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Evaluation of the effects of construction activities on the physical properties of polymeric soil reinforcing elements

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ABSTRACT: This paper describes a site trial which reproduced UK practice for the construction of reinforced soil structures. The polymeric soil reinforcing geogrid was carefully recovered from the site trial and visual inspections and short and long-term tensile tests were carried out. The effects of construction activities are evaluated and recommendations for design are given.

1 INTRODUCTION

Before new polymeric geogrids were used in the Civil Engineering industry a controlled site trial was carried out to verify their effectiveness in withstanding the stresses and practices of reinforced soil construction. The paper describes standards for reinforced soil construction within the UK and organisation of the trial to reproduce construction practice.

The performance of 'Tensar' SR80 geogrid is assessed under two fill gradings and under single and multi-layer constructions. On recovery, the geogrids were inspected and tested and these results are presented. The effects of construction are evaluated and trends indentified. Suggestions are given for the application of these results to reinforce soil design.

A similar type of site trial was used as part of the assessment of fitness for purpose of 'Tensar' SR2 geogrids by the British Board of Agrément (Roads and Bridges Agrément Certificate 86/27, 1986) and also by the West German Institut fur Bautechnik in their Approval Certificate (Z20.1 -102, 1986).

2 TEST METHOD

In the UK, reinforced fill is selected and compacted according to the Department of Transport's "Specification for Highway Works" (1986). The compaction requirements are given in the form of a method specification for which the Engineer

1. classifies the fill type and appropriate method for compaction.
2. selects a compactor type and chooses the appropriate size of plant for the construction project.
3. reads from the specification the compacted layer thickness and number of passes.

For the proposed site trial of 'Tensar' SR80 geogrid:

1. A subangular limestone frictional fill was selected because it is very widely used in the UK.
2. A towed vibratory roller of mass 3300 kg/m width of roll was chosen as being typical of construction plant used on a large scale reinforced soil project.
3. The specification indicated that a 200mm thick layer of the correct density could be achieved with four passes of the selected roller.

3 SITE TRIAL

The site trial was carried out in a limestone quarry near Clitheroe in Lancashire, England. The trial area was organised into bays, shown in Figure 1. Two fill gradings are reported (Figure 2). One, designated fine fill, has 100% passing a 10mm sieve and 85% retained on a 5mm sieve. This is used in bays A and B. The other, designated medium fill, has 100% passing a 75mm sieve and 92% retained on a 37.5mm sieve. It is used in bays C and D.

