Stability on slope of earthfill on geosynthetics lining system

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ABSTRACT: Geosynthetics are widely used on slopes in several civil engineering structures such as waste facilities and hydraulic works, generally named geostructures, in particular to assure the waterproofness of these works. Generally, several geosynthetics are associated to meet the various expected functions (waterproofness, drainage, anti-puncturing...), so the stability of materials implemented over these geosynthetics systems is widely dependent on characteristics of the geosynthetics interfaces between them or in the contact with grounds surrounding the system and on the geosynthetics internal stability especially in the case of geocomposites. On the basis of these characteristics, different methods of calculation are used to justify the stability of these works.
The present communication approaches the various aspects of the justification of the stability of these works. A first part is dedicated to the calculation of stability for the thin layers on slope on a geomembrane lining system of dam or waste disposal which can be realized on the basis of the standard NF G 38-067 (AFNOR 2017). But in numerous situations, this approach presents limits and questions remain open on the hypotheses and the consideration of the behavior of materials.
In a second part, we propose answers, on one hand, we have therefore developed a numerical approach based on the use of the FLAC software which enables to realistically model the behavior of geosynthetics taking into account the mechanical nonlinearities of the materials and interface constitutive laws; on the other hand we lead works for the determination of interfaces and internal shear resistance of geosynthetics ; new proposals of operating procedures are made to overcome the limits of the current standards.

Keywords: friction angle, inclined plan, shear box, stability calculation, GLS

1 INTRODUCTION

Generally in geosynthetics lining systems (GLS) several geosynthetics are associated to meet the various expected functions (waterproofness, drainage, anti-puncturing...), so the stability of materials implemented over these geosynthetics systems is widely dependent on characteristics of the geosynthetics interfaces between them or in the contact with grounds surrounding the system. On the basis of these characteristics, different methods of calculation are used to justify the stability of these works.

Methods of calculation were developed at first for the determination of the stability of layers of thin protections organized on these geosynthetics complex which often have low characteristics of interfaces friction, in particular in the interface with geomembranes. Calculation principles, reminded to the paragraph following, are simple but do not answer the diversity of the situations. In this context we present two ways of researches led at present to Irstea, on one hand, the numerical modelling and, on the other hand, the determination of interfaces and internal shear resistance of geosynthetics.

2 STABILITY OF THIN LAYERS ON SLOPE

Geomembrane lining system (GLS) are widely use on earthfill dams and lanfills (see Figure 1) and in most cases the geosynthetic lining system is protected with an earth or gravel layer. The risk of sliding of the protection layer on the geomembrane must be estimated to define and design a reinforcing geosynthetics with an anchoring at the top of the slope.

(a) (b)

Figure 1. Example of protectives layers on GLS: (a) Selvet dam, (b) landfill.

2.1 *Stability principle*

The analysis of stability corresponds simply to the balance between the driving forces due to the weight of the protection itself and the stabilizing forces constituted by the friction force that can be mobilized on the interface being studied and a safety factor can be to determine according to the ratio between the driving force and the resisting forces.

In most cases, stability is ensured by an abutment and/or by anchoring the geosynthetics at the top of the slope. Calculation of the dimensions of these two elements has been presented by Poulain and al (2004) with methods including the situations with total or partial saturation of the protective layer.

These methods of calculation don't take into account partial factors of safety such as recommended by the Eurocodes. So, an approach on the same principle by adding it partial coefficients has been developed for the stability of a protective layer without abutment and without pore pressure at the interface of calculation. This method is described in a French standard; we present here the main elements of this standard.

2.2 *French standard NF G38-067 (AFNOR 2017)*

The determination of the stability of a thin layer on a geosynthetic system and the design of the anchoring eventually necessary to provide this stability is the object of the French standard NF G38-067 entitled "Geosynthetics, geotextiles and products related - Stabilization of a thin layer on slope - Justification of the sizing and elements of design".

