Third International Conference on Geotextiles, 1986, Vienna, Austria

WERNER, G., Chemie Linz AG, Austria

DESIGN CRITERIA FOR THE SEPARATION FUNCTION OF GEOTEXTILES ON THE BASIS OF MECHANICAL TEST PROCEDURES

BEMESSUNGSGRUNDLAGE FÜR DIE GEOTEXTILTRENNFUNKTION AUF BASIS MECHANISCHER GEOTEXTILPRÜFUNGEN

LE DIMENSIONNEMENT DE GEOTEXTILES JOUANT LE ROLE DE SEPARATEUR SUR LA BASE D'ESSAIS MECANIQUES

The separation function of geotextiles is the primary function in the majority of geotextile applications. When considering international specification tendencies that aim to guarantee the separation function of geotextiles one finds the CBR-puncture Resistance, Muller Burst Strength and Tear Strength as essential specification criteria. However these test results can only be viewed as suitable criteria for specifications if they are considered in relation to site related stresses. Tests which have been carried out show that in a practical context modification of the standard CBR-test may result in a significant reduction of the puncture resistance of various geotextiles. They indicate the necessity for additional specifications and classifications that consider the importance of strength and elongation in relation to on-site conditions.
This paper specifically evaluates the relevant stress situations for geotextiles by means of puncture, burst and tear analysis of the mechanical properties of Polyfelt TS non-woven (continous filament needle punched polypropylene geotextile).

Introduction

The specification and classification of geotextiles without reference to influencing factors related to the actual construction site contradicts engineering principles. In order to determine the geotextile stresses during insertion and after completion, a correlation must be created between the existing material properties, established by geotextile testing, and those material properties required on the basis of loading conditions.

1) Geotextile stresses
Puncture and burst stresses are the main types of stress for geotextiles placed between soft soil subgrades of low bearing capacity and the fill (Fig. 1). The stress-strain behaviour of the geotextile adapted to the types of stress must be such as to ensure the geotextile's separation function.

a) General elongation analysis
A geotextile's high elongation at break enables it to adapt undamaged to the unevenness and irregularity of the surface of the terrain and the granular material regardless of the order of magnitude of the subgrade reaction.
Geotextiles with high elongation at break are thus also unaffected by the specification criterion of tear propagation strength, since even in the case of dynamic loading the occurrence of perforations, which are a starting point for tear propagation stresses, is unlikely.

b) General strength analysis
The geotextile must be able to continuously absorb without damage
- local stress concentrations resulting from point loading by correspondingly high puncture strength, and
- the burst pressure resulting from uniform contact pressure by "bridging" the voids of the granular material, i.e. it must have adequate burst strength.

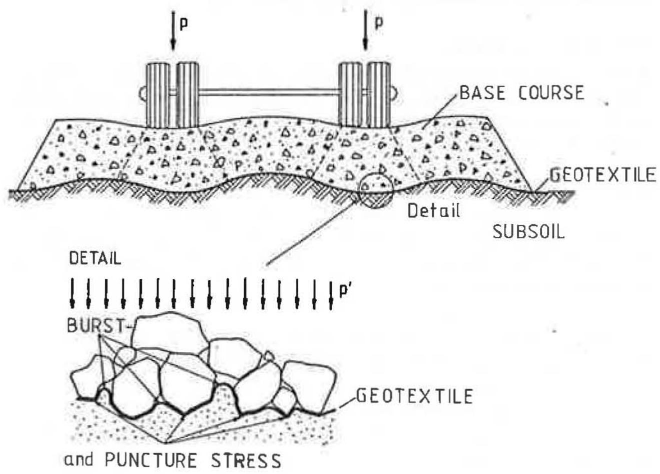
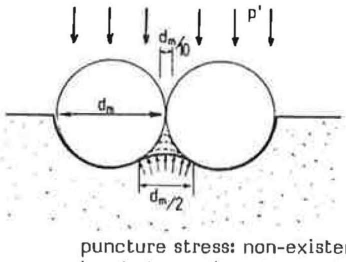


Fig. 1 Geotextile stresses decisive for the separation function

c) Analysis of boundary values for deformation geometry
A prerequisite for the following analysis of boundary values is a sufficiently soft consistency of the suboil, permitting stones or other granular materials to be pressed into the soft earth under realistic loading conditions.

