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Partial factors for geosynthetics specific to limit state approach

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ABSTRACT: In limit state approach, Partial Factors are applied to geosynthetics both for Ultimate Limit State [ULS] and Serviceability Limit State [SLS] analyses. Most commonly, Partial Factors are determined by comparing the 'before' and 'after' strengths of geosynthetics obtained from short-term Constant Rate of Strain [CRS] test. The Partial Factors, so obtained, are then applied to Reference Strength obtained from long-term sustained load creep test in order to obtain long-term Design Strength of geosyntheics. It is indicated in this paper that totally different amount and nature of strain components are measured in CRS and creep tests. Therefore, Partial Factors obtained from CRS test should not be applied to obtain long-term Design Strength. Further, it is identified for a range of geosynthetics that Partial Factors are both time and strain level dependent. This suggests that different values of Partial Factors should be used for the limit state being considered.

1 INTRODUCTION

Important input parameters for geosynthetics in designs are their Reference Strength, Partial Factors and Design Strength. Reference Strength is the strength of Ex-works materials. Partial Factors are the factors that allow for any change of geosynthetics due to construction damage and environmental degradation. Design Strength is the strength obtained by dividing the Reference Strength by the Partial Factors.

1.1 *Reference strength*

Various design codes and methods define Reference Strength in different ways for geosynthetics.

DIBt (1998) and AASHTO (1997) use the maximum load at rupture of the 'Ex-works' materials under Constant Rate of Strain [CRS] tensile testing as the basis of defining the Reference Strength of geosynthetics. The Reference Strength, to avoid long-term creep rupture, is then obtained by dividing the CRS rupture strength by a Reduction Factor. The DIBt and the AASHTO design methods specify 33% per minute and 10% per minute strain rates respectively, for the CRS tests employed. Kabir (1984) have shown that the CRS test can give different strengths at different test strain rates and temperatures. Therefore, even for a particular type of geosynthetic the same Reduction Factor may not be applicable to all CRS data in order to obtain the long-term creep rupture strength, i.e. the Reduction Factor is dependent on the strain rate used in the CRS test.

BS8006 (1995) and Jewell (1996) defined the Reference Strength as the load to cause creep rupture of 'Ex-works' specimens at the end of design life. Typically, geosynthetics exhibit a wide range of scatter of creep rupture strains for different sustained [creep] load levels. Hence, the Reference Strength, defined on the basis of load at creep rupture for a specific design life, can be very difficult to select with any certainty related to the strain level developed at creep rupture, McGown et al (1998).

Some design methods define the Reference Strength as the load obtained from the Isochronous Load-Strain curves, corresponding to a Performance Limit Strain, for example the TBW Method (1998) and the HA 68/94 Design Method (1997). Performance Limit Strain is always less than Instability Strain Limit and hence Reference Strength for Ultimate Limit State [ULS] design based on Performance Limit Strain can be seen to be a conservative choice, McGown et al (1998).

To summarize, currently the Reference Strength for geosyntheics is defined in two different ways, (i) on the basis of long-term creep rupture strength and (ii) on the basis of long-term creep at a limiting strain.

1.2 *Partial factors*

The strength of Ex-works geosynthetics requires to be modified by applying Partial Factors in order to obtain their Design Strength. Four Partial Factors o major concern have been identified by Voskamp and

Risseeuw (1987) and Jewell and Greenwood (1988) for geosynthetics. These are:

a) The Damage Factor; to allow for mechanical damage during handling, transportation and construction.
b) The Environmental Factor; to allow for the chemical environment, UV radiation and microbiological exposure in the ground.
c) The Material Factor; to allow for the uncertainty inherent in the extrapolation of test data, and
d) The Overall Factor; to allow for the properties of materials not meeting the manufacturer's specification.

Partial Factors are determined by comparing the strength of geosynthetics 'before' and 'after' the construction damage or environmental degradation. Different design codes/methods and different researchers suggest different methods of determining Partial Factors for geosynthetics.

Bush (1988), Watts and Brady (1990) and Koerner and Koerner (1990) used CRS tests to identify damage effects on geosynthetics. They determined the Damage Factors for various geosynthetics by comparing the CRS loads for rupture 'before' and 'after' damage effects. BS8006 (1995), DIBt (1998), AASHTO (1997), TBW (1998) and HA 68/94 (1997) adopt the same method for the determination of Partial Factors for geosynthetics.

