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Analytical Approach to Determine Long-Term Creep Behaviours of Geosynthetic Reinforcements by Strain Compatibility

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ABSTRACT
To calculate the long-term allowable strength of geosynthetic reinforcement, replacement method was recommended. In an isochronous curve at a given time, we can read the allowable strength at allowable creep strain. The allowable strain is specified by directors or manufacturers according to the allowable displacement of reinforced structures. The allowable strength can be determined in relation to the allowable horizontal displacement for each structure case by case. The effect of installation damage on isochronous behavior of geosynthetic reinforcement was small. From the analytical consideration, the strain compatibility was recommended to determine long-term allowable strength of geosynthetic reinforcements considering tensile deformation between reinforcement and soil.

1. INTRODUCTION

Geosynthetic reinforcements are generally used in the field of segmental retaining wall construction systems. The long-term tensile strength of geosynthetic reinforcements used in reinforced earth walls is determined by considering the retained rate of short-term tensile strength during service life. Namely, many factors for considering the strength reduction in geosynthetic reinforcements buried in reinforced earth structures were introduced and used to calculate the long-term tensile strength. The extensible geosynthetic reinforcement is different from steel reinforcement because the geosynthetic should be deformed in structure due to larger external loading. For assessing the long-term tensile deformation, creep strain of 10 % has been used as critical value but, there is no basic theory or empirical data to support 10% creep strain. It is considered that 10% is a relatively large allowable long-term strain in a reinforced earth wall. Another criteria for creep related properties of geosynthetic reinforcement, is creep rupture strength. Creep rupture in a geosynthetic shows brittle tendencies because of the rapid loading rate in the test procedure. Besides these shortcomings creep factors for long-term allowable strength from each criterion are different to each other. Also these two characteristics are never able to explain the long-term deformation of geosynthetic reinforcement. So it is required that the replacement method is used to explain the long-term deformation. The isochronous creep curve was used to define the relationship between creep strain and allowable strength. In an isochronous curve at a given time, we can read the allowable strength at allowable creep strain. The allowable strain is specified by directors or manufacturers. The allowable creep strain varies according to its facing batter, facing type and critical aspect. In this study, the allowable strength can be determined from long-term creep behavior of geosynthetic reinforcement in relation to the allowable horizontal displacement. The validity of this consideration was analyzed through the strain compatibility.

2. THEORETICAL BACKGROUND

2.1 Allowable Tensile Strength by Reduction Factors

Reduction factors, which affect the final properties of geosynthetics, are applied to the calculation of design strength in the GRI GG-4. The types of reduction factor are variable according to the application field, and the usual reduction factors follow this formation.

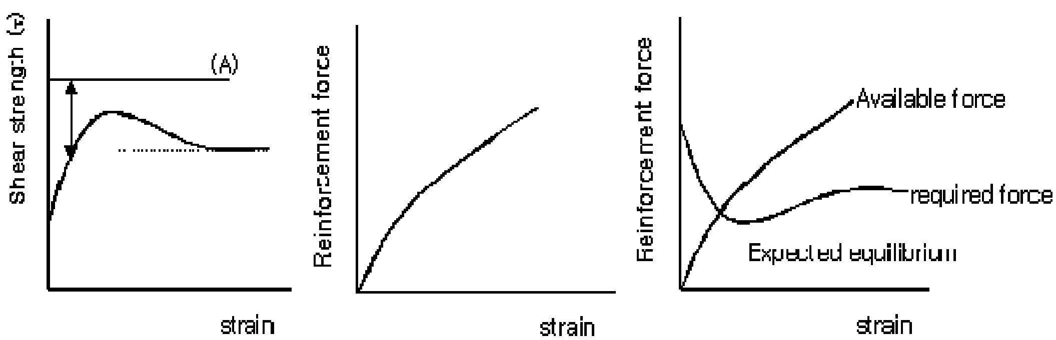
$$T_{allow} = T_{ult}\left[\frac{1}{\prod RF}\right] = T_{ult}\left[\frac{1}{RF_{ID} \times RF_{CR} \times RF_{CD} \times RF_{BD}}\right] \quad [1]$$

where, T_{ult}= ultimate tensile strength
T_{allow} = allowable tensile strength
RF_{ID} = reduction factor for the installation damage
RF_{CR} = Reduction factor for the creep
RF_{CD} = Reduction factor for the chemical degradation
RF_{BD} = Reduction factor for the biological degradation

In most project sites the possibility and consequence of chemical and biological damage is very small, so the reduction factor values are close to 1.0. If there is poor construction management, the installation damage reduction value will be higher than this value. Therefore, when the construction conditions are considered, the possibility of worker's misunderstanding the work, careless work and installation equipment will be applied in the calculation of the installation damage reduction factor.

