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Friction at geosynthetic interfaces under hydraulic conditions: new inclined plane test procedures and applications

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ABSTRACT: The geosynthetic systems on slopes are, in most cases, subjected to unfavourable hydraulic conditions. To design these systems, it is therefore necessary to take these conditions into account. A new inclined plane, test procedures and related interpretation methods are proposed here with the objective of providing a more accurate representation of the different situations encountered, in particular wetting of the interfaces and seepage in the protective soil cover. A wet friction angle, generally smaller than the dry friction angle, is defined and the negative role of the water pressure at the slide interface is evaluated. As well as this, a revised version of the standardised procedure is proposed for determining the friction angle when the sliding observed in the course of the test is gradual; this proposal is based on the force necessary to hold back the upper box or the geosynthetic placed immediately above the slide interface. Results are presented to demonstrate the interest of the new types of tests developed.

1 INTRODUCTION

Geosynthetic liner systems are increasingly widely used in many types of civil engineering structures: dams, basins, canals, waste landfills etc. The particularity of the geosynthetic complexes in these liner systems, when they are placed on slopes, is that they are usually subjected to low normal stresses and to varied hydraulic conditions. If the required dimensions of these systems are to be calculated, it is necessary to characterise the friction between the different materials of which they are composed. This characterisation is generally carried out using apparatus of the "shear box" or "inclined plane" types.

After an examination of the bibliographical data concerning such apparatus and experiments (Briançon, 2001), the inclined plane seemed to be the best suited to this type of characterisation under low normal stress. Among the different experiments noted, few took the influence of water into account yet, in the light of the different cases of failure observed, hydraulic conditions would appear to be an element that has a slightly negative effect on stability.

The aim of the present study is to improve the analysis of the stability of these geosynthetic liners on slopes by providing a more reliable calculation of the friction characteristics at the interfaces; an apparatus of the inclined plane type was designed and a test and interpretation methodology was developed. This methodology is an adapted version of the existing tests (Girard et al., 1990; Lalarakotoson et al., 1999) and of the French (AFNOR, 1994) and European (prEN, 2000) standards. It aims essentially to take into account varied hydraulic situations at the interfaces.

2 DEVELOPMENT OF A NEW INCLINED PLANE

2.1 *Apparatus*

The new apparatus that we have designed and developed is composed of a lower box that can be inclined and on which rests an upper box; the latter is equipped with a system of wheels and can move along rails laid out on either side of the lower box. The two boxes can be filled with soil; their dimensions (L=2.0 m; W=1.2 m and H=0.3 m for the lower box; L=1.0m; W=1.0 m and H=0.5 m for the upper box) make it possible to carry out tests on samples of geosynthetics of large dimensions (1m x 1m).

Figure 1. Photo of the inclined plane

The geosynthetics are laid out between the two boxes; depending on the interface to be tested, they may be attached to the upper box or fixed, uphill from the lower box, to anchor grips coupled with force sensors measuring the tensions developed in the geosynthetics. The adjustable gap between the two boxes enables testing of geosynthetic systems of varying thickness that can be composed of between one and four geosynthetics. A computer-piloted, motorised winch inclines the plane at variable, controlled speeds (0.5 to 3.5°/min).

The inclined plane is equipped with the instruments required (displacement, force and incline sensors) to monitor, as the plane is inclined, the relative displacements of the geosynthetics and to determine the friction between the various materials.

This inclined plane can also be set up in "hydraulic configuration" by installing watertight walls and systems to wet the geosynthetics, generate seepage in the soil and simulate filling or rapid drawdown.

3 PRESENTATION OF THE TEST PROCEDURES

We carried out almost 150 tests using the different test procedures presented in Table 1.

Table 1. Details of the different test procedures used on the inclined plane

Procedure	Measurement	Upper box.	Upper GSY *
D_1	β_R	free	free
D_2	T	free	anchored**
F	F_B	fixed	fixed to upper box

* *geosynthetic located above the interface being tested*
** *end fixed to the lower box by a system measuring the tensions generated.*

3.1 *Test described by the standards (D_1)*

The friction test described in the standards mentioned above (referred to here as D_1) enables the measurement of the angle β_R at which we observe sliding between the two materials (two geosynthetics or one geosynthetic and the soil), one of these two materials being attached to the upper box. This slide angle is defined on the basis of a criterion corresponding to the plane incline angle for which the displacement of the box reaches 50 mm.