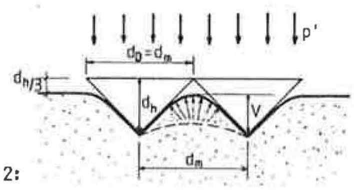
I) rounded, blunt granular materials



puncture stress: non-existent
burst stress: $d_B = d_m/2 - d_m/10$
where
d_B = effective burst diameter
d_m = average diameter of round stone

II) sharp-edged, pointed granular materials

ad Fig. 2:



puncture stress: $d_D \geq d_m$
burst stress: $d_B = d_m$
where
d_D = effective puncture diameter
d_m = average diameter of angular stone

Fig. 2: Deformation geometry of the geotextile separation layer

Borderline cases I and II provided the basis for the test establishment to compile rating diagrams for puncture and burst analysis. However, as this stress situation would impose over-extreme standards of performance on a geotextile for separation function requirements in the normal situation where crushed rock is used, the actual strain diameters were reduced accordingly (see sections 2 and 3).
Furthermore, according to (1), it can be assumed that on average there is one contact point per 10 cm diameter on the contact surface of the fill and the geotextile.

2) 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.

2.1. Puncture strength

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

$CBR_{req} = d_m{}^2 \cdot \pi/4 \cdot p' \cdot f_s$ . . . . . (1)

whereby should be considered that the magnitude of the contact forces depends upon the number of contact points.

CBR_{req} = required CBR strength as a function of load and fill
d_m = average diameter of the granular material
p' = max. pressure exerted on the geotextile (traffic load or embankement load)
f_s = factor of safety

The existing puncture strength can be determined eiter by using a modified CBR test with pyramidal piston points, or by an unmodified CBR test according to DIN 54307 E, allowing for the grain form by means of a form factor.
The value obtained via equation (1) must be compared with the CBR values from the modified piston punching test in which a 3-sided pyramid with sides 5.0 cm long and a height of 2.5 cm was used as the piston point, i.e. with the CBR values calculated using the form factor:

$CBR_{req} \geq CBR_{mod}$ or $CBR_{req} \geq CBR \cdot S_f$ . . (2)

where
CBR_{mod} = CBR strength from modified CBR test
CBR = CBR strength according to DIN 54307 E
S_f = shape factor for rock, varying from 0.8 for round blunt shapes to 3.0 for pointed, sharp-edged shapes (2)

The pyramid selected corresponds to the sharp stone aggregate in boundary case II and to a shape factor of S_f = 2 to 3, i.e. a shape factor for crushed rock (2).
A safety factor of f_s = 1.2 is recommended for local stress concentratins to allow for possible inhomogeneities in the geotextile.

2.2. Punture elongation

High elongation at break guarantees maximum security against puncture, as the geotextile can thus adapt undamaged to the irregularities of the subsoil and the granular material. Possible penetration depth V of a rock in the soft subsoil as in Fig. 2 is taken as the elongation criterion:

$V \geq 2/3 \cdot d_h$ . . . . (3)

where
V = penetration depth of the piston in the modified CBR test
d_h = average height of the granular material

The correlation between penetration depth V and elongation ε in the CBR test using a 3-sided pyramid is shown in Fig. 3. The elongation, corresponding to a strip tensile elongation of 80 %, is sufficient according to the geometric elongation criteria to adapt to the discontinuity of the subsoil without damage. The vertical stresses, induced into the subsoil by traffic and embankment load, will force the geotextile to deform until it fits in with the aggregate surface. If this deformation can happen without puncture and burst, there will be no further stress-increase in the geotextile, even if the vertical stresses in the subsoil are significantly increased. Therefore it is a major need to have a high initial elongation as well as a high failure elongation to absorb most puncture forces during installation as well as in final condition without damage.

