Determine geotextile-geomembrane interface frictional properties using inclined plane test

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ABSTRACT: Recent years have seen a large growth in engineering solutions involving the implementation of geosynthetic materials. One of the key issues concerning the mechanical characterization of geosynthetics is the friction at soil-geosynthetic and geosynthetic-geosynthetic interfaces. An estimation of this property is very important in optimizing geotechnical solutions such as slope-liner systems, which are very commonly used in landfills and basins. Direct shear-box and inclined-plane experiments have been applied to estimate the characterization of interfacial friction behavior, each with its own specifications and features. To characterize the friction at the geosynthetic interfaces under low vertical stress, the inclined plane is recommended. A new inclined plane test has been developed in the Department of Civil engineering at the Islamic Azad University (Iran, Arak). Therefore this paper presents results of the first test performed on various interfaces using a new device.

Keywords: Geotextile, Geomembrane, Inclined plane test, Friction angle, Laboratory test

1 INTRODUCTION

Ramp tests, or inclined plane tests, are relevant to study the stability of cover systems of waste disposal areas or for erosion control in slopes. In slopes of waste disposal areas, beside the cover soil, more than one type geosynthetic can be present, such as geomembranes(GMB), geocomposites(GCD) and geotextiles(GTX), to play different roles. If the cover soil stability is not properly used, failure can occur.

Inclined plane test, as demonstrated by several studies (Izgin and Wasti 1998, Lalarakotoson et al. 1999, Wasti and Özdüzgün 2001, Palmeira et al. 2002, Palmeira 2009, Reyes Ramirez and Gourc 2003, Wu et al. 2008, Briançon et al. 2011), can be a suitable tool to assess and quantify the interaction between soil-geosynthetic or geosynthetic-geosynthetic interfaces. one of its advantages is the possibility of simulating normal stress lower than 5 kPa. European Standard codes as EN ISO 12957-2 (2005) rules the inclined plane test describing the characteristics of the apparatus and the interpretation of test results. Several studies (Gourc and Reyes Ramirez 2004, Pitanga et al. 2009, Briançon et al. 2011) demonstrated that the assessment of the interface friction angle, as expected by EN ISO 12957-2 (2005), can provide a non-conservative value. For this reason, Gourc and Reyes Ramirez (2004) and Briançon et al. (2002,2011) proposed two different test procedures (Displacement and Force Procedure) to evaluate the interface frictional properties properly.

This study draws a comparison between test result values obtained by the different procedures in order to assess the interface parameters properly. In particular, this work is focusing on the geotextile-geomembrane interface behaviour, considered to be the critical interface of the system.

2 BACKGROUND

2.1. *Displacement procedure*

The Standard EN ISO 12957-2 describes a method for determining the friction angle (δ) of geosynthetic interfaces (geotextiles and geotextile-related products) in contact with soils at low normal stress using an inclined plane (called also a tilting-plane) apparatus with specific variations for geosynthetice-geosynthetic interfaces. This method has been primarily used as a performance test for site-specific soils, but it may also be used as an index test. Among the many discussed points, the most relevant ones are discussed below. In any friction method, the normal force to the interface, W.cosβ, must be evenly applied to obtain a regular distribution of the normal stress over the entire surface of the specimen. EN ISO 12957-2 specified that the applied normal force must be such that initial normal stress (for $\beta=0$) that is equal to 5.0 ± 0.1 kPa. The plane must be equipped with a mechanism for tilting the plane slowly and at a constant rate, (for instance:$d\beta/dt = 3.0 \pm 0.5$_/min). The geosynthetic (lower layer) must be fixed to the inclined plane apparatus to limit any relative movement between the layer and the plane. The techniques used to fix the lower geosynthetic are sewing or gluing, coupled with using a rough support to increase the coefficient of friction, or anchoring the layer outside the contact area. Regarding the dimensions of the apparatus, the displacement prescribes minimum dimensions for both the upper (length, $l_u = 0.3$ m, and width, $b_u = 0.3$ m) and lower ($l_l = 0.4$ m, $b_l = 0.325$ m) boxes (parameters as shown fig. 3). For others tests that are made on different sides of the sample or in a different direction undisturbed samples should be used. The front and rear sides of the upper box are kept parallel, and their inclination is predetermined to be close to the vertical during the sliding phase. Following the “Displacement Procedure”, the friction angle δ_{stan} of the geosynthetice-geosynthetic interface is determined by measuring the inclination angle, β_{50}, of the apparatus at which the upper box with attached geosynthetic slides to a displacement of u= 50 mm. by using static equilibrium the relative friction angle (δ_{stan}) is presented, as follows:

