Equipment for measuring the friction between soils and geosynthetics with control of total suction

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ABSTRACT: When working with geosynthetics on brackish, expansive or contaminated soils, such as waste disposals, substantial changes of water content can occur within the reinforced soil, following major changes in the soil-geosynthetic friction. The increasing interest for geosynthetics, along with the experience gained from unsaturated soils, has prompted the Laboratorio de Geotecnia (CEDEX) to devise an equipment for measuring the friction between soils and geosynthetics with control of total suction. This equipment basically consists of a rolling plate, where the geosynthetic is fixed, and a square frame for the compacted soil, in an arrangement similar to a direct shear box, but held in an air-tight cell. The total suction is controlled by the partial pressure of the water vapour within the cell in equilibrium with a water-salt solution. Prior to a series of friction tests, the determinations of the suction-water content relationship of the soil and the geosynthetic were carried out. Thus, the friction parameters of a reinforced soil slope can be derived from its water content profile. The equipment arrangement, the control of the total suction and some tests are discussed in this paper.

1 INTRODUCTION

The increasing interest of the Laboratorio de Geotecnia of CEDEX for geosynthetics, together with its experience on unsaturated soils (Escario and Sáez, 1987) has resulted in a new testing equipment that links both fields. A Doctoral Thesis about this subject is due to be submitted to the Civil Engineering School in Madrid. This device is aimed at measuring the friction between a geosynthetic and a soil when both are subjected to a total suction, established by means of the vapour of a water solution.

It is apparent that the friction angle between an expansive soil and a geosynthetic is strongly dependent on the water content of both materials. Seemingly, the best way to ensure a controlled water content, both in the soil and the geosynthetic in contact, is by means of applying suction with the techniques developed for unsaturated soils.

The water content of both the soil and the geosynthetic (not necessarily the same) at a fixed suction can be deduced from:

– the relationship between water content and suction (here the effect of overburden is overlooked). This can be easily obtained by means of the standard laboratory equipment for unsaturated soils;
– the friction test itself. In this manner, the moderate influence of the overburden can be also assessed.

2 DESCRIPTION OF THE EQUIPMENT

It consists of three main elements: a 60 × 60 mm perforated metal frame where a 20-mm thick sample of soil is placed; a rolling plate on which the geosynthetic is stretched out and clamped; and a load cell of 1 kN, fixed onto a vertical support. Four stainless steel ball-bearings are fitted to the plate, so that it can roll frictionless along the base rails.

All of them are inserted into a sealed plastic cylindrical cell (Fig. 1), with the corresponding O-rings between the cylinder and the base and the lid. The cell is mounted on an ordinary device for direct-shear tests at which the vertical load and the horizontal displacement to the rolling plate are applied. The friction test consists of displacing the rolling plate at a constant rate, so that the friction forces developed at the soil-geosynthetic interface be transmitted to the load cell. The tests are run at different vertical stresses, applied to the soil through a spreading load plate and the vertical loading piston.

All the testing must be performed at constant temperature, according to the explanations in paragraph 2.1. In this case, the equipment has been placed in a room with a temperature control system that balances any departure beyond ±0.25º C from the set temperature.

