Rupture Index for Puncture Resistance Classification of Geotextiles

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ABSTRACT: In order to determine the puncture resistance of geotextiles used for separation, CBR plungers with standard, pyramidal and hemispherical tips were used on a wide range of fabrics. Shape factors for predicting failure load under rounded and angular aggregate from standard plunger CBR puncture tests are shown to be fabric-specific, and different from previously quoted values. Conventional methods of expressing deformation as elongation make comparisons difficult, and it is proposed that deformation be expressed by CBR plunger displacement at failure. A rupture index for puncture resistance classification using results from the standard plunger CBR puncture test, is proposed.

1 INTRODUCTION

Separation is the primary function in most geotextile applications, and usually a secondary function in other situations. Tests which have been devised to determine the suitability of geotextiles as separators include CBR and drop cone puncture tests (Alfheim and Sorlie, 1977) and pyramid-tipped plunger puncture tests (Werner, 1986; Pühringer, 1990).

In Australia, geotextiles are frequently selected using the G-Rating, which is obtained by taking the geometric mean of the failure load (F_p) in a CBR puncture test on a 150mm diameter specimen (AS 3706.4, 1990), and the height (H_{50}) from which a cone must be dropped to give a 50mm diameter hole in a drop cone test on a 150mm diameter specimen (AS 3706.5, 1990).

$$G = \sqrt{F_p \times H_{50}} \qquad (\mathrm{N.mm}^{1/2}) \qquad (1)$$

This classification combines the results of two very different tests. According to Alfheim and Sorlie (1977), the drop cone test was developed because dynamic puncture resistance could not be related to tensile strength as measured in a CBR puncture test. They used the hole diameter to compare the resistance to penetration of various fabrics. The drop height (H_{50}) is not directly related to deformation of the geotextile.

A testing program was undertaken to see whether puncture resistance could be characterised by a single test. Tests were also carried out using modified CBR plungers with pyramidal and hemispherical tips, to model the shape of typical field penetrants eg. angular or rounded stone or aggregate.

2 TESTING PROGRAM

Samples of most of the geotextiles available in Australia in 1992 were obtained and tested in CBR puncture tests to AS 3706.4 (1990) using the standard, flat-ended plunger, and pyramid-tipped and hemispherical-ended plungers, all of 50mm diameter. Tests were performed in a controlled temperature (23±3°Celsius) and relative humidity (65±5%) environment, with samples conditioned in the environment for at least two hours before testing. A computer-controlled Instron testing machine was used, with automatic data-logging and result print-out.

The tip of the pyramid plunger had the following shape:

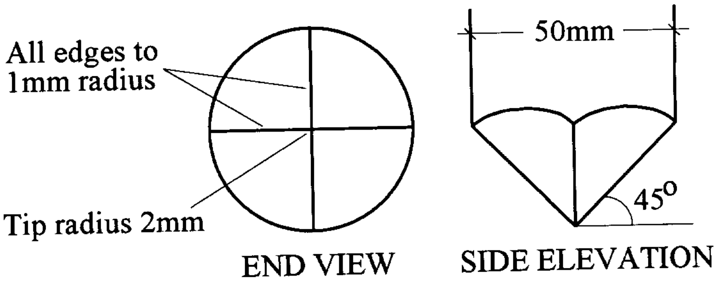

Figure 1 Dimensions of the pyramid-tipped CBR plunger.

The geotextiles tested, and a brief description of them, are given in Table 1.

Table 1 Summary of geotextiles tested.

Geotextile	Fabric type	Number	Polymer	Bonding method
Bidim	A 12	N_1	PET*	C. F. N. P[1]
	A 14	N_2	"	"
	A24	N_3	"	"
	A29	N_4	"	"
	A34	N_5	"	"
	A44	N_6	"	"
Polyfelt	TS 420	N_7	PP+	"
	TS 500	N_8	"	"
	TS 550	N_9	"	"
	TS 600	N_{10}	"	"
	TS 650	N_{11}	"	"
	TS 700	N_{12}	"	"
	TS 750	N_{13}	"	"
Polytrac	155	W_1	PET	Woven
	C	C	PP/PET	C. W./ N. P[2]
Polyweave	R	W_2	PP	Woven
	F	W_3	"	"
	HR	W_4	"	"
Propex	2002	W_5	PP	"
Terrafix	310 R	S_1	PET	S. F. N. P[3]
	360 R	S_2	"	"
Terram	700 SUV	H_1	PP/PE#	C. F. H. B[4]
	1000 SUV	H_2	"	"
	3000 SUV	H_3	"	"

* Polyester + Polypropylene # Polyethylene.

