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THE GEOTEXTILE SOLUTION IN THE STUDY AND THE FINAL EVALUATION OF A RETAINING STRUCTURE PROJECT

DIE LÖSUNG GEOTEXTIL IN DER BEARBEITUNG UND DER BILANZ DES PROJEKTES EINER STÜTZKONSTRUKTION

LA SOLUTION GEOTEXTILE DANS L'ETUDE ET LE BILAN D'UN PROJET DE SOUTENEMENT

When studying a retaining structure, the incidences of a judicious choice, technically as well as economically, are particularly important. The geotextile solution, recently developed, offers new possibilities to the designer. At first, the results of an analysis of well-tried solutions are presented for two practical examples where the retaining structure is in particular linked with stability problems. The geotextile solution is then analysed for these same examples. The problems of mechanical stability, geometry, adaptation to the environment, durability and construction are treated. Finally, a technical and economical comparison between well-tried solutions and the geotextile solution leads to an overall and critical evaluation.

1. FOREWORD

Civil engineering structures, and more particularly those incurring risks involving the safety of persons and property such as retaining structures, require thorough technical studies which provide several solutions to the same problem. The choice of one or other of the solutions offered is directly related to the economic conditions connected with the project. The adoption of one solution rather than another is therefore made by striking a balance between technical and economic factors.

On the basis of two retaining structure projects, the authors propose to examine and compare a solution having recourse to geotextiles, and more traditional solutions such as anchored walls and Reinforced Earth. The first case considered is a retaining structure of limited dimensions but which, by reason of environmental constraints and conditions of access, seemed to lend itself to the use of geotextiles. The second case is more general in respect of its geometrical configuration and allows to consider several scenarios integrating the external stability of the structure. For traditional solutions, structural design calculations are based on models in common use. In the case of geotextile solutions, the authors apply the approach advocated by the University of Grenoble [1].

The various evaluations of the cost of the work are made in the Swiss context. The reports on both studies are presented in such a way as to draw attention to the sensitive points of these two projects, in particular their facility of implementation and their long-term behaviour.

2. CASE A : EROSION GULLY AND UNSTABLE SLOPE

2.1. General situation

In a steep, wooded slope dominating a molassic cliff and topped by an embankment carrying a main railroad of the Swiss Federal Railways (CFF), a deep, narrow erosion gully formed in the course of time in the moraine and the underlying interglacial gravel constituting the slope. This erosion was attributed to the free flow of water from the overflow of a main-sewer emerging from the toe of the CFF embankment. By regressive action, the toe of the embankment was grooved, endangering the stability of the entire CFF slope and consequently of the railroad itself (figs 1a and 1b).

Analysis of the topographic, geological, hydrogeological and geotechnical conditions led to the study of three corrective solutions.

2.2. Corrective solutions

The **first solution** (fig. 2a) consists of erecting, half-way up the slope, in the narrow part of the erosion gully, a reinforced concrete wall, 6.5 m by 6.5 m, set into the stable soil and held by 4 prestressed tie-rods 12 to 15 m long sealed into the interglacial gravel. To prevent excessive deformation of the wall under the prestressing forces and at the same time to ensure drainage at its rear, the wall leans on a porous concrete mass. In the direction of the railroad, the remainder of the gully is backfilled at an angle of 33°.

The **second solution** (fig. 2b) comprises the construction in the lower, wider part of the gully of a Reinforced Earth wall. For topographic reasons, this retaining structure consists of 4 tiers of total height 7.40 m. Their lenght varies from 7.7 m to 13.0 m. The reinforcing strips, slightly inclined at the base of the first tier in order to limit the excavations, are between 4.0 m and 4.5 m long. Because of difficulties of access to the site and of the capricious topography of the gully, steel facing units rather than concrete panels were chosen. Since this retaining structure, close to the rock cliff, rests on talus, its stability is insured by a small reinforced concrete wall set into the sound rock. In the direction of the CFF tracks, the rest of the gully is backfilled at an angle of 36°. Because of the nature of the fill material, the Reinforced Earth mass does not include a drainage system. However seepage water is collected along the entire gully.

The **third solution** (fig. 2c) consists of erecting, in the place of Reinforced Earth, a mass reinforced by geotextiles. The other characteristics of the project remain the same. The retaining structure studied, in the shape of a parallelogram, is 7.0 m high and 3.7 m wide. The front face is inclined at an angle of 58°. The length of the structure is the same as that of the Reinforced Earth. Granular material was chosen to consitute the mass reinforced by geotextiles, so that no peripheral drainage of the mass is required.

