Geosynthetics: Installation Damage and the Measurement of Tensile Strength

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ABSTRACT: The Transport Research Laboratory has undertaken a programme of work to assess the effect of installation damage on the short term strength of geosynthetics. Trials were undertaken using a coarse grained aggregate and three woven fabrics, a strip material, and three geogrids. The changes in strength of the geosynthetics were determined from tests on both 200mm and one metre wide specimens at strain rates of 10% per minute and 2.5% per hour.

For geosynthetics which are either robust or particularly susceptible to installation damage, the effects of specimen width and strain rate on the measured change in strength is small. However the situation is less clear for other geosynthetics. It would appear that the variability of the measured tensile strength decreases with increasing of width of the test specimens. Thus it may be better to undertake tensile tests on a few larger specimens than on a large number of smaller specimens.

1. INTRODUCTION

The Transport Research Laboratory (TRL) has undertaken a programme of work to assess the effect of installation on the short term strength properties of geosynthetics. A method for applying damage to geosynthetics was developed, which reproduces site activities and allows the exhumation of the test samples without applying any significant further damage.

Trials were undertaken using two levels of compactive effort:
(i) in accordance with the requirements of the Specification for Highway Works (SHW), (MCHW 1) for compacting backfills, and
(ii) to simulate, effectively, compaction to refusal.

The change in strength was initially determined from tests on metre wide specimens at a strain rate of 2.5% per hour; the results of these tests have been reported by Watts and Brady (1990). These conditions were chosen to minimise the variability in the test data.

More recently, damage trials have been completed where the losses in strength were determined from tensile tests undertaken in accordance with BS 6906:Part1 (1987). The results from these two series of tests were generally not in good agreement, and so further trials were undertaken where the change in strength was determined from tests on both 200mm wide specimens at a rate of 2.5% per hour, and one metre wide specimens at 10% per minute.

Details of the materials and procedure for undertaking the trials are given in this paper. A summary of the results of the trials is presented, and the suitability of the methods for determining losses in strength is discussed.

2. DETAILS OF MATERIALS

2.1 Backfill

The fill used in the trials was a well graded crushed limestone aggregate. The particle size distribution of the fill is given in Figure 1.

2.2 Geosynthetics

The geosynthetics used in this study were:
(i) polypropylene fabric P1:
Terram W20/4, supplied by Exxon Chemical Geopolymers Ltd. Plain weave; weight 600g/m^2; tensile strength 200kN/m warp, 40kN/m weft.
(ii) polypropylene fabric P2:
Lotrak 45/45, supplied by Don and Low Ltd. Plain

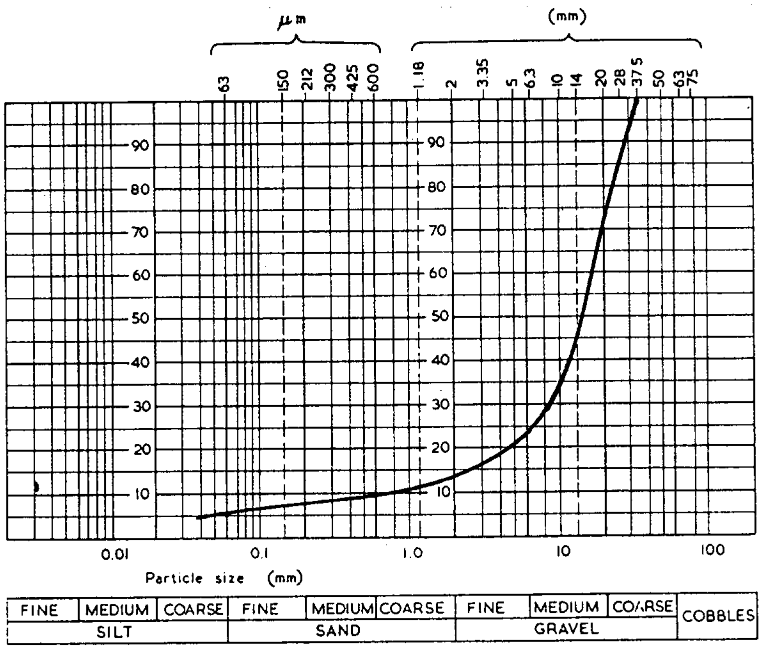

Figure 1: Particle size distribution of fill

weave; weight $240g/m^2$; tensile strength 45kN/m warp, 45kN/m weft.

