Third International Conference on Geotextiles,
1986, Vienna, Austria

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THE USE OF THREE DIMENSIONAL GEOTEXTILE TO COMBAT RAINWATER EROSION

DIE ANWENDUNG EINES DREIDIMENSIONALEN GEOTEXTILS GEGEN REGENEROSION

FONCTIONNEMENT ET REGLES D'EMPLOI D'UN GEOTEXTILE TRIDIMENSIONNEL UTILISE POUR LA LUTTE CONTRE L'EROSION PLUVIALE

In order to combat rainwater erosion, a new kind of three-dimensional geotextile has been designed and put to the test on a wide variety of working sites in recent years. After describing this new geotextile, the authors analyse the way it works on the basis of results obtained in the laboratory on a scale model. Its stability with respect to plane sliding is studied. A description is then given of the principal applications both in France and abroad (Transgabonais railway) and the conclusions drawn from them. On the basis of these observations and of laboratory studies, the rules to be followed in order to ensure the efficacity of this product are set forth.

1. RAINWATER EROSION: ITS MANIFESTATION AND THE FACTORS INFLUENCING IT

Very broadly, it may be said that the phenomenon of rainwater erosion is engendered as soon as a first particle, detached from the rest of the soil by the combined action of the impact of raindrops and the dispersing property of water, is carried along in the flow of run-off water. From that moment on, the flow is concentrated; hence its volume and its rate at the point where the initial particle was located increases. This makes it easier for it to carry along the next particle, and so on.

Rainwater erosion is thus a phenomenon which, once initiated, continues and accelerates so long as the rainfall conditions which initiate it do not regress. If they do, the phenomenon can re-occur as soon as they are resumed.

This gives rise to different types of disorders which gradually develop from the small rivulet or rill (a few centimetres wide and deep) to the gully, (a few tens of centimetres wide and deep) and ultimately to veritable erosion ditches attaining several metres and which can seriously imperil the stability of slopes and subgrades.

So this is indeed a phenomenon which, in certain cases, poses difficult problems, whose magnitude should be assessed in the project stage in order that if necessary special arrangements may be made and put into effect when the work is carried out.

In order to tackle this estimation, it should be borne in mind that the importance of rainwater erosion in the case of a given project depends on three categories of factors (1).

The first category called the erosiveness of rainwater, characterizes its greater or lesser potential for detaching the initial particles of soil and thereby initiating the phenomenon of erosion. The erosiveness of rainwater depends of course on the energy which it is capable of releasing when it arrives on the ground; to a first approximation, this energy can be assessed on the basis of the accumulated duration of sequences of rainfall of intensities greater than given thresholds.

The second category of factors on which the importance of erosion depends concerns the intrinsic parameters of the soil which characterize its greater or lesser vulnerability to erosion under the action of rainwater of a given erosiveness. This property is called the erodability of the soil, and it involves:

* the parameters defining the nature of the soil: principally clay content and particle size distribution.

* the parameters defining its condition: cohesion, compactness, degree of saturation, permeability.

The third category of factors to be considered concerns factors relating to the modulation of the erosive action. This includes all the factors specific to the project, namely:

* topographical characteristics: gradient and height of the slopes, presence or absence of berms, etc.

* the rates at which vegetation can grow on newly constructed slopes.

* special constructional arrangements, other than those concerning the planting of grass, which may be made in order to combat erosion. In the order in which they are most commonly applied, these include:

- methodical compaction of the slope.

- systems for collecting and evacuating run-off water, such as impervious drainage ditches at the top of cutting slopes, amply dimensioned downpipes, etc.

- the placing on all or part of the slope of elements such as fascines, mulch, rubble, various geotextiles, etc. designed to break up the energy of the flow of water and to retain the particles of soil liable to be carried away.

The three-dimensional geotextile ARMATER falls into this last-named category of constructional arrangements and may be considered as the industrial version of fascining, which up to the present has been performed in an artisanal method, involving considerable labour costs.

2. DESCRIPTION AND CHARACTERISTICS

The ARMATER three-dimensional geotextile is made from a needled nonwoven sheet of continuous polyester fibers partially impregnated with resin in order to give it slight rigidity, thereby facilitating its laying.

