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Modelisation and design of geotextiles submitted to puncture loading

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ABSTRACT : There are many uses of geotextiles. These geotextiles always serve as separation function even if they serve another function which is considered as the primary function. The application that best shows the use of geotextiles as separator is its placement between soft soil subgrades of low bearing capacity below it and fill above it (figure 1).
The geotextile is thus placed on the site and the stone dumped, spread and compacted above it. When studying the separation function, it appears that the required properties are the puncturing resistance, the burst resistance and the tear resistance. These properties can be studied from laboratory tests results but these results may be viewed as suitable criteria for later specification if they are considered in relation to site related stresses. Tests which have been carried out show that the puncturing resistance of geotextiles is a function of the subsoil bearing capacity.
This paper evaluates the relevant stress situations for geotextiles by means of puncture analysis of the mechanical properties of continuous filament needle punched polypropylene nonwoven geotextiles.

1. ON SITE BEHAVIOUR OF GEOTEXTILES

A geotextile's high elongation at break enables it to follow the uneveness and irregularity of the surface of the terrain and the shape of the stones without damage. Geotextiles with high elongation at failure are thus also unaffected by the specification criterion of tear propagation strength since even in the case of dynamic loading the occurence of perforations, which are a starting point for tear propagation stresses, is unlikely.

It is not easy to give precise value because it would depend of the way the geotextile is placed, risks of puncturing being lower if the geotextile is looser. According to Giroud {1}, an elongation at failure in the order of 100 % measured in a plane-strain tensile test is likely to prevent puncture of the textile in most cases.
Practically elongation of most geotextiles in plane-strain test is much lower than 100 %, so, this lack of deformability must be made up for by puncture resistance.

When placed in use, the geotextile must be able to undertake without damage :

- the local stress concentrations resulting from point loading by correspondingly high puncture strength (figure 2);
- the burst pressure occuring when a geotextile bridges gaps on one side and is subject to soil pressure in the other side (figure 3).

2. TEST PROCEDURE

So far the puncture strength of geotextile has been determined either by using a modified C.B.R. test with a pyramidal piston points (a 3-sided pyramid with sides 5,0 cm long and a height of 2,5 cm) or by an unmodified C.B.R. test according to DIN 54.307 E allowing for the grain form by means of a shape factor varying from 0.8 for round blunted shapes to 3.0 for pointed sharp-edged shapes {2}.

If these tests are easy to be carried out, they don't consider the subsoil bearing capacity. It is possible to take the subsoil into account by modifying the C.B.R. test (figure 4).

A cylinder 200 mm high is filled with a soil an the piston, 50 mm in diameter, is

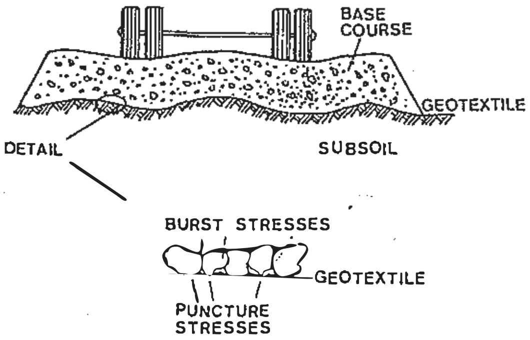

Figure 1 : Geotextile used as a separator

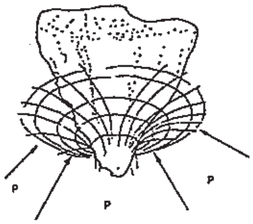

Figure 2 : Visualization of a stone puncturing a geotextile (after {5})

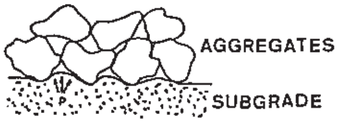

Figure 3 : Visualization of the burst pressure

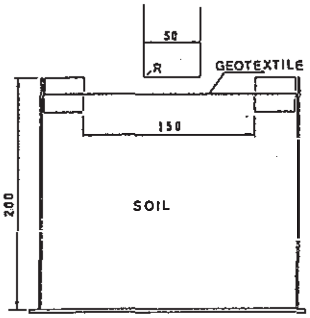

Figure 4 : Test device : puncture test taking into account the soil bearing capacity

pushed through the geotextile until failure. The force-elongation curve is recorded. Two ring diameters have been used for the experiments.
The ring outside diameter is the cylinder inside one.

