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MECHANICAL REINFORCEMENT OF LOW-VOLUME ROADS BY GEOTEXTILES

DIE ROLLE DER MECHANISCHEN EIGENSCHAFTEN DER GEOTEXTILIEN IN STRASSEN MIT SCHWACHEM VERKEHR

ETUDE DU ROLE MECANIQUE DES GEOTEXTILES DANS LES CHAUSSEES A FAIBLE TRAFIC

The use of geotextiles in order to reinforce low-volume unpaved roads is tempting. The CEMAGREF, which deals with the design of rural and forest roads, initiated a study on this topic. This included two steps : first a test in a 2m x 2m pit : the studied structure consisted of a natural gravel layer on a silt with poor mechanical characteristics. Various ways of placing the geotextile were investigated : at the in terface between gravel and silt, anchorage, use of two sheets. Three types of geotextiles were used : needle punched non-woven, heat bonded non-woven, woven. Numerous punching tests (with a rigid plate), with measurement of vertical stresses, were carried out in order to examine the influence of these parameters. Then tests with trucks were carried out on an experimental road with different sections using the same types of geotextiles as these tested in the pit.

INTRODUCTION

Geotextiles were first used in roads as separation elements : this part is now well established and represents the majority of applications of this type of material. However, it was tempting to try to make the best possible use of all the properties of geotextiles : research was then undertaken about their possible part as reinforcement elements. Although there was some dissension on this topic, positive results (1) (2) (3) (4) led the CEMAGREF to investigate it : many of the roads subsidized by the Department of Agriculture, farm and forest roads, are indeed unpaved ; moreover, they are often built on weak natural soils and the low volume traffic makes rather big deformations allowable ; these facts are favourable, because the previous studies showed that actual mechanical reinforcement by geotextiles is the most likely in these conditions.

LARGE SCALE TESTS IN A PIT

They were made in a 2 x 2 x 1,30 m (deep) (6,56 x 6,56 x 4,27 ft.) pit with an experimental device which is described in detail in another paper (5). This device makes it possible to carry out loading tests with a rigid plate (diameter 0,30 m - 0,98 ft.). So the test conditions are very similar to the field conditions (loading area, thickness, loads). The thank was filled with a silt (W_L = 34 %, I_P = 10 %) which has 95 % of particles less than 80μ and 22% less than 2μ : this soil is quite typical of the subgrade of rural roads. The aggregate used for the top layer was a well graded river gravel, with a maximum particle size of 30 mm (1,2 inch) and 3% of particles less than 80μ. The inplace water content was 5% and the inplace unit weight of dry soil γ_d was 18,7 kN/m3, which is about 93 % of maximum γ_d (standard Proctor).

In order to have a weak subgrade soil, the water content of the silt was about 24 %, which is the plasticity limit ; moreover, its inplace γ_d, 15,7 kN/m3, was low since it was only 87 % of maximum γ_d (standard Proctor).

Its bearing capacity was estimated with a small dynamic penetrometer ; a correlation was established between the driving in for a blow and the C.B.R. : the inplace CBR was about 0,9.

Three types of geotextiles were used, representing the main categories of these materials :

- a non-woven needle punched polyester (Bidim*)
- a non-woven heat bonded polypropylene (Typar**)
- a woven polypropylen (Propex***)

The main properties of these geotextiles are described in table 1 (the plane strain modulus has been obtained from tensile tests on large width samples 0,50 m x 0,10 m in the direction perpendicular to the tensile load (19,7 x 3,94 inch), for elongation values between 10 % and 20 %).

TABLE 1 - Properties of geotextiles tested

	Propex 6066	Typar 3807-4	Bidim U 64
mass per unit area (kg/m2)	0,525	0,28	0,56
thickness (mm)	1,8	0,7	4
tensile force per unit width at failure α_f(kN/m)	75	18	46
elongation at failure ε_f(%)	18	47	47
95 % opening size O_{95} (μm)	125	40	45
plane strain modulus K (kN/m)	480	35	80

For each geotextile, four kinds of soil-geotextile-aggregate structures were tested (fig. 1)

a - the geotextile is only laid between the silt and

(*) Rhone Poulenc Company
(**) Dupont Company
(***) Amoco Company

the aggregate (free edges)

b - the geotextile is anchored by stones

c - the geotextile is anchored by folding it inside the aggregate layer on about 0,50 m (19,7 inch)

d - two sheets of geotextile are laid, the first one at the interface silt-aggregate as for case a., the second one in the middle of the aggregate layer.

