LINING SYSTEMS STABILITY IN LANDFILL SLOPES: PARAMETRIC STUDY

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SUMMARY: One of the important aspects in designing new landfills is the stability of drainage and waterproofing system along the slopes. A simple analytical method was developed to define stresses transmission into the different layers. This allowed to point out the limits of the compatibility of strains between clay and geomembrane; a finite elements method was used.

1. INTRODUCTION

The first objective when designing a new storage landfill is to insure the time-resistance of the waterproofing system. That's the reason why it is necessary to use a double waterproofing system formed by :

- a synthetic waterproofing (geomembrane);
- a mineral waterproofing (clay).

The drainage of the leachates at the bottom of the landfill is insured by a gravel layer. Along the slopes, gravel is also used, generally encapsulated into gabions.
Based on the experience, the most elementary combination of waterproofing system and drainage layer is shown on Figure 1.

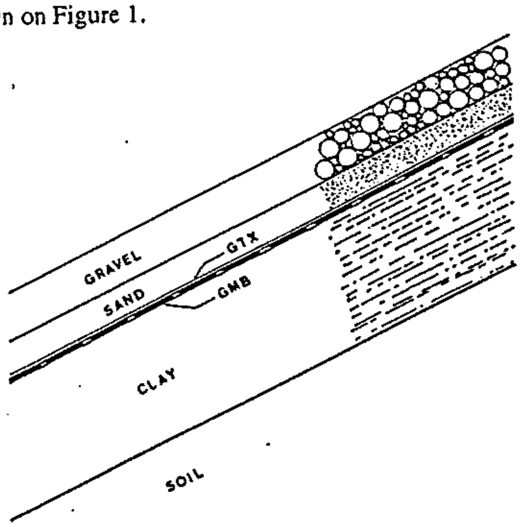

Figure 1. Drainage and waterproofing system.

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That system is based on the following considerations:

- the geomembrane must be separated from the granular material by means of a sand layer;
- due to gravity, the drainage layer could slide down; it is so useful to create a preferential slip surface between the drainage layer and the layers below. This can be obtained by a smooth geomembrane separated from the sand layer by a geotextile.

2. STATIC EQUILIBRIUM OF THE DRAINAGE-WATERPROOFING SYSTEM

We can imagine a cross-section of the slope and the different layers of the drainage-waterproofing system. The Figure 2 gives the free body diagram of the upper layers of the slope:

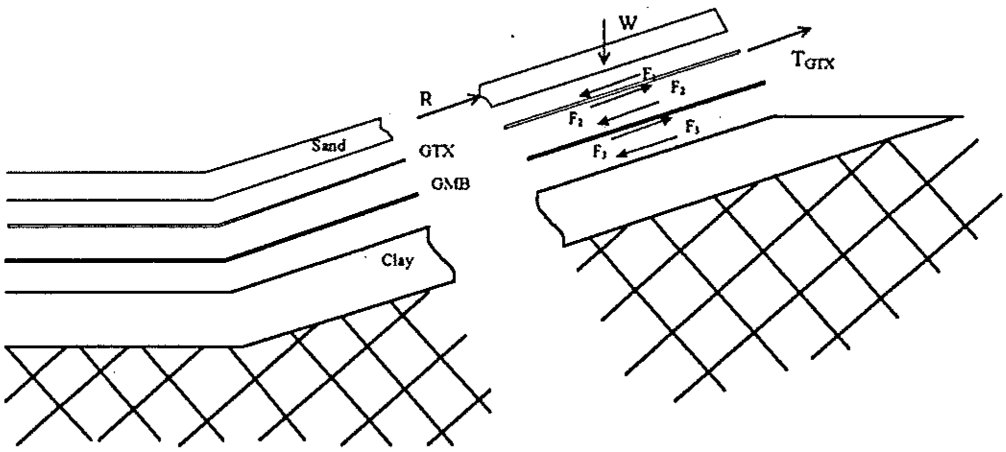

Figure 2. Free body diagram of the drainage and waterproofing system.

