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Assessment of geogrids for soil reinforcement in Hong Kong

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ABSTRACT: To promote the safe use of polymeric reinforcements as construction materials, the Hong Kong Government requires a detailed listing of all factors that could possibly lead to a loss of strength and also a quantitative prediction of the strength at the end of design life. These factors are expressed as partial safety factors and a different way of handling these partial factors is suggested.

1 INTRODUCTION

Reinforced soil walls in Hong Kong are built for a design life of 120 years under a load at temperature of 35°C, and in saturated soil. As the experience of using polymeric geogrid reinforcements in Hong Kong is limited, the Geotechnical Engineering Office (GEO) has requirements on a detailed listing of all factors that could possibly lead to a loss of strength and a quantitative prediction of the strength at the end of design life. One of the most important factors to be evaluated is the creep and rupture stress allowable within the design life span. This can be predicted by measuring the time to failure at loads just below the ultimate tensile strength, and extrapolating the short times to failure at higher loads to longer times at lower loads. From this, a design load can be derived. This design load must then be reduced by a number of partial safety factors to account for the possible reductions in strength during the design life span. The objective is to set the applied loads at a level that will reduce the risk of any failure to an acceptable level.

2 STRESS RUPTURE

The most frequently quoted mechanical property of a geogrid is its strength, measured by a machine which draws the material apart at a constant rate until it breaks. Test results are generally the average of five measurements. A manufacturer often quotes a minimum strength for the geogrid, based for example on a 95% 'characteristic' strength. Only one sample in twenty would be expected to be weaker. This tensile strength does not reflect the behaviour of the material in the long term. Any polymer left under constant load at normal ambient temperatures will elongate with time or 'creep'. If the load is high, creep may lead to failure or 'stress rupture'.

Both aspects of creep and stress rupture, i.e. elongation and rupture under constant load, must be taken into account in the design of reinforced fill structures. Excessive elongation of the reinforcement could lead to distortion and possible instability, and stress rupture could lead to sudden failure.

3 METHOD OF ASSESSMENT FOR STRESS RUPTURE LOAD

All the methods of assessment used to predict the occurrence of stress rupture during a design lifetime are based on the results of tests with comparatively short duration. Creep stress rupture behaviour is predicted by testing specimens of material under a constant load at a controlled temperature and humidity and measuring the time to failure; the lower the load, the longer the lifetime. The specimens are often small and it is important to ensure that they are representative of the behaviour of the material in bulk. By plotting the load against the rupture time, or more commonly the logarithm of rupture time, a curve can be fitted and extrapolated to derive the load which, if applied permanently to the material, would lead to rupture