The aggregate thickness was 0,30 m (11,8 inch) for each test ; moreover, a control test was carried out with this same aggregate thickness, but without geotextile.

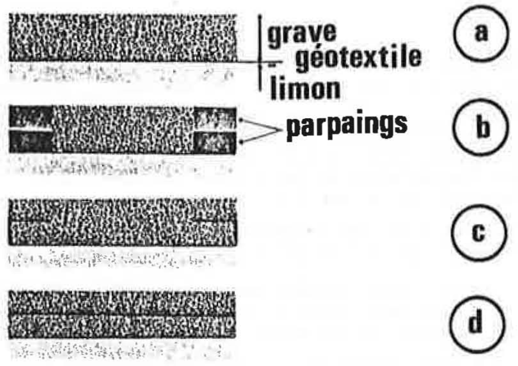

Fig. 1 : Types of soil-geotextile-aggregate structures (pit tests)

On a given structure, the test is made in three steps : a slow rate of load increase until a pressure of less than 0,1 MPa is reached in order to get only small displacements, then a few fast cyclic loadings with an invariable maximum pressure identical to the one of the first loading, finally the true punching test, with an ultimate displacement of about 0,10 m (4 inch). The vertical stress is measured during steps 1 and 3 at the level of the two stress gauges (one at the interface, the other in the middle of the silt layer). At the end of each test, the aggregate is carefully removed as well as the geotextile, and the surface deformation of the silt (interface) is measured (6).

PIT TESTS RESULTS

During the first step of the test, we find again the now well established result that the geotextile has a negligible effect when the deformations are small (a few mm) : the load-displacement curves are not very different one from another and not very different from the control test curve (fig. 2) ; this is found for all the structures, including the 2-sheets structure (structure (d) of fig.1). However this must be completed by the values of apparent elasticity modulus obtained from cyclic loading (step 2 of each test) ; this modulus is defined by the following way (Boussinesq equation) :

$$E^* = \frac{\pi}{2}\frac{pR}{e}(1 - \nu^2)$$

where p is the applied pressure on the plate, R its radius and e the recoverable part of the displacement.

Some values of E^* are given in table 2, where (a), (d) correspond to the structures of fig. 1.

TABLE 2 : Apparent elasticity modulus

	control test	Bidim (a)	Bidim (d)	Typar (a)	Typar (d)	Propex (a)	Propex (d)
E^* (MPa)	6,2	9,2	13,7	6,2	9,4	9,2	8

Table 2 shows that the apparent modulus increases slightly, compared with the control test without geotextile, but this rigidity remains small, even for the 2 sheets Bidim for which it doubles.

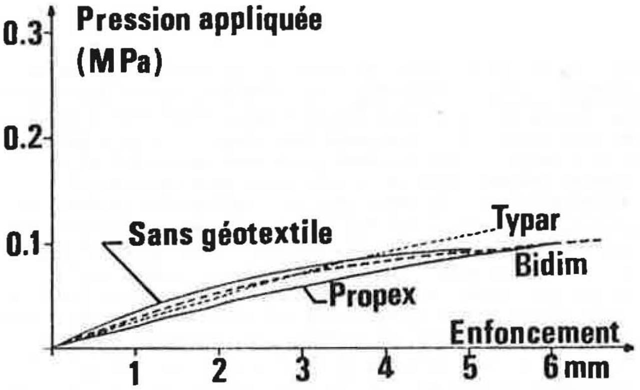

Fig. 2 : Load-settlement curves (small pressure)

The relationship between the vertical stress at the interface and the applied pressure on the plate show the same pattern for the various tests (fig. 3) : a first straight line starting from the zero point, then another one with a larger slope ; this modification of slope is likely to be related to the beginning of plastic strains : the corresponding value of the pressure is indeed the same as the one corresponding to the end of the initial

