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Geosynthetic liners on landfill cover slope: Possible reinforcement of the stability of veneer soil layer

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ABSTRACT: Stability of Geosynthetic Lining Systems on cap cover slope of landfill or reservoir slope is a difficult matter. Several specific geosynthetics were recently proposed by the manufacturers in order to mobilize a higher friction at the interface with the soil veneer. A sophisticated Inclined Plane Test device is used to assess the efficiency of this new geosynthetic in comparison with standard materials.

1 INTRODUCTION

Stability of Geosynthetic Lining Systems (GLS) on landfill slope (Fig.1) is, from a geotechnical standpoint, a complex matter. The GLS design is based on the separation of the different functions. The main components are from the bottom (in interface with waste) to the top a geomembrane for sealing, a geospacer for runoff water drainage, a geotextile for filtration to avoid clogging of the geospacer, and a veneer cover soil for protection (thickness between 0.20 and 0.50 m).

Unfortunatly several superficial failures were observed due to the soil sliding down the smooth geosynthetic interface (Fig.2). Consequences are often severes because in the same time the global GLS is very often pull out, consequence of the upper anchorage failure and should be completely replaced.

It was demonstrated previously by Gourc and Reyes-Ramirez (2004) that Inclined Plane Test is appropriated for analysing this phenomenon.

For reinforcing the stability of the veneer soil, many geosynthetic manufacturers propose a new kind of geotextile (geotextile reinforced by a geomat, "GT mat") in place of the conventional filter with both functions, filtration (for the geospacer) and reinforcement (for the soil veneer). A comprehensive study of the interface behaviour was carried out, testing a lot of different "GT mat" structures in contact with soil, using a sophisticated Inclined Plane device.

Initial sliding conditions and residual friction corresponding to large displacements are assessed. It is demonstrated that a significative effect could be obtained for a stability point of view. However this effect is not miraculous since only the local stability in a limited layer of soil in the vicinity of the geotextile (GT) is concerned. Design of the GLS should be modified, taking into account these new conditions.

2 SPECIFIC APPROACH OF THE INTERFACE FRICTION TEST AT THE INCLINED PLANE

The Inclined Plane Test is used to determine either soil-geosynthetic or geosynthetic-geosynthetic interface

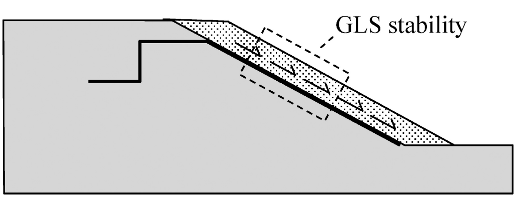

Figure 1. Landfill slope barriers: stability problems considered.

Figure 2. Example of sliding of the veneer layer along the geosynthetic interface.

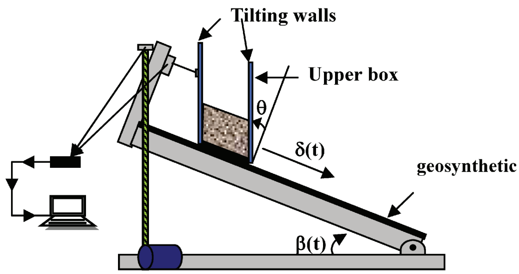

Figure 3. Main features of the inclined plane device.

properties, especially in cases where the stress normal to the interface is small (σ' less than approximately 30 kPa). The interface friction test, when performed in accordance with the current European test standard, only provides a value of the interface friction angle. The parameter usually deduced from the Inclined Plane Test is the interface friction angle ϕ (Izgin and Wasti, 1998; Lala Rakotoson et al., 1999; Palmeira *et al.*, 2002). This friction angle is calculated for a conventional displacement ($\delta = 50$ mm) in accordance with the standard Pr EN ISO 12957-2 (2001) denoted here as angle ϕ_{50}^{stat}.

In this report, the potential for drawing considerably greater information from the test is demonstrated. It has been shown in two previous paper (Reyes-Ramirez and Gourc, 2003) that the in-depth study of the diagram of the tangential displacement along the interface (δ), as a function versus the inclination (β), prior to "non-stabilized sliding" (obtained for an inclination $\beta = \beta_s$), enabled distinguishing the behavior of interfaces which display an identical value of the standard friction angle (ϕ_{50}^{stat}).

