STABILITY AND ANCHORAGE OF GEOSYNTHETIC SYSTEMS ON SLOPES : DEVELOPMENT OF A NEW DESIGNING TOOL

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ABSTRACT: In Geomembrane Liner Systems (GLS) or all other systems involving the use of geosynthetics on slopes, the "geosynthetic" complex constitutes a preferential slip plane for the layers (topsoil, gravel, rocks, concrete blocks…) that cover and protect it. 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 is presented here.
The methods of calculating slope stability of the GLS are generally all based on the same principle of calculation at failure, consisting of the force equilibrium between a passive block at the foot of the slope and an active block composed of the cover layers. Additions have been made to the method of calculating stability on the slope with the aim of improving the way hydraulic conditions are taken into account.
On the basis of these methods, a calculation software was produced making it possible to study the stability of a GLS on a slope, to define any forces that might be necessary to retain the cover layers and to calculate the dimensions of the anchorage at the crest. The main characteristics of this software are, on the one hand, the ability to take into account a system comprising up to 4 geosynthetics and 3 layers of protection, with an upper layer that can be of varying thickness to improve the abutment and, on the other, the possibility of taking into account a large number of hydraulic conditions.

1 INTRODUCTION

Geomembrane Liner Systems are increasingly widely used, in particular on hydraulic structures (dams, basins, canals) and landfills. In such structures as well as in all other systems involving the use of geosynthetics on slopes, the "geosynthetic" complex constitutes a preferential slip surface for the layers (topsoil, gravel, rocks, concrete blocks…) that cover and protect it. In most cases, the angle of the slope is too steep for the protective layer to be self-stable; in such conditions, stability is ensured by an abutment and/or by anchoring the geosynthetics at the top of the slope. A software programme to calculate the required dimensions of these two elements has been developed at the Cemagref.

In this paper, we begin by a reminder of the methods used to calculate slope stability and the dimensions of the anchor system, before going on to present the possibilities offered by this tool and its application to a concrete example.

2 CALCULATION OF SLOPE STABILITY

In this paper, we will consider only the stability of the layers of structures protecting the geosynthetics; only the risk of plane slippage along the geosynthetic complex is taken into consideration. However, the designer will also need to check the internal stability of the protective earth cover installed on the slope on either side of the geosynthetic complex, as well as the global stability of the slope.

The thickness of the protective layers is generally limited to a few tens of centimetres or, at the most, to around a metre in the most common examples of hydraulic structures waterproofed with geosynthetic liners and landfill covers; the same goes for structures to protect against erosion installed on a geotextile. The stresses applied to the GST interfaces are therefore relatively weak (a few tens of kPa or less); in these conditions, the characterisation of the interfaces and in particular the measurement of friction angles will preferably be carried out using apparatus of the inclined plane type enabling tests with low stresses.

In this paper, we will not give a detailed presentation of the calculation method used when there is not an abutment. Indeed, in such cases the analysis of stability corresponds simply to the balance between the driving forces due to the weight W of the protection itself and the stabilising forces constituted by the friction force F that can be mobilised on the interface being studied, to which is then added any anchor force T there might be at the top of the slope (figure1):

$T + F = W.\sin\beta$ with $F = W.\cos\beta.\tan\delta$

It is important to note that, for the calculation of the friction that can be mobilised, we should take into account the uplift force Fw that can occur at the geosynthetic interface in case of total or partial saturation of the protective layer(s). In this case, F is define by the relation :

$F = (W.\cos\beta - Fw)\tan\delta$ with $Fw = \gamma_{water} .e_{sat}. \cos\beta.h/ \sin\beta$

