Table of contents Search Author index

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

Apparatus for measuring the friction between soils and geosynthetics with control of matric suction

E. ASANZA & J. SÁEZ, Laboratorio de Geotecnia, Centro de Estudios y Experimentación, CEDEX, Madrid, Spain

ABSTRACT: This paper describes an apparatus for measuring the friction between samples of soil and geosynthetics, with control of matric suction. It was devised to study how sensitive the variation of water content is with respect to the friction parameters. As water content is directly related to suction, the retention curves, both of the geosynthetics and the soil, were previously obtained. Unlike a recent apparatus (Asanza & Sáez, 2000) this one controls, not total suction, but matric suction. However, this new apparatus is capable of applying matric suctions in a wide range, between 0.01 MPa and 5 MPa, and results more advantageous. Two series of friction tests were carried out with an expansive soil in contact with three different geosynthetics, with suctions ranging between 0.025 and 0.5 MPa. Moreover, the capillary break effect, caused by placing the geosynthetic between the soil and the base that exerts the suction, is examined.

1 INTRODUCTION

At present, codes and recommendations are more permissive with respect to the use of non up-graded soils for civil works, providing a feasibility study is carried out (i.e. PG-3 Code in Spain). In this regard, the use of expansive soils as fill material in retaining structures is becoming less unusual.

Whenever geosynthetics are used for earth retaining structures, the mechanical interaction between the soil and the geosynthetic must be assessed. Moreover, if the soil behaviour is sensitive to water content changes (collapsible or expansive), an appraisal of this effect turns out to be valuable.

The Laboratorio de Geotecnia of the Centro de Estudios y Experimentación de Obras Públicas, which depends on the Public Works Ministry, has research into the interaction between soils and geosynthetics. Firstly, a series of pullout tests with a one-cubic-meter box was carried out (Díaz, M. A., 2000); secondly, the capacity of geosynthetics for taking up water, which is determined by the water retention curve, was studied; and thirdly, the effect of the water content both of the soil and of the geosynthetic in relation with the friction parameters in their interface has been studied. The first part of this latter study (Asanza & Sáez, 2000) presented another apparatus, but controlling not matric, but total suction. The second part of the study, which is the topic of this paper, describes this new apparatus and provides some results of friction angles at different suctions. It seems that the best way to fix a constant water content in both materials is by means of applying suction.

The previous apparatus proved to be useful for measuring the friction at high levels of suction (from 2 to over 20 MPa), and in turn, the relation between the water content and the friction angle could be derived.

This new apparatus was devised for measuring the friction forces developed at the soil-geosynthetic interface when both are subjected to a moderate level of matric suction. At equilibrium, both materials, soil and geosynthetic, in this common environment reach a constant water content, but different one from each other, depending on the water affinity of each material. The relation between the water content at equilibrium and the fixed suction (that is, the retention curve) must be previously determined in the laboratory (Asanza & Sáez, unpubl.). To the authors´ knowledge, this type of test has been reported only once (Stormont et al. 1997), under very low suctions and focused on the hysteretical behaviour of geotextiles.

The friction tests were carried out with an expansive clay and three types of geosynthetics.

Figure 1 shows the retention curve of the soil and a geocomposite. It can be derived that the vertical surcharge plays an important part on the water content at equilibrium.

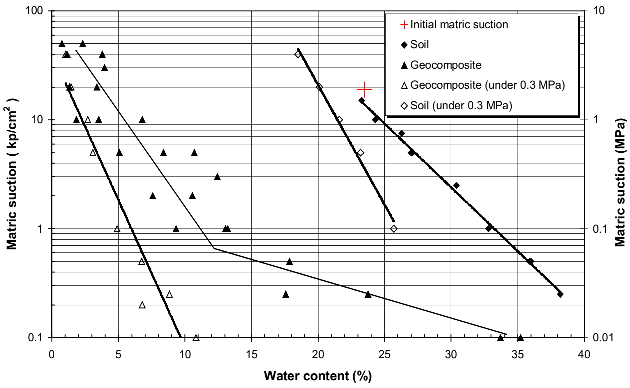

Figure 1. Retention curves of the soil and a the geocomposite, including the effect of a vertical surcharge of 0.3 MPa.

On the other hand, it was observed the significant influence of the stress path on the results of the friction parameters. That is why two types of tests have been run, each following a certain stress path before subjected to friction.

Moreover, the capillary effect, caused by interposing a geosynthetic between the source of suction and the expansive soil, trying to take up water, was tested.