This procedure requires the interpretation of an entire dynamics phase, in particular the phase during which the upper box is engaged in uniformly-accelerated movement. Two new parameters are also defined, called angle (ϕ_o) of initial friction (static conditions) and angle (ϕ^{res}) of residual friction (dynamic conditions).

2.1 *Study of the dynamic sliding phase of the inclined plane*

Under standard test conditions, a geosynthetic layer is installed bonded to the base plane. This plane is inclined at a constant speed ($d\beta/dt = 3°$/min) and the upper box, whose displacement (δ) is measured, has been filled with a soil used for measuring interface friction with respect to the geosynthetic (Fig. 3).

In the classical case, the behavior may be separated into three phases, as follows:

– Phase 1 (static phase): upper box practically immobile ($\delta = 0$) over the inclined plane until reaching an angle $\beta = \beta_0$;
– Phase 2 (transitory phase): for an increasing value of inclination ($\beta > \beta_0$), upper box moving gradually downwards;
– Phase 3 (non-stabilized sliding phase): upper box undergoes non-stabilized sliding at an increasing speed ($d\delta/dt$), even if plane inclination is held constant ($\beta = \beta_s$).

As indicated both in the previous paper (Reyes-Ramirez and Gourc, 2003), one can distinguish a mechanism of "sudden sliding" where $\beta_0 = \beta_s$ and a mechanism of "gradual sliding" where $\beta_0 < \beta_s$ which corresponds to the majority of tests presented here. The non-stabilized sliding (dynamic, Phase 3) arises very often for plane displacement values of less than the value $\delta = 50$ mm conventionally considered when measuring the standard friction angle (ϕ_{50}^{stat}).

From the inclination value $\beta = \beta_s$, the sliding rate of the upper box becomes significant and the mechanical analysis must definitively be conducted using a dynamic approach (taking into account the displacement acceleration, γ) and not using a static approach as is typical practice. A constant dynamic friction angle (ϕ^{res}) is found, characterizing the interface friction during the phase 3 so long as the acceleration γ is taken into account:

$$\tan\phi^{res} = \frac{(m_b + m_s)\cdot g\sin\beta - T_{guide}^{dyn} - (m_b + m_s)\cdot\gamma}{(1-\alpha)\cdot m_s\cdot g\cdot\cos\beta} \qquad (1)$$

where $m_b \cdot g$ = weight of the upper box; $m_s \cdot g$ = weight of soil in the upper box; and T_{guide}^{dyn} = friction of the box guides.

In the general case of a correctly-built device, the guides of the box absorb not only the normal component of the box weight, but ultimately a portion ($\boldsymbol{\alpha}$) of the normal component of the weight of soil contained in the box (by friction along the box walls), as therefore:

$$N_{guide} = (m_b g \cos\beta) + \alpha\,(m_s g \cos\beta) \qquad (2)$$

with: $0 \le \alpha << 1$.

Equation 1 naturally applies to the special "static" case ($\gamma = 0$), which strictly accurate for the end of Phase 1 ($\beta = \beta_0$, $\delta = 0$). The new equation is given below:

$$\tan\phi_o^{stat} = \frac{(m_b + m_s)\cdot g\sin\beta_0 - T_{guide}^{stat}}{(1-\alpha)\cdot m_s\cdot g\cdot\cos\beta_0} \qquad (3)$$

ϕ_o^{stat} is considered as a characteristic value for the friction interface. The static limit equilibrium is reached for β=β_0.

Now consider the case of the present experiment. Friction due to guidance system is independent of the movement conditions ($T_{\boldsymbol{guide}}^{\boldsymbol{stat}} = T_{\boldsymbol{guide}}^{\boldsymbol{dyn}} = T_{guide}$, Fig. 4).

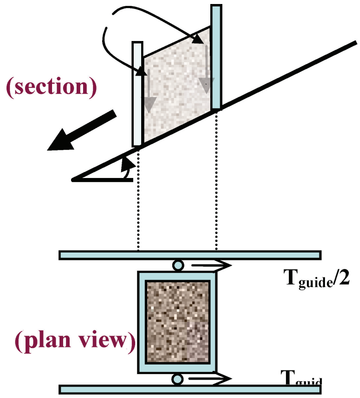

Figure 4. Conditions of sliding of the inclined box.