The field of application of this standard is the following:

- Constant slope of embankment (without berm)
- Thickness lower than 5 % of the length of the slope
- Normal confining pressure lower than 20 kPa (about 1 meter of eathfill)
- No abutment
- No pore pressure at the interface (absence of water in the cover layer or drainage being enough for avoiding a putting in pressure)

Inputing data of the materials are:

- Natural materials of the cover: wet and saturated volume weight, long-term internal friction and cohesion
- Geosynthetic system: Characteristics of friction of interfaces obtained by inclined plane for the low thicknesses of layer (below 75 cm) - NF IN ISO 12957-2 or by shear box for higher thicknesses - NF IN ISO 12957-1
- Geosynthetic of stabilization if necessary for anchoring: short term and long term traction resistance

Calculation takes into account partial factor of safety as indicated in table 1.

Table 1. Partial factors

		Factor of safety
Actions	Soil weight on the slope	1.35
	Soil weight on the trench of anchoring	1
	Weight of the temporary overload (snow for example)	1.5
Soil parameters	Specific weight, internal friction and cohesion	1
Soil strength	Sliding resistance	1.1
Geosynthetics strength	Resistance in the internal shear	1.35
	Resistance in the sliding of interface	1.35
	Tensile force	1.25

This French standard also proposes a method of calculation of the anchoring trenches based on a semi-empirical method. The whole approach enables designing the GLS in particular the stability of its protection layer.

However, these calculations lead us to use simplifying hypotheses which can question the result of the calculations in particular in complex cases. Besides, it is necessary to arrange mechanical characteristics of the interfaces; the determination of which remains often complex. In particular the situations and the main following questions are not resolved by the presented method:

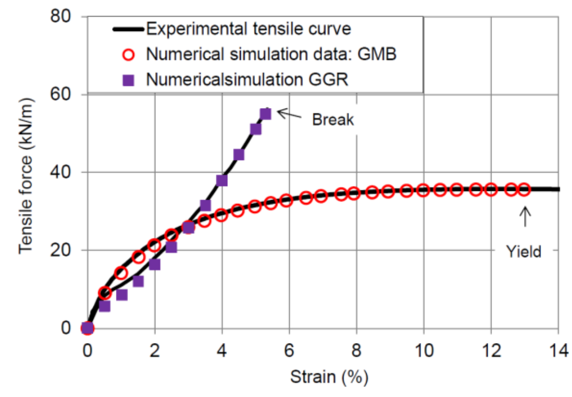
- The consideration of the efforts and the strains in the various geosynthetics
- The shear strengths and the relative displacements in the interfaces
- The existence of pore pressure or suction in the interface
- The characterization of the interfaces in particular the determination of the interfaces friction angle
- The characterization of the internal shear resistance for any type of geocomposites
- The stability of large embankment on a GLS

To contribute to answer these questions we present below two ways of researches led by Irstea, the numerical modelling and the determination of characteristics of geosynthetics interfaces.

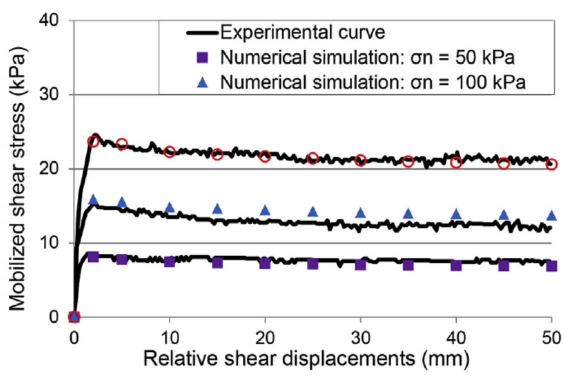
3 NUMERICAL MODELLING OF THE STABILITY OF GEOSYNTHETICS LINING SYSTEMS

Geotechnical constructions that involve geosynthetics, such as landfills, are traditionally designed by using limit equilibrium methods (Giroud and Beech, 1989; Koerner and Hwu, 1991). However, these methods cannot be used to assess the integrity (e.g., strain or tensile forces) (Long et al., 1995) of the construction components and do not consider whether stresses are compatible with strains and displacements.

