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# Evaluation of the long-term performance of geosynthetic reinforcements from their reduction factors

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## Abstract

We have compared the long-term performance of geosynthetic reinforcements in the form of membrane drawn, warp/knitted, junction bonded and composite types of geogrid, and strip-type reinforcement, from their total safety factors calculated from the combined reduction factors. To evaluate these reduction factors, wide-width tensile measurements, installation damage, creep deformation and chemical and biological degradation tests were performed. The total safety factor for the geosynthetic reinforcements was calculated from the experimental results of these reduction factors. The long-term design strength of the geosynthetic reinforcements was calculated using equations contained in the Geosynthetic Research Institute Standard Test Method GG4. Among the geosynthetic reinforcements studied, strip-type reinforcements and composite-type geogrids showed excellent long-term performance.

*Keywords:* Geosynthetic reinforcements; Long-term performance; Creep deformation; Reduction factor; Total factor of safety; Long-term design strength

## 1. Introduction

A geogrid is a type of geosynthetic reinforcement which consists of connected parallel sets of tensile ribs, with apertures of sufficient size to allow a strike-through of surrounding soil, stone or other geotechnical material. The primary function of a geogrid is to serve as reinforcement material in geotechnical, transportation, and environmental applications [1–3]. Besides geogrids, many types of geosynthetic reinforcement are in wide use for the same purpose in geotechnology. The number of end uses of geosynthetic reinforcements is expanding in the geotechnical and environmental fields, owing to their higher tensile properties than those of geotextiles which may be nonwoven, knitted or woven, used in civil engineering applications [5,6].

The long-term performance of geosynthetic reinforcements is dependent on the total safety factor, which is calculated from the reduction factors due to installation damage, creep deformation, chemical and biological resistances, etc. Among these reduction factors, creep deformation and installation damage

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Table 1
Specifications of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Manufacturing process | Extrusion | Knitting | Bonding | Extrusion/insertion | Extrusion/insertion/drawing |
| Polymer | HDPE membrane | High-tenacity polyester yarn (coating resin = PVC) | Strip-type polyester | HDPE and high-tenacity polyester yarn | HDPE and high-tenacity polyester yarn |

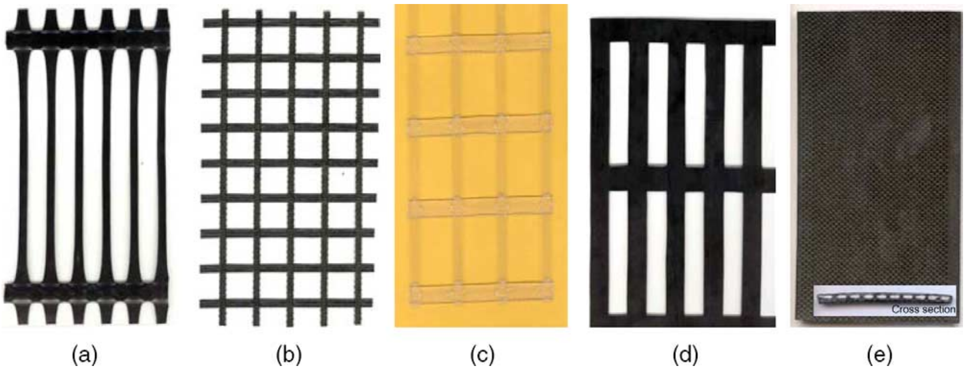

Fig. 1. Photographs of geosynthetic reinforcements: (a) membrane drawn-type geogrid, (b) warp/knit-type geogrid, (c) junction bonded-type geogrid, (d) composite-type geogrid, (e) strip-type reinforcement.

Table 2
Wide-width tensile properties of the geosynthetic reinforcements

| Geosynthetic reinforcement | | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|---|
| Tensile strength (kN/m) | MD | 28.6 | 20.8 | 26.4 | 30.5 | 34.1 |
| | TD | 24.3 | 7.3 | 25.8 | 27.8 | N/A |
| Tensile strain (%) | MD | 14.8. | 12.4 | 13.2 | 10.4 | 11.8 |
| | TD | 12.4 | 8.8 | 12.9 | 8.4 | N/A |

MD, machine direction, TD, transverse direction, N/A, not possible to test.

