Shear strength of geomembrane-cohesive soil interfaces

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Abstract. Despite the increasing use of geosynthetics, the behavior of polymeric materials inserted in the soil is complex, and the wide availability of products on the market makes it difficult to standardize and predict the behavior of the interaction. Therefore, understanding the fundamental mechanisms that involve each type of geosynthetic and its use is a way of directing test conditions to obtain accurate parameters to investigate the behavior of interactions between soil-geosynthetic. In this article, tests were carried out to estimate the interface strength of the soil-smooth geomembrane and soil-textured geomembrane were conducted with cohesive lateritic soil in direct shear equipment with a shear box measuring 300 mm x 300 mm and a reduced area model. The objective of the study was to investigate the influence of soil particle size distribution, the type of geomembrane surface (smooth or textured), and the filling in the lower half-box (with soil or rigid base) on the resistance of the soil-geosynthetic interface. The results demonstrated the efficiency of the interaction between cohesive soil and a textured geomembrane. For the interaction with a smooth geomembrane, cohesive soil did not exhibit significant mobilization of resistance.

1 Introduction

The uses of geosynthetic materials have been common in civil engineering constructions. Geomembranes are among the most widely used geosynthetics in various civil engineering applications. The most common application is to act as a lining system in modern landfills, with application beginning in the 1970s. Therefore, the primary function of a geomembrane is to act as a barrier to the flow of liquids and/or vapour. However, it can be a separation material [1-3].

The geomembranes can be made of different polymers, including polyester (PES), polyethylene (PE) and polypropylene (PP). The most common is high-density polyethylene (HDPE) geomembrane. This is a waterproof barrier material with high strength made of polyethylene resin with a specific formula and further processing. There are two types: smooth and textured geomembranes. The textured HDPE geomembrane is widely used in

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works with high environmental responsibility because it increases friction characteristics and safety, reducing the risk of ruptures due to slipping between interfaces [4-5].

It is worth mentioning that a geomembrane installed over a layer of soil generates a contact zone between the materials. In this contact zone, a force that prevents the relative movement between the two materials is called shear force. This contact shear strength is a function of the friction angle between the two materials. This parameter depends on the characteristics of both the soil (granulometry, moisture content, degree of compaction, among others) and the geomembrane (raw material and texture of the material) [5].

The shear resistance between the soil body and geosynthetic has been the major challenge in landfill design. Several properties of geosynthetics are determined in their manufacturing process, but interface shear strength is not one of them. Direct shear, inclined board or ring shear are specific laboratory tests for this parameter. Direct shear testing has been almost exclusively used to determine interfacial shear strength parameters. Tests are often conducted under high normal stresses and it is believed that test results at low normal stresses may need to be more accurate due to mechanical difficulties. More recently, "inclined board" or "tilting table" tests for interface shear strength. The apparatus consists of a board hinged on one side and raised on the other side till sliding occurs along an interface [6-8].

Evaluation of the shearing resistance (or shear strength) between geosynthetics and soils has received relatively broad exposure in the technical literature [1,8-11].

Therefore, this paper presents the results of direct shear tests conducted using a large-scale apparatus (300 mm x 300 mm) with well-established boundary conditions grounded in practical applications for one cohesive soil (lateritic clay). The study observed the influence of geomembrane surface type (smooth or textured) and the filling in the lower half-box (with soil or rigid base) on the soil-geosynthetic interface strength.

2 Materials and methods

2.1 Test materials

2.1.1 Soil

The cohesive soil samples were collected in the Bonfim Paulista District, in the city of Ribeirão Preto - Brazil, from an excavation for the foundation of a commercial building in the southern region. Figure 1 illustrates the soil, while Table 1 provides the characterization of the soil.

Fig. 1. Cohesive soil.

Table 1. Cohesive soil characteristics.

Properties	Test method	Cohesive Soil
Particle size distribution	NBR 7181 [12]	Silty Clay
USCS classification	ASTM D2487 [13]	MH
Maximum dry density- (γd)	NBR-7182 [14]	1.58 g/cm³
Optimum water content	NBR-7182 [14]	27.8%
Plastic Limit—PL	NBR 7180 [15]	38
Liquid Limit—LL	NBR 6459 [16]	54

2.1.2 Geomembranes

For the testing campaign, two types of geomembranes were employed, smooth (GM1) and textured (GM2), both of the HDPE (High-Density Polyethylene). These geomembranes are manufactured using the flat die extrusion process, which imparts higher quality and superior performance to the product compared to conventional production processes. Figure 2 illustrates these geomembrane samples, while the properties are presented in Table 2.