As an alternative, such constructions may be designed by using numerical modelling methods (Fowmes et al., 2008); these methods not only account for the above-mentioned aspects but also account for the multiple interactions between geosynthetics, the strain softening at the interface between geosynthetics, the difference between the compressive and tensile behavior of the geosynthetics and the nonlinearity of their axial stiffness. Even if these criteria have been discussed by many authors, they are rarely considered in numerical modeling (Tano et al., 2016).



2a.Tensile force vs. axial strain measured by uniaxial tensile test compared with results from numerical simulations for a geomembrane (GMB) and a geogrid (GGR).



2b. Shear stress vs. relative shear displacement measured by direct shear test compared with results of numerical simulations for a geotextile-geomembrane interface.

Figure 2. Comparison between experimental curves and numerical simulation (Tano et al. 2017).

A numerical procedure was developed using the finite difference code FLAC2D to overcome these difficulties. This general code enables to consider multilayered geosynthetic interactions while modeling structural elements and interfaces with a nonlinear stress-strain law (Figure 2). Each geosynthetic was modeled as a concatenation of several structural elements to allow each individual structural element to be varied independently of the other parts of the geosyntheticss and as a function of strain. A similar approach was developed for modeling of soil-geosynthetics interaction to enable each part of the geosynthetic soften independently.

This procedure was tested on different configurations such as conventional uniaxial tensile test, direct shear tests and a large-scale test that was used to assess the overall behavior of a reinforced geosynthetic system that spanned over a cavity (Figure 3). The results showed very good agreement with experimental data for the three configurations studied.

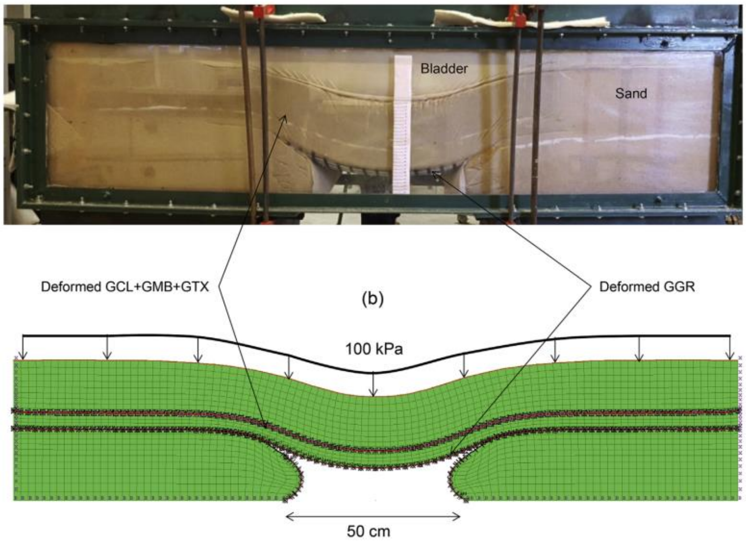


Figure 3. Overall deformed shape of reinforced lining system: (a) experiment, (b) numerical model (Tano et al., 2017a).

The procedure was applied to the case of a piggyback landfill expansion (PBLE). The numerical modelling was conducted using the finite difference code FLAC 2D, focusing on a typical PBLE and considering geosynthetic interface strain softening, the nonlinear stiffness of geosynthetics, and the differentiation between the compressive and tensile behaviours of geosynthetics. Among the results obtained by the simulation it was shown that neglecting the strain softening at the interface between the geosynthetics affects interface shear stresses, relative sliding displacements between geosynthetics and force distribution within the geosynthetics (Figure 4).

