Soil-Geosynthetic Interface Shear Strength by Simple and Direct Shear Tests

Détermination de la résistance au cisaillement de l'interface sol – géosynthétique par des essais de cisaillement simple et direct

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ABSTRACT: Soil-reinforcement interaction mechanism has an utmost importance in the design of reinforced soil structures. This mechanism depends on the soil properties, reinforcement characteristics and elements (soil and reinforcement) interaction. In this work the shear strength of an interface between siliceous sand and a high strength geotextile was characterized through direct and simple shear tests. The direct shear tests were performed on a large scale direct shear apparatus. The scale effect of the direct shear box was also analysed. Unreinforced sand and one layer reinforced sand were characterized trough simple shear tests. Notwithstanding the differences between the shear strength characterization through simple shear and direct shear tests, it was concluded that the shear strength of the reinforced sand is similar to the interface direct shear strength.

RÉSUMÉ : Le mécanisme d'interaction sol – renforcement a une importance extrême dans le dimensionnement des structures avec des sols renforcés. Ce mécanisme dépend des propriétés du sol, des caractéristiques du renforcement et des éléments (sol et renforcement) d'interaction. Dans ce travail, la résistance au cisaillement de l'interface entre une sable siliceux et un géotextile de haute résistance a été caractérisée à travers des essais de cisaillement simple et direct. Les essais de cisaillement direct ont été réalisés sur un appareil de cisaillement direct de grande dimension. Du sable sans renforcement et une couche de sable renforcé ont été aussi caractérisés avec des essais de cisaillement simple. Nonobstant les différences entre la caractérisation de la résistance au cisaillement à travers des essais de cisaillement simple et direct, on a conclu que la résistance au cisaillement du sable renforcé est similaire à la résistance au cisaillement direct de l'interface.

KEYWORDS: Soil Reinforcement; Soil-Geosynthetic Interfaces; Direct Shear; Simple Shear.

1 INTRODUCTION

Soil-reinforcement interaction mechanism has an utmost importance in the design of reinforced soil structures. This mechanism depends on the soil properties, reinforcement characteristics and elements (soil and reinforcement) interaction. The accurate identification of the interaction mechanism and the choice of the most suitable test for its characterization are important factors. Figure 1 presents a potential failure mechanism of a reinforced soil slope. In the upper part of the retained reinforced soil mass, the reinforcement is pulled out, so the soil-reinforcement interaction can be best characterised by laboratory pullout tests. Near the base of the slope, soil sliding is expected and the interaction between the two materials is better characterized trough direct shear tests.

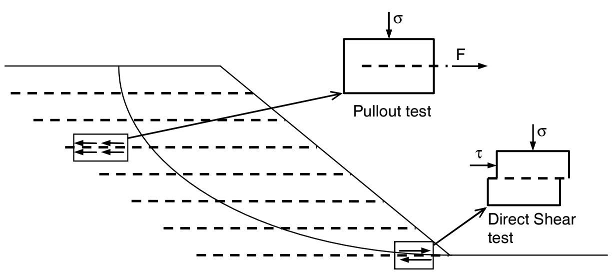

Figure 1. Potential failure mechanism of a reinforced soil slope and the most suitable laboratory tests to soil-reinforcement characterization.

Numerous experimental studies have been conducted to investigate the shear behaviour of soil-geosynthetic interfaces through direct shear tests (Vieira *et al.* 2013; Liu *et al.* 2009; Hsieh and Hsieh 2003; Lee and Manjunath 2000). The use of the simple shear device to characterize interfaces behaviour is very scarce and is limited mainly to sand-steel interfaces (Uesugi and Kishida 1986; Evgin and Fakharian 1998). In this work, simple shear tests were used to characterize the behaviour of a dry sand reinforced with a high strength geotextile.

2 MATERIALS

In the laboratory study herein presented, the interface between siliceous sand and a high strength geotextile (geocomposite reinforcement) was characterized. According to the Unified Soil Classification System, the sand is classified as SP - poorly graded sand and it was referred as SP49. This sand has mean diameter of 0.45 mm, uniformity coefficient of 1.9 and coefficient of curvature equal to 0.9.
The geocomposite is a high strength composite geotextile, consisting of polypropylene continuous filament needlepunched nonwoven and high strength polyester yarns (unidirectional reinforcement), with a nominal strength of 100 kN/m and elongation at nominal strength of 13%. This geocomposite was referred as GC100.