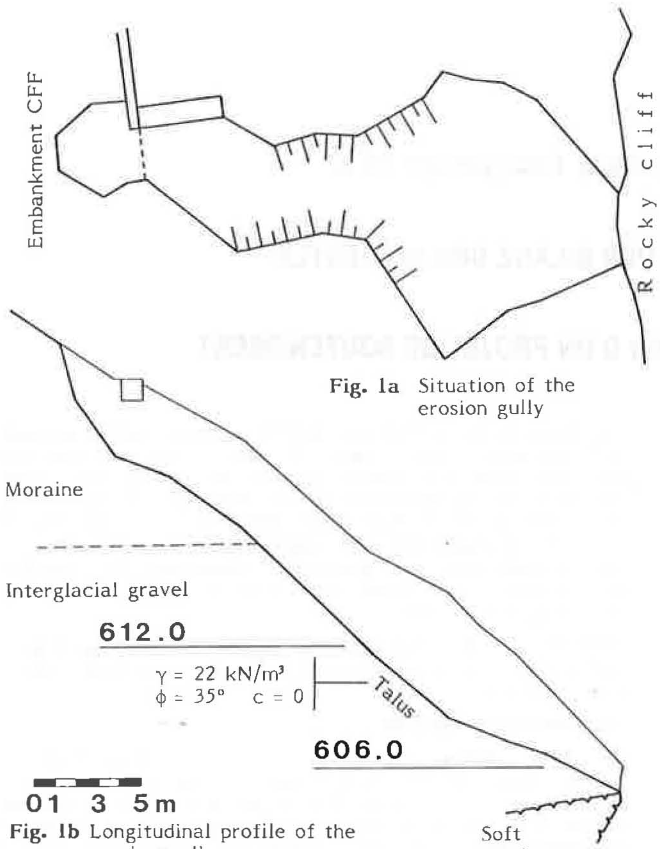


Fig. 1a Situation of the erosion gully

Fig. 1b Longitudinal profile of the erosion gully

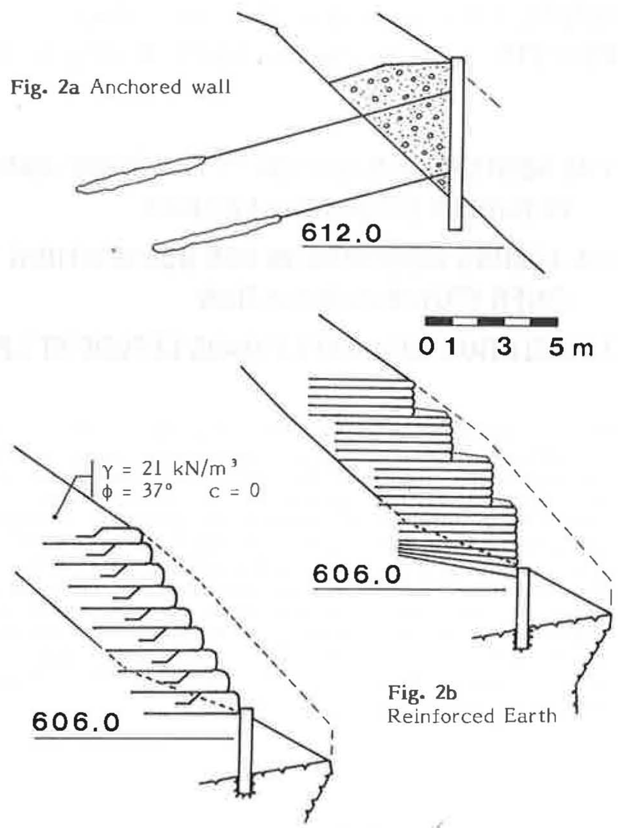


Fig. 2a Anchored wall

Fig. 2b Reinforced Earth

Fig. 2c Mass reinforced by geotextiles

2.3. Design

The design methods applied for the first two solutions will not be described. A conventional method of determining earth pressure was adopted for the **anchored wall.** The **Reinforced Earth** structure was designed in accordance with the specifications in force.