Wishing to study of the subsoil bearing capacity, the soil used for experimentation was an Hesbayan silt. By increasing the soil water content, it was possible to decrease the soil bearing capacity. The soil characteristics are given table 1.

Table 1. Characteristics of the soil used for experimentation

Atterberg limits $w_p = 21.1$ %
$w_\ell = 31.2$ %

w %	γ/γ_w	c_u (kPa)	θ (°)
20	1.98	66.8	27
22	1.96	41.8	27
24	1.93	23.5	27
26	1.92	11.9	27

where : w is the water content by weight
γ/γ_w is the density
Cu is the undrained shear strength
θ the friction angle

The undrained shear strength decreases rapirapidly as the water content increases (figure 5).

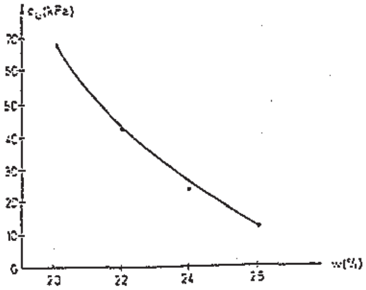

Figure 5 : Evolution of the soil undrained shear strength with its water content

3. TESTS RESULTS

It appears that the 120 mm diameter ring was too small for a puncture test and the results given here after are only the ones of the 150 mm diameter ring (tables 2 and 3).

Table 2. Puncture resistances obtained with a 150 mm diameter ring (w)

μ (g/m2)	Cu = 66.8	Cu = 41.7	Cu = 23.5	Cu = 11.9	without soil
90	2240	2050	1840	1575	980
140	2960	2575	2185	1950	1360
200	3625	3250	2910	2675	1800
280	4655	4385	3975	3645	2425

Table 3. Piston displacement at break (mm)

μ (g/m2)	Cu = 66.8	Cu = 41.7	Cu = 23.5	Cu = 11.9	without soil
90	30	37	35	41	36
140	36	38	36	43	34
200	40	48	44	60	40
280	44	43	43	54	38

Tensile tests were also performed according to RILEM proposals. The results are given table 4.

Table 4 : Tensile tests results

μ (g/m2)	R_1 (N/m)	R_2 (N/m)	ε_1 (%)	ε_2 (%)
90	6230	6800	80	34
140	9600	9840	83	42
200	12700	13800	110	56
280	19440	20600	111	69

where : R_1 is the tensile resistance in the direction of production

R_2 is the tensile resistance in the direction perpendicular to production

ε_1 is the strain at failure for the tests in the direction of production :

$$\varepsilon_1 = \frac{\ell_1 - \ell_0}{\ell_0} = 100\ \% \text{ (figure 6)}$$

ε_2 is the strain at failure for the tests in the direction perpendicular to the direction of production :

$$\varepsilon_2 = \frac{\ell_2 - \ell_0}{\ell_0} = 100\ \%.$$

The soil above which the geotextile is laid can absorb a big part of the puncture energy. The higher is the soil undrained shear strength, the higher is the puncture force that the soil-geotextile system can absorb.

The piston displacement at break is for a given geotextile a constant. Moreover the failure always occurs in the direction perpendicular to the direction of production. It seems then that the rupture criteria is a function of the strain ε_2. We also noticed that the displacement of a given point of the geotextile during a puncture test follows a vertical straight line. So it appears that there wouldn't be any radial strain.