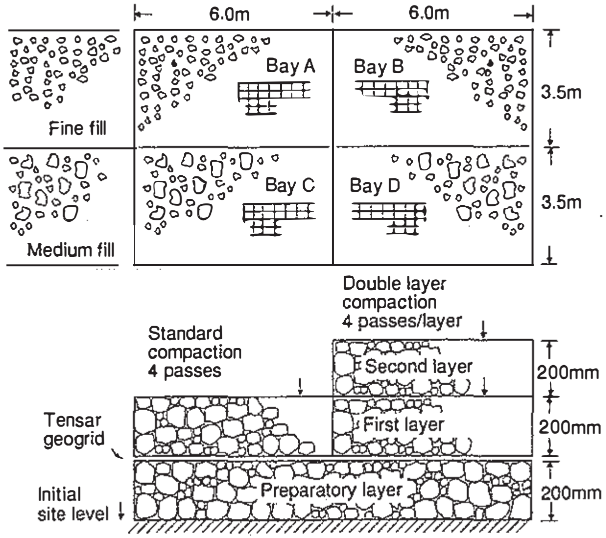

Figure 1 Schematic layout of test bays

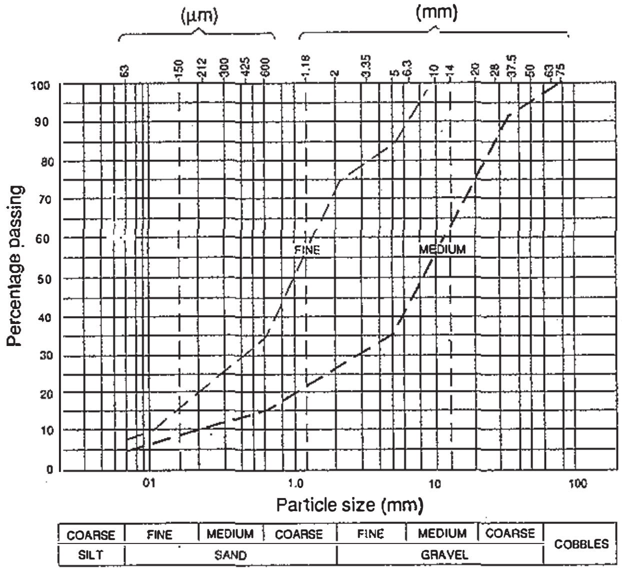

Figure 2 Particle size distribution curves

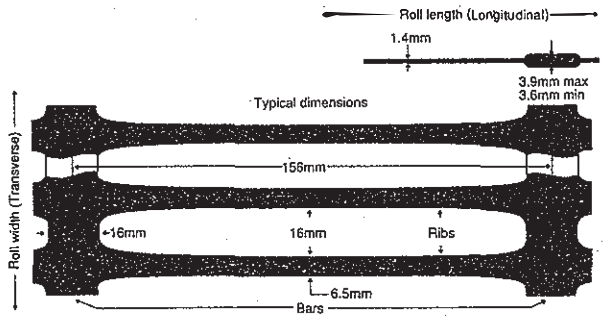

Figure 3 'Tensar' SR80 geogrid

A preparatory layer of each bay's fill was compacted on the quarry floor to produce a level surface on which the 'Tensar' SR80 geogrid reinforcing elements were placed. Typical dimensions of 'Tensar' SR80 are shown in Figure 3.

Fill was dropped from an excavator bucket onto the geogrid as shown in Figure 4. This is not good practice but unfortunately fill is often tipped from delivery wagons directly onto the reinforcement, so poor site practice was reproduced. The fill was dozed into a level layer and compacted with a towed vibratory roller as shown in Figure 5.

In bays B and D a second layer was spread and compacted to reproduce multi-layer construction practice.

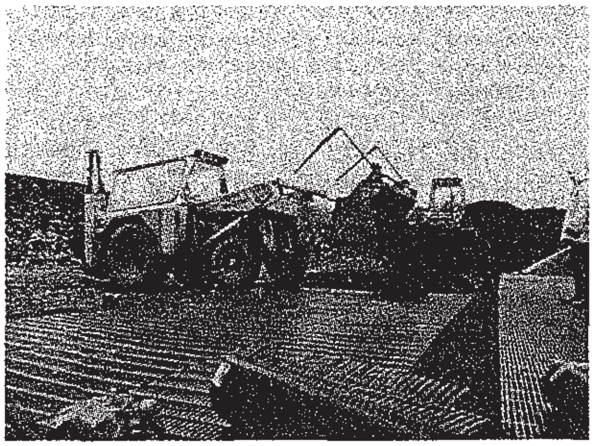

Figure 4 Excavator dropping fill

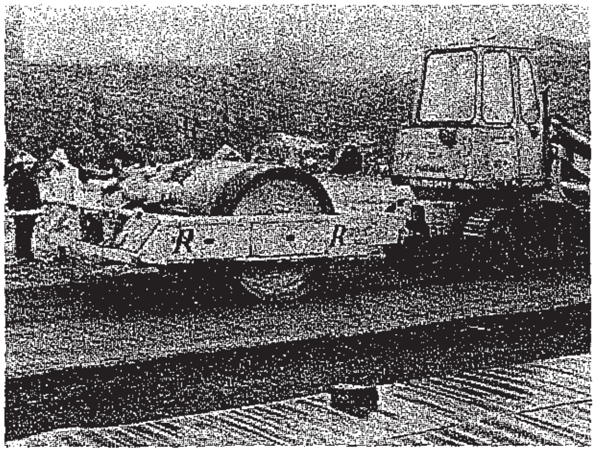

Figure 5 Compaction

Table 1. Test bay data and visual classification of damage.

Fill Type	Bay code	Mean layer thickness First	Second	General abrasion	+ Bruises	+ Splits	+ Cuts
Fine	A	171mm		25%	0	2	0
Fine	B	225mm	195mm	25%	1	0	0
Medium	C	149mm		63%	40	3	0
Medium	D	224mm	205mm	50%	27	16	0

+ Incidence of damage on six large size test specimens

The mean compacted layer thicknesses in the bays are shown in Table 1.

