International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988
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TEXSOL: Already more than 50 successful applications

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Abstract. The TEXSOL method of soil reinforcement presented at the Las Vegas and Vienna conferences on geotextiles is now developing on many job sites in France. The paper presents some significant jobs and indicates the results of tests on retaining structures and on repeated loading behaviour of the material.

1. Introduction.

The TEXSOL technique is a three-dimensional development of the geotextile technology. Its principle has been described in papers presented at the Las Vegas (1982) and Vienna (1986) conferences on geotextiles (1), (2) and at the 11th Soil Mechanics Conference in San Francisco (1985) (3). It is the mixing of continuous polymer yarn and soil to form a composite in which the yarn brings its tensile resistance. In the present practice, the soils used to produce TEXSOL are essentially natural sands; this is for several reasons: the mixing of soil and yarn is easier with granular materials than with cohesive materials; mechanical performance of sands is very strongly improved by the tensile strength of yarn; in many areas, local natural sands are cheap materials. However the principle of the TEXSOL method is also applicable to other types of soils; such applications are experimented and will be developed both from the point of view of production equipment and new uses of the TEXSOL material.

The TEXSOL technology has been developed by the Research Network of the French Ministry of Publics Works which owns the original patent. For contracting and site application, the TEXSOL Company has been established; the TEXSOL Company is performing jobs in France and developing the method abroad through Joint Ventures and Licensees. The first license contract has been for Japan in 1987.

TEXSOL is a new material with unusual performances. The effect of yarn is to create a cohesion in the granular material; however, in contrast with materials bound with cement, bitumen or other binders, the TEXSOL material has a fairly high deformability: simple compression tests lead to failure for 6 to 10 % of axial deformation and, secondly, TEXSOL is as permeable as the material without yarn.

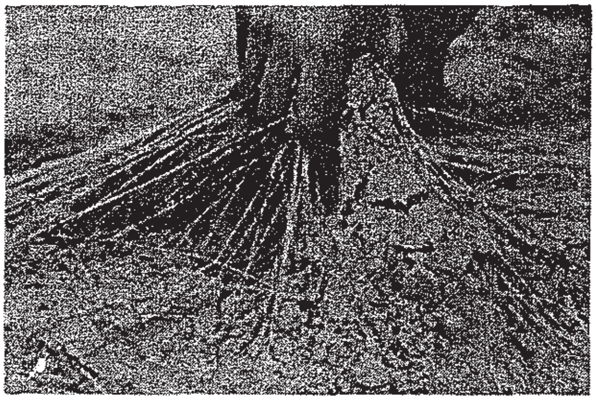
According to the method and equipment used for production, the geometrical arrangement of the yarn within the material may vary; in present practice, this arrangement is preferably horizontal and it has been shown that the resulting cohesion is anisotropic.

Anisotropy of cohesion is taken into account in the design of TEXSOL structures.

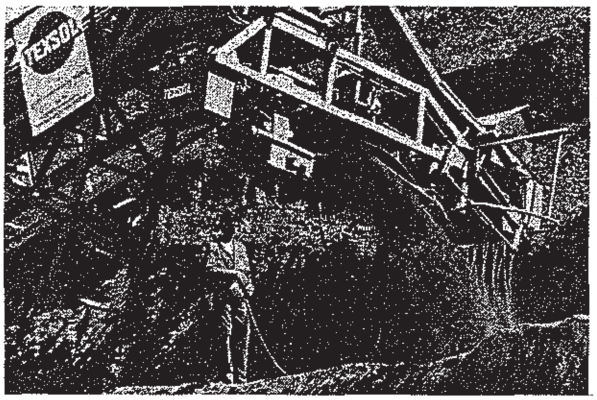
The TEXSOL material has a wide variety of potential applications: retaining structures, foundation layers under railroads and roads, shear resistant drains and filters, foundation blankets on soft soils, antiseismic structures, protection against erosion, shock resistant structures, etc... Presently, the application which has been essentially developed are retaining structures. Some of the corresponding jobs are described below, along with more special applications already performed or at the design stage. After these examples of application, tests results are presented, dealing with failure loading of full size retaining structures and with the behaviour under dynamic stresses and repeated loading conditions, in view of seismic applications and railroad construction.

2. Retaining structures in France.

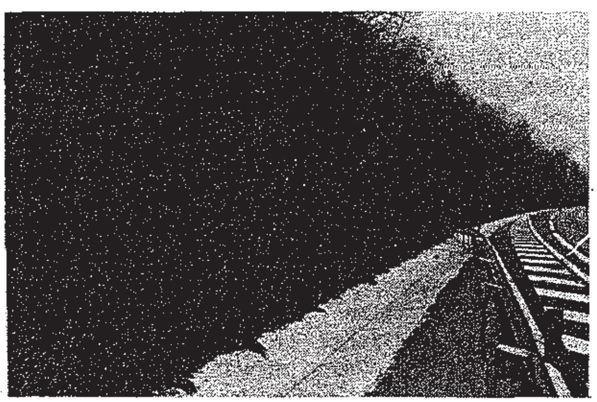
So far, in June 1988, TEXSOL has been used on 50 job sites in France; half of these have



TEXSOL, a new material with unusual performances.



