TENSILE STRENGTH FOR SEISMIC DESIGN OF GEOGRID MADE FROM POLYESTER

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ABSTRACT

A lot of geotextile reinforced soils are designed and constructed in Japan where earthquakes happen frequently. Therefore, the stability of the geotextile reinforcement soil during earthquakes is very important. In general, the decrease of reinforcement due to creep is considered in ordinary (non-seismic) design. On the other hand, in seismic design, it is reasonable to use the tensile strength retained after a certain period of load history. In this research, a series of tests was conducted to investigate the residual strength and creep performance of a geogrid made frompolyester fiber. This paper describes the validity of the allowable strength of geogrid and proposes the extra coefficient of allowable strength of geogrid for seismic design.

Keywords: Geotextile, polyester, reinforced soil, seismic design, extra coefficients

INTRODUCTION

Today reinforced soils using geotextiles are widely used for road embankments constructed in Japan. It is a standard practice that these geotextile reinforced soils are designed and constructed in compliance with the standard manual(PWRC.2000). With the Great Hanshin Earthquake of 1995 and a variety of earthquakes occurring later on, its high resistance to earthquake has been suggested. It has been suggested that the strength of geotextiles against shock loads such as earthquake load is high.The reality is, however, that there has never been an established method of finding the design tensile strength of the geotextile used for seismic design.

This paper shows the tensile characteristics of geogrid consisting of polyester fibers covered with polypropylene and reports the results of creep characteristics and tensile strength with a certain load applied for a long period of time. Based on the results of a series of tests, an extra coefficients of tensile strength for geogrid seismic design is proposed.

DESIGN TENSILE STRENGTH

Design Tensile Strength for Normal Design

In the design of reinforced soil according to the geotextile manual, geotextile's design tensile strength is defined by equation (1) below. This equation considers various conditions for design, including geotextile's uses, environmental responsiveness, and long-term durability.

$$T_A = \frac{T_{\max}}{F_{cr} F_D F_C F_B} = \frac{T_{cr}}{F_D F_C F_B} \tag{1}$$

where:

$T_=$ Geotextile's design tensile strength for non-seismic design (kN/m)

T_{max}=Geotextile's maximum tensile strength, product's reference strength according to the performance evaluation test method (kN/m)

F_{cr}= Material safety factor considering creep

F_D= Material safety factor considering durability (long-term deterioration characteristics such as weather resistance or chemical resistance)

F_C= Material safety factor considering damage during construction

F_B= Material safety factor considering the connections' deteriorated strength

T_{cr}=Geotextile's critical tensile strength considering creep (kN/m)

Critical tensile strength considering creep, T_{cr}, which is the most dominant in non-seismic design can be found by multiplying the geotextile's maximum tensile strength T_{max} with creep reduction coefficient μ as equation (2). The creep reduction coefficient μ, is found by creating a creep limit line chart based on the creep test results.

$$T_{cr} = \mu T_{\max} = \frac{T_{\max}}{F_{cr}} \tag{2}$$

Design Tensile Strength in Seismic Design

According to Yamauchi, Fukuda and Sudoh(Yamanouchi et al. 1985), the geotextile made of polymer material used in reinforced soil has a tendency to show larger values for both tensile strength and tensile rigidity as load rates increase.

It is considered that shock load works in the short term during earthquakes. Therefore it is reasonable to find geotextile's design tensile strength for seismic design from the relationship shown in Eq. 3.

$$T_A = \frac{T_{\max}}{F_{cr} F_D F_C F_B} = \frac{T_{cr}}{F_D F_C F_B} \tag{3}$$

where,

T_{cr} = Geotextile's critical tensile strength considering creep (kN/m)

μ = Geotextile' creep reduction coefficient

T_{AE} = Geotextile's tensile strength(kN/m) used for seismic design

CHARACTERISTICS OF GEOGRID

Shapes and Characteristics of Geogrid

The geotextile that this research takes on is made from high-strength polyester fiber. This type of geogrid is manufactured from strands of high-strength polyester fiber coated with polypropylene resin. As shown in Fig. 1, this geogrid has a cross array configuration of flat-woven stereoscopic grid, with approximately 7-11 mm-wide strands arranged at an interval of 40 mm vertically and horizontally. Cross-points of strands are welded so that all parts are integrated into a single grid.

