Field Studies on the Mechanical Behavior of Geosynthetic-Reinforced Unpaved Roads

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Many French forest or agricultural engineers now use geosynthetics to protect base courses from clay contamination, but few of them design their roads taking into account the reinforcement effect. Several studies have been conducted since 1983 to evaluate this effect, using physical models and real structures. The usefulness of geosynthetic reinforcement for unpaved roads is analyzed, including practical and economical aspects.

Gravel roads are not as common in Europe as in large countries like the United States, Canada, or Australia. Nevertheless, they are widely used in agriculture and forestry as resource access roads because the low added value of such activities does not permit large investments. In Europe, France is particularly interested in unpaved roads because its rural areas are important. The length of the gravel-road network is unknown, but probably exceeds 200 000 km.

The design of such roads has rapidly included geotextiles to protect subbases from clay contamination, but more rarely has the reinforcement effect been considered. One reason for this is the absence of a design manual that explicitly indicates the expected thickness reduction. For temporary roads like improved subgrades, the Laboratoire Central des Ponts et Chaussées recommends a maximum thickness reduction from 13 to 19 percent (*1*), which is probably conservative in some cases since it takes into account the separation effect. The French guidelines on geotextiles in low-volume roads (*2*) gives some indication of the adequate geotextile properties but cannot be easily used to evaluate the reinforcement effect. Research has been carried out in the laboratory and in the field since 1983 to obtain useful data on the mechanical behavior of geotextile-reinforced unpaved rural and forestry roads.

One program was conducted in the laboratory (physical model) and in the field (on a rural road in the Massif Central), and another was held in timberland (on a public forest road in the Champagne-Ardenne region). The mechanical behavior was studied by simple field tests such as plate loading, deflexion of the Benkelman beam, and measurement of rutting due to accelerated traffic. Sections with different thicknesses and geosynthetics were compared. Practical and economical aspects, very important in this type of road, were also examined.

RURAL ROAD IN MASSIF CENTRAL

Presentation

The Massif Central is an old mountainous massif with a mean altitude of about 1000 m. The regrouping of lands in the Lozère Department required a new rural road network, and some experimental geotextile-reinforced sections were built in September 1984 with a grant from the Agriculture Department.

The design of the experimental roads was based on previous results obtained on physical models (a rigid box 2 m long and wide and 1.4 m deep in which different soil-fabric-aggregate systems are loaded by a plate), the details of which have been published elsewhere (*3*). They led to these conclusions:

- The reinforcing effect was important only for large plastic strains, corresponding to a rut depth of more than 5 cm;
- The anchoring of geotextiles did not reduce the deformability of the system, a result somewhat contradictory to other research work (*4*); and
- A two-layer geotextile structure (one geotextile between the subgrade and the base and one geotextile inside the base) has a greater reinforcing effect than a single-layer structure.

Experimental Sections

The experimental road comprised five 4-m-wide sections. The subgrade was a sandy clay (85 percent particles less than 80 μm, 50 percent particles less than 2 μm) with a California bearing ratio (CBR) of 3 percent at 15.5 kN/m^3 optimal density (Proctor normal French standard compaction). The aggregate cover was a local arenite 0/30 with 5 to 15 percent particles less than 80 μm. Its water content ranged from 4.9 to 8.5 percent during the construction (mean 6.4 percent), and ranged from 6.5 to 10 percent in May 1985 (mean 7.8 percent, close to the optimum for the CBR test).

One reference section (without a geotextile) was 15 m long and 30 cm thick. Three sections 50 m long and 20 cm thick had a two-layer reinforcement of a woven geotextile (main transverse properties according to French standards: 525 g/m^2 mass per unit area, 75 kN/m tensile strength, 18 percent elongation at failure), a spunbonded nonwoven geotextile (280 g/m^2 mass per unit area, 18 kN/m tensile strength, 47 percent elongation at failure), and a needlepunched grid-reinforced nonwoven geotextile (this experimental fabric has no published properties). The last section, 120 m long and 20 cm thick, had only one layer of the spunbonded nonwoven geotextile.

Tests in 1985

In early spring 1985, a first test was carried out on all the sections except the single-layer reinforced layer. The real thicknesses were found to be somewhat different from the design values: 16 to 18 cm for the woven geotextile, 21 to 24 cm for the spunbonded nonwoven geotextile, and 32 to 36 cm for the needlepunched nonwoven geotextile.