Table 3
Junction strength of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Junction strength (kN/m) | 40.2 | 21.4 | 28.5 | 34.8 | 23.6 |

Table 4
Strength retention of installation damage of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Strength retention (%) | 99.3 | 90.3 | 94.6 | 98.2 | 99.4 |

Table 5
Chemical resistance strength retention of the geogrids

| Geosynthetic reinforcement | | Membrane drawn-type geogrid | | | Warp/knit-type geogrid | | | Junction bonded-type geogrid | | | Composite-type geogrid | | | Strip-type reinforcement | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | | 25 | 35 | 70 | 25 | 35 | 70 | 25 | 35 | 70 | 25 | 35 | 70 | 25 | 35 | 70 |
| Strength retention (%) | pH 3.5 | 99 | 98 | 99 | 98 | 98 | 98 | 97 | 97 | 98 | 98 | 99 | 98 | 98 | 98 | 97 |
| | 7.3 | 98 | 98 | 98 | 98 | 98 | 98 | 96 | 95 | 96 | 98 | 98 | 98 | 97 | 98 | 98 |
| | 12.4 | 98 | 98 | 98 | 98 | 98 | 98 | 84 | 79 | 70 | 98 | 98 | 98 | 98 | 98 | 98 |

were observed to be very important in determining the long-term performance of geosynthetic reinforcements. However, these reduction factors are also dependent on the manufacturing method, composition and the type of junction of the geosynthetic reinforcement [7–9].

In this study, the long-term performance of five types of geogrid having design strengths of 8 t/m was compared: membrane drawn, warp/knit, junction-bonded, and composite types of geogrids. In addition to the above, strip-type reinforcements having the same design strength were used to assess their applicability as geosynthetic reinforcements in place of geogrids for soil retaining wall constructions. The reduction factors for installation damage, creep deformation, chemical and biological resistance of the geosynthetic reinforcements were evaluated from the experimental results. The experimental results were also used to analyze and predict the long-term behavior of geosynthetic reinforced soil retaining wall structures utilizing the different types of geosynthetic reinforcement.

## 2. Theoretical background

Using the Geosynthetic Research Institute (GRI) Standard Test Method GG4, developed at Drexel University, Philadelphia, PA, USA [4], the allowable strength of geosynthetic reinforcements can be calculated using Eq. (1), taking into consideration the ultimate strength and the total factor of safety in the geosynthetic reinforcement

$$T_{\text{allowable}} = T_{\text{ultimate}}\left[\frac{1}{\text{FS}}\right] \qquad (1)$$

where $T_{\text{ultimate}}$ = the ultimate strength of the geosynthetic reinforcement, $T_{\text{allowable}}$ = the allowable strength of geosynthetic reinforcement, and FS = the total factor of safety of the geosynthetic reinforcement.

The reduction factors of geosynthetic reinforcements in an application are expressed in the following form

$$\text{FS} = \text{RF}_{\text{id}} \times \text{RF}_{\text{cr}} \times \text{RF}_{\text{cd}} \times \text{RF}_{\text{bd}}, \qquad (2)$$

where $\text{RF}_{\text{id}}$ = reduction factor due to installation damage, $\text{RF}_{\text{cr}}$ = reduction factor due to creep deformation, $\text{RF}_{\text{cd}}$ = reduction factor due to chemical degradation and $\text{RF}_{\text{bd}}$ = reduction factor due to biological degradation.

