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Dry friction behaviour of a geosynthetic interface using inclined plane and shaking table tests

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A B S T R A C T

Inclined plane test is widely used, especially in Europe, for the friction characterization of geosynthetics liner systems, for example in landfill applications. However, interpretation of the test is more complex and less consensual than for the direct shear test. In this paper, a comprehensive analysis of interface behaviour at the Inclined Plane device is presented for a non-woven geotextile on a geomembrane in dry condition.

New test procedure are proposed, and the related parameters of friction are defined in order to properly characterise friction behaviour. For the Inclined Plane, the shear strength of a geosynthetic interface cannot be characterised by a single parameter, as the interface behaviour is sensitive to the different kinematic conditions.

To this purpose, a comparison is shown with the results of complementary tests carried out using the Shaking Table test. For both test procedures, particular attention was paid to the influence of the relative sliding velocity. Finally, the sensitivity of the interface to mechanical damage caused by large relative displacements was quantified.

1. Introduction

Many geotechnical and hydraulic works require the use of several typologies of geosynthetics to handle specific functions such as reinforcement, filtration, drainage, waterproofing, separation and erosion control (Giroud, 2012).

To accomplish these functions, geosynthetics are often combined in multi-layer systems (Zamara et al., 2014) and may even be placed on slopes, such as in the case of lateral barriers and landfill covers. Interfaces may be weak discontinuities, and sliding may occur as a consequence of an improper assessment of the interface shear strength (Bacas et al., 2011; Blight, 2007; Eid, 2011; Moraci et al., 2014a; Palmeira, 2009). Consequently, a comprehensive study of geosynthetic interface shear strength is required. The topic is complex as it involves many different aspects, such as the nature of the surfaces in contact (Hebeler et al., 2005), temperature (Akpinar and Benson, 2005; Karademir and Frost, 2013) and humidity. The interface strength may also change due to mechanical damage (Gourc and Reyes Ramirez, 2004), time-dependent processes (ageing), loading conditions such as repeated loading (Moraci and Cardile, 2009) and the joint effect of time and stress/strain-dependent processes (creep or relaxation) (Moraci, 2011).

The specificity of landfill cover systems is determined by:

- the presence of different layers (multi-components) and, consequently, different geosynthetic–geosynthetic and soil-geosynthetic interfaces;
- the low value of the normal stress acting on the different interfaces;
- the possible presence of water (runoff and infiltration) at different depths;
- the complex kinematics of the relative tangential displacements at the different interfaces;
- the occurrence of dynamic loading especially in seismic areas.

To characterise the interface shear strength, the direct shear test is widely used (Delmas et al., 1979; Fox and Ross, 2011; Fox et al.,

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1998, 2006; Gilbert et al., 1996; Reyes Ramirez and Gourc, 2003; Zornberg et al., 2005; Triplett and Fox, 2001) whereas the pull-out test is used for the design of liners anchorage (Cazzuffi et al., 2011; Moraci and Cardile, 2012; Moraci and Recalcati, 2006; Moraci et al., 2014a, 2014b).

Inclined plane tests (Briançon et al., 2011; Gourc and Reyes Ramìrez, 2004; Palmeira, 2009; Wu et al., 2008) and shaking table tests (Carrubba et al., 2001; De and Zimmie, 1998; Park et al., 2004; Yegian and Kadakal, 1998) are supplementary tests which can be used to investigate friction behaviour under dynamic conditions. Indeed, during the lifespan of a structure, high relative displacement rates may occur along the interfaces, as in the cases of the unrolling of geosynthetics on a slope, the compaction of soil veneer, and seismic loading. Therefore, Inclined Plane and Shaking Table tests can provide supplementary information (with respect to that obtained by the traditional direct shear and pull-out tests), useful in understanding some of the complex mechanisms induced by relative displacements.

One of the aims of this paper is, in fact, to demonstrate that even though it is complicated to interpret, Inclined Plane and Shaking Table Tests can provide additional information about relation friction-kinematics. From this point of view, the tests are considered to be “Performance tests”, rather than “Index tests”.

Generally, friction tests like the inclined plane and shaking table tests, are performed in dry conditions, as was the case of this research. However, wet conditions were studied by Briançon et al. (2002) using the inclined plane test, and by Park et al. (2004) using the shaking table test. These studies show that in the case of a geosynthetic–geosynthetic interface, such as the one investigated in this study, taking the interstitial water pressure into account, its behaviour does not differ significantly. Noteworthy exceptions may arise for interfaces such as geocomposite clay liner (GCL), whose behaviour can be completely different in dry and wet conditions (Daniel et al., 1998; Fox and Ross, 2011; Fox et al., 1998; Gilbert et al., 1996; McCartney et al., 2009; Triplett and Fox, 2001).