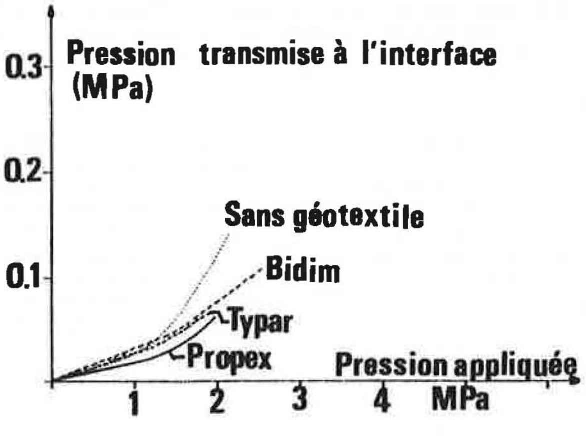

Fig. 3 : Interface vertical stress σ_z

linear part on the pressure-displacement curves for punching tests (fig. 4 and 5) ; besides, the relationship between the vertical stress in the middle of the silt layer and the applied pressure on the plate also shows the same pattern, with smaller stresses, of course.

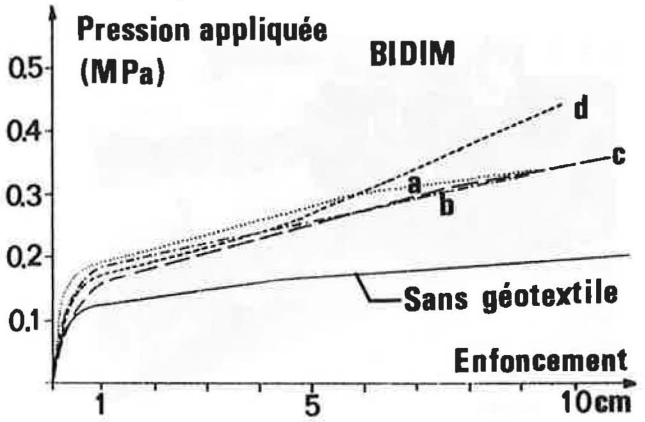

Fig. 4 : Load-settlement curves (punching)

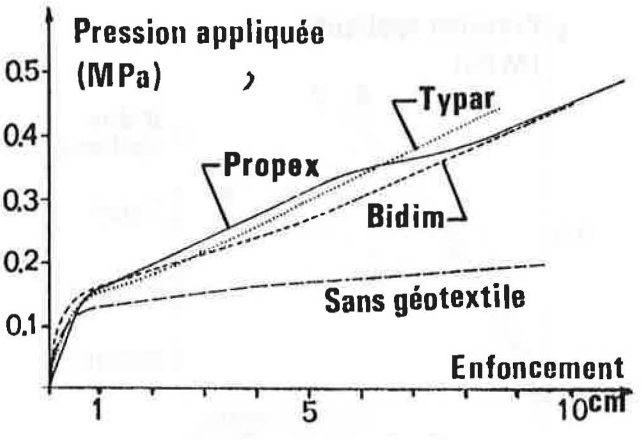

Fig. 5 : Load-settlement curves (punching)

For small applied pressures, the complex soil-geotextile-aggregate has a linear behaviour and this behaviour is almost the same as for the control structure without geotextile. This was made more precise by using the multilayer linear elastic computer program BISTRO (made by Shell Company). With an elastic modulus of 7 MPa for the aggregate layer and 4 MPa for the subgrade silt, the experimental slopes of the linear relationship between the interface vertical stress as well as the plate displacement and the applied pressure were found again ; the BISTRO program makes the assumption of a uniform applied pressure instead of a rigid plate : the relationship between the elastic displacement and the applied pressure p was modified by a $\pi/4$ multiplying factor using Boussinesq equations (R radius of the plate) :

$e = 2\,\frac{pR}{E}\,(1-\nu^2)$ at the center of the plate (uniform pressure)

$e = \frac{\pi}{2}\,\frac{pR}{E}\,(1-\nu^2)$ uniform displacement (rigid plate)

As for the goal of mechanical reinforcement, the punching test gives most of the interesting informations ; the comparison between the load-settlement curve of a given structure and the load-settlement curve of the control structure makes it possible to evaluate an increasing bearing capacity because of the geotextile : it may be computed as the difference Δp between the applied pressures (ordinates) for a given displacement (abscissa) of the plate ; this value of Δp, as it is shown for instance on figure 4, varies with the value of the displacement. This increasing bearing capacity Δp was investigated for e = 5 cm (2 inch) (allowable rut depth for a rural unpaved road) then again for the maximum displacement reached by the plate, 8,5 to 13,7 cm (3,35 inch to 5,4 inch) according to the test (mean value 11,5 cm (4,5 inch).

