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Proposed method to determine the safety capacity of reinforced soil structures during the lifetime

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ABSTRACT: The method to calculate the design strength of geogrids as outlined in BS 8006 is described. Partial factors are used to reach the factored design strength. As the circumstances which lead to reductions in the strength can be sometimes time-dependent, a considerable additional safety margin is available in the design strength; this safety margin is not earlier quantified. In this paper a method is proposed to determine the extra safety in an earlier built structure (safety capacity). This method, based on the analysis of the creep-strain history of the structure, would allow to determine the expected additional service life of the reinforcement when the load in the reinforcement is not changed or to determine the additional load that could be allowed in the structure in relation to the lifetime.

1 INTRODUCTION

Calculation of the design strength according to BS 8006. The design strength of soil reinforcement material should be higher than the load in that material (multiplied with load factors).

This design strength is based on the long term characteristics of the material and further reductions of strength which could take place during the service life are introduced as partial reduction factors.

1.1 *Unfactored design strength*

According to the British standard BS 8006, the design strength of soil reinforcement should be based on the strength to prevail at the end of the design life. The unfactored strength of reinforcement = T_B. This design strength may be governed by considerations of serviceability or tensile creep rupture.

T_{CR} is the extrapolated creep rupture strength at the end of the selected design life and at maximum operational temperature.

T_{CS} is the extrapolated tensile load which gives rise to a maximum creep strain.

The unfactored design strength T_B is reduced by the reinforcement material factor f_m, resulting in the reinforcement design strength $T_D = T_B / f_m$.

At any instant of time during the life time of the structure, the factored design strength T_D should equal or exceed the design load.

1.2 *Partial factors*

f_m is the partial material factor for reinforcement and has two components.

$$f_m = f_{m1} * f_{m2} \quad (1)$$

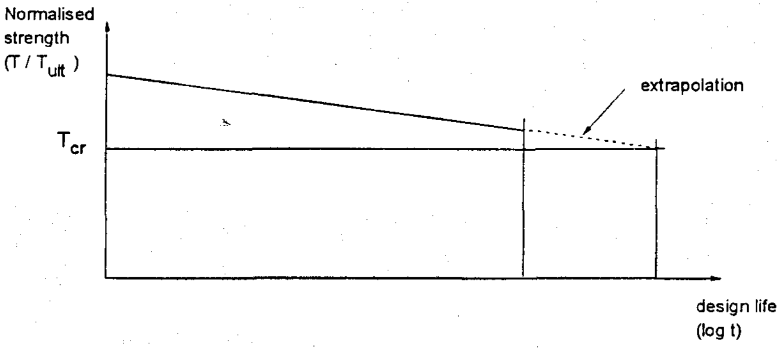


Figure 1 Stress-rupture line.

where f_{m1} = a partial material factor related to intrinsic properties of the material; f_{m2} = a partial material factor concerned with construction and environmental effects.

f_{m1} has two components:

$$f_{m1} = f_{m11} * f_{m12} \qquad (2)$$

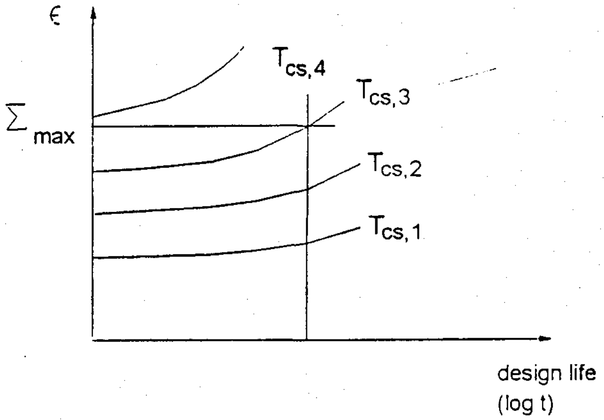


Figure 2 Isochronous lines.

where f_{m11} = a partial material factor related to the consistency of manufacture of the reinforcement and how strength may be affected by this and possible inaccuracy in assessment; f_{m12} = a partial factor related to the extrapolation of test data dealing with the base strength.

The value of f_{m1} depends on the availability of test data and accuracy of test data and quality control standards. It is a fixed value which reduces the design strength and is of the overall safety factor type. This factor results in a lower loading condition of the material during lifetime. In the following analysis we call this a type A behavior.

$$f_{m2} = f_{m21} * f_{m22} \qquad (3)$$

where f_{m21} = a partial material factor related to the susceptibility of reinforcement to damage during installation in the ground; f_{m22} = a partial material factor related to the environment in which the reinforcement is installed.

