Analysis of time-dependent behavior of geogrids by creep and stress relaxation tests

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ABSTRACT: To examine the relationship between time dependent strain and stress behaviors, creep and stress relaxation tests were done for geosynthetic reinforcements. Long-term performance of geogrid is dependent on the viscoelastic behaviors for longtime period. Viscoelastic properties are mainly influenced by not only creep deformation behaviors at the constant confining load and temperature but also stress relaxation behaviors at the constant strain and temperature. In this study, elastic and viscose mechanical model was suggested and ap-plied to examine the viscoelastic properties of geogrid. Experimental results of creep and stress relaxation tests of geogrid were compared to verify the applied mechanical model.

Keywords: strain and stress behaviors, geosynthetic reinforcements, relaxation behaviors, creep strain

1 INTRODUCTION

The purpose of geogrid is depending on the reinforcement of the permanent structure and long-term property of geogrid has become very important. For their analysis is then add-ed to a constant load, how to interpret the changes according to the time -dependent strain creep tests and constant strain - stress changes over time, how to interpret the stress relaxation test. In this study, the long-term behavior of ge-ogrid by setting new concept viscoelastic model was examined through the evaluation and comparison of stress relaxation and creep experimental results.

2 EXPERIMENTAL

Geogrid higher utilization in the domestic, design strength of 8 ton/m was used as sample. In accordance with ASTM D 5262, creep loads of 40, 50, 60% of ultimate tensile strength of geogrid were applied and creep deformation was evaluated under 21, 35, 50℃ for 1,000 hours. In order to evaluate the stress relaxation behavior of geogrid at room temperature, the additional strain was set 4, 6, and 8%. In here, to consider the polyester geogrid of strain at the yield point of the 8 % that were set up by a range of additional strain.

3 RESULTS AND DISCUSSION

3.1 *Stress relaxation behavior*

Stress relaxation behavior was measured and shown in Figure 1. As shown in Figure 1, relaxation behavior of polyester geogrid was very fast-paced and it was revealed that the relaxation time of 10 hours after the relaxation curves showed gentle and asymptotic behaviors. This is due to polyester plastic behavior of geogrid used in this study for very fast-paced stress relaxation.

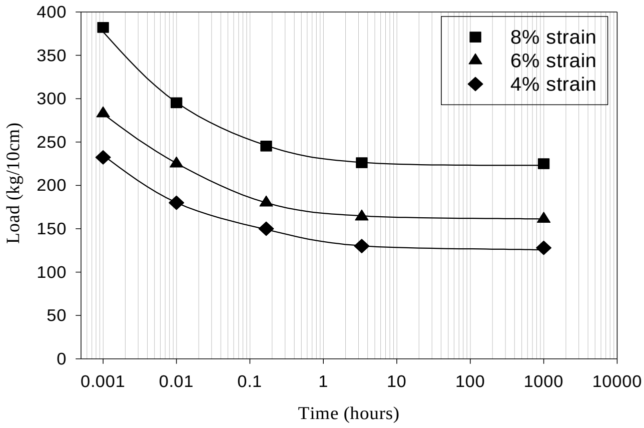


Figure 1. Stress relaxation curves of 8ton/m polyester geogrids with various strains.

3.2 *Viscoelastic model for long-term behavior analysis*

For typical polymeric materials, the long-term behavior can be explained through viscoelastic model consisting of a ternary system within the range that creep rupture does not appear. Connected in the form of Kelvin elements and stiffness E2 and E1 of the spring element stiffness is defined as viscosity η is expressed as the standard viscoelastic model consists. This model is shown in Figure 2 and has three components; the resulting constitutive equation is expressed as follows.