The so-called block method of calculation was used (1) for the design of the **mass reinforced by geotextiles,** for which a polyester product was selected, a safety factor of 5 being applied to its tensile strength. The following soil-geotextile parameters were applied : angle of friction 24°, cohesion zero.

The total tensile strength mobilized in the geotextile clothes, of which there are 9, corresponding to layer thicknesses of 0.60 to 0.80 m, was calculated to be 66 kN/m'. This relatively low value allows the mass to be reinforced with either a nonwoven or a woven geotextile. The safety factors against overturning and base sliding of the mass are respectively 13.3 and 1.5. The total length of geotextile required per metre of retaining structure, including anchoring lengths, is 61 m.

2.4. Technical evaluation

The three solutions studied have certain differences which should be pointed out.

The **anchored wall** must be sufficiently set into the soil to prevent its lateral faces becoming unprotected in the long term. This solution allows to fill only the upper part of the erosion gully. Though the interglacial gravel slopes are partly cemented, there is still a risk of long-term instability in the lower part of the gully.

The construction of the **Reinforced Earth** or of the **mass reinforced by geotextiles** needs little excavation and thus avoids a remolding of the stable soils. Both of these solutions make it possible to fill the gully completely, thereby eliminating the risk of long-term instability of its lateral slopes.

The durability of each of these retaining structures is linked mainly with that of their stabilizing elements, that is to say respectively the tie-rods, steel strips and woven or nonwoven geotextiles. The long-term behaviour of buried tie-rods and steel strips is the subject of specifications; this is not so for geotextiles at the present time. In the present state of our knowledge and in the light of ageing studies, it appears that under non-exceptional environmental conditions synthetic materials do not suffer deterioration such as to compromise significantly their initial characteristics. It should be noted that under permanent tensile stresses and under normal conditions of temperature, certain materials, in particular polypropylene, tend to creep. This phenomenon must be taken into account in terms of factors of safety. It is known that synthetic materials are sensitive to ultra-violet radiation. For this reason, the project comprises a protection of the facing of the structure by means of vegetation.

2.5. Economic evaluation

An estimation of the total cost of the three solutions, based on Swiss economic conditions at the end of 1985, gave the following results (rounded values) :

Anchored wall :	SFr	170'000.--	100 %
Reinforced Earth :	SFr	170'000.--	100 %
Mass reinforced with woven geotextiles :	SFr	140'000.--	82 %
Mass reinforced with nonwoven geotextiles :	SFr	135'000.--	80 %

In judging these costs, account must be taken more particularly of the difficulties of access to the working site, and the particular local topographic conditions which among other things require excavating and filling to be done by hand, and using only small and lightweight plants. It will be noted that the cost of the first two solutions is the same, although, depending it is true on site conditions, Reinforced Earth is often more economical than a so-called traditional solution. The geotextile solution leads to a saving of about 20 %, accounted for mainly by the cost of purchasing and implementing the geotextile.

3. CASE B : CORRECTION OF A ROADWAY

3.1. General situation

This case has been suggested by a project of correcting a cantonal road, requiring the construction of a retaining structure, in Switzerland. No overall comparative analysis is made as in case A; the study involves rather the comparison of solutions of the retaining structure in terms of a specific topographic, geological, hydrogeological and geotechnical profile, for different heights of the structure. This study thus allows to draw more general technical and economic conclusions.

On a natural slope inclined at an angle of 4°, it is planned to build an embankment to carry a road. For reasons of space, this embankment has to be limited and requires thus the construction of a retaining structure. Three heights have been studied : 3, 6 and 9 m. The subsoil of the site consists of a layer of compressible colluvial deposits 4.5 m thick resting on a rocky substratum of marl and soft sandstone (molasse), not very deformable (fig. 3).

The retaining structures were studied in function of one or two types of soil used as fill material (soil taken from a gravel pit 10 km far from the site (sandy gravel GW) and soil taken from nearby (clayey silt CL)). The geotechnical parameters of the soils when set in place were fixed at:

sandy gravel : $\gamma = 21$ kN/m^3
$\phi = 35°$, $c = 0$

clayey silt : $\gamma = 20$ kN/m^3
$\phi = 25°$, $c = 10$ kN/m^2

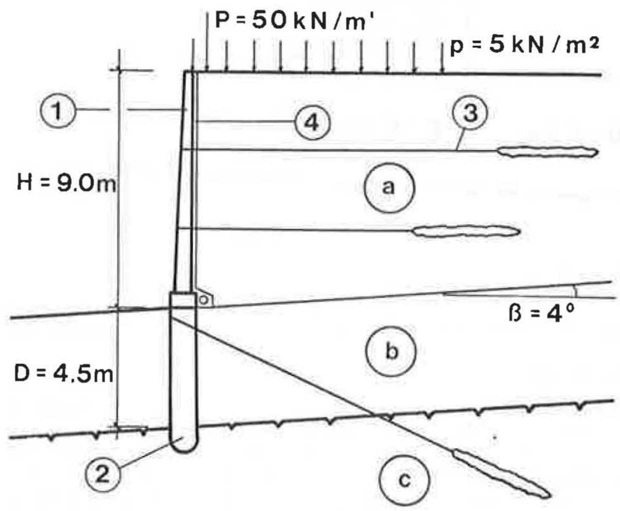
3.2. Solutions

Three types of retaining structure were studied and compared, namely a conventional structure, a Reinforced Earth mass, and a mass reinforced by geotextiles.

Among conventional solutions, the one chosen after comparison with other variants (counterfort wall, cantilever wall, etc.) was an **anchored wall.** By reason of the high deformability of the colluvial deposits, the structure has to rest on deep foundations, namely driven cast-in-place piles set into the rock (fig. 3). This solution was analysed for the two types of backfill mentioned above (GW, CL).

The second solution, **Reinforced Earth,** does not require the loads to be transmitted to the rock. Differential settlements of the structure (taking account of its variable height) are acceptable indeed for this type of structure (< 1/100) (fig. 4). To conform to Reinforced Earth specifications, only selected granular material was adopted for the reinforced mass. Because of the low permeability of the colluvial deposits, a drainage at the base of the mass is required.

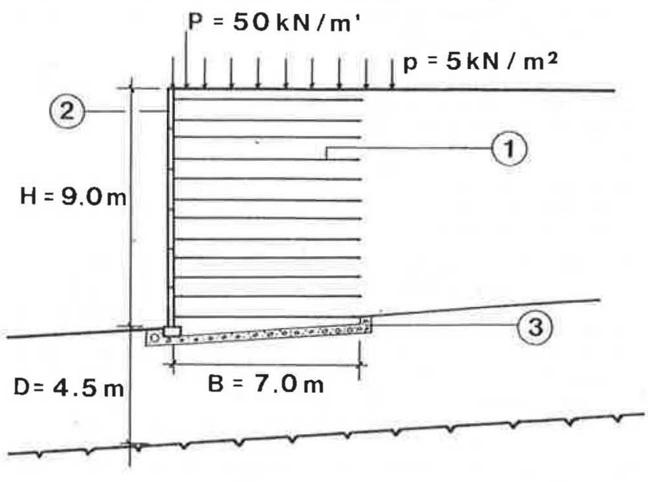
The third solution, a **mass reinforced by geotextiles,** by reason of its flexibility, does not require loads to be transmitted to the rock in the context of this project (fig. 5). To allow for the specific aptitudes of different geotextiles, the retaining structure was studied either as a sandy-gravel mass reinforced by a woven geotextile, or as a clayey-silt mass reinforced by a composite geotextile (a combination of woven and nonwoven). As in the case of the Reinforced Earth solution, the geotextile mass rests on a drainage blanket.



a backfill (GW, or CL stabilized with lime)
b colluvial deposits : $\gamma = 19$ kN/m^3, $\phi = 20°$, $c = 15$ kN/m^2
c soft sandstone and marl (molasse)

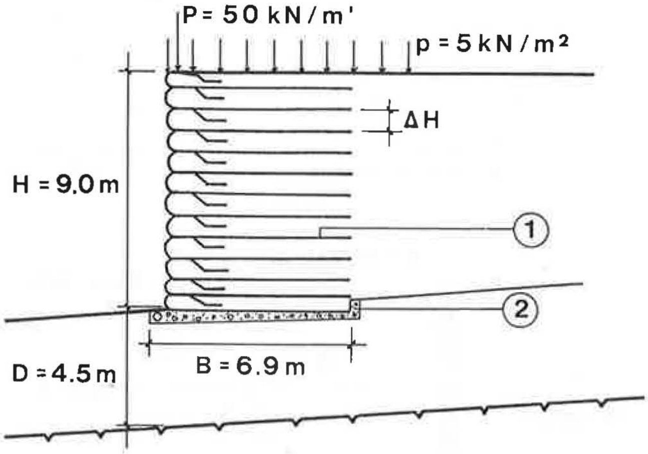
1 reinforced concrete wall, 20 to 60 cm thick
2 spaced piles : Ø 80 to 100 cm
3 tie-rod : L = 12 to 15 m
4 drainage