Partial Factors, determined by comparing the CRS strengths 'before' and 'after' an event, are considered to be constant in these codes over the whole design life of a Geosynthetic Reinforced Soil Structure [GRSS]. Therefore, most of the design codes/methods specify a single value of Partial Factor for geosyntheics to obtain their Design Strength, regardless of design life and operational strain level. The underlying assumption of such specification is that the effect of an event, i.e. construction damage or environmental degradation, on a particular geosynthetic 'today' will cause no further deterioration of its properties after '100 years'. Due to the elasto-visco-plastic nature of geosynthetics, this assumption is very unlikely to be true always.

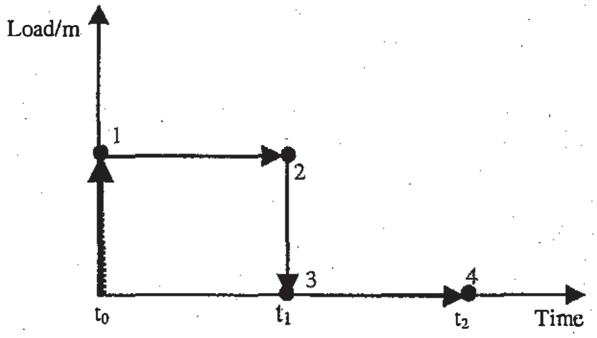
1.3 *Design strength*

It was mentioned earlier that most of the design codes/methods define Reference Strength in two different ways, i.e. on the basis of long-term creep rupture strength or on the basis of long-term creep at a limiting strain. Partial Factors, on the other hand, are specified on the basis of short-term CRS test results. Design Strength is then obtained by dividing the long-term Reference Strengths by the Partial Factors obtained from short-term CRS test. It may be appreciated that totally different amount and nature of strain components are measured in CRS and creep tests. Therefore, applying partial factors obtained from short-term CRS test to Reference Strength obtained from long-term creep test does not seem to be compatible. This is explained more in detail in the following section.

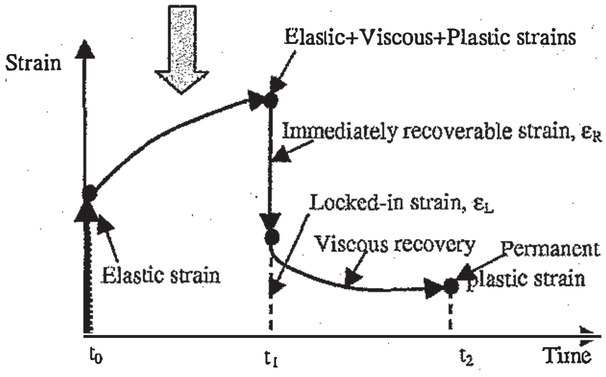
2 BEHAVIOUR OF GEOSYNTHETICS UNDER DIFFERENT LOADING REGIMES

Geosynthetics exhibit elasto-visco-plastic behaviour. This means that their mechanical behaviour is in part similar to that of elastic solid, in part similar to that of a viscous liquid and in part similar to that of a plastic, with all these parts being temperature dependent. Therefore, when subjected to an externally applied load as shown in Figure 1a, they respond by exhibiting a combination of elastic displacement, viscous flow and irrecoverable plastic deformation, Figure 1b.

The elastic deformation may be termed the Immediately Recoverable Strain and is denoted by ε_R. The viscous and plastic component together may be termed the 'Locked-in' Strain and is denoted by ε_L. The 'Locked-in' Strain, ε_L, comprises of one time dependent recoverable part, i.e. viscous strain and the other never recoverable part, i.e. plastic strain. It may be appreciated that for a certain loading regime a particular limiting strain can be reached by a geosynthetic with a number of combinations of Immedi-



(a) Loading



(b) Response

Figure 1. Typical behaviour of geosynthetics.

ately Recoverable Strain, ε_R and 'Locked-in' Strain, ε_L. This means that the same limiting strain ε_l can be reached with a high value of ε_R and a low value of ε_L (point A) or a high value of ε_L and a low value of ε_R (point B). The probable strain envelop for a limiting strain ε_l is shown in Figure 2.