From Eqs. (1) and (2), the long-term design strength of a geosynthetic reinforcement can be expressed in the form of Eq. (3), as described in the GRI Standard Test Method GG4(b), 'determination of the long-term

Table 6
Biological resistance strength retention of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Strength retention (%) | 99.8 | 99.8 | 99.9 | 99.8 | 99.8 |

Table 7
Limit of the creep strain of the geosynthetic reinforcements at $T = 20$ °C (60% of $T_{\mathrm{design}}$)

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Limit of the creep strain (%) | 13.5 | 16.8 | 15.3 | 9.6 | 14.6 |

Table 8
Reduction factors by installation damage of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Reduction factor | 1.02 | 1.4 | 1.3 | 1.02 | 1.01 |

Table 9
Creep deformation reduction factors of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Reduction factor | 2.16 | 2.62 | 2.28 | 2.12 | 2.07 |

design strength of flexible geogrids'

$$T_{\mathrm{allowable}} = T_{\mathrm{design}}\left[\frac{1}{\mathrm{RF}_{\mathrm{id}*} \times \mathrm{RF}_{\mathrm{cr}*} \times \mathrm{RF}_{\mathrm{cd}} \times \mathrm{RF}_{\mathrm{bd}}}\right], \tag{3}$$

where $T_{\mathrm{design}}$ = the long-term design strength of the geosynthetic reinforcement.

## 3. Experimental

### 3.1. Preparation of samples

The geosynthetic reinforcements used had a design strength of 8 t/m, and were used to assess the long-term performance of membrane drawn-type, warp/knitted-type, junction bonded-type, composite-type geogrids, and strip-type reinforcement. The composite-type geogrid was specifically designed and manufactured to investigate geogrid junction and creep properties, and to compensate for the disadvantages seen in typical geogrids. Table 1 shows the specifications and Fig. 1 shows photographs of the geosynthetic reinforcements used in this study.

### 3.2. Engineering properties of the geosynthetic reinforcements

#### 3.2.1. Wide-width tensile and junction strength

The wide-width tensile strength and junction strength of the geosynthetic reinforcements were tested using the specifications in ASTM D 4595 and the GRI Standard Test Method GG2.

#### 3.2.2. Installation damage

The ISO/TR 10722-1:1998(E) standard was used to test the installation damage in the geosynthetic reinforcements. The degree of installation damage was estimated from the strength retention value after installation.

#### 3.2.3. Creep deformation

Creep deformation tests were performed according to ASTM D5262-92, 'evaluating the unconfined tension creep behavior of geosynthetics'. Three loading levels were 40, 50, and 60% of the design strength of the

Table 10
Chemical resistance reduction factors of the geosynthetic reinforcements

| Geosynthetic reinforcement | | Membrane drawn-type geogrid | | | Warp/knit-type geogrid | | | Junction bonded-type geogrid | | | Composite-type geogrid | | | Strip-type reinforcement | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | | 25 | 35 | 70 | 25 | 35 | 70 | 25 | 35 | 70 | 25 | 35 | 70 | 25 | 35 | 70 |
| Strength retention (%) pH | 3.5 | 1.01–1.02 | | | 1.01–1.02 | | | 1.02–1.03 | | | 1.01–1.02 | | | 1.01 | | |
| | 7.3 | 1.02 | | | 1.01–1.02 | | | 1.04–1.05 | | | 1.02 | | | 1.01 | | |
| | 12.4 | 1.02 | | | 1.01–1.02 | | | 1.2–1.4 | | | 1.02 | | | 1.01 | | |

geosynthetic reinforcements and the test time was kept constant at 1000 h for the three test temperatures of 20, 35, and 50 °C.

### 3.2.4. Chemical and biological resistance

The resistance to chemical degradation by the geosynthetic reinforcements was assessed after a period of 180 days at pH 3.5, 7.3, and 12.4, at temperatures of 25, 35, and 70 °C with reference to the EPA 9090 test method and ASTM D 5322. Interring the geogrids in soil for a period of 12 months was used for the test of resistance to biological degradation. The degree of chemical and biological resistance was estimated from the strength retention, measured in 30-day periods.