Figure 2 shows a graph that compares polyester for geogrid with regular industrial polyester. The polyester fiber used as the core material is manufactured for use as geogrid. Unlike regular industrial polyester fibers, it features high-strength, low deformation, and high elastic modulus (PWRC. 2008).

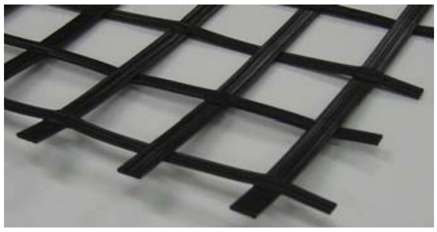

Fig. 1 Shape of geogrid.

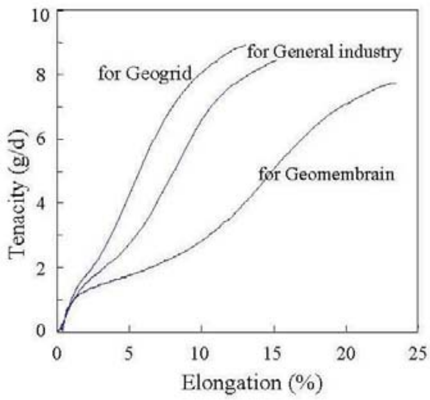

Fig. 2 Various polyester fiber.

Tensile Strength of Geogrid

Figure 3 shows the results of the geogrid tensile test conducted with a constant-rate-of-extension-type tensile testing machine. The sample tested was fixed by winding it up around the chuck in such a way that there is no variation in tension, then pulled at a tension strain rate of 1%/min. Figure 4 shows the constant-rate-of-extension-type tensile testing machine.

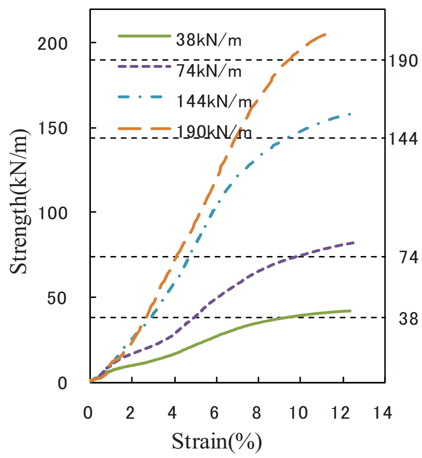

Fig. 3 Tensile strength of geogrid

Fig. 4 Tensile testing machine

CREEP REDUCTION COEFFICIENT

Test Method

Figure 5 shows the equipment used for the test and the test set up. Three vertical strands of geogrid were cut out as test sample and fixed to the chuck with both ends wound around a chuck. The load conditions for the creep load test conducted were as shown in Table 1.

Fig. 5 Tensile creep testing machine and test set up

Table 1 Creep loading ratio with respect to geogrid strength

Criterion strength T_{max}(kN/m)	Loading ratio (%)					
38	73	79	85	94	97	99
74	71	77	83	92	95	97
144	67	73	78	87	90	92
190	65	71	76	85	87	89

Results of Creep Load Tests

Figures 6 to 9 show the relationship between creep loading time and elongation strain of each geogrid.