If a CRS test is carried out on a geosynthetic to reach a limiting strain of ε_l at a very fast rate of strain, more Immediately Recoverable Strain, ε_R will develop than 'Locked-in' Strain, ε_L (point C). The 'Locked-in' Strain, ε_L will not have sufficient time to develop and mostly the contribution to total strain ε_l will be due to the Immediately Recoverable Strain, ε_R.

If, however, a long-term creep test is carried out on the same geosynthetic to reach the same limiting strain of ε_l in say 1000 hours, more 'Locked-in' Strain, ε_L will develop than Immediately Recoverable Strain, ε_R (point D). In this case, there will be sufficient time for the 'Locked-in' Strain, ε_L to develop and mostly the contribution to total strain ε_l will be due to the 'Locked-in' Strain, ε_L.

This indicates that a geosynthetic is likely to respond differently in terms of its strain components in different loading regimes and it may not be appropriate to apply data obtained from one test methodology to the other. Therefore, it may be suggested that for long-term applications, both the Reference Strength and Partial Factors should be determined on the basis long-term sustained load creep test results.

3 SUGGESTED PROCEDURE FOR DETERMINING PARTIAL FACTORS

In this approach, the Partial Factors may be defined as the ratio of the load carrying capacity of a geosynthetic at a particular strain 'before' and 'after' an event, e.g. 'before' and 'after' the construction damage or environmental degradation. The strain level should be chosen on the basis of Limit State being considered, i.e. different strain level should be identified for ULS and SLS analyses.

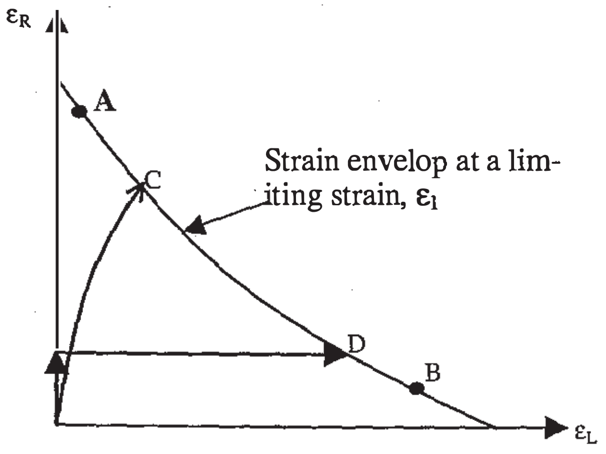
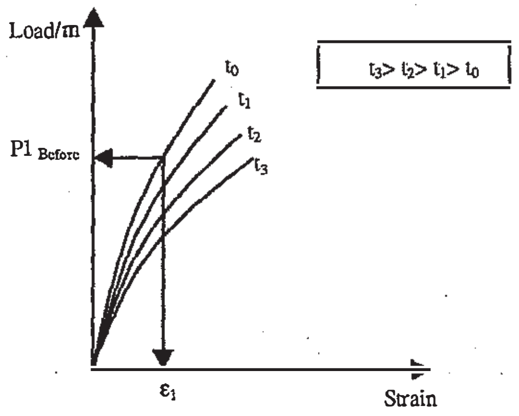
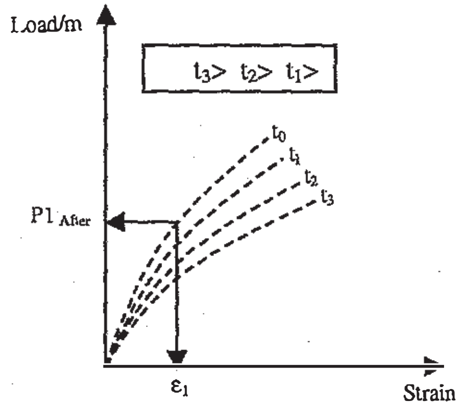


Figure 2. Possible variation of strain components.

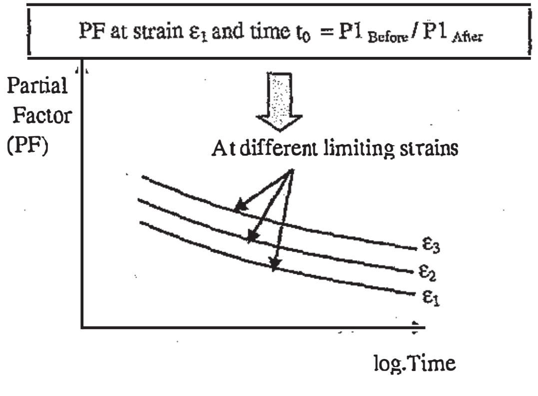
According to this approach, first, the Isochronous Load-Strain curves for a geosynthetic should be obtained 'before' and 'after' an event, Figures 3a, b. The ratio of the load carrying capacity of the geosynthetic is then obtained at different strain levels to obtain the Partial Factors at that strain level. Partial Factors, so obtained, are then plotted against log-Time for different strain levels, Figure 3c.



