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In service performance of geotextile separators

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ABSTRACT: Data from a set of field and laboratory simulated damage trials on various geotextile types is presented. A good correlation was found between the retained strength determined from field damage and that from laboratory simulated damage trials. The retained strength is correlated against mass per unit area, strain energy and the deflected shape of the geotextile insitu. Mass per unit area gives the best correlation and is therefore proposed as the best means of specifying a geotextile for separation applications.

1 INTRODUCTION

Geotextile separators have been used in road construction for over 30 years. Their primary function is to separate two different soil layers and to preventing intermixing at the interface between these layers, for example separating a granular subbase from a soft subgrade. By removing intermixing at the soil/fill interface the full potential frictional strength of the fill can be utilised. A secondary function of a geotextile in a separation application is to allow free movement of water out of the subgrade.

The ability of a geotextile to perform its function for the full service life of the road pavement relies on the geotextile surviving installation. Unfortunately the test methods available for the assessment of geotextile properties are mainly index tests. These allow direct comparison of the properties of one geotextile type with another manufactured using the same process but provide little information on the ability of a geotextile to perform its separation function. At present site trials are the only means available to assess the ability of a geotextile to fulfill its function in separating soils. Many authors have provided guidance on the selection of geotextiles in relation to the measured index properties. These generally relate to mass per unit area (Merkblatt, 1994) or strain energy determined from index tests on damaged or undamaged samples (Watn et al, 1998, Blivet, 1999).

Results from a series of damage trials, both field and laboratory simulated, carried out on a wide variety of geotextile types currently used as separators is presented. The methodology used in the site trials is described. A detailed analysis of the performance of the geotextiles tested is presented. The assessment was performed using, mass per unit area, strain energy and assumptions about the deflected shape of the geotextile under a protruding object. The simulated damage trials were performed using the laboratory index standard, ISO 10722-1 (1998), for the assessment of installation damage. A comparison is made between the strength properties determined from the field trials and the laboratory index tests. Retained strength defined as the ratio of tensile strength after damage to initial tensile strength is used to correlate *in situ* tests to the new index standard.

Finally, recommendations are made for the selection of geotextile separators.

2 INSTALLATION DAMAGE TRIALS CONDUCTED FOR THIS STUDY

In order to quantify the magnitude of the strength reduction experienced by a geotextile a number of products representing a range of geotextile types were exposed to both field and laboratory simulated installation damage. The principle aim of the trials was to expose the geotextiles to installation damage and to assess their survivability by measuring their retained tensile strength and to correlate this reduction in tensile strength to current assessment procedures. In total eight geotextile products, one woven, four thermally bonded and three mechanically bonded where tested in the trials. Table 1 summarises their initial properties as reported in the manufacturers' literature.

Table 1. Properties of geotextiles used in field and laboratory damage trials as given in the manufacturers' literature.

Geotextile	Mass per unit area (g/m$^{2)}$	Peak tensile strength (kN/m)	Peak strain (%)	Field / laboratory damage
W	90	18 / 9*	26 / 24	Both
HB1	135	8.0	25	Both
HB2	246	18	33	Lab
HB3	350	22	33	Lab
HB4	138	8.4	60	Both
MB1	147	8.8/7.0*	80/50*	Lab
MB2	392	15.6/24.9*	140/135*	Lab
MB3	105	8.0	95	Field

* Machine direction / Cross machine direction

2.1 *Field trials*

Field trials were conducted on 10 m by 4.5 m sections of each geotextile. The geotextiles where placed on a 200 mm layer of scalpings which overlay a stiff subgrade with an estimated CBR > 25 %. The geotextiles where then covered with UK Department of Transport Type 1 (DoT, 1993) material to a minimum depth of 200 mm. In all cases the depth of fill did not exceed 300 mm. Traffic damage was then simulated by 14 passes of a 4 axle truck with a gross weight of 32 t. Samples of the geotextiles immediately below the wheel tracks where carefully exhumed and tested. Enough material to perform 6 standard wide width tensile tests on each geotextile type was recovered. The retained tensile strength and retained peak strength both expressed as percentages of the manufacturers' quoted values are shown in Table 2.

Table 2. Retained tensile strength and peak strain after field trial.

	W	HB1	HB4	MB3
Retained tensile strength (%)	8*	45	40	43
Retained peak strain (%)	34*	60	38	54

* Machine direction only

2.2 *Laboratory index test for field damage*

The laboratory index test for installation damage (ISO 10722, 1998) was used to assess the performance of one woven, four thermally bonded and two mechanically bonded geotextiles. The retained tensile strength and retained peak strain after simulated damage presented as percentages of the manufacturers' quoted values are presented in Table 3.