The accelerated traffic (11 loading cycles by a 130-kN rear axle) and elastic modulus (about 35 MPa) derived from a 30-cm-diameter plate loading test were similar on all the sections. The two-layer structures showed a vertical displacement less than 5 cm on the surface (rut depth) and less than 4 cm for the upper geotextiles, whereas the reference section showed rut depths from 10 to 17 cm.

Plate tests at high stress (0.5 to 0.8 MPa) also exhibited better behavior for the reinforced section. The exception was the section with the woven geotextile, whose subgrade had the highest water content—30 percent instead of 20 to 24 percent elsewhere—and whose thickness was the lowest.

The deformation pattern was similar for upper and lower geotextile in each structure. Detailed results were published elsewhere (*3*)

Tests in 1987

In early spring 1987, investigations confirmed some unevenness in pavement thickness and subgrade strength. It was difficult to classify the reinforcement ability of the different geosynthetics without making detailed measurements. At the same point on each section, pavement thickness tests, plate loading tests, and trench openings were made after accelerated traffic.

The high-stress plate loading seemed to better distinguish the nonwoven spunbonded and the woven-geotextile-reinforced sections: for a 4-mm plate displacement, the vertical stress is 0.1 MPa for the reference section (>41 cm thick), 0.4 MPa for the woven-geotextile-reinforced section (18 cm thick), 0.5 MPa for the spunbonded nonwoven-geotextile-reinforced section (22.5 cm thick), and 0.6 MPa for the needlepunched nonwoven-geotextile-reinforced section (40 cm thick).

The accelerated traffic tests (16 loading cycles by a 210-kN rear tandem axle) showed lower ruts than in 1985: 1 cm on the reference section and the needlepunched nonwoven-geotextile-reinforced section, 2 cm on the spunbonded nonwoven-geotextile-reinforced section, and between 2 and 3 cm on the woven-geotextile-reinforced section.

According to the plate tests and elasticity theory, the subgrade would have a CBR of about 6, but the reference section would have a CBR of about 10. On the single-layer section (12.5 cm thick, computed CBR = 5), the accelerated traffic (12 times loading cycles by the same axle) generated 0.5-cm-deep ruts while deflections were more than 500/100 mm.

Overview of Results

Taking into account subgrade CBR and aggregate thickness, plate loading tests and accelerated traffic tests generally showed better behavior for the woven- and spunbonded nonwoven-geotextile-reinforced sections.

The reference section (40 cm thick and CBR = 10) and the single-layer geotextile-reinforced section (12.5 cm thick and CBR = 5) did not show significant differences in rut depth for similar loading cycles. According to elastic theory or empirical findings (5), the influence of pavement thicknesses is relatively greater than the influence of subgrade modulus on the mechanical behavior of roads; thus the geotextile would reduce the rut depth.

The double- and single-layer geotextile-reinforced sections did not show significant differences in rut depth for similar loading cycles either, so the two-layer structure is not so efficient (for rutting) as may be expected from the laboratory physical model.

The rutting tests were made for very few loading cycles. For more loading cycles, significant differences in rut depth might, however, appear.

FOREST ROAD IN CHAMPAGNE-ARDENNE REGION

Presentation

Many timberlands in northern France lie on clayey soils, and harvesting often occurs during the cold and wet season. Geotechnical problems are then commonly encountered by foresters, especially in road engineering. Accordingly, the National Forest Office, Champagne-Ardenne Region, has funded research in the field of geosynthetic-reinforced roads since 1989. The experiment related here began in 1992 near Troyes.

Previous experiments (6) showed that aggregate thickness and subgrade should be as homogeneous as possible. The continuous checks during the work (not part of common practice because of limited human resources) and the homogeneity of the site allowed these conditions to be fulfilled. Single-layer geosynthetic-reinforced sections were designed to cost approximately 25 percent less than the normal regional cost. It is thus more an economic comparison than a purely scientific one. Two-layer geosynthetic-reinforced sections were not tested since the foresters would not accept an apparent overcost of \$3/m^2 or more for materials.

Experimental Sections

Eight sections were built by combining three geosynthetics and different aggregate thicknesses. The length was short (315 m) to permit easily detailed investigations.

The subgrade undrained cohesion evaluated by an unconsolidated, undrained triaxial test was about 60 kPa (with a 34.6 percent water content). In the field, vane shear tests indicated values from 80 to 95 kPa (with a 36.5 percent mean water content), which is far more regular than in the first experiment. Taking into account the plasticity index of the subgrade (35 percent), the real undrained cohesion may vary from 70 to 85 kPa. No water content measurements were made on the limestone crushed aggregate, but this seemed to be too dry for an optimal compaction.