Based on a comprehensive study of one interface (a nonwoven geotextile in contact with a smooth geomembrane in dry conditions), the aim of this paper is to highlight the influence of experimental parameters such as kinematic conditions, normal stress and mechanical damage on the results of inclined plane and shaking table tests.

New procedures for the inclined plane and shaking table tests are also proposed to characterise the behaviour of geosynthetic interfaces. Finally, compatibility between the results provided by the Inclined Plane (IP) and the Shaking Table (ST) tests are discussed. This kind of comparison is rarely addressed in literature.

2. Theoretical background

The inclined plane test allows for testing under low normal stress and to investigate the interface behaviour at different relative displacement levels. Depending on the dimensions of the apparatus, the displacements can range from small to very large.

In Europe, the inclined plane test is ruled by EN ISO 12957-2 (2005). According to this standard, the interface friction angle is evaluated when the plane inclination reaches an angle (β_{50}) corresponding to a conventional upper box displacement of 50 mm. Following this approach, here defined as the *“Standard Procedure”*, the standard interface friction angle (ϕ_{stand}) is calculated by considering the static equilibrium, so that $\tan\phi_{\text{stand}} = \tan\beta_{50}$. However, considering that the upper box is moving downwards, this static interpretation may not be fully accurate (Briançon et al., 2011; Gourc and Reyes Ramìrez, 2004; Moraci et al., 2014a,b; Pitanga et al., 2009).

An alternative procedure, the *“Displacement Procedure”*, was proposed by Gourc and Reyes Ramirez (2004) in order to analyse the motion of the box during sliding in terms of upper box acceleration. In order to overcome the experimental problems encountered when measuring low acceleration values, Briançon et al. (2011) introduced the *“Force Procedure”* in which the static condition of the box is studied instead of the dynamic condition.

The design of composite structures in seismic areas also requires the characterisation of the geosynthetic interface shear strength under dynamic loading, and shaking table tests are usually carried out for this purpose. The basic approach for assessing dynamic behaviour is that described by Newmark (1965). In Newmark's analysis, the dynamic interface shear strength is considered to be constant and independent of the loading conditions. However, variations of the mobilised friction angle may occur during the motion, which can influence the accuracy of the analysis (Matasovic et al., 1998; Zania et al., 2010b). Moreover, as found by different studies (Carrubba et al., 2001; De and Zimmie, 1998; Kotake et al., 2011; Zania et al., 2010a), the dynamic interface shear strength is difficult to evaluate because, in addition to the aforementioned parameters involved in static conditions, it is affected by various testing parameters typical of dynamic loading, such as motion amplitude, frequency content and duration.

3. Materials, devices and methodologies

3.1. Materials

One of the most common composite systems in geotechnical barriers is that involving the coupling of a geotextile with a geomembrane, due to their complementary advantages (Karademir and Frost, 2013; Koerner, 2005; Stark et al., 1996). The geotextile used in this research was a thermally bonded nonwoven geotextile with a unit mass of 130 g/m^2 and tensile strength of 8 kN/m. The geomembrane was a high-density polyethylene (HDPE) smooth geomembrane, 2 mm thick, with a unit mass of 2000 g/m^2 and tensile strength of 30 N/mm^2. This kind of geomembrane has been used extensively with geotextiles or geospacers in order to mitigate the friction between these geosynthetics (Gourc et al., 2004; Reyes Ramirez and Gourc, 2003) and to limit the tensile load in the geomembrane. In this case, another geosynthetic is purposely set above to sustain the veneer layer.

It is important to note that all geosynthetics in contact with each other are tested along the direction of the machine production which generally corresponds to the direction of slope. In this experimental programme, the non-woven geotextile was always fixed to the upper support in both devices, while the geomembrane was fixed to the plane (lower layer).

The main objective of a typical interface friction test (under both static and dynamic load conditions) is to assess the limit shear stress (τ) under various normal effective stresses (σ'). In dry conditions, as was the case for this research, the effective stress corresponds to the total stress ($\sigma' = \sigma$).

3.2. Inclined plane and shaking table devices

3.2.1. Inclined plane device (IP)

A typical Inclined Plane device is composed of 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 $d\beta/dt = 3.0 \pm 0.5°/\text{min}$.

The inclined plane available at the LTHE laboratory (Fig. 1a) was modified in order to allow for a large sliding displacement (Gourc and Reyes Ramirez, 2004). It has the following dimensions: