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Testing procedure with an inclined plane device to assess the residual friction characteristics at geosynthetics interfaces

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ABSTRACT: This study presents a new testing procedure to assess the residual friction characteristics of geosynthetics-geosynthetics (GSY-GSY) interfaces using an inclined plane (IP) device. The residual friction characteristic corresponds to the friction angle of a GSY-GSY interface determined for a uniform sliding motion condition. A series of tests on a geotextile-geomembrane interface was performed following this residual friction testing procedure. From the results, it was shown that the proposed new testing procedure assessed a residual friction angle φ_{res} that did not depend on the "sliding history". It was shown that this residual friction angle is more conservative than the friction angle obtained from the European standard EN ISO 12957-2 (AFNOR, 2005).

1 INTRODUCTION

The use of geosynthetic materials is a widespread technical solution for various specific/combined applications in geotechnical structures like watertightness, drainage, filtration and protection. The design of such systems on slope requires the knowledge of friction characteristics at soil-geosynthetic or geosynthetic-geosynthetic interfaces. These characteristics are fundamental in the context of space optimisation that induces steeper slopes (e.g. landfill cells). The measurement of interface friction angle including geosynthetics can be performed using the direct shear box test, following the European standard EN ISO 12957-1 (AFNOR, 2005), and the inclined plane (IP) test, following the European standard EN ISO 12957-2 (AFNOR, 2005). It has been shown that the IP test is more appropriate than the direct shear box test for the friction angle measurement at geosynthetic interfaces under normal stresses lower than 10 kPa (Koutsourais et al. 1991, Izgin and Wasti 1998, Palmeira et al. 2002). However, some recent studies indicated that the standardised testing procedure of the IP test could give a non conservative measurement of the friction angle.

In fact, Reyes Ramirez and Gourc (2003) showed that the standardised testing procedure of the IP test assessed the friction angle φ_{50} from a static analysis for conditions that were actually dynamic. Pitanga et al. (2009) showed that the friction angle corresponding to the initiation of sliding and the friction angle corresponding to sliding at constant acceleration were generally lower than φ_{50}. However, they did not conclude on the friction angle value that should be considered. Briançon et al. (2011) proposed a modified procedure IP device, called "force procedure". From this procedure, they obtain lower angle friction values than those obtained from the standardised testing procedure of the IP test. From these various studies, it appears that the measurement of the friction angle at geosynthetic interfaces is a pending question.

The aim of this paper is to propose a testing procedure with an IP device that allows the measurement of residual friction angle at geosynthetics interfaces with uniform sliding motion condition. From tests performed on a geomembrane (GMB) – geotextile (GTX) interface, the proposed testing procedure is compared to the standardised one.

The following paragraph depicts the IP device and then describes the standardised testing procedure of the IP test and the proposed testing procedure. Lastly, the experimental program carried out on a geomembrane – geotextile interface is presented.

2 MATERIALS AND METHOD

2.1 *Inclined plane device*

The IP device consists of a tilting plane onto which an upper box is set up that can move thanks to wheels on rails located on either side of the plane. The length and width of the upper box are both equal

to 1 m. A monitorised winch, managed by computer, allows to control the inclination rate.

2.2 *Standardised testing procedure*

The standard EN ISO 12957-2 (AFNOR, 2005) is a testing procedure to assess the friction angle at geosynthetics or soil-geosynthetic interfaces, under low normal stress using an IP device. The test consists in measuring the plane inclination β_{50}, increasing at constant rate, when the upper box, filled with soil to applied normal stress, slides to a tangential displacement δ of 50 mm (Figure 1). The length and the width of the tested interface have to be at least equal to 0.3 m. The required inclination rate of the plane is $d\beta/dt = 3.0° \pm 0.5°$/min. The initial normal stress σ_0 (for $\beta = 0°$) is equal to 5.0 ± 0.1 kPa. The normal stress σ varies during the test as a function of the plane inclination β, i.e. $\sigma = \sigma_0 \cos\beta$. To obtain a uniform normal stress on the whole interface area, the front and rear sides of the upper box should be tilted before the test beginning to be inclined close to the vertical during the sliding phase.