There was one reference section 40 cm thick (called R40) with a spunbonded nonwoven geotextile (290 g/m^2 mass per unit area, 21 kN/m tensile strength, 46 percent elongation at failure), which represented the normal regional design. Two sections were 30 cm thick, with the same geotextile and with a woven one, particularly resistant (330 g/m^2 mass per unit area, 55 kN/m tensile strength, 10 percent elongation at failure). These were respectively called S30 and W30. Three sections were 20 cm thick with the same two geotextiles and with a geogrid (200 g/m^2 mass per unit area, 20.5 kN/m tensile strength, 10 percent elongation at failure), respectively called S20, W20, and G20. Two 15-cm-thick sections, one with the same geogrid and one without a geogrid (reference section), were respectively called G15 and R15.

What was new in the second experiment was the testing of a common geogrid and the easy comparison between each section due to even subgrade strength and aggregate thickness.

Tests in 1993

The same measurements as in the first experiment were done in early spring 1993. The results, and the undrained cohesion corresponding to each section, are reported in Table 1.

The deflection test showed that the type of geosynthetic had less influence than aggregate thickness, even for the geogrid. S30 was stiffer than R40, but no measurements of the subgrade cohesion were taken here. Some variations on aggregate quality might explain this result on such thick sections: aggregate grade is more crude on R40 (0/100 instead of 0/60).

The reinforced 15-cm-thick section was surprisingly more deformable than the nonreinforced one, according to plate tests. The slightly lower undrained cohesion of the reinforced section (80 MPa in comparison with 85 MPa) might explain this result on such a thin section. The maximum measurable 2-cm plate-sinking is not sufficient to stretch the geogrid, but it seems difficult to invoke some slippage of the cover on the geogrid at low plate-sinking as could be the case for geotextiles, especially woven ones, considering their frictional properties.

TABLE 1 Results of Tests Carried Out in 1993

	Section							
	R40	S30	W30	G20	S20	W20	G15	R15
Undrained cohesion (kPa)	—[a]	—	—	—	85	70	80	85
Deflection by 190-kN axle (mm)	6.8	4.7	8.7	12.3	11.6	13.8	15.1	
Plate-sinking at 0.35 MPa (mm)	—	—	—	8.6	10.4	10.0	19.2	14.3
Rut depth (cm)								
At 5 cycles	—	—	—	2	3	3	5	5
At 10 cycles	—	—	—	5	5	10	10	10
At 30 cycles	—	—	—	8	12	19	17	23

[a] No measurements made.

For the same 20-cm thickness, G20 behaved the best according to the plate test. Undrained cohesion below G20 was unfortunately not measured during the tests. It is assumed to be slightly higher than that below W20 from laboratory CBR tests issued before the construction of the road.

The accelerated traffic test (30 loading cycles by a 130-kN rear axle), carried out on the 15- and 20-cm-thick section only, showed limited rut depths until five loadings, then higher ones.

The shape of the deformed geosynthetics after 30 truck loadings is reported in Figure 1 for the 15- and 20-cm-thick sections except G20. By comparison with R15, G15 showed the well-known influence of fabric on the deformation mechanism (larger soil mass involved in the plastic deformations). The spunbonded