Table 3. Retained tensile strength and peak strain after laboratory simulated damage trial.

	W	HB1	HB2	HB3	HB4	MB1	MB2
Retained tensile strength (%)	31*	57	82	97	50	58*	96*
Retained peak strain (%)	31*	64	81	69	14	47*	76*

* Machine direction only

2.3 *Comparison of field and laboratory index tests*

While the laboratory simulated damage test does not represent the actual field behaviour of a geotextile in terms of localized damage due to protruding objects it does show a similar trend in terms of retained tensile strength to that seen in the field trials. Geotextiles that suffered large reductions in strength and strain in the field trials also suffered large reductions in the laboratory simulated damage test. To that end the laboratory test is useful for comparing trends rather than comparing the actual magnitude of the retained tensile strength or strain.

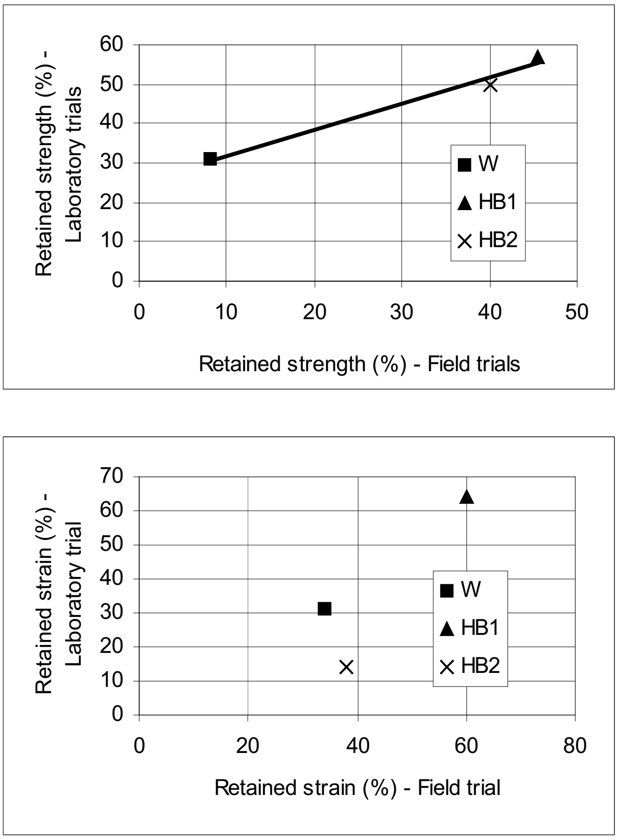

Figure 1. (a) Comparison of field and laboratory retained tensile strengths (b) comparison of field and laboratory retained peak strains.

Figure 1 shows a comparison between the retained strength and retained peak strain for the geotextiles tested in both the field and laboratory trials (W, HB1, HB4). It can be clearly seen that the retained strength from the laboratory trial is much higher than that actually measured in the field. This may be explained by the high CBR of the subgrade in the field trial. The retained peak strains show considerable scatter and no firm conclusion can be drawn from the data.

3 EXAMINATION OF CURRENT ASSESSMENT PROCEDURES FOR GEOTEXTILE SURVIVABILITY

Several methods of assessing the survivability of a geotextile have been proposed. The principle methods are mass per unit area, strain energy and deflected shape of the geotextile in the ground. These methods are now reviewed using the data determined from the field and simulated damage laboratory testing.

3.1 *Mass per unit area*

Mass per unit area in an intrinsic property of a geotextile and has therefore been proposed as a method of assessing a geotextile's survivability by Lawson (1991 & 1995). Figure 2 shows the retained strength from the laboratory simulated damage trials plotted against mass per unit area. The data shows that a good correlation exists between mass per unit area and retained strength. The correlation appears to be independent of the manufacturing process. Products with similar initial mass per unit area, HB1, HB4 and MB1, all show similar reductions in tensile strength of approximately 50 to 60 %.