Mixing of soil and yarn by special machines.



TEXSOL retaining wall on A7 Motorway (after turfing).

been for retaining structures for cuts in natural ground, fifteen for retaining fills and ten for more particular uses.

The sites where the largest amount of TEXSOL has been used are located on the A7 Motorway,

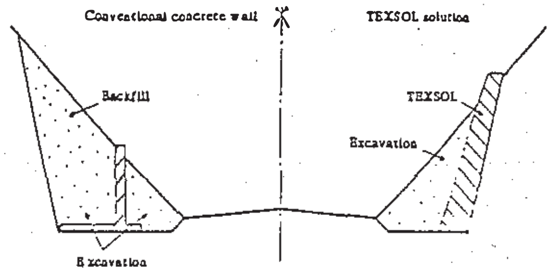


Fig. 1 Comparison of concrete wall and TEXSOL solutions for retaining structures.

south of Lyon, towards the Mediterranean sea. The problem was to add one lane to the motorway in each direction without enlarging the right of way ; therefore the slope of the cut sections had to be steepened. For long term stability these sections needed a retaining structure.

As shown on figure 1, the TEXSOL solution is a trapezoïdal inclined structure. As compared with conventional retaining walls, this solution has two main advantages : cost and appearance.

Savings are mainly due to the reduction of earthmoving quantities and to the use of local natural sand for the production of TEXSOL.

Environmental performance is excellent due to grass growing on the TEXSOL surface, as shown on figure 2. In fact, the appearance of TEXSOL after one or two years is such that the motorist does not even notice that there is any retaining structure along the motorway, which is just the best result that can be expected. Experience has also shown that maintenance of the vegetative cover is performed without any problem, which is not the case when the retaining structure is made of concrete elements intermixed wih soil and vegetation. The total amount of TEXSOL produced on the three sites of A7 motorway is 44.000 m3. On these sites, the outer slope of TEXSOL is 60°, the height being between 2 and 9 m.

Another interesting site is the A12 motorway in the Paris area. The situation was similar to that of A7. The quantity of TEXSOL has been 3.500 m3 on this site ; the soil being retained is calcareous clay on one part of the site and clean sand on the other part. The outer slope of TEXSOL is 65° and the maximum height is 12 m.

In such situations, the calculation of the structure is performed according to conventional methods, where the parameters used for calculating the strength of the TEXSOL material for internal stability evaluation are the only specific elements. TEXSOL is characterized by angle of friction and cohesion. As mentioned earlier in this paper, the present method of production leads to an anisotropic cohesion. This has been introduced in the calculation program. For practical purposes, charts have been established for the most usual situations. For design, usual practice is to use values of angle of friction and cohesion that are known to be normally obtained with natural sands and usual proportion of yarn (between 0.15 and 0.2 percent), and then, to check and adjust the type and quantity of yarn with laboratory tests on the sand to be used on site.

Another interesting example of retaining structure is given by the work performed at Deauville. The job was to create a 4 m deep cut in a water-bearing low-plasticity clay slope which was already at the limit equilibrium state before the cut was made. Because of this situation even short term stability was not ensured and the cut had to be made by short lengths, the TEXSOL retaining body being constructed at the same rate to follow closely the excavation. An interesting feature in that case is that TEXSOL being made of sand could perform the filtering and the draining functions that were necessary for such a water-bearing finegrained soil. Therefore, The TEXSOL body is at the same time the retaining structure, the filter and the drain. It is then obvious that large savings may be obtained with this technique, due to the extreme simplification of design and execution.

The last example of retaining structure presented here deals with a case where TEXSOL is used as a fill retaining material. At Longefoy in the Alps region, a mountain road had suffered a slip failure of the natural slope under the road. Reconstructing the road platform is almost impossible with an ordinary fill because of the steep slope of the mountain and is very expensive using piles and concrete structures due to lack of space and because of required time and manpower. TEXSOL allowed a fast repair of the slip failure with a 60° slope angle and a maximum height of 9 m.