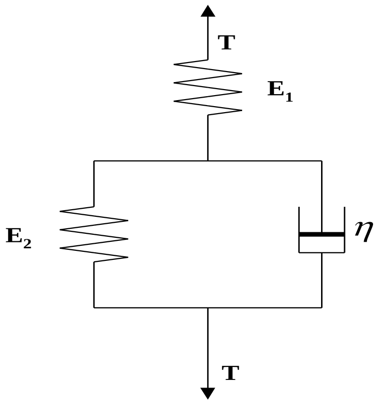


Figure 2. Standard 3-element viscoelastic model.

$$\frac{1}{E_1} = \left(\frac{d}{dt} + \frac{E_1 + E_2}{\eta}\right) T = \left(\frac{d}{dt} + \frac{E_2}{\eta}\right) \quad (1)$$

, where T = per unit width loads, ε = strain, t = is the time.

$$\frac{d\varepsilon}{dt} + \frac{E_2}{\eta}\varepsilon = \frac{E_1 + E_2}{\eta E_1} T \quad (2)$$

Eq. (2) is expressed as the load and strain as below.

$$\frac{e}{T} = \frac{1}{E^*} - \frac{1}{E_2}\exp\left(-\frac{E_2}{\eta}t\right) = \phi(t) \quad (3)$$

, where $\phi(t)$ =elastic modulus, E^* =standard rheological models of delay (delayed elastic modulus) function and creep is shown below.

$$E^* = \frac{E_1 E_2}{E_1 + E_2} \tag{4}$$

So according to the time-dependent strain relaxation test under constant strain $\frac{d\varepsilon}{dt}$ of subsection Eq. (1) can be expressed as follows.

$$\frac{dT}{dt} + \frac{E_1 + E_2}{\eta} T = \frac{E_1 E_2}{\eta} \varepsilon \tag{5}$$

Organized in terms of load and strain Eq. (5) can be expressed as follows.

$$\begin{aligned} \frac{T}{\varepsilon} &= (E_1 - E^*)\exp\left(-\frac{E_1 + E_2}{\eta} t\right) + E^* \\ &= \Psi(t) \end{aligned} \tag{6}$$

, where $\Psi(t)$ is the relaxation function and Eq. (3) and (6) mean the immediate behavior by t=0.

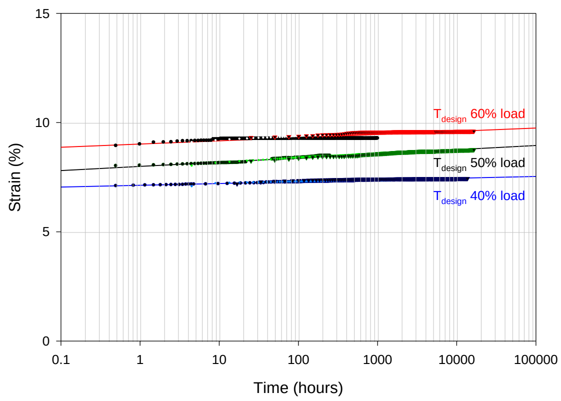
Eq. (7) is the same relationship for instantaneous response as Eq. (6).

$$\frac{T}{\varepsilon} = E_1 \tag{7}$$

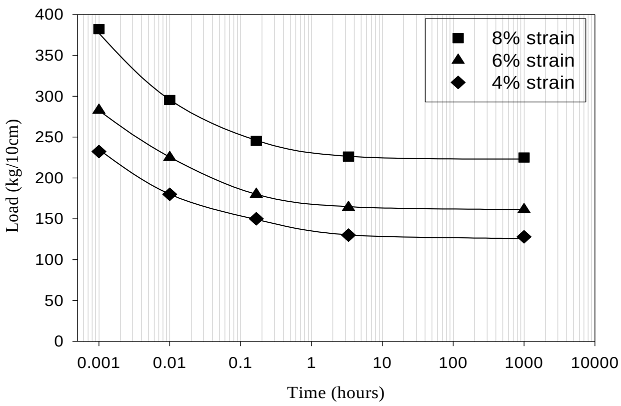
Also represents a long time asymptotic behavior of Eq. (3) and (6) after the load is added to the geogrid.

$$\frac{T}{\varepsilon} \to E^* \quad \text{as} \quad t \to \infty \tag{8}$$

Figure 3 (a) and (b) showed the experimental results of the experimental creep deformation and stress relaxation behavior, respectively. Also, the tendency for each instantaneous and asymptotic response is shown in Figure 4 (a) and (b).



