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Assessment of design life for polyester based geosynthetics

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ABSTRACT: The long term creep characteristics of a family of coated polyester reinforcement materials are presented in terms of creep rupture and residual strength data. A new procedure for determining the allowable load in polyester based geosynthetics is presented. The procedure uses a combination of partial factors and material creep life assessment to determine the allowable load in a reinforcement material. A comparison is made between current assessment procedures and the new method for a family of polyester based geosynthetics. It is found that current assessment procedures are overly conservative and that polyester based geosynthetics can be loaded to a higher percentage of their ultimate tensile strength than previously thought while still preventing creep rupture.

1 INTRODUCTION

Several factors affect the design life of polyester based geosynthetics. These factors can be summarised under the following principle headings: manufacture, creep and durability. In general the design life of a material is calculated by applying partial factors of safety to the ultimate strength of the material. The partial factors are calculated based on an assessment of the reduction in the strength of the material resulting from variability in manufacture, its installation in the ground, the effects of the environment in which it is placed and creep resulting from application of a sustained load over time. In terms of creep the principle objective is to guard against creep rupture of the reinforcement occurring during the design life of the structure.

1.1 *Current method of assessing the partial factor for creep.*

Current assessment procedures for creep strength are based on creep rupture data, generally gathered from sustained load test performed on representative samples of the geosynthetic over a long period of time. Creep rupture data collection is both time consuming and expensive. Other techniques are been applied to the creep assessment of geosynthetics, such as the stepped isothermal method (Thornton at al, 1998) which aid the generation of creep rupture data points for polyester based materials.

The design tensile strength of the geosynthetic is calculated based on the design life of the structure and the creep rupture data. Currently, the partial factor for creep is calculated from the creep rupture line as if it represented the reduction in strength due to creep, Figure 1(a). After applying partial factors for manufacture, installation damage and the effects of the environment the effects of creep are taken into account. This method of assessment is considered conservative and overly reduces the load that can be applied to the reinforcement to preventing creep rupture.

1.2 *Residual strength of polyester subjected to sustained load over time*

As discussed the creep rupture line does not represent the reduction in tensile strength of a polyester material due to creep. Rather it has been found that the tensile strength of polyester based geosynthetics is maintained at its initial strength until it approaches creep failure (Orsat et al, 1998). Near creep failure the polyester experiences considerable reduction in strength before failure occurs on the creep rupture line. The process is shown diagrammed in Figure 1(b).

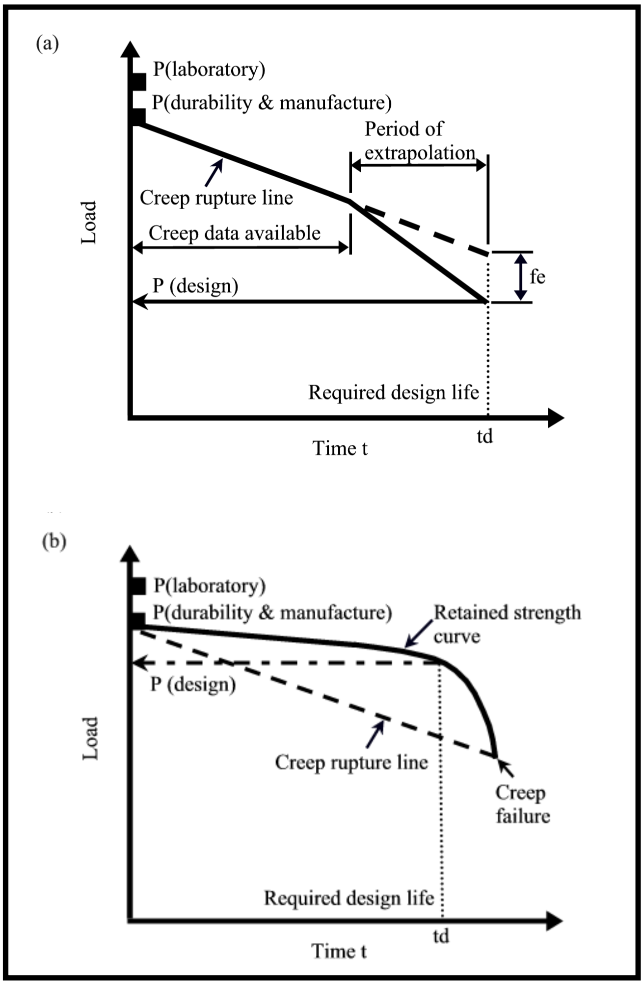

Figure 1. Diagrammatic presentation of the concept of (a) current creep rupture assessment and (b) the residual strength assessment.

