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Residual strength: An alternative to stress-rupture for earth reinforcement design

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ABSTRACT: Current procedures for applying partial safety factors to a design strength based on the extrapolated stress-rupture curve lead to an unnecessarily high factor of safety. The use of residual strength curves would lead to the definition of a more realistic design strength. Strength reductions due to mechanical damage and environmental degradation can be incorporated into the procedure.

1 DEFINITION OF UNFACTORED STRENGTH

According to the British Standard BS 8006 the design strength of soil reinforcement should be based on the strength remaining at the end of the design life. The unfactored strength of reinforcement T_B which is the lower of the two strengths T_{CR}, which is governed by limit strain, and T_{CS}, governed by serviceability.

T_{CR} is derived from materials properties as follows. The stress-rupture curve defines the time to failure t_f if a load T is applied continuously to the geosynthetic. The curve is conventionally plotted as applied load (or its logarithm) against the logarithm of time to failure (Fig. 1). If a design life t_d is specified, it is then possible to read off an unfactored strength T_{CR} which would lead to fracture at the end of the design life at the maximum operating temperature (Jewell and Greenwood 1988).

T_{CS} is the extrapolated tensile load which gives rise to a maximum acceptable creep strain ε_{max} at time t_d.

The unfactored strength T_B is reduced by the material factor of safety f_m, resulting in the reinforcement design strength $T_D = T_B / f_m$. At any instant of time during the lifetime of the structure the design load should be less than or equal to T_D. f_m is the product of further partial factors including f_{m21}, which reflects the susceptibility of the reinforcement to damage during installation in the ground in the process of construction, and f_{m22}, related to the environment in which the reinforcement is installed, including the effects of ultraviolet light, the hydrolysis of polyester and the oxidation of polyolefins. f_m is a single factor which is applied to the unfactored design strength independently of time.

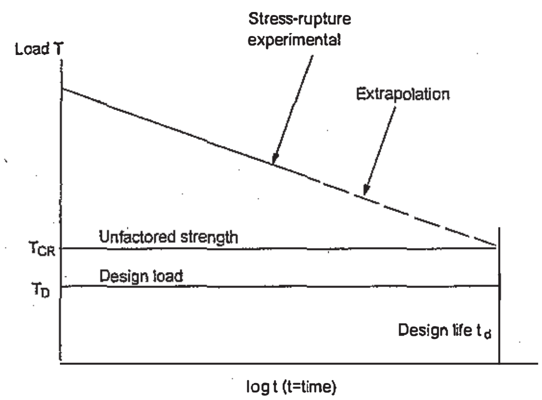

Fig. 1 Stress-rupture diagram

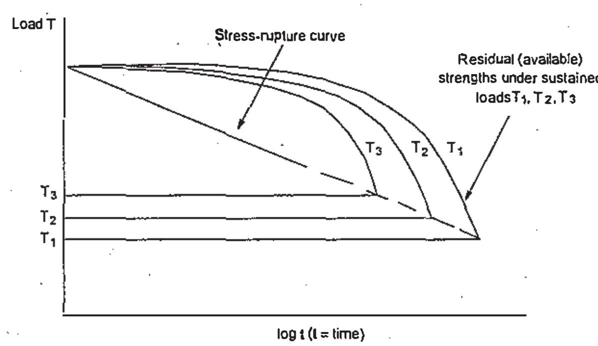

Fig. 2 Residual strengths as a function of time

2 UNDERESTIMATE OF T_D

It is the purpose of this contribution to point out that certain aspects of this procedure lead to overdimensioning due to an underestimate of T_D.

The design load should reflect the ratio between the applied load and the available strength. In spite of its appearance, the stress-rupture curve does not depict the reduction of strength with time in the same manner as, for example, degradation due to exposure to weathering. For each load level T and time t there is an available or residual strength T_R which remains close to the tensile strength of the material for most of the design life, falling to meet the stress-rupture curve at t_f at which point $T = T_B$ (Fig. 2).

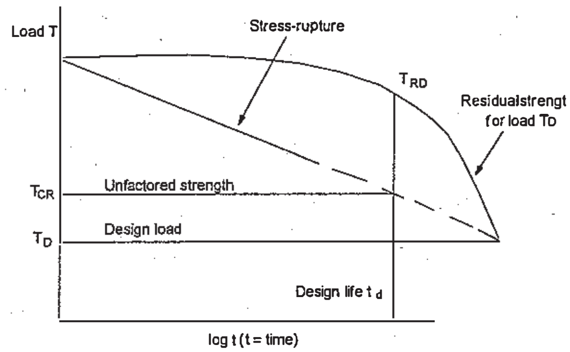

Fig. 3 Definition of T_{RD}, the residual strength at the end of design life t_d under sustained load T_D. $T_D / T_{CR} = f_m$.

If the applied load T is reduced from T_B to T_D, the residual strength T_{RD} at the design life t_d will remain close to the original tensile strength and the effective factor of safety will be increased from T_D/T_B to T_D/T_{RD} (Fig. 3).

