LEFLAIVE, E., Laboratoire Central des Ponts et Chaussées, Paris, France
LIAUSU, PH., Société d'Application du Texsol, Paris, France

THE REINFORCEMENT OF SOILS BY CONTINUOUS THREADS
BODENBEWEHRUNG MIT ENDLOSFASERN
LE RENFORCEMENT DES SOLS PAR FILS CONTINUS

The main features of the behaviour of the material, called Texsol, resulting from the reinforcement of a soil by continuous threads are reminded. Results from triaxial tests are presented. Then work-site construction is described.

Les principaux aspects du comportement du matériau, appelé Texsol, obtenu par renforcement d'un sol par fils continus sont rappelés. Les résultats d'essais triaxiaux sont présentés. On décrit ensuite les réalisations de chantier actuelles.

The principle of the thread reinforcing technique is described in a paper presented at the II° International conference on geotextiles (1). The present paper gives the results of triaxial tests to illustrate the mechanical behaviour of the material and describes work sites.

Triaxial tests

Samples are Ø=100 mm, H=200 mm, compacted, saturated, tested with a strain rate of 0.085 mm/minute. Threads are multifilament untwisted polyester.

1 - Sand 0/5 mm - Thread 330 dtex

Sand : partially crushed 0/5 mm without fines, D_{50}=0.8 mm ; ϕ=43 ° with ε_{1f}=5 %.

Thread : 330 dtex 60 filaments, tenacity 36 cN/tex, strain at failure 25 %. The average proportion of thread in weight is 0.2 %. Dry density of sample = 1.90 g/cm³.

Values of lateral stress : σ_3'=50, 100, 150 and 200 kPa.

Results are given on Table 1. Cohesion is calculated in two ways :

- for each value of σ_3', cohésion is calculated assuming that the angle of friction of the mixture is the same as that of the sand, i.e. 43 ° ;
- for the whole set of tests, the envelope is determined, which gives Ø and c of the composite.

Table 1 - Results of triaxial tests
Sand 0/5 mm - Thread 330 dtex

Proportion of thread ‰	σ_3' kPa	$(\sigma_1'-\sigma_3')$max kPa	c for Ø=43° kPa	Ø and c global	ε_{1f} %
2.09	50	1 338	244	Ø=48 ° c=190 kPa	7.2
1.89	100	1 611	257		7.2
1.82	150	1 797	250		7
2.09	200	2 260	305		6.8
mean value 1.97			mean value 264		mean value 7

2 - Sand 0/2 mm - Thread 167 dtex

Sand : natural 0/2 mm with 10 % fines (smaller than 80 microns) and D_{50}=0.3 mm.

Thread : 167 dtex 30 filaments, tenacity 36 cN/tex, strain at failure 26 %.

The average proportion of thread in weight is 0.14 %. Dry density 1.59 g/cm³, σ_3' = 50, 100, 150 kPa.

Results are given in Table 2.

Table 2 - Results of triaxial tests
Sand 0/2 mm - Thread 167 dtex

Proportion of thread ‰	σ_3' kPa	$(\sigma_1'-\sigma_3')$max kPa	c for Ø=37° kPa	Ø and c global	ε_{1f} %
1.37	50	713	141	Ø=38° c=134 kPa	16
1.43	100	903	151		14
1.40	150	1 028	145		16
mean value 1.40			mean value 146		mean value 15

3 - Sand 0/0.3 mm - Thread 50 dtex

Sand : natural sand with a very uniform grain size distribution 0.1/0.3 mm, D_{50}=0.2 mm, without fines, Ø=36°, dry density OPN=1.60 g/cm³.

Thread : 50 dtex 16 filaments, tenacity 40 cN/tex, strain at failure 25 %.

Average proportion of thread in weight : 0.215 %. Dry density of samples : 1.62 g/cm³.

Results are given in Table 3.

Table 3 - Results of triaxial tests
Sand 0/0.3 mm - Thread 50 dtex

Proportion of thread ‰	σ'_3 kPa	$(\sigma'_1-\sigma'_3)$max kPa	Ø and c global
2.34	50	1 599	Ø=36°
2.09	100	1 528	c=356 kPa
2.01	150	1 895	
mean value 2.15			

Figure 1 show the stress-strain curve corresponding to one of the tests of this last group.

