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Evaluation of creep behavior from field performance of a geotextile reinforced earth retaining wall

D.T.T.Chang & T.C.Chen
Department of Civil Engineering, Chung Yuan University, Chung Li, Taiwan

D.D.S.Chen
Sino Geotech, Inc., Taipei, Taiwan

ABSTRACT: In this study, creep behavior of an instrumented geotextile reinforced earth retaining wall was evaluated through a numerical analysis and in situ observations. The instrumented R.E. wall was 5-meter in height, 40-meter long and was constructed to resist a small scale landslide of a mudstone slope in S.W. Taiwan. The R.E. wall consisted of 4 sections, each a combination either of geotextile, N-1 (Woven geotextile) or G-1 (composite of local product), embedded in either alluvium sandy soil or fly ash stabilized decomposed mudstone. In the numerical model, cable element were used to simulate the flexible member of geotextile, and the simple supports were set at the boundary elements. The body of the numerical model was then constituted by the series parameters (density, cohesion, friction angle, shear modulus, etc.). Through this analysis procedure, the in situ geotextile creep behavior could be evaluated.

1 INTRODUCTION

In order to improve the stability problem of mudstone slopes, the authors's systematic study aims at evaluating the feasibility and efficiency of using geotextile and fly ash to reinforce the site and stabilize the backfill material, respectively. Based on the findings of previous laboratory studies by Chang, et. al.(1987,1989,1991), this project instrumented a geotextile reinforced test wall to evaluate its effectiveness in application. The test section is located at Provincial Highway No.3 from 358km+120 to 358km+160. The side slope of this section had slide due to toe failure of a concrete gravity type retaining wall. To replace the damaged wall, two tiered test wall was designed, with the lower and upper tiers, 3m and 2m high, respectively, and installed. Combination of two types of woven geotextiles (woven geotextile and composite of local product) and two types of fill materials (alluvial sand and fly ash-cement treated weathered mudstone)were used and arranged into four test sections along the site. Based on the tensile behavior of geotextile and the frictional characteristics of backfill-geotextile interface,the wall design was made by the conventional tieback wedge analysis method.

The slope had been monitored and found stabilized for a period of two years, series of monitoring data were collected from the installed instrumentation system. The numerical analysis proposed in this study was made to evaluate the field performance.

2 BACKGROUND REVIEW

The creep behavior of geotextile is known as the one of the most important latent factors to affect the performance of reinforced earth. Numerous of studies have been conducted to establish practical guidance for the design of earth reinforcement.

From the previous studies (McGown, et.al.,1984), confining condition, temperature, fiber type , and fabric structure, were evaluated as the major factors to influence the creep behavior of geotextile. In general, it was qualitatively concluded that the creep strainincreases as the temperature increases while creep strain decreases as confining pressure or strength of geofabrics increases. However, the quantitative relationships between creep strain and above factors were still difficult to establish. Therefore, additional factor of safety had been used in practice for the design of reinforcement. Bell et.al (1980) gave the limitations on the design tensile strength for various fiber materials; Keorner and welsh (1981) suggested the use creep strain curves for soil and geotextile, but the designer's judgement could produce considerable differences; Christopher and Holtz (1986) provided the limitations on the design strength (<25% of tensile strength) and creep strain (<5%).

The rapid growth of geofabric application in engineering practical necessitate a more accurate quantitative understanding of soil-geofabric behavior, the numerical study proposed herein take into consideration of the factors indicated by McGown, et.al.(1984), and hope by using a more rational approach which may reduce the conservatism in design practice.

3 PROPOSED STUDY PROGRAM

The analysis program was developed as shown in Fig.1. Since the numerical analysis program reported in this paper needs to employ the previous works for laboratory and field studies, a brief summary is presented in Table 1; the R.E. wall was instrumented as shown in Fig.2.;typical test results used in the analysis program are provided in Fig.3 to Fig.8.

4 NUMERICAL MODELLING

Since the tensiometer and extensiometer only present the "local behavior" (shown in Fig.2), the numerical model needs to be preliminarly studied for comparison purpose. Before processing to the numerical analysis, some assumptions based on the field condition were made :

1. The model is an equilibrium system;
2. Water table is low and backfills materials are assumed to be homogeneous and unsaturated;
3. The strain of wall is assumed to be small;
4. After compaction, backfill soils and geotextile are bonded together and displacements are equal;
5. The Mohr-Coulomb theory is applicable for stress analysis.