The standardised procedure determines the interface friction angle φ_{50} (Equation 1) when the plane inclination β_{50} is reached, that is to say when the upper box slides to a tangential displacement δ of 50 mm. The interface friction angle φ_{50} is calculated, according to the free-body diagram displayed on Figure 1, by the following equation:

$$\tan\varphi_{50} = \frac{W_s \cdot \sin\beta_{50} + fr(\beta_{50})}{W_s \cdot \cos\beta_{50}} \quad (1)$$

where W_s is the weight of the soil and $fr(\beta_{50})$ is the resulting force required to hold back the empty upper box.

Three tests on virgin interfaces are required to calculate the arithmetic mean $\overline{\varphi}_{50}$, mean friction angle of the studied interface.

It is essential to note that Equation (1) results from a static analysis whereas sliding conditions are dynamic, that is to say the dynamic force of the upper box is neglected. That is why some authors like Reyes Ramirez and Gourc (2003) showed that the standardised procedure was not suitable to determine the friction angle of geosynthetics interfaces.

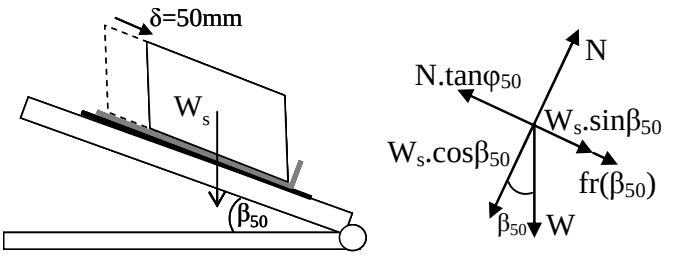

Figure 1. Free-body diagram for the standardised procedure of the IP test.

2.3 *Residual friction testing procedure*

This procedure aims at determining the residual friction characteristics at geosynthetics interfaces. It consists in measuring the force F required to retain the upper box that can slide on the tilting plane, whatever the plane inclination, thanks to a spring. The force F is linked to the tangential displacement δ by the spring following the relationship:

$$F = k \cdot \delta \quad (2)$$

where k ($N.m^{-1}$) is a constant that depends of the spring that has to be chosen in order to allow a tangential displacement at least equal to 20 mm at the end of the test and to hold down a negligible acceleration during the test.

Initially, the spring used to retain the upper box is lightly tightened with a force lower than or equal to 100 N. This initial force permits to avoid an accelerated sliding motion of the upper box. Then, the plane inclination β is increased. For a plane inclination β_0 depending of the tested interface, the beginning of the upper box sliding is observed (tangential displacement $\delta >> 0$ mm). Then, the test continues and the plane inclination β keeps on increasing. The elastic strain of the spring induces a uniform sliding motion of the upper box and the measurement of the force F permits to determine the friction strength T at the interface using Equation 3, deduced from the free-body diagram (Figure 2):

$$T = W_s \cdot \sin\beta + fr(\beta) - F(\beta) \quad (3)$$

where $F(\beta)$ is the resulting force required to hold back the upper box.

The friction characteristics of the tested interface can be determined following the (β, T/N) curve. If the (β, T/N) curve presents a peak $(T/N)_{peak}$, corresponding to the maximal friction strength, and a plateau $(T/N)_{res}$, corresponding to the ultimate friction strength, it is possible to determine two friction angle values φ_{peak} and φ_{res} using respectively Equations 4 and 5. If the (β, T/N) curve does not present any peak, only φ_{res} can be determined.

$$\tan\varphi_{peak} = \left(\frac{T}{N}\right)_{peak} = \frac{T_{peak}}{W_s \cdot \cos\beta_{peak}} \quad (4)$$

$$\tan\varphi_{res} = \left(\frac{T}{N}\right)_{res} \quad (5)$$

The parameter (T/N) is selected to determine the friction angle because, when the ultimate shearing strength is reached, the friction strength T varies due to the variation of the normal force N.