(iii) polyester/polyamide fabric P3:
Terram WB20/5, supplied by Exxon Chemical Geopolymers Ltd. Plain weave; weight $400g/m^2$; tensile strength 200kN/m warp (polyester), 50kN/m weft (polyamide).

(iv) polyester strip P4:
Paraweb 50kN, supplied by Exxon Chemical Geopolymers Ltd. Polyester fibres sheathed with polyethylene; 90mm wide; tensile strength 50kN.

(v) polyethylene grid P5:
Tensar SR80, supplied by Netlon Ltd. High density polyethylene grid; tensile strength 80kN/m.

(vi) polyethylene grid P6:
Tenax TT 401-AMP, supplied by Tenax Plastics Ltd. High density polyethylene grid; tensile strength 80kN/m. (This geogrid is no longer commercially available, being superseded by geogrid TT 401-SAMP).

(vii) polyester grid P7:
Fortrac 55/30-20, supplied by MMG Civil Engineering Systems Ltd. Polyester yarns interwoven to form a grid, and coated with PVC; tensile strength 55kN/m warp, 30kN/m weft.

The weight and strength values quoted above are as reported by the suppliers.

3. DETAILS OF TEST METHOD

3.1 Procedure

The arrangement for the trials is shown schematically in Figure 2. The procedure was as follows:

(i) A 20mm thick steel plate (2.0 x 2.1m) was placed on a level and clean concrete floor. Lifting chains were attached to eyes provided at one end of the plate.

(ii) A layer of soil was placed over the plate, and compacted in accordance with the SHW (MCHW 1).

(iii) Two geosynthetic samples (1 x 2m) were placed on top of the compacted soil, directly over the area of the steel plate. (For the polyester strip, two metre long samples were used).

(iv) The second layer of soil was placed over the samples and compacted either as specified in the SHW (MCHW 1) or to effective refusal (see Section 3.2).

(v) To exhume the samples, one end of the plate was raised about one metre with the lifting chains. The samples were then clamped to the raised end of the plate, as shown in Figure 3.

(vi) The plate was lifted to an angle of about 45° and then struck with a rubber headed sledge-hammer to loosen the fill.

(vii) The plate was then raised slowly whilst being moved horizontally to displace the fill from around the samples.

The 200mm wide specimens were cut from predetermined positions across the width of the exhumed samples.

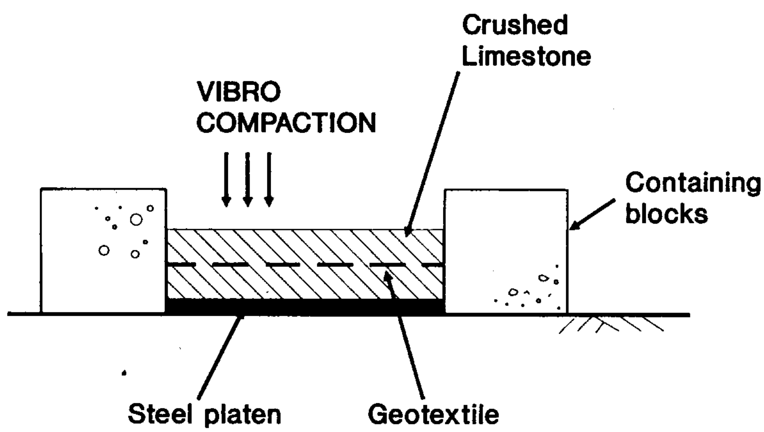

Figure 2: Schematic arrangement for the trials

3.2 Compaction

The compaction plant used for these trials, was a Bomag 160 AD tandem vibratory roller. The mean mass per unit width, for each roller, was 2510kg/m.