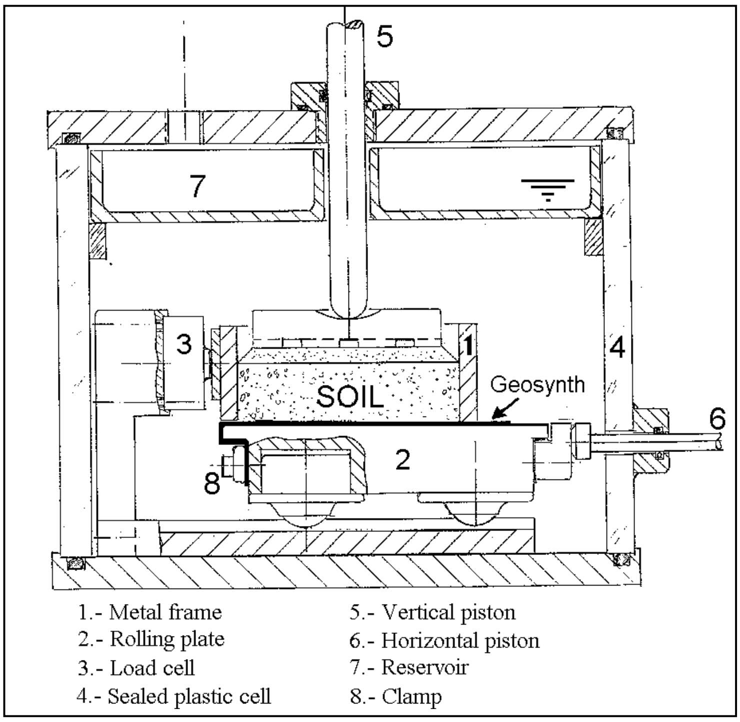

Figure 1. Front view of the equipment.

2.1 *The control of total suction*

It is demonstrated through the principles of thermodynamics that the total suction of water (e.g. in a soil), that is, the potential of water related to matric forces (capillarity and adsorption) and osmotic forces that hold back water, can be controlled through the relative humidity of the atmosphere within a cell. The concepts of suction can be successfully extended to the field of geosynthetics, since they may hold back water as well (Asanza and Sáez, unpubl.). The lower the relative humidity in the cell, the higher the suction (either of the soil or geosynthetic).

At equilibrium, the water content of the soil and that of the geosynthetic may differ from each other, but the water potential is the same throughout the cell.

The cell also contains an O-shaped reservoir with a water solution that, depending on the solute concentration and the temperature, fixes the required relative humidity (the partial pressure of water vapour in equilibrium with a salt solution at a certain temperature, relative to that with pure water at the same temperature); hence, the requirement of a temperature controlled room for conducting this kind of tests.

The most common solutes for this purpose are ClNa, which provides total suctions up to 10 MPa (pF = 5) and H_2SO_4, reaching suctions even 100 times higher. Table 2 shows the concentration of ClNa solutions for different total suctions at 20º C.

Table 1. Relationship between suction and concentration of a ClNa solution at 20º C.

Suction (MPa)	Relative Humidity (%)	ClNa (g / litre H_2O)
1	99.28	11.78
2	98.56	23.66
4	97.15	47.67
8	94.38	96.73
10	93.02	121.80

2.2 *Preparation and test performance*

The soil is moulded at a water content and compacted at a certain density in the perforated metal frame. In order to speed up the water transfer between the atmosphere and the soil, filter paper strips should be attached to the vertical sides of the soil sample. The sample of geosynthetic is clamped to the rolling plate. Then, the elements are arranged in the cell as shown in Figure 1, with the reservoir filled with the solution. Afterwards, the vertical stress is applied by a loading yoke. The test is divided in two stages:

- The equilibrium period: Once the equipment is mounted, water evaporates or condenses until equilibrium is reached; in other words, when the total potential of the water in the soil equals to that of the solution. A vertical LVDT records settlements (or heave, if any) during this period, that extends for approximately two weeks.
- Applying the friction: When the vertical movement is negligible, the rolling plate is set into motion. The displacement rate of the horizontal piston is set at 0.05 mm/min with a final relative displacement of 12 mm.

2.3 *Measurements and data acquisition system*

The output response parameters –displacement of the rolling plate, vertical movement (either settlements during the equilibrium period or dilatancy during the friction stage) and the load cell– are read at time and load intervals, transmitted to a computer and stored through a data acquisition system. The software supports the data control management and organizes data display and storage.

