Geosynthetics, J. Kuwano & J. Koseki (eds)


# Analytical approach to determine long-term creep behaviors of geosynthetic reinforcements by strain compatibility

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ABSTRACT: To calculate the long-term allowable strength of geosynthetic reinforcement, alternative method was recommended. In isochronous curve at given time, we can read the allowable strength at allowable creep strain. The allowable strain gets from specification 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 each structures case by case. The effect of installation damage on isochronous behaviours of geosynthetic reinforcement was little. 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

The long-term tensile strength of geosynthetic reinforcements used in reinforced earth wall is determined by considering the retained short-term tensile strength during service life. Namely, many factors for considering the strength reducing in geosynthetic reinforcements buried in reinforced earth structures were introduced and used to calculating the long-term tensile strength.

The extensible geosynthetic reinforcement shows large deformation than steel reinforcements due to its inherent features. 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 10% creep strain. 10% is relatively big one that of allowable long-term strain in reinforced earth wall.

Another criteria for creep related properties of geosynthetic reinforcement, is creep rupture strength. Creep rupture in geosynthetic shows brittle tendency because of rapid loading rate in test procedure. Besides each improper aspect, creep factors for long-term allowable strength from each criterion are different each other. Also these 2 characteristics never are able to explaining the long-term deformation of geosynthetic reinforcement. So it is required that the alternative method to explain the long-term deformation.

In this study, the isochronous creep curve was introduced to define the relation between creep strain and allowable strength. In isochronous curve at given time, we can read the allowable strength at allowable creep strain. The allowable creep strain can be various according to its facing batter, facing type and critical aspect. Therefore, the allowable strength can be determined to 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

$$T_{\text{allow}} = \frac{T_{ULT}}{\Pi\, RF} = \frac{T_{ULT}}{RF_{ID} \times RF_{CR} \times RF_{CD} \times RF_{BD}} \quad (1)$$

where,

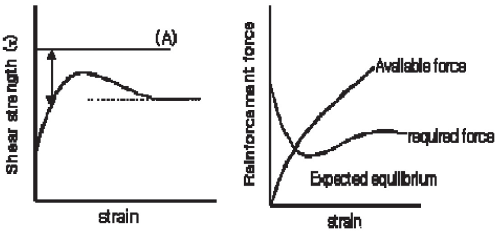
- $T_{ult}$ = ultimate tensile strength
- $T_{\text{allow}}$ = allowable tensile strength
- $RF_{ID}$ = reduction factor for installation damage
- $RF_{CR}$ = Reduction factor for creep

- $RF_{CD}$ = Reduction factor for chemical degradation
- $RF_{BD}$ = Reduction factor for biological degradation

## 3 STRAIN COMPATIBILITY

Tensile deformation of geosynthetic reinforcements must be accompanied to 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 behaviors 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 more equilibrium condition was shown in Figure 1(b). In general, geosynthetic reinforcement is deformed within the soil structure and then the resistance force should be exhibited. The resistance force could have the largest value in the fracture surface within the soil structure and therefore the largest deformation would be occurred at this condition.



(a) (b)

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

The cross 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 cross point would be in the larger deformation range, excess deformation may be occurred due to the allowable tensile strength of geosynthetic reinforcement with this cross point. For this case, we must select the other compatible geosynthetic reinforcement

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

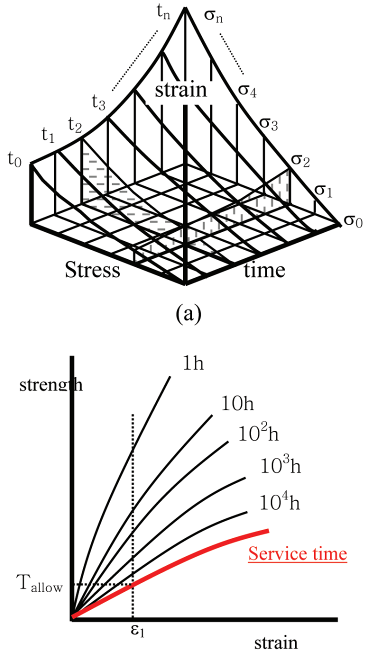
### 4.1 *Through isochronous creep deformation curves*

One assumption should be needed to evaluate the long-term deformation behaviors of segmental retaining wall with creep deformation data of geosynthetic reinforcement. This means geosynthetic reinforcement must induce all the tensile forces of 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 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 of creep behaviors for geosynthetic reinforcement.

Figure 2 shows the isochronous creep curves in the time-stress-strain axis. From the creep curve at t = $10^4$hr, we can determine the creep strain and the allowable strength of geosynthetic reinforcement.



(b)

Figure 2. Relation for strain compatibility: (a) Mobilized soil shearing resistance, (b) Compatibility curve for determining the equilibrium in reinforced soil.

If geosynthetic reinforcement is responsible all the horizontal deformation of soil structure, the allowable strain of soil structure is as same as the allowable strain of geosynthetic reinforcement, $\varepsilon_1$.

