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Geotextile-reinforced retaining structures: A few instrumented examples

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ABSTRACT: Based on a few examples of instrumented real structures, this paper emphasizes the influence, on the behaviour of polymeric reinforced structures, of various parameters such as :

- the method of placement, of both the formwork and the facing ;
- the possible use of clayey soil ;

The conclusion to be drawn from these few instrumented examples is that the tensile forces, and in particular, their distribution in the structure, depend to a large extent on the conditions of placement, but also on the way structure is stressed.
In addition, on attempt should be made to optimize the mobilization of the forces by choising a type of form that allows pretensioning of the geotextile and holds deferred deformations of the structure to a minimum.

1 INTRODUCTION

The principle of retaining structures consisting of a reinforced soil mass has led to routine applications primarily through the work of la Terre Armée (TA). From this viewpoint, geotextile-reinforced structures may be compared to TA reinforced-earth structures. These two processes do have a number of points in common. But an analysis of their internal behaviour reveals differences.

The stiffness of the reinforcements, again calculated for one layer and a width of one metre, is between 25 and 100 times smaller in the case of geotextiles than in TA. This results in differences in behaviour, characterized by larger strains within the geotextile-reinforced structure for similar forces.

These findings explain why, in observations of geotextile-reinforced structures, an effort has been made to measure the strains of the reinforcements and of the soil. In the case of real structures, it is important to be able to make sure of a level of strain that is acceptable for the structure, whether locally, in the soil (to remain below the peak shear strength values), in the geotextile or at the contact surface, or more generally with respect to the superstructures or the facing.

It should also be noted that the design of all of the structures examined below assumes a maximum mobilizable strength in the tiers of geotextile that is less than 10 % of the ultimate tensile strength. This affords some protection against creep and means that there is no risk from damage to the geotextile during compaction.

In the course of specific tests carried out on various products placed between two layers of flint-bearing clay dumped from a height of 1.5 m and compacted to 95 % of the normal Proctor optimum in layers 30 cm thick, Perrier (1986) found that the compaction could decrease the maximum tensile strength of the geotextile by as much as 30 % , and alter its stiffness, either increasing or decreasing it.

Based on a few examples of instrumented real structures, we shall attempt in what follows to determine the influence on the behaviour of the structures of :

- the method of placement of the formwork and of the facing ;
- the use of clayey soil .

In practice, the stability of the structures with respect to the equilibrium of forces is ensured by the tensioning of the reinforcement sheets inside the soil mass. However, the overall behaviour of the structure will depend primarily on how the sheets of geotextile are tensioned and how the strains are induced. Indeed, for a given structure, overall static equilibrium can be ensured for different stress conditions in the geotextiles depending on how the strains occur in the soil mass.

Accordingly, placement will undeniably be a key stage in the generation of the forces in the reinforcement sheets. The few instrumented structures described here show, in effect, that in certain cases the final forces can be reached as soon as the construction of the structure is completed, independently of the of the subsequent loading conditions.

This is explained by the stiffness of the geotextiles, which means that rather large strains of the soil mass are required to generate the tensile forces that ensure stability. It follows that correct placement of the sheet is critical: no pleats, if possible manual tensioning before compaction of the fill, etc. However, the type of compaction and the way in which the fill is cased will in general be the two factors that determine the final strains in the soil mass. In addition, the facing, and its relative stiffness, will also be a factor to be taken into account in understanding the limit-state strains of the structure.

2 LA HOUPETTE EMBANKMENT

To carry out the widening of a road on an embankment 4 m high and 300 m long, it was decided to build a geotextile-reinforced structure consisting of a vertical part 1.4 m high reinforced by two layers of UCO 44614 topped by a bank having a batter of 3 in 2 (figure 1). For practical reasons, the contractor chose to build the lower part in forms placed all at once.

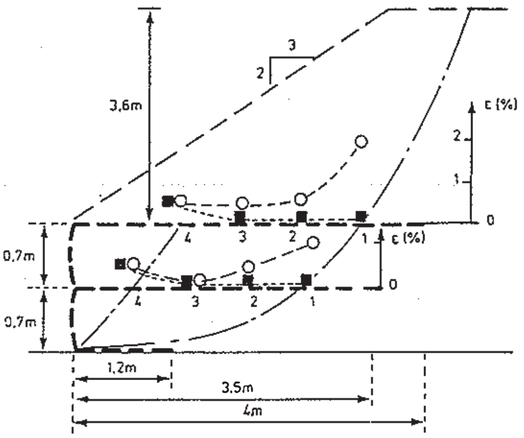

Figure 1: La Houpette embankement. Deformations of geotextile during construction: h = 1.4 m,
h = 4 m.

The fill is on aggregate having a continuous 0/250-mm grading and the following geotechnical properties :
γ_d = 22 kN/m^3 c' = 0 kPa
φ 35° to 40°.