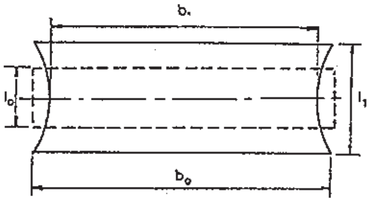

Figure 6 : Dimensions of the tensile test specimen

The shape taken by the geotextile sample during the test may be assumed to be parabolic (figure 7). So for a given value of the piston displacement r, it 's possible to determine the length L^* of this parabole. Indeed, if we assume (figure 7.b.) that for :

$$x = 0,\ y = 0$$

$$x = L \quad y = r \quad \text{and } y' \frac{dy}{dx} = 0$$

$$y = ax^2 + bx + c$$

then we have $y = -\frac{r}{L^2}x^2 + \frac{2r}{L}x$

and $L_1^* = \int_0^L \sqrt{(1 + (\frac{dy}{dx})^2)}\ dx$

Moreover if we assume that the stress at the ring is the ratio of the force at failure and the perimeter : $\sigma = F/2\pi r$, we can, using the force-elongation curve, calculate the strain at the ring. We assume too that the strain at break at the piston is ε_2 and that the strains vary linearly between the piston and the ring, then we can also determine the length of L_2^* of the parabole (figure 8).

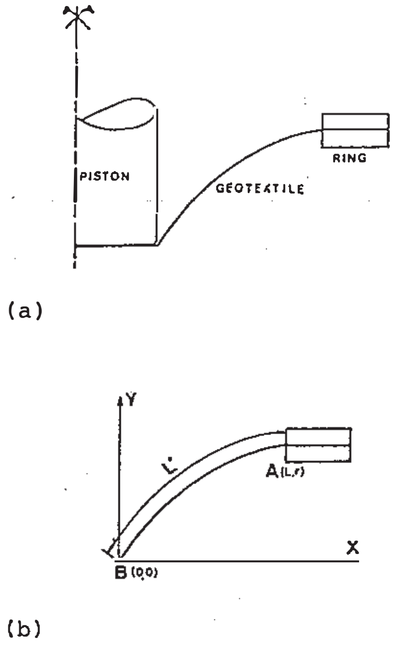

Figure 7 : Parabolic shape of geotextiles index puncture loading

$$L_2 = \frac{\varepsilon_2 + \varepsilon_{ring}}{2} L$$

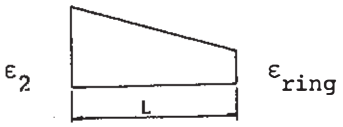

Figure 8 : Strain diagram

Table 5 : Results table

μ (g/m2)	ε_2 (%)	ε_{ring} (%)	L_1^* (cm)	L_2^* (cm)	$\frac{L_1^* - L_2^*}{L_1^*}$ x 100 %
90	34	17	6.4	6.4	0.0
140	42	14	6.6	6.5	1.5
200	56	19	7.2	6.9	4.2
280	69	19	7.2	7.3	-1.4

These comparison of L_1^* and L_2^* shows that the rupture criteria seems to be the value of the strain at break of the geotextile in the direction perpendicular to the direction of production in a tensile test.

4. PUNCTURE ANALYSIS

Both puncture elongation and puncture strength must be taken into account when assessing the risk of puncture of a geotextile under static loading - whereby the traffic loading from traffic movement on the construction site is also assumed as a static load.

Puncture strength

The forces acting at the contact points of geotextile and rock must be determined in order to evaluate the required puncture strength. The required puncture strength of a geotextile is generally expressed as :

$$F_{req} = \frac{\pi}{4} p' f_s d_m^2 \qquad (1)$$

Whereby should be considered that the magnitude of the contact force depends upon the number of contact points.
In this relation (1), we have :

F_{req} is the required strength as a function of load and fill (kN)
d_m is the average diameter of the granular material (m)
p is the maximum pressure exerted on the geotextile (kN/m^2)
f_s is a factor of safety.

The existing puncture strength is determined with a C.B.R. test with soil underneath the geotextile. The shape of the grain can be taken into account by means of a shape factor S_p.
According to {2} the shape factor varies from 0.8 for round blunt shapes to 3.0 for pointed, sharp-edged shapes.