The characteristics of this nonwoven fabric are as follows (3):

- Nominal thickness : 2.4 mm
- Mass per unit surface: 350 g/m2
- Tensile strength (3):
  - machine direction : 25 KN/m
  - cross direction : 16 KN/m
- Tearing strength:
  - machine direction : 1.2 KN/m
- Permittivity : 0.7 s^{-1}
- Transmissivity : 1.36 x 10^{-6} m2/s
- Porometry : $O_f = D_{95} = 95\ \mu m$

To make this three-dimensional geotextile, the sheet of nonwoven fabric is cut into strips whose width is equal to the required height of the cells; then the strips are assembled along seams perpendicular to their length; the distance between two seams then determines the length of the side of the cell.

When the geotextile, produced in this way, is spread out on the ground, it looks like a honeycomb whose cells, appreciably hexagonal, are 10 cm high and 40 cm in diameter (in the case of the model most commonly produced).

The characteristics of the finished product are as follows:

- Packaging for transport: on 450 kg pallet comprising ten panels.

- Surface covered by one panel when unfurled: about 120 m2.

- Mass per unit surface of the unfurled sheet: 300 to 350 g/m2.

- Tensile strength of the seams: 10 KN/m (i.e. markedly less than the tensile strength of the basic product).

- Slow tearing strength of the seams (3): 0.21 KN.

- Dynamic tearing strength of the seams: 0.23 KN.

3. HOW THE SYSTEM WORKS

We do not yet fully know, in theory, how the ARMATER geotextile works once it has been laid on the slope to be protected. In particular, we are not at present able to design a product structurally (dimensions of the cells, strength of the sheet and its seams, etc.) meeting given conditions of slope gradient, rainwater erosiveness, nature of the underlying soil and fill-soil, etc.

However, observations made on slopes which have been treated for more than four years enable us to propose a qualitative analysis of how this geotextile acts, based on the fact that it simultaneously performs the three following functions:

* The dissipation of energy of the run-off water currents. The path of these currents, which follow the line of steepest gradient, is systematically deviated when they come into contact with the vertical side of a cell, and they are re-routed - losing speed in the process - along another direction, where inevitably they encounter another vertical cell side, and so on.

* Confinement of the material in the enclosures formed by the cells; this means that if erosion is initiated in the lower part of a cell, it can develop upwards only until it encounters the nearest vertical side upstream; thus gullying is confined to small cracks which are not propagated from one cell to another.

* Mechanical reinforcement, attributable to the tensile strength of the geotextile sheet which counteracts slipping of the fill material along the surface of the slope. This function makes it possible in particular to ensure the stability of a layer of topsoil on a slope of gradient up to 100% (whereas experience shows that in the absence of ARMATER such stability is not ensured on a gradient of more than 66%).

At the present time, laboratory research is in progress to specify the relative share of each of these three functions in the efficacity of the product.

4. LABORATORY STUDIES

In order to specify the way the ARMATER geotextile works quantitatively, a model was built (figure 1) simulating a slope whose

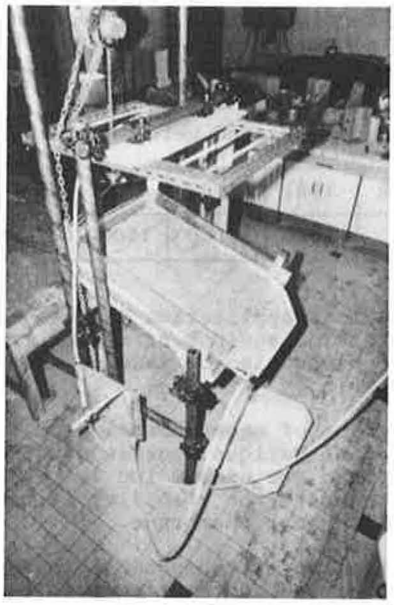

Figure 1 - Set-up used for studying the functioning of the three-dimensional geotextile.

gradient can be set as required, and in which a cell 10 cm high and with a 20 cm side, filled with different types of soil, can be placed. The whole can be subjected to artificial rainfall of selected intensities.

Few tests have been made so far. They have mainly consisted of quantifying the effect of the geotextile by comparing the carrying along of material, measured with and without geotextile, in the case of a very erodable uncompacted sand (D_{50} = 0.3 mm;
$Cu = \frac{D60}{D10} = 4$; % < 80 μm = 10%; ES = 36;
category RTR (2) B1/B2), resting on a mass of compacted clay; the comparisons were made for different gradients and different rainfall intensities. An example of the results is given in figure 2.

