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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.

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

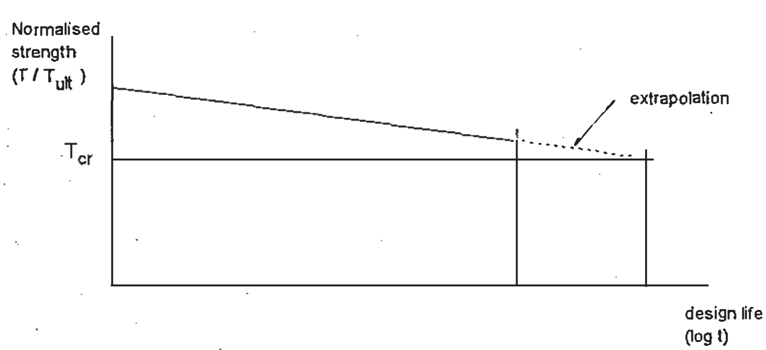



Figure 1 Stress-rupture line.

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:

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

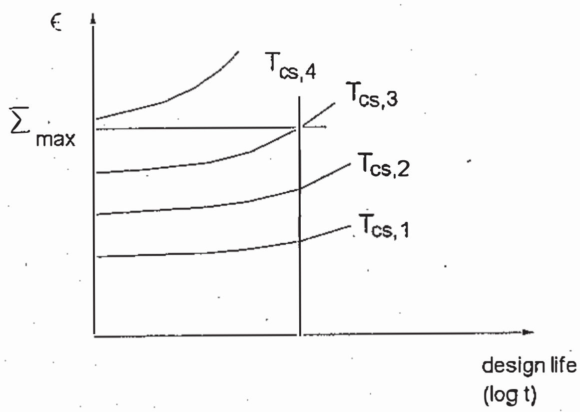



Figure 2 Isochronous lines.

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.

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

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

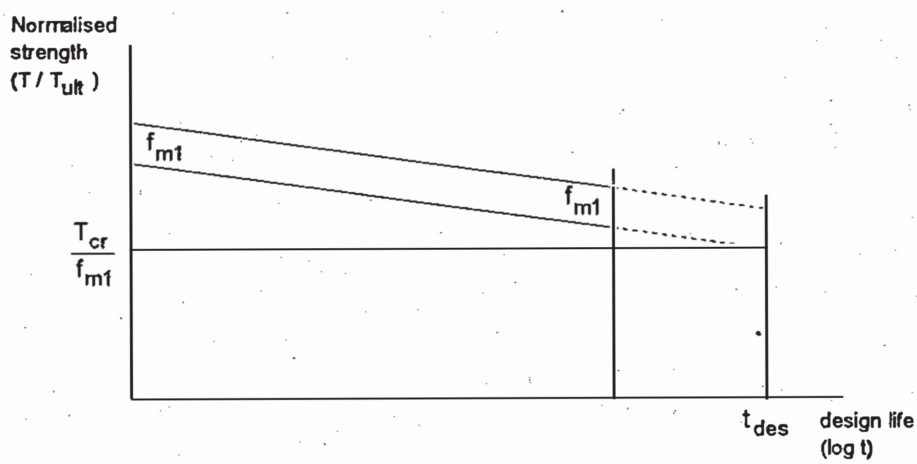



Figure 3 Stress-rupture line with calculated reduction due to $f_{m1}$.

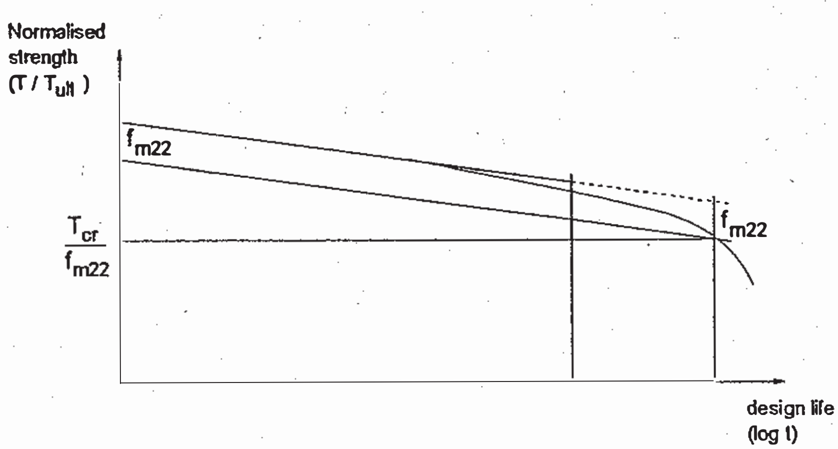



Figure 4 Stress-rupture line with calculated reduction due to $f_{m2}$.

