory.
- For a given soil, interface strengths with geomembrane were lower than with geogrid. This was noted in all test configurations.
- For a given soil-geosynthetic interface tested in direct shear, the interface friction angle decreases when the inclination increases. Therefore, parameters estimated from conventional (horizontal) direct shear may be unconservative for applications on sloping surfaces. Moreover, tilt tests always resulted in lower friction angles than the direct shear and may be considered as giving conservative results for design purposes.

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