3 PRELIMINARY FRICTION TESTS

3.1 *Tested materials*

The friction tests have been performed with a slight expansive clay of common occurrence in Madrid locally called "*peñuela*", mixed with 7 % of Na-montmorillonite, resulting in a highly expansive soil, with a free swelling of 18 % and a swelling pressure of 0.35 MPa. The soil was compacted to 1.45 g/cm^3 and at a water content of ≈ 23 %.

A composite geotextile with non-woven polypropilene continuous filament and high tensile strength polyester yarns was also selected (Polyfelt Rock PEC 75). Its tensile strength is 75 kN/m, with 13 % of strain at failure. Its weight is 340 g/m^2.

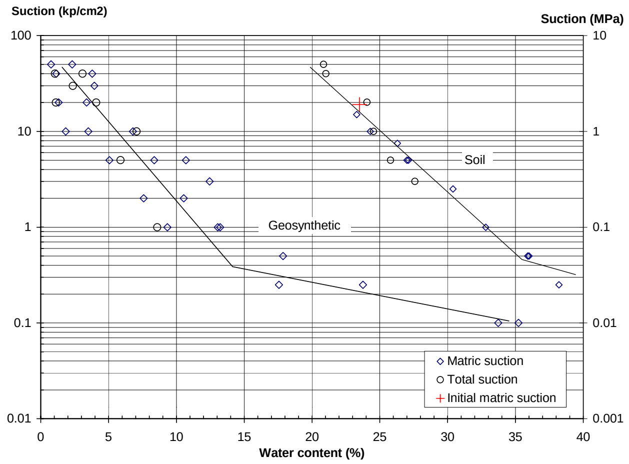

Figure 2. Suction vs. water-content relations of the soil and geosynthetic.

3.2 *Results*

The relations between suction and water-content of the soil and of the geosynthetic (Fig. 2) were previously determined with the standard testing equipment for unsaturated soils. The matric suction was applied by means of pressure membrane cells, whereas the total suction, with vacuum desiccators. This relation, also known as the retention curve, enables to connect water content with friction parameters (confinement is neglected).

Three friction tests, undergoing suctions of 2, 4 and 8 MPa, at three vertical loads each (0.05, 0.15 and 0.30 MPa) have been carried out. The test with a total suction of 4 MPa is depicted in Figure 3. The main features of the displacement vs. shear-stress curves in all the tests are:

- an initial steep increase of the shear stress, up to the break-up of the moderate interlocking and bonds generated within the interface;
- a steady build-up of the shear stress until a clear peak value;
- a smooth decrease towards a constant residual value.

The obtained peak and residual friction angles are listed in Table 2. Tests with a nearly identical clay presented a constant peak angle of internal friction of 33º (Escario and Sáez, 1987) for this range of suctions, with an increasing apparent cohesion.

Table 2. Results of the friction tests with different total suctions

Total suction	2 MPa	4 MPa	8 MPa
Peak friction angle (º)	25.5	27	31
Residual friction angle (º)	17.5	22	23
Water content of the soil (%)*	23	20	17
Water content of the soil (%)**	19-20	15-17	14-16

* From the suction-water content relationship.
** Obtained after oven-drying the samples from the friction tests.