3. Other types of applications.

In a few instances TEXSOL has been used to improve the stability and the erosion behaviour of earth or sand levees built for protection of industrial or military areas. In one case sand levees were displaced by wind action ; a fairly thin cover of TEXSOL avoided sand to be blown away and solved the problem. In another instance earth levees were progressively washed down by rain action ; TEXSOL allowed to restore their initial slope,

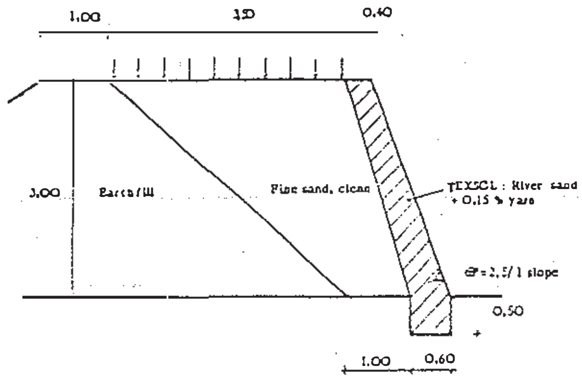


Fig. 2 Diagram of full size tests of retaining structures.

in some places with a steeper slope, while keeping the shock absorbing ability of the levees, which was required on this site where explosions could occur.

Other applications are presently planned where the shock absorbing ability of TEXSOL will be put to use. One is for protection of roads or constructions against falling rocks in mountain areas. To stop very large rocks heavy structures are the cheapest means but large embankments often cannot be built because of the slope angle of the natural ground. Thus a TEXSOL wall with a steep slope retaining a mass of ordinary fill is a good solution. In addition to static stability, TEXSOL is a deformable material which can absorb considerable shock energy through large deformations.

Another shock absorbing application presently at the testing stage is for road safety.

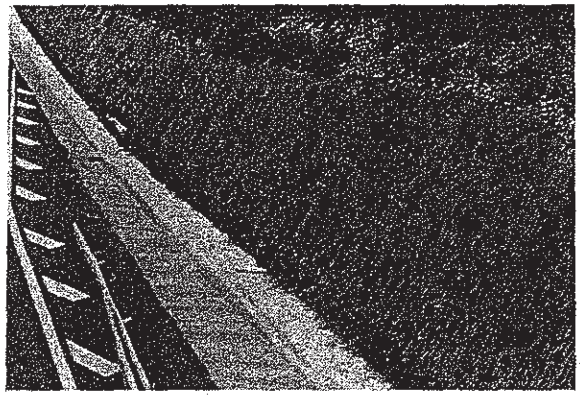
Vibration absorption and seismic performance are commented upon later in this paper, as well as performance under repeated loading.

4. Full-size testing of retaining structures.

Loading tests of 3 m high retaining walls of TEXSOL have been performed in Rouen in 1987. The purpose of these tests was to observe the type of failure of a TEXSOL wall retaining a sand fill and to see if the failure conditions were to be different according to the method of laying the TEXSOL, either in horizontal layers or inclined inwards or outwards with respect to the retained fill.

The testing layout is shown on figure 2. The materials were as follows :

TEXSOL : clean 0-5 mm river sand with 0,15 % polyester yarn 330 dtex 36 CN/tex.



TEXSOL retaining wall on A7 Motorway (before turfing).

Fill : clean fine sand 0-0,3 mm.

The loading was obtained by a fill constructed above the fill with vertical walls (either concrete wall elements or geotextile reinforcement), with the addition of iron blocks on top of the fill, to reach the failure load.

Three tests have been performed, two on six meters long TEXSOL walls and the last on an 18 m long TEXSOL wall.

The results did not show significant differences between the tests, in which the angle of deposit of TEXSOL during production was different. This is in some manners logical since the angle of deposit has an effect on the shear strength of the material (according to the value of the angle between the deposit plane and the shear plane) and that failures in all three tests were not due to shear failure of the TEXSOL material but occured as an overall overturning rotation of the TEXSOL wall.

This behaviour has been the most interesting result of these tests ; displacement measurements during failure showed a rotational movement around the base of the wall. The failure load above the fill has been approximatively 75 kN/m2 for the three tests.

5. Laboratory testing of fatigue and dynamic behaviour.

a) Fatigue tests. In view of the use of TEXSOL under traffic (either under railroads or road pavements) the behaviour of the material under repeated loading has to be tested. Two types of tests have been performed : repeated loading triaxial tests performed in Rouen and simulation testing in a railroad testing facility in the Paris area.

Triaxial tests used a uniform fine natural sand 0-0.3 mm, without fines, with a 50 dtex polyester yarn at a proportion of 0,3 % in weight. Static triaxial tests had given a value of $\sigma 1 - \sigma 3$ at failure, for $\sigma 3$ = 50 kPa, of 1,8 MPa. Repeated loading tests were performed with $\sigma 3$ = 50 kPa and a value of $\sigma 1 - \sigma 3$ oscillating between 0 and 0,7 MPa (i.e. 40 % of the failure load).