1.3 *Proposed new assessment procedure.*

A new assessment procedure is proposed based on creep data for a family of polyester based geosynthetics where both creep rupture and residual strength data is available. The creep rupture data was gathered from long term (over 12 years) creep tests and the residual strength data is available from two research programs.

The new assessment procedure is based on a combination of partial factors and material creep life assessment. Partial factors are used to assess manufacture, installation and environmental damage. The load to be carried over a design life is estimated and used in combination with partial factors on design life to calculate a material creep life.

2 PROPERTIES OF THE POLYESTER BASED GEOSYNTHETIC FAMILY

The family of geosynthetics considered in this paper consist of high tenacity polyester encased in a polyethylene sheath. The manufacturing process allows the production of both rectangular and circular sections. Figure 2 shows a typical stress strain curve for a rectangular section determined in accordance with a modified ISO 10319 (1992). The test method had the following modifications:

1. The test specimen consisted of a single element 90 mm wide rather than the standard 200 mm,
2. The grip separation of 390 mm instead of 100 mm.

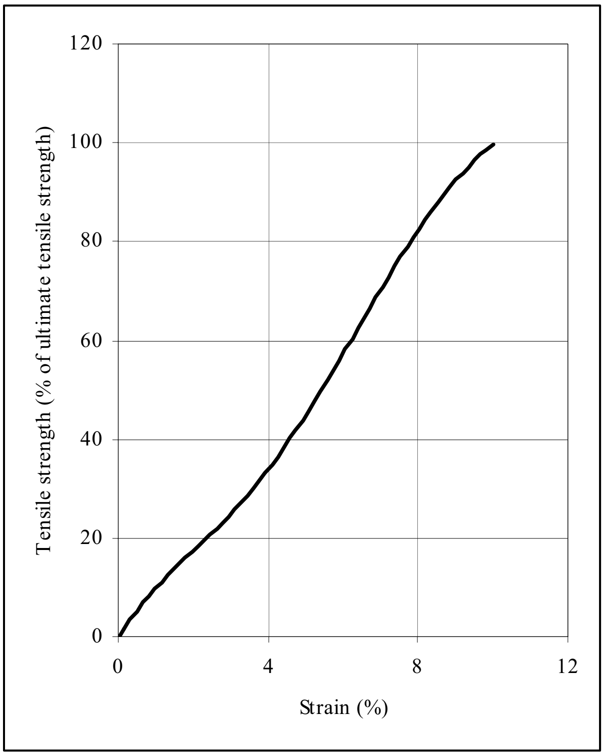

Figure 2. A typical stress strain curve for the family of polyester.

Partial factors for the effects of manufacture, installation and environmental damage are also available for the materials. Table 1 summarises typical partial factors for rectangular sections.

Table 1. Typical partial factors for manufacture, installation and environmental damage for 120 year design life.

Condition	Partial factor
Manufacture, fm	1.05
Installation damage, fid	1.05
Environmental damage, fed	1.10

Creep data is available for this family of polyester from three sources:

1. Conventional sustained loads tests on straps of the geosynthetic with a rectangular section carried out over a 12 year period. Some results from this test program are reported in Greenwood at al (2000),
2. Residual strength determined for samples from the sustained load test described in 1 (Greenwood, 1998),
3. Residual strength tests on straps of the geosynthetic with a circular section. The results of this test program where reported by Orsat et al (1998).

2.1 *Sustained load tests on polyester material*

Greenwood et al (2000) reported on long term sustained creep tests on the material. Figure 3 shows the creep rupture for straps with rectangular sections. Greenwood et al (2000) reported the following regression for the creep rupture line:

$$\sigma = 85.68 - 2.843 \log t \quad (1)$$

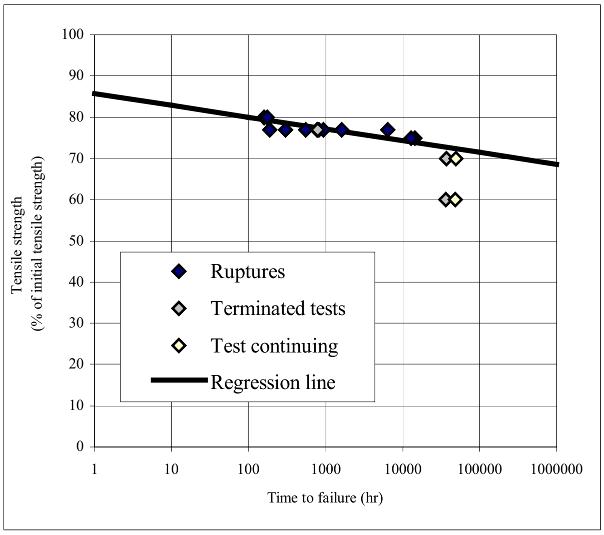

Figure 3. Creep rupture data, after Greenwood et al (2000).

2.2 *Residual strength of polyester*

Two research programs are available with residual strength values for materials from the family of geosynthetics.

2.2.1 *Residual strength from sustained load tests.*

The residual strength of three samples initially included in the test program described in Section 2.1 where determined after they had each carried a sustained load for various periods of times. Table 2 shows the percentage of ultimate tensile strength the samples carried, the time the straps were subjected to the sustained load and the residual strength of the straps.

Table 2. Residual strength after sustained load tests.

Load carried by strips (% of ultimate strength)	Duration of sustained load (hr)	Residual strength (% of ultimate strength)
63	36282	96
74	36618	102
81	765	95

2.2.2 *Residual strength test program*

A research program described by Orsat et al (1998) was conducted to assess the residual strength of the polyester geosynthetics. Straps with a circular section were load for different periods of time. The straps where then unloaded and their tensile strength determined. The results of the residual strength program are shown in Figure 4.

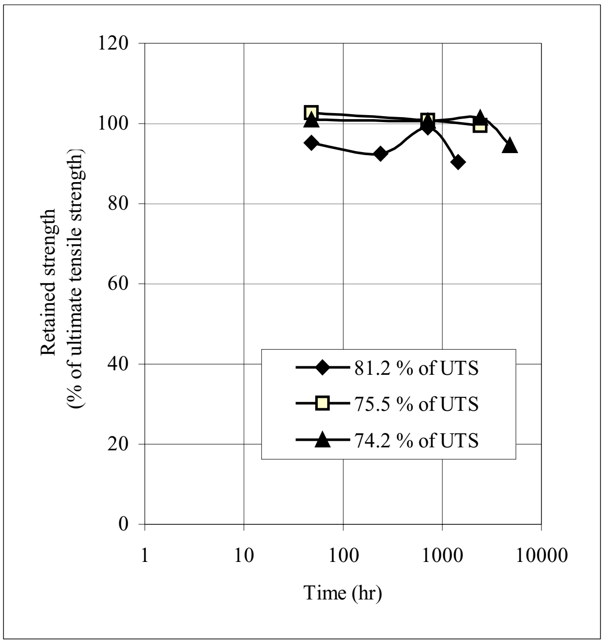

Figure 4. Results of residual strength test program, after Orsat et al (1998).

2.3 *Creep properties for the family of geosynthetics*

Based on the results of the sustained load tests the creep rupture response of the geosynthetic family is well understood. The duration of the test, 12 years, means that the data is only extrapolated over 1.6 log cycles for a 120 year design life. This considerably reduces the uncertainty in calculating the creep rupture life of the geosynthetics. Based on the creep rupture line shown in Figure 3 the allowable load in the reinforcement for a 120 year design life is 68.56 % of the available tensile strength. A partial factor for extrapolation of data can be calculated as 1.2^{x-1}, where x is the number of log cycles over which the data is extrapolated, Greenwood (1997) and has a value for a 120 year design life of 1.12 for this family of geosynthetics.

Two sets of data are available for the assessment of the residual strength of the material. The data covers samples loaded to a high percentage of their ultimate tensile strength for short durations and samples loaded at lower percentage of ultimate tensile strength but for longer durations. In both cases it was found that the residual strength was the same as the original strength and that the effects of creep had not reduced the strength capacity of the material.