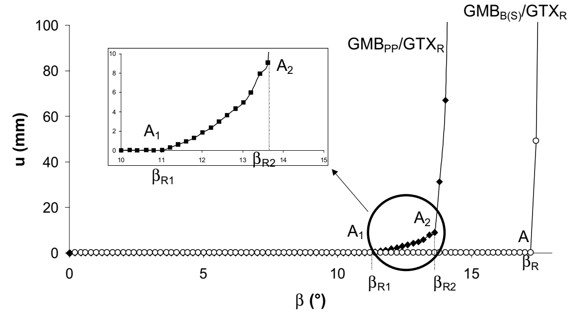

Figure 2. Interpretation problems of a test of type D_1

The friction angle δ is calculated on the basis of this slide angle β_R by working out the balance, at failure, of the forces applied to the interface being tested and projected parallel to the slope:

$$W_S \sin \beta_R + fr(\beta_R) = W_S \cos \beta_R \tan \delta \quad (1)$$

with W_S: weight of the soil contained in the upper box,
$fr(\beta)$: force necessary to hold back the empty upper box in relation to the incline of the plane.

Depending on the interface being tested, we observed two modes of displacement of the upper box:

- no displacement of the upper box for $\beta<\beta_R$ then brutal displacement (Figure 2, bituminous geomembrane (smooth side) $GMB_{B(S)}$ / unwoven, needle-punched reinforcement geotextile GTX_R interface),
- no displacement for $\beta<\beta_{R1}$ and then slow, gradual movement of the upper box for $\beta_{R1}<\beta<\beta_{R2}$ and finally brutal displacement for $\beta>\beta_{R2}$ (Figure 2, polypropylene geomembrane GMB_{PP} / unwoven, needle-punched reinforcement geotextile GTX_R interface).

In the former of these two cases, the criterion defined in the standard can be used to determine the failure angle β_R without the slightest ambiguity (Figure 2, point A). However, in the second type of case, determining the failure angle β_R is a more delicate task; actually, if the criterion specified in the standard is applied, it leads to an angle $\beta_R=\beta_{R2}$ (Figure 2, point A_2) greater than the angle β_{R1} at which the box begins to move (Figure 2, point A_1). The difference between β_{R1} and β_{R2} varies from one interface to another; it can be very large and lead to differences in friction angle of up to 5°. With the aim of proposing a failure criterion for those interfaces that pose interpretation problems, we developed the new test procedures described hereafter and the interpretation methods that go with them.

3.2 *New friction characterisation test (D_2)*

3.2.1 *Test procedure*

This type of test (referred to as D_2) was developed in order to provide a new interpretation method capable of reducing the uncertainties in the measurement of the friction angle encountered in the analysis of tests of type D_1 applied to certain interfaces. It consists in measuring the tensions T generated in the anchored geosynthetic (Figure 3). The procedure is presented here through the example of a test of the friction between two geosynthetics but it is also valid for characterising the friction between a soil and a geosynthetic.

This test makes it possible to determine the friction angle at the interface between the anchored geosynthetic and the geosynthetic fixed to the lower box (anchored interface) by measuring the tension generated in the anchored geosynthetic; the geosynthetic is fixed to the lower box either by gluing it or by placing it on a high-friction surface (or a soil).

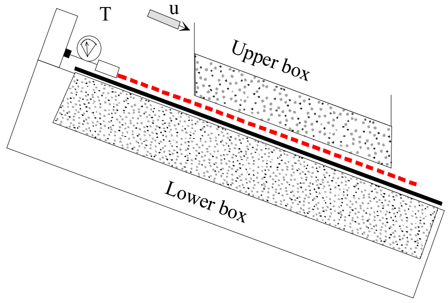

Figure 3. Diagram of a test of type D_2

3.2.2 *Related interpretation method*

Measuring the tension T generated in the anchored geosynthetic then makes it possible to determine the value of the angle λ between the result of the driving forces (applied to the anchored interface that is to be characterised) and a normal line to the inclined plane, in relation to the incline β of the plane (Figure 4) :

$$\tan \lambda = \frac{F_M - T}{N} \quad (2)$$

with F_M: driving forces applied (=Ws.sinβ+fr(β)),
T: tension generated in the anchored geotextile,
N: component of the weight of the soil perpendicular to the slide surface (=Ws.cosβ).