conditions and test results are categorized and values fixed. These fixed values reduce the design strength and are of the overall safety factor type, (type A). $f_{m22}$ is based on testing and extrapolation under environmental conditions. The estimated reduction in strength during the service life of the structure is determined and applied as a fixed value as factor. The strength reduction as a result of the environmental conditions is not linear in the time. We call this non linear behavior type B.

Typical examples of these circumstances are hydrolysis of polyester, oxidation of polyolefins, UV attack.

### 1.3 *Factored design strength*

The factored design strength $T_D$ is:

$$T_D = T_B \;/\; f_m = T_B \;/\; (f_{m1} * f_{m2}) \tag{4}$$

and is the calculated strength to prevail at the end of the design life.

## 2 UNDER ESTIMATION OF THE DESIGN STRENGTH

### 2.1 *Description of model of analysis*

There are two aspects in this calculation which can result in considerable under-estimation of the design strength.

This is the easiest to describe when we use the expression:

$$T_D = \sigma_S * A \tag{5}$$

where $T_D$ = the design strength ( N ); $\sigma_S$ = the specific strength of the material ( N / mm$^2$ ); $A$ = the cross-sectional area ( mm$^2$ )

When we assume that the specific strength of the material does not change in time, the design strength is directly proportional to the cross-sectional area A of the load bearing elements of the reinforcement.

$$T_D = f(A) \tag{6}$$

### 2.2 *Strength reduction at the begin of the design life*

The partial factors which are fixed values and which are based on the maximum reduction of strength during installation, or accuracy of data etc. (type A), result directly in a larger cross-sectional area of the load bearing elements of the reinforcement. This results in a situation that either the cross-section ( $A$ ) is over-dimensioned or in the case that all negative factors apply, in an exactly correct value of A. This means that in most cases the cross-sectional area is over-dimensioned, which automatically leads to a lower normalised ( $T_D$ / $T_{Ult}$ ) stress condition.

### 2.3 *Strength reduction developing during the service life*

When the environmental effects on the strength increase in time (type B behavior), the cross-sectional area ( $A$ ) is calculated, based on the available strength at the end of the service life (acc. BS 8006). As the speed of the process increases in time, it is clear that the factored design strength $T_D$ leads to an over-estimated cross-sectional area ( $A$ ) at the begin of the life time. This over-estimate reduces in time leading to the correct cross-sectional area at the end of the service life of the structure.

The design strength $T_D$ is based on the extrapolated creep-rupture strength at the end of the design life time (or limited by strain requirements). The creep speed and therefore the rupture strength is depending on the normalised strength. So if we over-estimate the cross-sectional area of the load bearing elements and if we over-estimate the loadings in the soil mechanical design by means of load factors, we reduce the normalised strength of the reinforcement considerably. This lower

