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Use of inclined test to assess stress mobilization of liner on slope

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ABSTRACT: For liner systems on slopes, a separation of the functions of the different geosynthetics is generally proposed. The geomembrane acts as the sealing layer while a geotextile reinforces the stability of the soil veneer layer. This paper is dedicated to the key-issue : how to obtain from laboratory accurate friction interface relationships, since tensile force mobilization is very sensitive to the interfaces behaviour.

1 INTRODUCTION

Composite liners systems are widely used for river banks, dams, reservoirs, landfill caps (Gourc et al 1998). The watertightness fonction is provided by a geomembrane with a soil veneer as protection. But in the past, many local failures of this system were observed, due to the sliding of the soil layer on the geomembrane slip surface or tensile failure of the geomembrane due to the friction tangential stresses at the interface with the soil veneer (Girard et al 1990). The updated design suggests to separate the functions of the different geosynthetics : while the geomembrane (GM) acts as the sealing layer, a geotextile (GTX) of reinforcement ensures the stability of the cover soil. Systems with intermediate component (geospacer) for drainage are not considered here. However the distribution of forces within each component is complex and results mainly from the tensile stiffness (J) of the geosynthetics and frictional interaction between components. The authors previously presented a FEM approach adapted to this problem , and compared with experimental results obtained at several monitored sites : sloping side of the bottom barrier of a landfill (Villard et al 1997, 1999 and 2000 for a large experimentation in progress).

In the present time, the role of every component is clearly understood, but the evaluation for design of the tensile force actually mobilized in the different geosynthetics remains very difficult to predict, due to extreme sensitivity to the friction relationships. As in any problem of reinforcement, ultimate limit state is relatively easy to consider but serviceability limit state where elongation and relative displacements at the interface are predominant, a very accurate knowledge of the friction relationships and also laying of geosynthetics conditions are required. In this framework, the interpretation of the field experience of the figure 1 (Cahors, Briançon 2002) is in progress on the sloping bank of a reservoir two different liner systems are monitored, bituminous geomembrane (GMb) for the trial P1 and polypropylene geomembrane (GMpp) for P2 associated to a geotextile non-woven reinforced by fibers (GTX). Forces in the geosynthetics (fixed at the top edge) and displacement are collected while loading the granular material layer up the slope (increasing Lc value).

On figure 2, tensile forces in the geosynthetics are plotted versus Lc. The efficiency of the geotextile to sustain the soil cover weight is clearly demonstrated, since the reported tensile value in the two geomembranes is very low. On the other hand, the tensile force in the geotextile associated to the GMpp (P2)

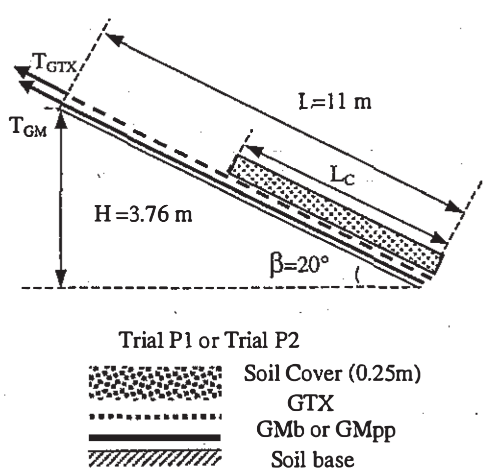

Figure 1. Field experimentation: Tensile mobilization for rising cover soil and two different liner systems *(this experimentation was realized thanks to the participation of the owner – ASF : Autoroutes du sud de la France- and of 2 producers- Bidim Geosynthetics ans Siplast)*

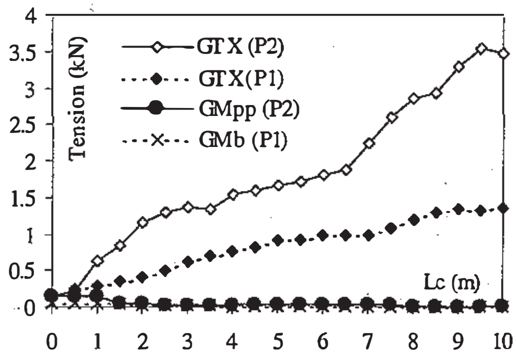

Figure 2. Field experimentation: Tensile mobilization in the geosynthetics for the two liner systems.

is twice as large as the force in the case of GMb (P1). This is correlated without any doubt to the interface (GTX/GM) properties. The laboratory tests exhibited below are dedicated to these materials.