Two levels of compactive effort were used in the trials: i) to simulate normal construction practice, compaction was in accordance with the method specification for fill to reinforced earth structures as given in Table 6/4 of the

Figure 3: Clamping the samples to the plate

SHW (MCHW 1). With this plant, the method required a compacted depth of 175mm to be achieved with four passes of one roll, i.e. two full passes of the tandem roller. This method was referred to as 'standard compaction'.

ii) to simulate compaction to effective refusal, as may be encountered on a haul road reinforced with geosynthetic, ten full passes of the tandem roller were applied to the same thickness of soil as in (i). This method was defined as 'compaction to refusal'.

The standard compaction trials using the crushed limestone fill provides a severe but not unrealistic simulation of site conditions. The compaction to refusal reflects an extreme condition that may occur on a construction site.

4. MEASUREMENT OF TENSILE STRENGTH

4.1 Clamps

The clamping arrangement for geosynthetics is critical to obtaining reliable tensile test results. Two methods were used in these trials; jaw grips for the geogrids P5 and P6, and roller clamps for the other materials. The clamps were fixed parallel to each other, neither clamp being fitted with a universal joint. It was essential with this arrangement to correctly position the specimen when placing it in the clamps.

4.2 Tensile tests

A number of tests was undertaken to determine the repeatability of the procedure.

It could be anticipated that the variability in the results of the tensile tests would reduce with increasing size of specimen and so fewer tests on large specimens would be required to determine a reliable estimate of strength. The ratio of the overall size of the metre wide and 200mm wide specimens was about 12:1. However tests on large specimens are less convenient as they require specialised test apparatus.

The mean strain of the test specimen was determined from the gauge length of the specimen, typically about one metre, and the change of separation of the clamps. Measurements of local strain, for about a 250mm gauge length, along the centre-line of the material were also made with a non-contacting laser extensometer. The gauge length recommended in BS 6906:Part1 (1987) is 100mm.

Due to the time dependent strength of polymeric materials, the rate of strain can substantially affect their measured strength. The rate of strain and the width of specimen as specified in BS 6906:Part1 (1987) are 10% per minute and 200mm respectively, and though these tests are suitable for index testing or quality control, they do not model in situ conditions.

4.3 Programme of tests

The combinations of specimen width and rate of strain were as follows:

(i) 200mm wide specimens at a rate of strain of 10% per minute.

(ii) 200mm wide specimens at a rate of strain of 2.5% per hour.

(iii) 1metre wide specimens at a rate of strain of 10% per minute.

(iv) 1metre wide specimens at a rate of strain of 2.5% per hour.

Tests on the 90mm wide polyester strip P4 were undertaken at rates of strain of 10% per minute and 2.5% per hour.

At least 5 tests were undertaken on pristine (undamaged) specimens for each combination.

5. RESULTS

A summary of the results of the tensile tests is presented in Table 1. By way of example, typical load-strain relations are given in Figure 4, for each test combination of the polyester fabric P3.

Usually rupture occurred as the maximum load was attained. However, in the tests undertaken at a rate of 2.5% per hour on pristine specimens of geogrids P5 and P6, cold drawing created a plateau in the load-strain relation: thus in these cases the strain developed on the