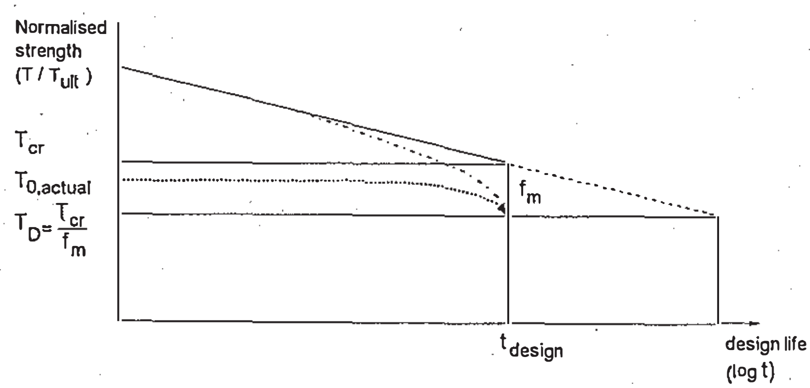
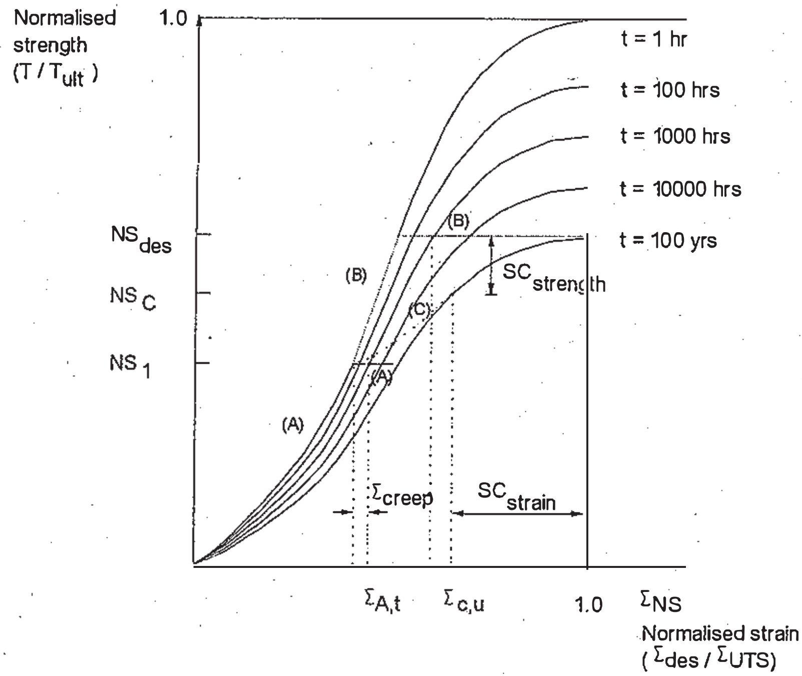



Figure 5 Stress-rupture line with $T_D$, actual and $T_D$, theoretical.




$NS_{des}$ = 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.

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.

## 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

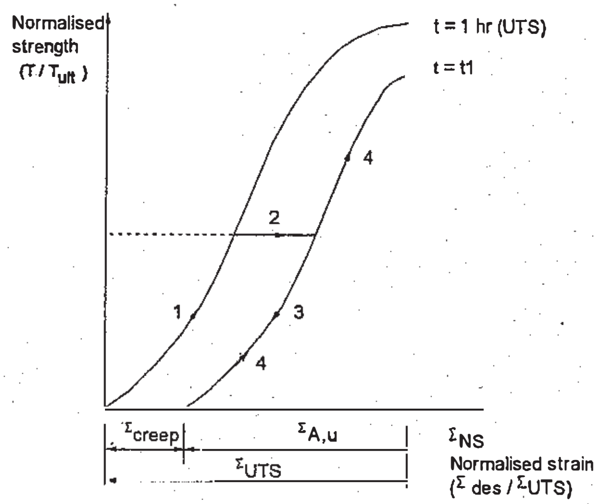



Figure 7 Creep history during loaded situation.

strain at failure are found. The strain which is found ($\Sigma_{A,u}$) is lower than the strain at failure ($\Sigma_{UTS}$) when virgin material is tested. This is due to the fact that the material has been creeping. The reduction in strain ($\Sigma_{UTS}$ - $\Sigma_{A,u}$) as indicated in the figure below is the creep ($\Sigma_{creep}$) that has taken place. This creep value is determined.

In the normalised stress-strain isochronous curves

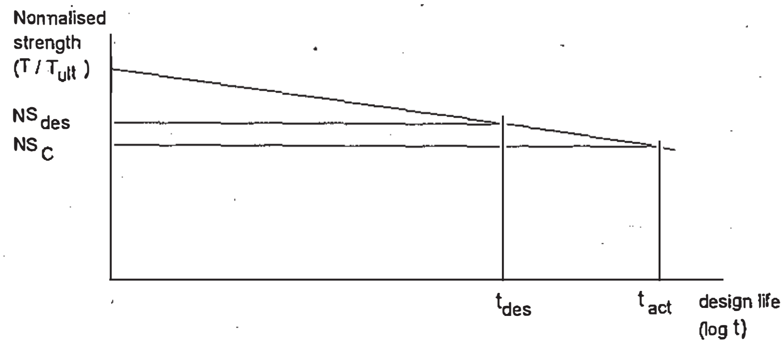



Figure 8 Stress-rupture line, safety capacity in years.