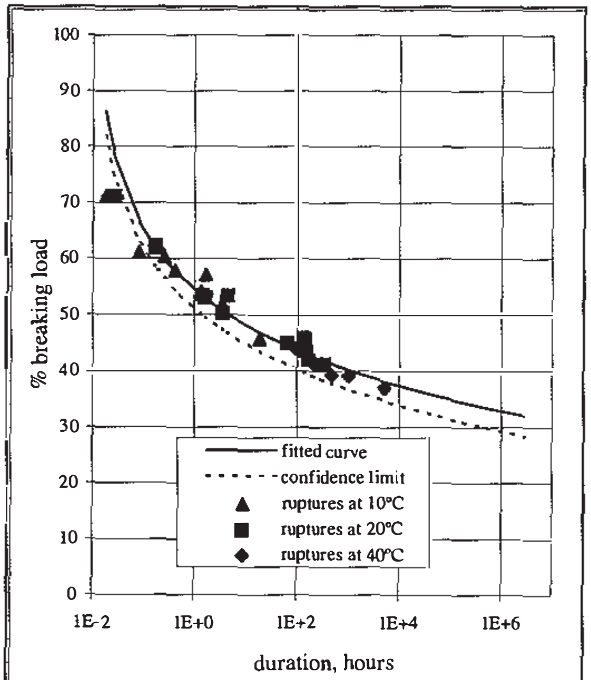

Figure 1 - Stress-Rupture of Polyethylene Geogrids at 35°C

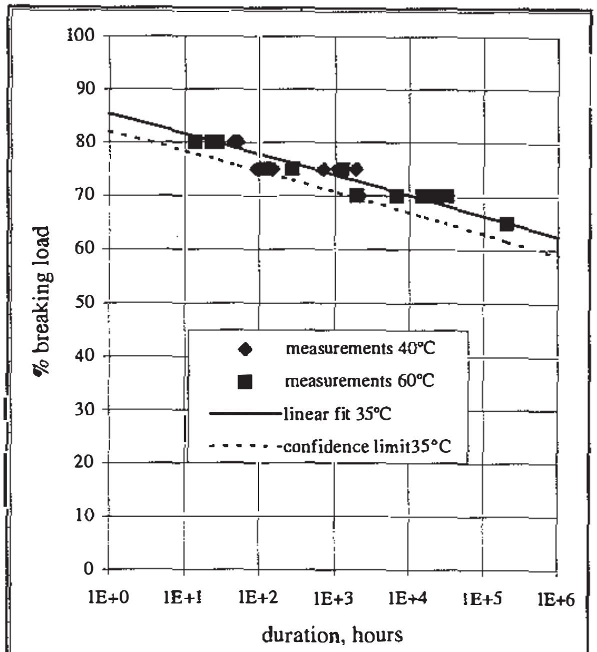

Figure 2 - Stress-Rupture of Polyester Geogrid Shifted to 35°C (Log Time Shift Factor 0.0663/°C)

at the end of the design life. This is termed as the "design load" based on rupture criterion. Likewise, a creep strain limit, i.e. 5%, can be applied as a serviceability criterion instead of rupture. A "design load" which would lead to a 5% strain deformation at the end of the design life could similarly be defined based on the same methodology.

Creep and stress rupture, in common with many other chemical and physical processes, can be accelerated by raising the testing temperature. The means of elevating temperature to accelerate the creep and rupture process is more effective for polymers such as polyethylene and polypropylene which are more sensitive to temperature than to polyester which is not. The transfer of data from one temperature to another is performed empirically by shifting the creep or stress rupture curves horizontally, plotted as applied load against the logarithm of time, along the time axis until they superimpose. This method is particularly important in Hong Kong, where operation temperature of the design load is predicted to be 35°C (Howells & Pang, 1989), and creep tests at standard laboratory conditions are performed under a temperature of 20°C.

This method has been applied successfully to a range of polyethylene geogrids (Small & Greenwood ,1993). While there were too few results on any one geogrid to describe a stress-rupture curve, by expressing the load as a percentage of the ultimate tensile strength of the batch in question and then time-temperature shifting, it was possible to create a combined stress-rupture graph for 35°C (Figure 1). To this a curve was fitted empirically. Different curve fitting techniques can be applied to the data. There are no established fundamental physical laws governing the behaviour of these materials which can be called on for extrapolation.

A similar approach can be applied to the stress-rupture data for a polyester geogrid (den Hoedt et al, 1994), as shown in Figure 2. Data are presented here for 40°C and 60°C. Although polyester is less temperature sensitive and there is less difference between the data, it is possible likewise to construct a stress-rupture curve for 35°C (Figure 2). The corresponding lower confidence limit will, when extrapolated, lead to the design load.

Statistical methods can be used to generate confidence limits, as demonstrated in Figures 1 & 2. The results are plotted as a log curve for polyethylene as:

$$\sigma = \sigma_0 + b \log(\log 1000{*}t + \Delta T) \qquad (1)$$

and a straight line for polyester as:

$$\sigma = \sigma_0 + b(\log t + \Delta T) \qquad (2)$$

Stress σ, the independent or set variable, is plotted on the y axis and time t, the dependent or measured variable, on the x axis. The amount of temperature (horizontal) shift, ΔT = log time shift factor x change of temperature, is accounted as a time effect on the x axis in the form of x = (log t + ΔT) or (log 1000*t + ΔT) as appropriate.