So in our opinion in the present time it is reasonable to admit that, even if by inverse calculation it is possible to justify the tensile mobilization in the different components, geosynthetics actual tensile values are generally impossible to foretell with accuracy.

As large scale experimentations are costly and heavy to implement, a joint research program was carried out, based on specific laboratory facilities and associated finite element code (Goliath), to predict the behaviour of liner systems on slopes.

2 EXPERIMENTAL SIMULATION OF THE LINER SYSTEM SLOPE KINEMATICS

A specific inclined plane apparatus (figure 3) was designed at the Cemagref Bordeaux (Briançon 2002) to characterize geosynthetics interfaces and to simulate sliding.

This device, called Inclined Plane for hydraulic applications (IPH) is an evolution of the first Cemagref apparatus (Girard et al., 1990) and the Lirigm Grenoble Standard Inclined Plane (IPS), (Gourc et al 1996, Lalarakotoson et al 1998). In case of low normal stresses, the characterization of the liner interfaces falls outside the scope of the standard Shear Box (SB), generally used for a pressure range σ of 25 to 200 kPa. Then, the inclined plane apparatus is more appropriated. As the Lirigm IPS, the Cemagref IPH, provides during the progressive inclination β of the box, the monitoring of the tensile forces by clamping the sheets at their head and the monitoring of the displacement or force (if attached) on the upper box (figure 4). In addition the IPH allows to induce different hydraulic conditions on the interfaces. The surface of contact between the upper box and the base geosynthetics is $1 m^2$.

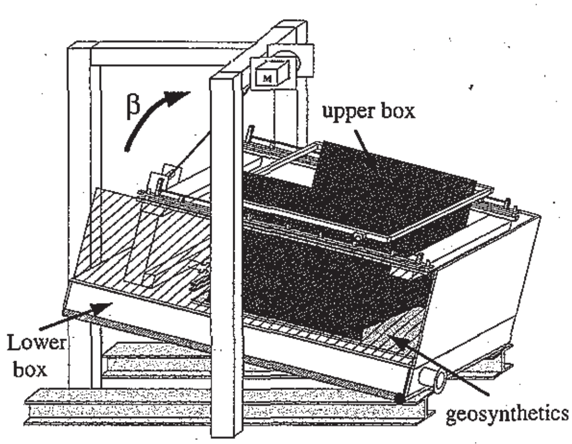

Figure 3. CemagrefInclined Plane facility (IPH).

The test of reference with the upper box empty and attached at the top gives the evolution of the force Fo required to sustain the box alone (figure 5) :

$$Fo = Wb \cdot \sin\beta - Fr \qquad (1)$$

Fr corresponding to the residual friction of the box guides is relatively low, and Wb is the weight of the empty box (1.28 kN). Figure 10 exhibits the measures collected during a test likely to simulate partially the conditions of the large scale experimentation of the figures 1 and 2. The upper box is filled with sand (thickness 0.23 m, γh = 16.6 kN/m^3) and the two geosynthetics are fixed ahead. The main features of the liner system behaviour are as following :

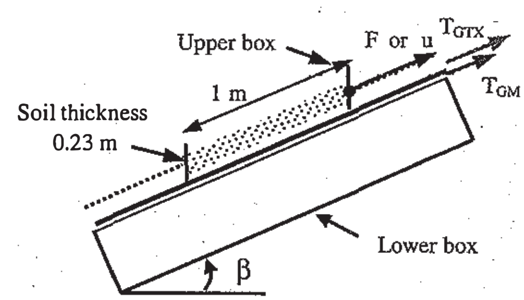

Figure 4. Monitoring in the Cemagref Inclined Plane (IPH).

