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LANDSLIDING CONFORTATION WITH GEOTEXTILE REINFORCED EARTH WORK
BEHANDLUNG VON ERDRUTSCHUNGEN DURCH GEOTEXTILVERSTÄRKTE BAUWERKE
TRAITEMENT DE GLISSEMENTS DE TERRAIN PAR OUVRAGES RENFORCES PAR GEOTEXTILES

Landslide stabilization is one of the most embarrassing problems the geotechnical engineer has to solve, because of the geometry of the site, difficulty of access, the poor properties of the soils, and the need to devise a solution that will accept the strains induced by the unstable mass.

The construction of a geotextile-reinforced earth abutment may be an original and low-cost solution. The authors present:

- a design method making it possible to determine the forces exerted by the moving earth on the reinforced structure and to take them into account in the stability calculation;

- its application to an actual case.

INTRODUCTION

The stabilization of landslides, or even of slopes of doubtful stability, is one of the trickiest problems the geotechnical engineer has to solve. The variety of particular cases that may arise makes the general use of standard solutions impossible. However, quite often, when the site allows, the combination of an abutment and adequate drainage will be the most effective and least expensive approach.

A geotextile-reinforced abutment may turn out to be especially advantageous. In addition to the possibility of modifying the geometry of the abutment (making the downhill face vertical, for example), geotextiles allow for the use of soils having only average mechanical properties, so reducing the overall cost of the structure. In addition, their flexibility of use is a great advantage at the hard-to-reach sites typical of slide areas. Finally, once the work has been built, the geotextiles will enable the abutment to withstand any strains imposed by the unstable mass on the uphill side without damage.

1. DESIGN

The stability analysis of a geotextile-reinforced abutment calls for a number of design stages. After a first check of the suitability of the type of stabilization chosen to the type of landslide to be dealt with, it will be necessary:

- to study the stability of the slope and earthworks, taking into account both the real failure surface, extending into the earthwork along the layers of geotextile, and the potential failure surfaces uphill and downhill of the earthwork and within it;

- to study the stability of the abutment with respect to overturning, shear, or foundation bearing failures under the forces engendered by the unstable masses.

Depending on the type of failure, the level of safety to be required must take into account both the actual risk of failure, which depends on the degree of knowledge of the mechanical and hydraulic properties of the materials, and the precision of the design method.

* Thus, for the real failure surface, general practice is to start by checking, on the initial slip profile, that the parameters characterizing the site (shear strength, pore pressure) give a factor of safety FS = 1 on the soil shear strength in a back analysis of stability. Then, taking the type of stabilization chosen into account (here, the geotextile-reinforced earthwork), it must be determined that the gain in stability $\Delta F/F$ it contributes is significantly greater than the smallest value of $\Delta F/F$ that would forestall future damage. Generally, the desired increase in safety will be between 15 and 30 % in the case of earthworks.

* For potential failure surfaces, including those within the reinforced earthwork, the factor of safety on the shear strength of the soil is conventionally set at FS = 1.5.

The analysis of the surfaces intercepting the geotextiles will also require taking account of additional factors of safety on the soil-reinforcement friction and on the tensile strengths of the materials, in particular to allow for the risk of creep of the polymers (Delmas et al. [1]).

* For the "external" modes of failure of the earthwork, the regulations applying to retaining works [2] may be used for guidance, but the design methods must be adapted to the deformable character of the structure, especially in the evaluation of the vertical stresses at the base of the earthwork. It will however be noted that this last analysis requires an evaluation of the uphill forces exerted on the reinforced abutment.

While, below the real slip line, determining the forces exerted by the soil on the uphill side poses no special problem, and can be done by conventional active calculations, analysis of the forces engendered by the unstable mass is more delicate.

In the case of retaining works, Virollet et al. [3] have proposed an approach to the forces on the uphill face of the wall based on limit-state calculations. The authors show clearly that the forces exerted may be very large, and reach values close to or even greater than those yielded by a passive state calculation.