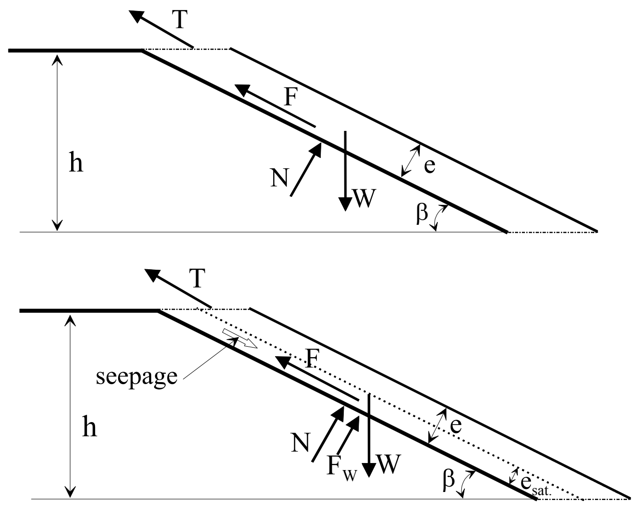

Figure 1 Forces involved in a protection without abutment

In general, when there is an abutment, the classic approach for the stability to failure of this type of protection is based on dividing the protective layer into two blocks. Such methods are proposed in particular by Soong and Koerner (1996) and by Giroud (1995). The main difficulty in this case is taking the hydraulic conditions into account. Several cases must be taken into consideration and they are described below.

2.1 *Saturation of the Protective Layers*

Even in the absence of a reservoir above the protective structure, this structure can become partially or totally saturated due to atmospheric precipitation. Such is the case, for example, of layers of topsoil put down to cover landfills, or also of a relatively fine (sand …) granular transition layer laid down under a layer of rocks. This saturation has two consequences:

- an increase in the weight of the protective layer,
- the development of uplift pressure at the geosynthetic interface when there is no drainage system.

This uplift is taken into account by the calculation of the effective stress σ' at the interface in question, defined by the relation:

$\sigma' = \sigma - u$ (1)

with: $\sigma = \gamma_{soil}.e.\cos\beta$

$u = \gamma_{water}.e_{sat}.\cos\beta$

Note that, in this case, seepage in the protective layer is considered as being parallel to the slope.

The friction is defined by the relation:

$\tau = \sigma'.\tan\delta$ with δ friction angle (2)

$\tau = (\gamma_{soilsat}.e-\gamma_{water}.e_{sat}).\cos\beta.\tan\delta$

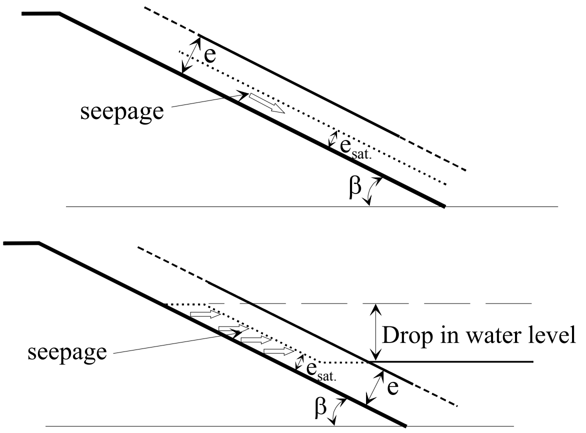

Figure 2 Seepage in the protective layer

2.2 *Presence of a reservoir*

The presence of reservoir (basin, dam, canal…) above the geosynthetic complex and its protection leads us to add in hydraulic forces; the main difficulty in doing this is to take into account a rapid drop in the water level. In this case, the principle of the calculation is that defined by POULAIN (2000) for navigable canals; we should note that, in this calculation, we consider that, in the zone concerned by the drop water, seepage is horizontal in the protective layer(s) that remain(s) saturated and that, as a result, uplift pressure u is expressed by the following relation:

$u = \gamma_{water}.e_{sat}/\cos\beta$

Then σ' and τ can be calculated by relations (1) and (2)

The two approaches described above can be used simultaneously on 2 parts of the slope if there is a reservoir and at least partial saturation of the protective layers in the upper part of the slope above the water. We then apply the 2 methods defined above on the saturated upper part and on the part located below the normal level of the body of water respectively.