The effect of the type of geotextile for a given structure may be investigated (figure 5 for instance) or the reverse (figure 4 for instance).

For a 5 cm (2 inch) displacement :

* Δp for structures (a), (b), (c) remains small, except for Bidim

* The noticeable values of Δp for all the geotextiles with structure (d) are the largest for Propex and then Typar.

For the maximum displacement :

* Δp for structures (a), (b), (c) are similar ; so are they for the various types of geotextiles, about 0,1 MPa, with a little bit more for Bidim (about 0,15 MPa).

* Δp for structure (d) is always much larger than for other structures ; Typar gives a somewhat larger Δp than the other geotextiles

From the measurement of the surface deformation of the silt (interface), values of e* and B* (fig. 6) are evaluated ; then a theoritical value Δp* of the increasing bearing capacity can be computed, with the modulus K of the geotextile, according to the methods carried out in Grenoble I.R.I.G.M. (7) (8), either in plane strain or for axisymmetrical problems.

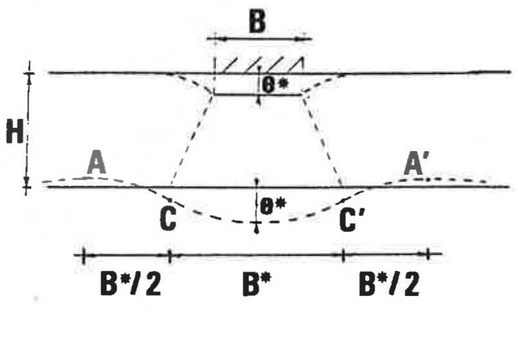

Fig. 6 : Structure deformation pattern

The so computed values of Δp^* (axisymmetry) are similar to the experimental values for Typar, much smaller than the experimental ones for bidim and much larger for Propex;it can be noticed than Δp^* computed in plane strain from the same values of e^* and B^* would have been much smaller than axisymmetrical Δp^*. The discrepancy between Δp^* and experimental Δp may partly be explained for Propex by the displacement of points A and A' of figure 6, when the previous method made the assumption they did not move. For Bidim, it could be the effect of the vertical stress which increases its modulus, as for the non-woven of this kind (9).

A cyclic test was carried out on the control structure and on a structure (a) with Bidim, under a maximum pressure of 0,16 MPa applied during 2s and then suppressed ; a 20s interval was established between each loading; the results (fig. 7) clearly show the stengthening effect of the geotextile with respect to the rutting evolution.

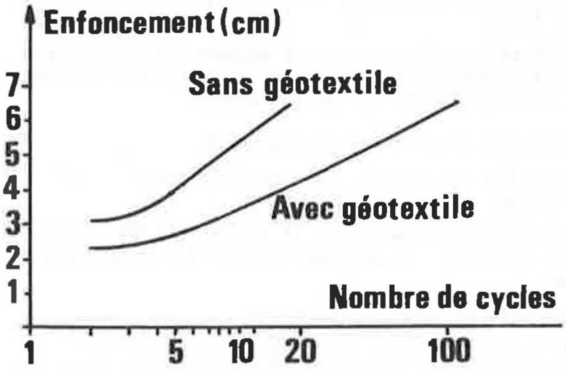

Fig. 7 : Cyclic tests

EXPERIMENTAL ROAD

A full scale experimental road was built in september 1984. It is a road in a mountainous area in the center of France, with a rather hard climate. The natural subgrade soil has a maximum particle size of 10 mm (0,4 inch), 85 % of particles less than 80 μ and 50 % to 60 % of particles less than 2 μ ; there is some scattering because of some stones of 10 to 40 mm (0,4 to 1,6 inch). WL is between 60 % and 75 % and IP between 25 and 33 %. Its inplace unit weight of dry soil γd was about 15,5 kN/m3, approximately the maximum γd (standard Proctor), which displayed a noticeable variability with the different samples. The laboratory study gave a 3 CBR value for optimum Standard Proctor and between 1 and 3 for other water contents.

