Twelve year creep tests on geosynthetic reinforcements

J.H. Greenwood
ERA Technology Ltd, Leatherhead, United Kingdom

G.T. Kempton
Terram Ltd, Pontypool, United Kingdom

G.R.A. Watts
Transport Research Laboratory, Crowthorne, United Kingdom

D.I. Bush
Highways Agency, London, United Kingdom

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ABSTRACT: This paper reports the results of creep tests of up to 12 years' duration on six different reinforcing geotextiles. The measured creep strains are close to those which would have been predicted after 1 year, thus providing some assurance that the strain predicted for a design life of 120 years may be correct. Creep rupture data are provided for polyester strip and for polyethylene grid, with times to rupture of 3 years and tests at comparable loads lasting for 12 years. Partially factored design strengths (T_{CR}/f_{m122}) determined according to BS 8006 (1995) are presented.

1 INTRODUCTION

The design life of a reinforced soil structure may be as long as 120 years. The design strengths are predicted on the basis of creep-rupture (stress-rupture) (T_{CR}) and creep strain data (T_{CS}) extrapolated to the design life. Since most of the available data are from tests lasting typically for one year, codes of practice impose a partial safety factor (f_{m122}) for extrapolation by which the predicted strength is divided. According to BS8006 (1995) the partial safety factor f_{m122} is set equal to the logarithm of the ratio of the design life to the duration of the longest test, with a minimum value of 1.0. Thus for a 120 year lifetime data from creep tests lasting just 1.2 years will incur a partial safety factor of 2.0, halving the design load or doubling the quantity of material required. On the other hand, data on creep tests lasting 12 years will incur a minimum partial safety factor of 1.0. Long-term data are also essential for validating accelerated methods of determining creep strain and creep-rupture.

This paper presents the results of creep and creep-rupture tests lasting for up to 12 years.

2 MATERIALS AND TEST PROGRAMME

Most of the tests reported here were commenced in 1987-1990, as part of a multi-client study coordinated by ERA Technology. The test details were reported by Greenwood (1990) and Watts et al (1998). Temperature was controlled to 20 ± 2ºC from the start and to 65 ± 5% relative humidity from 1991 onwards. In view of the scatter in the initial strain data two additional creep tests were undertaken: the strain of the long-term test after 1 h was then adjusted to equal the mean of the strains of the three tests. ERA's creep loading practice Greenwood and Palmer (2000).

The materials were as follows. (The values of tensile strength were reported by Watts et al (1998)).

Polypropylene fabric P1	plain weave, 570g/m^2, tensile strength 206kN/m warp, 33kN/m weft.
Polypropylene fabric P2	plain weave, 240g/m^2, tensile strength 49kN/m warp, 49kN/m weft.
Polyester/polyamide fabric P3	plain weave, 400g/m^2, tensile strength 203kN/m warp (polyester), 48kN/m weft (polyamide)
Polyester strip P4	polyester fibres sheathed with low density polyethylene, tensile strength 58kN, 90mm wide
Polyethylene grid P5	high density polyethylene grid, tensile strength 81kN/m

A further material was added to the programme in 1994:

Polyester strip P6	polyester fibres sheathed with low density polyethylene, 90mm wide. The tensile strength was originally measured by the manufacturer as 58.5kN and more recently to a modified ASTM D 4595 (1994) as 55.6kN.

3 RESULTS

The results of the creep tests are shown in Figures 1 to 8: the creep-rupture curves are presented as load versus log time. Note that (i) 100,000h is equivalent to 11.4 years, (ii) on-going tests are shown as thick lines, and (iii) ruptures are shown as black squares.

4 POLYPROPYLENES

Figures 1 and 2 show the results for polypropylene weaves P1 and P2 respectively. There are no abrupt changes in behaviour. The creep strains at 100,000h, 7.83% and 14.26%, are respectively 3% and 14% higher than the strain values predicted by Watts et al (1998) on the basis of 50,000h data. Ruptures have occurred at higher loads: at lower loads the time to rupture increases and the strain at rupture decreases.

The logarithm of the creep strain rate for polypropylene P2 at 15 kN/m has been plotted against strain (Figure. 3). This indicates that the creep strain rate is approaching the secondary stage of the creep process with a constant value of about 2×10^{-7} h^{-1}. The secondary creep rate can be related to a thermally activated process (Wilding and Ward, 1994). Some design procedures base the design strength on the load leading to the onset of secondary creep.