[1] Continuous filament needle punched.

[2] Composite woven / needle punched.

[3] Staple fibre needle punched.

[4] Continuous filament heat bonded.

3 TEST RESULTS

The failure load for the three plungers is given in Table 2, each number being the average of ten individual tests.

Compared with the standard plunger, the pyramid plunger failure load was 50-75 % less for all but the S fabrics, for which the failure load was almost the same. The pyramid plunger cut all fabrics except the S. The W and heavier N fabrics were most affected by cutting.

Compared with the standard plunger, the hemispherical plunger failure load was 2-20 % less for the N and H fabrics, 20-35 % less for the W fabrics and about 30 % less for the C fabric. The S fabrics showed a 13-20 per cent higher failure load. This behaviour of the S fabrics is attributed to the localisation of failure at the tips of both plungers, with the fibres sliding and re-aligning, rather than stretching and breaking.

Table 2 Average failure loads for the standard, pyramid and hemispherical plungers.

Geotextile	Failure load (N)				
	Standard	Pyramid	(a)*	Hemispherical	(b)*
N_1	1575	834	-47	1499	-5
N_2	1869	774	-59	1729	-8
N_3	2654	1113	-58	2317	-13
N_4	3125	1193	-62	2890	-8
N_5	3792	1570	-59	3687	-3
N_6	4520	1815	-60	4443	-2
N_7	1639	635	-61	1441	-12
N_8	1843	727	-61	1442	-22
N_9	1903	618	-68	1530	-20
N_{10}	2523	845	-67	2152	-15
N_{11}	2729	865	-68	2417	-11
N_{12}	3451	1166	-66	2969	-14
N_{13}	4635	1568	-66	4085	-12
W_1	3621	807	-78	2361	-35
C+	1493	595	-60	1020	-32
W_2	1866	635	-66	1371	-27
W_3	2764	1023	-63	2094	-24
W_4	4651	1188	-75	3486	-25
W_5	3506	935	-73	2693	-23
S_1	1363	1403	3	1540	13
S_2	1871	1894	1	2267	21
H_1	934	403	-57	820	-12
H_2	1182	601	-50	1094	-8
H_3	2547	1022	-60	2495	-2

* Columns (a) and (b) give the percentage difference in failure load compared with the standard plunger.

\+ Values for this fabric are the average of tests on both faces.

4 SHAPE FACTORS

So that the effects of angular or rounded aggregates can be allowed for when only standard CBR puncture test data is available, several authors have proposed the application of shape factors (Bell and Koerner, 1984; Warwick, 1991). In this investigation, a shape factor is defined as

$$\frac{F_p}{F_{mod}} \tag{2}$$

where F_p is the failure load in a standard CBR puncture test and F_{mod} is the failure load in a modified plunger CBR puncture test. Values calculated for the fabrics tested and the plungers used are given in Table 3.

Table 3 Average shape factor values for the fabrics tested.

Geotextile	Average shape factor	
	Pyramid	Hemispherical
N_1	1.9	1.1
N_2 - N_6	2.4	1.1
N_7 - N_8	2.5	1.2
N_9 - N_{13}	3.0	1.2
W_1	4.5	1.5
C	2.5	1.5
W_2- W_3	2.8	1.3
W_4	3.9	1.3
W_5	3.8	1.3
S_1 - S_2	1.0	0.9
H_1 - H_3	2.3	1.1

Assuming that the two plungers adequately model real aggregates, the values of 3.0 and 0.8 quoted in the literature for angular and rounded aggregates are too general to be of any real use in geotextile choice. The value of 0.8 for rounded aggregate is obviously unsatisfactory. It is apparent that shape factor values depend mainly upon fabric type, particularly for angular aggregates, and on weight to a lesser extent.

5 ELONGATION OF FABRICS

In conventional analysis of the CBR puncture test, fabric elongation has been defined in two ways - by Equation 3 (DIN 54.307) or by Equation 5 (Cazzuffi et al., 1986).

$$\left(\frac{x-a}{a}\right)\times 100 \qquad (3)$$

$$\left(\frac{x-a}{a+r}\right)\times 100 \qquad (4)$$

$$\left[\frac{\pi(R+r)x+\pi r^2-\pi R^2}{\pi R^2}\right]\times 100 \qquad (5)$$

where the symbols used are defined in Figure 2.

Each equation assumes that the stretched fabric shape in cross-section is made up of straight lines. Equations 3 and 4 are based on linear dimensions of a section through the specimen while Equation 5 is based on the area of the specimen.