In this type of test we see that erosion, expressed in terms of the weight of material carried along, is not completely arrested by the presence of the geotextile, but that:

- on the one hand, in the case of medium to steep gradients (⩾50%), the three-dimensional geotextile prevents the layer of fill from slipping (figure 3), and this reflects its "mechanical reinforcement" function;

- furthermore, in all cases we observe a marked decrease in the weight of materials carried along corresponding to at least 50% of the figures obtained (all other things being equal) without the geotextile.

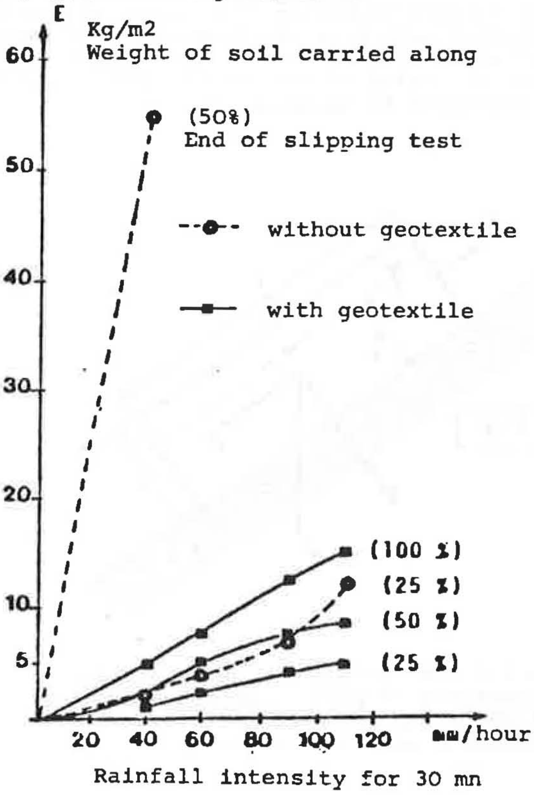

Figure 2 - Weight of soil carried along in function of rainfall intensity and gradient, for a B1/B2 sand (2).

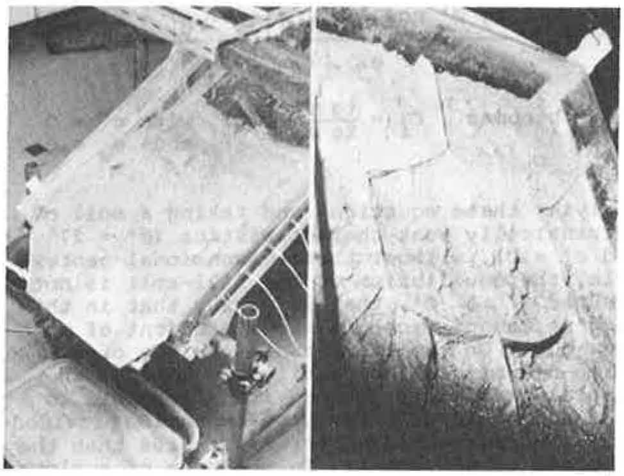

Figure 3a - Slipping of material without ARMATER, for a gradient of 1/1 (100%). Intensity 40 mm/h for 30 mn.

Figure 3b - The same test with ARMATER, gradient 1/1.

These observations led to a more precise examination of the contribution of the geotextile to the surface stability of slopes. A simple calculation made from the diagram of the analysis of plane slipping stability (figure 4) tells us that the value of the coefficient of safety F is expressed by equation (1).

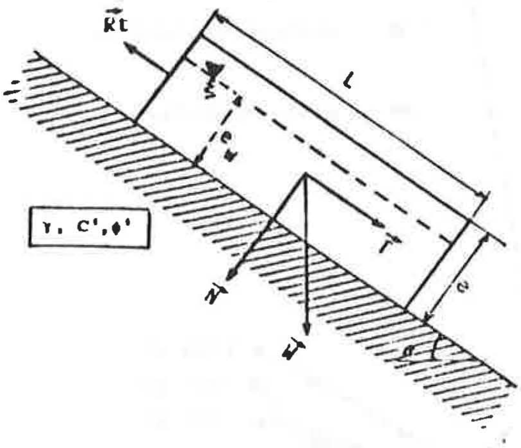

Figure 4 - Diagrammatic representation of the analysis of plane slipping stability. Equilibrium of an "element" of fill-soil of length L and thickness e.

$$F = F_i + \frac{Rt}{L.e.\ \gamma \sin\beta} \qquad (1)$$

in which Fi is the value of the coefficient of safety for a thickness e of fill-soil, and Rt is the force of retention due to the geotextile.