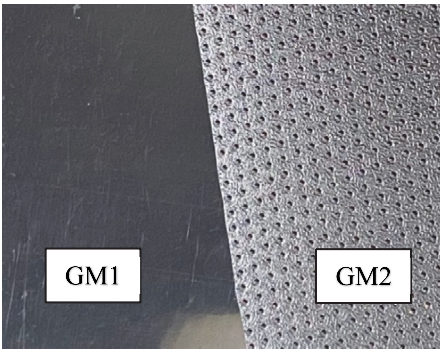


Fig. 2. Geomembrane samples.

Table 2. Geomembranes properties.

Properties	Test method	GM1	GM2
Type	-	Smooth	Textured
Raw material	-	HDPE	HDPE
Thickness (mm)	ASTM D5994 [17]	1,5	1,5
Asperity height (mm)	ASTM D7466 [18]	-	0,4
Density (g/cm³)	ASTM D1505/D792 [19, 20]	0,94	0,94
Yield strength (kN/m)	-	22	22
Yield elongation (%)	-	12	12
Break strength (kN/m)	ASTM D6693 [21]	40	16
Puncture resistance (N)	ASTM D4833 [22]	480	400
Tear resistance (N)	ASTM D1004 [23]	187	187

2.2 Experimental Methods

2.2.1 Test devices

The direct shear apparatus used for this study was developed in the Geosynthetics Laboratory at the University of São Paulo at the São Carlos, Brazil. The equipment is of large dimensions, and the tests are conducted with half-boxes of the same area (reduced area test), 300 mm x 300 mm, with adaptations made based on the specifications recommended by NBR ISO 12957-1 [24]. Figure 3 illustrates the equipment.

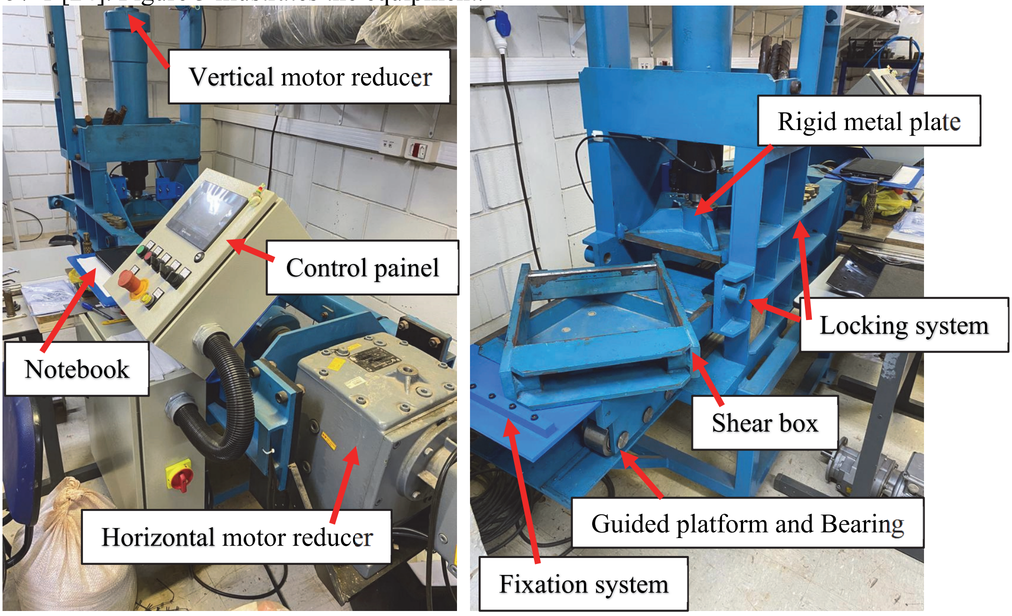


Fig. 3. Equipment details.

2.2.2 Test procedures

The laboratory work for the direct shear test begins with the preparation of the materials involved in the analysis: the soil and geosynthetic test specimens.

The test assembly involves, in simplified terms, placing two layers of the soil mixture or the rigid support in the lower half-box. Subsequently, the geosynthetic is attached to this box, the metal parts of both boxes are lubricated, and the upper half-box is positioned over the lower one, filling it with two layers of soil. Compaction should be carried out between the layers.

Once the test setup is completed, the boxes are moved to the horizontal load piston, secured with a pin, and through the automated system, the descent of the rigid plate responsible for applying the vertical load is initiated.