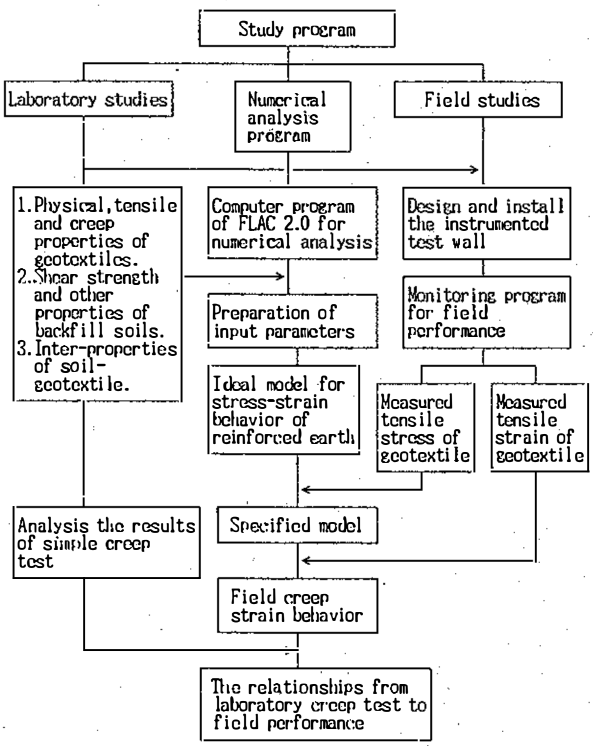

Fig.1 Analysis Program

Table 1. Summary of Previous Works for Laboratory and Field Studies

Laboratory Studies	Geotextile Only	1. Stress-strain relationships was obtained by wide width tensile test (ASTM 4595-86, 1987), tangent modulus was also evaluated 2. Simple creep test to obtain creep strain-loads curves [All details refer to the studies by Chang et. al. (1990, 1991)]
	Backfill Soils Only	1. Alluvial sand material and fly ash -cement treated weathered mudstone were used as backfills. 2. Max. γd, OMC from Miniature Harvard Compaction Test 3. C, ϕ from soaked undrained direct shear tests [All details after Chang, et.al (1987, 1990)]
	Soil - Geotextile Interaction	1. Stress-strain curve and frictional angle of interface, ϕSF, was determined by direct shear method (ASTM), tangent modulus was also obtained from curve. [All details after Chang, et. al. (1989, 1990)]
Field Studies	Design and Construction of Test Wall	1. Conventional wedge analysis method was used for reinforced earth earth wall design. 2. Procedure and specification of construction were based on the suggestion by Christopher and Holtz (1986). 3*. Six types of instrumentation were installed at the test site. Only the monitored results for tensile stress and strain (elongation) are to be used in this study, data are presented in Table 5. [All details after Chang, et.al. (1990, 1991)]
*Location and arrangement for instrumentation systems installed at test site are shown in Fig.2.		