2.3 *Protection of Non-Constant Thickness*

We also wished to tackle the case of protective structures of non-constant thickness; this is a solution that is often used to improve the abutment. In this case, the calculation is performed using the hypothesis that the forces exerted by the passive block on the active block (Ep) and vice-versa (Ea) remain parallel to the slope (Figure 3) in the same way as when the layers are of a constant thickness; for this hypothesis to remain reasonable, the difference between the slope of the upper surface of the protective layers and that of the geosynthetic complex is limited to 2°, which corresponds to most of the structures in question.

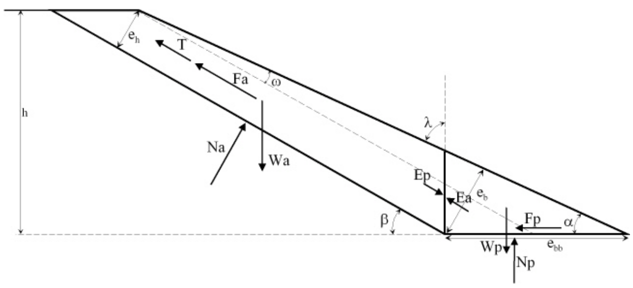

Figure 3 Protection of non-constant thickness

3 DIMENSIONS OF THE ANCHOR

In most cases, GST are anchored at the top of the slope by digging a trench into which the GST is fixed, thus taking up the stresses required for the liner system to be stable on the slope (Figure 4). Sometimes there is no trench and this structure is merely horizontal; in such cases, it is referred to as run-out anchorage.

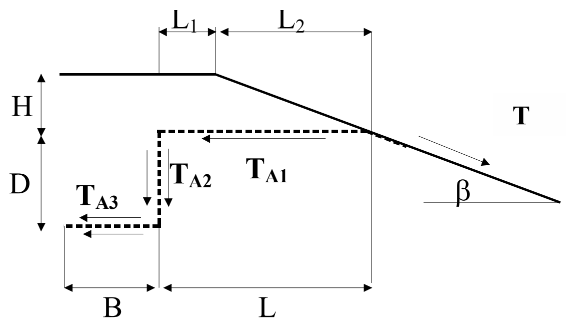

Figure 4 Anchorage at the top of slope

The method selected to determine the trench or run-out anchor capacity is that defined by BRIANCON (2003). We will mention only the outlines of the method here:

- anchor capacity T is equal to the sum of the friction forces that can be mobilised on the linear parts of the anchor system (Figure 4) and we thus have T= TA1+TA2+TA3 ;
- with safety in mind, the effect of any angles, which tend to increase the anchorage capacity, is not taken into account ; this choice was the result of a campaign of tests conducted at the Cemagref, which showed that the gain in anchorage capacity due to the effects of the angles is low;