$$F_i = \frac{tg\ \emptyset' \cos\beta\,(e.\gamma - e_w \cdot\gamma_w) + c'}{e.\ .\ \sin} \qquad (2)$$

which becomes $F_i = \frac{tg\ \emptyset'}{tg\ \beta}$ (3) with $c' = 0$ and $e_w = 0$

Applying these equations and taking a soil of intrinsically weak characteristics ($\emptyset' = 27°$ and $c' = 0$), without three-dimensional geotextile, the equilibrium of the fill-soil is not ensured if $\beta \geq \emptyset'$, that is to say that in this case we cannot exceed a slope gradient of more than 50%. On the other hand, the use of the three-dimensional geotextile can improve the general stability, because it is possible to take advantage of a force of retention provided that the corresponding stress is less than the strength of the seams. In the case of a slope of 12 m from top to bottom and a fill-soil density of 1.80 T/m3, the general stability is ensured for a gradient steeper than the above; 67% instead of 50%, and this with Rt < 0.4 T/ml (strength of seams - 4 per linear metre). This system can therefore help to limit the overall slipping of the fill-soil.

5. PRINCIPAL APPLICATIONS

Since 1981, when it was first marketed, ARMATER geotextile has been used on many working sites, mainly in France but also in several other countries, including Italy, Australia and Japan.

The surfaces treated were as follows:

YEAR	1981	1982	1983	1984	1985
m2	1500	3000	16000	90000	200000

The principal application has been and still is the protection against rainwater erosion, but mention should also be made of the following other uses:

* protection of geomembranes used in the construction of various storage dams, whose slope gradients do not exceed 100 %; the geotextile helps to ensure the stability of the material protecting the geomembrane.

* construction of submersible foundation rafts; the role of the geotextile is to constitute a flexible container which is filled with pebbles like a traditional crib.

* the construction of a slab made of concrete blocks; the role of the geotextile is to constitute a sacrifice formwork in which the concrete is poured.

Where protection against erosion is concerned, the most noteworthy applications, in the sense of those which have contributed most to a knowledge of how the product works and what its limitations are, are shown in Table 1.

The observations made on these working sites and the initial results of laboratory studies making it possible to lay down the rules for laying which must be conformed to in order to guarantee the efficacity of the system are set forth in the conclusion.

6 - CONCLUSIONS: RULES FOR LAYING

Rainwater erosion is a cause of damage to structures whose technical and financial consequences are often underestimated at the planning stage of the project.

But there exist conditions of soil and climate in which it is practically certain that this phenomenon will assume considerable proportions, and hence the usual precautions (compaction of the slope, planting of grass, etc.) are not adequate. In these cases, the engineer must make provision for specific arrangements (fascining, rubble facing, etc.).