The statistical analyses using confidence limit is the best estimate of the minimum lifetime (i.e. to 95% probability) of the geogrid under a constant load, taking into account the existing measurements. Reference of the procedure can be made to the draft European standard on creep, prEN ISO 13431 (ISO, 1995). However, the analysis does not take into account of any variability in the material beyond the samples tested and refers only to the environment in which the tests were performed. Examples of application of this technique on creep stress rupture data at different temperature are demonstrated in Figure 3. It should be noted that no temperature shifting has been applied to these data.

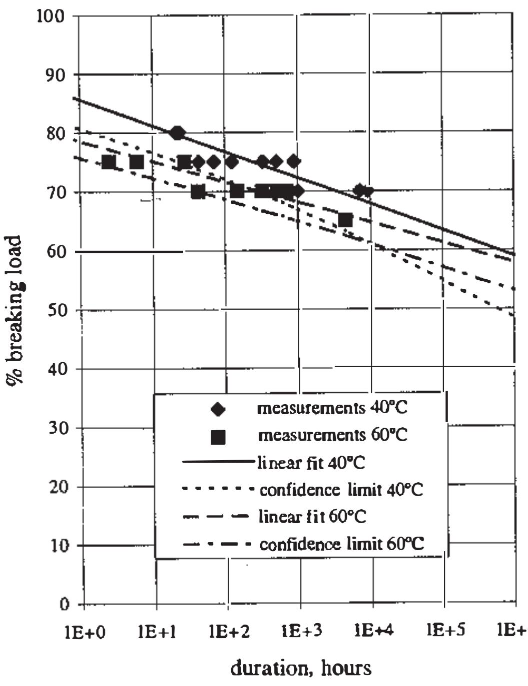

Figure 3 - Stress-Rupture of Polyester Geogrid

4 PARTIAL FACTORS OF SAFETY

For the Hong Kong conditions, the design load is set for the extrapolated creep rupture load at 95% lower confidence limit of the available test data at 35°C for 10^6 hours or 114 years. The extrapolation is based on the results of a limited number of stress-rupture tests of small specimens of geogrid, in air at controlled temperature and humidity, lasting for less than one year. It is necessary to consider all the physical factors that may influence this prediction over the life of the reinforced soil structure and, where necessary, to reduce the design load by an appropriate partial safety factor. The factors have been described in detail by Greenwood & Shen (1994), and are discussed briefly as follows.

The partial factors can be divided into three broad categories:

(a) Measured and Predicted Statistical Variability

- Variability of the stress-rupture data. Since the design load is already based on the 95% confidence limit, this factor may be set at 1.0.

- Validity of the characteristic strength. It may be necessary to re-examine the manufacturer's data to confirm whether the characteristic strength really represents a 95% lower confidence limit for all batches and, if necessary to introduce a corrected value.

(b) Measured and Predicted Reductions in Strength

- Mechnical damage. The partial safety factor for mechanical damage is the ratio of the measured tensile strengths of the damaged and undamaged material, ranging typically from 1.0 to 1.5. In the first 25 years' experience of geogrids, mechanical or installation damage, which occurs during construction, has been shown to be the major cause of loss of strength of exhumed samples.

- Temperatures in excess of the design temperature. For example, it is unlikely for the design temperature in Hong Kong to exceed 35°C for more than a few days a year. Calculations suggest that the additional effect of these days is insignificant and no further partial safety factor is required.

- Junctions, connections and joints. If junctions, connections and joints are to be used in the design, then measurements should be made of the factor by which their inclusion reduces the strength of the geogrid.