This was pointed out by Schardin-Liedtke (1990). As she remarked, however, there is a lack of data on residual strength.

It is possible to derive an analytical expression for the residual strength based on brittle fracture crack growth principles, where it can be shown that if the stress-rupture of geosynthetics is expressed as a power law

$$T = (t/B)^{-n}$$

then for a polyester n is approximately 40 and that this can be associated with a high available or residual strength over most of the design life. Such high indices have little physical meaning, however. Horrocks (1996), working with polypropylene, has noted that stress-rupture should be regarded as a chemical process which may be associated with a long initiation time to set up the conditions for local rupture. This would leave the residual strength unchanged until shortly before failure.

3 REVISED DESIGN PROCEDURE

3.1 *Residual strength due to sustained load alone*

It is proposed that instead of using the stress-rupture curve directly, the design load could be based on the residual strength curve T_R corresponding to the anticipated design load T_D. In the absence of an analytical function to describe the residual strength curves, an iterative process will be required to derive the load T_D which, at the end of the design life, will maintain a factor of safety f_m between the applied load and the residual or available strength T_{RD} such that $T_D = f_m . T_{RD}$ (Fig. 4).

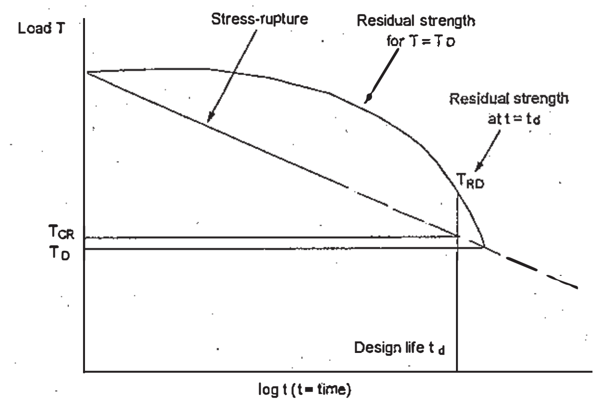

Fig. 4 Redefinition of T_D such that $T_D / T_{RD} = f_m$

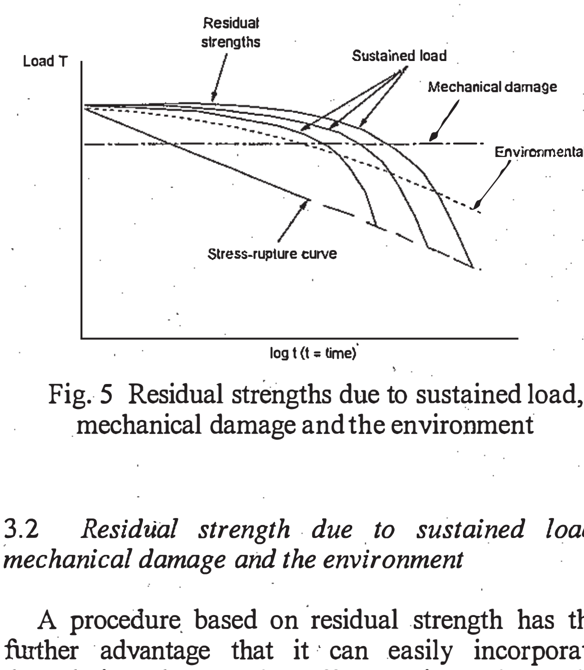

Fig. 5 Residual strengths due to sustained load, mechanical damage and the environment

3.2 *Residual strength due to sustained load, mechanical damage and the environment*

A procedure based on residual strength has the further advantage that it can easily incorporate degradations due to other effects. Fig. 5 shows the residual strength due to sustained load, mechanical damage and environmental effects individually. If all the effects - load, mechanical damage and

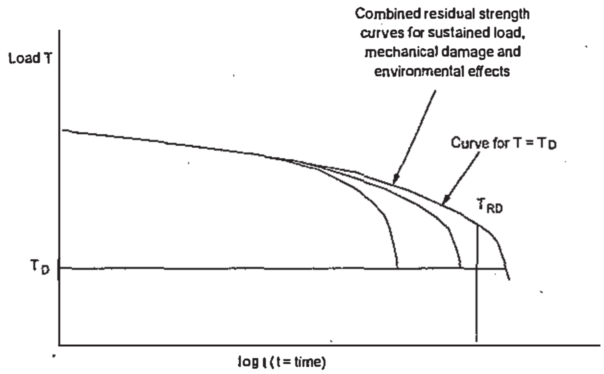

Fig. 6 Combined residual strength curves for sustained load, mechanical damage and the environment; redefinition of T_D such that $T_D / T_{RD} = f_m$

environmental - apply simultaneously but without any synergistic effects such as enviromnental stress cracking, the degradation curves expressed as fractions of the initial tensile strength may be multiplied to provide a set of reduced residual strength curves as shown in Fig. 6. The design load T_D may then be calculated such that, at time t_d, $T_D/T_{RD} = f_m$ in the same manner as in Fig. 4 but using the reduced curves.

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