3. STRAIN COMPATIBILITY

At tensile deformation of geosynthetic reinforcements the reinforcement must exhibit the reinforcing strength for segmental retaining wall system. But there is no guide and specification for the magnitude of this deformation. Only the theories of behavior between segmental soil structure and geosynthetic reinforcement have been suggested. The basic concept of strain compatibility between soil structure and geosynthetic reinforcement by R. A. Jewell (1996) is analyzed through the shear strength vs. elongation curves by direct shear test. Figure 1(a) shows this relation curve and the required force to approach the equilibrium condition is shown in Figure 1(c). In general, geosynthetic reinforcement is deformed within the soil structure and then the resistant force should be exhibited. The resistant force could have the largest value in the fracture surface within the soil structure and therefore the largest deformation would occur at this condition. The intercept point of available force and required force means the critical equilibrium condition and the soil structure should be more stable under this condition. If this intercept point is in the larger deformation range, excess deformation may occur due to the allowable tensile strength of geosynthetic reinforcement at this intercept point. For this case, we must select another compatible geosynthetic reinforcement.



(a) (b) (c)

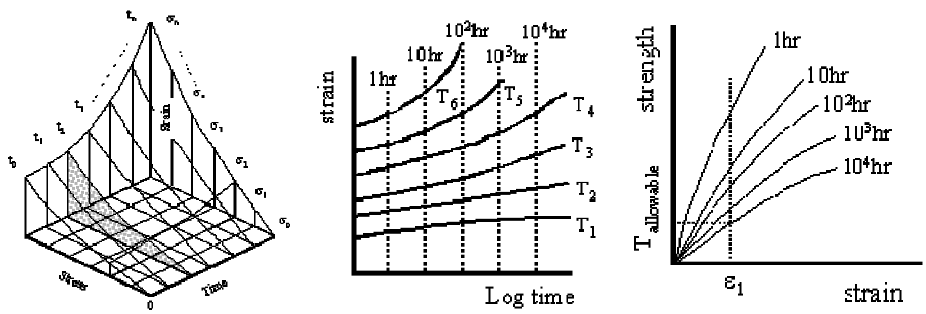
Figure 1. Relation for strain compatibility: (a) Mobilized soil shearing resistance, (b) Mobilized reinforcement force, (c) Compatibility curve for determining the equilibrium in reinforced soil

4. DETERMINATION OF LONG-TERM ALLOWABLE STRENGTH BY STRAIN COMPATIBILITY

4.1 Through Isochronous Creep Deformation Curves

One assumption should be needed to evaluate the long-term deformation behaviors of segmental retaining walls with creep deformation data of geosynthetic reinforcement. This means geosynthetic reinforcement must induce all the tensile forces of the reinforced soil structure and exhibit the induced horizontal deformation in this condition. Therefore, we can determine the allowable strength to be considered the deformation of the reinforced soil structure through the analysis of long-term deformations of soil and geosynthetic reinforcement. In this case, isochronous creep curve means the relationship between long-term load and elongation creep behaviors for geosynthetic reinforcement. Figure 2 shows the isochronous creep curves in the time-stress-strain axis. From the creep curve at t=10^4hr, we can determine the creep strain and the allowable strength of geosynthetic reinforcement.

If geosynthetic reinforcement is responsible for all the horizontal deformation of a soil structure, the allowable strain of the soil structure is the same as the allowable strain of the geosynthetic reinforcement, ε_1. Therefore, the allowable strength of geosynthetic reinforcement can be written as the function of long-term strain and determined to consider the allowable strain of the soil segmental wall. For the same allowable strain, allowable strength should increase in the isochronous creep curve if the design period decreases. The long-term allowable strength of geosynthetic reinforcement with isochronous creep curve should be dependent on the allowable deformation of soil structure and must be determined with respect to the application system.