The 'Tensar' SR80 geogrid then had to be recovered from the trial bays. The bulk of the compacted fill was loosened and removed using the excavator back hoe and the remainder was manually removed using shovels and hand brushing. Any damage caused by recovery operations was clearly marked so that this damage would not be attributed to the trial.

4 SAMPLE PREPARATION

The geogrids were washed to remove any loose aggregate. Large size specimens of 'Tensar' SR80 geogrid, 15 ribs wide by 5 bars long, i.e. approximately 350mm wide by 610mm long, were cut at random from the lengths of recovered material. The specimens were conditioned for 24 hours at 20°C before visual inspection and tensile tests were carried out. Control specimens from the same batch of material were prepared and tested in the same manner.

5 VISUAL ASSESSMENT OF DAMAGE

The 'Tensar' SR80 geogrid specimens were inspected for the following categories of damage:-

1. General abrasion of the geogrid surface - a subjective assessment.
2. Bruising or flattening of the ribs or bars.
3. Splitting of the ribs or bars allowing the passage of light.
4. Cutting or severance of the ribs.

Six large size specimens from each bay were inspected and the total incidence of damage in each category was recorded as shown in Table 1.

6 SHORT-TERM INDEX TENSILE TESTS

Short-term Index tensile tests were carried out following the procedures developed by McGown et al (1984) for large size geogrid specimens. For this test, the specimens were placed in an Instron 1170 tensile test machine at 20°C, and extended at a constant rate of strain of 2% per minute.

In Figure 6 the load/strain curves show the range of results of test specimens from bay C, medium fill, single layer, against the mean load/strain curve of the control specimen. Figure 7 shows data from bay B, fine fill, double layer.

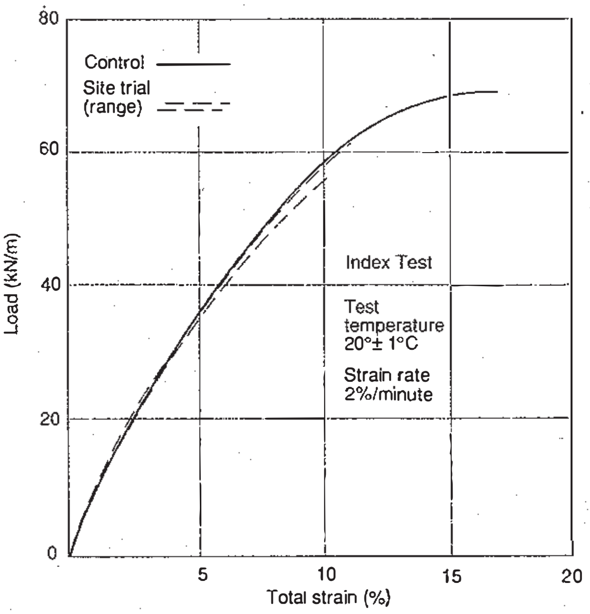

Figure 6 Load/strain curves for 'Tensar' SR80 from bay C and control

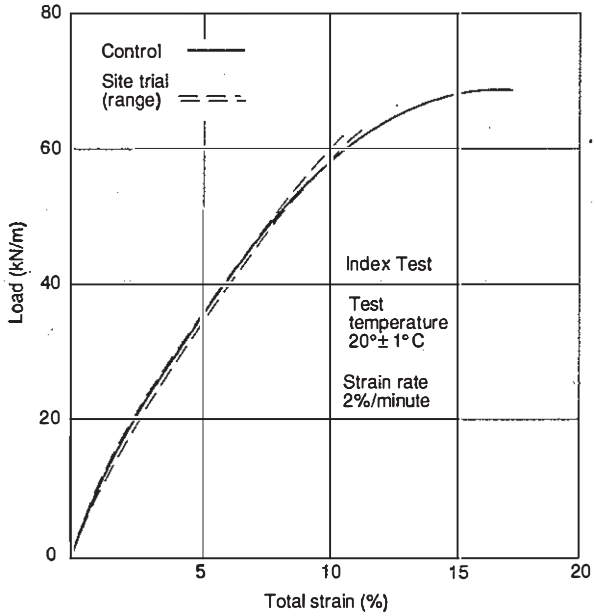

Figure 7 Load/strain curves for 'Tensar' SR80 from bay B and control

The secant modulus at 5% strain was calculated and the ratio of the secant modulus of the site trial specimens to the control specimens is shown in Table 2.