3 DIRECT SHEAR TESTS FOR SAND/GEOSYNTHETIC INTERFACE CHARACTERIZATION

3.1 *Large scale direct shear device*

The conventional direct shear device can only accommodate small size specimens, which imposes serious limitations in terms of reproducing real conditions. Based on this evidence, a large scale direct shear test device able to perform load and displacement controlled cyclic tests was designed (Vieira et al. 2013).

The developed large scale direct shear device is based on a hydraulic actuation with closed loop command computer control. The apparatus consists of the shear box, a support structure, five hydraulic actuators and respective fluid power unit, an electrical cabinet, internal and external transducers and a computer. Figure 2 shows a schematic view of the apparatus.

The shear box comprises an upper box, fixed in the horizontal directions, with dimensions of 300 mm × 600 mm in plant and 150 mm height, and a lower box, with dimensions of 340 mm × 800 mm in plan and 100 mm height, rigidly fixed to a mobile platform running on low friction linear guides. More details can be found in Vieira *et al.* (2013).

The direct shear tests were performed with a rigid base placed on the lower box (constant contact area tests). The sand was placed inside the upper shear box, at its air-dried water content, with relative density (I_D) of 70%. It was compacted in two thick layers with 25 mm height to the target unit weight. The tests were conducted with a constant displacement rate of 1 mm/min at normal stresses of 50, 100 and 150 kPa.

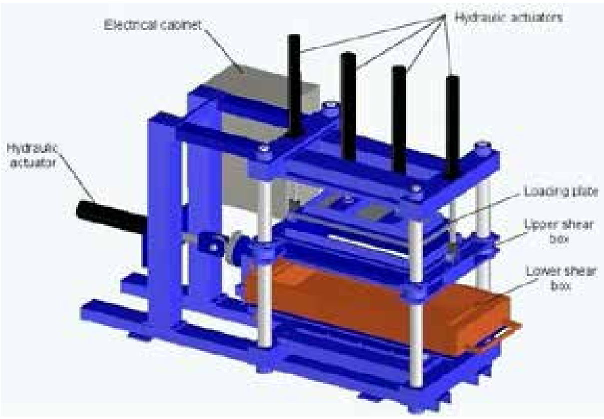

Figure 2. Schematic view of the direct shear test apparatus.

3.2 *Direct shear tests results*

The evolution of the shear stress and the vertical displacement of the rigid plate centre, as function of the shear displacement, for the sand SP49/geocomposite GC100 interface is shown in Figure 3.

The shear stress-shear displacement curves (Figure 3a) show a well-defined peak shear strength, which was recorded for shear displacements that increased with the confining pressure. As expected, initially, the sand exhibited a contraction followed by a dilating phase (Figure 3b). After reaching the peak of the interface shear strength, the vertical displacement progress during shear for confining pressure of 100 kPa is similar to the one observed for the lower stress (50 kPa).

Figure 4 presents the peak and the large displacement shear strengths for the three values of the confining pressure (50 kPa; 100 kPa, 150 kPa), as well as the corresponding linear best fits. Following Coulomb failure criterion, the SP49/GC100 interface presented an apparent adhesion $c_{a,p}$ = 1.4 kPa and a peak friction angle δ_p = 35.8°. The large displacement strength can be defined by an apparent adhesion $c_{a,cv}$ = 3.0 kPa and friction angle δ_{cv} = 30.2°. The failure envelopes show an apparent adhesion for the sand/geotextile interface due to the nonlinearity of the relationship between the shear strength and the normal stress at lower confining stresses. Even so, the values for this parameter can be considered without great significance.

Notice that, the apparent adhesion has also been reported by other authors for sand/geosynthetic interfaces (Ling *et al.* 2002; Liu *et al.*2009).