(a) (b) (c)

Figure 2. Relation for strain compatibility: (a) Stress-strain-time relationship, (b) Traditional creep test results, (c) Isochronous creep strain curves

4.2 Creep Limit Strain of Geosynthetic Reinforcements

The long-term allowable strength of geosynthetic reinforcement must be determined if the predicted stress-strain relationship would be obtained and the allowable horizontal deformation standard of segmental retaining wall would be set through the isochronous creep curves. Table 1 shows the vertical tolerance of segmental retaining wall criteria in various guides.

Table 1. Vertical tolerance of segmental retaining wall criteria in various guides

Structure	Terms	Value	Range	Source of Data
Segmental block wall		3.0 cm	Every 3 m	Collin, J.F.P.G., 1997
		7.6 cm	Height	
Concrete panel wall	Vertical tolerance	±0.03H or 30 cm	Height	Japanese Geotechnical Society, 1986
Reinforced wall	Bulging	±20mm	Every 4.5 m	BS 8006, 1995
	Vertical tolerance	±5mm	Every 1 m	
Concrete facing wall	Vertical tolerance	13mm	Every 3 m	Elias et al., 2001
Reinforced wall	Vertical tolerance	±0.03H or 30 cm	Height	Technical anual by Korean Geotechnical Society, 1999

5. RE-ANALYSIS OF PRECEDENT RESEARCHES

5.1 Analysis by M. Koutsourais

M. Koutsourais tested the creep behaviors of high tenacity polyester woven type geogrids. The added creep load was 30.1-57.9% of the ultimate tensile strength and test period was 20,000-30,000hours. Figure 3 shows the results of this test and the creep strain was less than 2% when design period is 114 years. For this case, the added creep load was 60% of the ultimate strength. Also, the creep strength was the same as the secant modulus at 3% and 8% when the serviceability strain limit is 5% and 10%, respectively.

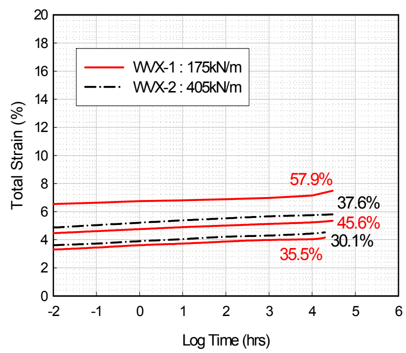


Figure 3. Creep of woven PET geogrids at 20°C.

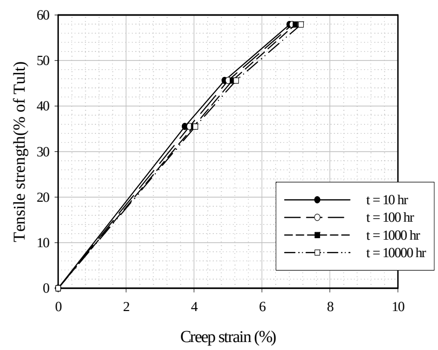


Figure 4. Isochronous creep curves of woven geogrid.

Through Figure 4, the allowable strength should be changed with the creep allowable strain for the creep curve of 10^4hr. However, this analysis has the disadvantage that the allowable strain must be fixed within the range of 7.5-8% for 60% creep load addition. To solve this problem, long-term strength must be determined with the creep limit strain.

5.2 Analysis by Niegel E. Wrigley

Niegel E. Wrigley did the creep test of HDPE extruded geogrid and Figure 5 shows the result of this creep test. From this result, we can get the information of creep behaviors below 20% creep load and this is very comparable with the creep behavior over 30% creep load.

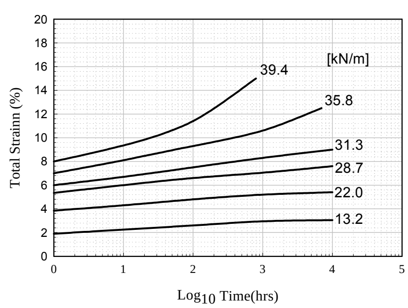


Figure 5. Strain-time relationship for uniaxial HDPE geogrid at various load at 20°C.

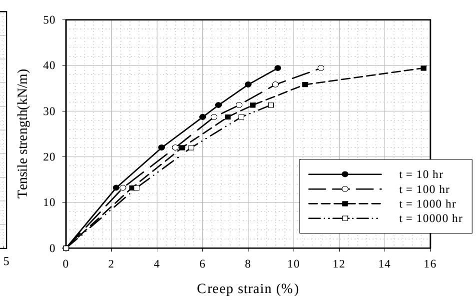


Figure 6. Isochronous creep curves of HDPE extruded geogrid.