5 POLYESTERS

Figures 4 and 5 show the results for polyester weave P3 and polyester strip P4 respectively. The linear relationship between strain and the logarithm of time persists such that the strains are all within ± 2% of those predicted by Watts et al (1998). This provides a degree of assurance that predictions of the behaviour for the remainder of the 120 year lifetime are reliable. In Figure 5 the gradient (strain/log time) of the creep curve at 8.5kN, 15% of the short-term tensile strength, is higher because the load is in the range of the gauche-trans transition that gives the stress-strain curve of polyester its characteristic S shape. This gradient would be expected to diminish later to equal that at higher loads. In Figure 4 two creep curves are given for specimens at 45.5kN/m, 22% of the short-term tensile strength, one of which has been deliberately damaged by installation in a coarse limestone fill (Brady et al, 1994). The results demonstrate that, although the initial strains differ, the gradient of the creep curve of the damaged material is the same as that for the undamaged material. However, the damaged specimen would be expected to fail first.

The tests on polyester strip P6 differed in that they were deliberately aimed at determining the times to rupture. The creep strains, which are not shown, all show an increase in gradient before rupture. The times to rupture are shown in Figure 6. The results show the expected creep-rupture characteristic. A regression line has been fitted with the equation:

$$\sigma = 85.68 - 2.843 \log t$$

where σ is the applied load expressed as a percentage of tensile strength and t is the time to failure in hours. T_{CR} for 120 years is 68.6% of the short-term tensile strength.

The longest time to rupture to date is 26,125h (2.98 years) at 73% of tensile strength, but a second test at the same load has lasted for 27,000h (3.08 years) without breaking. According to BS8006 (1995) the partial safety factor f_{m122} is log(120/2.98) = 1.60, thus the partially factored design strength T_{CR}/f_{m122} is 68.6/1.6 = 42.7% of the short-term tensile strength. Strip P5 has withstood 57% of the short-term tensile strength for 100,174h (11.4 years) and if this result is included in the calculations the extrapolated load for 120 years is reduced to 52.6%, but as f_{m122} is reduced to 1.02 T_{CR}/f_{m122} is increased to 51.5%.

Eight tests were performed at 77% of short-term tensile strength with times to rupture ranging from 190h to 6,400h, a scatter of 1.5 decades of time. The 95% (one-sided) lower confidence limit (reflecting the scatter of the test results alone) is given by the equation:

$$\sigma = 86.85 - 3.220 \log t - 7.113\{0.1176 + (\log t - 3.110)^2/41.67\}^{0.5}$$

giving a value at 120 years of 63.4% of the short-term tensile strength.

6 POLYETHYLENE GRID

Figure 7 shows the results from creep tests on extruded polyethylene grid. At 58%, 48% and 43% of tensile strength the times to rupture progressively increase and the strains to failure increase. Rupture is preceded by a period during which the gradient increases. At 20% of tensile strength the gradient was still decreasing at 28,000h when the test was terminated.

A test performed at 38% of tensile strength failed after 11,374h but this was eliminated as being faulty. A replacement test has continued for 97,600h (11.1 years) with no consistent change in gradient. The strain of 10.17% is 18% higher than the strain value of 8.60% predicted by Watts et al (1998) since the gradient has increased instead of decreasing.

Figure 8 shows the creep-rupture results for the polyethylene grid. A regression line including the incomplete test (current practice is to include incomplete tests if they lie to the right of the regression line) predicts T_{CR} at 120 years as 31.1% of tensile strength. A double logarithmic relationship predicts 33.4%. With a duration of 97,600h the partial safety factor f_{m122} is log(120/11.1) = 1.03.

7 CONCLUSIONS AND SUMMARY

Creep strain measurements of up to 12 years are reported for five different geotextiles. The data show that the strains predicted after 1 year will be correct to within ± 2% for materials where the strain varies linearly with log t, but may underestimate by as much as 18% for those where the gradient of strain against log t increases.

The creep-rupture behaviour of a polyester strip has been measured with the longest time to rupture of 2.98 years. T_{CR} for a 120 year design life is 68.6% of tensile strength with a lower confidence limit of 63.4%. A similar strip has withstood 57% of tensile strength for 11.1 years without failure. T_{CR} for a polyethylene grid is found to be 33.1% of tensile strength. The principal benefit of such long-term data is that the partial safety factor f_{m122} is close to unity.