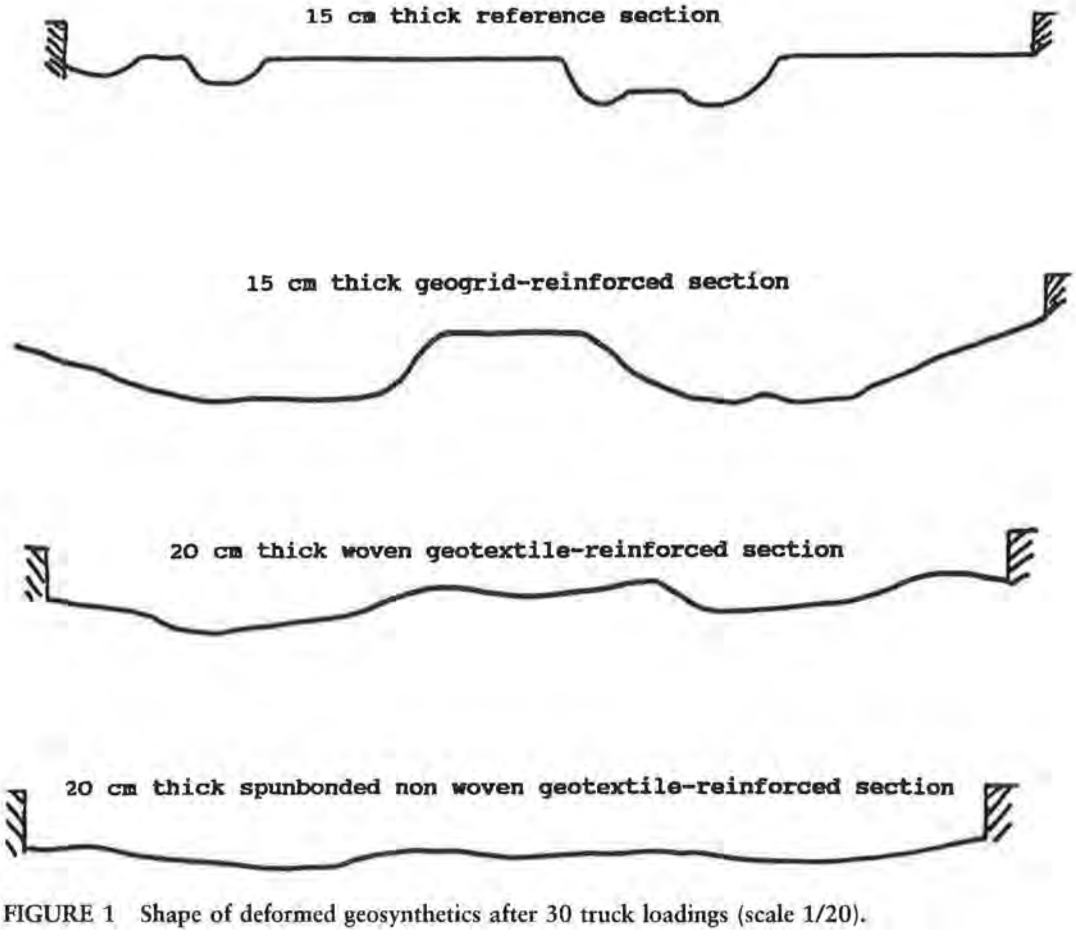

FIGURE 1 Shape of deformed geosynthetics after 30 truck loadings (scale 1/20).

nonwoven geotextile was less rutted than the woven one. These results are consistent with rut depth measurements. The spreading angle after repeated loadings, a classical parameter in several design methods, was evaluated by the distance between the inflection points, whose location is not always as accurate as desired (see Figure 1) according to Riondy (*4*). The highest value, 45 degrees, is found in G15, the middle value of 35 degrees in S20, and the lowest value of 28 degrees in W20. Other measurements are desirable to confirm that these angles do depend on the fabrics, which was verified in small-scale models (*4*). R15 showed an angle close to 25 degrees, not far from the theoretical angle of 45-phi/2, phi being the friction angle of the crushed limestone, probably close to 35 degrees.

Note at least that the deformed shapes are roughly symmetrical toward the center of the road, but not toward the wheels (higher curvature inside, lower curvature outside). This fact is not always accounted for in physical or analytical models, although it seems foreseeable that the soil-fabric-aggregate system has asymmetrical behavior toward the wheels (the transverse profile geometry is not symmetrical toward them).

Overview of Results

Taking into account the subgrade cohesion, it can be argued from plate tests on the 20-cm-thick sections that (*a*) the geogrid strengthens the road more than the spunbonded nonwoven geotextile, and (*b*) the woven geotextile strengthens the road more than the spunbounded nonwoven geotextile.

Considering the rutting tests, S20 shows from 30 to 50 percent less degradation than W20 while the variation of subgrade cohesion is less than 20 percent. Thus the spunbonded nonwoven geotextile would strengthen the road more than the woven geotextile.

It appears that the different tests do not always give the same geosynthetic "rank" for a given section. The deflection test is generally not sufficient to evaluate geosynthetic reinforcement because the structures are not deformed enough. From a practical point of view, the accelerated traffic test is probably the most relevant since loading is very close to reality and takes into account the dynamic and repetitive effect of traffic. Moreover, it allows statistical analyses, which are more difficult to deduce from plate tests.