Equation 4 is a modified version of Equation 3, with the inclusion of the plunger radius in the denominator accounting for deformation across the base of the plunger. This equation gives elongation values 33 % lower than Equation 3. Equation 5 gives values 11 % lower than Equation 3.

As the fabric is distorting in three dimensions, Equation 5 seems to be the most appropriate to describe elongation behaviour. However, it is observed that, between A and B, the fabric is curved and, as peak load approaches, the fabric makes contact with the sides of the plunger near the tip. Therefore, Equation 5 only approximates actual behaviour.

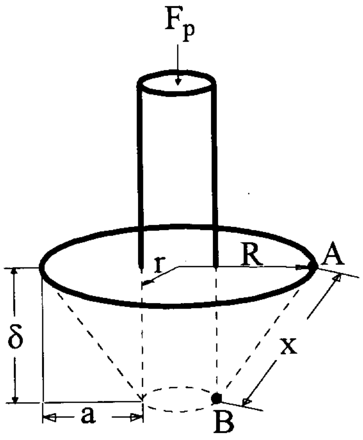

Figure 2. Variables for CBR puncture test elongation calculations (after Murphy and Koerner, 1988)

The use by authors of different definitions of elongation, none of which accurately represent the actual behaviour of the materials, makes comparisons between studies difficult. This could be overcome by adopting the displacement at failure of the CBR plunger as the measure of deformation.

6 RUPTURE INDEX

Rupture resistance has been defined as the product of failure load per unit width and elongation at failure, as measured in a wide strip tensile test (Foch, 1990). In fulfilling the separation function, resistance to rupture caused by puncture and bursting is as important as resistance to tensile rupture. Giroud (1981) has stated that a geotextile which does not reach 100 % elongation in a plane strain tensile test must have an increased tensile strength in order to adequately resist puncturing. Resistance to puncturing in the CBR puncture test is due to both tensile strength and deformation capacity, and not to one or the other acting independently.

A rupture index is proposed, defined as the product of failure load and plunger displacement at failure in the standard plunger CBR puncture test.

$$RI = F_p \times \delta \qquad (\text{kN.mm}) \qquad (6)$$

where F_p is the failure load in a standard plunger CBR puncture test in kN and δ is the plunger displacement at failure.

Values of the index for the fabrics tested in this investigation are given in Table 4.

Table 4 Rupture index values for the fabrics tested.

Geotextile	Rupture index (kN.mm)	Geotextile	Rupture index (kN.mm)
N_1	63	N_{13}	213
N_2	78	W_1	115
N_3	113	C	35
N_4	143	W_2	62
N_5	173	W_3	100
N_6	208	W_4	176
N_7	66	W_5	132
N_8	79	S_1	100
N_9	87	S_2	136
N_{10}	115	H_1	47
N_{11}	122	H_2	62
N_{12}	156	H_3	131

A plot of RI against pyramid plunger failure load is given in Figure 3. Except for the two S fabrics RI correlates well with pyramid plunger failure load, and this plunger models angular aggregates, which are of most concern with respect to puncture resistance. Suggested ranges of RI for puncture resistance classification are shown on the figure.

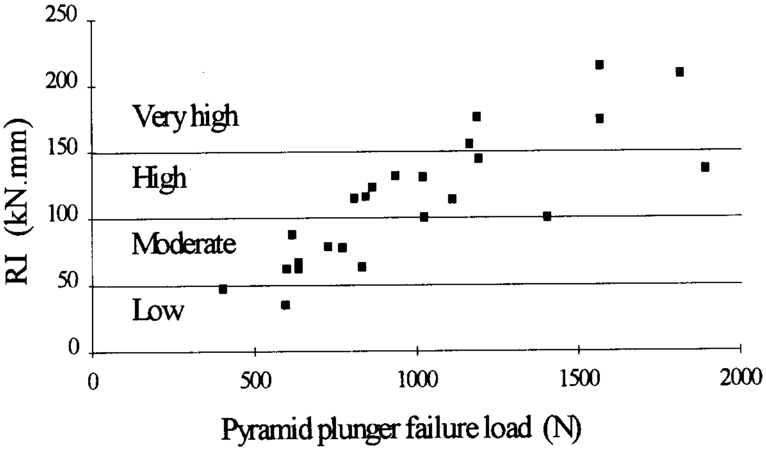

Figure 3 RI ranges for puncture resistance classification.

7 CONCLUSIONS

For geotextiles used in the separation function with angular aggregate, the rupture index should be a good performance indicator. Data from field trials would provide necessary verification to aid in its adoption.

The shape factor values quoted in this paper are different from those quoted in other papers, and appear to be fabric-specific, especially under the pyramid plunger.

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