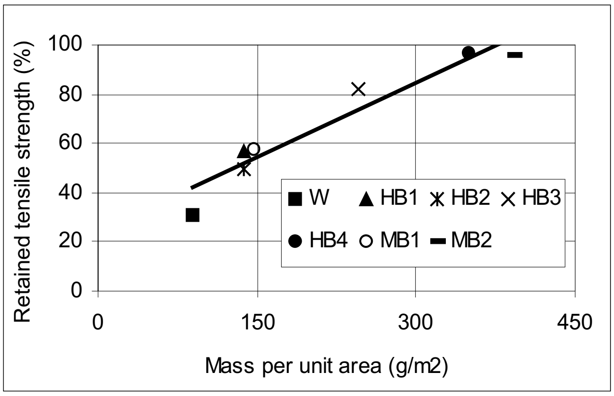

Figure 2. Correlation between mass per unit area and retained strength.

3.2 *Strain energy*

Watn et al (1998) proposed stain energy as a method of assessing the survivability of geotextiles. The method involves calculating the area under a stress strain curve for the geotextile. Of the test methods available the wide width tensile test is most often used. The strain energy method has been incorporated into a number of classification schemes. In these schemes the strain energy is calculated using the following simplified equation:

$$\text{Strain energy} = \tfrac{1}{2} T_{peak} * \varepsilon_{peak} \qquad (1)$$

Where T_{peak} is the peak tensile strength of the geotextile determined from the wide width tensile test and ε_{peak} is the corresponding strain at peak tensile strength.

The simplified method of calculating the strain energy of a particular geotextile assumes that the stress strain curve from the wide width tensile test is linear. Where the stress strain curve is nonlinear, as is the case with both woven and thermally bonded nonwoven geotextiles, the strain energy can be underestimate by between 25 and 40 %, Figure 3. The error in the calculated strain energy is proportional to the degree of nonlinearity of the stress strain curve.

The strain energies, calculated using the simplified method for the geotextiles with similar mass per unit area exposed to simulated damage in the laboratory index test are presented in Table 4. The strain energies show considerable variation and in general do not show a correlation to the retained tensile strength, Figure 4.

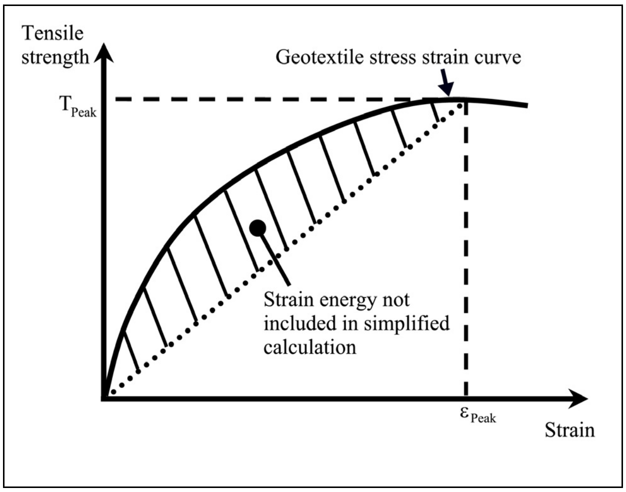

Figure 3. Discrepancy in the calculated strain energy using the simplified method.

Table 4. Strain energies of geotextiles of similar mass per unit area which were exposed to simulated installation damage.

Geotextile	W	HB1	HB4	MB1
Strain energy (kJ/m^2)	2.34	1.00	2.52	3.52

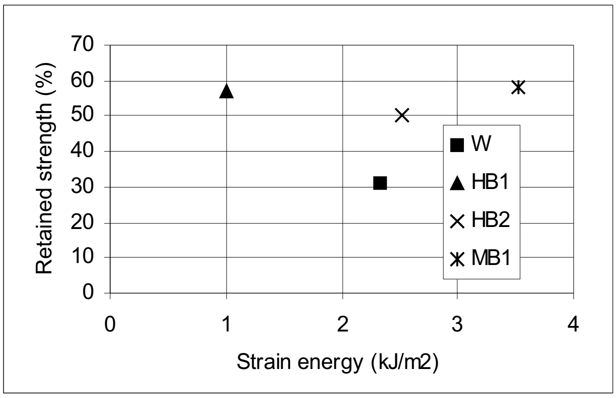

Figure 4. Comparison of strain energy and retained strength for samples examined in the laboratory trial.

3.3 *Deformed shape of the geotextile and minimum strain values.*

Giroud (1999) presented a theory based on the displaced shape of a geotextile under a protruding object, which showed that the greater the deformability of a geotextile the lower the tensile strength required. The theory was proposed in isolation with no reference to the stress strain characteristics of the geotextiles and was presented as such. A simplified calculation assuming plane strain conditions shows that a semicircular protruding object will result in a strain in the geotextile of 57 %, Figure 5.