Table 2. Mean secant modulus at 5% strain of site damaged specimens expressed as a percentage of control specimens.

Product	Fill Type	Level of compaction (Number of passes)	
		Standard (4)	Double layer (4/layer)
Tensar SR80	Fine	96.3	100.4
	Medium	99.6	99.1

The peak load was recorded and the ratio of the peak load of the site trial specimens to the control specimens is shown in Table 3.

Table 3. Mean peak tensile strength of site damaged specimens expressed as a percentage of control specimens.

Product	Fill Type	Level of compaction (Number of passes)	
		Standard (4)	Double layer (4/layer)
Tensar SR80	Fine	95.7	91.8
	Medium	83.4	88.2

7 LONG-TERM SUSTAINED LOAD TENSILE TESTS

Long-term sustained load tests were carried out in accordance with the recommendations of Andrawes et al (1986) and Murray and McGown (1987). For these tests a load of 36.4 kN/m was applied within 5 seconds to the large size specimens of 'Tensar' SR80 geogrid and sustained whilst measurements of elongation with time were recorded. All tests were carried out at 20°C.

Figure 8 shows the strain/log time curve of specimens from bay D, medium fill, double layer and control. Sherby-Dorn curves of strain/log strain rate for these specimens, shown in Figure 9, were constructed from the strain/time data. These specimens had not reached failure when long-term testing stopped, but had passed the performance limit strain of 10%, used in the design of reinforced soil structures.

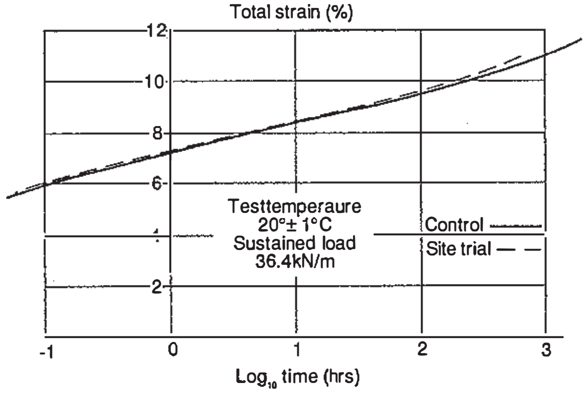

Figure 8 Strain-time curves for 'Tensar' SR80 from bay D and control

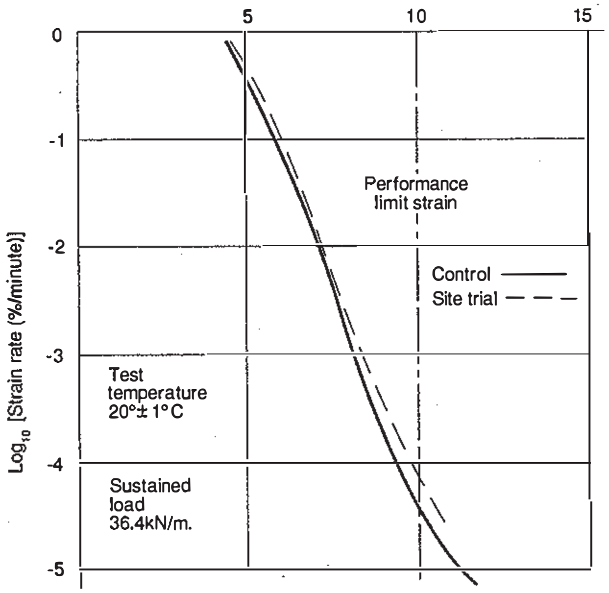

Figure 9 Sherby-Dorn curves for 'Tensar' SR80 from bay D and control

8 DISCUSSION

The site trial reproduced typical conditions for extensive reinforced soil constructions within the UK and the heavy towed vibrating compactor was similar to those used on projects such as basal reinforcement or steep embankments. However, specifications for reinforced soil walls limit the mass of the compactor within 2 metres of the face in order to reduce compaction stresses on the wall face. Close to a retaining wall face the mass per metre roll of vibratory compactor would be limited to 1300kg compared to the 3300kg of the site trial vibratory compactor, so data derived from this site trial would be conservative when applied to reinforced soil retaining walls.

The trial also reproduced some typical examples of bad construction practice, such as dropping fill directly onto reinforcing elements rather than spreading fill by cascading it forward from a stockpile with a bulldozer.