$$\tan\delta_{stan} = \frac{W_s \cdot \sin\beta_{50} + Fr(\beta_{50})}{W_s \cdot \cos\beta_{50}} \tag{1}$$

The interface friction angle δ_{stan} calculated with Equation (1), is obtained from a static analysis.

Actually, since the sliding rate of the upper box becomes significant during the motion, the mechanical equilibrium analysis must be conducted using a dynamic approach. Gourc and Reyes Ramirez (2004), with modifying a displacement inclined plane device, proposed an interpretation of test results, here called ″Displacement Procedure″, taking into account the acceleration of the upper box during the sliding. In the modified configuration, the dimensions of the upper ($lu = 0.18$ m and $bu= 0.7$ m) and lower ($l_l = 1.3$ m, $b_l = 0.8$ m) boxes were altered to increase the length of the sliding displacement in the slope direction. The initial normal stress is applied using metal plates as overload and the lateral guides of the upper box, which ensure that sliding does not deviate with respect to the slope, are assumed frictionless. From test results using this modified setup, Gourc and Reyes Ramirez (2004) divided the upper-box sliding behaviour into three characteristic phases, as follows:

- Phase 1 (Static Phase): The upper box is practically motionless (the displacement of the upper box equals zero) over the inclined plane until a critical angle, β_0, is reached,
- Phase 2 (Transitory Phase): With increasing inclination beyond β_0, the upper box moves gradually downward, and the acceleration γ of the upper box increases, and
- Phase 3 (Non-Stabilized-Sliding Phase): At $\beta= \beta s$, the upper box undergoes non-stabilized sliding at an increasing speed (constant acceleration γ_c), even if the plane inclination is held constant at β_s.

Here, β_0 is defined as the plane-inclination angle at the static limit of equilibrium and β_s is the inclination angle for non-stabilized sliding.

2.2. *Force procedure*

The “Displacement Procedure” is not always easy to apply because monitoring the acceleration value during the friction test could be very difficult. For this reason, Briançon et al. (2002, 2011) proposed a new test procedure, called “Force Procedure”. This method consists of determining the interface friction angle, here denoted as δ in order to differentiate it to the previous one, through the inclined plane apparatus by measuring the force required to restrain the upper box above a limiting value of the sliding displacement u_{lim}. To perform the Force Procedure, the inclined plane device, described by Reyes Ramirez and Gourc (2003), was modified. Thus, a force sensor, fixed to the device frame, is linked to the upper box by means of a loose cable (Fig. 1). Upon reaching a predetermined value, u_{lim}, of the upper box displacement corresponding to an inclination $\beta=\beta_{lim}$, the cable is stretched and the force F(β) required to restrain the upper box that is measured (Briançon et al. 2011). The test consisted of three steps (Fig. 2):

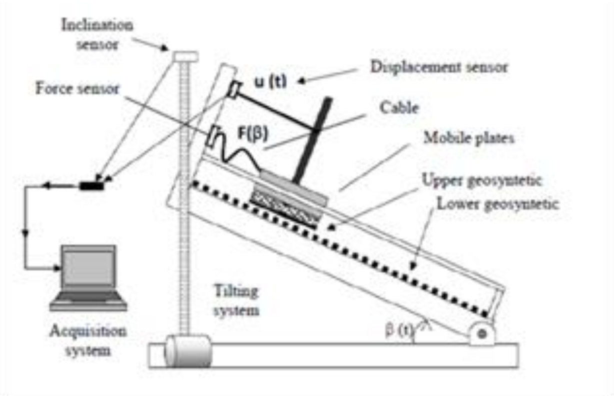

Figure 1. Incline Plane apparatus modified to apply the Force Procedure. [Carbone et al. 2012]