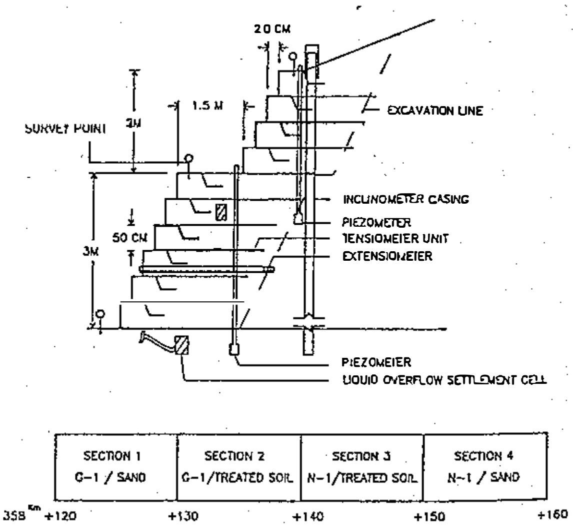

Fig.2 Arrangement of Instrumentation System from Typical Cross Section

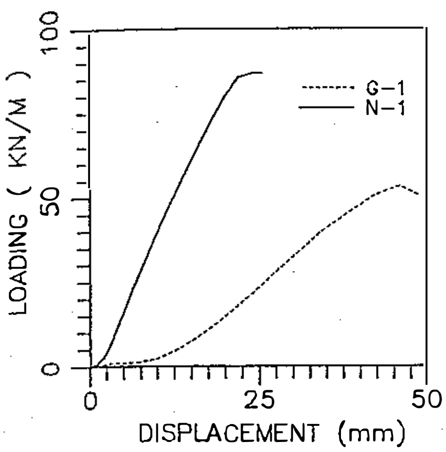

Fig.3 Results of Wide Width Tensile Test of Geotextiles

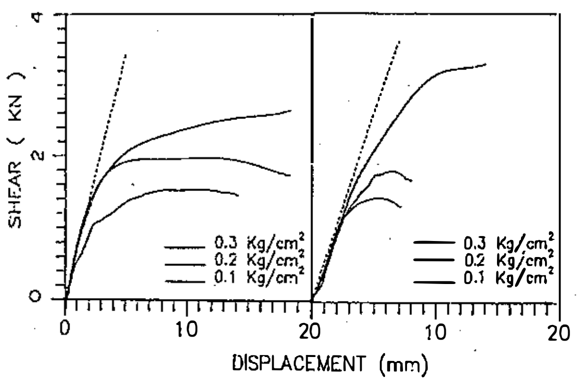

Fig.4 Results of Treated Soil/G-1 Direct Shear Test

Fig.5 Results of Sand/G-1 Direct Shear Test

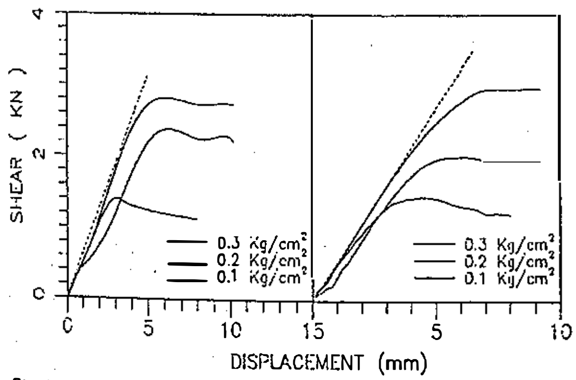

Fig.6 Results of Treated Soil/N-1 Direct Shear Test

Fig.7 Results of Sand/N-1 Direct Shear Test

According to the above assumptions, the computer program, "FLAC", is used to do the analysis. "FLAC" is developed using on the finite difference (FD) method for analyzing the static soil-structure interaction problems. The soil and structure are meshed into grids. The motion equation is solved by the explicit Finite Difference method. The time-stepped reactions, displacement and velocity, are obtained by transforming the stress of each element before the equilibrium condition of the system is reached.

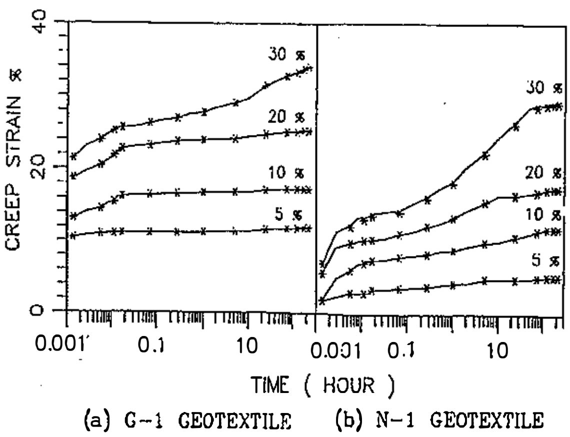

Fig.8 Results of Geotextiles Creep Test

In this study, 960 elements were used to simulate the cross section of test wall (as Shown in Fig.9). Simple support system was given for simulating the behavior of the boundary. For completing the model, three types of elements are used in the study, they are soil element, reinforcing element (geotextile), and interface element.

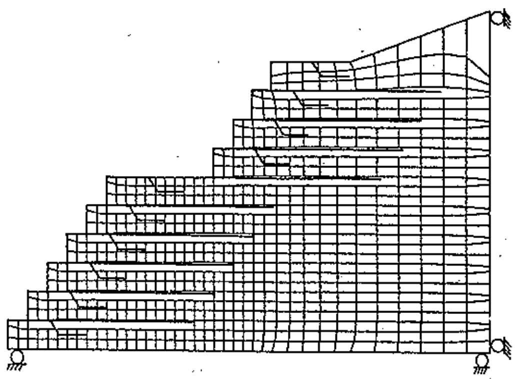

Fig.9 Elements of Numercial Model

For soil and reinforcing elements, are used to simulate the theoritical stress-strain behaviors of the reinforced earth mass. The additional element, interface element, is engaged to simulate the inter-behaviors of above two elements. The combination of these elements, therefore, is estabilished the numerically simulated earth mass. Based on the monitored stress data, the responsing strain behavior can be obtained through the numerical calculation procedure. And, the comparison can be made between the field monitored elongation and the calculated strain. It is believed that the difference could be influenced by the creep effect in the field.