The value of f_{m21} is determined based on the results of tests under actual construction conditions. The

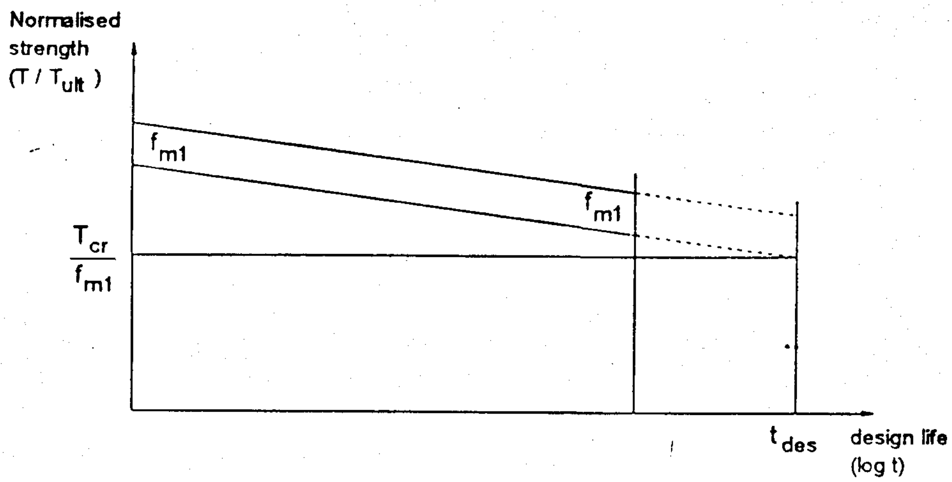


Figure 3 Stress-rupture line with calculated reduction due to f_{m1}.

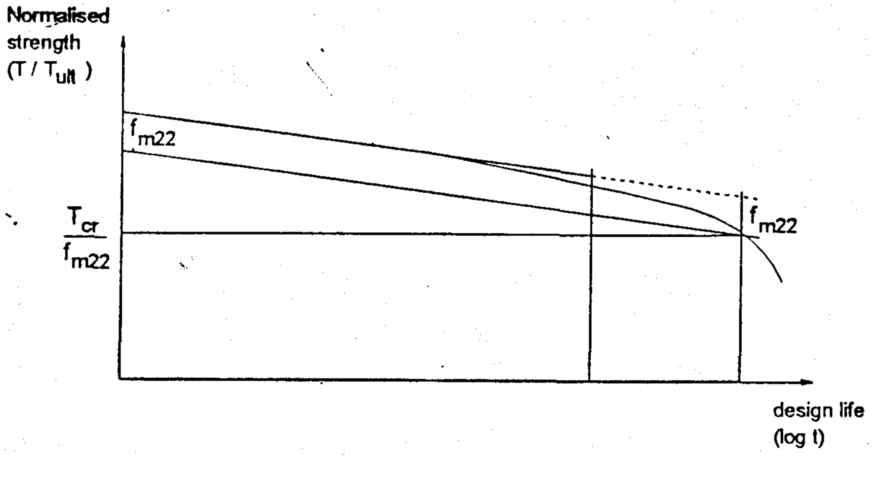
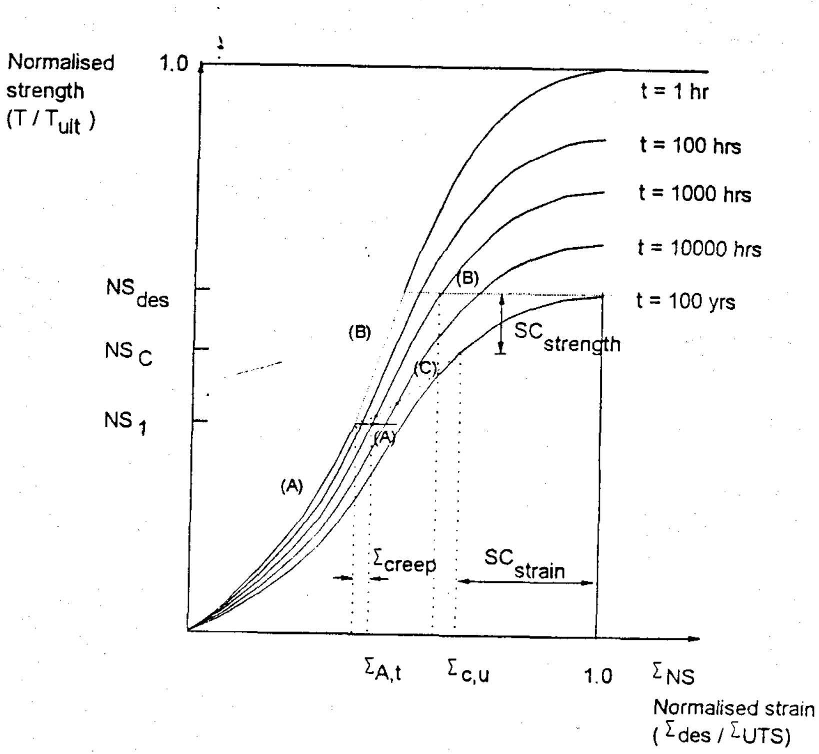


Figure 4 Stress-rupture line with calculated reduction due to f_{m2}.