- Step 1: corresponds to the static state of the upper box with respect to the lower plane during the tilting process ($\beta<\beta_0$),
- Step 2: corresponds to the transitory state; the upper box slides, gradually or suddenly, until the stretching of the cable corresponds to u_{lim} ($\beta_0 \leq \beta \leq \beta_{lim}$) and the box is in a dynamic state, and
- Step 3: corresponds to the stretched condition of the cable after the sliding; here, the variation of F is monitored during the continuous tilting process ($\beta>\beta_{lim}$). The upper box can be considered to be in a static state with respect with the lower box if the elongation of the cable under the tensile force F is not considered.

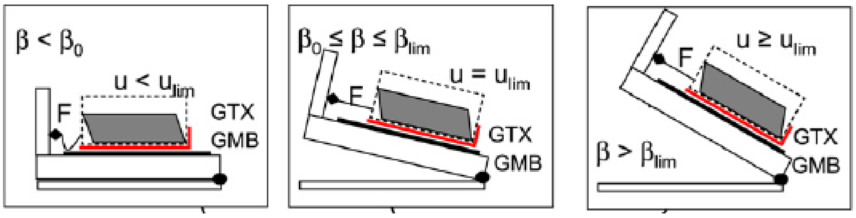

Figure 2. Schematization of the different phases during the "Force Procedure" test. [Briançon et al. 2011]

During Step 1:

$$\tan\lambda = \tan\delta = \tan\beta \tag{2}$$

During Step 2:

$$\tan\lambda = \tan\delta + \frac{\gamma}{g\cos\beta}$$

(3)

During Step 3:

$$\tan\lambda = \tan\delta = \tan\beta - \frac{F(\beta)}{W\cdot\cos\beta} \tag{4}$$

As discussed in this section, the "Displacement Procedure" is unsatisfactory for determining the friction angle; however, the dynamic approach taking into account the acceleration is not easy because monitoring the acceleration during the friction test is difficult. Therefore, a new test procedure was developed. Briançon et al. (2002) proposed a variant to the "Displacement Procedure" for determining interfacial friction angle with the inclined plane apparatus by measuring the force required to restrain the upper box above a limiting value of the sliding displacement u_{lim}. This method is called the "Force Procedure" to distinguish it from the previous one, which is called the "Displacement Procedure" because only displacements are monitored.

Since 2002, experiments have been performed on many interfaces using both the "Displacement Procedure" and "Force Procedure" tests. The "Force Procedure" has been modified to improve the feasibility and the repeatability of the test

3 MATERIAL AND METHODOLOGY

This section presents the new developments in determining the friction at the geosynthetice-geosynthetic interface with the “Force Procedure” test and in comparison with “Displacement Procedure” results.

3.1 *Inclined plane device(IP)*

A typical Inclined Plane device is composed with an upper box sliding along an inclined support. The test allows the sliding behaviour of the upper box to be studied while the inclination of the plane (β) continuously increases at a constant rate of dβ/ dt = 3.0 ± 0.5 °/min. Normal force (N) must be such that the initial normal stress (for β = 0) is equal to 5.0 ± 0.1 kPa.

A new inclined plane test has been developed in the Department of Civil engineering at the Islamic Azad University (Iran-Arak) with following dimensions:

l_u = 0.9 m and b_u= 0.70 m for the upper box and l_l = 2.00 m and b_l = 0.80 m for the lower plane. The device was equipped with a displacement sensor to measure the box displacement, (u). In addition, a force sensor was fixed to the plane framework and linked to the upper box by means of a cable, to monitor the tensile force, F, required to restrain the box after full sliding, as shown in Fig. 3.