3 PROPOSED NEW METHOD OF ASSESSEMENT

The proposed method of assessing for creep in designing structures constructed using geosynthetics is based on material creep life assessment. Greenwood et al (2001) discussed material creep life time assessment in relation to seismic design. The principle is based on predicting the lifetime of the structure and applying partial factors to time. Based on residual strength it has been shown that there is not a gradual reduction in strength due to creep therefore it is not appropriate to apply a partial factor to the strength of the material. The proposed assessment procedure is shown diagrammed in Figure 5. The procedure can be divided into two elements:

1. Assessment of the reduction in strength due to manufacture, installation and environmental damage. These partial factors are applied to the characteristic strength, P(characteristic) of the reinforcement. The resultant strength P(factored) is the strength that the reinforcement element will retain until creep failure.
2. Assessment of the design life and sustained load, P(design taf) that the reinforcement can carry while preventing creep rupture of the reinforcement before the design life is reached.

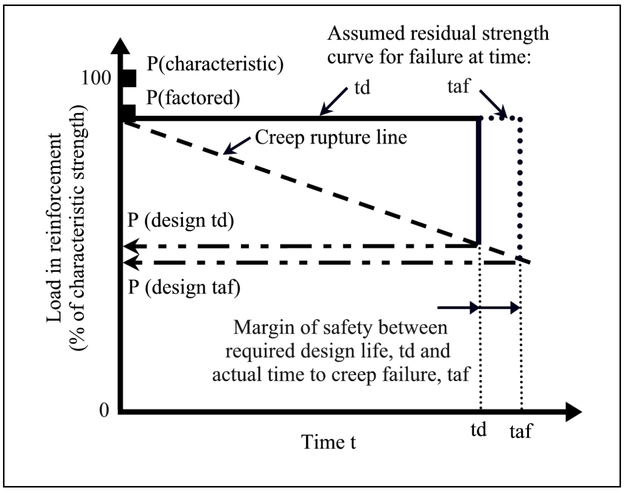

Figure 5. Diagrammatic representation of material creep life assessment.

3.1 *Assessment of creep life of geosynthetics*

The creep life assessment procedure proposed is based on determining the allowable stress in the reinforcement to prevent creep rupture of the reinforcement occurring before a time, taf, which is equal to the design life, td, multiplied by partial factors. Two partial factors are proposed:

1. A factor to account for uncertainty in the shape of the residual strength curve, especially near creep rupture,
2. A factor to account for the ramifications of failure of the structure.

The first partial factor accounts for any uncertainty in the shape of the residual strength curve arising from the assumption that the strength of the polyester reinforcement is maintained right up to creep rupture and that this strength reduces immediately to a value on the creep rupture line at failure. The residual strength curve is assumed to be a 90^0 elbow as shown in Figure 5. It is proposed that this partial factor should have a value of 1.10.

The philosophy of a partial factor for the ramifications of failure is already used in design, BS 8006 (1995). The magnitude of this factor is dependent on the class of structure and the consequences of the structure failing. In BS 8006 (1995) this partial factor is applied to the tensile strength, however in a residual strength procedure it is more appropriate to apply the factor to the design life. In the proposed procedure two categories of structure are defined and the value for each is shown in Table 3.

Table 3. Proposed partial factors covering the ramifications of failure applied to design life.

Category	Partial factor	Examples of structures
A	1.05	Structures where failure would result in moderate damage and loss of service
B	1.10	Abutments, structures directly supporting motorways and other principal roads, railways or inhabited buildings

The time to creep rupture should be calculated taking into account the scatter that exists in the creep rupture data. Greenwood et al (2001) proposed that the 95 % lower confidence limit for single sided data be used. This limit for the data presented in Section 2.1 can be calculated from Equation 2 (Greenwood et al, 2000).

The new design procedure can be represented by the flow chart shown in Figure 6.

$$\sigma = 86.85 - 3.220 \log t - 7.113 \left[0.1176 + \frac{(\log t - 3.110)^2}{41.67} \right]^{0.5} \quad (2)$$