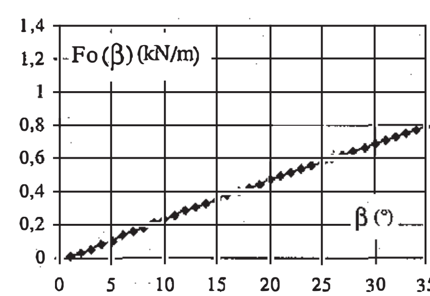

Figure 5. Tangential active force during sliding of the box without soil (IPH).

-for an inclination less than 12.5°, surprisingly there is no tensile mobilization of the geotextile (GTX) for sustaining the upper box. The assumed cause of this phenomenum is the initial laying of the geotextile without prestressing. The modelisation (figures 10 and 11) below will confirm this assumption.

For β> 12.5°, the increasing value of the tensile force in the geotextile during the plane tilting corresponds to sliding at the interface GTX /GMpp. The tensile force value in the GM is also increasing but remains very low.

-Sliding of the upper box u is also increasing but remains under control until β = 30° corresponding to its global sliding.

The limit equilibrium formula provides values of the friction angle ϕg for the two interfaces :

$$\tan \phi g = (Ws \cdot \sin \beta + Fo) / Ws \cdot \cos \beta \qquad (2)$$

With Fo (figure 5) and Ws soil weight=3.9kN/m

β = 12.5 GTX/GMpp ϕg = 16.5°
β = 30° GTX/sand ϕg = 38°

In conclusion this experience provides values of the limit friction angle but the progressive mobilization of the shear stresses at the interfaces seems questionable. More informations could be got by a meticulous observations of standard tests as generally implemented for the design of liner systems on slope.

3 EXPERIMENTAL SIMULATION OF THE LINER SYSTEM SLOPE KINEMATICS

Standard tests were carried out at the Lirigm on the materials considered above, both using an Incline Plane (IPS) and a shear box (SB) of (0.3 X 0.3 m^2).

As previously indicated, Shear tests are performed under normal stresses higher than 25 kPa. So results are only indicative, since normal stresses in the conditions of figure 1 (field) and figure 3 (laboratory simulation) are lower than 5 kPa. However the present authors (Lalarakotoson et al 1999) report compatibility between friction angle values obtained with SB and IPS (ϕg decreases with increasing σ). Results for GM/GTX interfaces are reported on the figure 6 and the table 1. For the same interfaces, tilting tests (IPS) were performed : GM is glued on the upper plate (no upper box and so no residual friction due to the guides : at the slip angle, β = ϕg .

In reference to the surprising behaviour observed on the test of figure 10, GTX which in the standard case is glued on the lower support, was only fixed ahead (figure 7) : before global sliding obtained for the same limit inclination, displacement u of the upper plate is significantly higher if the GTX is not glued (progressive tensile and shear mobilization : elongation and distortion of the GTX).

Figure 8, for the GMb/GTX interface, exhibits the level of repeatability of tests.

A summary of the friction angles at the different interfaces and for the different devices is presented on table 1. A good compatibility is obtained between

Table 1. Interface friction for different interfaces and different facilities.

Interface	SB	Lirigm IPS	Cemagref IPH
GMpp/GTX	11.9°	16°	16,5°
GMb/GTX	15.6°	23°	23°
Sand/GTX	/	39.3°	38°
σ/cosβ (kPa)	> 50	3.2	3.9

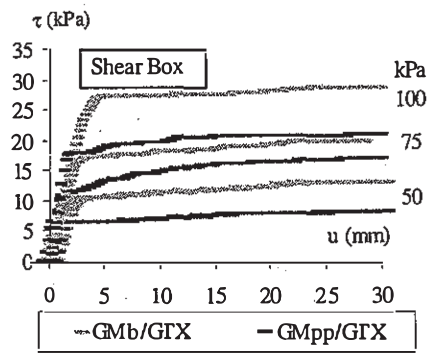

Figure 6. Friction tests between geomembrane and geotextile in the Lirigm Standard Shear Box (SB).

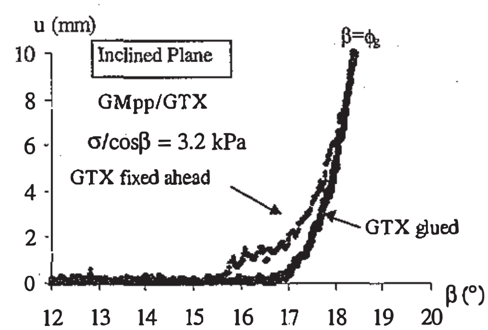

Figure 7. Lirigm Standard Inclined Plane (IPS): influence of the geotextile contact with the rigid support (GMpp/GTX).