5. ADAPTED DESIGN METHOD

It can be possible to define the right geotextile to use from what it is said before (figure 9).
By formula (1) it is possible to find the required resistance of the geotextile as a function of d_m and p'.
Having the required resistance, it is possible to determine the geotextile to use.

Example :

For a truck with a tire inflation pressure of 800 KPa in the stone base above the fabric; p' the pressure on the geotextile is according to {2} equal to 0,75 x tire inflation pressure.
So p' = 0,75 x 800 = 600 kN/m^2.
So for stones of 8 cm in size, the required resistance is, for a safety factor of 1 equal to :

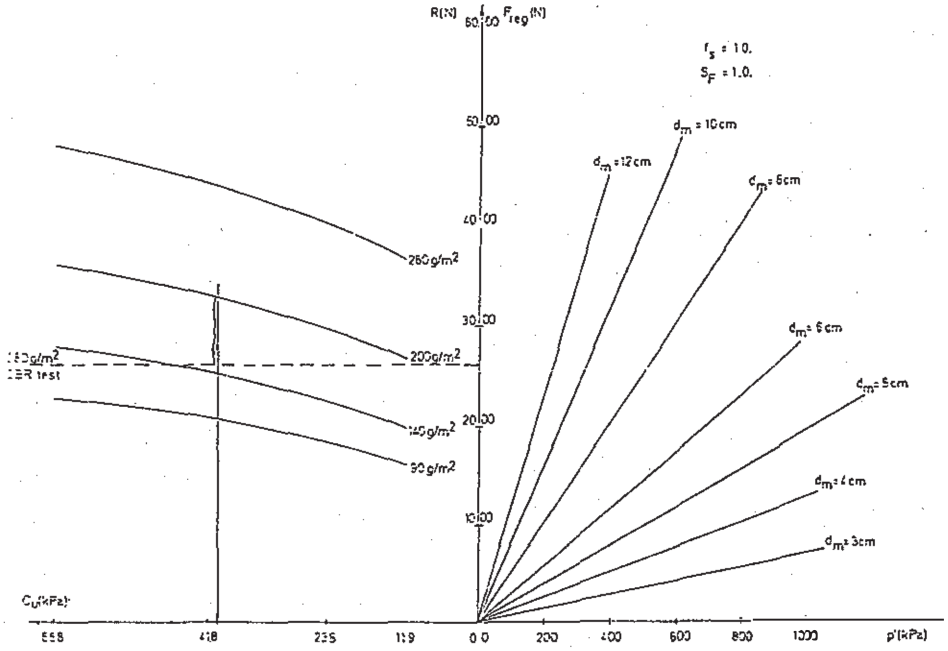

Figure 9 : design chart

$$F_{req} = \frac{\pi}{4} \times 600 \times 0{,}08^2 \times 1 = 3{,}02 \text{ kN}$$

For a soil with a Cu of 40 KPa, the required geotextile is, for a shape factor equal to 1, a 280 g/m^2 geotextile.
Let's note that according to DIN 54307 E, the puncture resistance of a 280 g/m^2 geotextile is only 2600 N so according to DIN 54307 E, the geotextile 280 g/m^2 wouldn't be sufficient (dotted line).
So the gain with soil beneath is obvious.

6. CONCLUSIONS

- It appears that the presence of soil beneath the geotextile has a great importance. In the case developed above, the gain was 27 %. Moreover this tests represents better the reality than the C.B.R. test.
- Without soil, the values obtained with the C.B.R. test or the modified C.B.R. test (with a 3 sided pyramidal piston) are very different. With a pyramidal piston with soil underneath the geotextile, there is probably a gain too, comparatively to the case without soil.
  A bearing effect existing with the cylindrical piston will probably disappear to give place to a more local effect.
- The rupture criteria seems to depend only on the strain at break in the direction perpendicular to production.

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