Based on this analysis Blivet (1999) has proposed that geotextiles should have a minimum strain at peak tensile strength of 50 %. A strain less than this value should be compensated for by the tensile strength being increased to maintain the same strain energy. While a semi circular protruding object may result in a strain of 57 % under plane stain conditions it will also cause the geotextile to carry a high sustained load that can be easily estimated from the stress strain curve. Any geotextile material which carries a sustained load over time will, by virtue of its polymeric structure, creep to failure at some point in time. Depending on the magnitude of the sustained load and the duration this may lead to failure of the geotextile due to creep rupture within its service life. This behaviour is shown diagrammatically in Figure 6.

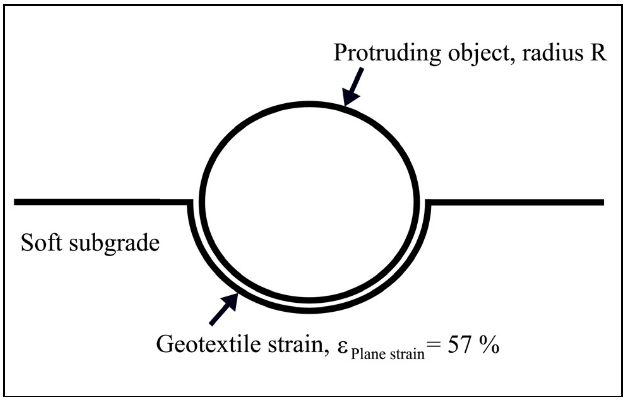

Figure 5. Assumed deflection of a geotextile under a semi circular protruding object in plane strain.

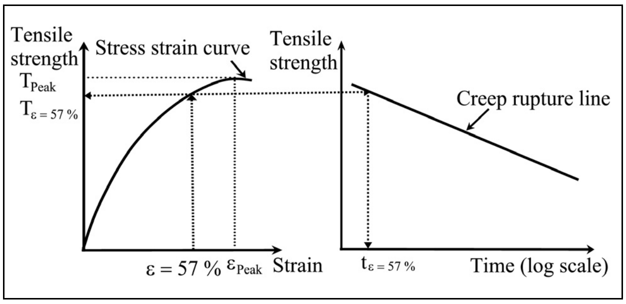

Figure 6. Creep rupture characteristic of a geotextile carrying a tensile strength corresponding to a strain of 57 %.

Based on a required peak strain of 50% or greater Table 5 presents estimates of the sustained loads carried by the geotextiles with peak strain > 50% loaded to 50% strain. The values were calculated assuming a linear stress strain curve. This assumption is valid for all mechanically bonded materials examined. For woven and thermally bonded geotextiles this assumption underestimates the load by approximately 10%. For MB2 which has anisotropic strength properties the lower strain value was taken.

Table 5. Percentage of ultimate tensile strength carried by each geotextile at $\varepsilon = 50$ %.

Geotextile	Peak strain (%)	Percentage of peak tensile strength (%)
HB4	60	83
MB2	135	37
MB3	95	53

Levacher et al. (1994) examined the creep behaviour of both woven and nonwoven geotextiles manufactured from polypropylene and reached the following conclusions:

1. Geotextiles manufactured from polypropylene exhibit significant creep that is mainly tertiary behaviour. The creep rate in terms of log(ε) – log(t) is 10 times that of polyester materials. The duration of tertiary behaviour is strongly influenced by the magnitude of the load.
2. With the exception of initial strains no significant difference in creep behaviour due to structure (woven or nonwoven) was found. This allows the creep behaviour of all geotextiles to be assessed using data generated from one geotextile type.

Both Levacher et al (1994) and Greenwood et al (2000) presented data on the creep behaviour of woven polypropylene geotextiles. The rupture data is summarised in Table 6. Considerable scatter exists in the times to creep rupture. For a geotextile loaded to approximately 50 % the time to failure can vary from 0.25 to 5.7 years. The time to creep rupture for the geotextiles given in Table 5 are estimated in Table 7. Only MB2 would survive past 7 years. It should be noted that MB2 is a heavy weight geotextile with a mass per unit area of 392 g/m^2.

Table 6. Times to creep rupture for woven polypropylene geotextiles, after Levacher et al (1994) and Greenwood et al (2000).