According to the accelerated traffic test, W20 does not perform as well as G20 or even as well as S20, although the woven geotextile has the highest strength and the nonwoven has the lowest stiffness. Other properties such as friction or even flexibility may play a role in general mechanical behavior, particularly in the rut formation. The reinforcement effect for small rut depth, studied more in recent years (*7*), could invoke these properties instead of the classical geotextile properties used to compute membrane effects (tensile strength and modulus).

PRACTICAL AND ECONOMICAL APPROACH

Practical Approach

The research presented here is devoted to a better use of geosynthetics in road engineering to reduce the investment and maintenance costs of rural and forestry unpaved roads. The aim is not to develop purely theoretical models. Therefore, some care must be taken before modeling reinforcement effects: the modeling hypotheses must be close to what occurs in the field. Some remarks are necessary here.

First, the membrane effect is negligible unless rut depth exceeds 5 to 10 cm (*3,4*), which is not desirable for permanent rural and forestry uses. Graders and rollers are not continuously available to quickly offset deep ruts as is the case for construction traffic roads or improved subgrades. Moreover, recreational use could require good serviceability, hence limited rut depth. Theories based on the membrane effect have been well developed because they are readily adapted to computations, but they do not entirely meet the real needs of unpaved concerning rut depth.

This membrane effect depends on the frictional stress outside the axle, which depends itself on the thickness and the width of the aggregate cover, and to a certain extent on fabric anchorage. These are particularly low on rural and forestry roads, and anchoring is not common practice.

The stress applied to geosynthetics during construction may be higher than that applied in service. The second experiment suggested this, although no measurements were made. Localized rheological contrasts (stones, stumps, roots, soft spots) can stretch or puncture geosynthetics under construction traffic. For that reason, foresters in the Champagne-Ardenne region do not use geosynthetic whose mass per unit area is less than 200 g/m^2. Geogrids have been revealed to be very sensitive to this kind of stress. In many situations (only one access, very narrow subgrade) it is difficult for construction traffic not to work directly on the geosynthetics, so this problem has to be accounted for.

The particularly narrow width of rural and forestry roads theoretically requires short rolls, which are not always available since the main market for geosynthetics is highways. The rolls width is not always optimized for rural roads. Anchoring the extra-width geotextile in the aggregate cover does not provide more reinforcement (*3*). The roll may be cut at the desired width, which is not recommended for geotextiles, especially woven ones. This must be done for geogrids because of their higher flexural stiffness, but the cut is much easier than for geotextiles.

Last but not least, the handling of geogrid rolls is much easier than reinforcement geotextile rolls, except perhaps some woven geotextile with sufficient tensile strength and low mass per unit area, since the weight per unit area of geogrids is particularly low.

Economical Approach

Geosynthetics will not be developed for reinforced unpaved road unless their cost is lower than the cost of the aggregate saved by the reinforcement. The results obviously depend on the cost difference between aggregate and fabrics and must be adapted to each case. For instance, the National Forest Office found that common geotextiles were worthwhile but not geogrids in the Ardenne Department.

Other advantages should be taken into account, such as these:

- Less damage to the access road network, helping maintain cordial relationships with forest managers, who may otherwise forbid haul traffic, as occurs in some French timberlands;
- Less likelihood of encountering bad weather conditions because of the shorter duration of the work (these advantages do not easily lend themselves to economical computations); and
- Lower maintenance cost.

Research programs on geosynthetic-reinforced unpaved roads that take into account the influence of fabrics on maintenance cost are welcome.

CONCLUSION

The results of the two experimental programs did not clearly show the key geosynthetic properties for reinforcement purposes, nor the expected aggregate thickness reduction. For heavy traffic, it can be argued that building roads with an aggregate thickness of less than 20 cm is not recommended, whatever the geosynthetic. The thickness reduction range due to the geosynthetic reinforcement is usually evaluated to be from 10 to 40 percent (even more according to some fabric producers). The experiments presented here confirm this.

It seems that all fabrics do not generate the same mechanical behavior. The differences do not directly depend on geosynthetic modulus, a result already found by others when there is no anchoring (*4*), or when the subgrade is compressible (*8*).

The results and reflections presented here show the state of the art in designing geosynthetic-reinforced unpaved rural and forestry roads in France. Design thickness and geosynthetic survivabiliy specifications seem less crude in the United States (*9*) than in France (*2*). Research work should now be disseminated more widely, with refinements carried out to optimize geosynthetic choices for rural and forestry unpaved roads.

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