(a) Before event load-strain isochrones



(b) After event load-strain isochrones



(c) Partial factor-time plot

Figure 3. Proposed approach for determining partial factors.

It should be noted that a value of Partial Factor greater than unity indicates a reduction of the original intrinsic property of a geosynthetic and a value less than unity an increase in the original intrinsic property. Further, Partial Factors obtained according to this approach is likely to exhibit their time and strain level dependency.

4 DETERMINING PARTIAL FACTORS FROM THE EXPERIMENTAL DATA

Al-Mudhaf (1993) and Esteves (1996) studied the effects of construction damage and environmental degradation for a range of geosynthetics. A brief description of the test sites, the type of soil, construction equipment and environmental conditions are given in the following sections. The data obtained from these tests are then analysed and Partial Factors are determined according to the approach proposed in Section 2 of this paper.

4.1 *Damage factor*

For the evaluation of the construction damage effects, a site damage trial was carried out in Kuwait on a uniaxial geogrid and a woven geotextile. The compaction was performed during the month of May, when the maximum temperature reached 45°C and the humidity ranged between 40% and 80%. The storage room in the laboratory was kept at a constant temperature of 25°C. The soil at the site was a fine medium sandy soil without any traces of water. The soil from the site was used for fill and placed over the geosynthetics in a 0.3m thick layer. It was compacted to the maximum dry density at the optimum moisture content. The compaction was performed using hand operated compaction equipment of 3.0 kN of weight, vibrating at a rate of 3.33 Hz. The compaction plate dimensions were of 0.3m x 0.5m.

For the trial, the materials were laid out one beside the other, without any overlapping, in a test bay of 12m x 6m. They were covered with the fill and then subjected to 12 compaction passes over a period of two working days. The materials remained in the soil for one more week. Thereafter, they were carefully removed, stored and returned to the laboratory for testing.

CRS and sustained load creep tests were carried out on the 'Ex-works' and 'Damaged' specimens of the geosynthetics in the laboratory. CRS tests were carried out at 10% strain/minute and the creep tests were carried out up to 1000 hours for each load level.

Isochronous Load-Strain curves for the 'Ex-works' and 'Damaged' specimens of the uniaxial geogrid were plotted from these test data, Figures 4 a, b. The Damage Factor was then calculated according to the method described in Section 2. The varia-

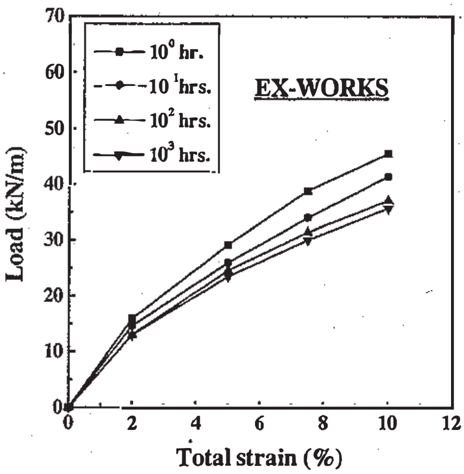


Figure 4(a). Isochronous load-strain curves for ex-works uniaxial geogrid at 20°C (after Esteves, 1996).

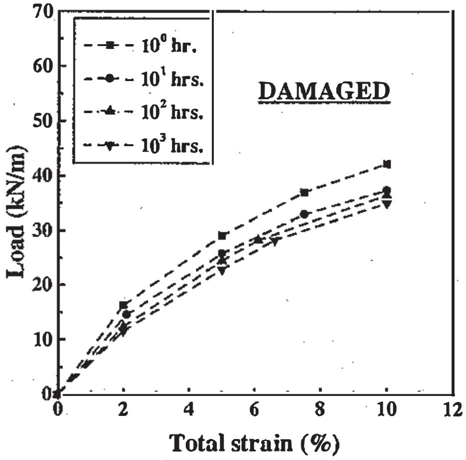


Figure 4(b). Isochronous load-strain curves for damaged uniaxial geogrid at 20°C (after Esteves, 1996).