The geosynthetics were placed between the two boxes depending on the tested interface, they were either attached to the upper box or fixed to anchoring grips on the lower box. The space between the two boxes is adjustable, thus it enables the testing of Geosynthetic Liner Systems of varying thicknees and composed of one to four geosynthetics.

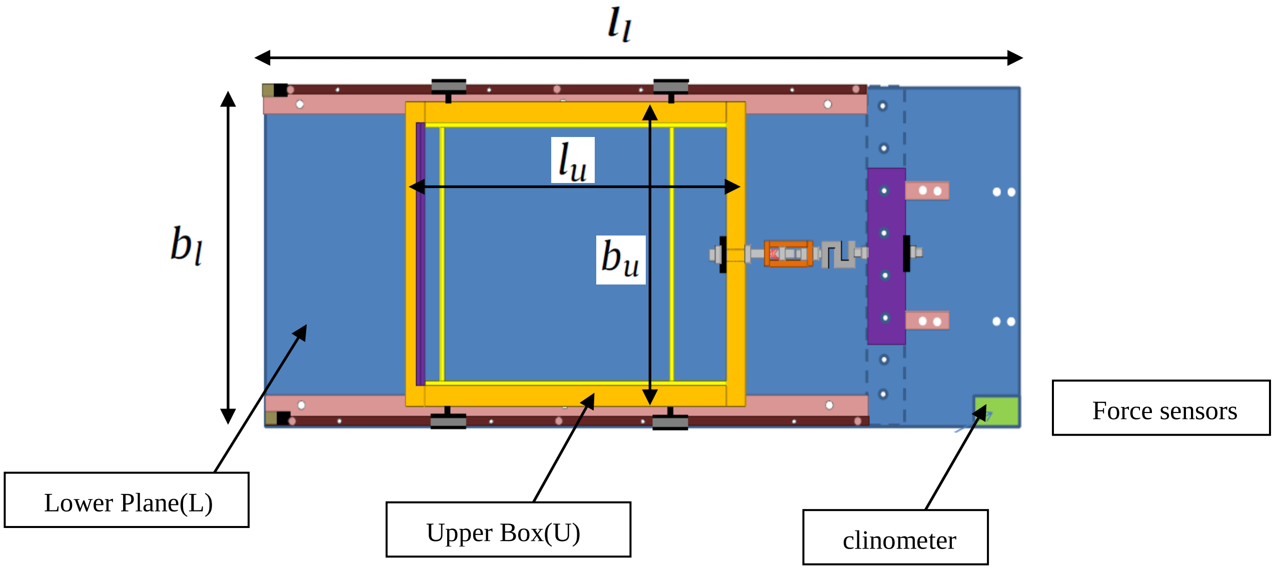

Figure 3. Schematization of the Incline Plan device.

3.2 *Material tested*

“Force Procedure” was applied to several geosynthetic- geosynthetic interfaces. More specifically the tests campaign emphasizes on geotextile – geomembrane interface which is often a critical interface of a geosynthetic liner system. The geotextile is a thermally bonded nonwoven(GTX_{nwn}) and woven geotextile (GTX_{wn}) and also the gomembrane is a polyvinyl chloride geomembrane (GMB_{pvc}). Smooth geomembranes have been used for all tests in the landfill while it is usual to set cover system to lay out a smooth geomembrane under a reinforcement geotextile (or a geocomposite drain). This obtains a maximum tensile force in the geotextile and to minimizes the tensile force in the geomembrane. All interfaces are tested with the “Displacement Procedure” to compare the result with the force procedure.

4 RESULTS AND DISCUSSION

Several examples by using 2 types of geotextile-geomembrane interfaces are presented in this section. As noted above, it is not possible to calculate the variable friction angle (δ) during Step 2, as the acceleration (γ) is not monitored.