Three test sections and one control section without geotextile were built : a local material was used for the road layer ; this aggregate has a maximum particle size of 30 mm (1,2 inch) with 5 to 15 % of particles less than 80 μ and a sand equivalent between 25 and 45 ; its inplace γd is about 19 kN/m3, which is 95 % of the maximum γd (modified Proctor compaction). The theoritical thickness of the control section is 0,30 m (11,8 inch) and 0,20 m (8 inch) for the other sections.

On the three sections with geotextile, the type of structure (d) was chosen, with the second sheet in the middle of the road layer. The same geotextiles as for the pit tests were used, except for Bidim : a special one reinforced by a polyester grid was used.

Several kinds of tests were carried out on this road during the spring of 1985 :

1 - tests with a rigid plate (diameter 0,30 m - 11,8 inch) (fig. 8) ; the cyclic loadings, with a maximum applied pressure small enough to remain in a linear behaviour, gave similar values of the apparent elasticity modulus E^* on all the sections, including the control section, about 35 MPa ; a little more scattering was noticed on the Typar section : $E^* = 31$ and 49 MPa.

Tests were also carried out by increasing the pressure as much as was allowed by the loading device : most of the time, there is no punching, except on the control section and on one of the areas of the Propex section where there is a beginning of punching (fig. 9).

Fig. 8 : Plate tests (experimental road)

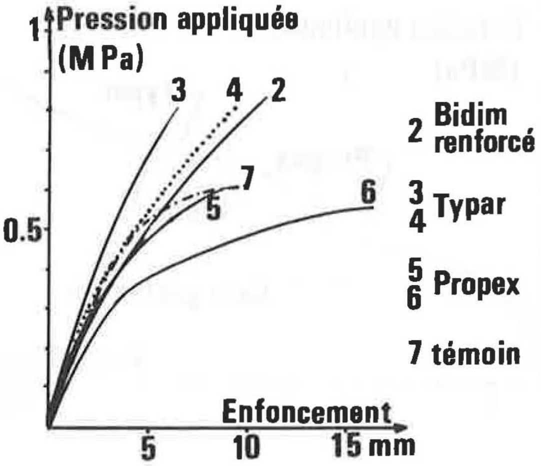

Fig. 9 : Load-settlement curves (experimental road)

2 - rutting tests after several passes of a truck, with a load of 130 KN (29 kips) on the rear single axle ; the initial transverse profile of the road surface was measured : two profiles on each section and one on the

control section ; the transverse profile was again measured after 11 passes of the truck (fig. 10) ; the control section could then be considered as wrecked, with 0,17 m (6,7 inch) deep ruts (fig. 11), the transverse profile of the figure 10 being a less damaged area. On the sections with geotextile, the ruts are less than 5 cm (2 inch), and there is no problem of driving on it for this kind of road;no differences between the behaviour of the various sections with geotextile can be noticed.

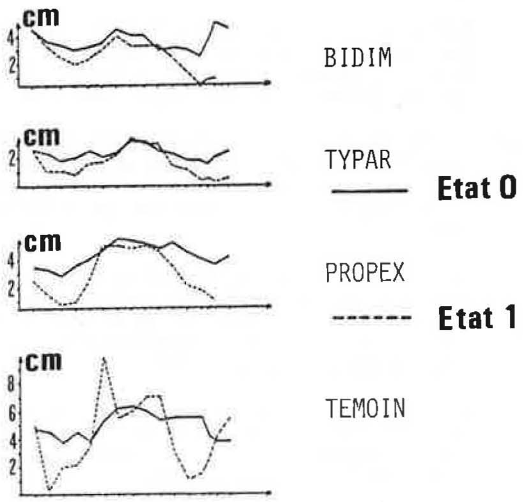

Fig. 10 : Transverse profile evolution

Fig. 11 : Ruts on the control section

A trench was then dug in each geotextile section (fig. 12) and the pattern of the transverse profile of the first sheet investigated : differences of level of 2 to 4 cm (0,8 to 1,6 inch) between the wheel paths and the middle of the road were measured, therefore a little smaller than on the road surface ; it would be necessary to remove the aggregate as far as the natural subgrade soil to investigate its deformed shape : this had not yet been carried out when this paper was written.