Fig. 3. First solution : anchored wall



1 steel strip
2 precast concrete panel
3 drainage blanket

Fig. 4. Second solution : Reinforced Earth



1 geotextile
2 drainage blanket

Fig. 5. Third solution : mass reinforced by geotextiles

3.3. Design

Anchored wall : as the anchored wall must be founded on piles, it had to be designed by introducing the earth pressure from the bedrock. Stresses were calculated by considering the relative deformation of soil and wall. The structure includes 1, 2 or 3 levels of anchors, depending on whether its height H is 3,6 or 9 m.

Reinforced Earth : the structure was designed in accordance with the specifications in force. The computed widths B of the mass are 3, 4 and 7 m for the heights H of 3, 6 an 9 m respectively.

Mass reinforced by geotextiles : the method developed by the University of Grenoble was applied for its design (1). The following soil-geotextile parameters were introduced into the calculation : friction 23°, cohesion zero (GW) and friction 17°, cohesion 6 kN/m² (CL). A factor of safety of 5 was applied to the tensile strength of the woven and nonwoven polyester geotextiles. The results of the computation are shown in Table 1.

Fig. 6 represents graphically the relationship between the height and the width of the reinforced mass for both types of fill and geotextile.

For all the cases studied, the external stability of the structure, determined by the "disturbance" method, is sufficient, the factor of safety against an overall sliding remaining greater than 1.40.

In addition, an analysis of the external stability of the mass 9 m high, reinforced by woven polyester geotextiles (fill material GW) was made, for identical geological an geotechnical conditions, but with a natural slope inclined at an angle of 18°. The factor of safety against an overall sliding then dropped from 1.43 to 1.15. The degree of external stability of the mass becomes insufficient for a permanent structure; it requires the construction of a structure designed to increase the safety of the colluvial deposits against sliding, for example an anchored pile wall placed at the toe of the reinforced mass.

Table 1 : Results of design of masses reinforced by geotextiles

H	Reinforced mass : GW + woven, tensile strength 215 kN/m'				
	B	ΔH	Total length of geotextile/ m' structure	Safety against overturning	Safety against sliding
m	m	m	m		
3	3.8	0.6 à 0.8	28	15.48	3.70
6	5.9	0.4 à 0.8	72	9.95	2.97
9	6.9	0.6 à 0.8	119	6.19	2.34
H	Reinforced mass : CL + composite, tensile strength 100 kN/m'				
	B	ΔH	Total length of geotextile/m' structure	Safety against overturning	Safety against sliding
m	m	m	m		
3	3.1	0.6 à 0.8	23	9.34	7.00
6	5.2	0.4 à 0.8	76	5.15	2.59
9	Unrealistic (too many layers)				

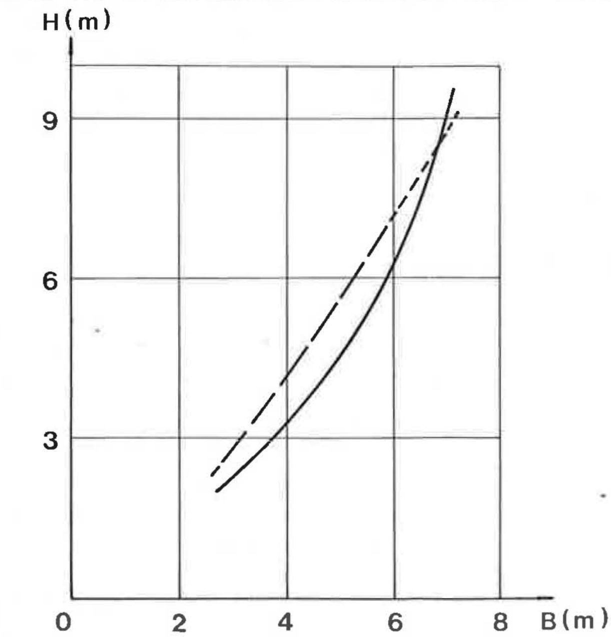


Fig. 6. Mass reinforced by geotextiles : width B related to height H

3.4. Technical evaluation

The **anchored wall** has the drawback of requiring, apart from the earthworks, three types of operation (piles, tie-rods, reinforced concrete wall). It is a rigid structure which supports only slight differential settlements. On the other hand, its backfill can consist of more or less good quality materials, provided adequate measures are taken to set them in place properly. Concreted in situ, such a wall matches without too much difficulty when the longitudinal profile is irregular.It is aesthetically acceptable.