4.1 *Force procedure*

4.1.1 *Performance of geomembrane* $GMB^{L}_{(pvc)}$*- geotextile* $GTX^{U}_{(nwn)}$ *interface*

Figure 4 shows the test results of $GTX_{(nwn)}$ – $GMB_{(PVC)}$ interface. During the tests, the force F(β), the displacement, u, of the upper box and the plane inclination angle, β were measured (Fig. 4b). Consequently, for the "Force Procedure", the parameter λ calculated from Equation (4), is plotted versus the plane inclination β (Fig. 4a). In this case, the length of the cable was adjusted to obtain u_{lim} = 10 mm.

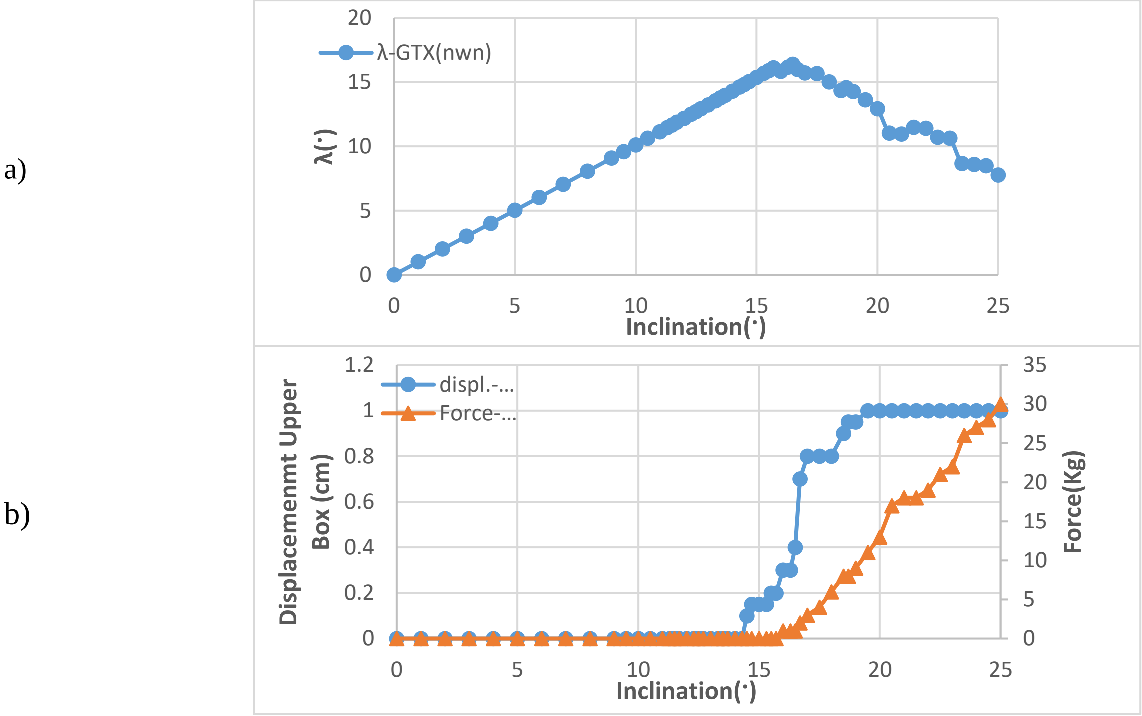

Figure 4. Force Procedure test results on $GTX_{(nwn)}$ – $GMB_{(pvc)}$ interface. a) Interface friction angle (λ) plotted versus the plane inclination (β) during the three test steps; b). Displacement and Force versus the plane inclination in a gradual sliding behaviour;

The mechanism of sliding was sudden sliding and the analysis of the interface behaviour during the Force Procedure is discussed below:

- Step 1:

During Step 1, ($\beta < \beta_0$) the mobilization of friction is partial and, as the driving forces ($W \cdot \sin\beta$) are less than the maximum resistant forces ($W \cdot \cos\beta \cdot \tan\delta$), the value of λ increases to a peak corresponding to the beginning of the mobilization of the force F(β). It is possible to define the first friction angle (δ_0) corresponding to the initialization of the sliding for $\beta = \beta_0$ following the equation (2):

$$\tan\lambda = \tan\delta = \tan\beta$$

In the case of "sudden sliding", λ_0, at the end of Step 1, corresponds approximately to the peak value of λ. The force F(β) increases suddenly, here, for β_0 =14.8°.