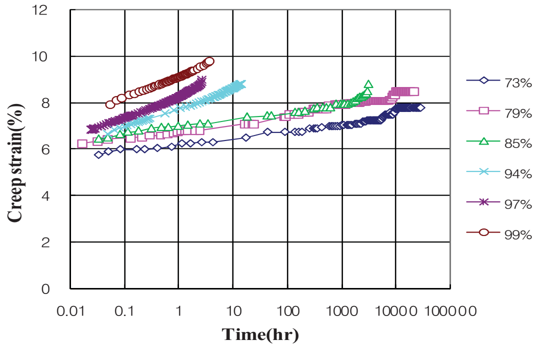

Fig. 6 Creep elongation strain for grid with T_{max}=38kN/m

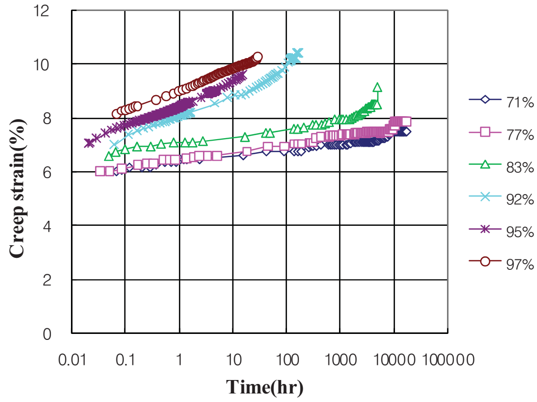

Fig. 7 Creep elongation strain for grid with T_{max}=74kN/m

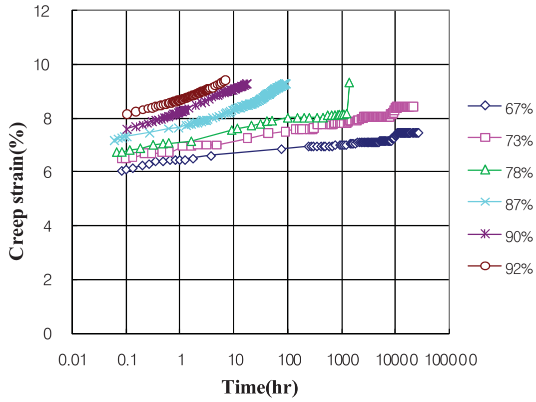

Fig. 8 Creep elongation strain for grid with T_{max}=144kN/m

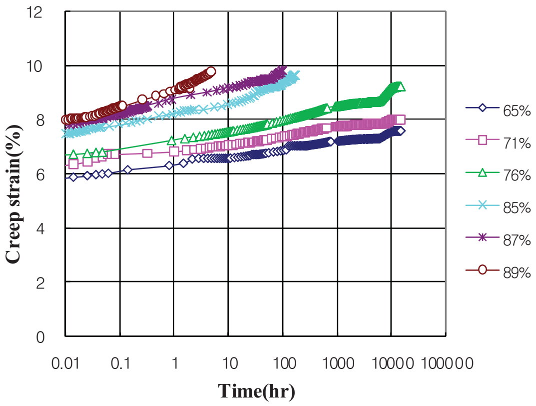

Fig. 9 Creep elongation strain for grid with T_{max}=190kN/m

Under the certain load conditions, the creep elongation strain increases over time. For the sake of convenience, the creep limit strain was set at 8%. Figs 10 to 13 show the relationships between the creep limit time and creep limit strength.

The creep limit strength and the creep reduction coefficient for 1,000,000 hours with a creep limit strain of 8% was as shown in Table 2.