However, in the case of a conventional abutment earthwork made with a frictional material, these forces may be approximately determined by the stability analysis along the imaginary slip surface extending the existing surface into the earthwork. In this way, the horizontal reaction (RH) of the uphill soil mass on an imaginary vertical line of abscissa x can be plotted as a function of x (Cartier [4]) (figure 1).

$$RH(x) = \sum_{o}^{x} (N_i \sin \alpha_i - T_i \cos \alpha_i)$$

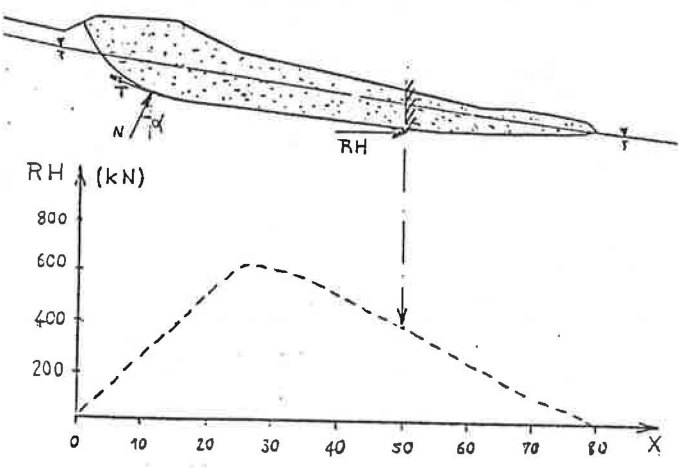

Fig.1. Evaluation of the horizontal force (RH) along a slip line, after Cartier [1]

In the case of geotextile-reinforced earth abutments, this second approach seems the more reasonable, since the work will act on the slide not as a rigid retaining work but rather as an earthwork capable of providing considerable shear strength.

2. EXAMPLE: LANDSLIDE AT LIXING, FRANCE

2.1. Description of the site

When a new lane was built near Sarreguemines, France, in 1977, the Lixing cutting, with a total height of 18 m, located at the foot of a natural hillside with a slope of 17°, suffered damage and had to be resloped to tan $\beta = 1/2$ during the course of the work, with a berm 6 m wide half-way up the hillside.

There was no further apparent damage until 1983, when a large landslide affecting both the cutting and the hillside above it occurred.

While water circulates in the calcareous marl formations of the Muschelkalk, with a dip of 30° toward the pavement, the hydrogeological survey failed to reveal the presence of a water table in the slope. So the causes of the damage must be sought in the combined effects of the relieving of the foot of the hillside by the cutting and of the slow evolution of the mechanical properties of the marly materials.

The geotechnical survey served to determine the nature and dip of the geological layers and the slip surface, which is plane and follows the base of a marly level resting on a fractured bed of limestone (figure 2). Investigation of the mechanical properties of the intact marly layers confirmed the local experience of these formations: an angle of internal friction $\varphi' = 20°$ and a cohesion ranging from 5 to 10 kPa depending on depth. A back analysis of stability along the fossil failure surface was used to determine the residual strength values of these materials ($C'_r = 0$ kPa, $\varphi'_r = 20°$).

2.2. Design of stabilization work

The stability analysis revealed the main parameters of the instability, namely the modification of the geometry of the slope and the decline in the mechanical properties of the marls, given that the hydraulics of the site do not seem to have been a major factor in initiating the movements, except for the flows in the limestone beds.

It was therefore decided to stabilize the slope by strengthening it by an abutment at its foot. However, because of the geometry of the slide surface, skewed with respect to the slope, and the magnitude of the masses in movement, the placement of a facing at the foot of the slide called for the use of a very large volume of material.

To reduce the volume of borrow fill, the solution finally chosen uses an earth embankment divided into two parts:

- a downhill earthwork to ensure the stability of the foundation of the uphill earthwork and stabilize the downhill part of the slide;