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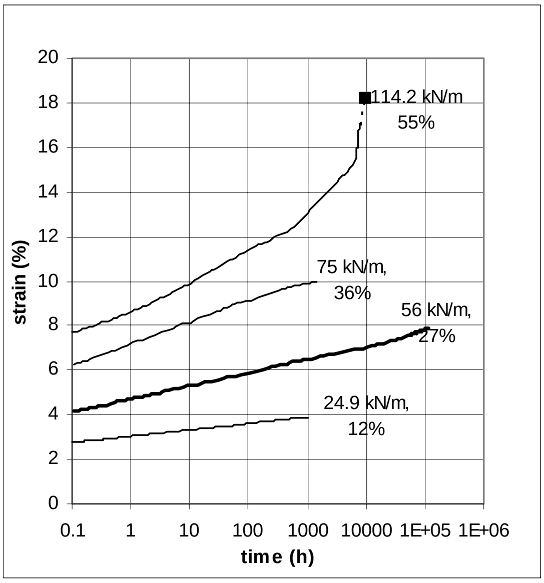

Figure 1. Creep of polypropylene P1

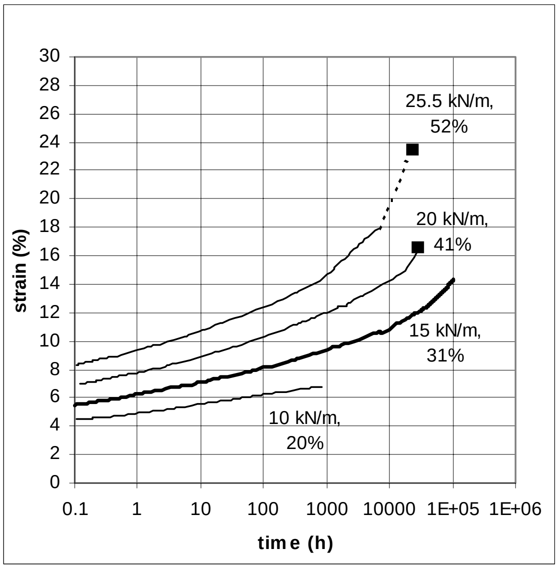

Figure 2. Creep of polypropylene P2

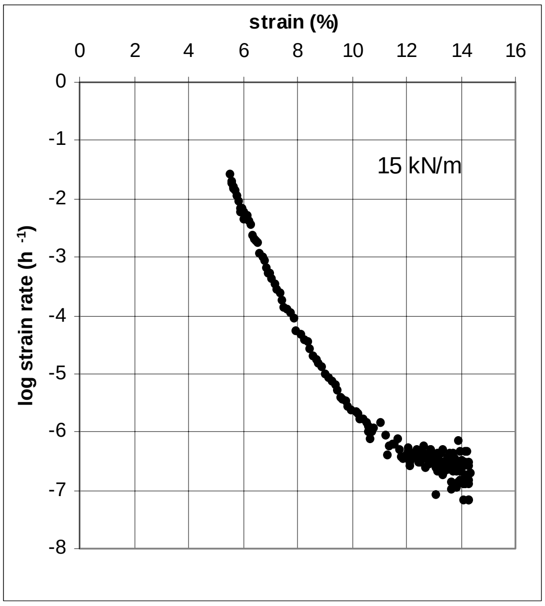

Figure 3. Logarithm of strain rate plotted against strain for polypropylene P2

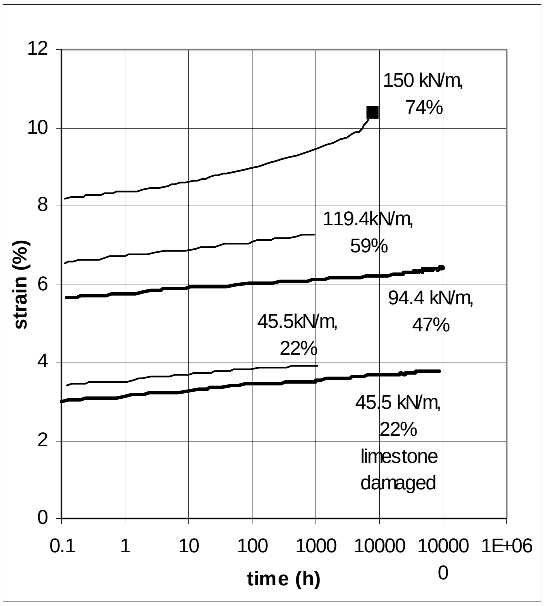