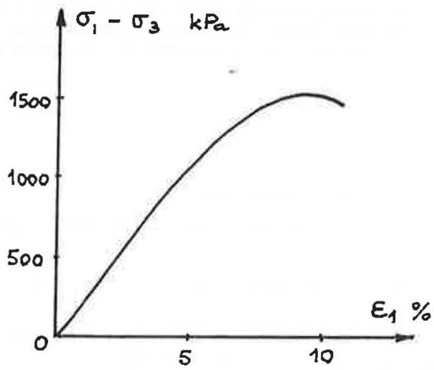

Figure 1 - Example of stress-strain curve resulting from a triaxial test

These results, and many others, show the large amount of cohesion obtained with the soil-thread mixture. Dividing cohesion by proportion of thread to have comparative values corresponding to a uniform value of 0.1 %, the obtained values are close to 100 kPa in examples 1 and 2 above and is equal to 165 kPa in the third. In the first case, assuming Ø=43 ° (which is already a relatively high angle of friction), the mean value which is obtained is 2.64 : 1.97 = 134 kPa. These values are much higher than those given by Mc Gown et al (2) with mesh elements incorporated into soil, the cohesion values given by these authors being of the order of 50 kPa for an average proportion of inclusion of 0.18 %, which would give approximately 25 to 30 kPa for a proportion of 0.1 % (as a conventional measure of efficiency).

Theoretical approach

A theoretical calculation assuming that all threads are at their maximum stress and that the system is isotropic gives the isotropic stress H due to the threads. The resulting cohesion is c = H tg Ø.

The calculation leads to :

$$H = \frac{1}{3}\, 10^7\ m\gamma t$$

where H is expressed in Pascals
m = proportion of thread in weight (dimensionless)
γ = soil volumic mass in g/cm³
t = tenacity of thread in cN/tex.

Example :

$m = 0.1\ \% = 10^{-3}$
$\gamma = 1.8$ g/cm³
$t = 50$ cN/tex

one obtains H = 300 kPa.

For an angle of friction of 35 °, tg Ø = 0.7 H = 210 kPa.

The obtained value, resulting from an idealized calculation, is of the same order of magnitude as the experimental results. It must be mentioned that failure of compacted samples in triaxial tests occurs with rupture of the threads along the failure surface of the sample.

A7 Motorway

The Texsol technique is used for retaining structures of steep cuts made for widening the A7 motorway south of Lyon in France. 20 000 m³ of material are produced on this site in two periods during 84/85 and 85/86 winters.

The final outside slope is 60 ° with respect to horizontal ; height is between 3 and 7 m ; thickness at the base depends on height and is given by stability calculations. Calculations are made with standard soil mechanics programs, assuming Ø=36 ° and c=100 kPa for the material and a safety factor of 1.5. Thickness at the base are between 0.8 and 1.8 m.

Fig. 3 shows the situation before widening of the motorway and figure 4 an example of stability calculation.

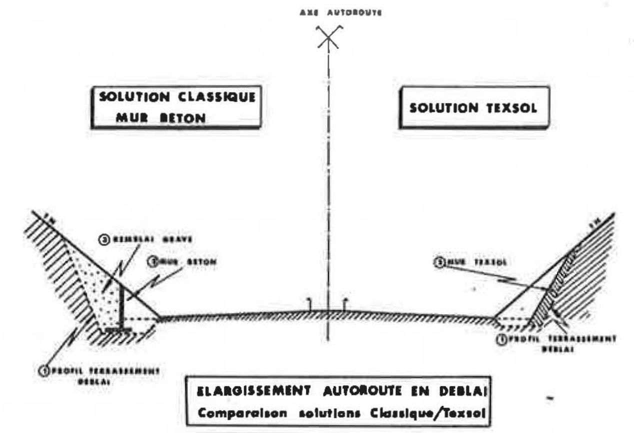

Figure 2

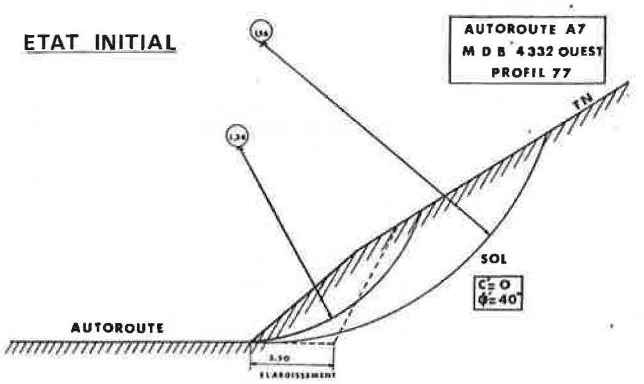

Figure 3

The type of thread to be selected and the proportion to be used result from a laboratory study performed with the natural sand available on the site. Figures 5, 6 and 7 give data on this study. The choice of a 167 dtex thread with a proportion of 0.15 % gives the desired result with an additional coefficient of safety.