Table 1 - Different applications of the three-dimensional geotextile

Location of working site Year - Surface treated	Nature of the problems arising	Observations and Conclusions
Mireval (Hérault) France Departmental road embankment 1980 - 200 m²	Repair of an eroded embankment slope 5 m high, gradient 100% Initial study of the laying and behaviour of a honeycombed geotextile with square cells, assembled by stitching, used as an industrial fascining process to combat erosion.	Excellent efficacity of the honeycombed geotextile used to ensure the stability of the topsoil on a 100% gradient. Ease of laying and filling of the honeycombed geotextile. High values of tensile and tearing stresses at the joins between the cells, justifying stitching; but this is costly.
Narbonne (Aude) France Embankment of Autoroute A9 (4) 1980 - 600 m²	Repair of a very eroded motorway embankment slope: height 8m, gradient 66%, on which it was not possible to plant vegetation (Mediterranean climate). Initial study of the use of a honeycombed geotextile with hexagonal cells, assembled by high frequency welding. Experimental investigation of the influence of the size of the cells on the efficacity of the procedure.	Confirmation of the efficacity of the honeycombed geotextile with hexagonal cells assembled by high frequency welding. Confirmation of ease of laying and filling of the honeycombed geotextile. Reduction of tensile and tearing stresses at the joins between the cells in the case of hexagonal cells. Satisfactory behaviour of high frequency welds. Selection of the dimensions of 20 m cell side and 0.10 m height as values applicable to most working sites.
Libourne (Gironde) France Embankment on a Route Nationale. 1980 - 1,000 m²	Repair of a very eroded embankment slope, gradient 66%, height 12 m. Initial trial of three-dimensional geotextile with hexagonal cells, assembled by adhesion (instead of high frequency welding, which would have been too complex).	Confirmation of the efficacity of the product produced by adhesion, though the strength of the joins is slightly less than that of high frequency welds. Final definition of the ARMATER commercial product.
Transgabonais Railway (5) (Gabon) Africa 1981 - 1,200 m²	Repair of cutting and embankment slopes of variable gradients (between 50% and 100%) and considerable length of slope from top to bottom (> 20 m), in highly erodable soils and in an equatorial climate. Trial of the ARMATER geotextile under different condition of laying and filling. - on very eroded slopes, with or without reprofiling before laying the geotextile. - on slopes with concavities and convexities of large and small radii. - using different fill materials: cohesive soils, argillaceous gravel, ballast, etc.	A trial of major importance, because it made it possible to deduce the rules and limits of use of the ARMATER geotextile under the worst conditions of rainfall erosiveness and soil erodability that could be encountered (these rules and limits are set forth in the conclusion of this communication).
Argelès (Pyrénées-Orientales) France Cutting on a Route Nationale 1982 - 1,200 m²	**Repair of a cutting slope, gradient 66%, height 15 to 20 m, very eroded.** Operational use of the ARMATER geotextile, applying the rules for laying derived from the Gabon trial.	**Confirmation of the validity of the rules for laying derived from the Gabon trial.** The ARMATER geotextile at this point became a recognized operational procedure for protection against rainfall erosion.
Lorient 1984 1,200 m² Orléans 1985 7,000 m² Perpignan 1985 9,000 m² etc.	Prevention of deterioration due to erosion (in the case of structures where the probability of gullying was high).	The first structures for which the application of ARMATER geotextile was planned at the design stage.

The application of the ARMATER three-dimensional geotextile, an industrial version of fascining, is a technique whose reliability is assured whatever the conditions of soil and climate, provided certain rules of laying are conformed to. The more advanced the stage of deterioration, the more important it is to conform to these rules.

These conditions are as follows:

(a) The essential condition is that the ARMATER be laid in such a way that it rests on the surface of the slope at all points. This means that:

- there must be no pre-existing gullies before the ARMATER is laid.

- there must be no shallow concavities.

To meet the first requirement, the ideal procedure is to programme the laying of the ARMATER at the time when new structures are built. When ARMATER is laid as a curative measure to repair a slope that is already eroded, the slope should first be prepared by filling in and carefully compacting pre-existing gullies before laying.

Where concavities are concerned, there is no point in covering slopes with concavities of a radius less than about 10 m. In any event, in the case of pre-existing filled-in gullies or deep concavities, it must be considered a matter of course to refill the cells a few months or a few years after being installed.

(b) The second condition is to cover the entire surface of the slope to be protected. If the sheet of ARMATER stops halfway down the slope it creates a privileged point for the initiation of erosion, which by regression will drain the cells from the bottom upwards. One may possibly cover only the upper part of a slope if it is divided into two by a berm; in this case, the whole of the upper part as far as the berm must be treated, and the lower part, especially if it has a lower gradient, can be left as it is.

(c) The conditions relating to the nature of the fill materials of the cells are relatively less restrictive; practically any material is suitable, in so far as the size of the largest elements does not exceed the height of the cells. In point of fact, the choice of material mainly depends on the final appearance which it is desired to give to the slope. However, on argillaceous slopes it is advisable to avoid filling with very permeable materials (clean sand or gravel) because of the risk of breakage of the joins. This was revealed in laboratory studies.

(d) The operation of filling the cells and finally smoothing the slope must be performed carefully and methodically. It should always be done from top to bottom, meticulously depositing small heaps of 0.2 to 0.5 m3 of material regularly, so as to facilitate the task of manual smoothing (if heaps more than 0.5 m high are deposited, there is a risk of breakage of the weaker joins).

(e) The compaction of the material in the cells is in principle not essential under ordinary circumstances; but it is clear that even a light compaction using suitable machinery (shovel bucket, slope compactor, etc.) contributes appreciably to the efficacity of the procedure. In particular, recourse should be had to compaction in cases where dependability is not totally guaranteed a priori (e.g. the repair of slopes that are already highly eroded, slopes with concavities, very steep slopes, etc.).

Lastly, if the climate and the fill material allows, it is always desirable to plant the slope with vegetation immediately after its treatment. Moreover it may be considered that a combination of ARMATER and the planting of grass constitutes the most suitable technique for achieving a grass-covered surface of the highest quality.

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