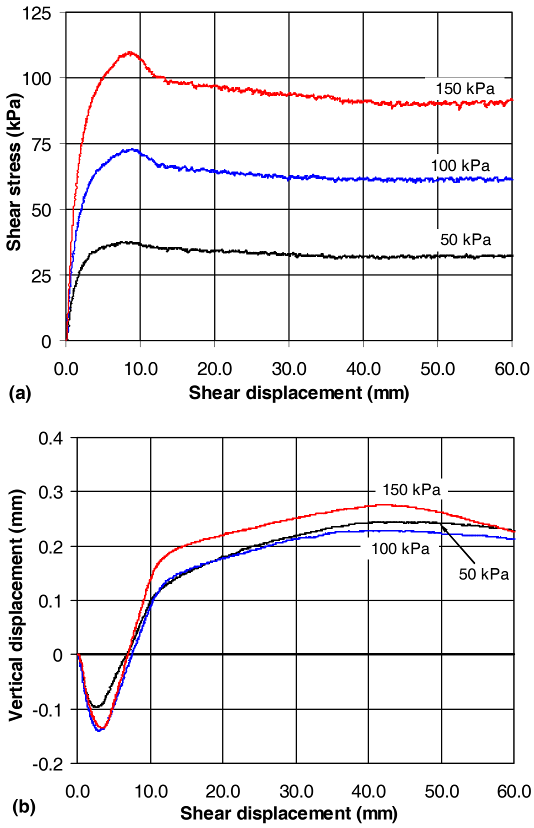

Figure 3. Direct shear tests results for different normal stresses (50, 100 and 150 kPa): (a) shear stress-shear displacement; (b) vertical displacement-shear displacement.

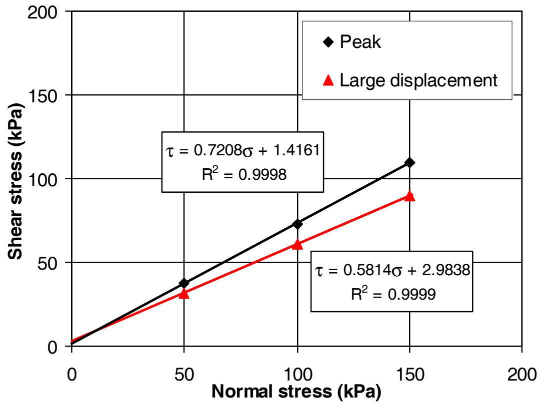

Figure 4. Peak and large displacement shear strengths as a function of the applied normal stress.

4 CHARACTERIZATION OF GEOSYNTHETIC REINFORCED SAND BY SIMPLE SHEAR TESTS

In this work a simple shear device Norwegian Geotechnical Institute type, model Geonor h-12 was used. It is a linear simple shear apparatus, which differs from the conventional direct shear devices since tilting elements delimit the vertical boundaries of the specimens, allowing a more uniform deformation of the soil and the rotation of principal stresses. Besides the failure planes are not imposed.

The specimens are cylindrical, with a height of 16 mm and a diameter of about 80 mm, enclosed in a wire-reinforced membrane. In the tests of reinforced sand the thickness of geosynthetic was deducted from the height of specimen to determine the amount of sand corresponding to the desired relative density (I_D = 70%). The sand was deposited in two layers, being the geosynthetic placed between them. Figure 5 presents a reinforced sand specimen already placed on the simple shear device.

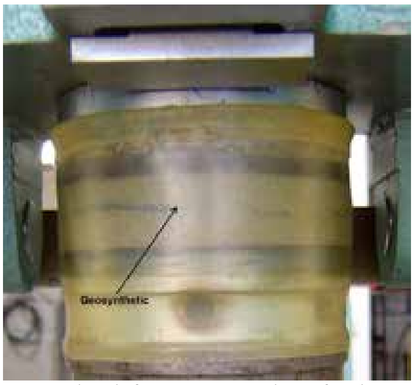

Figure 5. Geosynthetic reinforced sand specimen for simple shear test.

Figure 6 illustrates the shear stress *versus* shear strain behaviour, as well as, the vertical displacement of the reinforced sand specimen during shear.