Table 1. Summary of tensile test results

Material	Condition	Width of specimen, nominal rate of of strain							
		200mm, 10%/min		200mm, 2.5%/hr		1000mm, 10%/min		1000mm, 2.5%/hr	
		T_r	ϵ_r	T_r	ϵ_r	T_r	ϵ_r	T_r	ϵ_r
Polypropylene P1	Pristine	206	13.9	196	14.3	227	11.7	198	12.7
	Standard	205	11.3	186	13.9	174	8.3	180	11.3
	Refusal	177	10.4	147	12.9	142	7.6	118	8.4
Polypropylene P2	Pristine	57	10.8	49	12.0	51	10.0	46	11.2
	Standard	39	6.9	24	6.9	33	5.9	42	9.4
	Refusal	37	7.0	25	7.2	19	4.7	26	7.2
Polyester P3	Pristine	211	8.7	187	9.1	204	8.6	183	7.5
	Standard	97	4.7	84	4.6	72	4.1	104	5.1
	Refusal	65	3.8	72	4.5	58	3.9	69	4.5
Polyester strip P4*	Pristine	60	13.4	55	13.7				
	Standard	60	12.6	54	13.6				
	Refusal	59	12.5	53	13.6				
HDPE grid P5	Pristine	79	12.1	53	32.5	75	12.8	57	20.5
	Standard	64	9.0	37	13.5	62	9.2	45	9.6
	Refusal	60	8.2	48	11.9	57	8.4	45	9.1
HDPE grid P6	Pristine	80	19.0	52	36.4	73	16.4	52	27.7
	Standard	80	16.9	48	17.5	75	16.2	49	13.3
	Refusal	78	16.4	48	14.7	71	13.5	46	11.9
Polyester grid P7	Pristine	57	14.2	51	12.7	54	11.1	50	11.4
	Standard	33	8.4	28	9.1	32	7.7	38	9.0
	Refusal	38	9.3	30	9.9	30	7.4	29	8.2

T_r mean tensile load at rupture. Units kN/m for P1 ,P2, P3, P5, P6 and P7, but kN/strip for P4

ϵ_r mean strain at rupture (%)

* 90mm wide polyester strip tested at the rates shown

attainment of the maximum load was less than at rupture.

Good agreement between the two measurements of strain was usually obtained on tests on the pristine specimens but, because of local non-uniformities in the damaged specimens, the measurements of strain from the laser extensometers were sometimes unrepresentative of the whole specimen. Therefore, for consistency, the strains reported herein were determined from the gauge length of the specimen and the relative movement of the clamps.

A partial factor of safety for installation damage (f_m) for a geosynthetic, may be defined as:

$$f_m = \frac{T_P}{T_D}$$

where T_P = strength of the pristine material
T_D = strength of the damaged material

Site specific trials should be used to provide such information, but some manufacturers and certifying authorities have published default values of f_m, for example Agrément Certificate No 92/69, for the use of Fortrac geogrids, British Board of Agrément (1992). By necessity, default values should be conservative and therefore provide less economic designs: moreover the margin of safety provided will vary according to the type of fill and compactive effort.

The mean and range of values of f_m, derived from the standard level of compactive effort, are given in Table 2; the mean values of f_m for compaction to refusal are also given.

6. DISCUSSION

The results of the tensile tests showed that the original strength of the materials was only slightly affected by the width of the test specimen. However, higher strengths were measured in tests at the higher rate of strain.

The results of the trials demonstrated that;

i) both the load and strain at rupture decreased,

ii) the degree of damage increased with increasing intensity of compactive effort, and

iii) the decreases in load and strain were such that the initial stiffness of the materials was largely unaffected.