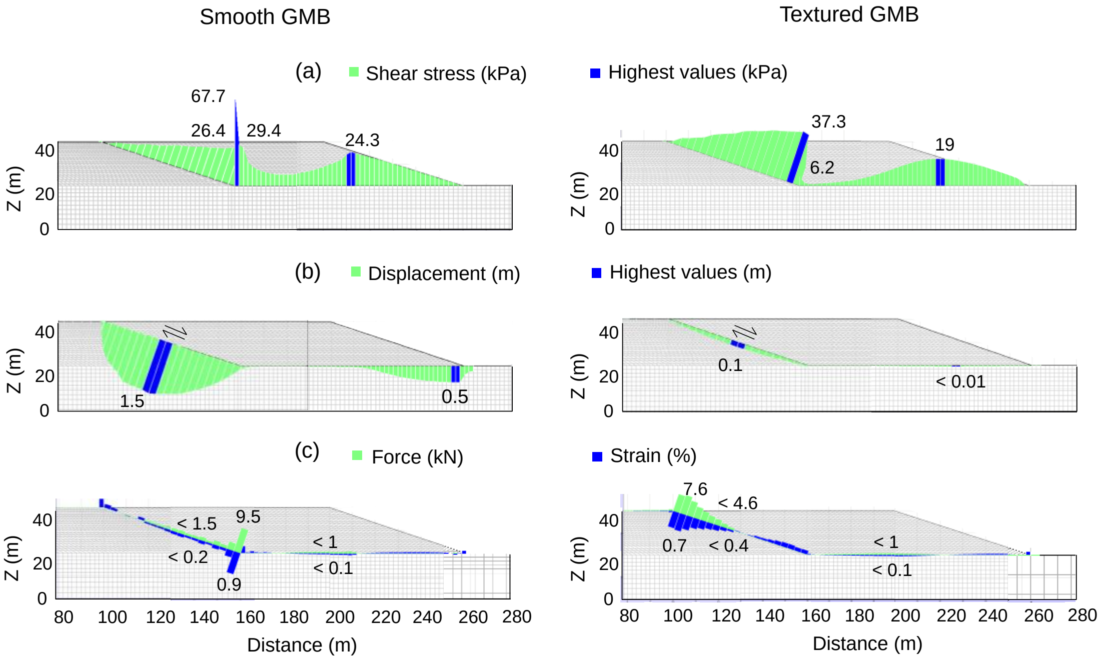


Figure 4. Comparisons between smooth GMB and textured GMB at H=20 m. (a) Shear stress along critical interface, (b) displacements along interface I2, (c) force and strains in geomembrane (Tano et al., 2017b).

4 DETERMINATION OF INTERFACES AND INTERNAL SHEAR RESISTANCE

4.1 *Interface shear resistance*

To design geostructures including geosynthetics, engineers need the mechanicals properties of geomaterials, geosynthetics and their interfaces, in realistic conditions, that is to say conditions related to in-situ conditions (real materials, hydraulic conditions, physico-chemical conditions, etc.). Moreover, to ensure the sustainability of the geostructure, the long term properties of materials need to be well known if ageing phenomenon is likely to decrease the performances of geosynthetics products.

Concerning the shear resistance of interface including geosynthetics, it has been shown that many parameters may affect the mechanical behaviour of such interface, depending of geosynthetics: for example normal stress and kinematic conditions following Carbone et al. (2015), moisture content following Ferreira et al. (2015), temperature following Yesiller et al. (2016), relative displacement following Baca et al. (2015), sliding history following Vieira et al. (2013) and Stoltz et al. (2013).

Beyond the interface shear resistance, another mechanical characteristic, not often used and discussed, is relevant: the interface relative displacement that induces the maximal shear resistance, from which peak friction angle is calculated. In particular, this characteristic is used to model the shearing curves displayed in Figure 2b.

