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Numerical modelisation of the stability of liner systems under hydraulic conditions from inclined plane tests

FEKI . N, University of Sfax, Tunisie,
BIANCON L., POULAIN D., Cemagref of Bordeaux, France
VILLARD P., GOURC J.P., University of Grenoble, France

ABSTRACT: The use of geosynthetics liner system in civil applications submitted to water flow enhanced the development of a new apparatus adapted to conduct tilting tests under hydraulic conditions. To simulate partially the field conditions, these tests are realized with all the components of the liner system in dry then in wet conditions. The test results allow evaluation of the friction properties of geosynthetic interfaces, and the tensile forces developed in the geosynthetic layers. A finite elements code is used for an accurate evaluation of the theoretical tensile forces and to emphasize the influence of water flow on the stability of the system.

1 INTRODUCTION

The stability of composite liners systems is widely studied both by large scale experimentations and numerical models.

In the present time, the geosynthetics are frequently used in constructions with water flow as landfill caps, retention basins, water canals….

In these applications, the stability of the liner system is more sensitive than in dry conditions if the friction characteristics are affected with water seepage at the interface.

For this aim, a new apparatus of inclined plane developed at Cemagref Bordeaux, is adapted to conduct tilting tests under hydraulic conditions.

To simulate partially the performance of the system as in large scale experimentation, tilting tests are released with all the components of the liner system (a sandwich) with monitoring the tensile forces in the geosynthetics in dry conditions and with water flow conditions.

A numerical approach using a finite element code is used to modelise these tests and to determine numerically the tensile forces developed in the geosynthetics.

2 TILTING TESTS ON INCLINED PLANE APPARUTUS

2.1 *Tilting tests in dry conditions*

A specific inclined apparatus was designed at the Cemagref of Bordeaux (Briançon, 2002) to characterize geosynthetic interfaces and to simulate sliding (Fig. 1).

The inclined plane is more appropriated than the standard shear box to conduct tilting tests under low normal stresses as in field conditions. In addition the inclined plane allows to induce hydraulic conditions on the interfaces.

As standard tilting tests, this inclined plane provides during the progressive inclination β of this plane, the monitoring of the tensile forces by clamping the geosynthetic sheets at their head. The contact surface between the soil and the base of the geosynthetic sheet is 1 m^2.

To simulate partially the performance of the geosynthetic liner system as in large scale experimentation, tilting tests with all the components of the liner system, are first conducted in dry conditions. For the present test, the upper box is filled with sand (γ_h = 17 kN/m^3). The upper lining system is composed of a reinforcement geotextile non-woven needlepunche (GTX) and a polypropylene geomembrane (GMB) fixed at their head (Fig. 2).

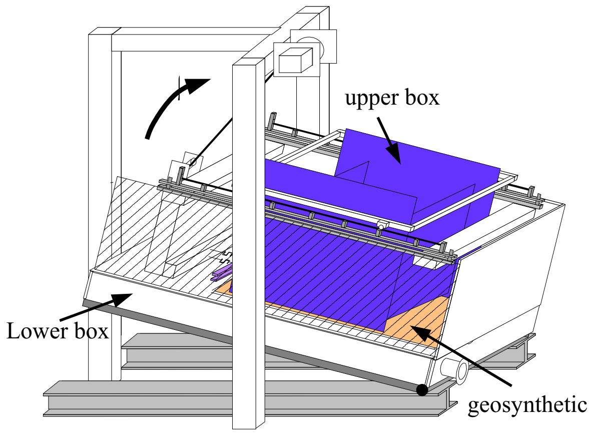

Figure 1. Inclined plane apparatus developed at Cemagref of Bordeaux

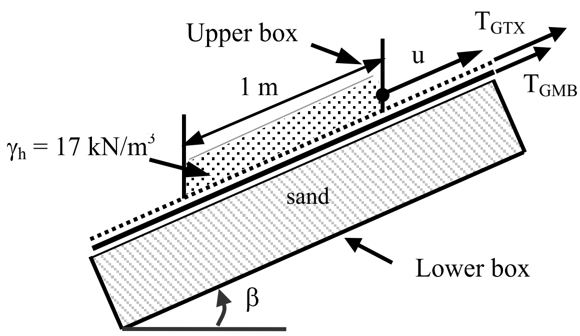

Figure 2. Example of tilting tests in dry conditions

The behavior of the liner system is presented in Figure 3. The details of the main features can be obtained in the publication (Gourc et al, 2001).

This kind of tests provides values of the limit friction angles of more one interface. Figure 3 shows that there is no tensile mobilization of the geotextile until an inclination of 12.5°. The increasing value of the tensile force in the geotextile for an raising more than 12.5°, corresponds to sliding at the interface GMB/GTX at the raising of 12.5°.

The displacement of the upper box increases until the global sliding on the geotextile for an raising of 30°.

This tilting tests provide values of the limit friction angles, but not the progressive mobilization of the shear stresses at the interfaces which remains of great importance for numerical modelisation.

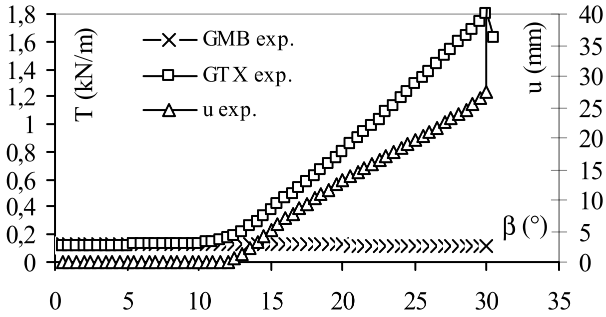

Figure 3. Experimental results of tilting test in dry conditions

2.2 *Tilting tests under hydraulic conditions*

The geosynthetic lining systems are actually frequently used in civil constructions under hydraulic conditions. The stability of the liner system is obviously affected by the water seepage which induce a reduction of the normal stress and so the friction forces at the interfaces, and the increasing of the tangential active force. For this aim, the inclined plane apparatus is adapted to conduct tilting tests with water seepage in the soil and at the interfaces.

A second test is conducted with the same liner system used in the previous test under hydraulic conditions.

For this test, only the geomembrane sheet is clamped on the head. Two levels of water are respectively considered h_w = 0.1 and 0.2 m. The test is conducted in 3 steps:

- inclination of the plane until an angle of 30°;
- seepage of water at the interface;
- seepage of water in the cover soil, the level of water is maintained constant at the top and the base of the layer of sand.

As the plane is first inclined until the limit angle of sliding (β= 30°), the force needed to sustain the upper box (F) will be monitored instead of its tangential displacement (u) (Fig.4). This original method for conducting tilting test under hydraulic conditions is largely tested in dry conditions (Bianςon, 2002).

Different tests conducted with different kind of geotextiles and geomembranes, give lower friction angles then those in dry conditions. The difference is about 5°.

The increasing of the force during the test is presented in Figure 5. The force F needed to sustain the upper box at an inclination of 30° is equal to 1.76 kN. In the previous test, this force is supported by the reinforcement GTX. The force F increases to 2.5 kN after the seepage of water in the cover soil at a level of 0.2 m.

The increase of the force F to sustain the upper box, improve that the geosynthetic layers will be more required

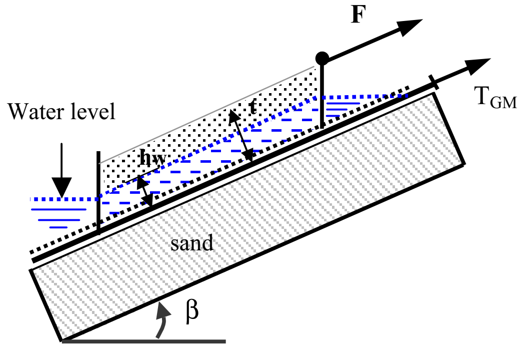

Figure 4. Tilting tests under hydraulic conditions

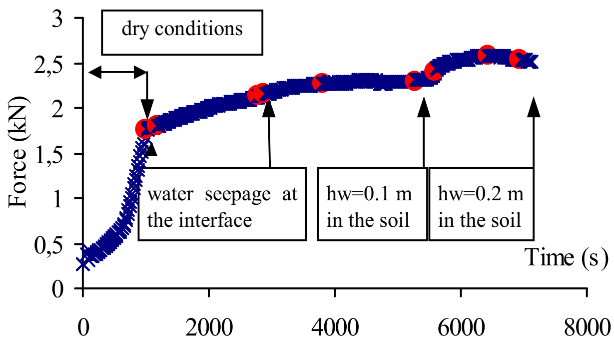

Figure 5. Experimental results of tilting test under hydraulic conditions

The Force F can be approached by limit equilibrium concept. The relationships between the forces acting on the system (upper box with cover soil + GTX) (Fig.6) are given by equations 1 and 2.

$$W_s \sin\beta - f = F - F_o \quad (1)$$

With f is the sum of friction forces = $\Sigma\tau dS$ and W_s is the weight of soil and F_o is the force needed to sustain the upper box empty.

$$W_s \cos\beta = N + U_n \quad (2)$$

With U_n is the water pressure and N = f / tan ϕ_g (ϕ_g is the friction angle at the interface GTX/GMB).

The combination of the equations (1) and (2) gives the expression of F (3):

$$F = F_o + W_s \sin\beta - (W_s \cos\beta - U_n) \tan\phi_g \quad (3)$$

with $W_s = [\gamma_{sat} h_w + \gamma (t - h_w)] L$, γ_{sat} is the saturated weight of the soil , t is the soil thikness and $U_n = \gamma_w h_w \cos\beta$

The friction angle at the interface GTX / GMB is found unchanged after water seepage ϕ_g = 16.5°. γ_{sat} = 20.7 kN/m^3 ,t = 0.3 m and F_o = 0.78 kN.

From (3), the force F needed to reach the equilibrium of the system is of 2.7 kN with h_w = 0.2 m (the experimental force is 2.5 kN). Without water seepage, this force is only 2 kN.

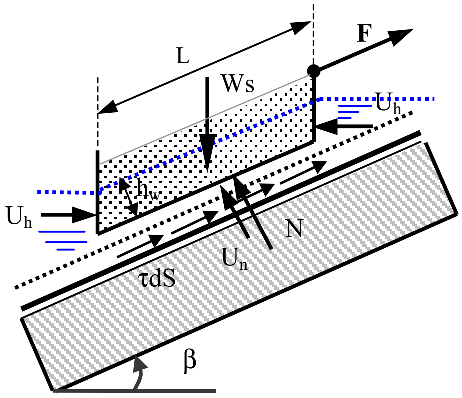

Figure 6. Forces acting on the cover soil plus the GTX

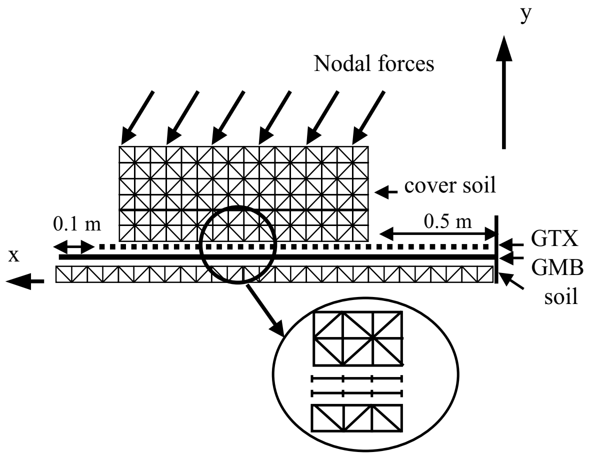

Figure 7. Finite elements mesh for modeling the tilting test in dry conditions.

3 NUMERICAL MODELISATION OF TILTING TESTS

3.1 *Modeling of tilting tests in dry conditions*

A numerical approach of the tilting tests is performed using the Finite Elements code developed at the Lirigm (Villard, 1996).

The meshing adopted for modeling the tilting test in dry conditions is presented on Figure 7. The lining system components were individually divided by two-nodded bar elements (the geotextile is discretised into 32 bar elements and the geomembrane into 35 bar elements). The sand in both the lower and upper boxes, supposed to be rigid, was modeled by 320 three-node triangular elements.

The various components of the liner system were interconnected by contact conditions that allow considerable relative displacements between the interface nodes (Villard, 1996). Three sliding surfaces are considered:

- sliding surface between the cover soil (sand in the upper box) and the GTX anchored on the head;
- sliding surface between the GTX and the GMB anchored on the head;
- sliding surface between the GMB and the support (sand in the lower box).

The weight of the upper box W_b (W_b = 1,31 KN), is applied by nodal forces in the two directions (x and y) to the upper nodes of the soil (Fig.7). The weight of soil in the upper box is applied by volumetric forces to the triangle elements in the two directions (x and y) for each raising of the plane.

The inclination of the plane is simulated one degree per one degree.

The friction relationship was supposed to be elastic perfectly plastic with a Mohr-Coulomb failure criterion (Fig.8). The relative displacement u_p required to reach the maximum shear strength τ_{max} was considered independent of the normal stress σ_n.

The no tensile force mobilization in the geotextile until the inclination β = 12.5° (fig. 3) can be related to its laying by the development of wrinkles during the filling of the sand in upper box. For the numerical approach, the geotextile is supposed no stressed by considering a very low tensile modulus J_2 (Table 1) until a strain ε_c = 0.4 % (Fig. 8). This strain corresponding to a displacement of 1 mm of the upper box, was found (Gourc et al., 2001) sufficient to stretch the geotextile.

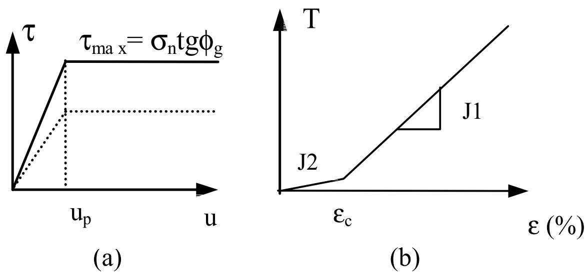

Figure 8 a. Geotextile/Geomembrane friction behavior and b) Tensile modulus of geotextile

The main characteristics of the model are presented in Figure 8 and Table1. The comparison (Fig. 9) between the theoretical and the experimental curves (tension T of the geosynthetics and displacements u of the upper box versus box plane inclination β) shows a good compatibility.

The problem is arising from the difficulty of estimating u_p from the inclined plane test results. To underline its importance, a second computation is done with very low u_p (u_p (GTX/GMB) = 0.2 mm and u_p (GMB/soil) = 0.1 mm). The tensile behavior of the geotextile is perfectly elastic with a tensile modulus J_1 (J_1 = 624 kN/m).

The comparison with the experimental behaviors on figure 10, can also explain the no tension mobilization of the geotextile until the sliding on the geomembrane.

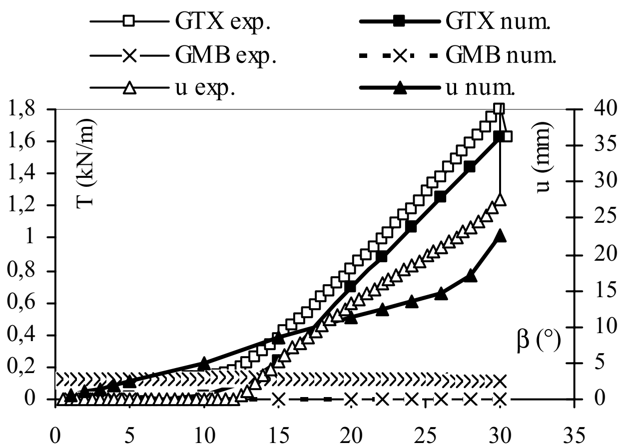

Figure 9. Comparison between experimental and theoretical behaviors in dry conditions