- Chemical degradation and hydrolysis. The prediction of chemical degradation and hydrolysis of polymers in soils is still a subject of discussion. No partial safety factor has been proposed for polyethylene geogrids, while the assessment of polypropylene geogrids based on tape or multifilaments, with their large surface areas, will require accelerated oxidation testing in an air oven. Data on the degradation of polyester fibres by hydrolysis, initiated by the presence of water alone but accelerated by high acidity or alkalinity have been published, Burgoyne & Merii (1993) and Schmidt et al (1994). For Hong Kong condtions, Greenwood (1995) proposed a mean value of 76% retained strength for high tenacity polyester at 35°C over 10^6 hours where no other data are available. This factor of 76% is included in the calculation of the design strength together with an associated partial safety factor of 1.5 which reflects the variability of the materials in question and the confidence in the degree of extrapolation. In addition, polyester should not be used without further testing if the local pH exceeds 9 (highly alkaline soils) and an additional factor of safety should be applied if the local pH is less than 4 (highly acid soils);

(c) Other Uncertainties

- Confidence in the method of extrapolation. GEO recommends a partial safety factor of between 1.0 and 2.0 for extrapolation not more than 2 decades of logarithm time (a factor of 100), depending upon the quality and duration of long-term creep data. If the data were generated on another product, an additional factor of typically 1.25 might be applied.

- Changes in the mode of rupture. Any change in the mechanism of failure of the material immediately invalidates the extrapolation.

- Lack of independent or calibrated data. Manufacturers are encouraged to put forward at least some measurements by an independent laboratory, to demonstrate that their laboratory is accredited to a national approvals scheme, or at least that the equipment is regularly and traceably calibrated.

- Mechanical damage. As mentioned above, the partial safety factor for mechanically damage is based on measurements of short-term strength. The effect of such damage on long-term strength is, however, unknown and an additional partial safety factor is applied to allow for this uncertainty.

- Degradation of geogrids by weathering may be significant if exposed for a long duration of time.

5 EXAMPLE OF TREATMENT OF PARTIAL SAFETY FACTORS

In practice, all partial factors of safety are multiplied to give a resultant lump factor. This procedure has been adopted by GEO and is confirmed in BS8006 (BSI, 1995). For example, the partial factors of safety applied to the design load at 35°C, for a polyester geogrid might be as follows (the numbers do not represent any particular product):

● Variability of the stress -rupture data	1.0
● Validity of the characteristic strength	1.0
● Mechanical damage (in frictional fill)	1.0
● Temperatures in excess of design temperature	1.0
● Junctions, connections & joints strength (pull-out tests satisfactory)	1.0
● Chemical attack and hydrolysis predicted strength	1.3
● Uncertainty associated with extrapolation for the chemical attack and hydrolysis	1.5
● Confidence in the method of extrapolation for stress rupture (last data point at 8760 hours)	1.3
● Changes in the mode of rupture mechanism (no mechanism known)	1.0
● Lack of independent or calibrated data (for product with evidence presented)	1.0
● Weathering (covered as according to specification)	1.0

The resulting factor of safety, equal to the product of all the above, is 2.5.

6 DISCUSSION

It has been a subject of constant discussion that by multiplying all the partial factors of safety identified would yield an unrealistically large factor which may reflect an excessive degree of conservatism. In many cases, the resultant factor can be larger than the lump factor of 3 to 4 based on conventional practice. A different treatment of partial factors is here suggested for consideration.

As the partial factors of safety represent different levels of risk, those which represent real or predicted independent reductions in strength should be multiplied, i.e. the factors for construction damage and hydrolysis. The remaining factors, whether derived statistically or estimated, together with the 95% confidence limit used to derive the design load, represent levels of risk and uncertainty for which the chance of all occurring simultaneously is remote. It could therefore be argued that a different, statistically based, method should be used to combine these factors, thus to obtain a more realistic partial factor to reflect the uncertainties.

With the improvement of design concept using partial factors, it is optimistic that a better way of handling these partial factors will be derived.

7 ACKNOWLEDGEMENTS

This paper is published with the permission of the Director of Civil Engineering of the Hong Kong Government and the Directors of ERA Technology Ltd.

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