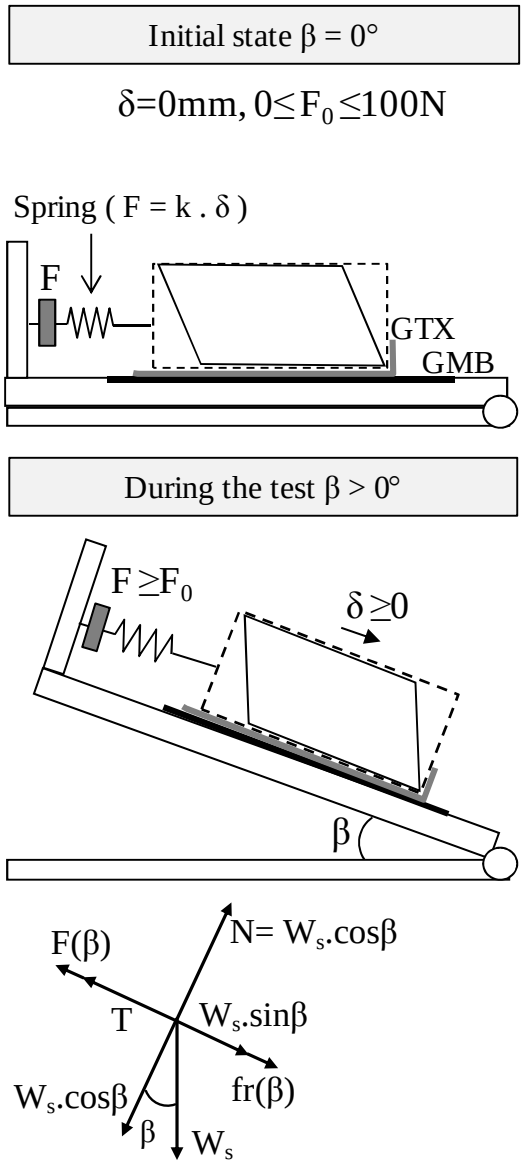

Figure 2. Schematic of the residual friction testing procedure of the IP test and corresponding free-body diagram.

It can be noted that Equation 3 is valid if: (1) the upper box is static (condition reached before the beginning of sliding), (2) the upper box has a uniform sliding motion (condition reached in the last part of the test), and (3) the upper box has a negligible acceleration γ (condition that has to be verified at the beginning of sliding). The equation of the force diagram that includes the dynamic force arisen from the acceleration γ is expressed as follow:

$$W_s \cdot \sin\beta + fr(\beta) - T - F(\beta) = W_s \cdot \gamma / g \quad (6)$$

Equation 6 simplifies in Equation 3 if:

$$\sin\beta >> \gamma / g \quad (7)$$

Equation 7 has to be verified throughout the test to determine the friction strength T using Equation 3. If these conditions are not verified, the spring has to be changed to adjust the adequate constant k. In this study, the spring was chosen to have a constant k, defined by Equation 2, equal to 25.10^3 N.m^{-1}.

2.4 *Experimental program*

The tested interface was a structured geomembrane (with spikes) fixed to the tilting plane on which was a woven geotextile fixed to the upper box.
Three tests on virgin interfaces were carried out following the standardised procedure EN ISO 12957-2 (AFNOR, 2005) of the IP test. The slight difference compared to the standardised procedure were the inclination rate which was $d\beta/dt$ = 1.5°/min instead of 3°/min and the initial normal stress which was 4 kPa.
Three tests on virgin interfaces were carried out following the residual friction testing procedure. The three interfaces were denoted A, B and C and the corresponding first test on the virgin interface was denoted A-0, B-0, C-0. To test a non virgin interface, that is to say an interface which has already slid, two additional tests were performed on interfaces A and B, respectively denoted A-1, A-2 and B-1, B-2. For these tests, the normal stress σ_0 = 4 kPa was maintained between the tests that is to say that test A-0 was performed on a virgin interface, then the IP was put back in its initial position and then test A-1 started. Test A-2 followed test A-1. The same sequence was applied to interface B.
Lastly, to test the "sliding history" of an interface, the interface B that had slid three times was unloaded (σ = 0 kPa) after test B-3 and then reloaded (σ_0 = 4 kPa) to undergo a new series of three tests denoted B'-0, B'-1 and B'-2.