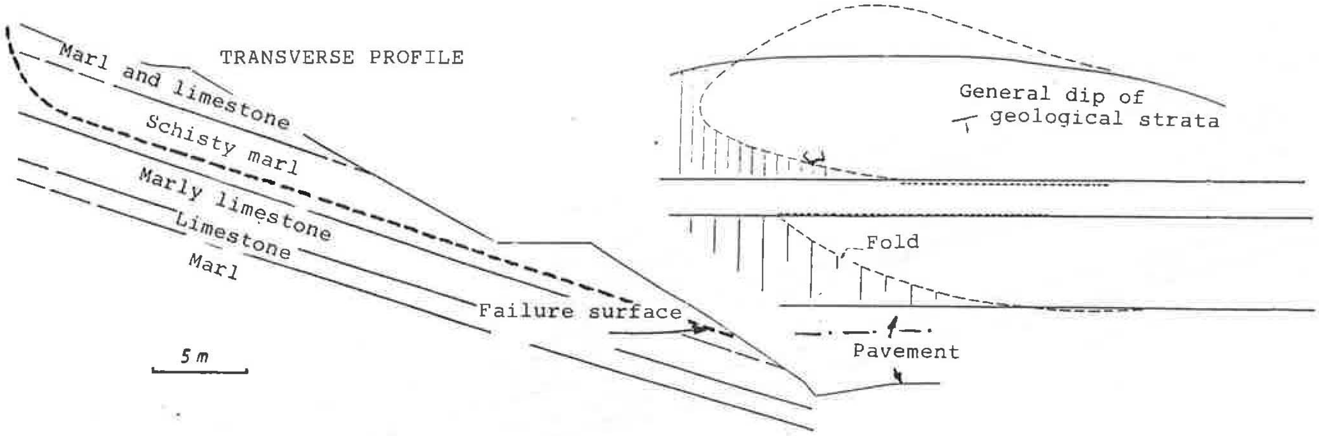

Fig. 2. Transverse profile and plan view of the landslide site at Lixing, France

- an uphill earthwork to stabilize the slide on the uphill side.

Geotextile reinforcement was chosen primarily as a way of making the most efficient use of the volume of fill, with a vertical face on the downhill side, and of holding its cost to a minimum by using the sand (Vosgian sandstone) available from a nearby quarry, which has only average mechanical properties (c' = 0 kPa and φ' = 35 to 95 % of the normal Proctor optimum, or γ_d = 17 kN/m^3).

The stability analysis and design work followed the methodology described earlier:

. Stabilization of slide:

The stability calculation along the failure surface (1) (figure 3) makes it possible to determine the width of the uphill abutment once the soil-geotextile coefficient of friction and the gain in safety $\Delta F/F$ have been set. In the case dealt with here, for a friction value of tan φ_g = 2/3 tan φ' and $\Delta F/F$ = 20 %, the calculation gives a wall width of 5 m for a height of 4.5 m. The calculation also serves to evaluate the thrust on the abutment resulting from the slide, RH = 90 kN/m.

. "External" stability of the uphill earthwork:

The stability of the earthwork with respect to overturning, foundation bearing, and shear failures under the loads calculated above was analyzed and the forces transmitted to the subsoil by this uphill abutment were evaluated.

. Stability of downhill earthwork:

The downhill abutment was then designed so as to ensure the stability of the slope, in particular with respect to the actions of the uphill abutment. This ensures a factor of safety FS = 1.5 with respect to failure along surfaces (2) and (3), provided that a downhill abutment 3 m high is built.

. Internal design of earthworks:

The internal design of the earthworks took the soil placement conditions (layer thickness a submultiple of the spacing of the layers of geotextile, Δh = 0.75 m) into account in determining the main characteristic parameters of the geotextile required to ensure the stability of the various potential failure surfaces and to satisfy the criterion of admissible strain of the structure. Calculation by the displacement method (Delmas et al. [1]), to ensure a displacement of less than 0.025 m along any potential failure surface, gives the following characteristics for the geotextile:

Modulus K = 500 kN/m; T_R > 100 kN/m

2.3. Execution of work and surveillance of the structure

The work was done in a two-month period, from October to December 1984. The uphill earthwork, the total length of which is 80 m, was built in two parts to ensure optimum stability during the execution of the work. A special procedure was developed for joining these two parts.

It will also be noted that the structure was given a reasonably attractive appearance through the combined use of the formwork and the facing, patented by the Laboratoires des Ponts et Chaussées (figures 4 and 5).