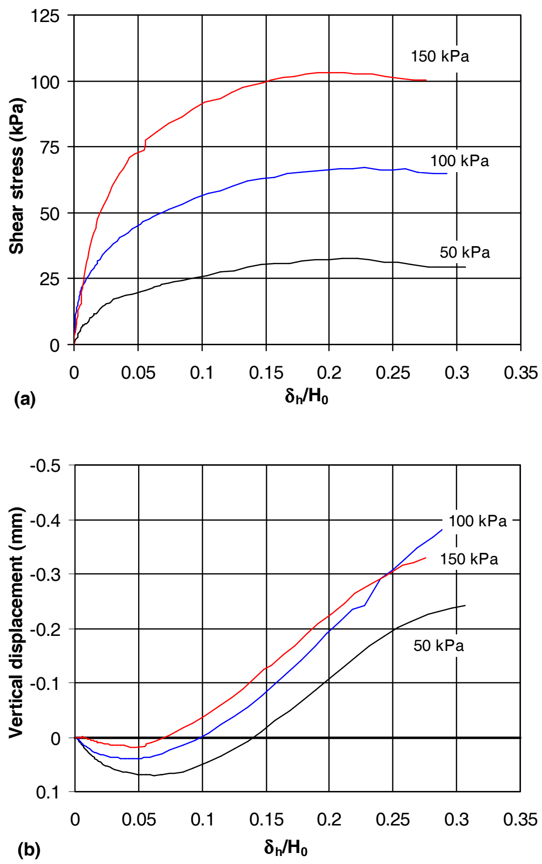

Figure 6. Simple shear tests results for reinforced sand: (a) shear stress-shear strain behaviour; (b) vertical displacements during shear.

The maximum shear strengths for the three values of the confining pressure and the failure envelopes for unreinforced and reinforced sand are compared in Figure 7. Unexpectedly, the shear strength of the reinforced sand tended to be lower than the shear strength of the unreinforced sand. This evidence is probably justified by the fact that the presence of the reinforcement led to a looser layer of sand over the geosynthetic, due to the damping caused by its presence during the deposition process of the sand.

Figure 8 confirms the hypothesis above-mentioned. When a reinforcement layer is placed within the specimen, greater settlements (positive values of the vertical displacements) were recorded and the dilatant phase had less significance. To simplify the figure, it was decided to present only the vertical displacements related to the tests performed with the highest and lowest value of the normal stress.

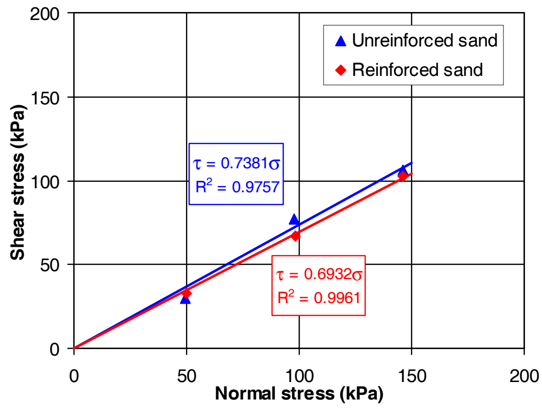

Figure 7. Comparison of the failure envelopes for unreinforced and reinforced sand.

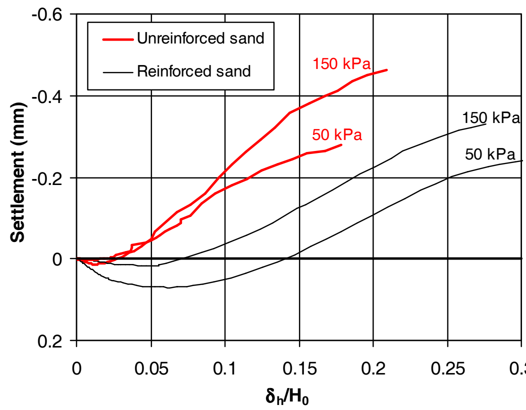

Figure 8. Comparison of vertical displacements of the specimen in simple shear tests on unreinforced and reinforced sand .

5 COMPARISON OF THE RESULTS

Prior to the comparison of the results achieved with the developed large scale direct shear device and those obtained with simple shear tests, it will be analyzed the scale effect of the direct shear box on the sand-geotextile interface shear strength.

Regarding the influence of the dimensions of the shear boxes on the test results, contradictory opinions can be found in the literature. Palmeira (1988) stated that the scale effects do not affect the peak value of the friction angle obtained from direct shear tests. Hsieh and Hsieh (2003) found that, in general, the shear strength obtained in shear boxes with large dimensions is greater than that obtained with smaller shear boxes.

Notwithstanding the fact that the conventional direct shear device can only accommodate small size specimens, which might impose serious limitations in terms of reproducing real conditions, direct shear strength for several interfaces obtained with the developed device were compared by Vieira (2008) with results achieved in a small (60 mm × 60 mm) conventional direct shear apparatus. Figure 9 presents the evolution of the shear stress with the shear displacement, normalized by the length of the box, obtained with the large scale and the conventional direct shear devices for the interface under analysis in this work.