Load in geotextile as a percentage of peak tensile strength (%)	Time to rupture		Reference
	(hr)	(years)	
50	2133	0.25	Levacher et al (1994)
75	0.73	-	Levacher et al (1994)
55	10,000	1.14	Greenwood et al (2000)
52	50,000	5.70	Greenwood et al (2000)
41	65,000	7.42	Greenwood et al (2000)

Table 7. Estimated time to creep rupture for HB4, MB2 and MB3.

	HB4	MB2	MB3
Time to rupture (years)	< 0.25	0.25 to 5.70	> 7.42

The following conclusion can be drawn from the analysis of the deflected shape of the geotextile and specifying a minimum strain of 50 %. All geotextiles currently on the market, irrespective of initial peak strain, will fail when subjected to a protruding object. Where the peak strain < 50 % this will occur immediately after installation. For peak strain > 50 % this will occur in the times given in Table 7. These times are considerably less than the required service life, which is typically 25 years.

It is more appropriate to consider the average strain in the geotextile when examining the performance of the material insitu. The average strain in the geotextile away from these localized area is considered to be quite low, < 20 %. Studies by Watn et al (1998) have gone some way to confirming this. In their laboratory study of geotextile survivability they recorded strains in the geotextiles of between 4 and 10.3 % depending on geotextile type. Strains in thermally bonded geotextiles were considerably less than those in mechanically bonded materials of similar mass per unit area. This may in part be explained by the higher initial stiffness of thermally bonded geotextiles compared with mechanically bonded geotextiles.

4 COMPARISON OF ANALYSIS WITH OTHER STUDIES

Limited information is available in the literature on the measurement of geotextile survivability. Two recent studies that examined exhumed samples are presented by Black & Holtz (1999) and Rathmayer (2000).

Black & Holtz (1999) exhumed a number of geotextiles of various types five years after the construction of a paved road in Washington State. It was concluded that all the geotextiles types used appear to have survived both construction and use reasonably well. In some cases a migration of fines through random holes in the geotextiles did occur up to 50 mm into the subbase at some locations, but this was independent of geotextile type and appears not to have affect the performance of the roadway. It was also concluded that the initial thickness of the base course during compaction had a significant effect on the strength and elongation at peak load of the exhumed samples. It can be further concluded from the data presented in the paper that the exhumed samples did not exhibit the type of distress that would be expected if they had been carrying a high percentage of their peak tensile strength as a sustained load. This would indicate that the geotextiles where not loaded significantly and that the strain in the geotextiles away from isolated protruding objects was quite low.

Rathymayer (2000) conducted a series of field trials on a number of geotextile types. Geotextiles were installed at two locations and their performance assessed. At one site penetrations of the fill, which consisted of crushed gravel, into the soft subgrade resulted in localized strains of between 11 and 76 % in the geotextiles. These locations where randomly spaced and were due mainly to penetrations of single stones. At the second site the fill material, consisting of stone with a maximum size of 200 mm, caused surface strains in the geotextiles of between 5 and 28 %. Again these localized deformations where caused by single stones penetrating into the subgrade.

It can be concluded that the survivability of a geotextile is a function of the thickness of subbase placed over the geotextile during installation. Random ruptures of the geotextile will occur and these will be mainly due to localized randomly scattered stones penetrating into the subgrade. While these localized ruptures may allow migration of fines into the subbase it appears not to adversely affect the performance of the road. This experience is confirmed by the successful use of the full range of geotextile types as separators over the past 30 years.

5 CONCLUSION

The effects of installation damage have been assessed for a number of geotextile types. All geotextiles with mass per unit area less than 175 g/m^2 appear to lose 50 % of their initial tensile strength immediately after installation. Based on limited data a correlation appears to exist between retained strength determined from field and simulated damage in the laboratory. A number of methods currently used to assess the survivability of a geotextile were reviewed. Of the three methods examined mass per unit area appears to be the best method for assessing the retained strength of a geotextile. Strain energy and the shape of the deformed geotextile insitu do not seem to be good indicators of a geotextile's survivability.

The quantity of field data on the performance of geotextile separators in the literature is quite limited. From the reported trials holes appear randomly due to penetrations of single stones into the subgrade. However these ruptures may not affect the performance of the road. Retained strength obtained from simulated laboratory tests indicate that mass per unit area appears to give the best indication of the survivability of a geotextile. It is therefore proposed that given the current knowledge of the in-service performance of geotextiles that all geotextiles be specified on the basis of their mass per unit area.

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