NS_{des} = factored normalised design strength (theoretical); NS_1 = factored normalised design strength (actual, due to over estimation of cross section A); (A) = stress - strain path (actual); (B) = stress - strain path (theoretical, design); (C) = stress - strain path (due to time dependent strength reduction processes)

Figure 6 Isochnous curve with actual stress-strain path.

load

normalised strength results in lower creep speeds, which result in longer time before rupture takes place. Or it results in under-estimating the rupture strength. This is the main reason why relatively low strains are measured in prototypes under long term loading.

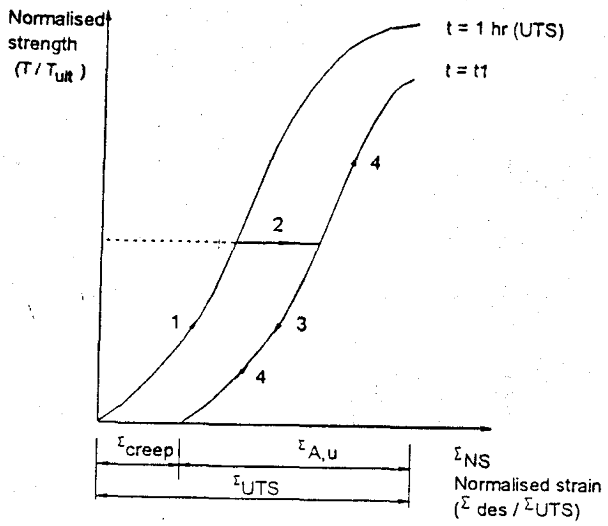


Figure 7 Creep history during loaded situation.

3 PROPOSED METHOD TO DETERMINE THE LONG TERM SAFETY CAPACITY OF A REINFORCED SOIL STRUCTURE

3.1 *Description of method*

The creep strain development in time is shown on isochronous curves. If we use these curves we can determine together with the elapsed time, what the actual stress level has been during the service life of the structure.

The factored design strength results in a stress-strain path indicated with (B). The actual stress-strain path, as result of over-dimensioning, is indicated with (A). This over-dimensioning is the result of the fact that the reduction in strength of the virgin material has not occurred in practice (f_m factor is a "safety factor"). However, we do not know exactly at what normalised strength the material has actually been loaded.

When we remove parts of the reinforcement from a built structure or from loaded test samples, we can execute a tensile strength test. The strength and the strain at failure are found. The strain which is found ($\Sigma_{A,u}$) is lower than the strain at failure (Σ_{UTS}) when virgin material is tested. This is due to the fact that the material has been creeping. The reduction in strain (Σ_{UTS} - $\Sigma_{A,u}$) as indicated in the figure below is the creep (Σ_{creep}) that has taken place. This creep value is determined.

In the normalised stress-strain isochronous curves

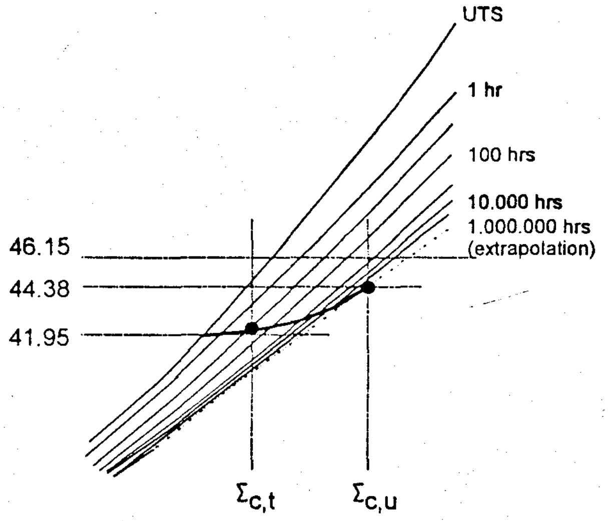


Figure 10 Detail isochronous curve of Figure 9.

$$SC_{strain} = 12.5 / 7.2 = 1.73. \qquad (11)$$

The safety capacity in service life is:

$$SC_{service\ life} = 10^{16} / 10^{8} = 10^{8} \text{ hrs.} \qquad (12)$$

When the loading factors which apply in the geotechnical design are taken into account the above mentioned safety capacity values will be even much more resulting in a further decrease in creep and consequently resulting in an additional safety capacity.

4 CONCLUSION AND FURTHER RESEARCH WORK

As shown above this method gives the opportunity to analyze the actual loads in the reinforcement based on the creep history of the material. With this back calculation method it is possible to get a reasonable accurate value of the load in the reinforcement.

The effects of the extra safety due to the over estimation in cross section of the reinforcement can be analyzed in the same way. At Akzo Nobel Geosynthetics research laboratories, a number of long term tests are being executed, some test points already more than 6 years. Some of these test samples will be used for validation of this method.

The author intends to verify this theory further by additional testing and detailed analysis of already available (long term) test data. When the initial findings and the method are confirmed it will form an excellent base to determine the safety capacity of already constructed reinforced soil structures. It can eliminate the uncertainty, leading to unnecessary high safety factors in the design of (semi) permanent structures.

REFERENCES

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