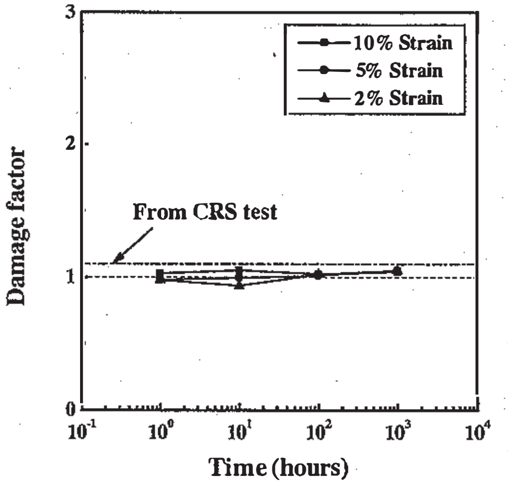


Figure 5. Damage factor-time relationship for uniaxial geogrid at 20°C.

tions of Damage Factor for the uniaxial geogrid with time and limiting strains of 2, 5 and 10 per cent are shown in Figure 5.

Similar test data were analysed for the woven geotextile and the variations of Damage Factor with time and strain levels are shown in Figure 6.

4.2 *Environmental factor*

Another study was undertaken in Kuwait for the evaluation of the environmental degradation on the strength of a uniaxial and a biaxial geogrid. Kuwait experiences air temperatures ranging from 45°C in summer to 0°C in winter and has an extremely high UV radiation level with long hours of uninterrupted sunshine most of the days of the year.

The test set-up for air temperature measurements comprised one temperature sensor located in a shaded housing above ground. A Pyranometer was used to measure the solar radiation at the test site. The recorded variations in air temperatures indicated a maximum of 49°C in summer and 12°C in winter with daily variations of 1 to 3°C. The cumulative UV radiation over the 12 months of the study was measured as 1,800,000 Wh/m^2. The rate of radiation in the summer was twice that in the winter.

Each type of geosynthetics was set out vertically on the test site and left open to all weathering conditions including direct sunlight. These were removed for testing after 12 months of exposure and severe temperature cycling on both a daily and seasonal basis. Test specimens were then cut from these samples and prepared for testing in the laboratory.

Thereafter, laboratory CRS and sustained load creep tests were carried out on the 'Ex-works' and 'Exposed' specimens of the geosyntheics. CRS tests were carried out at 10% strain/minute and the creep tests were carried out up to 1000 hours for each load level.

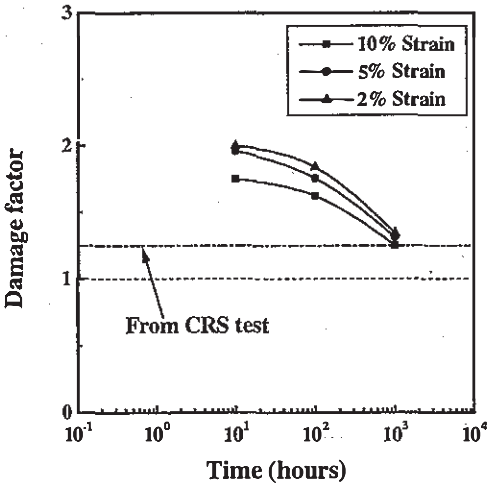


Figure 6. Damage factor-time relationship for woven geotextile in machine direction at 20^{0}C.

Isochronous Load-Strain curves for the 'Ex-works' and 'Exposed' specimens of uniaxial geogrid were plotted from these test data, Figures 7a, b.

The Environmental Factor was then calculated according to the method described in Section 2. The variations of Environmental Factor for the uniaxial geogrid with time and limiting strains of 2, 5 and 10 per cent are shown in Figure 8.

Similar test data were analysed for the biaxial geogrid and the variations of Environmental Factor with time and strain levels are shown in Figure 9.

5 CONCLUDING REMARKS

Total strain of a geosynthetic comprises of an Immediately Recoverable Strain part and a 'Locked-in' Strain part. A particular limiting strain can be reached by a geosynthetic with different combinations of these strain components.