Overall, interface shear resistance is related to two materials in contact, either two geosynthetics or geomaterial and geosynthetics. So, the determination of the interface shear resistance is linked to a performance test, the concept of index test being not relevant. The main parameter to characterize the interface shear resistance is the friction angle. This parameter can be measured with the direct shear box (SB) test according to standard EN ISO 12957-1 (AFNOR, 2005) and with the inclined plane (IP) test according to standard EN ISO 12957-2 (AFNOR, 2005) (Figure 5). In the SB test, the normal stress range applied is comprised between 50 and 150 kPa and in the IP test, the normal stress applied is 5 kPa. The SB test is then more suitable in the case of stabilized earth wall and the IP test is more suitable for the design of a thin soil layer, applied on multi-layer geosynthetics on slope.

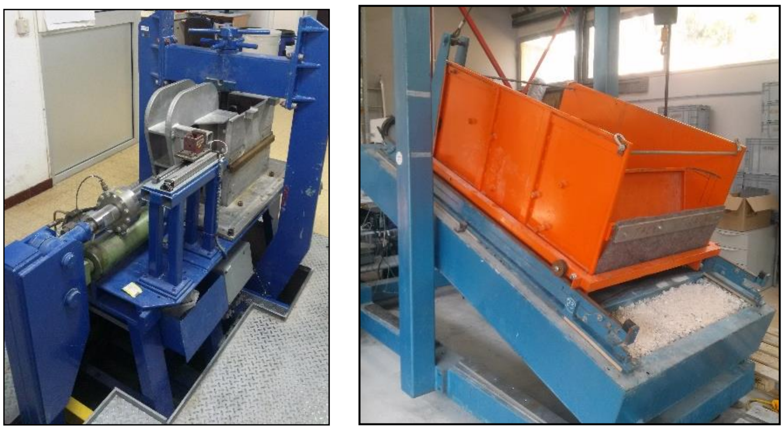


Figure 5. Picture of the large scale shear box device (left) and the large scale inclined plane device (right) in Irstea Aix-en-Provence.

Beyond the normal stress, it should be noted that the testing procedure of this two tests is different: in the SB test, the tested interface is loaded by increasing displacement at controlled speed while in the IP test, the tested interface is loaded by increasing shear stress at controlled speed.

Some authors (Wasti and Özdüzgün, 2001; Reyes Ramirez and Gourc, 2003; Feirrera et al., 2016) compared results obtained from IP and SB tests but the comparison could be biased because of the various normal stresses of each test and the means of applying normal stress: directly by soil weight for the IP device and generally with a jack for the SB device. In addition, the various types and sizes of experimental devices that may be used can also contribute to bias the comparisons, primarily due to various "edge effects", which was shown by Stoltz and Hérault (2014) who compared results from IP and SB tests with same testing conditions (normal stress and method used to apply this stress, sample size, upper box of the device, etc.).

The IP test, which consists in increasing shear stress until the tested GSY interface begins to slide, was extensively studied (Koutsourais et al., 1991; Palmeira et al., 2002; Briançon et al., 2002). However, some recent studies indicated that the standardized 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 standardized testing procedure of the IP test assessed the (standardized) friction angle 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 the standardized friction angle. However, they did not conclude on the friction angle value that should be considered for design. Briançon et al. (2011) developed a modified procedure with IP device, called "force procedure". From this procedure, they obtained lower angle friction values than those obtained from the standardized testing procedure of the IP test. Stoltz et al. (2012) proposed another procedure, close to the "force procedure" from Briançon et al. (2011). In this procedure, the method used to retain the upper box was a deformable element, which enabled a controlled sliding of the upper box during the measurement of the force required to retain it. Following this testing procedure, the interface friction forces could be assessed during the whole sliding of the interface (Figure 6). More recently, Carbone et al. (2015) suggested another procedure, called "Unified Inclined Plane Procedure", which led to the determination of static and dynamic interface friction angle. Finally, it is quite clear that the complex and various mechanical behavior of interface including geosynthetics explain this large devolvement of various testing procedures using an IP device. Finally, it appears that all these efforts to improve the testing procedure of the IP test are mainly link to the fact that the current standard does not enable to assess the interface friction angle at large displacements which are required for the mechanical numerical modeling of geosynthetics multi-layers in geostructures (cf Part 3). So far, no testing procedure of the IP test has demonstrated that it enables to assess the interface friction angle at large displacements for any type of interface which remains a pending question.