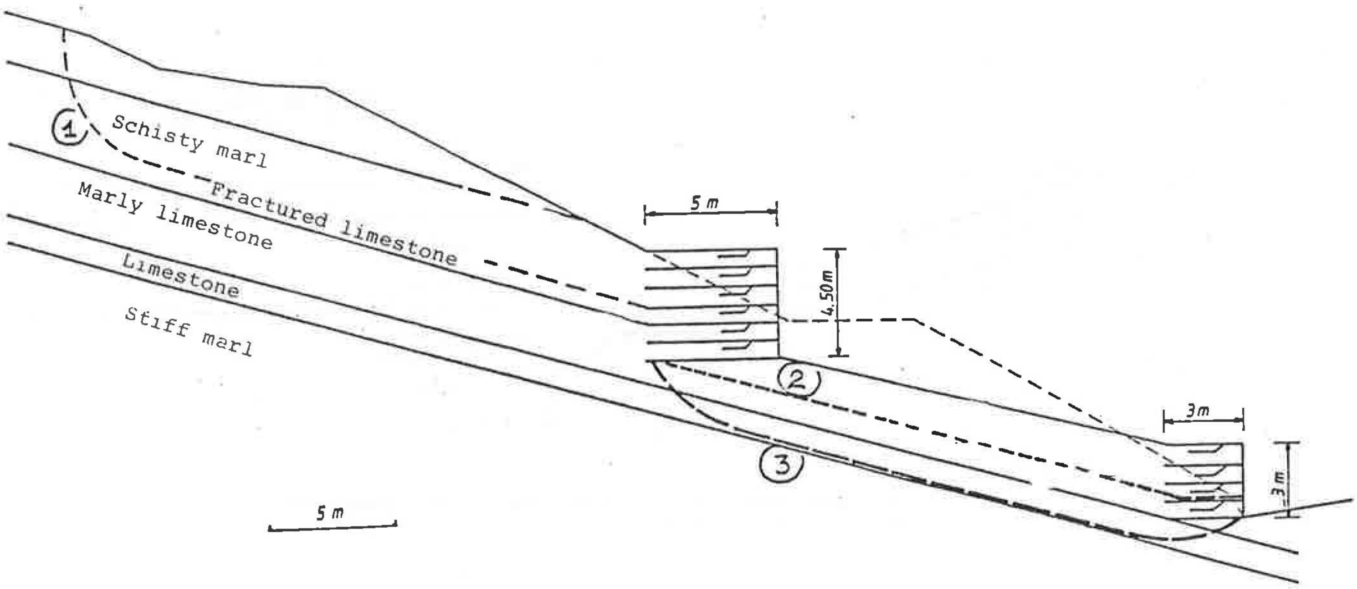

Fig. 3. Transverse profile of proposed solution and slide surfaces analyzed in the stability calculation

Fig. 4. General view of site after stabilization

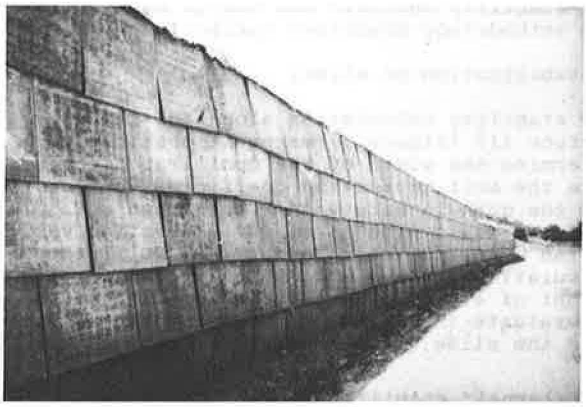

Fig. 5. Partial view of wall

The measurements made on the structures, using strain gauges glued to the layers of geotextile and inclinometers, are presented in table I; they confirm the design predictions.

After 12 months, the localized variation in strain is not more than 0.3 %.

Table 1

Strain of geotextile		
UPHILL WALL		
layer no.* / Distance from face	2	4
1 m	2.6 %	2.0 %
2 m	1.3 %	2.5 %
3 m	0.85 %	0.94 %
4 m	0.55 %	0.82 %

* The layers are numbered from the bottom up.

Inclinometric measurements over 12 months	
UPHILL WALL	DOWNHILL WALL
Movement less than 1 mm	Movement less than 1 mm

CONCLUSION

Reinforcing the abutment used to stabilize the landslide at Lixing, France, with geotextiles not only made it possible to employ an innovative approach, but also, most important of all, yielded a substantial cost saving by allowing for the use of an inexpensive fill material and optimizing the use made of that material.

The latest developments in design methods (in the displacement method, in particular) made it possible to take the specific character of the behaviour of the geotextiles in the earth abutments into account in the design.

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