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 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 application system.

### 4.2 *Creep limit strain of geosynthetic reinforcement*

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<br>7.6 cm | Every 3 m<br>Height | Collin, J.F.P.G., 1997 |
| Concrete panel wall | Vertical tolerance | ± 0.03 H or 30 cm | Height | 日本土質工學會, 1986 |
| Reinforced wall | Bulging<br>Vertical tolerance | ± 20 mm<br>± 5 mm | Every 4.5 m<br>Every 1 m | BS 8006, 1995 |
| Concrete facing wall | Vertical tolerance | 13 mm | Every 3 m | Elias et al., 2001 |
| Reinforced wall | Vertical tolerance | ± 0.03 H or 30 cm | Height | Technical Manual by Korean Geo-technical 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 20,000-30,000 hours.

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 same as the secant modulus at 3% and 8% when the serviceability strain limit is 5% and 10%, respectively.

Through Figure 4, the allowable strength should be changed with the creep allowable strain for the creep curve of $10^4$ hr. 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.

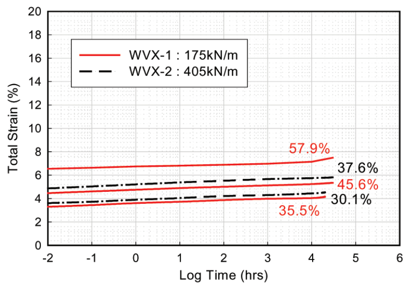



Figure 3. Creep of woven PET geogrid at 20°C .

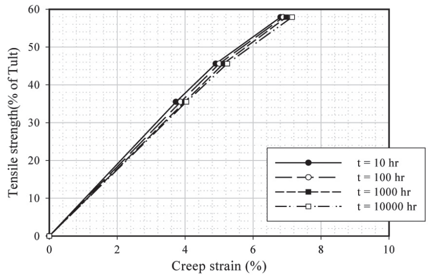



Figure 4. Isochronous creep curves of woven geogrid.

### 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.

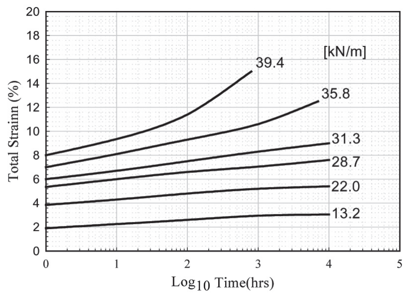



Figure 5. Strain-time relationship for for uniaxial HDPE geogrid at HDPE various Load at 20°C.

### 5.3 *Analysis by R.J. Muller*

R.J. Muller did the creep test of typical and developed geogrids and Figure 7 and 8 shows these results. From this analysis, long-term creep behaviors are very different for the same short-term tensile strength.

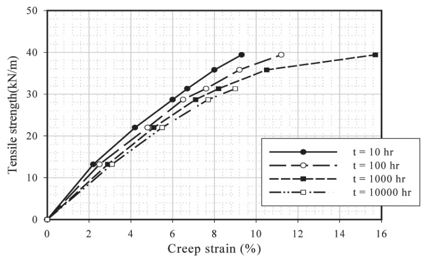



Figure 6. Isochronous creep curves of extruded geogrid.

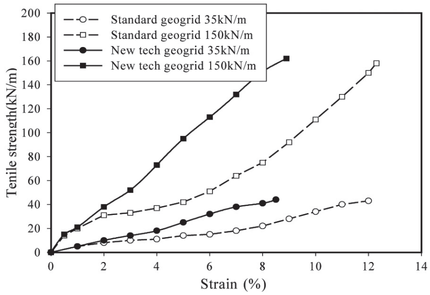



Figure 7. Short-term tensile properties of developed and typical geogrids.

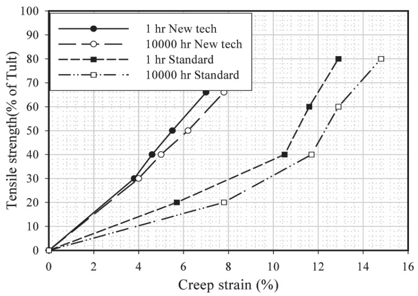



Figure 8. Isochronous creep curves of developed and typical Geogrids.

This difference could be determined only through the isochronous creep curves as Figure 8.

### 5.4 *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, geostrips and HDPE geogrids. They concluded that creep strain decreased by installation damage. In the isochronous creep curves, the decrease of creep strain was in the range of shorter time. From this curves, it may be seen that the long-term creep behaviors would be developed by 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 0.03 H and minimum reinforcement length as 0.7 H, it can be done that the allowable creep strain is 5%. Due to this premise, the long-term allowable strength were determined about 25-28% for geostrips and 35-44% for woven geogrids.

## 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 was considered tensile deformation of geosynthetic reinforcement and soil is fit for proper, correct and economic design for reinforced earth walls.

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