3 RESULTS AND DISCUSSION

3.1 *Results from the standardised testing procedure*

The friction angle of the studied interface obtained from the standardised testing procedure of the IP test ranged between 25° and 27° (Figure 3). The three tests allowed to assess a mean friction angle of 25°. It is worth noting that the sliding behaviour of the studied interface corresponded to a "sudden sliding".

3.2 *Results from the residual friction testing procedure*

3.2.1 *Virgin interfaces A, B and C*

For each test, the upper box displacement δ, the Force F retaining the upper box, the calculated friction strength T (Equation 3) and the corresponding T/N parameter are given in Figure 4 as a function of the plane inclination β. The results show that for β in the range 24° to 26°, δ and F increased significantly. These plane inclination values β_{peak} corresponded to a peak value for the friction, approximately equal to 28° for tests A-0 and A-1 and 30° for test A-2. After β_{peak}, δ and F increased linearly with β corresponding to a uniform sliding motion of the upper box. This resulted in a plateau for the friction angle, corresponding to the residual friction angle φ_{res}.

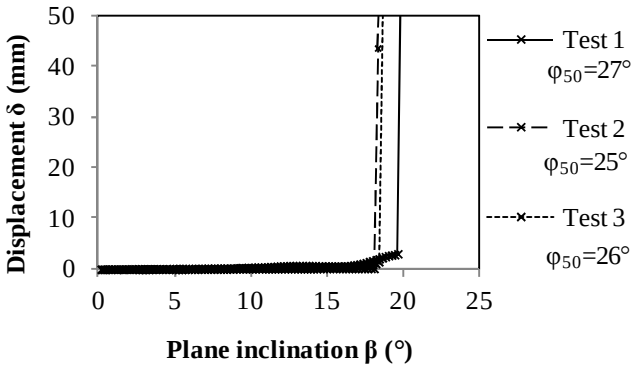

Figure 3. Results obtained from the standardised procedure of the IP test.