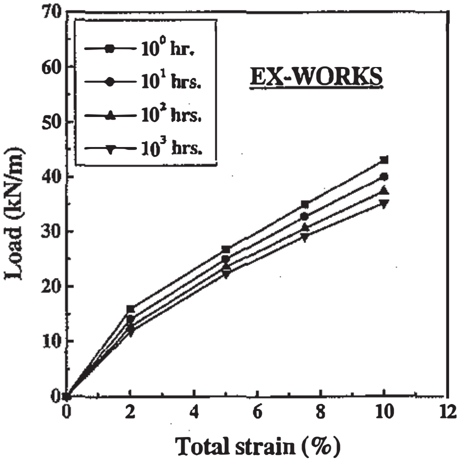


Figure 7(a). Isochronous load-strain curves for ex-works uniaxial geogrid at 20^{0}C (after Mudhaf, 1993).

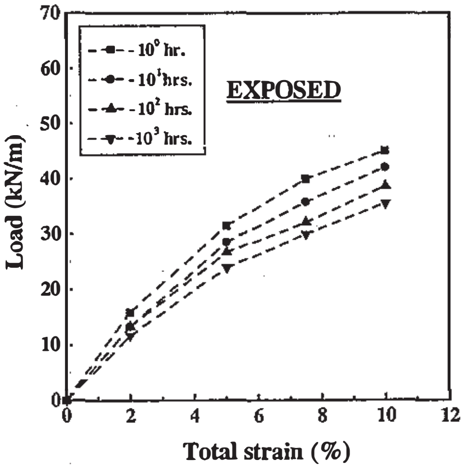


Figure 7(b). Isochronous load-strain curves for exposed uniaxial geogrid at 20^{0}C (after Mudhaf, 1993).

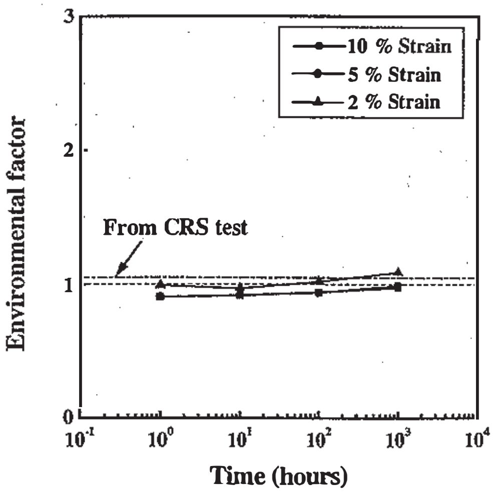


Figure 8. Environmental factor-time relationship for uniaxial geogrid at 20^{0}C.

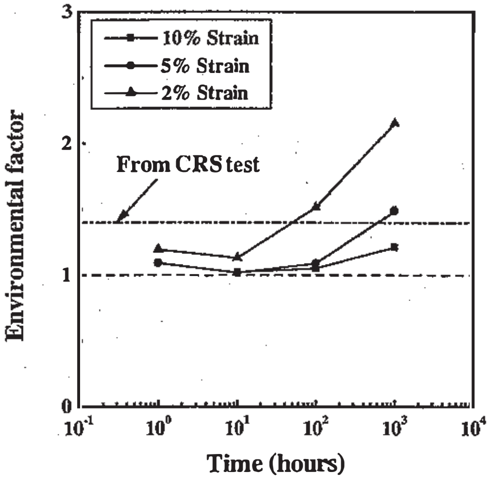


Figure 9. Environmental factor-time relationship for biaxial geogrid in longitudinal direction at 20^{0}C.

Different amount and nature of strain components are measured in short-term CRS and long-term creep tests. These two testing are, therefore, unlikely to provide the same value of a Partial Factor even for a particular geosynthetic. Indeed, it has been shown for a range of geosynthetics in this paper that Partial Factors obtained from short-term CRS test and long-term creep test are different from each other both in terms of their value and nature. It is suggested that for long-term applications Partial Factors obtained from long-term sustained load creep test should be applied to long-term Reference Strength of a geosynthetic in order to obtain its long-term Design Strength.

Partial Factors vary with time and strain level. Therefore, different values of Partial Factors should be applied over the design life of a GRSS for the limit state being considered, i.e while for ULS analysis Partial Factors associated with large limiting strain require to be considered, for SLS analysis Partial Factors associated with small limiting strain should be used.

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