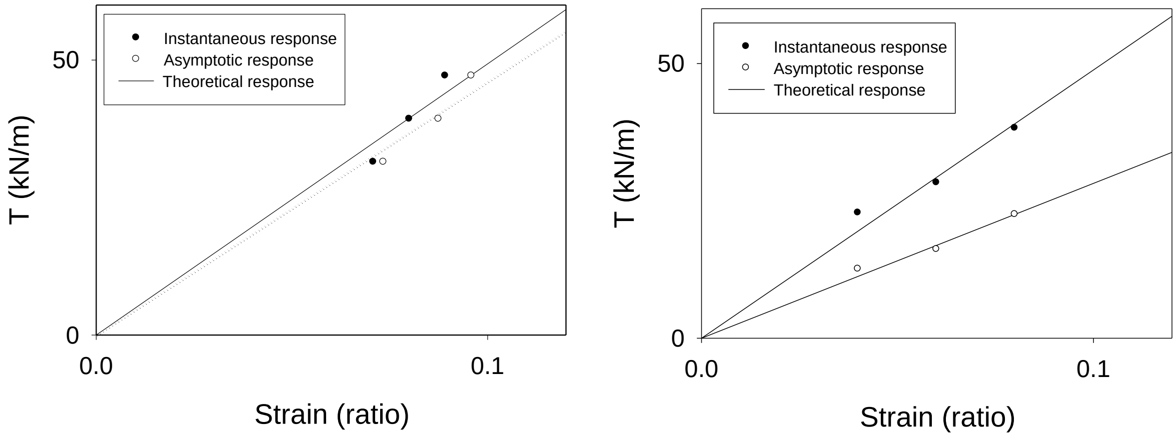
a) Creep strain curves



(b) Stress relaxation curves

Figure 3. Creep and stress relaxation test result for 8ton/m geogrid.

In here, instantaneous value E0=490kN/m and asymptotic value for creep deformation is E∞=460kN/m and for stress relaxation is E∞=282kN/m. Therefore, new concept mechanical model should be needed due to this different asymptotic value. Figure 4 (a) and (b) showed the linear trend of the load-strain relationship. From this, we can get the conclusion that we can use a linear mechanical model was used to spring from these linear relationships. Namely, because the modulus values indicating asymptotic linear behavior is so different from each other in the case of stress relaxation and creep deformation, the ternary system consisting of a standard mechanical model presented earlier cannot be explained.



(a) Creep strain curves (b) Stress relaxation curves

Figure 4. Instantaneous and asymptotic response of polyester geogrid.

From this review, it is seen that this modulus of stress relaxation is larger than creep deformation and this that may have proven the feasibility for introducing a plastic element to former 3-element mechanical model to examine the long-term behavior of geogrid. Figure 5 shows this new concept mechanical model. Total strain of Figure 5 is as same as sum of each strain and can be written as follow.

$$\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \tag{9}$$

, where $\varepsilon_1 = \frac{T}{E_1}$, $\varepsilon_2 = \frac{T}{R}$, $\varepsilon_3 = \varepsilon - \frac{T}{\zeta}$, $\zeta = (E_1 R)/(E_1 + R)$.

Therefore, constitutive equation of new concept mechanical model in Figure 5 can be written as below.

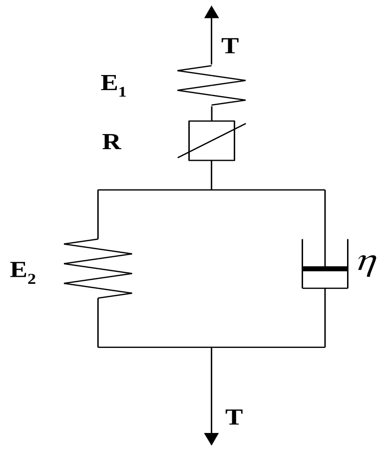


Figure 5. Modified viscoelastic model.

$$\left(1 + \frac{E_3}{\zeta}\right)T + \frac{\eta}{\zeta}\frac{dT}{dt} = E_3\varepsilon + \eta\frac{d\varepsilon}{dt} \tag{10}$$