The **Reinforced Earth**, relatively flexible, adapts well to differential settlements, provided they are not excessive. It requires no formwork. The friction to be mobilized at the interface soil - steel strip requires fill material meeting specific criteria. Aesthetically, precast concrete panels are as satisfactory, if no more so than uniform walls.

The **mass reinforced by geotextiles,** which is highly deformable, can withstand considerable differential settlements. Geotextiles are lightweight and easy to lay; they need however the help of a frontal mobile formwork. By reason of its transmissivity, a composite geotextile (a combination of woven and nonwoven), unlike a woven geotextile, contributes to consolidate fill material of mediocre quality. On the other hand, because of its somewhat lesser tensile strength, its application is unrealistic for high retaining structures (too many layers are required). Masses reinforced by geotextiles without a protective facing (vegetation, for example, which is however not suitable in the case of a vertical facing) are not of very attractive appearance.

The Reinforced Earth and geotextile solutions require, apart from earthworks, only one type of operation (erection of the retaining structure). This advantage means that the work does not last so long as in the case of a conventional structure. But these solutions do not always suit easily to an irregular longitudinal profile.

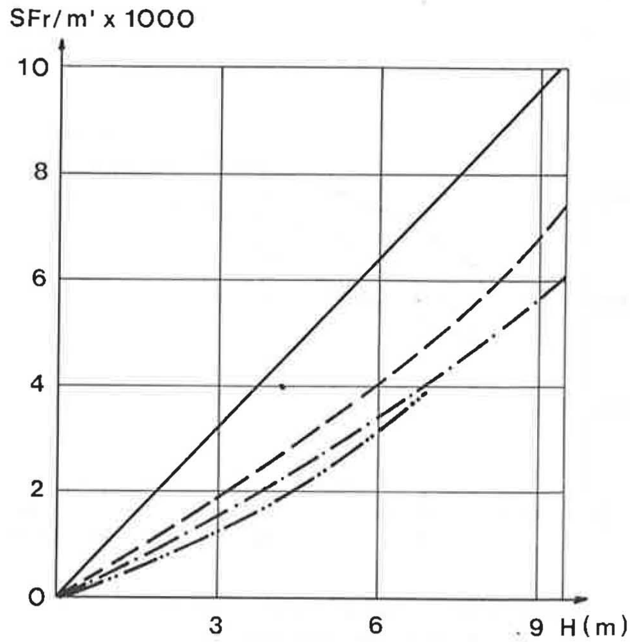
With regard to the durability of the three types of retaining structure, see par. 2.4.

3.5. Economic evaluation

In order to keep to general terms, the estimated cost of the three types of retaining structure was established without including general on-site installations. Furthermore, in order to differentiate these costs more clearly, the volume of fill included in the estimate was, for each height of structure, confined to that of the largest reinforced mass. The costs thus established are derived from a detailed study and are based on prices prevailing in Switzerland at the end of 1985.

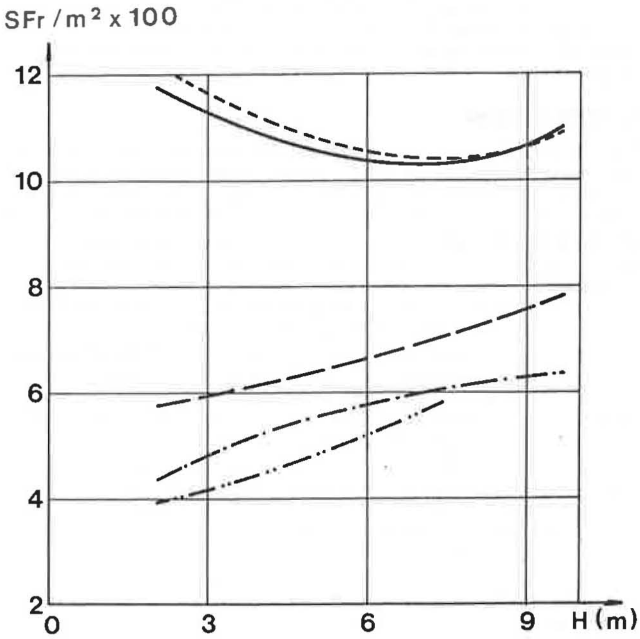
The result of these calculations is shown in graphic form, in each case in function of the height of the retaining structure. Fig. 7 shows the cost per linear metre of each type of structure. Fig. 8 gives the cost per square metre. It should be noted that the cost per linear metre of the anchored wall has been related to the height H, and not the height H + D (fig. 3) in order to deduce its cost per square metre. Fig. 9 shows at last the percentage of the cost of the Reinforced Earth and geotextile solutions related to that of the anchored wall.