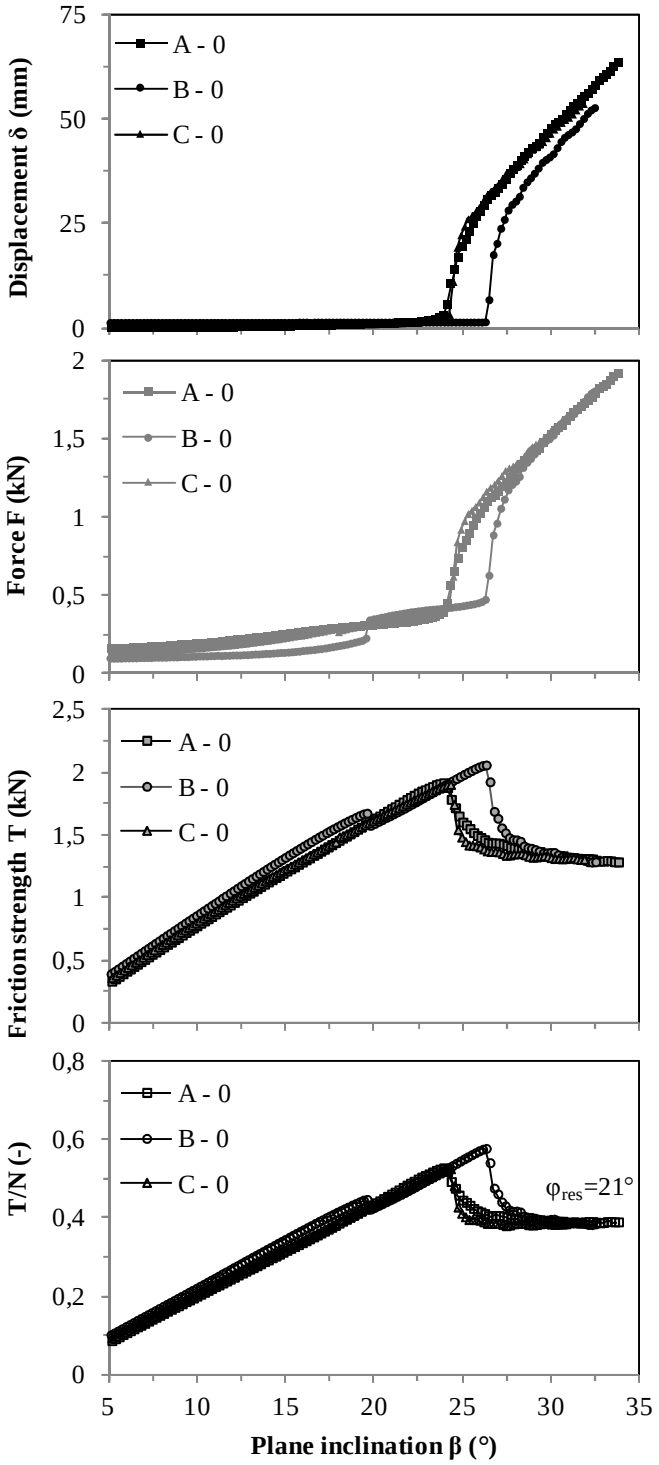

Figure 4. Displacement, force F, friction strength T and T/N parameter obtained from the residual friction testing procedure of the IP test for the virgin interfaces A, B and C.

From the three tests on virgin interfaces, φ_{res} could be assessed at 21°.

To apply Equation 3 throughout the test, Equation 7 has to be verified to confirm the negligible acceleration of the upper box at the beginning of sliding. The stronger acceleration for the tests was obtained for test A-2 at a plane inclination of 26.5°. This maximal acceleration was assessed at about 1.10^{-4}m.s^{-2}. Equation 7 with sin β equal to 0.446 is then well verified.

The residual friction testing procedure does thus allow to assess a residual friction angle φ_{res} for a geosynthetic interface for a uniform sliding motion condition.

3.2.2 *Successive tests A-1, A-2 and B-1, B-2*

Tests A-0 and B-0 carried out on virgin interfaces are compared to tests A-1, A-2 and B-1, B-2 respectively (Figure 5), corresponding to the interfaces that had already slid but had not been unloaded to 0 kPa. The result showed that the peak friction angle φ_{peak} was around 23° for the four tests A-1, A-2, B-1 and B-2 whereas it was larger than 28° in tests A-0 and B-0 on virgin interfaces. φ_{peak} is then significantly reduced once the interface has slid for the first time. For tests A-1, A-2, B-1 and B-2, the residual friction angle φ_{res} can be assessed between 20° and 20.5°, values very close to those obtained from virgin interfaces (tests A-0 and B-0). Thus, the decrease of φ_{peak} does not alter the value of φ_{res}.

3.2.3 *Tests on non-virgin interface B'-0, B'-1, B'-2*

Results in tests B'-0, B'-1 and B'-2 can be compared to results in tests B-0, B-1 and B-2, carried out on the same interface B but not subjected to unloaded. From tests B-0 and B'-0, the same values of peak friction angle were obtained although the interface B' had already been subjected to sliding during tests B-0, B-1 and B-2. Moreover, test B'-0 presents the same value of residual friction angle than test B-0. It can thus be concluded that the interface B was not damaged by tests B-0, B-1 and B-2. So, the decrease of the friction angle from φ_{peak} to φ_{res} does not correspond to a damage of the interface and the behaviour peak-plateau of the curve (β,T/N) is characteristic of the IP test. A maximum value of φ_{peak} is obtained when the tested interface has never slid. Thus, in the case of an interface which is not damaged during sliding, φ_{res} does not depend on the "sliding history" unlike φ_{peak} which is not an intrinsic characteristic of the interface.

3.3 *Comparison between the standardised and the residual friction testing procedure*

The standardised testing procedure of the IP test assesses the interface friction angle in sliding condi-

tions by considering a free-body diagram in static condition. Moreover, this friction angle is measured from the interface which has never slid.

From the tests performed following the residual friction testing procedure, it was shown that the friction angle measured during uniform sliding motion condition (φ_{res}) is lower than the friction angle measured at the interface sliding initiation (φ_{peak}). Moreover, the peak friction angle has a maximum value at the first interface sliding.