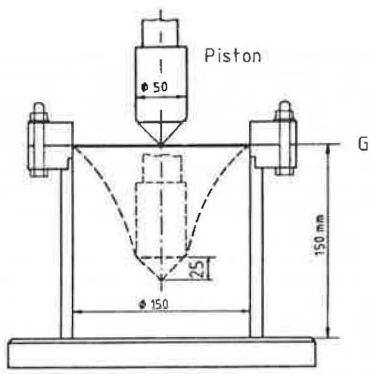


Fig. 3: Modified CBR test

The puncture tests with modified piston were carried out on mechanically bonded and heat bonded nonwoven geotextiles as well as on slit film fabrics, in order to determine by comparison possible differences in th puncture behaviour of various geotextiles available on the market.
The results of the modified CBR test are shown in Fig. 4.

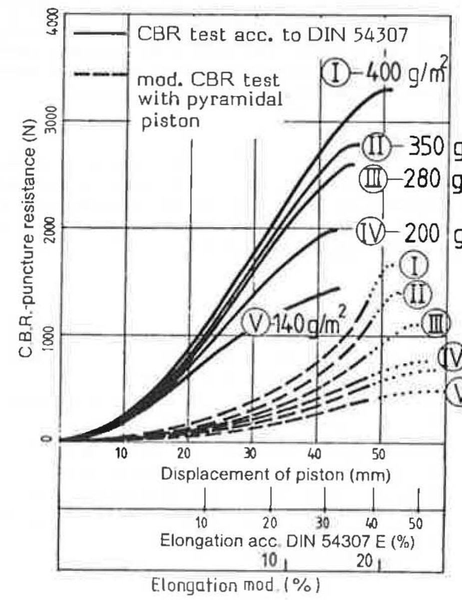
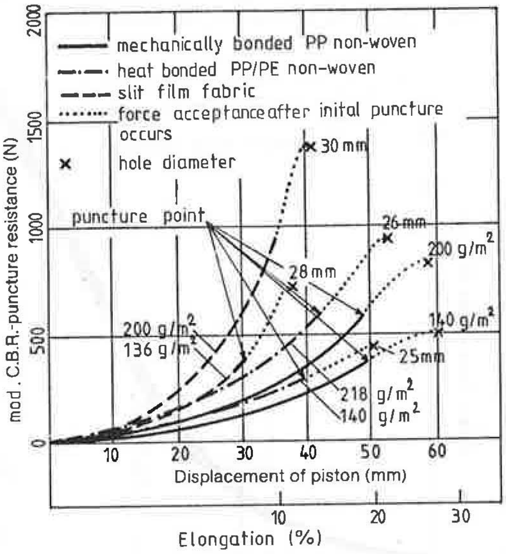
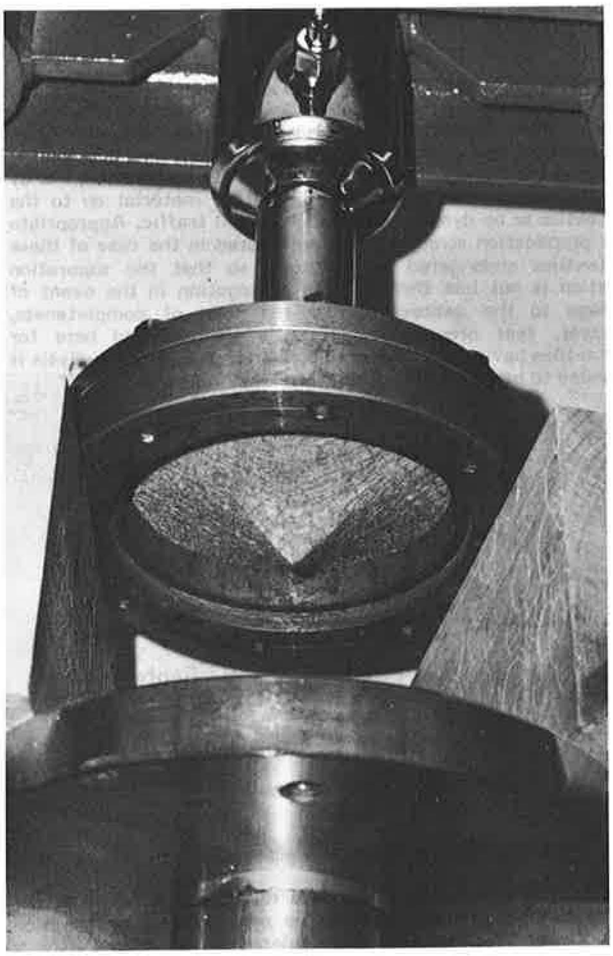