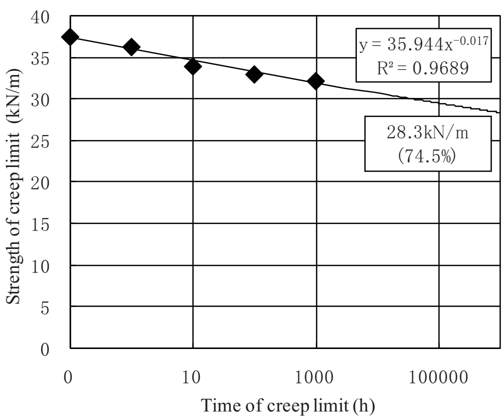

Fig. 10 Creep limit line chart for geogrid with T_{max}=38kN/m

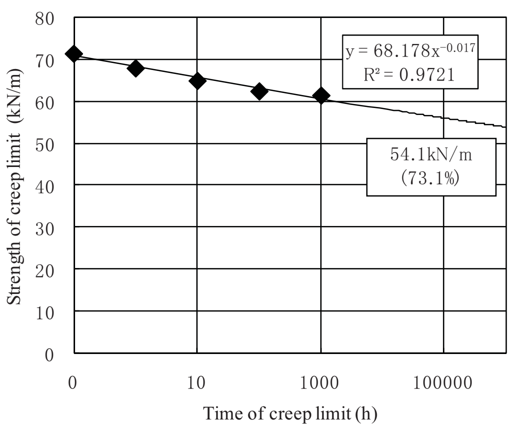

Fig. 11 Creep limit line chart for geogrid with T_{max}=74kN/m

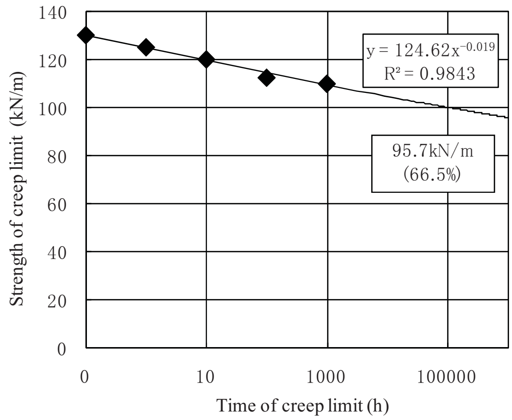

Fig. 12 Creep limit line chart for geogrid with T_{max}=144kN/m

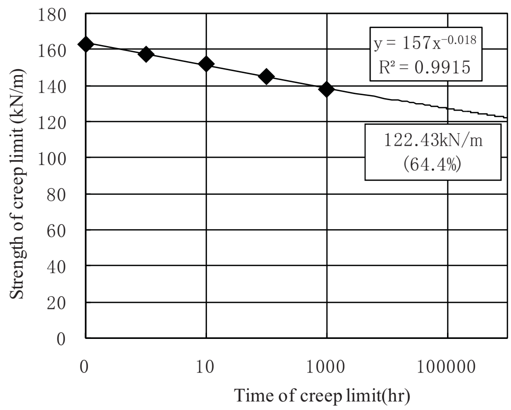

Fig. 13 Creep limit line chart for geogrid with T_{max}=190kN/m

Table 2 Creep limit strength and reduction coefficient at 1,000,000 hours

Criteria Strength (kN/m) : T_{max}	38	74	144	190
Strength of creep limit(kN/m)	28	54	96	122
Creep reduction factor (%)	75	73	67	64.

STRENGTH AFTER CREEP LOADING

Test Method and Test Cases

The unit under test for creep load was checked for tensile strength after creep load was applied. The load conditions for the creep loaded in the geogrid in advance were as shown in Table 3 to Table 6. The test was conducted in compliance with JIS K 7115, with the same tensile creep testing machine as for the creep test used for the creep load.

The tensile test was conducted with the test sample installed in the creep testing machine reinstalled into the constant-rate-of-extension-type tensile testing machine. The same test equipment and test method were adopted as for the above-mentioned performance evaluation test for checking the strength characteristics of geogrid, with a tensile strain rate of 1%/min.

Table 3 Creep load condition for geogrid with T_{max}=38kN/m

Loading ratio(%)	Loading time (hr.)			
89.5	10	100	500	
84.7	10	100	500	1000
78.7	1000	19000		

Table 4 Creep load condition for geogrid with T_{max}=74kN/m

Loading ratio(%)	Loading time (hr.)			
89.2	10	100	500	
82.8	10	100	500	1000
77.0	1000	10000		

Table 5 Creep load condition for geogrid with T_{max}=144kN/m

Loading ratio(%)	Loading time (hr.)			
83.3	10	100	500	
78.5	10	100	500	1000
72.9	1000	10000		

Table 6 Creep load condition for geogrid with T_{max}=190kN/m

Loading ratio(%)	Loading time (hr.)				
76.1	10	100	500	1000	14000
70.7	10	100	500		14000

Results of the Tensile Test after Creep Loading

Figure 14 shows the relationship between creep load time and elongation strain when creep load was applied to geogrid with a reference strength Tmax=74kN/m. The creep load for reference strength T_{max}=74kN/m shown in the legend of the figure is the value shown in Table 7.