With the existing design methods taking into account the strengthening effect of the geotextile, it is possible to evaluate the corresponding reduction of the aggregate thickness according to the bearing capacity of the subgrade, the traffic and the geotextile. Three different methods were used to draw the curves of the figure 13 (10) (11) (12) ; they were computed for 5 000 passes of a 80 kN axle, which is likely to be the traffic on the experimental road. Figure 13 shows a noticeable discrepancy between the suggested thicknesses, including the structures without geotextile. This can probably be explained by different assumptions on the allowable damages. Particularly, the method described in (11) does not take explicitly into account the traffic ; the smaller aggregate thicknesses probably correspond to a small amount of passes : the chosen rule, i.e a vertical stress on the subgrade soil smaller then its bearing capacity, related to its cohesion, is indeed similar to the "quasi-static" analysis described in (12).

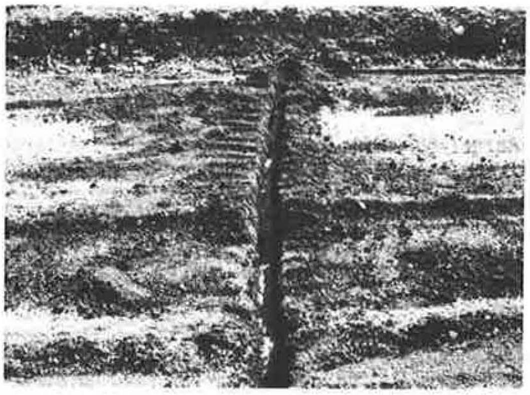

Fig. 12 : Trench in the experimental road

The soil CBR value was about 3 during the loading tests ; the chosen thicknesses corresponded rather to (11), taking into account the poor quality of the aggregate : the failure of the control section after only 11 passes of a 130 kN single axle, which are supposed to be "equivalent" to about 80 passes of a 80 kN (18 kips) single axle, confirms that this design (11) would correspond to a small amount of passes. The satisfactory behaviour of the geotextile sections will have to be corroborated by new loading tests that will take place in spring of 1986.

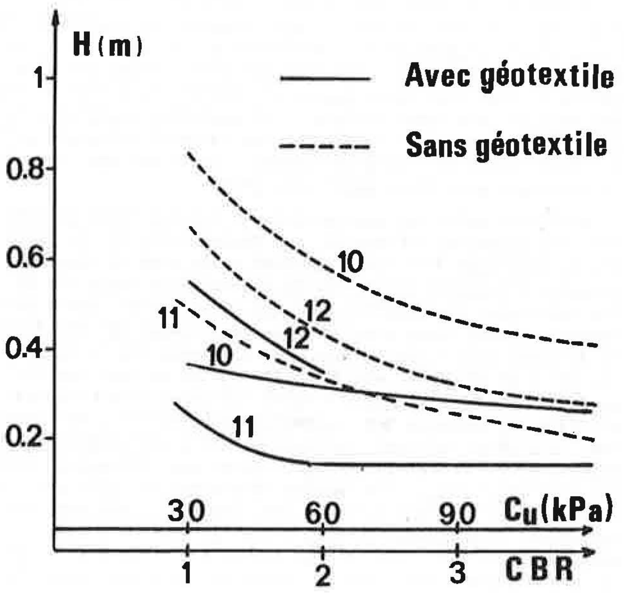

Fig. 13 : Design curves

CONCLUSIONS

The large scale pit tests confirmed that the larger the deformations the bigger the strengthening effect of geotextiles ; the various anchorage systems did not give any more strengthening in the conditions of the test ; the 2 sheet geotextile structure was the best one. These tests did not investigate the aggregate thickness parameter which may have a different effect according to the type of the geotextile.

The experimental road, in spite of a subgrade soil less homogeneous than hoped, made it possible to check the good behaviour of the 2 sheet structures. No difference of behaviour between the various kinds of geotextile was noticed up to now.

The theoritical computations for pit as well as design methods for low volume unpaved roads give only an approximation and require improvements.

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