The vertical load is applied for 60 minutes before initiating horizontal movement of the lower half-box. This time interval is sufficient to stabilize the loading plate's vertical displacements. The maximum displacement, corresponding to the end of the test, is 50 mm (16.5% of the box width).

For the same interface, four tests are required to determine the strength envelope. These tests should be conducted with constant vertical stresses of 50, 100, and 150 kPa, with two tests at 100 kPa.

After completing each test, the materials should be removed, and a new assembly should be carried out. Respecting and following the procedures outlined in this section for each test is essential.

2.2.3 Test conditions

The boundary conditions for the tests are as follows:

- Standard velocity of 1 mm/min;
- Normal stresses of 50, 100, and 150 kPa;
- For cohesive soils: Optimum moisture content (±1.0%) and 98% (±2%) standard Proctor compaction;
- End of the test: 50 mm.

3 Results and discussion

Two types of interactions were conducted: the first cohesive soil-GM1 and the second cohesive soil-GM2.
For the tests involving the cohesive soil-GM1 interface, the lower half-box was filled with a rigid base (wooden plate). Two test campaigns were carried out for the tests involving the cohesive soil-GM2 interface: one with the lower half-box filled with soil and another with the lower half-box filled with a rigid base.

3.1 Cohesive soil – GM1

As illustrated in Figure 4, it has been verified that the direct shear test provides a curve with a well-defined distinction between the maximum peak shear stress and residual shear stress. It is worth noting that no interface strength was mobilized for the normal stress of 50 kPa, necessitating a test with a stress of 75 kPa. The adhesion value is zero, and the interface friction angle is 8.9°.

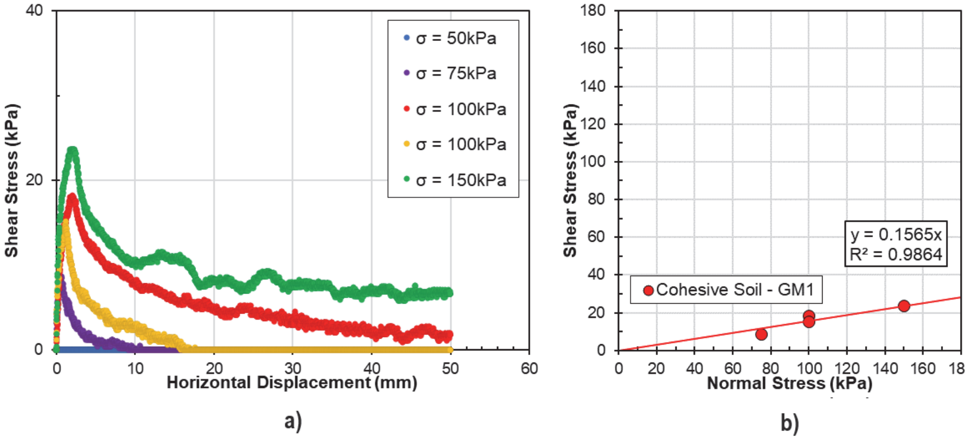
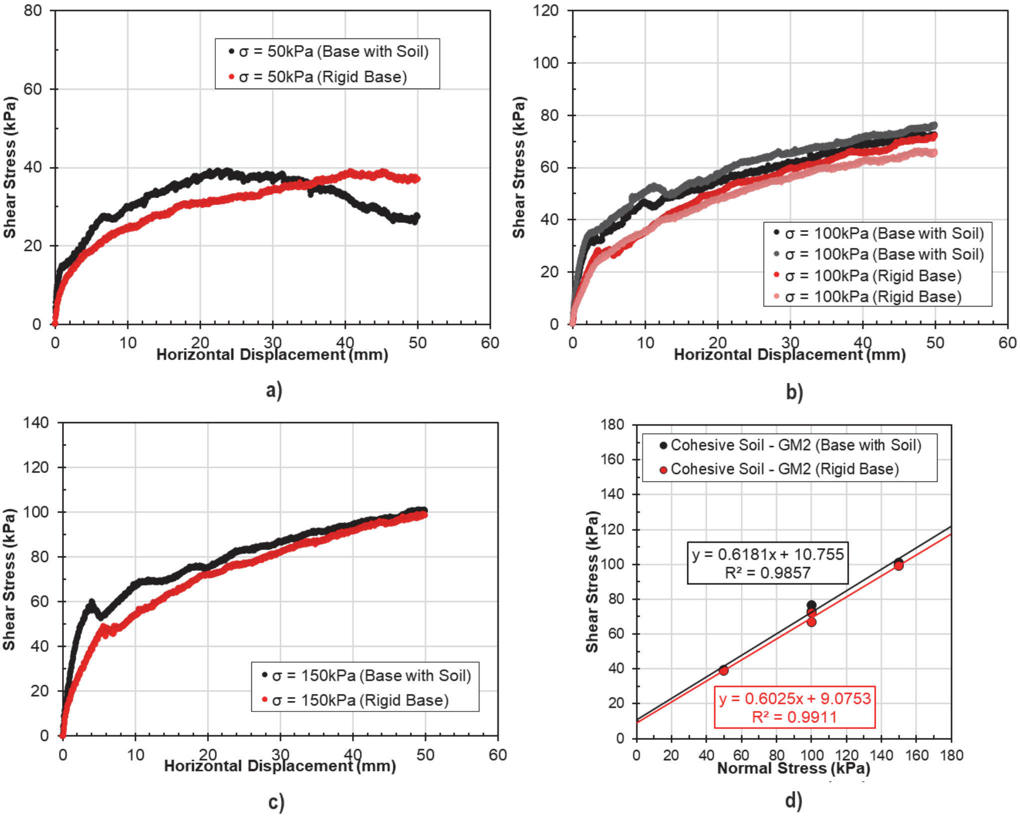