## 4. Results and discussion

### 4.1. Analysis of the engineering properties of the geosynthetic reinforcements

### 4.1.1. Tensile and junction properties

Table 2 shows the tensile properties of the geosynthetic reinforcements in the machining direction (MD) and the transverse direction (TD). The strip-type reinforcement showed the best tensile properties in the MD. However, it was not possible to evaluate the tensile properties in the TD, because of the uniform structure of the strip-type reinforcement. The composite-type geogrid showed excellent tensile properties in the MD and TD directions compared with the other geogrids, owing to its more stable connections afforded by its specially designed composition and manufacturing process. The junction strength of the geosynthetic reinforcements are shown in Table 3 and these showed the same tendencies as observed for the tensile strength.

### 4.1.2. Degree of installation damage

The strength retention values of the geosynthetic reinforcements for installation damage are shown in Table 4. The strip-type reinforcement was the most resistant to installation damage, owing to its uniform structure, as mentioned in the discussion of the TD tensile properties. The composite-type geogrid also showed excellent tensile strength in the MD and TD directions when compared with the other geogrids. This is due to the better bonding achieved from the extrusion → insertion → drawing manufacturing process of this geogrid.

### 4.1.3. Degree of chemical and biological resistance

Table 5 shows the chemical resistance of the geosynthetic reinforcements assessed from the strength retention. All the geosynthetic reinforcements showed

Table 11
Biological degradation reduction factors of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Reduction factor | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |

Table 12
Total factor of safety of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Total factor of safety | 2.27 | 3.78 | 3.62 | 2.23 | 2.13 |

Table 13
Long-term design strength of the geosynthetic reinforcements

| Geosynthetic reinforcement | Membrane drawn-type geogrid | Warp/knit-type geogrid | Junction bonded-type geogrid | Composite-type geogrid | Strip-type reinforcement |
|---|---|---|---|---|---|
| Long-term design strength (t/m) | 3.52 | 2.12 | 2.21 | 3.59 | 3.75 |

good chemical resistance at pH 3.5 and 7.3 at the temperatures studied. However, at pH 12.4, the junction bonded-type geogrid showed the poorest chemical resistance with temperature. This is due to the decomposition of the constituent polyester at higher temperatures and pH (i.e. under highly alkaline conditions).

The biological resistance of the geosynthetic reinforcements assessed from the strength retention is shown in Table 6. All the geosynthetic reinforcements showed the same, very stable biological resistance, and it can be seen that there was no significant change induced from exposure to chemicals, acidic or alkaline solutions, or microbes in the soil.

#### 4.1.4. Limit of the creep strain

The creep properties of the geosynthetic reinforcement are very important because the deformation behavior of geosynthetic reinforcement materials is the key to maintaining serviceability of the structural system. Geosynthetic reinforcements should fracture if creep deformation exceeds 10% for a given yield strength and, therefore, geosynthetic reinforcement materials must be maintained at less than 10% creep deformation at ∼60% yield strength. Table 7 shows the limit of the creep strain of the geosynthetic reinforcements at a temperature of 20 °C at a value of 60% $T_{\text{design}}$. The composite-type geogrid showed the lowest limit of creep strain for creep deformation. This is because the load transmission of the composite-type geogrid was the best among the geosynthetic reinforcements studied.

### 4.2. Reduction factors for applications

The reduction factors of the geosynthetic reinforcements for applications were determined from the engineering properties discussed in Section 4.1, using Eq.(2). The results are shown in Tables 8–11.

### 4.3. Total factor of safety of the geosynthetic reinforcements

The total factor of safety of the geosynthetic reinforcements were calculated using Eq. (3), and the values obtained are shown in Table 12. It can be seen that the highest total safety factor corresponds to the lowest long-term performance of the geosynthetic reinforcements. The strip-type reinforcement showed the lowest total safety factor among the geosynthetic reinforcements used in this study.

### 4.4. Evaluation of the long-term performance of the geosynthetic reinforcements

The long-term design strength for evaluating the long-term performance of the geosynthetic reinforcements was calculated using Eqs. (1) and (3) in accordance with the total safety factors in Table 12. Table 13 shows the long-term design strength of the

8-t/m geosynthetic reinforcements. The composite-type geogrid showed the best long-term design strength among the samples, meaning that it had the best overall long-term performance.

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