This embankment was instrumented with cable-type strain measuring devices. Each measuring point consists of two cables attached to the geotextile 20 cm apart (in the direction of the stress), protected from the friction of the fill material by a sheath, that extend out through the front of the soil mass.

The deformations measured immediately after the removal of the forms from the two layers, before the upper embankment was built, and at the end of its construction, are given in figure 1.

It will be noted that, as regards the strains of the sheets, the form removal stage corresponds with a mobilization along a surface of maximum tension located near the facing, while the stage of embankment construction mobilizes the reinforcements farther back in the soil mass, so justifying the anchorage lengths determined in the preliminary design stage.

We point out that the final distribution of strains in the geotextiles in fact corresponds to the sum of the strains resulting from each of the two stages of constructions.

3 STRUCTURE ON A7 MOTORWAY (geotextile as reinforcement and geogrid on slope)

For the widening of the A7 motorway between Saint Rambert and La Galaure, an approach combining geotextile reinforcement with a prefabricated wall was chosen for the embankment portions. The structure consists of a soil mass reinforced by six layers of woven polypropylene geotextile (UC044615) together with a polypropylene-ethylene grid placed on the facing to retain the topsoil on the embankment slope, 50° from the horizontal. This structure, which has a mean height of allow piping to pass. The fill is a pea gravel having good mechanical properties : $c' = 0$ kPa, $\varphi' = 41°$, for a placement density $\gamma_d = 22.5$ kN/m^3.

The tensile characteristics (NF 38014) of the geotextiles used are: for the woven polypropylene (tPP) $\alpha_f = 72.1$ kN/m and $\varepsilon_f = 13$ % for the geogrid polypropylene-polyethylene (G PP PET), $\alpha_f = 9.1$ kN/m and $\varepsilon_f = 8$ %.
Figure 2 shows the strains measured on the sheets and the settlements of the sheets at the end of construction and six months later. It will be noted that the lack of ties between the geotextiles and the facing grid, together with the low coefficient of friction of the two products, results in a relative slippage of about 2 cm. The local decompaction at the facing leads to local settlements, together with a small local increase in the tensile forces near the end of the reinforcing sheet and a slight rotation of the upper retaining structure.

It may be concluded from this particular example that proper compaction of the structure, in particular of the facing, is the key to the proper behaviour of the structure, and that the "reinforcing" and "facing" geotextiles must be tied together to confine the soil and pretension the sheet.

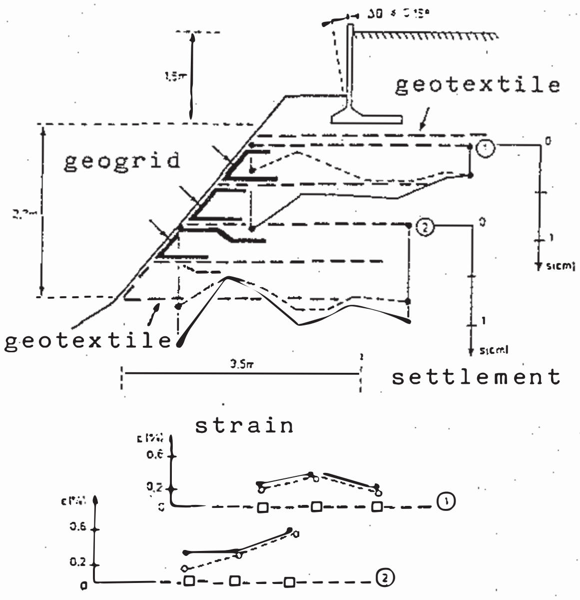

Figure 2: A 7 Motorway. Settlements (s) and strains of geotextile (ε) measured (○ end of construction 04-86; ● 6 months later 10-86).

New, we shall accordingly restrict ourselves to analyzing the deformations engendered by the process in which the form for each layer is placed directly above a fixed point and supported by a fixed reference, derived from the international patent held by the Laboratoires des Ponts et Chaussées (1985) and worked by the MUR EBAL company (FRANCE).

In this connection, we may mention the Langres structure.

4 LANGRES STRUCTURE

Where it goes round the ramparts of the town of Langres, national highway 19 is on the uphill side of a retaining wall 4 m high and includes a sharp bend with its convex side outwart. To correct the disorders of the existing wall, it was decided to build, under the cover of this structure, a geotextile-reinforced structure having its facing set back about 20 cm from the uphill facing of the existing structure, designed to take out thrust (Delmas et al., 1984).

The instrumentation implanted at the site included glued strain gauges 10 mm long capable of measuring strains up to 10 %. The gauges were bonded to the geotextile on a rubber cement that ensured a suitable surface condition. A laboratory calibration was carried out because we had little experience with gauges of this type and, in particular, this way of bonding them. This revealed, notably, that while in the short term the measured strain values were reliable up to 2 %, in the longer term the creep of the cement made adequate precision impossible.