- Step 2:

Step 2 is not used for the analysis and the shape of the curve during this step depends on the interface tested F increases fast and β rises from β_0 to β_{lim}.

- Step3:

At the end of the sliding ($u = u_{lim}$ and $\beta = \beta_{lim}$) Step 3 begins; the driving forces are higher than the friction resistant forces and there is a full mobilization of the friction corresponding to a displacement u_{lim}. The force F(β) of the cable increases to equilibrate the difference between the driving forces and the friction-resistant forces (Fig. 4a), and a slight additional displacement ($u > u_{lim}$) is observed corresponding to the elongation of the cable. It is worth noting that generally, as in the present test, λ versus β reaches a constant value (Fig. 4a).

Therefore, following Equation 4, a second characteristic parameter can be determined after the stabilization of the system ($\delta_{lim}=\lambda_{lim}$ for $\beta>\beta_{lim}$). Here δ_{lim} corresponds to the pseudo-static phase (Step 3) where Equation 4 is valid.

In this example δ_{lim} = 11.20°.

Therefore, it is possible to determine two different friction angles from the “Force Procedure” test: β_0, corresponding to the initialization of the sliding, and δ_{lim}, corresponding to the plateau value.

4.1.2 *Performance of geomembrane* $GMB^{L}_{(pvc)}$*- geotextile* $GTX^{U}_{(wn)}$ *interface*

Figure 5 shows test results of $GTX_{(wn)}$ – $GMB_{(PVC)}$ interface. During the tests, the force F(β), the displacement, u, of the upper box and the plane inclination angle, β were measured (Fig. 5b). Consequently, for the ″Force Procedure″, the parameter λ calculated from Equation (4), is plotted versus the plane inclination β (Fig. 5a). In this case, the length of the cable was adjusted to obtain u_{lim} = 10 mm.