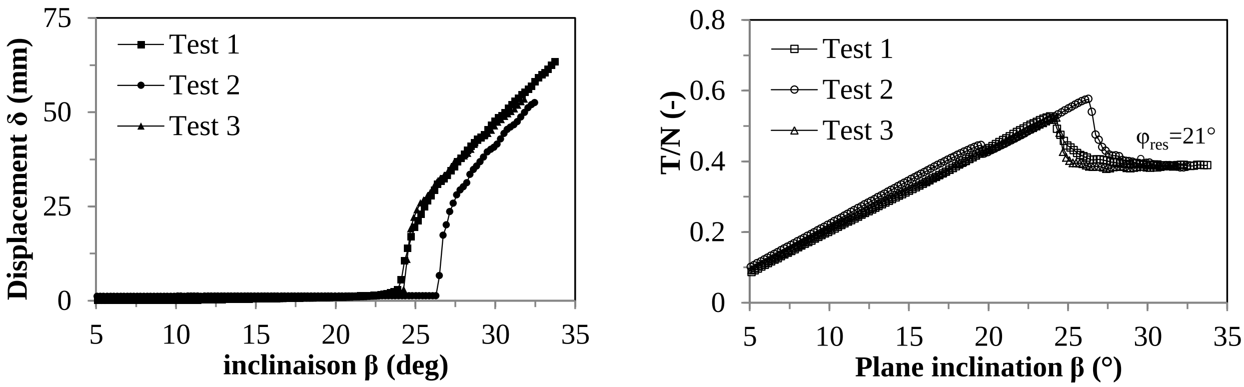


Figure 6. Example of results from the residual friction testing procedure using an IP device (Stoltz at al. 2012).

The SB test, which involves imposing a displacement at constant rate on the tested GSY interface, enables to assess the interface friction angle at large displacements (cf Figure 2b); but only the peak friction angle is determined following the standard EN ISO 12957-1 (AFNOR, 2005). Moreover, Stoltz and Auray (2014) highlighted that the maximal displacement of 50 mm, described in the standard, could not be enough for specific tested interface, like sand - geogrid for example, where an insufficient displacement does not enable to assess the interface friction angle at large displacements with the geogrid in full traction. At last, the interface relative displacement at maximal shear resistance could also be determined but the standard EN ISO 12957-1 (AFNOR, 2005) does not give the way for that.

Depending of the considered section in the geotructure including geosynthetics, it can be relevant to determine the interface friction angle following pull out test. For example, by pull out test with a large scale anchorage bench, Gorniak et al. (2016) assessed friction angles of various interfaces expanded clay light weight aggregates –reinforced geosynthetic products at low normal stresses (5 – 12.4 kPa). However, Gorniak et al. (2016) did not discuss about all the edge effects induced by the pull out tests (pullout box dimensions, vertical load application system, front wall effects, side wall effects, clamping system ,etc.)

As a partial conclusion, no current standard enables to supply the complete parameters of interface shear resistance (interface friction angle at low and large displacements and in a wide range of normal stress and interface relative displacement at maximal shear resistance) required for reliable mechanical numerical modeling of geosynthetics multi-layers in geostructures. There is still a major work to improve the current standards to supply geosynthetics characteristics adapted to field conditions especially hydraulic conditions, thermal conditions, etc.