5.3 Analysis by R. J. Muller

R. J. Muller did the creep test of typical and developed geogrds and Figure 7 and 8 show these results. From this analysis, long-term creep behaviors are very different for the same short-term tensile strength. This difference could be determined only through the isochronous creep curves in Figure 8.

5.4 J. Analysis by W. Billing, J. H. Greenwood and G. D. Small

W. Billing, J. H. Greenwood and G. D. Small reviewed the effects of installation damage on the creep deformation behaviors for PP and polyester woven geotextiles, strip type geosynthetic reinforcement and HDPE geogrids. Figure 9 shows the creep behaviors of installation damaged PP woven geotextiles and creep strain decreased by installation damage. In the isochronous creep curves, the decrease of creep strain was in the range of shorter time. From these curves, it may be seen that the long-term creep behaviors could be influenced by reduction factor of installation damage. But for larger creep strain, we cannot predict the horizontal deformation even if the stability of structure was developed when the strength decrease is small by installation damage. On the other hand, increase effect of allowable strength of geosynthetic reinforcement could be induced due to the decrease of creep strain in the isochronous creep curve when the strength decrease is larger. By isochronous curve, let the allowable horizontal displacement as 0.03H and minimum reinforcement length as 0.7H, it can be done that the allowable creep strain is 5%. Due to this premise, the long-term allowable strength of friction tie and woven geogrid were determined about 25-28% for friction tie and 35-44% for geogrids.

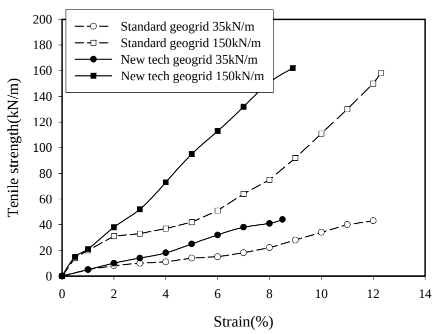


Figure 7. Short-term tensile properties of developed and typical geogrids

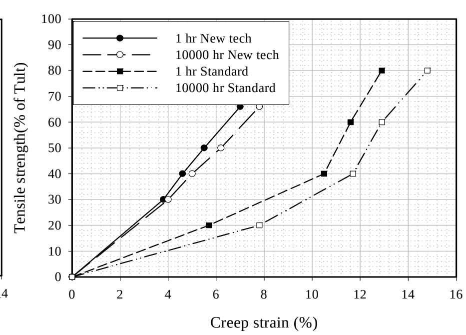


Figure 8. Isochronous creep curves of developed and typical geogrids

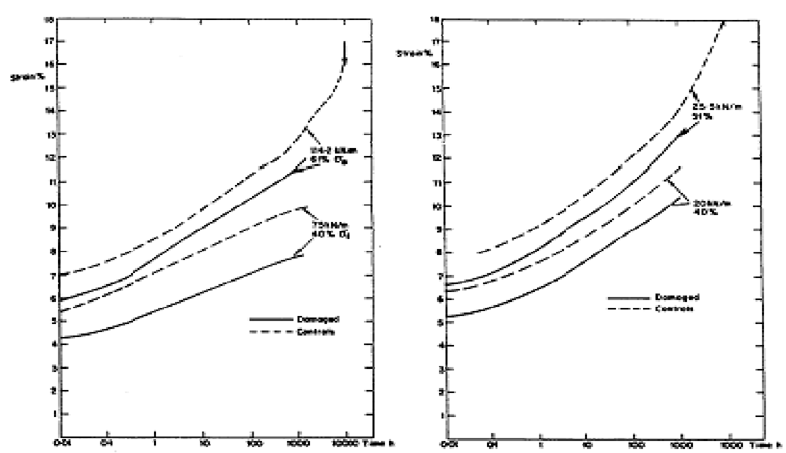


Figure 9. Effect of installation damage on creep behavior for 2-PP geotextiles

6. CONCLUSION

The method to determine the long-term allowable strength was suggested and analyzed through isochronous creep curves. To compare the long-term allowable strength and apply the strain compatibility, 2 or 5% secant modulus were selected but tensile strength at 2 and 5% strain showed no relation to long-term allowable strength. The concept of strain compatibility to determine long-term allowable strength of geosynthetic reinforcements considered tensile deformation of geosynthetic reinforcement and soil, and is fit for proper, correct and economic design for reinforced earth walls.

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