The shear stress-shear displacement curves obtained with the large scale direct shear tests tend to exhibit peak shear strength, not evident in the results achieved with the conventional apparatus. The maximum shear strengths reached with two devices are relatively close however they were achieved for lower values of the normalized shear displacement in the larger box.

Figure 10 compares the failure envelope obtained with simple shear tests for reinforced sand and the failure envelopes achieved in the direct shear tests (DS) performed with both devices (60 mm × 60 mm and 300 mm × 600 mm) to characterize the interface between the sand and the geotextile.

It should be noted that, while the direct shear tests characterize the interface between the two materials (sand and geotextile), the simple shear tests analyze the behaviour of the reinforced sand. Despite this difference, the analysis of Figure 10 shows that the shear strength of the reinforced sand approaches the shear strength of the sand/geotextile interface.

Table 1 summarizes the values of the friction angle and apparent adhesion relating to the failure envelopes for the direct shear tests and simple shear tests (reinforced sand).

Comparing the interface shear strength (evaluated with direct shear tests), it was found that it tends to be higher when large scale apparatus was used. As mentioned previously, the shear strength of the reinforced sand reached with simple shear tests approaches the shear strength of the interface between the two materials obtained with direct shear tests. The friction angle of the reinforced sand is within the range of values achieved with the two direct shear devices.

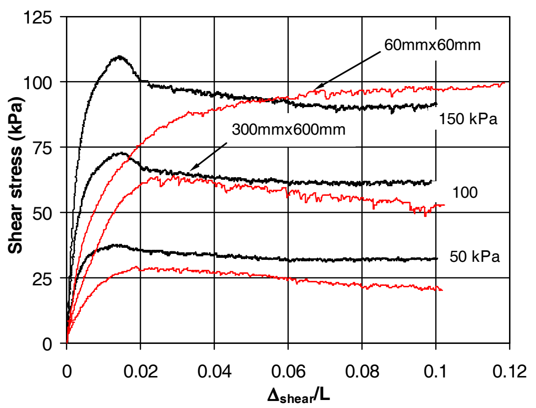

Figure 9. Comparison of shear stress-shear displacement curves obtained with two direct shear test devices.

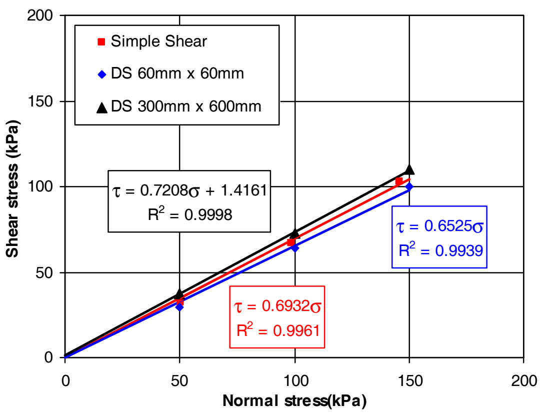

Figure 10. Comparison of the failure envelopes of sand SP49 reinforced with geosynthetic GC100 obtained with three shear devices.

Table 1. Comparison of the shear strength parameters reached with different devices.

Test	*adhesion (kPa)*	*Friction angle (º)*
Direct Shear Test (300mm × 600mm)	1.4	35.8
Direct Shear Test (60mm × 60mm)	-	33.1
Simple Shear Test	-	34.7

6 CONCLUSIONS

Based on the analysis and interpretation of the results of direct shear tests performed to characterize the interface between a silica poorly graded sand and a high strength geotextile and the results achieved by simple shear tests carried out with the sand reinforced with one layer of geotextile, the following conclusions can be drawn.

From the direct shear tests it was concluded that the large scale device overestimates the shear strength of the soil-geosynthetic interface comparatively to the results obtained with the conventional direct shear apparatus. Notice, however, that the large scale direct shear device should represent more accurately the real behaviour of the interface. Nevertheless, the differences between the results obtained with the two devices are not significant.

Although the characterization reached by the simple shear tests is distinct from that of the direct shear tests, it can be stated that the shear strength of the anisotropic material (sand and geosynthetic) approaches the shear strength of the interface between the two materials.

The conclusions presented are also valid for interfaces between other materials (Vieira, 2008).

7 ACKNOWLEDGEMENTS

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