Fig. 4. Cohesive Soil – GM1 interface results. a) Shear Stress vs. horizontal displacement; b) Failure envelope for cohesive soil - GM1.

3.2 Cohesive soil – GM2

It was observed, as shown in Figure 5, that there was no clear distinction between maximum peak shear stress and residual shear stress, with stress increasing over time, reaching its maximum at the end of the test.

For the interface with the lower half-box filled with soil, the adhesion value is 10.8 kPa, and the interface friction angle is 31.7°. Meanwhile, for the interface with the rigid base, the adhesion is 9.1 kPa, and the interface friction angle is 31.1°.



a)

b)

c)

d)

Fig. 5. Cohesive Soil – GM2 interface results. a) Shear Stress vs. horizontal displacement (σ=50kPa); b) Shear Stress vs. horizontal displacement (σ=100kPa); c) Shear Stress vs. horizontal displacement (σ=150kPa); d) Failure envelope for cohesive soil - GM2.

Figure 6 presents the Mohr-Coulomb failure envelopes for each interaction.

When comparing the interface parameters with the internal parameters of the soil, it is observed that in the soil 2 - GM1 interaction, there is a reduction of 67.0% in the friction angle and a complete reduction (100%) in adhesion. For the soil 2 - GM2 interaction with a rigid base, there is a 15.2% increase in the friction angle and a 2.2% increase in adhesion. Meanwhile, for the soil 2 - GM2 interaction with a base filled with soil, there is a 17.4% gain in the friction angle and a 21.3% in adhesion.

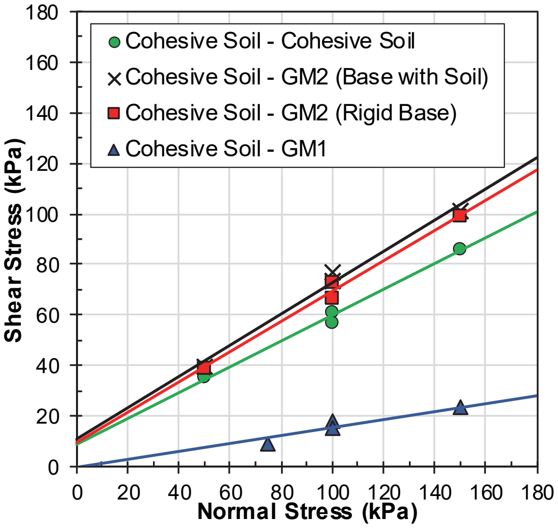


Fig. 6. Failure envelope for cohesive soil.

4 Conclusions

Based on the results of this investigation and within the limitations imposed by the number of tests performed, the following conclusions can be presented:

- For the interaction with a smooth geomembrane, cohesive soil did not perform well; the interaction efficiency was low, nullifying any adhesive effect, and the interface friction angle decreased by 67%. Moreover, at low confining stresses, no mobilization of strength was observed;
- It was evident that the geosynthetic interface significantly influenced the interaction results. When the geosynthetic was textured (textured geomembrane), the efficiency was higher;
- For the interaction with cohesive soil, the filling for the lower half-box did not significantly impact the results.

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