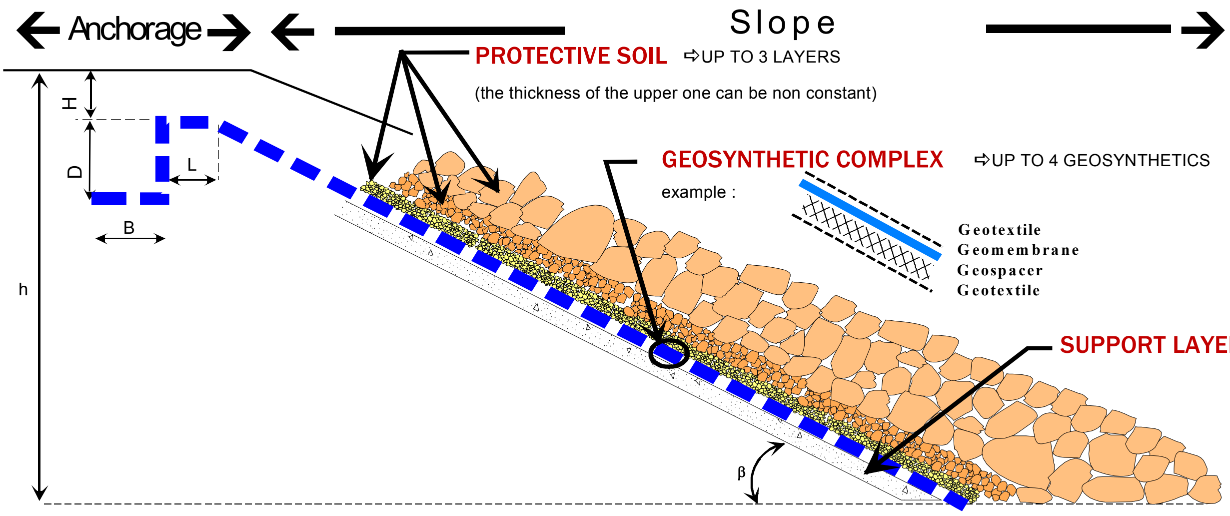

Figure 5 Possibilities of G-SCAP software

- when there is a trench, the value of the friction TA1 that can be mobilised along the horizontal length L is generally low compared with TA2 and TA3; however, even though length L has little influence on T, the designer will still have to opt for a great enough length to avoid the section between the slope and the trench breaking.

4 SOFTWARE PRESENTATION

On the basis of the calculation methods presented previously, a software programme G-SCAP (Geosynthetic Stability Calculation and Anchorage of Protective layers) has been developed to facilitate these simple but fastidious calculations, notably when there are several protective layers and complex hydraulic conditions. The possibilities of the 2 modules of this software are described below.

4.1 *Calculation of Stability on the Slope*

This first part of the calculation has the twofold aim of defining the factor of safety FS in relation to plane slippage in the absence of anchoring and of calculating, if FS is too low, the anchoring force required to achieve the desired safety factor.

In the current version, the safety factor FS applies only to the friction angles of the geosynthetic interfaces: the maximum shear stress is thus expressed as follows:

$\tau = \sigma'.\tan\delta / FS$

The calculation can deal with a large number of different configurations:

- a complex composed of 1 to 4 geosynthetics with the possibility of carrying out a calculation on the interface of your choice,
- from 1 to 3 protective layers, of which the upper one may be of non-constant thickness,
- the drainage, or not, of the interface concerned by the calculation and of the abutment,
- the partial or total saturation of the protective layers,
- the presence of a body of water, including in the case of a rapid drop in the water level.

Exceptional actions such as occasional excess load (machinery moving over the protective layer), surface load (snow…) or the presence of a groundwater surface under the geosynthetic complex can be taken into account.

If an anchor is required, the designer also has the option of defining the minimum breaking strength of the geosynthetic used for the anchor. To do so, the anchor force T is multiplied by 4 safety factors in accordance with the instructions in the "*guide technique : étanchéité par géomembranes des ouvrages pour les eaux de ruissellemnt routier*" (SETRA, 2000).

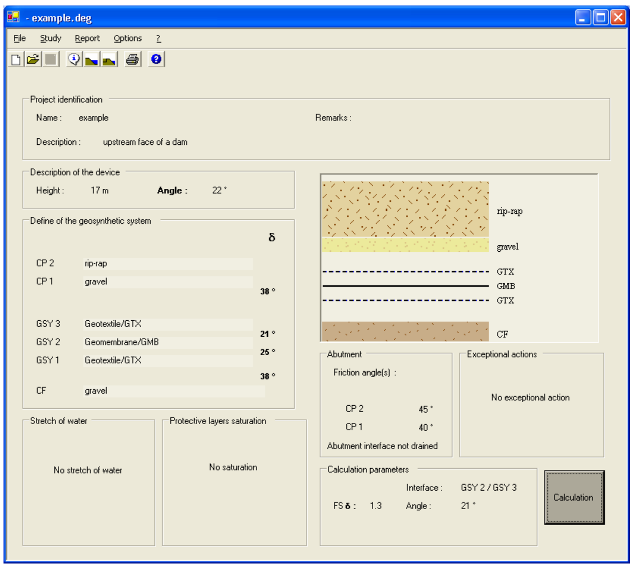

Figure 6 Data entry screen of the stability module

4.2 *Calculation of the Anchor Capacity*

Designers have two anchoring possibilities - either run-out anchorage or trench anchorage. As far as the materials covering the anchored GSY are concerned, it is possible to differentiate between that installed on the horizontal part (run-out anchor) and that used to fill the trench itself. To respond to the many situations encountered on different structures, the designer defines a distinct friction angle for each of the 2 sides of the anchored geosynthetic and for each of the parts of the trench. Figure 7 shows an example of the features of a data-entry screen.