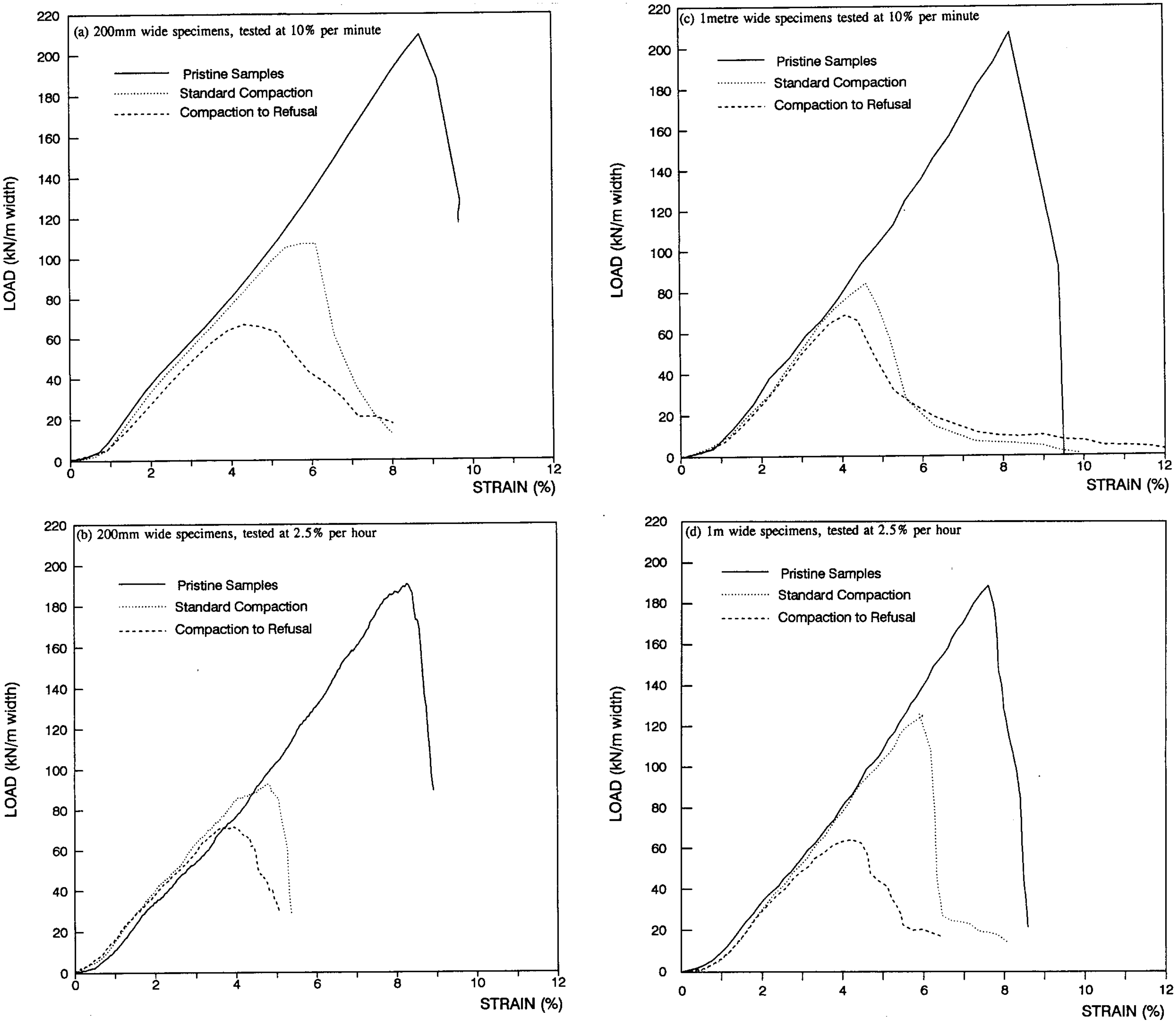

Figure 4: Load-strain relations for polyester fabric P3

It should be appreciated that any method used to determine the effects of installation can only provide an estimate of the change in strength, as the rate of strain used to characterise strength will not replicate in-service conditions.

The retained strength varied with the different geosynthetics and also with the test combination used to characterise strength. The variability in the results of the tensile tests on the pristine materials, particularly for the 200mm wide specimens, makes interpretation of the data difficult: moreover the range of measured strengths increased with the level of damage. Nonetheless, as expected, for the more robust materials, the effects of the size of the test specimen and the rate of test on the values of f_m were small. Thus for materials P4 and P6 where the mean value of f_m was less than about 1.1 for the standard level of compaction, it probably does not matter how the value of f_m is determined. In a similar vein, the high losses in strength for fabric P3 demonstrate its unsuitability for use with the aggregate used in these trials, and this conclusion could have been reached from the results of any of the sets of test. (The material may well prove suitable for use with finer grained soils).