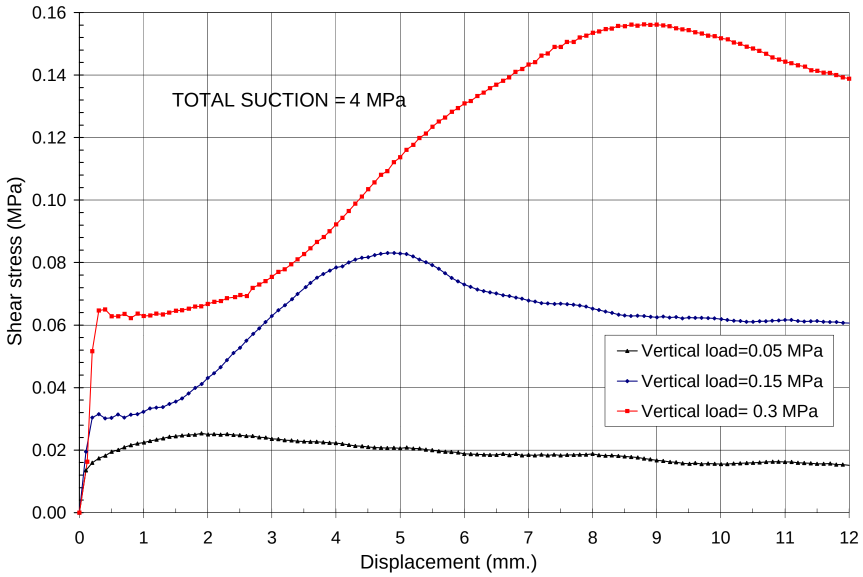

Figure 3. Friction tests curves with 4 MPa of total suction.

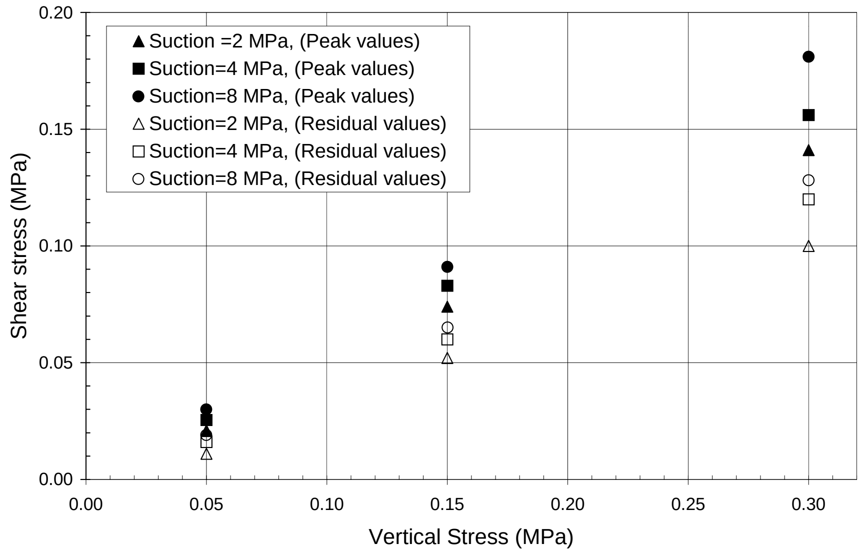

Figure 4. Envelopes of the friction tests (peak and residual values).

4 CONCLUSIONS

This equipment has been devised to obtain the friction angles between geosynthetics and soils at different water contents, extending the well-known testing techniques of unsaturated soils to the scope of geosynthetics.

In this case, neither the soil, moulded with distilled water, nor the geosynthetic exhibited osmotic suction (total minus matric). Nevertheless, the control of total suction proves to be advantageous when dealing with contaminated soils or in brackish areas, where osmotic forces may be much higher than the matric ones. However, the equilibrium at suctions under 2 MPa (involving relative humidities over 98.5 %. See Table 1) cannot be fully attained by this technique, unless an extremely sensitive temperature control system is used.

To solve this shortcoming, another testing equipment following the same mechanical design, but with control of matric suction below 2.5 MPa, has just been devised.

It must be pointed out that the water content of the samples after the test is lower than that from the retention curve, as a result of the overburden load. In this regard, the influence of loads on the water total potential of the soil can also be assessed.

Furthermore, currently ongoing tests have shown that this equipment can also be successfully used for testing the behaviour of geosynthetic clay liners.

The strength parameters of the unsaturated soil itself with control of the total suction can be determined in the same equipment, if a hollow rolling plate is placed instead. Thus, the efficiency of friction angle mobilization ($\tan \delta_{interface} / \tan \phi_{soil}$) can be evaluated in a range of water contents. These parameters can be used to work out the safety factor of reinforced soil slopes with the only requirement of obtaining its water content profile.

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