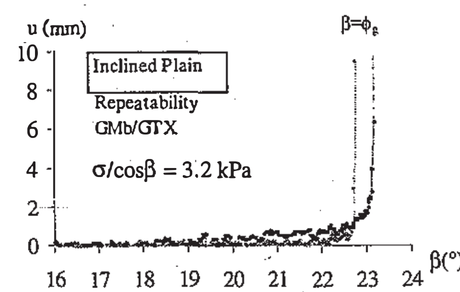

Figure 8. Repeatability of tests with the Standard Inclined Plane (IPS) on GMb/GTX interface.

the two Inclined Planes. However it's worth noting that in the present time in the IP test, only limit friction angle for continuous sliding is used. The information corresponding to the progressive displacement before sliding is useless. Figure 8. Repeatability of tests with the Standard Inclined Plane (IPS) on GMb/GTX interface.

4 NUMERICAL SIMULATION OF THE LINER SYSTEM SLOPE KINEMATICS

A numerical approach of the test of the figure 10 is performed using the FEM code Goliath of Lirigm (Villard et al 1999). The main characteristics of the model for geosynthetics and interfaces are recalled on figure 9 and table 2. The problem is arising of the Model 2 is an artefact to simulate wrinkles in the GTX before tilting. The compatibility is actually better for the tensile force in the GTX (and GMpp) and also for the upper box displacement (figure 11).

Table 2. Main parameters of the model.

	J_1	J_2	ε_c	ϕ_g	up
	kN/m	kN/m	%	°	mm
GTX	624	6	0.4		
GMpp	15				
Sand/GTX				38	10
GTX/GMpp				16.5	1
GMpp/support				20	2

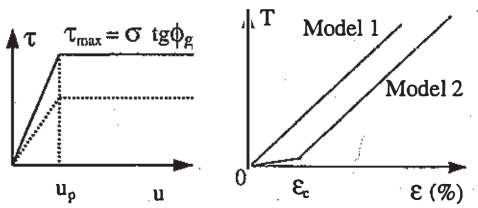

Figure 9. Numerical approach (Lirigm): modelisation of geotextile tensile behaviour and friction behaviour.

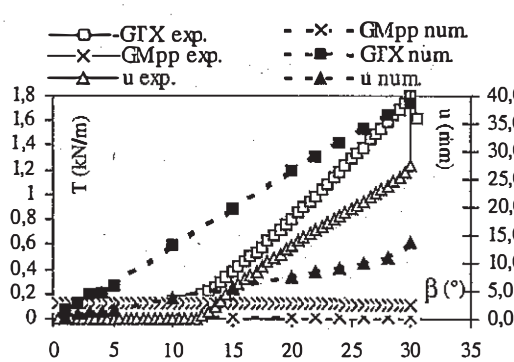

Figure 10. Comparison between experimental (IPH) and theoretical behaviours (model 1).

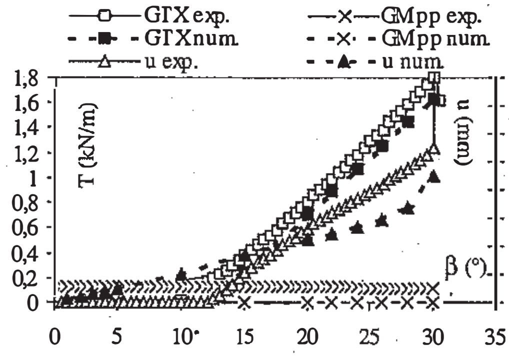

Figure 11. Comparison between experimental (IPH) and theoretical behaviours (model 2).

5 CONCLUSIONS

Composite liners systems with geosynthetics are widely used on slopes. However the distribution of forces within each component is complex. The evaluation of friction interfaces relationships from Inclined Plane tests is efficient only at the sliding limit state. Displacement before sliding remains unknown and the application of high-performance numerical codes is problematic as long as significative progress will not be obtained on interface friction relationships.

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