Total axial deformation was 1 mm after 10 cycles, 2 mm after 100 cycles, 2,6 mm after 10^3 cycles and 3 mm after 10^6 cycles. The compressive failure strength after 10^6 cycles was equal to that obtained without repeated loading. These results show a good behaviour under repeated loading, with no degradation of the yarn under the repeated stress applications.

The fatigue simulation tests used a very aggressive sand obtained from a railroad ballast quarry ; it was a 0-8 mm material with flat particles showing many sharp edges. The yarn was a 330 dtex polyester at the proportion of 0,21 %.

The testing machine is a system developed by the French Railways to simulate the effect of vibration loading on railway materials. A mechanical vibrator with eccentric wheels is attached to a beam connected with the two rails. These rails (a few meters long) are statically loaded at their ends. The static and dynamic loads applied on the rails are transmitted to one sleeper placed on the ballast and sublayer material to be tested.

This device has been used for many years and empirical correlations have been established between the effect of vibrations resulting from the machine and the actual behaviour of materials under railway traffic. A normal test is 100 hours long, corresponding to 18 million cycles (considered to be equivalent, as far as material behaviour is concerned, to 10 years of very heavy traffic).

For TEXSOL testing, a 21 cm thick layer of TEXSOL was made on the firm foundation clay soil, 3 m long x 1 m wide. A 25 cm thick layer of ballast was put above the TEXSOL, then the sleeper, rails and vibration system.

Measurements made dealt with density, settlements, stresses and acceleration.

For TEXSOL testing the total vibration time has been 143 hours, corresponding to more than 25 million cycles.

Measured accelerations in the TEXSOL layer varied between 10 and 20 g, with amplitudes between 1,5 and 2 mm.

During the test the density of TEXSOL increased from 1,85 to 2,06, with a corresponding reduction in layer thickness of 2,4 cm, from 21 cm to 18,6 cm. The total settlement of the sleeper has been 6,3 cm.

Directly under the sleeper the TEXSOL was disturbed on a few centimeters, but at a 20 cm horizontal distance the interface between the ballast and the TEXSOL was not damaged. The interface between the TEXSOL and the subgrade was not disturbed.

Fatigue damage on the yarn could be observed, specially at the upper part of the TEXSOL layer ; these damages were essentially local transverse compression of individual fibers pinched between grains.

The overall result is considered as quite excellent in view of the very severe testing conditions, since total deformations remained very limited and that no interpenetration occured neither between ballast and TEXSOL nor between TEXSOL and subgrade.

Two test sections are presently being built on an actual railway line, with thicknesses of 20 and 25 cm of TEXSOL under ballast ; measurements of deformation, stresses and acceleration will be made regularly.

b) Laboratory tests for evaluaton of dynamic behaviour.

Tests have been performed by Mr LUONG at Ecole Polytechnique near Paris in view of analyzing the mechanical behaviour of TEXSOL as compared with that of simple sand. These tests have explored cyclic loading behaviour, liquefaction and dynamic response as a function of frequency. The results have been presented in (4) and show that TEXSOL ductility and energy absorption capability are of great interest when vibrations are involved.

6. Conclusion.

TEXSOL, new construction material, has already proved its ability to solve in very economical and ecological conditions most of the problems of retaining walls, slope savings, anti-seismic and anti-vibration courses or foundations, protection against noises and shocks. New applications and other research are already moving and the Owners and Engineers are looking for its development with high interest all around the World.

7. Acknowledgements.

This paper describes works performed by the "Société d'Application du TEXSOL" (SACLAY, Boîte Postale n° 62, 91401 ORSAY Cédex, France) and tests conducted by C.E.T.E. Rouen (Boîte Postale 245Bis-247, 76120 GRAND QUEVILLY, France) - (part of the Research Network of the French Ministry of Public Works) and by Ecole Polytechnique ; their cooperation is gratefully acknowledged.

8. References.

(1) LEFLAIVE E., "The reinforcement of granular materials with continuous fibers", 2nd International Conference on Geotextiles, Las Vegas, U.S.A., 1982, pp. 721-726.

(2) LEFLAIVE E., LIAUSU Ph., "The reinforcement of soils by continuous threads" 3rd International Conference on Geotextiles, Vienna, Austria, 1986, pp. 523-528.

(3) LEFLAIVE E., "Soil reinforced with continuous yarns : the TEXSOL", 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, U.S.A., 1985, pp. 1787-1790.

(4) LUONG M.P., LEFLAIVE E., KHAY M., "Propriétés parasismiques du TEXSOL", 1er Colloque National de Génie Parasismique, Saint-Rémy-lès-Chevreuse, 1986, pp. 3/49 to 3/58.