Creep deformation of geogrid is explained by the following equation at $\frac{dT}{dt} = 0$.

$$\frac{d\varepsilon}{dt} + \frac{E_3}{\eta}\varepsilon = \frac{1}{\eta}\left(1 + \frac{E_3}{\zeta}\right)T \tag{11}$$

$$\frac{\varepsilon}{T}=\left(\frac{1}{E_3}+\frac{1}{\zeta}\right)-\frac{1}{E_3}\exp\left(-\frac{E_3}{\eta}t\right) \tag{12}$$

For stress relaxation behavior, $\varepsilon(t=0)=\varepsilon_1+\varepsilon_2$ and ε_2 is constant for $t \geq 0$, the following strain component can be written as below.

$$e=\varepsilon_1+\varepsilon_3=\varepsilon-\varepsilon_2=Constant \tag{13}$$

Eq. (13) can be written as following to consider deformation elements of new concept mechanical model.

$$\left(1+\frac{E_3}{E_1}T\right)+\left(\frac{\eta}{E_1}\right)\frac{dT}{dt}=E_3e+\eta\frac{de}{dt} \tag{14}$$

Typical constitutive equation for stress relaxation behavior of geogrid under $\frac{d\varepsilon}{dt}$ = 0 can be represented as below.

$$\frac{dT}{dt}+\frac{E_1+E_3}{\eta}T=\frac{E_1E_3}{\eta}e \tag{15}$$

To determine stress-strain relationship in Eq.(21),

$$\frac{T}{e}=\left(\zeta-E^{**}\left[1-\frac{\zeta}{R}\right]\right)\exp\left(-\frac{E_1+E_3}{\eta}t\right)+E^{**}\left(1-\frac{\zeta}{R}\right) \tag{16}$$

, where E^{**} means $E_1E_3/(E_1+E_3)$ relationship and also represents the value of delayed elastic modulus in the new concept mechanical model for polyester geogrid. The instantaneous response against the constant additional strain can be explained by Eq.(16) to consider the confining system such as soil retaining wall reinforced by geogrid. Also, the plasticity of soil confining structure to be used geogrid is dependent on additional stress and strain such as explained stress relaxation and creep deformation behaviors. In new concept mechanical model, plastic element represents the initial response that is immediately after the load is added to the polyester geogrid of the initial behavior and this can be explained by the below condition.

$$\frac{T}{\varepsilon}=\zeta \tag{17}$$

For additional constant load condition by Eq. (11) and (12), the asymptotic creep behavior of polyester geogrid is as following.

$$\frac{T}{\varepsilon}\to\frac{1}{E_3}+\frac{1}{\zeta} \qquad when \qquad t\to\infty \tag{18}$$

$$\frac{T}{\varepsilon}\to E^{**}\left(1-\frac{\zeta}{R}\right) \qquad when \qquad t\to\infty \tag{19}$$

To overall the above constitutive equations for stress relaxation and creep deformation behaviors by using polyester geogrid, it can be determined the values of E_1, E_3, R, η in the new concept mechanical model as following.

$$E_1 = 800\text{\textasciitilde}1{,}000\text{kN/m},$$

$$E_3 = 2{,}000\text{\textasciitilde}7{,}500\text{kN/m},$$

$$R = 300\text{\textasciitilde}500\text{kN/m},$$

$$\eta = 1{,}000\text{\textasciitilde}1{,}200\text{kN/m/h}$$

From these values, we can analyze the viscoelastic and plastic response of polyester geogrid against the external load and deformation during service period.

Finally, it is suggested that the new concept model can adequately describe the instantaneous and asymptotic responses of polyester geogrid.

REFERENCES

Ferry J.D.. 1995. Viscoelastic Properties of Polymers, 3rd Edition, John Wiley and Sons.
Finnigan, J.A.. 1997. The Creep Behavior of High Tenacity Yarns and Fabrics Used in Civil Engineering Applications, Proceedings of the International Conference on the Use of Fabrics in Geotechnics, Paris, France, p.645-650.
Sawicki A.. 1998. A Basis for Modelling Creep and Stress Relaxation Behavior of Geogrids, Geosynthetics International, 5(6), p.637.