So, if the two testing procedures are compared, it can be concluded that the testing conditions of the standardised procedure are close to those of the residual friction testing procedure that measures the peak friction angle. This is confirmed by friction angles values which are close: $\overline{\varphi}_{50}$ equal to 26° and $\overline{\varphi}_{peak}$ equal to 29° for the first tests A-0; B-0; C-0. Thus, the standardised testing procedure of the IP test assesses a non conservative friction angle unlike the residual friction testing procedure that assesses a conservative residual friction angle φ_{res}.

4 CONCLUSION

This study presents a new testing procedure to assess the residual friction characteristics of geosynthetics interfaces using an IP device. This residual friction testing procedure was compared to the standardised testing procedure of the IP test, the European standard EN ISO 12957-2 (AFNOR, 2005) from tests performed on a geotextile-geomembrane interface.

From the results obtained from the residual friction testing procedure of the IP test, the main conclusions can be drawn:

The proposed new testing procedure assessed a residual friction angle φ_{res} for the tested geosynthetic interface in uniform sliding motion condition.

The tested interface was not damaged during sliding that permits to show that φ_{res} does not depend on the "sliding history" unlike φ_{peak} which is not an intrinsic characteristic of the interface.

The standardised testing procedure of the IP test assesses a non conservative friction angle φ_{50} unlike the residual friction testing procedure that assesses a conservative residual friction angle φ_{res} for the tested interface.

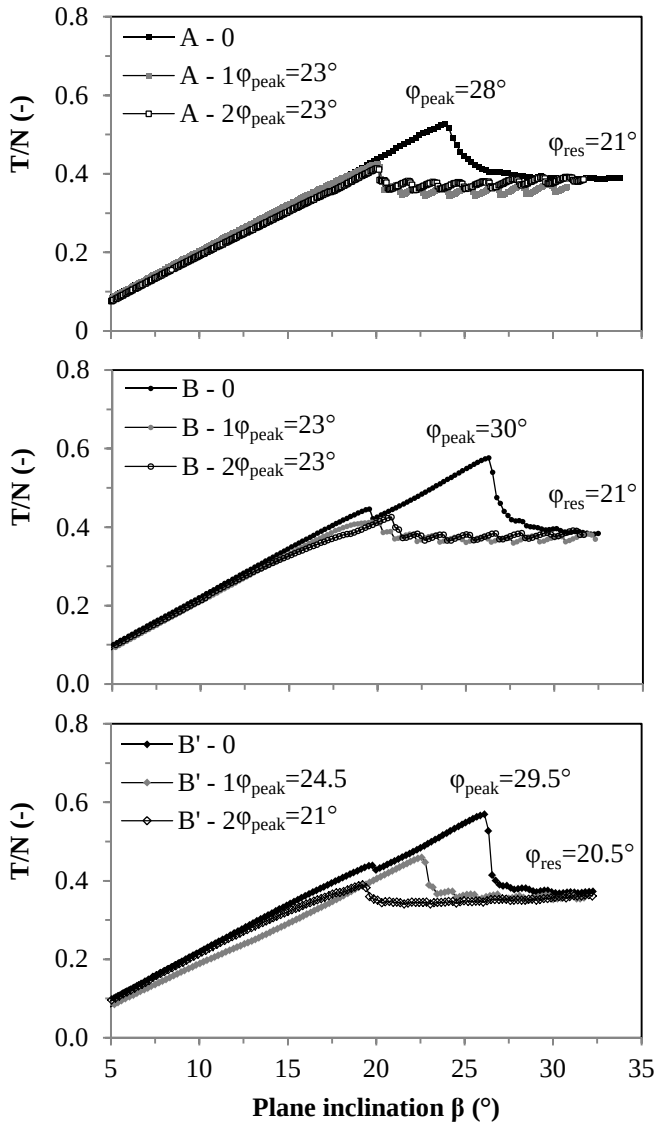

Figure 5. (β,T/N) curves and calculated friction angles of the various interfaces obtained from the residual friction testing procedure of the IP test.

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