We can write the static equilibrium of a cross section of the drainage-waterproofing system when the landfill is empty : the drainage system (weight W) acting on the underlayers can be decomposed in a normal effect $N = W.\cos\theta$ and a tangential effect $T = W.\sin\theta$.

The normal effect is integrally transferred to the underlayers according to the action-reaction principle. If the weight of the geomembrane and of the geotextile are neglected, the clay layer is thus submitted to a normal force $N=W.\cos\theta$.

The transmission of the tangential force is depending on the shear behaviour at the interface between two layers; it can be expressed as:

$F_{Ri} = c_i.l + N.\mathrm{tg}\,\phi_i$ where c_i = cohesion at interface i

ϕ_i = friction angle at interface i

l = length of contact between two layers

interface 1 : sand/geotextile
interface 2 : geotextile/geomembrane
interface 3 : geomembrane/clay

In a safe way, the cohesion is often neglected at interfaces 1 and 2.
In order to promote slipping at the GTX/GMB interface, it is more interesting to choose a geomembrane with a smooth upper surface ($\rightarrow \phi_2 \cong 10°$).

Hypothesis : $F_{R2} < F_{R1} \rightarrow tg\ \phi_2 < tg\ \phi_1$ (this hypothesis will always be verified)
$F_{R2} < F_{R3} \rightarrow N.tg\ \phi_2 < c_3.l + N.tg\ \phi_3$

Notations : F_{Ri} = maximum resisting stress at interface i
F_i = real stress at interface i

1[st] case : $\theta < \phi_1$

- Maximum resisting force at interface 1 :

$$F_{R1} = N.tg\ \phi_1 = W.\cos\theta\ .tg\ \phi_1 > W.\sin\theta = \text{applied load}$$

So, the force transferred at interface 1 is $F_1 = W.\sin\theta$

- Maximum resisting force at interface 2 :

$$F_{R2} = W.\cos\theta\ .\ tg\ \phi_2$$

If we make the extra hypothesis that $\theta > \phi_2$ (i.e. slope angle is greater than about 10°), then

$$F_{R2} < F_1 = W.\sin\theta$$

and the force transferred at interface 2 is

$$F_2 = F_{R2} = W.\cos\theta\ .\ tg\ \phi_2$$

A portion of the applied force is not compensated by friction. There is thus a risk of slipping between geotextile and geomembrane. This slipping will induce compression stress in the drainage layer (sand + gravel) and tension stress in the geotextile.

$$R + T_{GTX} + F_2 = F_1 = W.\sin\theta$$

$$\Rightarrow \quad R + T_{GTX} = W.\sin\theta - W.\cos\theta\ .tg\ \phi_2$$

where R = compression effort in the drainage layer
T_{GTX} = tension effort in the geotextile.

Tension in the geotextile can only occur if this one is anchored at the top of the slope.

- Maximum resisting force at interface 3 :

$$F_{R3} = c_3.l + N.tg\ \phi_3 > F_2 = F_{R2} = W.\cos\theta\ .\ tg\ \phi_2 = \text{applied load}$$

(by hypothesis).

The force transferred at interface 3 is

$$F_3 = F_2 = W.\cos\theta\ .\ tg\ \phi_2$$

The shearing force transferred to the clay layer is so

$$W.\cos\theta\ .\ tg\ \phi_2$$

<u>2nd case : $\theta > \phi_1$</u>

With a similar reasoning we can conclude as in the first case :

$$R + T_{GTX} = W.\sin\theta - W.\cos\theta\ .tg\ \phi_2$$

The shearing force transferred to the clay layer is $W.\cos\theta\ .\ tg\ \phi_2$

<u>Conclusions</u>: the solicitations of the different layers of the drainage-waterproofing system are (with the hypothesis above-mentioned):

- Geomembrane: pure shearing solicitation;
- Geotextile: tensile solicitation if anchored on the top of the slope;
- Drainage layer: longitudinal compression;
- Clay: normal force $N = W.\cos\theta$ and tangential force $T = W.\cos\theta.tg\ \phi_2$

Generally the shear stress in the clay layer will always be equal to N.tg ϕ_{min} where ϕ_{min} = minimum of (θ, ϕ_1 , ϕ_2,ϕ_3).