Fig. 4: Force -elongation diagram for
a) modified versus unmodified CBR test for continous filament needle punched polypropylene non-woven geotextile (I, II, III, IV and V types of different weights)



b) comparison of mechanically bonded and heatbonded non-woven and slit-film geotextiles



Picture to Fig. 3

The following design charts for puncture elongation and puncture strength have been compiled on the basis of the modified CBR results for continous filament needle punched PP non-woven (Fig. 5/6). Different CBR diameters of 5/12/15/22.5 cm were used to consider non-linear correlations between the diameter of the sample in the CBR test and the force-elongation behaviour of the nonwoven.

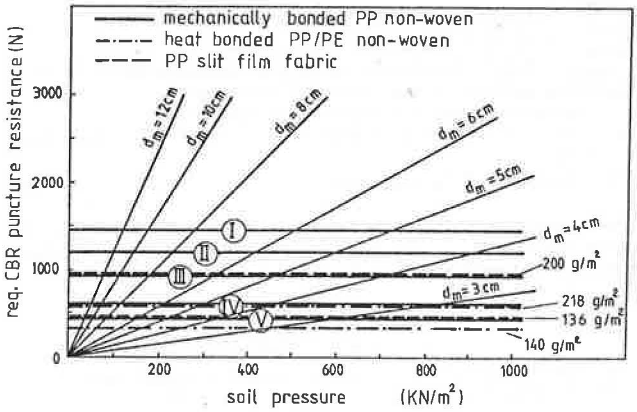


Fig. 5: Design Chart I for puncture strength

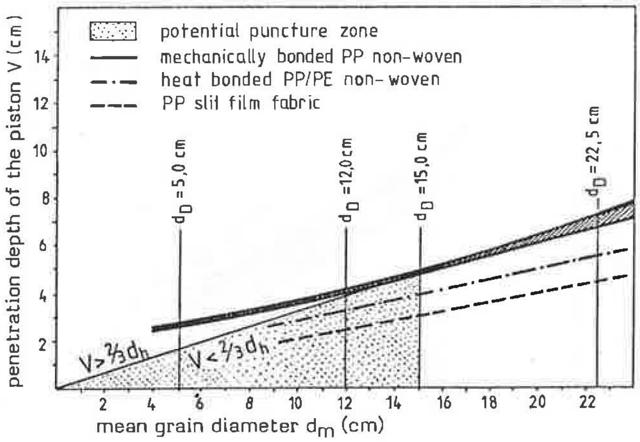


Fig. 6: Design chart II for puncture strength

The two simple design charts enable an assessment to be made on engineering principles of the puncture problems encountered in connection with a geotextile under static loading, thus also enabling meaningful specifications to be laid down in tender invitations for geotextiles for separation function applications.

2.3. Procedure for evaluating the problems associated with puncture

1) Calculation of maximum contact pressur p'
2) Determination of CBR req. in diagram I as f(p', d_m)
3) Comparison with CBR eff. in diagram I
4) Examination of V in diagram II as f (d_m)

If puncture strength $CBR_{req} > CBR_{eff}$, elongation no longer needs to be taken into consideration.
If puncture strength $CBR_{req} < CBR_{eff}$, the elongation, resp. required penetration depth V of the geotextile must be verified.

3) Burst analysis

The strength and elongation behaviour of a geotextile must also be investigated to assess its burst pressure behaviour.

3.1. Burst strength

The required burst strength can be approximately determined using the following equation:

$p_{test} \cdot d_{test} \cdot f(d_{test}) = p' \cdot d_B$ . . . . (4)

where

p_{test} = maximum burst test pressure
d_{test} = burst test diameter
$f(d_{test}) = f(d_B)$ = functional correlation between burst diameter and burst strength of the Polyfelt TS geotextile
p' = maximum pressure exerted on the geotextile
d_B = dm = maximum void diameter of the fill = actual burst diameter
dm = diameter of the aggregate

The functional correlation between burst diameter d_{test} and burst strength p_{test} was calculated as follows for the mechanically bonded continuous filament PP non-woven being tested:

$$f(d_{test}) = \frac{1}{e^{(0,65\, d_{test} - 1,95)}}$$

which produces the following expression for actual burst pressure p' by transformation of equation (4)

$$p' = p_{test} \cdot f(d_B) \cdot \frac{1}{33,3 \cdot d_B}$$

The additional assumption of a safety factor is not necessary, as any fines in the voids of the granular material will decrease the burst pressure and therefore result in conservative design for worst case situation (2).
The design chart for burst strength is given in Fig. 7.