From the economic point of view, it can be noted straightway that the reinforced soil solutions are more attractive than the conventional solution. The cost per metre of the anchored wall increases linearly with the height of the structure, whereas the cost of the reinforced soils obeys a somewhat different law. The evolution of the cost per square metre of the retaining structure in function of its height differs according to the type of structure. Taking the conditions of the project into account, fig. 9 shows the savings of the reinforced soil solutions over the conventional solution. The mass reinforced by geotextiles is about 10 % to 15 % cheaper than Reinforced Earth.



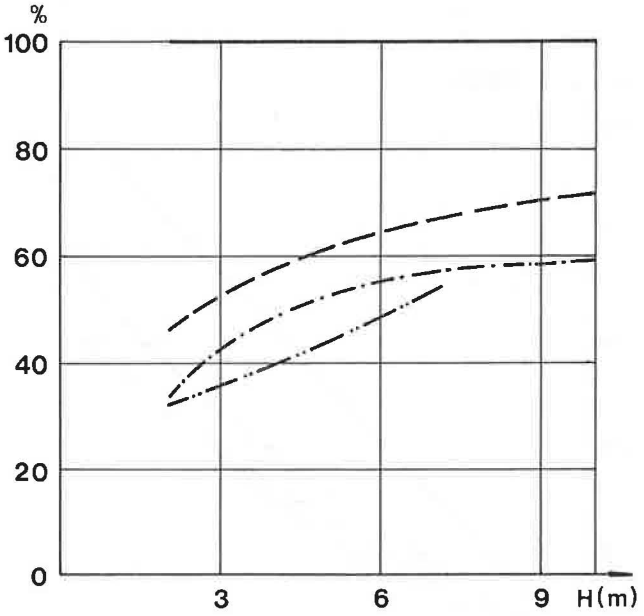
Anchored wall, backfill GW or CL ———
Reinforced Earth — — —
Mass reinforced by geotextiles :
—·— woven —··— composite

Fig. 7. Cost of retaining structures per linear metre



Anchored wall : ——— backfill GW - - - backfill CL
Reinforced Earth : — — —
Mass reinforced by geotextiles :
—·— woven —··— composite

Fig. 8. Cost of retaining structures per square metre



Anchored wall : ——— backfill GW or CL
Reinforced Earth : — — —
Mass reinforced by geotextiles :
—·— woven —··—composite

Fig. 9. Percentage cost of reinforced masses relative to anchored wall

It must be remembered however that the cost of the mass reinforced by geotextiles does not include the cost of a protective facing. This would mean that, on first analysis, a margin of about 10 % to 15 % remains to solve the problem of protecting the vertical facing of a mass reinforced by geotextiles.

4. CONCLUSION

The technical and economic evaluations of the retaining structure projects studied justify the confrontation of a mass reinforced by geotextiles and other solutions. By reason of its considerable aptitude for deformations and its facility of implementation, such a structure is particularly worth while under difficult topographic and geotechnical conditions. Soils of somewhat mediocre quality are also convenient tò its construction, provided a composite geotextile (a combination of woven and nonwoven) is chosen, which contributes to consolidate the fill material. Under normal environmental conditions, the geotextile is a durable product. But its long-term behaviour depends on the characteristics of the raw material from which it is made. Certain polymers, in particular polypropylene, tend to creep; this phenomenon must be borne in mind in the design. The protection of the vertical facing, especially of a permanent structure, still requires a satisfactory solution. Although being not universal, the geotextile solution is economically attractive in comparison with more traditional solutions.

Reference

[1] J.P. Gourc, A. Ratel, Ph. Delmas :
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