3. DISCUSSION OF THE HYPOTHESIS

3.1 Anchorage of the geotextile

It is useful to anchor the geotextile at the top of the slope in a trench. It allows to develop tensile stresses in the geotextile and to insure the local stability of the drainage-waterproofing system. However, it is necessary to verify the global equilibrium of the slope.

Indeed, the tensile stress must be entirely transferred to the anchorage trench; it mobilizes then a reaction into the soil mass which can produce, if too high, a failure of the slope.

3.2 Geomembrane/clay interface

We supposed $N.tg\ \phi_2 < c_3.l + N.tg\ \phi_3$, which means that the available force at the geomembrane/clay interface is greater than at the geotextile/geomembrane one. Laboratory tests should verify this hypothesis.

More generally, KRUSE Th.(1989) showed that the friction at the geomembrane/clay interface, determined by means of direct shear tests, is influenced by :

- the speed of shearing;
- the type of geomembrane (smooth, with spikes ...);
- the degree of saturation of the clay;
- the degree of consolidation of the clay.

The influence of these parameters has to be taken into account for the determination of the friction resistance at the geomembrane/clay interface.

4. LOADS DUE TO THE WASTE DEPOSIT

4.1. Hypothesis

When the disposal is fulfilled with wastes, these produce efforts on the slopes of the disposal. The stresses to be taken into account are the weight of wastes and the horizontal pressure.

For the study of the tangential effects, it is on the safe side to neglect the horizontal pressure. Indeed, the tangential stress will be maximum when the horizontal pressure is zero. For the following, we will consider only the stress due to the weight of wastes (Figure 3):

$$W = \left[\int_0^h \gamma(h) \, . \, dh\right] dx$$

$$\sigma = \frac{W \, . \cos\theta}{dS} \qquad \text{and} \qquad dS = \frac{dx}{\cos\theta}$$

$$\tau = \frac{W \, . \sin\theta}{dS}$$

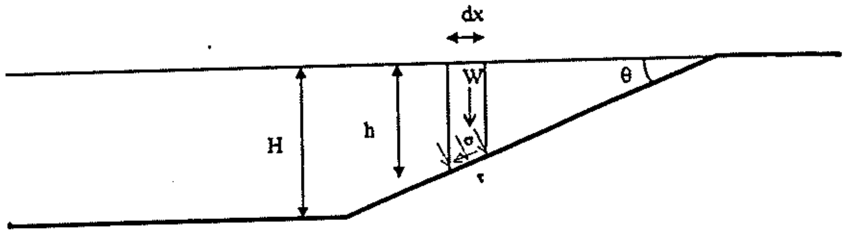

Figure 3. Effects of waste on the slopes

These efforts are to be added to the one resulting from the weight of the drainage system.

4.2. Specific weight of wastes

The Walloon policy for waste treatment is oriented to the selection and the grinding (followed or not by incineration), before disposal.

The characteristics of such a type of wastes coming from a disposal in the area of Liege have been determined.

Initially, the specific weight of the wastes coming in the disposal was 8,6 kN/m^3. A consolidation test has been realized and we deduced the evolution of the waste specific weight versus the normal stress and consequently the evolution of the specific weight versus the depth of the wastes. These results are presented on Figure 4.

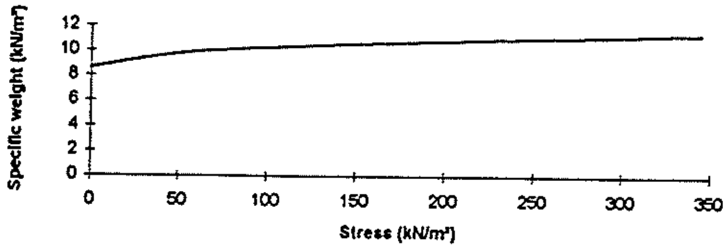

Figure 4. Variation of specific weight of wastes with vertical stress

5. STUDY OF THE CLAY LAYER

The paragraphs 2 and 3 showed that the clay layer along the slopes was stressed in compression and shear. It is evident that these stresses will produce a deformation of the clay layer and may also cause a failure in the clay layer.