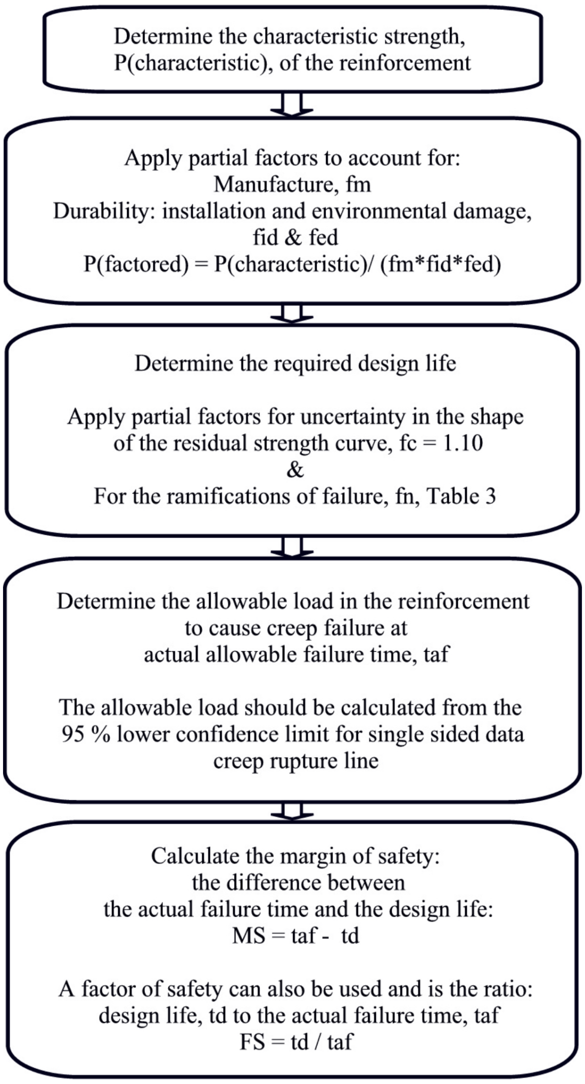

Figure 6. Flow chart for new design procedure for creep life assessment.

4 EXAMPLE OF THE NEW DESIGN ASSESSEMENT PROCEDURE

An example is presented on how to determine the allowable load in a polyester reinforcement element using the concept of residual strength. It is proposed to use a reinforcement element with a characteristic tensile strength of 500 kN/m in gravel with a pH of 7 for the reinforcement of a bridge abutment. The design life of the structure is to be a minimum of 120 years. What is the maximum allowable load in the reinforcement to guard against creep failure of the reinforcement? Following the procedure illustrated in Figure 6:

- Characteristic strength = 500 kN/m.
- The partial factors for the coated polyester are shown in Table 1. The strength of the reinforcement is therefore:
  P(factored) = P(characteristic) / (fm * fid * fed)
  P(factored) = 500 / (1.05 * 1.05 * 1.10) = 412.2 kN/m

  This is the strength that the reinforcement maintains until creep rupture occurs.
- The required design life of the structure is 120 years. The partial factor on design life for uncertainty in the shape of the residual strength curve is 1.10 and the partial factor for the ramifications of failure, Table 3 = 1.10. The actual time to failure, taf, is therefore: 120 * 1.10 * 1.10 = 145.2 years.
- From the 95 % confidence limit creep rupture equation given in Section 3.1 the allowable stress in the reinforcement for 145.2 years as a percentage of P(factored) = 63.1 % and corresponds to an allowable stress in the reinforcement of 260.1 kN/m. Loading the reinforcement to this value will cause the reinforcement to reach creep rupture in 145.2 year.
- The margin of safety available to prevent creep rupture of the reinforcement at the design life is 145.2 – 120 = 25.2 years. This corresponds to a factor of safety of 145.2 / 120 = 1.21 on the design life of the structure.

5 COMPARISON OF THE TRADITIONAL AND PROPOSED METHODS OF ASSESSEMENT

A comparison of the traditional and the proposed method of creep assessment is presented based on the design example above. In the traditional method fm, fid and fed and partial factors for the ramifications of failure, fn, and extrapolation of creep data, fextrapolation are applied to the characteristic tensile strength. From Section 2.3 the reduction in strength due to creep for a 120 year design life is 68.56 % of characteristic strength and the partial factor for extrapolation of creep data is 1.12. The total factor applied to the characteristic strength is: fm * fid * fed * fn * fextrapolation = 1.05 * 1.05 * 1.10 * 1.10 * 1.12 = 1.49. This results in an allowable stress on the reinforcement of 229.4 kN/m which is considerably less than that determined using the proposed creep life assessment procedure. Limiting the stress in the reinforcement to 229.4 kN/m will result in a creep rupture time of 3.1 million years based on the principle of residual strength.

6 CONCLUSIONS

The creep rupture and residual strength properties of a family of polyester based geosynthetics is presented. A new creep life assessment procedure for polyester based geosynthetics is proposed. The procedure uses a combination of partial factors and material life assessment to determine the allowable load in a reinforcement element. Current methods of creep assessment is shown to be overly conservative while the new procedure produces more realistic estimates of the creep life of geosynthetics. This should result in more economic design of soil reinforcement structures.

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