This calculation model can be used to define the anchorage capacity corresponding to the force required to pull out the anchored GSY, applying a safety factor chosen by the designer to the friction at the interfaces.

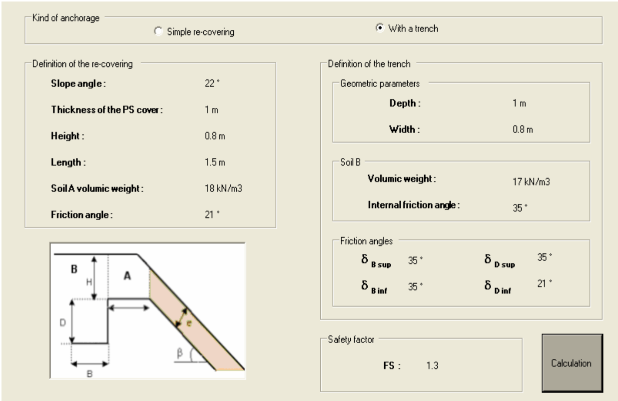

Figure 7 Part of the data entry screen of the anchorage module

4.3 *Example of a Calculation*

Let us consider, for example, a geomembrane liner system installed on the upstream face of a dam (figure 8), 17 m height with a slope of 22° and composed of the following components from the base layer upwards:

- a puncture-resistant geotextile (GTX1),
- a geomembrane (GMB),
- a puncture-resistant geotextile (GTX2),
- a layer of gravel of a thickness of 20 cm,
- a layer of rocks of variable thickness (1.40 m at the foot and 0.40 m at the top of the slope).

The stability calculation is performed with the following hypotheses:

- lowest friction angle of the geosynthetic complex: 21° (GMB/GTX2 interface)
- friction angle of the abutment: 45°
- unit weight of the protective layers:
  - 18 kN/m^3 (20 kN/m^3 if saturated) for the gravel
  - 20 kN/m^3 for the rock layer

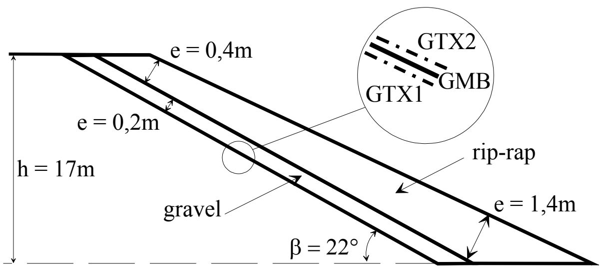

Figure 8 Example of a GLS with a protection of non-constant thickness

The safety factor FS calculated is 1.28 in "dry" conditions when the reservoir is empty. When it is full, this factor is higher (FS=1.61). However, in case of heavy rain saturating the gravel when the reservoir is empty and in the absence of drainage, in the present case, the safety factor drops to 1.09. A calculation in the same conditions shows that stability would not be assured without anchoring if the rock layer had a constant thickness of 0.9 m (and therefore the same total weight); in this case FS is 1.11 in dry condition and is about 1 with saturation of the gravel.

5 CONCLUSION

All the different studies we have conducted on the stability of geosynthetic systems on slopes have led to the elaboration of stability calculation methods that can take into account varied hydraulic conditions as well as a whole range of exceptional geometric forms and actions. All these results are grouped together in the G-SCAP calculation code which constitutes a practical, simple-to-use tool that can handle the stability of most of the geomembrane protection systems used on hydraulic structures and to cover landfills; the calculation can also serve to study the stability of other types of geosynthetic systems installed on slopes, notably anti-erosion protection.

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ACKNOWLEDGEMENTS

We should like to thank the CETMEF (Center of Maritime and River Technical Studies) and the producers Bidim Geosynthetics and Siplast Icopal for their participation to the previous research works.