Soils and Foundations 2015;55(2):393–403

HOSTED BY

ELSEVIER

CrossMark

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Reliability analysis of geogrid installation damage test data in Japan

Yoshihisa Miyata[a,*], Richard J. Bathurst[b,1]

[a]Department of Civil and Environmental Engineering, National Defense Academy, 1-10-20 Hashirimizu, Yokosuka 239-8686, Japan
[b]GeoEngineering Centre at Queen's-RMC, Department of Civil Engineering, Royal Military College of Canada, Kingston, ON, Canada K7K 7B4

Received 12 May 2014; received in revised form 28 October 2014; accepted 19 November 2014
Available online 23 March 2015

Abstract

The paper reports the results of the analysis of field installation damage tests carried out on geogrid soil reinforcement products used in Japan. The data are taken from Public Works Research Center (PWRC) product certification reports. The database comprises a total of 130 tensile tests performed on undamaged (reference) tests and 390 tensile tests performed on exhumed damaged geogrid specimens. A total of 78 installation damage factors were computed by the writers representing 26 different geogrid products from 12 different product lines in combination with three different aggregate types. The field tests were carried out using a standard PWRC protocol and the calculation of installation damage factors and spread in data was carried out in a consistent manner by the writers. The data are shown to be in good agreement with the results of tests carried out on similar products reported in other countries. The installation damage factors summarized in this study provide a useful benchmark for future field installation damage test results in Japan and worldwide. The statistical analysis of variability in installation damage test results is a prerequisite for future probabilistic analysis and design for the ultimate tensile rupture limit state in geogrid reinforced soil structures and for load and resistance factor design (LRFD) calibration of this limit state.

Keywords: Geogrid; Installation damage; Reliability; Bias; Load and resistance factor design; LRFD

1. Introduction

An allowable stress design (ASD) approach is currently used in Japan to compute the long-term allowable strength (T_{al}) for the ultimate tensile rupture limit state of geogrid layers in reinforced soil structures (Public Works Research Center—PWRC, 2013). The long-term allowable strength available at the end of design life is computed as

$$T_{al} = \frac{T_{ult}}{RF} = \frac{T_{ult}}{RF_{CR} \times RF_{ID} \times RF_{D} \times RF_{J}} \quad (1)$$

here T_{ult} is the in-isolation ultimate tensile (reference) strength of the geogrid material expressed in units of force per unit width of material and RF is the product of reduction factors to account for potential strength loss. The contributions to

Abbreviations: AASHTO, American Association of State Highway and Transportation Officials (USA); ASD, allowable stress design; ASTM, American Society for Testing and Materials (USA); CDF, cumulative distribution function; 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; WSDOT, Washington State Department of Transportation (USA)

*Corresponding author. Tel.: +81 468 41 3810; fax: +81 468 44 5913.
E-mail addresses: miyamiya@nda.ac.jp (Y. Miyata), bathurst-r@rmc.ca (R.J. Bathurst).
[1]Tel.: +1 613 541–6000x6479/6347/6391; fax: +1 613 541 6218.
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2015.02.013
0038-0806/

strength loss over the design life of the structure are installation damage (RF_{ID}), creep (RF_{CR}), degradation due to chemical/biological processes (RF_D), and reduced tensile capacity at any connections or junctions (RF_J). All reduction factors are equal to one or greater.

The maximum tensile load in a layer (T_{max}) is multiplied by a minimum specified factor of safety (F) for each limit state to compute the design tensile load ($T_{des} = F \times T_{max}$). The minimum factor of safety is $F = 1$ and 1.5 for tensile rupture design of walls and embankments, respectively, and $F = 2$ for pullout. 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 (i.e. $T_{des} \leq T_{al}$). Stated alternatively, the maximum tensile load in a reinforcement layer can be expressed as a function of the reference strength of the reinforcement and the product of two strength reduction factors (i.e. $T_{max} \leq T_{ult}/(RF \times F)$).

The primary focus of this paper is the calculation of the installation damage factor (RF_{ID}) used in Eq. (1) and quantification of the inherent variability in the calculation of this parameter based on Japanese data. The specific objectives of this paper are:

1. Review the methodology used in Japan to carry out field installation damage tests, estimate the reductions in tensile strength due to installation damage, and calculate RF_{ID}.
2. Create a database of installation damage test data from PWRC geogrid product certification reports available in Japan.
3. Summarize computed installation damage factors based on different combinations of product type and embedment soil.
4. Quantify statistical variations in reference tensile strength and predicted tensile strength after installation damage. These predicted strengths are commonly referred to as *nominal* strength values in North America.

In this study only installation damage test results from PWRC product certification reports are used. However, where applicable, some comparisons with installation damage factors from other studies are made. For example, a useful database of North American field installation damage testing collected from multiple sources can be found in the paper by Bathurst et al. (2011). Installation damage test results for similar products tested in Korea have also been reported by Lim and McCartney (2013). A valuable source of European installation damage test results can be found in the study by Hufenus et al. (2005). An overview of European practice with respect to assessment of installation damage and the calculation of long-term allowable tensile strength of geosynthetic materials can be found in the report by Greenwood et al. (2012).

This paper is a complementary investigation to the study by Miyata et al. (2014) that was focused on reliability analysis of geogrid creep data from PWRC product certificate reports available in Japan. The data from both studies are necessary for the prediction of probability of failure for the long-term tensile rupture limit state using a reliability-based approach and for calibration of the rupture limit state expressed in a load and resistance factor design (LRFD) format. The general methodology is described by Bathurst (2014) and the use of the data in the current study is demonstrated in the paper by Bathurst and Miyata (2015).

2. Installation damage testing methodology and interpretation

2.1. General

The current installation damage testing protocol and interpretation of results used in Japan is described in the Public Works Research Center (PWRC, 2013) guidance document. The guidance document in effect at the time of the field installation damage tests reported in the collected product certification reports was (PWRC, 2000a). However, there are no changes between these two revisions regarding installation damage testing methodology and interpretation. The general approach is to embed samples of geogrid taken from the same roll in a test pad (embankment) constructed using a standard aggregate, a standard vibratory drum roller and standard lift heights. The installation damage factor for a particular combination of geogrid product and soil type is computed as the ratio of the ultimate reference tensile strength of undamaged specimens to the strength of exhumed specimens. All the installation damage tests were carried out at the PWRC test site in Tsukuba using the same test protocol.

2.2. Aggregate

Three aggregate types are specified in PWRC (2013). Type 1 is a crushed granitic rock. Type 2 is crusher-run gravel screened to a maximum size of 40 mm. Type 3 is a sand and fine gravel material known locally in Japan as "Masado". The solid lines and gradation bands in Fig. 1 are the mean and spread of distributions from all particle size analyses reported in the source documents for the current study. The measured medium particle size for Soil Type 1, 2 and 3 are $D_{50} = 21$, 11 and 1 mm, respectively.

2.3. Test pad construction

Fig. 2 shows a cross-section of the test pad (embankment) used to simulate installation damage to candidate geogrid samples. The pad is built over a set of steel plates. These plates facilitate recovery of the test samples by tipping the entire 0.6 m depth of soil and thereby minimizing potential exhumation-related damage. A single 300-mm-thick layer of aggregate is placed over the steel plates using a backhoe with a maximum bucket size of 0.7 m^3. The layer is compacted followed by placement of a row of geogrid samples. The test samples are then covered with another single 300-mm lift of compacted aggregate. The test protocol requires each layer to be compacted using seven passes of a 9-t smooth drum compactor delivering a 100 kN dynamic load to the front