4.2 *Internal shear resistance*

The assessment of the geosynthetics multi-layers stability also required the internal shear resistance of each geocomposites and/or geosynthetics clay liner. There are two standards (EN ISO 13526-1/2) that enables the measurement of the strength of internal structural junctions; for geocell following the standard EN ISO 13256-1 (AFNOR, 2004) and for geocomposites and geosynthetics clay liner following the standard EN ISO 13256-2 (AFNOR, 2005). These two standards are well adapted when the tensile strength of each geosynthetic layer is stronger than the structural junctions resistance. But the standard EN ISO 13256-2 may not be adapted for specific geocomposites, for example when a geomat layer is stitched to a geotextile (see example Figure 7). To measure the internal shear resistance of such geocomposites, Stoltz and Hérault (2016) proposed a specific testing procedure using a modified large scale shear box (see example Figure 7). Once again, it is evidenced that efforts have to be made to enhance current standards or developed new ones to assess characteristics and performances of any type of geosynthetic product in any site conditions.

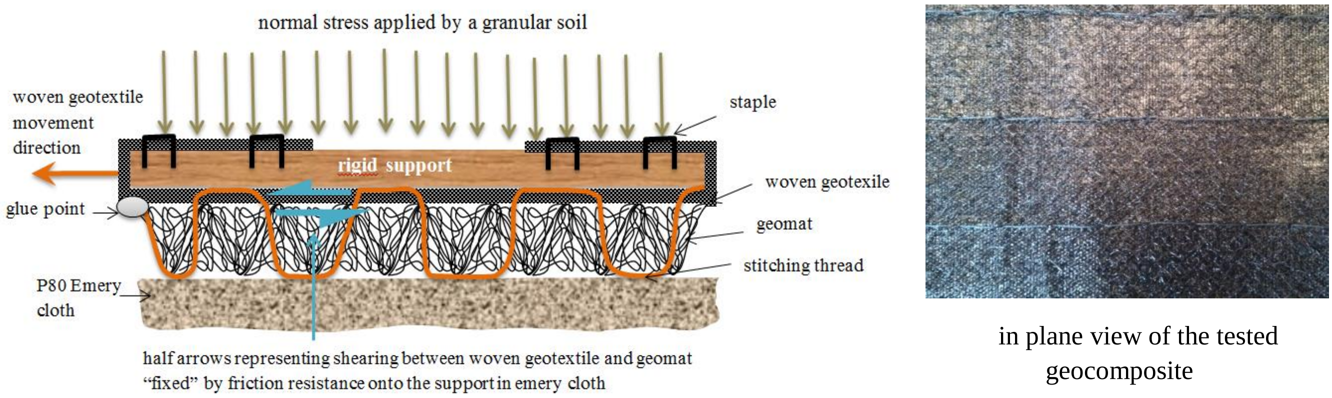


Figure 7. Schematic representation of the testing method to assess the internal shear resistance of a geocomposite with an in-plane view in the picture on the left (Stoltz and Hérault, 2016).

5 CONCLUSION

In this paper, a state of knowledge is depicted about the assessment of the stability on slope of earthfill on geosynthetics lining system. Three main aspects are highlighted:

- The first one is related to one analytical method that enables to make design in simple cases. The described method has the advantage to be standardized (in France) but does not enable to deal with complex situations. Thus, more elaborated methods using numerical modelling were developed;
- The second one presents a numerical method to assess the stability of geostructures including geosynthetics multi-layers on slopes. This method takes into account the complex mechanical behavior of each geosynthetic layer and particular their interfaces between another geosynthetic or a soil layer. This kind of method quantifies all the efforts and strain within each geosynthetic and the relative displacement for each interface. However, to compute calculations, several mechanical characteristics of geosynthetics and their interfaces are required and the current standard may be sometimes insufficient;
- The third one outlines all the current standards and modified testing procedures that enable the measurement of interfaces and internal shear resistance of geosynthetics. The insufficiencies of the current standards are evidenced and some research outlooks are emphasized.

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