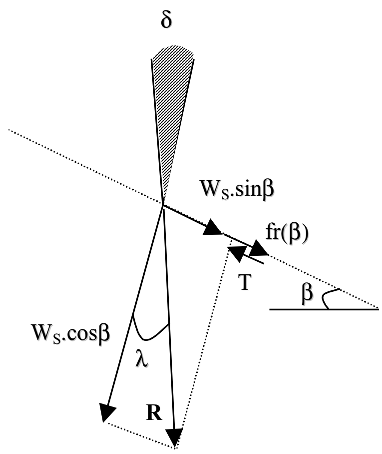

Figure 4. Angle λ of the resultant R with the slide plane normal line.

Figure 4 presents a diagram explaining the balance of forces when the incline of the plane is greater than β_R. It is supposed that the interface being characterised has a friction angle δ.

As long as $\beta<\beta_R$, the driving forces applied to the anchored interface are less than the resistant forces ($\lambda<\delta$ et T=0).

When β reaches the value β_R, angle λ reaches the value δ (relations 1 and 2) and tension T begins to be generated in the anchored geosynthetic; next, when β exceeds β_R, this tension contributes to balancing out each additional increase in driving force applied to the "anchored interface" and so λ remains equal to δ. As a result, the interpretation curve (Figure 5) representing angle λ in relation to β levels out and it becomes impossible to determine the friction angle δ at the "anchored interface" since δ=λ on this plateau.

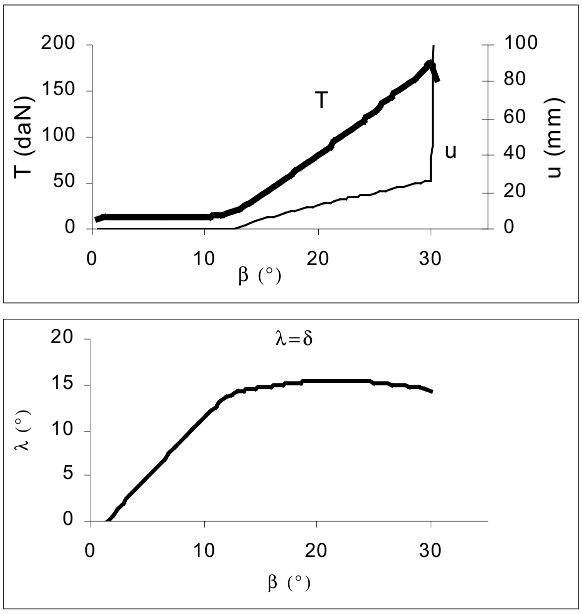

Figure 5. Unprocessed and interpretation curves of a test of D_2 characterising friction between a GTX_R and a GMB_{PP}

3.3 *Test adapted to the application of hydraulic conditions (F)*

This test (referred to as F) was developed to apply various hydraulic conditions to the geosynthetic system being tested. It consists in measuring the force F_B necessary to hold back the upper box as the plane is being inclined (Figure 6). In particular, this test makes it possible to incline the plane to angles that are greater than the slide angle of the interface being tested and then to apply given hydraulic conditions, β being constant.

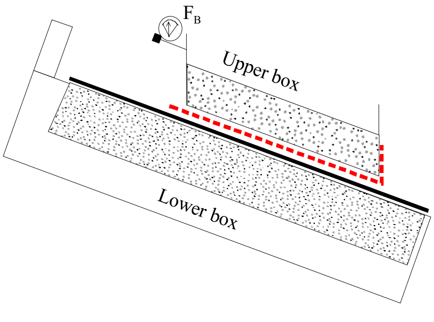

Figure 6. Diagram of a test of type F

As with the type D_2 test, measuring force F_B makes it possible to monitor changes in the value of angle λ and to determine, when λ reaches a plateau, the friction angle δ of the interface with the weakest friction characteristics of the system being tested.

4 VALIDATION OF THE NEW PROCEDURES

The geosynthetics used in this study were various geotextiles from the Bidim Geosynthetics range and various geomembranes from the Siplast range. To be more precise, these geosynthetics were a protection geotextile (GTX_P), a separation geotextile (GTX_S), a filtration geotextile (GTX_F) and a reinforcement geotextile (GTX_R), a polypropylene geomembrane (GMB_{PP}), a PEHD geomembrane (GMB_{HDPE}) and a bituminous geomembrane (GMB_B). We differentiated between the smooth side ($GMB_{B(S)}$) and the rough side ($GMB_{B(R)}$) of the bituminous geomembrane.

The PhD research work of Briançon (2001) studying different types of geosynthetic interfaces using tests of type D_1 and of types D_2 and F, provided the results hereafter. For interfaces that do not pose interpretation problems with the type D_1 test, there was a good match between the results obtained by applying the standards (D_1 tests) and those obtained with the new methods (D_2 and F tests). For the other interfaces tested with which the sliding was gradual, it was the angle corresponding to the beginning of the displacement of the upper box that led to results equal to those obtained in the tests of types D_2 and F. The criterion specified by the standards (50 mm criterion) produced friction angles greater than those from the tests of types D_2 and F (by up to 5°). The new procedures thus made it possible to resolve the interpretation difficulties encountered on certain interfaces using the tests described in the standards, interfaces that were not tested when the standards were written up.

On the basis of the many tests carried out, we checked the influence of different parameters on the friction characteristics. For example, it was possible to demonstrate the influence of the nature of the geomembrane on "geomembrane / geotextile" friction (Figure 7).

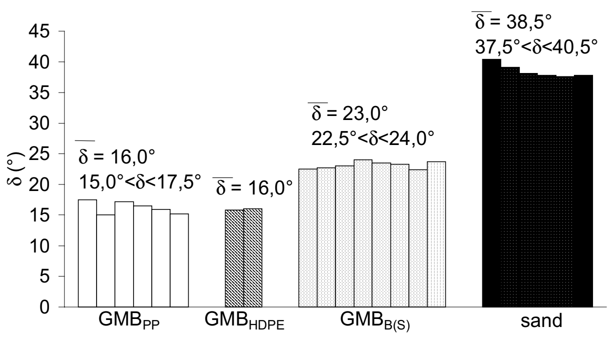

Figure 7. Influence of the nature of the geomembrane in contact with an unwoven, needle-punched reinforcement geotextile (GTX_R)

The repeatability of the measurements of the friction angle on the inclined plane was also checked. It was variable, depending on the types of test and of interface tested. Repeatability was good, that is to say that the measurements were not very widely dispersed (<1°) for the new tests and the D_1 test applied to certain interfaces; it was not so good for the tests of type D_1 applied to the "GTX / GMB_{PP}" interfaces, precisely those interfaces that pose interpretation difficulties.

5 HYDRAULIC TESTS

Different hydraulic conditions were applied to the geosynthetic systems. In particular, we studied the wetting of the geosynthetic interfaces and the saturation of the protective soil cover. The results obtained on the inclined plane for the application of hydraulic conditions were validated by two full-scale experiments (Briançon 2002).

5.1 *Wetting of the geosynthetic interface*

The first type of hydraulic test consisted in checking the influence of wetting on the friction angle at the interface being tested, by creating seepage without interstitial pressure at the interface between the geosynthetics in the liner system and by measuring the force F_B required to hold the upper box back (test of "type F"). The friction angle at the interface being tested was then determined using the same methods as those employed for the tests in dry conditions (D_2 and F).

Several interfaces were tested. These tests highlighted a marked influence of water on the friction of the interfaces being considered. The wetting of the geosynthetic interface being tested caused a decrease in the measured resistance to friction. Working on the assumption that seepage does not generate uplift at the interface (seepage with low flow rate), a slide angle β_{RH} can be measured and an angle δ_H corresponding to the friction angle with seepage at the interface can be calculated; this angle will be called "wet friction angle" from now on. For all the interfaces tested, wetting tends to reduce the friction. This influence of wetting varies from one interface to another and can vary from 1° to 5° in certain cases.

5.2 *Seepage in the protective soil cover*

This test (type F) makes it possible to determine the influence of seepage in the protective soil cover on the stability of the geosynthetic liner system being tested.

The friction test with seepage in the soil is presented through the example of a geosynthetic system composed of a bituminous geomembrane $GMB_{B(S)}$ (smooth side under the geotextile) and an unwoven, needle-punched reinforcement textile GTX_R placed under a layer of protective soil cover (sand) with a thickness of 0.3 m. For this test, the plane was inclined under dry conditions until 30° (Figure 8, portion AB). The wet friction angle δ_H was calculated after creating seepage at the interface (Figure 8, point C). Then, the influence of the seepage in the soil on the stability of the system was examined for two heights of water:

- e_{sat}=0.1m (Figure 8, point D),
- e_{sat}=0.2m (Figure 8, point E).

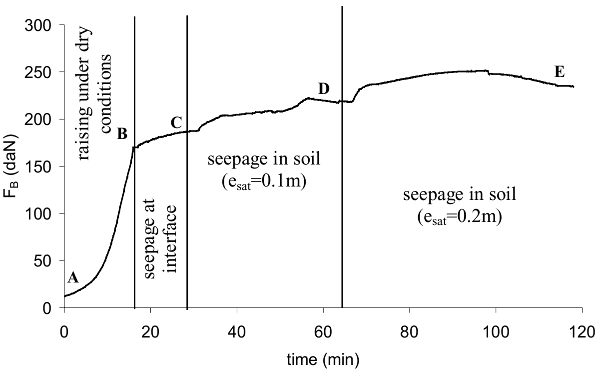

Figure 8. Test with seepage in the protective soil cover for a liner system composed of a geomembrane $GMB_{B(S)}$ and a geotextile GTX_R.

Table 2. Comparison between the measured and calculated values of F_B in the course of a soil cover saturation test

	thickness of saturated soil	
	(Fig.8, point D)	(Fig.8, point E)
e_{sat} (m)	0,1	0,2
$F_{B(exp.)}$ (daN)	219	252
F_{B1} (daN)	196	205
F_{B2} (daN)	224	262

Comparing the experimental measurements with the values calculated taking into account the interstitial pressure generated by the seepage (F_{B2}) or not (F_{B1}), it was possible to check that the interpretation of the test under effective stress was correct.

This experiment shows that the inclined plane is well suited to highlighting the influence of seepage in protective soil cover. This influence of the uplift generated by seepage in the soil on the stability of the geosynthetic system is shown by the decrease in the resisting forces applied to the system and is shown by an increase in the force required to hold back the device on the geomembrane. In the example shown, saturation of ⅔ of the thickness of the soil cover corresponds to an increase of almost 50% in the value of the anchoring force determined in dry conditions.

6 CONCLUSION

The development of new apparatus and new test procedures made it possible to improve the characterisation of friction at geosynthetic interfaces. The procedure proposing to measure the tensions generated in the geosynthetics provides a new approach to the characterisation of friction at geosynthetic interfaces. The procedure proposing to measure the force required to hold back the upper box enables the inclined plane to be set up so as to adapt it to the application of hydraulic conditions. In these conditions, the influence of water (wetting of the materials, saturation of the protective soil cover) was demonstrated. This influence is significant in most cases and must be taken into account when determining the dimensions of geosynthetic liner systems to be installed on slopes. To validate the many results obtained on the inclined plane, two full-scale experiments were carried out (Briançon, 2001); the results collected further to these experiments backed up and validated the measurements taken on the inclined plane.

The new prospects opened up by the use of this new inclined plane are many: as well as the continuation of hydraulic tests (rapid drawdown with less permeable soils) and those involving specific materials (paving, concrete,…), it will be possible, thanks to the deployment of more precise, local measurements of the relative displacements between the geosynthetics, to continue to improve knowledge of friction at geosynthetic interfaces.

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