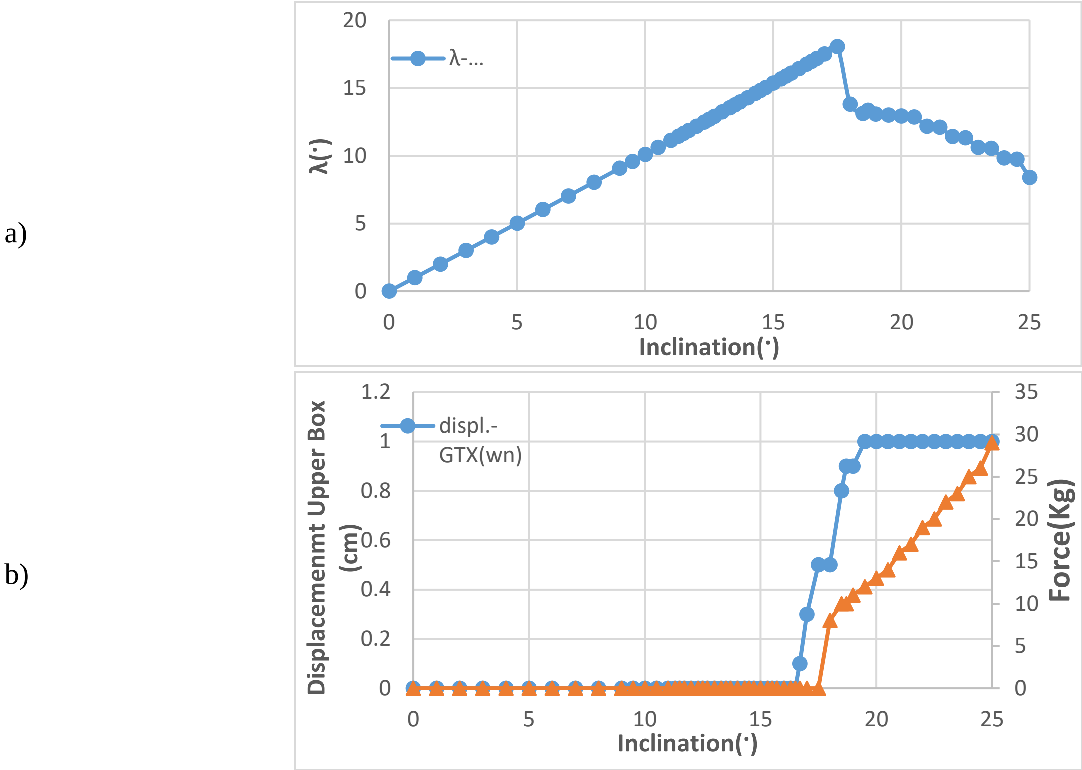

Figure 5. Force Procedure test results on $GTX_{(wn)}$ – $GMB_{(pvc)}$ interface. a) Interface friction angle (λ) plotted versus the plane inclination (β) during the three test steps; b). Displacement and Force versus the plane inclination in a gradual sliding behaviour;

- Step 1:

During Step 1, ($\beta< \beta0$) the mobilization of friction is partial and, as the driving forces (W.sinβ) are less than the maximal resistant forces (W.cosβ.tanδ), the value of λ increases to a peak corresponding to the beginning of the mobilization of the force F(β). It is possible to define that first friction angle (δ_0) corresponding to the initialization of the sliding for $\beta= \beta_0$ following the equation (2):

$$\tan\lambda= \tan\delta= \tan\beta$$

In the case of “gradual sliding”, λ_0, at the end of Step 1, corresponds approximately to the peak value of λ. The force F(β) increases suddenly, here, for β_0 =16.00°.

- Step 2:

Step 2 is not used for the analysis and the shape of the curve during this step depends on the interface tested F increases fast and β rises from β_0 to β_{lim}.

- Step3:

At the end of the sliding ($u = u_{lim}$ and $\beta= \beta_{lim}$) Step 3 begins; the driving forces are higher than the friction resistant forces and there is a full mobilization of the friction corresponding to a displacement (u_{lim}). The force F(β) of the cable increases to equilibrate the difference between the driving forces and the friction-resistant forces (Fig. 5a), and a slight additional displacement ($u > u_{lim}$) is observed corresponding to the elongation of the cable. It is worth noting that generally, as in the present test, λ versus β reaches a constant value (Fig. 5a). Therefore, following Equation (4), a second characteristic parameter can be determined after the stabili-zation of the system ($\delta_{lim}=\lambda_{lim}$ for $\beta>\beta_{lim}$). Here δlim corresponds to the pseudo-static phase (Step 3) where Equation (4) is valid. In this example δ_{lim} = 12.00°.

4.2 *Displacement Procedure*

The observation of many displacement (u) versus inclination (β) diagrams highlights, as indicated by Pitanga et al. (2009), that Phase 2 is maybe one of two types:

- Sudden sliding: abrupt displacement of the upper box under non-stabilized sliding with a nearly nonexistent Phase 2 ($\beta_0 \sim \beta_s$), and
- Gradual sliding: displacement u increases with inclination β, progressively increasing or displaying a stick-slip mode (jerky sliding). For the Phase 3, taking into account the dynamic conditions and considering a constant acceleration γ_c (Phase 3). Results are shown in Fig. 6:

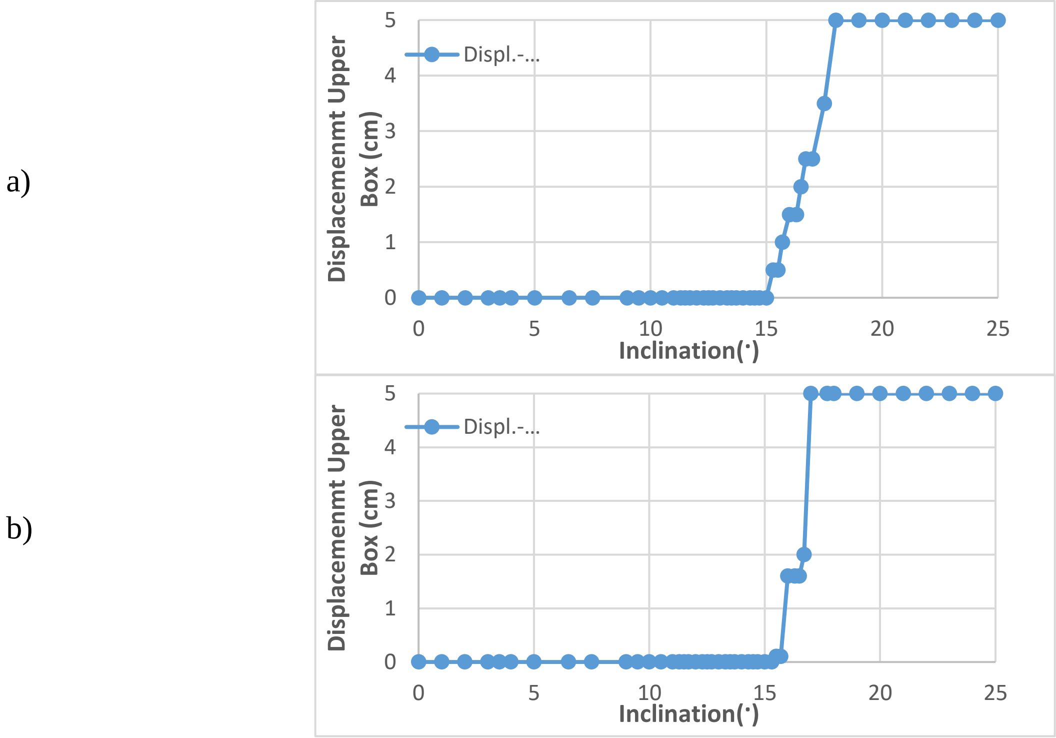

Figure 6. Displacement procedure applied on interfaces illustrating gradual sliding behavior; a) $GTX_{(nwn)}$ – $GMB_{(pvc)}$ And b) $GTX_{(wn)}$ – $GMB_{(pvc)}$

4.3. *Comparison of Force and Displacement prodceure values of the friction angle*

The comparison of the friction angles determined from the Displacement Procedure and those determined from the “Force Procedure” (Table 1) shows that the “Force Procedure” gave values lower than those found with the Displacement Procedure for all tested interfaces.

Table 1. Examples of friction angles determined with the “displacement Procedure” (δ_{stan}) and with the “Force Procedure” (δ_{lim})

δ_{stan} δ_{lim}	$GTX_{(nwn)}$	$GTX_{(wn)}$
$GMB_{(pvc)}$	21.00° 11.20°	21.50° 12.00°

5 CONCLUSIONS

Determination of a relevant interface friction angle is a complex issue. In this work a test series of geomembrane-geotextile interface to study the frictional properties at low normal stress using the Incline Plane device is presented. A comprehensive program of tests demonstrated that the friction parameter δ_{stan} measured with the "Standard Displacement Procedure" test overestimated the friction angle (Table 1). Moreover, the analysis of the Standard procedure is not rigorous because a static approach is proposed for dynamic conditions. Due to the difficulties of implementing the Standard Procedure in dynamic conditions, in particular for gradual sliding with very slow displacements or for jerky sliding, the "Force Procedure" test seems to be the best procedure with which to assess the friction angle at geosynthetic interfaces with the inclined plane with greater accuracy.

We proposed the selection of the residual angle δ_{lim} as the key parameter in the "Force Procedure" test for many reasons:

- The experimental conditions of the test are simple to implement, and the monitoring is easy to perform.
- This angle is not sensitive to the conditions of testing.
- This angle is the only intrinsic parameter of the interface since it is independent to the relative displacement at the interface u_{lim} from a minimum value of this displacement. With these considerations, it seems reasonable to suggest a revision of the EN ISO 12957-2 displacement methods.

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