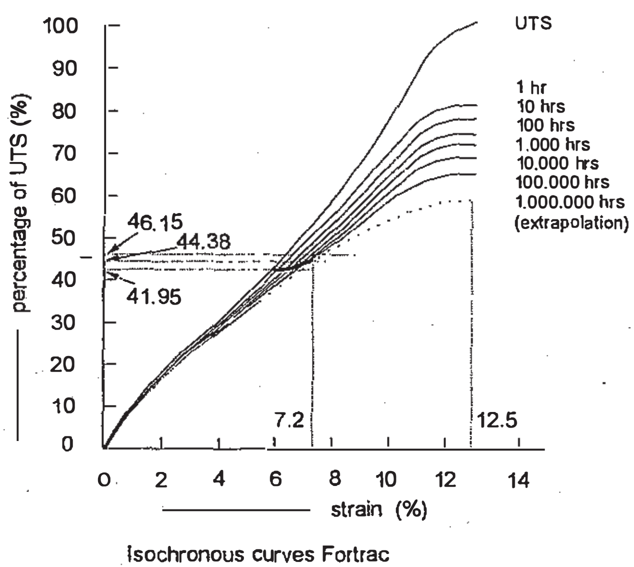



Figure 9 Isochronous curve.

we can indicate this strain. Curve (A) is the stress-strain path for the material loaded at actual load level (including $f_m$ ). Curve (B) is the stress-strain path for the material loaded at theoretical factored design level (including $f_m$ ). The creep value is measured from the $t$ = 1 line (UTS) to the $t = t_l$ line with $t_l$ = time over which loading has taken place. In this way the actual stress-strain condition point is found. The normalised strength for this point can be found (NS).

When a time dependent process takes place, the strain increases in time. This is indicated with the stress-strain path (C). It will now be harder to determine the strain at the end of the service life. However when more than 3 points are determined and when the theoretical description of the chemical process is known, the curve (C) can be calculated. Where (C) crosses the isochronous curve for the end of the service life, the strain at that point will be the actual strain at the end of the service life of the structure.

The actual safety capacity in strength in the reinforcement at the end of the service life of the structure is:

(Safety capacity is defined as the actual Factor of Safety available in the material as result of the multiplication of the various partial factors, while actually this factor should be 1.0, as the calculations are made in a limit equilibrium condition and load factors are applied on the design)

$$SC_{strength} = NS_{des} \;/\; NS_C \qquad (7)$$

The safety capacity in time can be determined with the stress-rupture curve. The lifetime $t_{act}$ is determined for $NS_C$ as normalised strength value.

$$SC_{time} = t_{act} \;/\; t_{des} \qquad (8)$$

The safety capacity in strain can be determined with

$$SC_{strain} = \epsilon_{des} \;/\; \epsilon_C \qquad (9)$$

In case the loading of a reinforced structure will change in the future, the safety capacity of the structure can be calculated, by calculating the creep that has taken place during the service life using isochronous curves. Based on the isochronous graphs it can then be calculated what increase in loading is allowed.

With this method the use of reinforcement can be optimized. Considerable reductions in materials can be reached when sufficient data is collected in the coming years as the combined effects of the various conditions that influence the reinforcement strength can be determined.

## 3.2 *Example*

When we assume that the material is over-dimensioned with a factor of 1.3 and when we assume that a factor of 1.1 for a time dependent process is applied, it can be calculated that for a typical PET material the available safety capacity for strength is:

$$SC_{strength} = 60 / 44.38 = 1.35. \qquad (10)$$

The safety capacity for strain is:

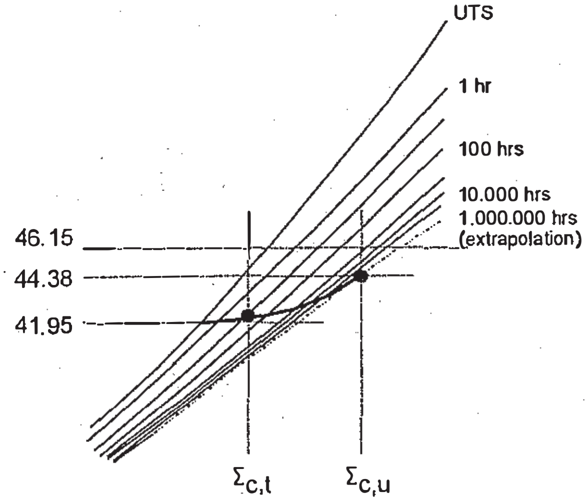



Figure 10 Detail isochronous curve of Figure 9.

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

The safety capacity in service life is:

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

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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