In addition it was assumed that the sides of the box are smooth and that no load was transferred to the box walls (i.e. $\alpha = 0$) (Reyes-Ramirez and Gourc, 2003):

$$\tan\phi_0^{stat} = \frac{(m_b + m_s)\cdot g \sin\beta_0 - T_{guide}}{m_s \cdot g \cdot \cos\beta_0} \tag{4}$$

ϕ^{res} is variable with the acceleration (γ). It will be shown, from tests results, that a generally uniformly accelerated movement (constant acceleration $\gamma = \gamma_c$) is reached at $\beta = \beta_s$ after an intermediate period necessary to go from $\gamma = 0$ to $\gamma = \gamma_c$. Therefore a second characteristic for the interfaces, the residual friction angle is obtained corresponding to the uniformly accelerated movement:

$$\tan\phi^{res} = \frac{(m_b + m_s)\cdot g \sin\beta - T_{guide} - (m_b + m_s)\cdot \gamma_c}{m_s \cdot g \cdot \cos\beta} \tag{5}$$

It's worth noting that, following the standard (Pr EN ISO 12957-2, 2001), the friction angle is conventionally determined for an inclination β_{50} corresponding to a sliding displacement $\delta = 50$ mm, with the assumption of a static equilibrium (Eq. 4 with β_{50} in place of β_0) which is a rough approximation.

2.2 *Experimental adaptation of the inclined plane device*

The displacement length available for the upper box of standard devices along the plane is generally insufficient for dynamic tests. The box was thereby modified in order to enable a trajectory greater than 500 mm. The box length in the direction of the slope, initially 1000 mm (Lala Rakotoson *et al.*, 1999), was subsequently shortened to L=180 mm. The width, measured transversally, was maintained at B=700 mm (Reyes-Ramirez and Gourc, 2003). The standard test does not generally provide an accurate enough measurement of the sliding displacement (δ) vs. time (t) to enable measurement of the speed (υ) and acceleration (γ_c) of either the box or the geosynthetic support plate. A wire sensor at the top of the inclined plane was installed to allow continuous displacement measurements to be taken with a recording rate of once every 0.05 seconds.

The following parameters were assessed and calculated during testing:

- β_0, plane inclination corresponding to the initialization of the upper box movement;
- β_s, plane inclination corresponding to the non-stabilized sliding;
- ϕ_0^{stat}, static (or initial) friction angle (arbitrary defined for $\delta = 1$ mm representative of a small relative displacement);
- ϕ^{res}, residual friction angle for $\gamma = \gamma_c$.

The initial normal stress ($\beta = 0$) is equal to σ_0' and for a plane inclination β:

$$\sigma' = \sigma'_o . \cos\beta \tag{6}$$

3 PERFORMANCE OF SMOOTH GEOSYNTHETICS IN INTERFACE WITH SOIL (REFERENCES TESTS)

Before to present the diagrammes corresponding to the rough geosynthetics with a mat dedicated to stabilization of soil veneer layer on slope, it was relevant to carry out tests on common geosynthetics which are assumed to exhibit less friction. These results will be used as a reference for the rough geosynthetics.

Four different materials were selected:

- High Density Poliethilene (HDPE) geomembrana ("GM hdpe") considered as the smoothest interface;
- Polipropilene woven geotextile ("GT woven");
- Heatbonded non-woven geotextile ("GT heat-bonded");
- Needlepunched non-woven geotextile ("GT needlepunched").

The tests were repeated on two or three different samples for each value of the normal stress σ' and the soil was a sandy sand at $\gamma_t = 14.2$ kN/m^3 and a water content w = 6.5%, commonly used on cap covers of landfill slopes.

$\sigma' = \sigma_o'$ initial normal stress (for horizontal plane: 2.8 kPa , 5.9 kPa and 10.4 kPa). The typical behaviour for these different geosynthetics is presented on Figure 5 for $\sigma_o' = 5.9$ kPa.

The values of residual friction obtained for different standard geosynthetics versus normal stress are presented on Figure 6.

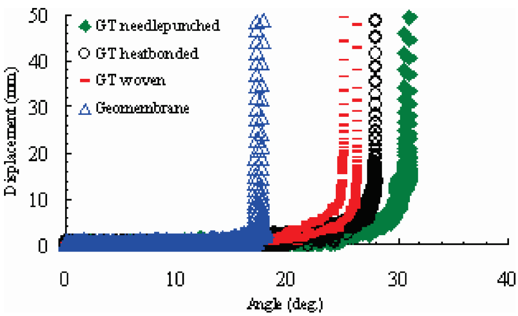

Figure 5. Sliding displacement versus the inclination β for $\sigma_o' = 5.9$ kPa for standard geosynthetics.