The parameters used in this modelling analysis were obtained from the laboratory studies (refere to Table 2,Fig 3 to Fig 7.), some adjustment as needed in order to fit the numerical models properly. They are briefiy described as follows:

Table 2 Basic Properties of Backfill Soils

Parameter	Treated Soil	Sand
Cohesion (N/m²)	4.37×10^4	1.95×10^4
Friction Angle (degree)	42.3	44.1
Shear Modulus (N/m²)	3.1×10^8	8×10^7

1.Parameters of soil element - Except for soil unit weight, cohesion, and internal friction angle may readily obtained from test results, shear modulus and bulk modulus also need to be considered. The shear modulus was determined by the slope of stress-strain curve from the results of direct shear test. While in order to obtain the bulk modulus, the suggested value by Cundall (1987) was used. The typical data used in the FLAC program is shown in Table 3.

Table 3 Parameters of Soil Element

Parameter	Treated Soil	Sand
Cohesion (N/m²)	2.9×10^4	1.3×10^4
Friction Angle (degree)	29.4	30.0
Shear Modulus (N/m²)	2.0×10^6	5.2×10^7
Bulk Modulus (N/m²)	4.4×10^8	1.0×10^8
Unit Weight (N/m³)	1440	1500

2.Parameters of reinforcing element - The required input parameters for reinforced element are reinforced area, yield strength, and Young's modulus. For reinforcing element of geotextile in the test wall, the parameters were respectively defined as the specimen size, tensile strength, and tangent modulus from the results of wide width strip tensile test (ASTM 4959). For the next two properties can be referred to Table 4.

Table 4 Parmeters of Reinforcing Element

Parameter	G-1	N-1
Yield Strength (N/m)	4.9×10^4	8.3×10^4
Young's Modulus (N/m²)	1.6×10^6	4.56×10^6

3.Parameters of interface element - bond stiffness and bond strength of grout are the mojor parameters to present the stress distribution behavior. In this study, the tangent modulus and peak stress of stress-strain curve of soil - geotextile interface from direct shear test were used respectvely as the parameters concerned above (as given in Fig 4 to Fig 7).

Since the Series stress - strain curves were obtained under different confining pressure during direct shear test, the various parameters were propely determined for each reinforcing lift of test wall.

5 RESULTS FROM NUMERICAL ANALYSIS AND MONITORING PERFORMANCE

The measured loads and displacement from tensiometers and extensiometers, respectively, are provided in Table 5. In order to numerically simulate the measured stress condition in the field, numerous trials with the varied input paramters have been conducted. Results indicated that the reduced parameters of soil element (as described previously) using one third of internal friction angle ($1/3\phi$), matched well with the simulated stress condition. The value of $1/3\phi$ was also suggested by Christopher and Holtz (1986) for the performance of field compacted backfill.

Table 5 Monitoring Results

Testing Wall Section	Tensiometer Monitoring Load(N)	Extensiometer Monitoring Displacement (mm)
Section 2 G-1/Treated Soil	2880	2.37
	4136	4.75
	6831	9.60
Section 3 N-1/Treated Soil	1957	0.80
	3147	1.85
	4062	3.64
Section 4 N-1/Sand	1683	3.55
	6229	4.45
	9006	9.25

* The section 1 had been distoried by the runoff of heavy rainfall

6 EVALUATING CREEP STRAIN OF FIELD PERFORMANCE

The reading obtained by extensiometer represents the sum of elongations from elastic strain and creep deformation (time dependent strain under sustrained constant stress). Therefore, the creep strain is obtained by subtracting the result from the previous analysis from field extensiometer reading, the results are summarized in Table 6.