Since similar construction equipment and techniques are used throughout the world, the results are not restricted to U.K. conditions.

During the recovery of the geogrid it was observed that when the excavator back hoe was loosening compacted fill, the free end of the length of geogrid was also moving. This clearly demonstrated the interlock and interaction between fill and 'Tensar' geogrid.

Visual inspection showed that the fine fill caused very little surface abrasion to the 'Tensar' SR80. The medium fill caused a little more surface abrasion and bruising to the geogrid.

From short-term Index test load/strain curves, examination of the change in secant modulus at 5% shows that there is little difference between any of the four bays and the control material. Working strains of up to 5% could be expected for steep embankment or soft foundation reinforcement and of up to 2% for retaining walls. Thus, neither of the fills used, nor the layered constructions compacted to the specification, alters the physical properties of 'Tensar' SR80 under working conditions.

The short-term Index tests did, however, show that there is a reduction in peak load carrying capacity of 'Tensar' SR80 geogrid. The medium fill influenced this trend more than the fine fill, double layers more than single layers and thinner layers more than thicker layers. Long-term strength of 'Tensar' SR geogrids is quoted for a performance limit strain of 10%. The short-term tests show that strain at rupture exceeds this peformance limit strain, so suggests there is no need to apply a partial factor of safety to account for change in rupture behaviour. This can be examined further with long-term tests.

The long-term sustained load tests have been carried out on geogrids in isolation, so there is no reliance on the effect of soil restraint. This is a lower bound condition and can be considered safe for all sites.

The effects of construction on the long term performance of 'Tensar' SR80 geogrids are found from examination of the strain/log time and Sherby-Dorn curves. These show a slightly higher strain than the control, but this variation is considered within the limits of experimental error.

The Sherby-Dorn curve is used to interpret the change in rate of strain with time and shows that the rate of strain continues to decrease beyond the 10% performance limit strain of 'Tensar' SR80. Furthermore, there is no suggestion of rupture in this range. This is confirmed by the short-term Index tensile tests.

9 DATA FOR DESIGN

The designer of reinforced soil structures needs to be able to assess the effects of construction on creep and rupture performance of the reinforcing elements.

UK practice has been to limit long-term strain (creep) in reinforced soil retaining walls and bridge abutments to the amounts specified in Technical Memorandum BE3/78 (revised 1987), i.e. 1% for retaining walls and 0.5% for bridge abutments. For the range of fill sizes reported, and construction to the UK specification, the experimental work described in this paper demonstrates that the "in isolation" test data of manufactured geogrids can be used with confidence for 'Tensar' SR geogrids to assess the effects of creep.

To guard against rupture of the reinforcing elements the designer uses a characteristic strength, above which the material will fail in tension from peak loading during the design life, and applies an overall factor of safety to take account of variations in loading and material properties.

The characteristic strength of 'Tensar' SR80 for a design life of 120 years and a performance limit strain of 10% is taken from manufacturer's literature (Netlon Limited, 1988), and is given in Table 4.

Table 4. Characteristic strength of 'Tensar' SR80 for a design life of 120 years.

In soil temperature	Characteristic strength of 'Tensar' SR80
10°C UK conditions	32.5 kN/m
20°C	30.5 kN/m

In the overall factor of safety there is a partial factor of safety, γ_{m2} which is intended to cover loss of strength due to site damage and non-uniform stress distribution across the reinforcement due to construction errors such as mis-alignment of the reinforcement and undulation of the compacted fill. Suggested values of γ_{m2} for 'Tensar' SR80 based on loss of peak strength are given in Table 5.

Table 5. Partial factors of safety γ_{m2}

Fill type	Well-graded fill of maximum particle size (mm)	Partial factors of safety γ_{m2} for 'Tensar' SR80
	125	
Coarse grained soils & crushed rocks		1.40
	75	
		1.30
	20	
		1.20
	2	
Sand, clay, PFA		1.10

However, this design approach for rupture appears to be unnecessarily conservative since it has now been shown that the long-term and short-term properties of 'Tensar' SR80 geogrid, under the range of fills compacted according to the specification, remain unaltered up to a performance limit strain of 10%.

It is suggested that for fills up to 75mm maximum size, compacted according to the specification, no partial factor of safety need be applied automatically to the long-term strength of the geogrid, but that the designers should consider what construction errors may arise outside the specified conditions and, if necessary, make a small allowance only for those conditions.

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