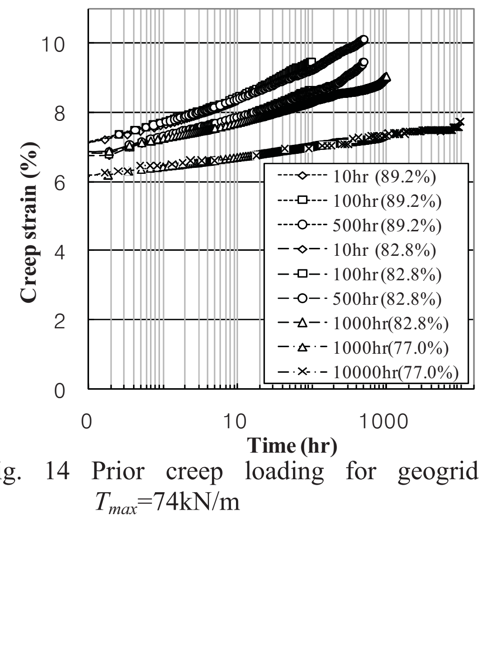

Fig. 14 Prior creep loading for geogrid with T_{max}=74kN/m

Table 7 Creep load for geogrid with T_{max}=74kN/m

Loading ratio (%)	Creep Load(kN/m)
89.2	66.0
82.8	61.3
77.0	57.0

Figs 15 to 17 show the geogrid elongation and tensile strength when a tensile test was conducted after creep loading.

The results of the tensile test for the geogrid T_{max}=74kN/m indicated that regardless of creep load or load time, the tensile strength was approximately the same as for geogrid without creep load. However, in the cases with creep load, tensile strain at the time of rupture decreases 1-2% in each case.