2 DESCRIPTION OF THE APPARATUS

2.1 *Physical principle to control matric suction*

As a first approach, the suction can be defined as the intensity of the forces of the particles of a soil (or a geosynthetic) trying to take up or to hold back water. Total suction is the sum of the matric component and the osmotic component. The first one refers to the forces exerted by the particles, and, in particular, the physical-chemical forces of clay platelets; the second one refers to the forces generated by the different salt concentration within the soil water. The latter is relevant on contaminated areas, whereas the control of matric suction alone proves to be accurate enough at low and medium range in most soils.

The matric suction is defined as the difference between the air pressure (atmospheric in nature) and the water pressure, that is, u_{air}-u_{water}. Therefore, matric suction can be exerted, either tensioning the water column, or raising the air pressure. The former is physically limited to nearly 0.1 MPa by the cavitation; the latter is currently the most extended method to apply suction in the scope of unsaturated soils. The air pressure is externally raised with nitrogen. It basically consists of keeping the sample in an air-pressurized cell but at the same time, in direct contact with a source of free water. It is achieved using a semi-permeable membrane between the soil and the free water. The membrane allows the water flow but prevents the pressurized air from escaping. The dissolved ions in the water can also move freely through the membrane.

2.2 *General arrangement of the apparatus*

The apparatus consists of three main elements:

1. A 60-by-60 metal frame, where a 25mm-thick soil sample is compacted
2. A circular metal rolling plate of 150mm in diameter. It has a circular saturated porous stone fitted on its upper face. Four ball-bearings attached at the base of the rolling plate allow it to roll freely along the rails on the base of the external cell, where all these elements are inserted.
3. A load cell, which measure all the friction forces generated at the soil-geosynthetic interface.

The rolling plate is provided with a lower and an upper flat ring, both screwed to the upper face of the rolling plate. The lower one fixes the semi-permeable membrane to the saturated porous stone, while the upper one clamps the circular geosynthetic sample, allowing a direct contact with the membrane. Therefore, at equilibrium, a relatively continuous water phase is formed through the geosynthetic up to the soil.

The apparatus is shown in Figures 2 and 3.

2.3 *How the apparatus works*

The metal cell has two inlets: one, where a manometer is fitted, and the other one, is used for pressurizing the cell with nitrogen. In relation to the means of applying the vertical surcharge and the horizontal force, it does not differ from an ordinary direct shear device.

The vertical surcharge is applied by a loading yoke which is activated by dead weights. The horizontal force that pushes forward the rolling plate is applied at a constant rate (0.015 mm/h) by an electric motor and gear box arrangement, by means of an horizontal piston with a total displacement of 12 mm. Nevertheless, there is a complex arrangement concerning the means of maintaining the constant matric suction.

As it has been discussed previously, a saturated porous stone in intimate contact with the semi-permeable membrane, and this, with the soil, is required, so that the value of the air pressure indirectly equals the matric suction.

There are two tubes diametrically opposite each other, connected to the porous stone of the circular rolling plate and to the internal wall of the cell, where they are connected again to their corresponding external tubes. All this tubing allows the air bubbles accumulated to be removed by circulating water from one external tube to the other.

As a result, a range of matric suction between 0.025 and 5 MPa can be accurately controlled by this system. From a practical point of view, this range covers nearly all the suctions relevant for engineering purposes, unless a contaminated soil is under study.

3 DESCRIPTION OF THE TESTED MATERIALS

3.1 *Description of the soil*

The soil consists of a slightly expansive clay of common occurrence in Madrid, locally called "*peñuela*", mixed with 7 % of Na-montmorillonite, resulting in a highly expansive soil. The soil was initially compacted to a dry density of 1.45 g/cm^3 and at a water content of ≈ 23 %.

The swelling properties were tested with an oedometer with control of matric suction, which allows the combination of matric suction and vertical surcharge. As matric suction and vertical surcharge are of different nature, the stresses that they produce should be drawn in different axis (Fredlund & Morgenstern, 1977). The locus of all the loading conditions alongside with the corresponding volume change is defined as the state surface. Figure 4 shows the region of the state surface at which the tested soil swellls.