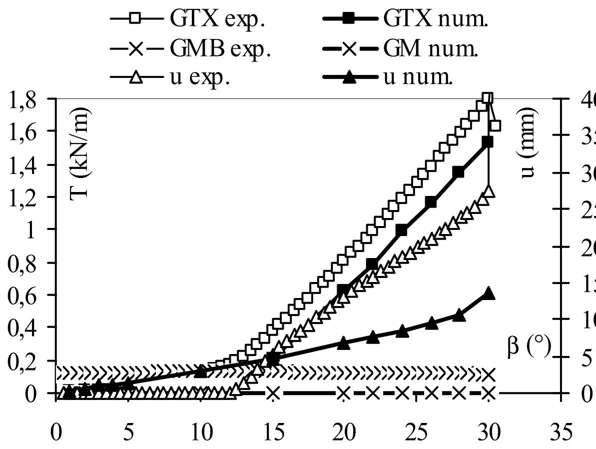

Figure 10. Influence of up on the geotextile tensile behavior

3.2 *Modeling of tilting tests under hydraulic conditions*

For the modelisation of tilting test under hydraulic conditions, a two-noded bar element is added with a high tensile modulus of 10 000 kPa to sustain the upper box to simulate test conditions (Fig. 11).

The influence of water seepage is modelised by applying the not gauged weight γ' to the triangle elements of the soil under water level ($\gamma' = \gamma_{sat} - \gamma_w$) with γ_{sat} is the saturated weight of soil and γ_w is the unit weight of water. Due to the particular cases studied (GTX-GMB friction), no change was made about the value of the friction angle (dry or wet interface).

Figure 12 shows that the considered model allows to find the needed force (F) to sustain the upper box until an inclination of 30° in dry conditions. After the water seepage, the normal stress decreases and induces an increase of the force F as the friction forces are reduced.

For this example the increase of F is only related to the weight of water and the decrease of the normal stress. The increase of the force F will more significant when the friction angle of the critical interface is lowered after the seepage of water.

The increase of the theoretical force under water seepage is acceptable per comparison to the experimental values (Fig. 12).

Table 1. Main parameters for the numerical approach

	J_1 kN/m	J_2 kN/m	ε_c %	ϕ_g degrees	up mm
GTX	624	6	0.4		
GMB	15				
Sand/GTX				38	10
GTX/GMB				16.5	1
GMB/soil				20	2

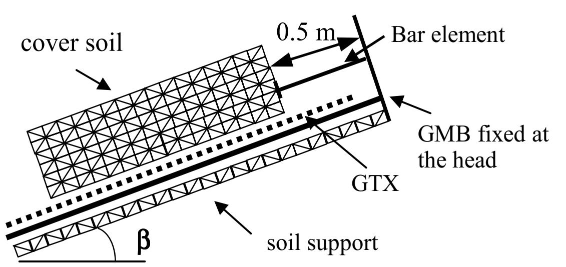

Figure 11. Numerical model for tilting test under hydraulic conditions

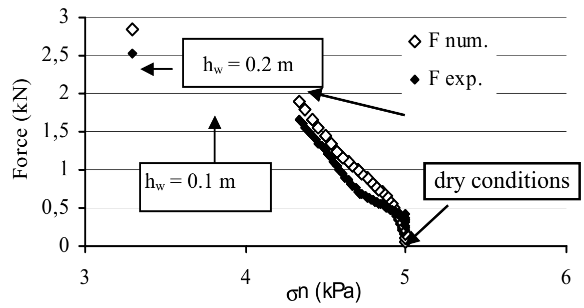

Figure 12. Comparison between experimental and theoretical behaviors under water seepage

4 CONCLUSION

The numerical modelisation of tilting tests in dry conditions shows that the laying of geosynthetic sheets can explain its low mobilization of tension at the beginning of the test. This can also be related to very low u_p at the interfaces which are not evaluated by this type of test.

The friction characteristics of the interfaces are found unchanged for the present example of tilting test under hydraulic conditions.

The numerical approach adapted to sustain the upper box has allowed to underline the influence of water seepage in the cover soil and at the interface. The force F measured after water seepage, allows to know the new friction angle if it is reduced.

In such applications, an accurate evaluation of the interface properties under hydraulic conditions is necessary since the tensile force supported by the reinforcement geotextile increases during water seepage.

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