In addition, the deformations of the facing were measured using inclinometer tubes set in PVC tubes placed on the outside of the facing and attached by straps anchored in the structure.

Figure 3 shows the strains measured in the sheets when the road was reopened. It can be seen that the measured strains do not exhibit the distribution normally expected in reinforcing structures, and in particular exhibit no maximum. Moreover, the measurements made immediately after the removal of the form from the layer corresponding to the sheet measured show that, at this stage, from 70 to 95 % of the final strains have been reached, with the balance appearing when the next layer is placed.

The structure was built using one form per layer, supported by the existing structure. Given the permanent character of this structure and the state of knowledge when it was built, the fill material chosen was a crushed limestone aggregate having a continuous 0/31.5-mm grading, placed at 95 % of the normal Proctor optimum, or $w = 5$ %; $\gamma_d = 20$ kN/m^3. The shear strength was estimated to be : $\varphi' = 45°$, $c' = 0$ kPa.
It would seem, in this particular case, that the placement of the fill soil, and especially its compaction, account for a large share of the final strains measured in the structure. This compaction resulted in a lateral deformation of the structure towards the wall in the layers from which the forms had already been removed. This deformation resulted in tensioning of the geotextile, which uniform strain along the sheets of reinforcement.

5 LUCHON STRUCTURE (Inflatable Formwork)

To restore access to the Hospice de France (the existing road was destroyed by a landslide), it was decided to build a new road on the opposite slope of the valley. For this work, a retaining structure 60 m long and 5 m high was built using a geotextile-reinforced soil mass. The patented construction process developed by the LPC, in conjunction with the facing of the EBAL construction company, was used to avoid disfiguring the site. The formwork bears against the facing during the placement of each layer, and can be removed thanks to a suitable inflation system, after the layer has been compacted (Delmas et al., 1986).

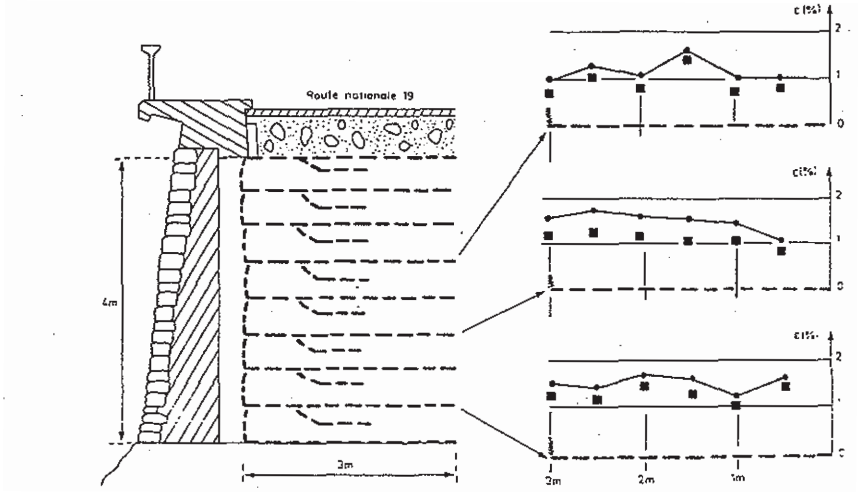

Figure 3: Langres structure. Strains of geotextile: ■ end of compaction of the soil layer just above the measured layer; • end of construction.

The fill consists of materials from the site - shales having a particle size range from 0 to 200 mm, with 70 % smaller than 20 mm. The geotechnical properties of the 0/5-mm fraction are as follows :

$c' = 10$ kPa

$\varphi' = 35°$

The compaction characteristics determined on the 0/20-mm fraction are :

$\gamma_{opn} = 18.7$ kN/m^3

$w_{opn} = 12.5$ %

The actual placement conditions were 7 % < w < 16 %, because of heavy rainfall at the site during construction ; compaction was carried out using a 50 kN vibratory roller. The structure was reinforced with a woven polyester multifilament (UCO 84464) having a tensile strength $\alpha_f = 217$ kN/m and a rigidity J = 800 kN/m. Soil-geotextile friction, as measured in the laboratory, was $\mathrm{tg}\,\varphi\mathrm{geo}/\mathrm{tg}\,\varphi' = 0.86$. The instrumentation included inductive and cable transducers to measure deformation of the geotextiles, horizontal inclinometers to measure settlement of the tiers, and levels to measure rotations of the formwork support facing. In addition, the total deformation of the geotextile facing with respect to the concrete facing was measured.