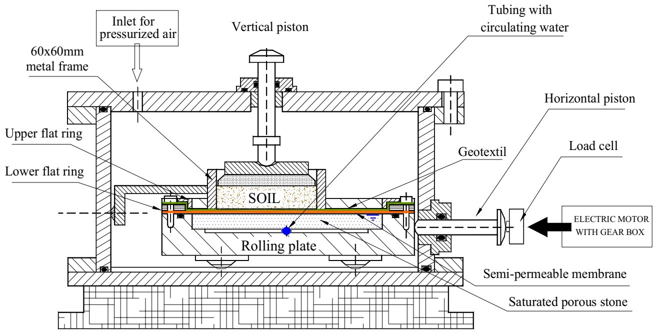

Figure 2. Front view of the apparatus

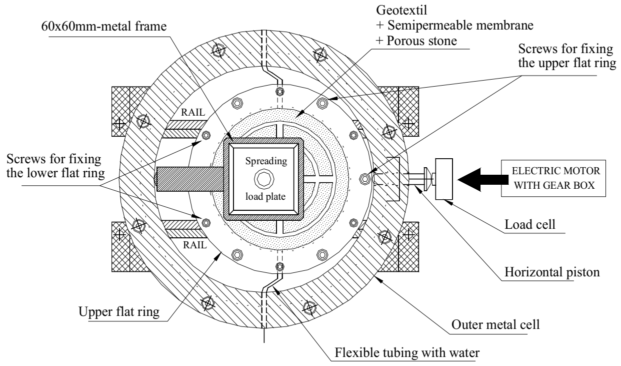

Figure 3. Top view of the apparatus

This soil has a free swelling of 13 %, a swelling pressure of 0.30 MPa and a initial matric suction of 2 MPa. Therefore, the state surface of the expansive soil can be plotted and is shown in Figure 4, where its vertices represent the free swelling (13 %), the swelling pressure (0.3 MPa) and the initial matric suction (2 MPa). This surface represents the swelling properties of the soil.

3.2 *Description of the geosynthetics*

Three types of geosynthetics were used for measuring the friction with the soil. Two of them are geotextile with non-woven polypropylene continuous filament, one with 200 g/m^2 and the other with 385 g/m^2. The third one is a composite geotextile with non-woven polypropylene continuous filament and polyester yarns, with a weight of 340 g/m^2. The main characteristics of the geosynthetics are listed in Table 1:

Table 2. Main characteristics of the three geosynthetics.

	Geotextile 1	Geotextile 2	Geocomposite*
Tensile strength (kN/m)	15.0	28.0	75.0
Elong. at max. load (%)	78.0	78.0	13.0
Thickness under 2 kPa (mm)	2.0	3.4	2.3
Static puncture strength (N)	2250	4200	-

* Its water retention curve is represented in Figure 1.

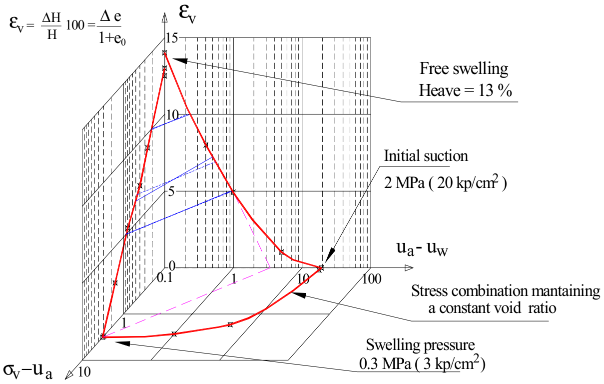

Figure 4. State surface of the soil, in the heave region

4 PERFORMANCE OF THE TESTS

4.1 *General preparation of the tests*

Once the soil is remoulded with the required water, it is poured into the metal frame and statically compacted. As the air pressure is dependent upon the temperature, the tests must be carried out in a temperature-controlled room.

On the other hand, the porous stone and the tubing are saturated by circulating water, whereas, the semi-permeable membrane is cut into a circular shape with the size of the rolling plate. Then, the membrane is placed on the rolling plate, in direct contact with the saturated porous stone, and fixed by the lower circular ring by means of 6 bolts. The circular geosynthetic sample is not placed until a second stage, once the equilibrium of water transfer is reached, under a stress path stage. It takes about 20 days. Otherwise, the water transfer would take much longer. This matter is discussed in a paragraph below.

Each test comprises three levels of vertical surcharges, 0.05, 0.15 and 0.3 MPa, all at the same matric suction. The test program included a suction range from 0.025 to 0.5 MPa. It means that most of the soil samples take up water, since they are subjected to suctions lower than the initial suction. Nevertheless, the vertical surcharge plays a part on reducing the water uptake (see Fig. 1).

It has been stated above that the friction forces developed at the interface are strongly dependent upon the strength path followed until the final conditions are reach. In this regard, two types of tests with different stress paths have been performed, termed from now on, Stress Path nº 1 and Stress Path nº 2.