What will be the consequences for the geomembrane? The normal and tangential stresses transferred to the clay increase with depth : consequently, the deformation will be greater at the toe of the slope. When the geomembrane has an underface with spikes, there is a solidarity between itself and the clay. A deformation of the clay will produce a deformation of the geomembrane and this deformation must be limited in order to insure time-resistance of the geomembrane. Moreover, if a failure occurs in the clay layer, tensile stresses will increase in the geomembrane and this can produce a tear of the geomembrane.

The study of strains in the clay layer has been realized using the finite element method. For this end, the non-linear calculation code LAGAMINE of the department MSM (University of Liege) has been used.

The geometry and the finite element discretisation of the system we studied is presented hereafter (Figure 5)

For these calculations, we used an Ypresian clay which is often used in Belgium for waterproofing in civil engineering. Its permeability coefficient is lower than 10^{-9} m/s. Its mechanical behaviour has been analysed by means of a number of laboratory tests.

thickness of clay layer : 0,6 m   height of the slope : 10 m   angle of the slope : 30°

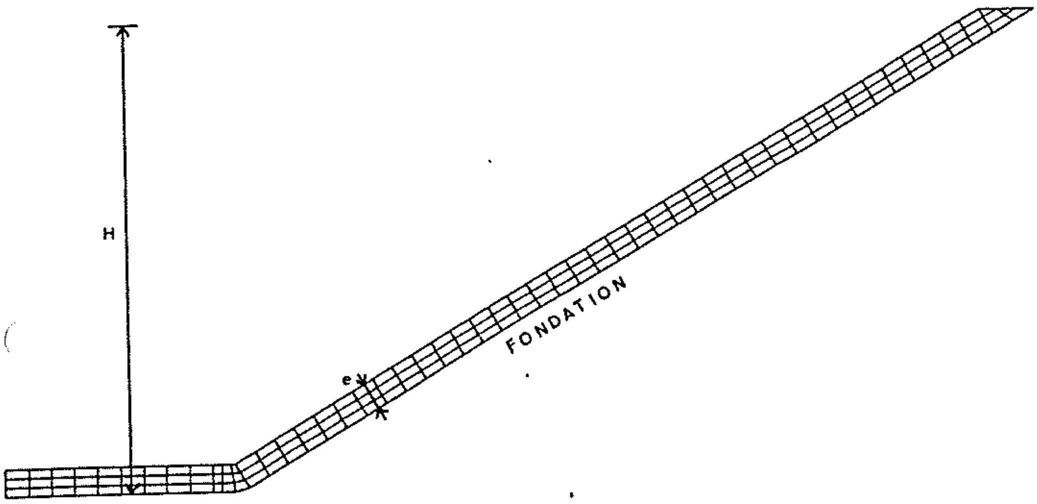

Figure 5. Discretisation of the clay layer

The clay used as waterproofing barrier in disposals has generally a degree of saturation near the standard Proctor optimum. One of the most difficulties is to determine a model for the behaviour of clay in a non-saturated state; the rheological model must take into account suction effects and compressibility of the pore fluid.

In a first step we used the parameters of a saturated clay. A consolidated-undrained triaxial gave a cohesion value of 71 kPa and a friction angle of 11°. This test showed that for deviatoric stress paths, the behaviour of the clay was non-linear in the elastic domain and of the DRUCKER-PRAGER type in the plastic domain.

A lot of calculations were carried out with this simplified model. The loads applied to the clay layer where those determined as described in paragraphs 2 and 4. The results showed that the strain of the geomembrane due to the deformation of the clay layer remains more than ten times below the yield strain.

The following steps will be the determination of a simple rheological model for unsaturated clay and the study of different geometries for the clay layer. That would lead to recommendations in the design of the slopes and the choice of the materials involved in the drainage-waterproofing system.

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