The main results of the deformation measurements are shown in figure 4. The most important point is the advantage of the type of formwork used to prestress the tiers of geotextile. 80 % of the final deformation is reached during compaction of the corresponding layer.

6 ROUEN EXPERIMENTAL RETAINING STRUCTURE (use of clayey soil)

In so far as it is not necessary to use dilatant soils in geotextile-reinforced structures, soils having a large fraction of fine materials can be used. If the soil used meets the usual specifications for fills, its use in a reinforced structure does not, a priori, pose any special problems if its mechanical properties are properly taken into account in the design and if the water content of the soil at placement is not likely to result in pore overpressures during subsequent loading.

The example of the experimental embankment at Rouen provides some additional information about the actual behaviour of reinforced fine soils having a high water content (Blivet et al., 1986). This experimental structure, 5.6 m high, was built with a silt having a water content of $w_{npo} + 5$ % and was reinforced with various types of geotextiles. Here we shall consider only two of them, on which pore pressure measurements were made : an Enka woven polyester and a needle-bonded nonwoven polyester in conjuction with a Rhône Poulenc grid.

The pressure sensor inside the embankment, outside the structures,

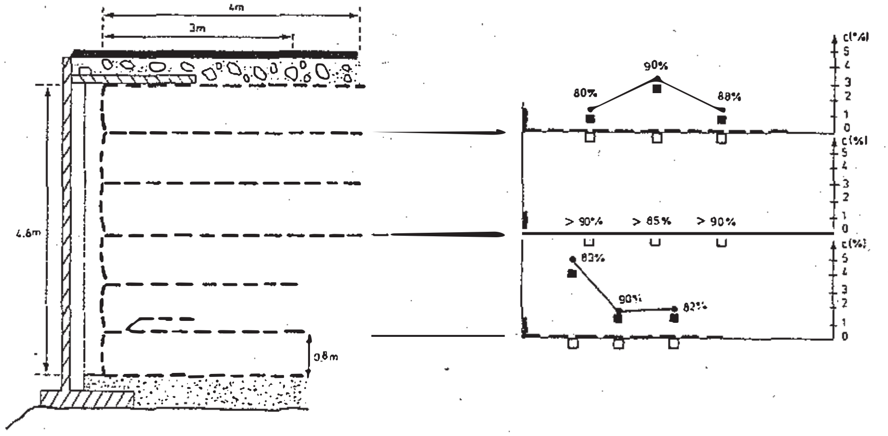

Figure 4: Luchon structure. Strains of geotextile: ■ end of compaction of the soil layer just above the measured layer (ε_1); • end of construction (ε_r) (80% = $\varepsilon_1 / \varepsilon_r$).

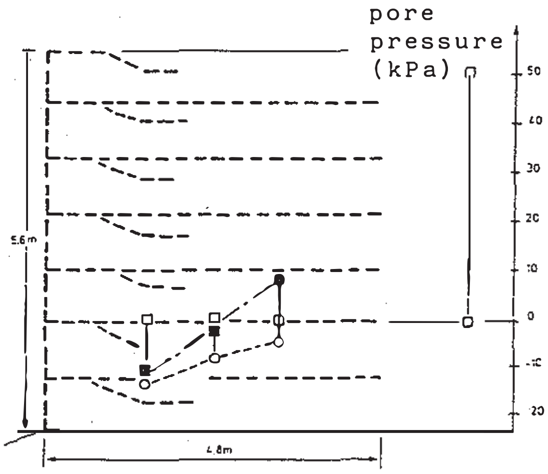

Figure 5: Rouen experimental wall. Pore pressure mesured 120 days after the end of construction: ○ in the needle punched nonwoven with grid, ■ in the woven.

reveals placement overpressures of as much as 50 kPa.

On the woven sheet, the pore pressures are positive at the back of the structure, then disappear and finally become negative near the facing.

One the composite geotextile, on the other hand, the pressures are negative over the whole length of the reinforcement (figure 5).

This difference in local behaviour can lead to large changes in overall stability : on a nearby test section reinforced with a woven polyester with its surface treated to be non-wetting, the soil mass turned over because of anchorage failure. An after-the-fact calculation revealed an effective angle of friction of 5°, as against a soil-geotextile angle of friction of 21° in a drained condition.

7 CONCLUSION

The conclusion to be drawn from these few instrumented examples is that the tensile forces, and in particular their distribution in the structure, depend to a large extent on the conditions of placement, but also on the way the structure is stressed.

In addition, an attempt should be made to optimize the mobilization of the forces by choosing a type of form that allows pretensioning of the geotextile and holds deferred deformations of the structure to a minimum.

This must be taken into account in designing these structures, and for this reason preference should be given to design methods in which the actual conditions of placement can be simulated and taken into account. In this connection, we may note the interesting approach made possible by the "displacements method" (Gourc et al., 1986) .

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