4.2 *Tests performed following the Stress Path nº 1*

This stress path is as follows: Once the membrane is screwed, the soil in the metal frame is set in the membrane and the metal lid of the cell is screwed, then, both the vertical surcharge and the nitrogen pressure are applied at once. It means that the subsequent water uptake is exerted by a soil that has been previously stressed, and therefore, a lower water content, relative to the Stress Path nº 2, is reached. The water content of the soil sample reaches the equilibrium after about 20 days. Then, the cell is dismounted with the purpose of fixing the geosynthetic sample, taking care that the soil sample keeps its moisture. Afterwards, the cell is mounted again and left for another 4 days.

4.3 *Tests performed following the Stress Path nº 2*

This stress path differs from the previous one in applying the vertical surcharge once the soil is in equilibrium with the applied suction. Only a light vertical surcharge is applied (only 0.02 MPa) at the beginning alongside with the suction, just to guarantee a good contact with the membrane. The soil sample takes up water and exhibit a partial heave, depending on the value of the suction. Once the swelling do not develop anymore (about 20 days), it is assumed that the equilibrium is reached, and then, the vertical surcharge is applied. After 7 days, the cell is dismounted so that the geosynthetic sample can be placed. Similarly to the previous case, a period of 4 days is allowed to regain the equilibrium.

5 FRICTION TESTS RESULTS

The peak friction angle at the soil-geosynthetic interface, at a certain suction, can be derived by plotting the envelope of the shear stress peak values at the three vertical surcharges.

Altough the residual friction angle is not attained, the shear-stress vs. displacement curves show a significant reduction, towards a constant value which tends to the residual value. Table 2 shows the resulting friction angles when the stress Path nº 1 was followed. The resulting friction angles corresponding to the Stress Path nº 2 are shown in Table 3.

Table 2. Results of the friction angles following Stress Path nº 1.

	0.5 MPa	0.1 MPa	0.025 MPa
Geotextile 1	29.0 (23-25)	31.0 (26-29)	28.0 (28-31)
Geotextile 2	28.5 (22-24)	30.5 (24-26)	27.5 (27-29)
Geocomposite	28.5 (19-21)	29.5 (23-25)	27.5 (28-29)

*In brackets (%) the mean water contents of the soil at the interface

Table 3. Results of the friction angles following Stress Path nº 2.

	0.5 MPa	0.1 MPa	0.025 MPa
Geotextile 1	26.0 (24-26)	28.0 (30-33)	25.5 (33-36)
Geotextile 2	27.0 (23-27)	28.0 (29-32)	25.0 (32-35)
Geocomposite	27.5 (24-26)	29.0 (29-33)	24.0 (32-35)

*In brackets (%) the mean water contents of the soil at the interface

In relation to whether a cohesion is generated during the consolidation process, due to the interlocking and adhesion of the soil within the geosynthetic filaments, the contacts between both materials have been examined just after the friction tests. As a result, it was observed that the soil sample stuck to the geosynthetic, in such a degree that the soil sample, together with the metal frame remained stuck to the geosynthetic when the rolling plate was put downwards. In terms of cohesion, it can hardly be higher than 0.01 MPa. The higher adhesion was reported at 0.1 MPa. The friction envelope backs up this fact, as it meets the vertical axis near the origin. Therefore, the cohesion itself is not much relevant, having an effect on the friction angle, though. The samples of the previous tests with control of total suction (Asanza & Sáez, 2000), carried out in the range of 2-20 MPa, did not developed adhesion at the interface.

6 THE EFFECT OF THE CAPILLARY BREAK

After the completion of a preliminary test, it was observed that the water transference process from the saturated porous stone up to the soil, took much longer than it did when there was no geosynthetic in between.

This phenomenon is known as capillary break (Koerner, 1997), and some studies have been carried out (Stormont & Morris, 1998). This can be graphically explained by means of Figure 5. The rise of the water column becomes more difficult as the average pore size increases. Once the water reaches the geosynthetic on its way upwards, the liquid phase is broken, and the water transfer do not occur as a water flow, but as vapor flow.

For the sake of speeding up the tests program, it was decided to mount the soil sample directly on the saturated porous stone (more precisely, on the semi-permeable membrane), and then, apply either the Stress Path nº 1 or the Stress Path nº 2. Once the equilibrium was reached, the apparatus was dismounted and the geosynthetic placed in its place, and mounted again in such a manner that no significant moisture was evaporated.

Alongside with the friction tests, a series of tests to measure the effect of the capillary break were carried out. The laboratory equipment (pressure membrane cells) are based on the same principle for applying matric suction as the friction apparatus. On one hand, four soil samples were subjected at different suctions (0.025, 0.1, 0.5 and 1 MPa) with a direct contact with the semi-permeable membrane; and, on the other, four identical soil samples, on the same conditions, but with the geotextile 1 in between.