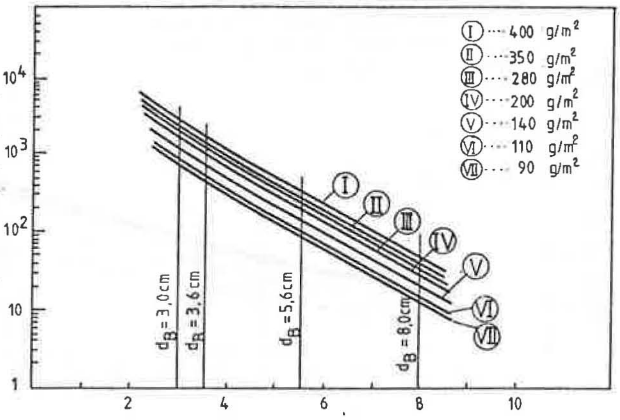


Fig. 7 Design Chart III for bursting strength

3.2. Burst elongation

Burst elongation is calculated via the height of the arch from the burst test. The elongation criterion is satisfied by the geotextile as soon as burst elongation exceeds 100 %, i.e. at an elongation of more than 100 % it can be assumed that under burst stress the geotextile will adapt to unevenness and to the voids in the fill material without tearing.
The burst elongation criterion for Polyfelt TS can be derived from Fig. 8 as a function of the actual burst diameter.

3.3. Procedure for verifying the problems associated with bursting

1. Calculating maximum subsoil pressure p'
2. Verification of the required geotextile burst strength as $f(d_m)$ in diagram III
3. Verification of the required geotextile burst elongation as $f(d_m)$ in diagram IV

The elongation criterion only has to be verified if the required burst strength cannot be attained by the geotextile.

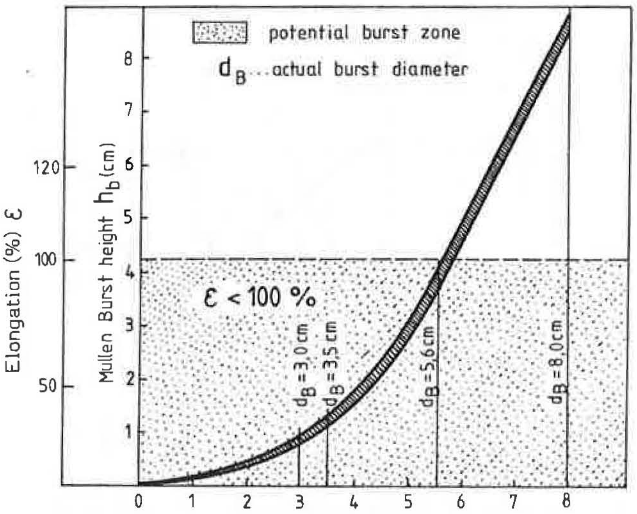


Fig. 8 Rating diagram IV for burst elongation

4) Analysis of tear propagation

Tear propagation stress is only a justified specification criterion for those geotextile which run the risk of being punctured due to their low elongation at break, through dynamic impact forces in the course of construction or after completion, i.e. by the tipping of sharp-edged rocks and fill material on to the geotextile or by dynamic loads such as rail traffic. Appropriate tear propagation strength must be assured in the case of these geotextiles endangered by puncture, so that the separation function is not lost through tear propagation in the event of damage to the geotextile. For the sake of completeness, however, tear propagation stress is also verified here for geotextiles having high elongation at break, since the analysis is intended to be generally applicable.

