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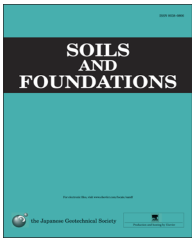

Reliability analysis of geogrid creep data in Japan

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Abstract

The data collected by creep testing carried out in conformity with current Japanese practice and reported in Public Works Research Center product certification reports are interpreted in order to identify and discuss differences between current Japanese practice and European and US practices. A database of 66 different geogrid products from 10 different manufacturers was reviewed comprising of 362 different constant load creep tests. An important outcome from the analysis of the creep test data collected to date is a strong case for the adoption of elevated temperature testing in order to eliminate the excessively long extrapolation times required to compute creep strength reduction factors.

Keywords: Geogrid; Creep; Creep testing; Reliability

1. Introduction

Current practice in Japan for the calculation of the long-term allowable strength (T_{al}) for geogrid layers in reinforced soil structures is based on an allowable stress design (ASD) approach. The general approach recognizes that the available tensile strength at the end of design life in the field is less than the original in-isolation ultimate tensile (reference) strength of a geogrid material in the laboratory (T_{ult}). The maximum tensile load in a layer (T_{max}) is multiplied by a minimum specified factor of safety (F) for each limit state (e.g. $F=1.2$ for tensile rupture and $F=2$ for pullout) to compute the design tensile load ($T_{des}=FT_{max}$). The design tensile load is assumed to act for the life of the structure and cannot exceed the long-term allowable strength of the reinforcement ($T_{des}\leq T_{al}$). The long-term allowable strength is computed as follows:

$$T_{al}=\frac{T_{ult}}{\mathrm{RF}}=\frac{T_{ult}}{\mathrm{RF_{CR}}\times\mathrm{RD_{ID}}\times\mathrm{RF_D}\times\mathrm{RF_J}}=\frac{T_{CR}}{\mathrm{RD_{ID}}\times\mathrm{RF_D}\times\mathrm{RF_J}}\tag{1}$$

Here, RF is the product of reduction factors to account for potential strength loss due to creep ($\mathrm{RF_{CR}}$), installation damage ($\mathrm{RF_{ID}}$), degradation due to chemical/biological processes ($\mathrm{RF_D}$), and reduced tensile capacity at any connection joints ($\mathrm{RF_J}$). Parameter T_{CR} is the creep-reduced strength (i.e.

Abbreviations: AASHTO, American Association of State Highway and Transportation Officials (USA); ASD, allowable stress design; ASTM, American Society for Testing and Materials (USA); COV, coefficient of variation (=standard deviation/mean); FHWA, Federal Highway Administration (USA); HDPE, high-density polyethylene; PWRC, Public Works Research Center (Japan); LRFD, load and resistance factor design; MARV, minimum average roll value; NTPEP, National Transportation Product Evaluation Program (USA); PET, polyester; POM, polyoxymethylene; PP, polypropylene; SIM, stepped isothermal method; TTS, time-temperature shifting; UK, United Kingdom; WSDOT, Washington State Department of Transportation (USA)

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$T_{CR} = T_{ult}/RF_{CR}$). The focus of this paper is on the calculation of the creep reduction factor (RF_{CR}) used in Eq. (1). The specific objectives of this paper are:

1. To review the methodology used in Japan to carry out constant load creep testing, interpret creep test results, estimate the creep-reduced tensile strength, and calculate RF_{CR}.
2. To identify differences between the Japanese approach and European and North American practices.
3. To create a database of creep test data from the PWRC product certification reports and interpret the test data in accordance with recommended Japanese practice as outlined in the Public Works Research Center, PWRC (2000a), guidance document.
4. To summarize computed creep reduction factors based on individual products and different product types (as applicable) and quantify statistical variations (bias) in reference strength and predicted creep-reduced strength.
5. To compare these values to a similar recent study of geogrid products from North America.

This paper compliments a related earlier study by Miyata and Bathurst (2012) that was focused on reliability analysis of soil-geogrid models used to predict the ultimate pullout capacity of many of the same products that appear in the current study.