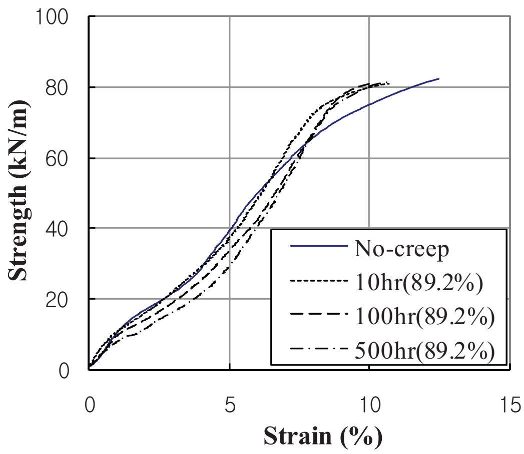

Fig. 15 Tensile test for geogrid(T_{max}=74kN/m) with 89.2% prior creep load

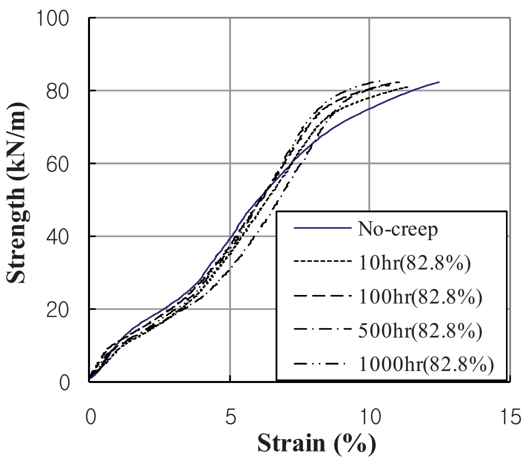

Fig. 16 Tensile test for geogrid(T_{max}=74kN/m) with 82.8% prior creep load

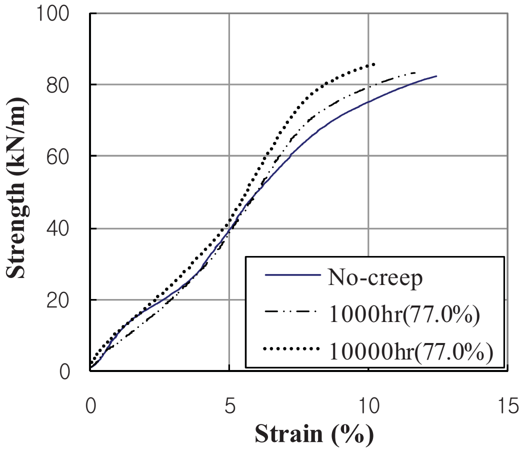

Fig. 17 Tensile test for geogrid(T_{max}=74kN/m) with 77.0% prior creep load

Figure 18 shows the relationship between the creep load time and tensile strength for geogrid with a reference strength T_{max}=74kN/m. In every creep load factor, the tensile strength was larger than the reference strength T_{max}=74kN/m.

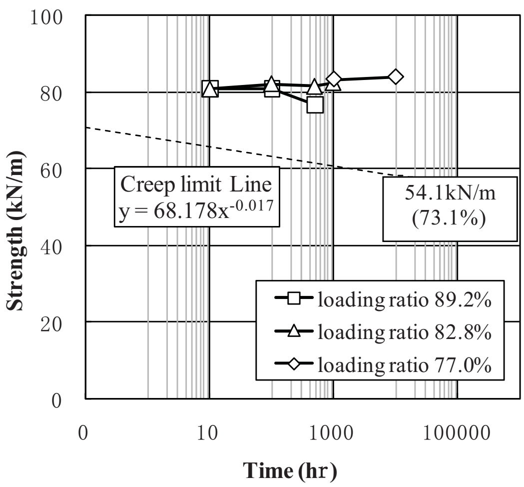

Fig. 18 Creep loading time and tensile strength

Residual Strength Ratio after Creep Load Applied

Figure 20 shows the relationship between residual strength ratio and creep load time of T_e with respect to geogrid's tensile strength T_{max} in all the cases that were conducted this time. Figure 21 shows the relationship between residual strength ratio and creep load time of T_e with respect to critical tensile strength T_{cr} , with creep reduction in mind. F_{cr}= 0.65 is assumed here.

It is known from these figures that tensile strength of geogrid with prior creep load has strength equal to or higher than the reference strength, with respect to T_{max} (product reference strength), regardless of creep load time. Also, 155% to 178% tensile strengths are shown for geogrid's critical tensile strength T_{cr} with creep reduction in mind. These tendencies are seen regardless of geogrid's tensile strength or creep load conditions.