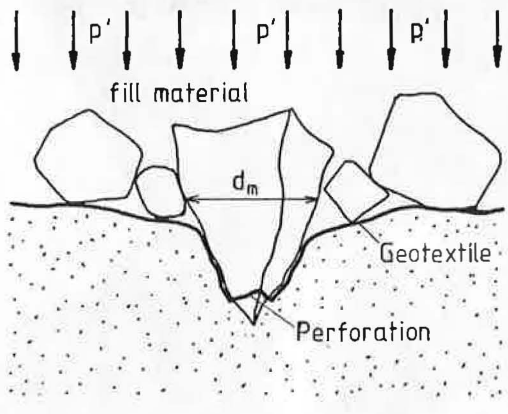


Fig. 9 Tear propagation stress of a geotextile

If a 3-sided pyramid is taken as a theoretical model for tear propagation stress (see Fig. 9), the required tear propagation strength can be approximately calculated via

$T_{req} = 0.1 \cdot d_m^2 \cdot p' \cdot S_f$ . . . . . (5)

where

d_m = mean grain diameter of filling material
p' = maximum subsoil pressure
S_f = cos α . sin α = form factor which varies from 0.1 for acuteangled to 0.45 for wide-angled objects

The greatest tear propagaton stress is imposed on the geotextile at an angle of
α = 45°, i.e. $T_{req} = 0.045 \cdot d_m^2 \cdot p'$

The required tear propagation strength can be derived from rating diagram V as f (grain diameter and subsoil pressure).

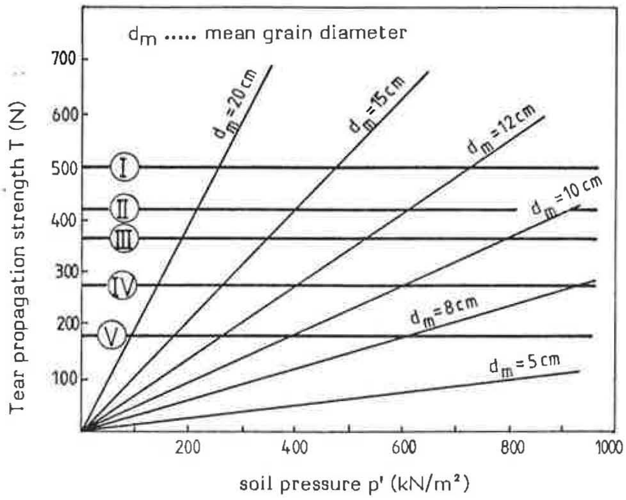


Fig. 10 Design Chart V for tear propagation strength (2)

5) Summary

The foregoing analyses for assessing the permissible geotextile stresses in road construction represent for static loads an alternative to arbitrary geotextile specifications. The analysis and associated tests yielded the following results:

- modification of the flat CBR piston by means of a pyramidal point approximating practical conditions, more closely resulted, in general, in a drastic reduction in CBR strength
- the reduction in CBR strength was as follows, in the materials investigated
  mechanically bonded continous filament PP non-woven 50 - 66 %
  heatbonded continous filament PP/PE nonwoven 70 - 75 %
  PP slit film geotextile 85 %
- the reduced strength can be compensated by a sufficiently high elongation at break
- the elongation criteria calculated from the deformation geometry were only satisfied by the mechanically bonded nonwoven fabrics among the various geotextiles investigated in this study
- there is no linear relationship between the actual burst puncture diameter and the stress-strain behaviour of the mechanically continous filament PP non-woven Polyfelt TS
- type selection can only be made by strength analyses but not by elongation analyses; elongation analyses can only be used for assessing break safety
- as a large proportion of standard geotextile specifications take into consideration, together with the required mechanical characteristics, only the loading condition after completion of construction work and not during the installation of the geotextile and the filling process, reproducible case studies closely related to practice must be required of those specifying geotextile, as a basis for puncture analysis and to supplement the static analysis

These results show that standard specifications can be developed on engeneering principles if the geotextile tests are viewed in relation to the stresses encountered on the construction site.

Further extensive tests are desirable, independ from the results obtained in this study, so that standard specifications do not incorporate merely arbitrary product characteristics but, realistic demands as to the application-specific characteristics of geotextiles.

Literature reference:

(1) Giroud,J.P., Geotextiles and Geomembranes-Definitions, Properties and Design, IFAI, 1984
(2) Bell,J.R.,Koerner,R.K., Design with Geosynthetics,Course Notes, Drexel University Philadelphia, 1984