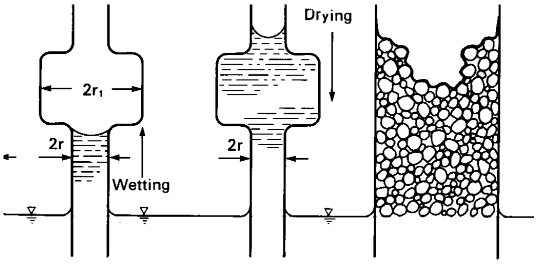

Figure 5. Schematic layout of effect on capillarity due to pore size (after Taylor, 1948)

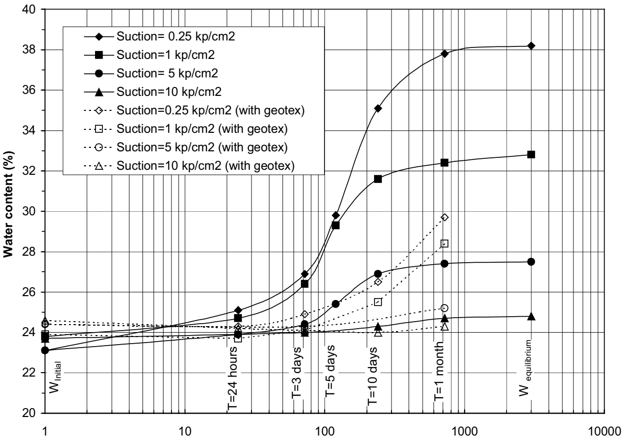

Figure 6. Front view of the apparatus

Figure 6 shows the results of these tests, which clearly indicates a sharp reduction in the rate of taking up water when a geotextile is interposed.

7 CONCLUSIONS

It has been devised an apparatus for measuring the friction between soil and geosynthetics with an accurate control of a constant water content in both materials.

Therefore, as a first conclusion, it can be drawn that the measurement of the friction angle of the soil-geosynthetic interface at a certain condition of moisture can be successfully obtained by means of suction, extending the laboratory techniques commonly used in studies of unsaturated soils.

In this regard, as the retention curve has been previously determined, the relation between the water content and the friction angle can be derived.

It has been found that the maximum friction angle takes place in the range of 0.1 MPa, resulting smaller at higher and lower ranges.

On the other hand, although the cohesion generated at the soil-geosynthetic interface is small and can be neglected in terms of strength, it has been reported that the maximum occurs in the range of 0.1 MPa. At lower suctions, the higher water content brings about a decrease in the adhesion. Moreover, tests carried out at higher suctions show also a reduction in the degree of the adhesion. Tests carried out at total suctions, at really high values, did not exhibit any adhesion in the contact.

It has been also been experimentally confirmed the importance of the stress path followed by the samples on the final friction conditions of the soil. The stress path rules the final water content, and, in turn, the friction angle.

Moreover, it has been proved that the effect of the capillary break can be successfully reproduced in laboratory using the techniques developed for unsaturated soils.

ACKNOWLEDGEMENTS

The authors acknowledge the valuable help given by Carlos Sánchez, Managing Director of Polyfelt Geosynthetics Iberia.

REFERENCES

Asanza, E. & Sáez, J. 2000. Testing equipment for measuring the friction between soils and geosynthetics under control of total suction. EuroGeo 2000, *2nd European Geosynthetic Conference*, Bolonia.

Asanza, E. & Sáez, J. 1999. Text results of suction-water content relation with geotextiles. *Unpublished report*, Laboratorio de Geotecnia, CEDEX.

Díaz, M. E. 2000. Estudio del comportamiento tenso-deformacional de geosintéticos en ensayos de arrancamiento con relación al diseño de terrenos reforzados. Ph.D. Dissertation. Universidad Politécnica de Madrid.

Fredlund, D. G. & Morgenstern, N. R. 1977. Stress state variables for unsaturated soils. *ASCE, J. Geotech. Div.* 103(5): 447-466.

Koerner , R. M. 1997. *Designing with geosynthetics*, 4th ed. New Jersey: Prentice Hall.

Stormont, J. C., Henry, K. S. & Evans, T. M. 1997. Water retention functions of four non-woven polypropylene geotextiles. *Geosynthetics International*. 4 (6): 661-672.

Stormont, J. C. & Morris, C. E. 1998. Method to estimate water storage capacity of capillary barriers. *Jour. of Geotech and Geoenv. Engng.* 124(4): 297-302.