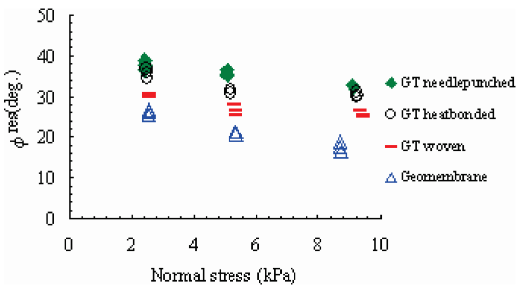

Figure 6. Summary of the values of residual friction obtained for different standard geosynthetics versus normal stress.

The main conclusions are:

- ϕ values are decreasing significantly when the increasing compression σ' (thickness of soil veneer);
- The interface soil-geomembrane exhibits a friction which could be considered as the "bottom value": ϕ(GM hdpe) < ϕ(GT woven) < ϕ(GT heatbonded) < ϕ(GT needlepunched);
- $\phi_0 < \phi^{res}$ for almost all the tests, in agreement with the observed behaviour "gradual sliding".

So the inclined plane is a relevant test to distinguish the friction performance of different geosynthetics under low values of normal stress.

4 PERFORMANCE OF GEOTEXTILE OF REINFORCEMENT + MAT IN INTERFACE WITH SOIL

To assess the efficiency of the geotextile associated to a mat for stabilizing a soil veneer, this product (see Fig. 7) is compared to the geotextile which exhibits the maximum friction (GT needlepunched).

The comparative results obtained at the inclined plane test for $\sigma'_0 = 5.9$ kPa are presented on the Figure 8. A surprising result is obtained since the same limit value of the inclination for complete sliding (β_s) is got for the mat and the non-woven needle punched. The corresponding friction characteristics are calculated on the Table 1.

Figure 7. Macro view of a geotextile of reinforcement + mat ("GT reinf Mat").

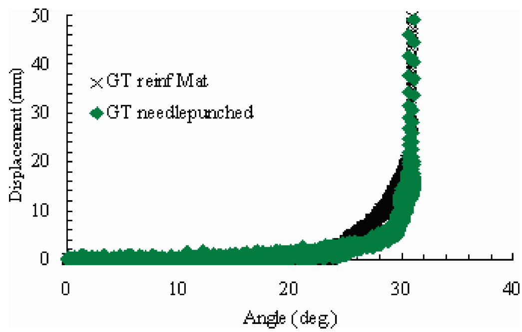

Figure 8. Comparison of the performance of a "GT reinf Mat" with a "GT needlepunched" for $\sigma'_o = 5.9$ kPa.

Table 1. Friction values of the characteristics angles.

Geosynthetic	σ'_0 (kPa)	ϕ_0 (deg.)	ϕ_{res} (deg.)	ϕ_{50}^{stat} (deg.)
GM		16	26	28
GT np	2.8	23	37	46
GT reinf Mat		46	37	47
Soil/soil			40	
GM		16	21	23
GT np	5.9	21	35	40
GT reinf Mat		30	36	40
Soil/soil			36	
GM		13	17	18
GT np	10.4	17	32	34
GT reinf Mat		24	31	34
Soil/soil			31	

The residual friction ϕ^{res}values are equivalent for the two geosynthetics despite the difference of interface structure. In addition the conventional friction for a displacement $\delta = 50$ mm and using a (wrong) static calculation are also quite identical. However the initial friction ϕ_0 corresponding to the inclination of sliding starting are different and allow an identification of the difference of shape of the two diagrams (Fig. 8).

To explain the identical ϕ^{res} value , complementary tests with soil in place of geosynthetic on the lower support were carried out (soil/soil tests), and it is demonstrated (Tab. 1) that ϕ_{res} obtained with soil /geosynthetic reachs the limit ϕ^{res} for soil /soil tests, limit which is logically impossible to pass beyond.

A remaining question is pending: what the actual meaning of the initial friction ϕ_0? One is authorize to interpretate this angle in term of angle corresponding to the initialization of the layer sliding. In this condition the "GT reinf Mat" exhibits a higher efficiency than the "GT needlepunched".

5 CONCLUSION

Design of GLS on slopes is a difficult matter. A large programme of Inclined Plane tests with a sophisticated device was carried out, specifically in order to assess the relative efficiency of geotextile of reinforcement with a mat interface which are presently proposed by several manufacturers .Comparing with a simple nonwoven needlepunched, the result is not at all obvious, in these specific conditions of very low normal stresses.

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