Table 6 Numerical Analysis Determined Field Creep Strain

Geotextiles	Loads (N)	Elastic Elongation (mm)	Measured Elongation (mm)	Creep Elongation (mm)	Creep Strain (%)
N-1	1080	0.107	0.80	0.69	0.058
	2806.7	0.129	1.85	1.72	0.143
	4308	0.162	3.55	3.48	0.290
	8595	0.360	5.45	5.09	0.424
	9500	0.472	9.25	8.79	0.732
G-1	1136.7	0.119	2.37	2.25	0.188
	3592	0.158	4.75	4.59	0.383
	6588	0.196	9.60	9.40	0.784

7 CORRELATION OF CREEP BEHAVIOR WITH LABORATORY AND FIELD PERFORMANCE

Based on the previous study by Chang et.al.(1991) and Figure 8,results from creep test are reproduced and plotted in Figure 10. In addition, for comparison purpose, creep strain data presented in Table 6 are also shown in Fig.10. The

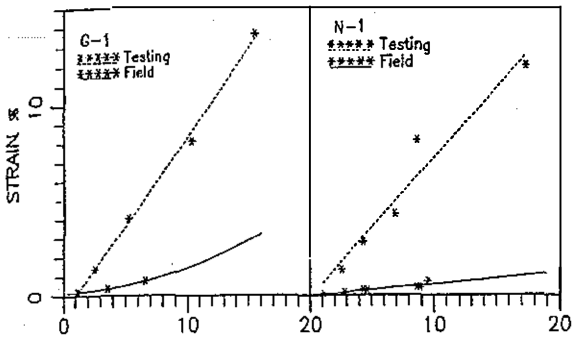

Fig.10 Performance of Lab. with Field Creep Strain

regression curves were plotted for G-1 and N-1 geotextiles of the laboratory and field behaviors, the equations for these curves can be expressed as following:

$$\varepsilon_{L(G-1)}, \% = 0.116+7.0*10^{-4}*F \quad (1)$$

$$\varepsilon_{L(N-1)}, \% = 0.00828+7.29*10^{-4}*F \quad (2)$$

$$\varepsilon_{F(G-1)}, \% = 0.139+3.21*10^{-5}*F \quad (3)$$

$$\varepsilon_{F(N-1)}, \% = -0.00791+6.02*10^{-5}*F \quad (4)$$

In which ε_L and ε_F are the creep strain (%) obtained from laboratory and field, respectively; F is the applied load, unit in N/M. Comparing the values of ε_L and ε_F for two geotextiles, the ratios of $\varepsilon_L/\varepsilon_F$ (=R)were determined and regression curves are shown in Figure 11. The curves may be expressed as

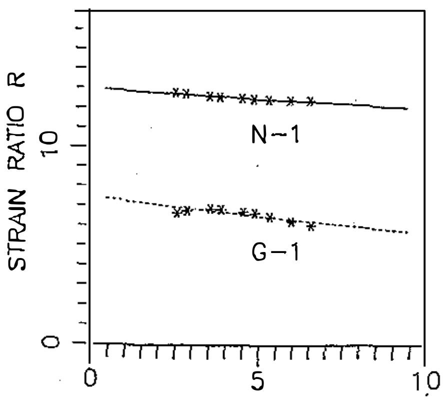

Fig.11 The Relationship of Lab. with Field Creep Strain

$$R_{(G-1)} = e^{(-2.85*10^{-5}*F)} *7.5 \quad (5)$$

$$R_{(N-1)} = e^{(-8.28*10^{-6}*F)} *16.8 \quad (6)$$

In which $R_{(G-1)}$ and $R_{(N-1)}$ are the ratios of ε_L to ε_F, for G-1 and N-1 geotextiles respectively;F is the applied load, in N/M.

By the above equations, ε_F can be obtained with the known R (by given F)and ε_L (by the simple ceep test). According to the findings of this study, the relationships of the field creep behavior and laboratory performance may be given by equations (5) and (6) which are developed for geotexiles G-1 and N-1. For more general application, the properies of various backfill soils and geotextiles are necessary to define the input parameters in the model.

Since the influeneces of factors are complicated, the "property ratio", such as stiffness ratio, modulus ratio, etc. is under consideration in the ongoing study by the authors, in order to simplify the problem .

8 CONCLUSIONS

Based on the numerical analysis program conducted and discussed herein, it may be concluded that:

1. The related properties of soil-geotextile interface which were determined from direct shear tests are compatible to the behaviors simulated from the numerical model.
2. Typical properties of geotextile obtained by wide width strip tensile test can be properly used to define the numerical model.
3. One third of internal friction angle (determined by direct shear test), is found to be compatible to the field behavior of reinforcing soil.
4. The model for evaluating the field creep behavior of geotextile reinforced earth wall is established in this study. Concerning the difference of soil type and kind of geotextiles, more generalized model is required in the future study.

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