The values of f_m for the standard level compaction for P1, P2, P5 and P7 varied according to the size of specimen and the rate of strain used in the tensile test. However the variability in the range of values of f_m was generally much lower with the tests undertaken on metre

Table 2. Partial factors of safety for installation damage (f_m)

Material	Condition	200mm 10%/min	200mm 2.5%/hr	1000mm 10%/min	1000mm 2.5%/hr
		Width of specimen, nominal rate of strain			
P1	Standard	1.00 (0.92-1.10)	1.05 (0.99-1.10)	1.30 (1.28-1.33)	1.10 (1.08-1.12)
	Refusal	1.16	1.33	1.60	1.68
P2	Standard	1.46 (1.22-1.64)	2.04 (1.88-2.12)	1.55 (1.38-1.77)	1.10 (1.04-1.17)
	Refusal	1.54	1.96	2.68	1.77
P3	Standard	2.18 (1.76-2.54)	2.23 (1.83-2.63)	2.83 (2.42-3.88)	1.76 (1.45-2.73)
	Refusal	3.25	2.60	3.52	2.65
P4*	Standard	1.00 (0.97-1.03)	1.02 (1.02-1.02)		
	Refusal	1.02	1.04		
P5	Standard	1.23 (1.18-1.30)	1.43 (1.14-1.88)	1.21 (1.19-1.26)	1.27 (1.17-1.34)
	Refusal	1.32	1.10	1.32	1.27
P6	Standard	1.00 (0.97-1.02)	1.08 (1.01-1.21)	1.00 (0.97-0.99)	1.06 (0.99-1.19)
	Refusal	1.03	1.08	1.03	1.13
P7	Standard	1.73 (1.57-2.04)	1.82 (1.79-1.87)	1.69 (1.28-2.03)	1.32 (1.28-1.37)
	Refusal	1.50	1.70	1.80	1.72

* 90mm wide polyester strip tested at the rates shown

Note: The range of values of f_m for standard compaction, determined from the test results, is given in brackets

wide specimens. The results obtained from the 200mm wide specimens would probably lead to the rejection of P2 and P7 when they may in fact prove to be adequate. The variability shows that the damage inflicted on the fabrics was not particularly uniformly distributed.

A comparison of the results for P1 and P3 shows that the ability to withstand installation damage is not solely a function of the original tensile strength of the material. It is dependent upon the type of polymer and the form of the geosynthetic. The data in Table 2 show for example, that polypropylene fibres seem less prone to damage than polyester fibres.

Over-compaction of the aggregate had little effect on materials P4, P5 and P6: these materials are suitable, and are indeed used, for reinforcing soils. The mean values of f_m for P1, P2, P3 and P7 generally increased with the intensity of compaction, but the increases were generally smaller for the values determined from the smaller sized specimens; it is unlikely that any of the materials P2, P3 or P7 would be accepted for high risk sites.

7. CONCLUSIONS

1. The tensile strength of the pristine materials was only slightly affected by the width of the test specimen. However, higher strengths were recorded from the tests undertaken at the higher rate of strain.
2. As a result of installation damage the load and strain at rupture decreased, but the initial stiffness of the materials was largely unaffected. The degree of damage increased with increasing intensity of compactive effort.
3. The ability of a material to withstand installation damage is not solely a function of the original tensile strength of the material, but is also dependent upon the make up of the material. For example, the type of polymer, weave or form of grid appear to be important.
4. For materials which are either robust or particularly susceptible to installation damage, the effects of specimen width and strain rate on the values of f_m is small. However the situation is less clear for other materials with values of f_m lying between about 1.1 and 1.7. It would appear that the variability of the measured tensile strength decreases with increasing of width of the test specimens. Thus it may be better to determine the value of f_m from tests on a few larger specimens than on a large number of smaller specimens.

8. REFERENCES

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