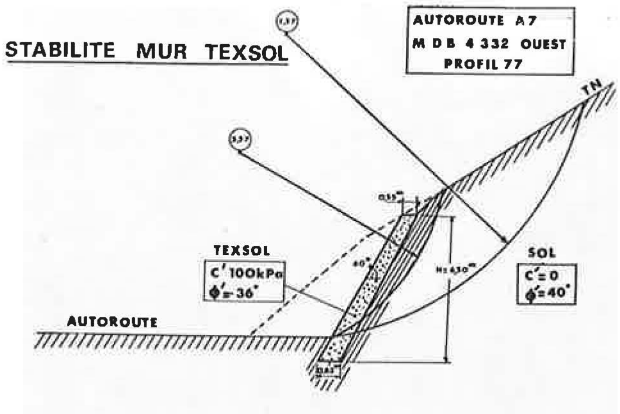

Figure 4

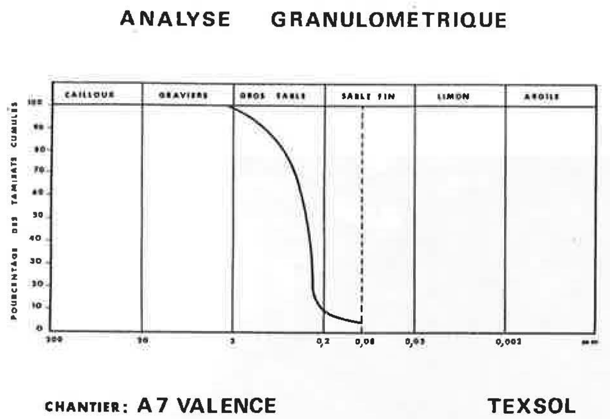

Figure 5

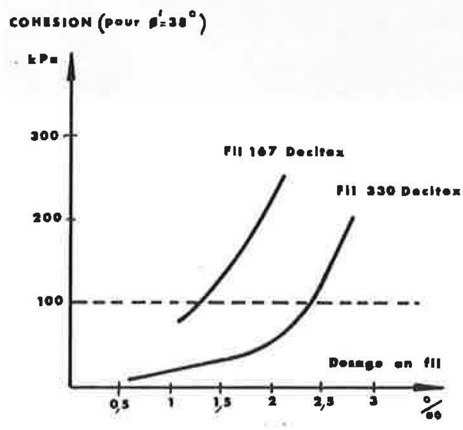

Figure 6

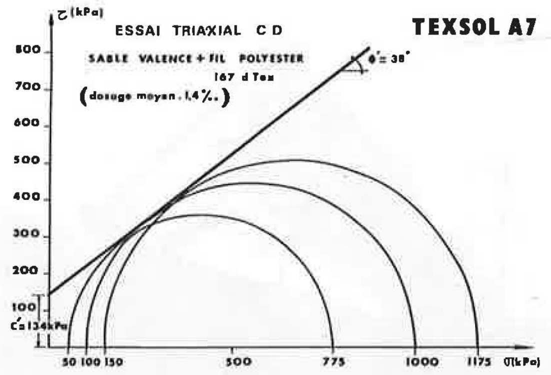

Figure 7

The production of the material on the site is made with a specially designed machine able to produce approximately 20 m³/h. 40 bobbins of thread of 15 kg each are located on the machine, corresponding to 12 hours of production.

After construction, the slope is vegetalized.

Figures 8 to 13 give illustrations of the works.

Figure 8 - General view of the machine

Figure 9 - View of bobbins on the machine

Figure 10 - View of the machine at work

Figure 12

Figure 11 - View showing a close-up of the retaining structure being constructed

Figure 13

Bibliography

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

(2) Mc Gown A., Andrawes K.Z., Hytiris N., Mercer F.B., "Soil strengthening using randomly distributed mesh elements",
11th Int. Conference on Soil Mechanics and Geotechnical Engineering, San Francisco, U.S.A., pp. 1735-1738, 1985.