2. Creep testing methodology and interpretation

2.1. General

Constant load (creep) testing in Japan is carried out in accordance with recommendations in the PWRC (2000a) guidance document. This protocol calls for a minimum of five 200 mm-wide multi-rib geogrid specimens trimmed from the same sample and tested at 23 ± 2 °C. The load levels are chosen so that they are in the range of 10–90% of the reference strength (T_{ult}) of the material. Each load is held for a minimum of 1000 h or until the specimen ruptures, whichever occurs first. However, tests may be taken out to 10,000 h. The database used in this study included a few tests that were continued for 60,000 h.

The data from a set of constant load tests are plotted together with semi-log strain-time axes. If the specimens rupture prior to 10,000 h and less than 10% strain (Fig. 1a) then a creep–rupture curve is generated as shown in Fig. 1b. If the specimens continue to strain to 10% strain or beyond (Fig. 1c) then plots of constant load versus time to reach 10% strain and 15% strain are generated (Fig. 1d). These load curves are similar to Fig. 1b but with rupture loads replaced with loads to reach 10% and 15% strain. Geogrid materials that can creep to 10% strain or more are identified by PWRC as "ductile" polymeric materials and polymeric geogrids that creep to rupture at lower strains are identified as "brittle" materials. For example, uniaxial HDPE and biaxial PP geogrids are classified as ductile materials while woven and knitted PET and Aramid geogrids are classified brittle materials. The use of these terms can be traced to the work of McGown et al. (1985). The creep reduction factor is computed differently for each response type. Implications of this classification system to calculation of creep-reduced strength at design life and comparison with creep test methodology and test interpretation in other countries are discussed later.

2.2. Creep-reduced strength for "brittle" material behavior

The creep-rupture curve for brittle materials is extrapolated to the design life of the structure (t_d) to give the creep-reduced tensile strength T_{CR} (Fig. 1b). A reasonable assumption for the design life of a permanent structure is $t_d = 1 \times 10^6$ h (approximately 120 years). Shorter design life values (e.g. for temporary structures) will correspond to larger values of creep-reduced strength. There is no explicit guidance in the PWRC (2000a) document on how to carry out the extrapolation of the creep–rupture curve to design life. Bathurst et al. (2012) reported that creep-rupture loads for polyester (PET) reinforcement products are typically characterized using a log-linear equation (e.g. EN ISO/TR 20432, 2007; WSDOT T925, 2009). For a set of creep tests on specimens from a single product type, the rupture load (T_t) at elapsed time t can be expressed as follows:

$$T_t = a_T + b_T \log t \tag{2}$$

Here, a_T and b_T are the unit-dependent constants determined from regression analysis.

For polyolefin (polypropylene (PP) and high-density polyethylene (HDPE)) reinforcement products, creep-rupture loads are best approximated using a log–log function (e.g. Wrigley et al., 1999; Thornton and Baker, 2002). Hence, for a single product type

$$\log T_t = a_T + b_T \log t \tag{3}$$

Here, the constant coefficients are dimensionless. Later in the paper, creep data from constant load tests on geogrid materials in the same product line are grouped together to form a composite 10% creep–strain curve in accordance with European and North American practice for the construction of creep–rupture curves (e.g. ISO/TR 20432, 2007; WSDOT T925, 2009; CUR, 2012). In order to group the data, the creep loads are normalized with the mean value of measured ultimate strength (i.e. $T_{ult} = \overline{T}_{ult,meas}$) from reference tensile tests carried out on specimens trimmed from the same sample used for the creep load specimens. Eqs. (2) and (3) fitted to composite rupture envelopes can now be expressed as follow:

$$P_t = a_P + b_P \log t \tag{4}$$

and

$$\log P_t = a_P + b_P \log t \tag{5}$$

where, P_t is the (predicted) fraction of original strength (T_{ult}) retained and a_P and b_P are dimensionless constants determined from regression analysis. The creep reduction factor corresponding to time t is the inverse of the fraction of strength