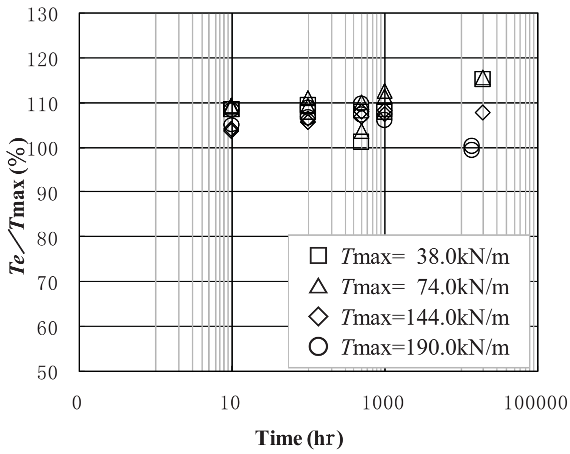

Fig. 20 Relationship between creep load time and T_e/T_{max}

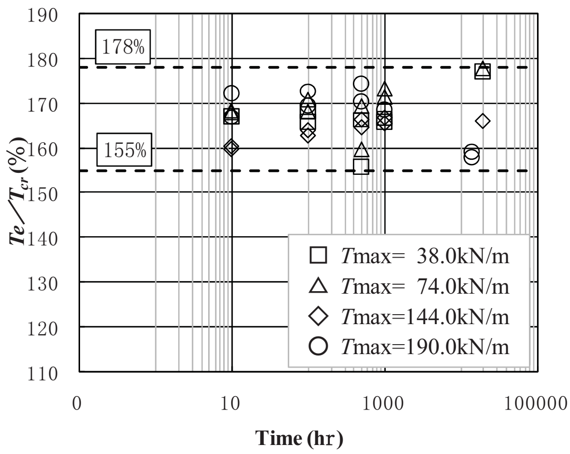

Fig. 21 Relationship between creep load time and T_e/T_{cr}

EXTRA COEFFICIENT FOR EARTHQUAKE

Assuming that the earthquake-time material safety factor for geogrid considering the influence of creep, is $F_E = T_{max}/T_{Emax}$, the following can be obtained from equations (1) and (3):

$$T_{AE} = \frac{T_{\max}}{F_E F_D F_C F_B} = \frac{T_{E\max}}{F_D F_C F_B} \quad (4)$$

$$\frac{\lambda T_{cr}}{F_D F_C F_B} = \frac{T_{E\max}}{F_D F_C F_B} \quad (5)$$

$$\lambda = \frac{T_{E\max}}{T_{cr}} \qquad (6)$$

where,

F_E = Material safety factor at the earthquake time involving creep influence

T_{Emax}= Geotextile's maximum tensile strength at the earthquake time considering normal-time creep in mind (kN/m)

T_{max}=Geotextile's maximum tensile strength (kN/m)

T_{cr} = Critical tensile strength (kN/m) considering geotextile's creep

λ = Extra coefficient for geotextile's seismic-design tensile strength with respect to non-seismic-design tensile strength

T_{Emax} is geogrid's tensile strength considering the influence of creep. Under ordinary construction work conditions, material safety factors except for creep are 1.0(PWRC.2008). Therefore, assuming that all material safety factors except for F_{cr} take the value of 1.0 in equation (1), T_A=T_{cr} .

Thus from Fig. 21, it can be said that λ in equation (6) is in the range of 1.55 to 1.78, and that if the extra coefficient at the earthquake time λ=1.50 with respect to geogrid's design tensile strength T_A, the value is sufficiently on the safe side.

CONCLUSIONS

In our research we conducted creep tests for geogrids made from high-strength polyester fiber and residual strength tests for grids after creep load was applied.

Especially in residual strength tests, the unit under test mounted in creep test equipment was remounted into a constant-rate-of extension type tensile testing machine, and thus the load to the unit under test was temporarily released. Also, all of the geogrid tensile strength tests were conducted with the performance evaluation test method (with as tensile strain rate of 1%/min), so the evaluations were made under different conditions with regard to tensile loading rates for geogrid than to be expected during an earthquake.

To cope with the first problem, we referred to the considerations of geotextile's creep deformation and tensile strength (Tastsuoka et al.2003) and the presented papers on the material viscosity of geotextile reinforced soil retailing walls (Hirakawa et al.2003), and then concluded that in the case of creep loads with proper settings to prevent creep rupture, geogrid's tensile strength is not influenced by the deformation history.

The second problem regards the geogrid's strain rate at rupture. The tensile strength of the geogrid itself is governed by the strain rate at rupture, and with the increase in strain rate, tensile strength also increases5). With evaluations made based on the performance evaluation test method, because strain speed caused onto the geogrid during an earthquake is higher, it can be said the evaluations are sufficiently on the safe side.

The following were confirmed as a result of the tests:

(1) The currently used creep reduction coefficients are valid.

(2) If the extra coefficient λ for geogrid whose core material is made of polyester fiber is set at 1.50 at the time of an earthquake, the value is sufficiently on the safe side.

In the future, for economic design, we plan to examine extra coefficients to be used to analysis the performance during an earthquake by conducting tests for influence to geogrid.

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