Figure 4. Creep of polyester weave P3

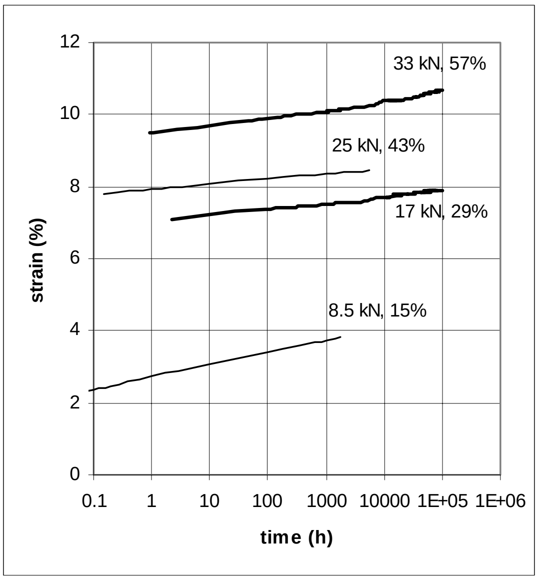

Figure 5. Creep of polyester strip P4

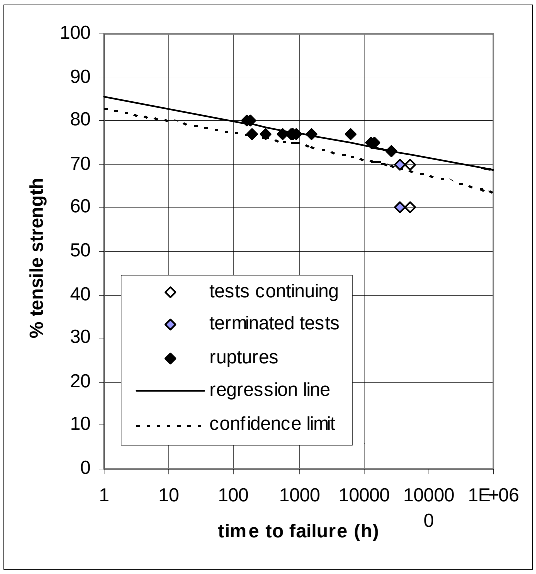

Figure 6. Creep-rupture of polyester strip P6

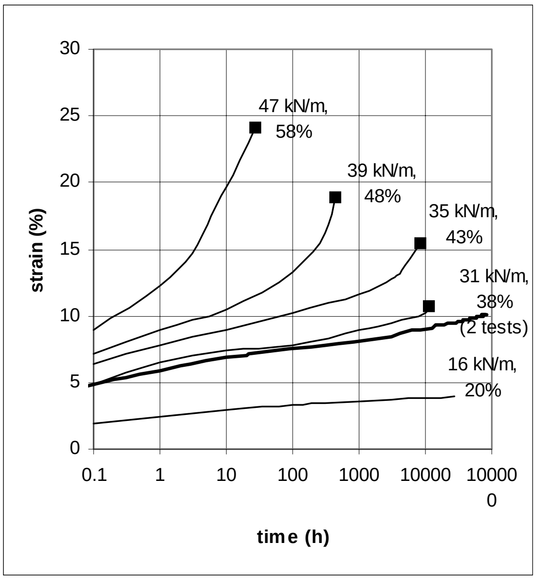

Figure 7. Creep of polyethylene grid P5

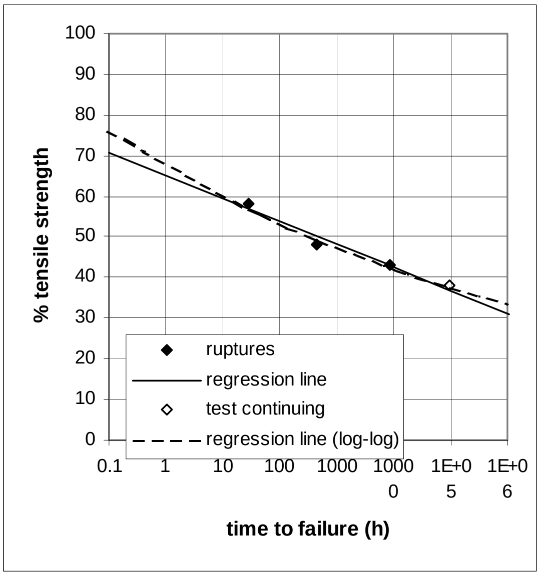

Figure 8. Creep-rupture of grid P5