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The creep behavior of geotextiles under confined and unconfined conditions

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ABSTRACT: Confined and unconfined creep tests were conducted for this study in order to determine the creep behavior of geotextiles. Evaluation was carried out to determine whether the safety factor 4 recommended in the relevant design manuals is overly conservative. Design loads ascertained using critical stress levels which exhibits the creep behavior was also studied. The amount of creep undergone by the geotextile was evaluated because this figure is directly influenced by friction between geotextile and soil during in-soil confined creep testing. It was found that under confined conditions a portion of the design load can be borne by this frictional resistance, greatly reducing the actual stresses borne by the geotextile itself. For this reason, it is proposed that the safety factor could be reduced by about 40%.

1 INTRODUCTION

The term "creep" refers to the increasing strain over time in materials to which fixed loads have been applied. Mikki et al have classified creep into three categories based on the different load levels of the geotextile, light loads result in dominant primary creep, which is a form of attenuating creep, moderate loads produces dominant secondary creep, and heavy loads cause dominant tertiary creep, which may lead to rapid rupture of the geotextile.

2 CREEP BEHAVIORS OF GEOTEXTILE

The creep behavior of geotextiles is influenced by many factors. McGown Allen , and Ingold , have identified a number of these factors:

1.Confinement Conditions: When geotextiles are under confinement by soil, frictional resistance between the two reduces the amount of creep undergone by the geotextile. McGown et al pointed out in the dominant primary creep state, confinement caused a particularly large reduction in creep. The findings of Peng confirmed these results.

2.Temperature and Geotextile Type: Allen and Ingold found that temperature could influence the creep behavior of geotextiles through its effect on the connections between the molecules (e.g. crystal-shaped or irregularly shaped) that make them up. The effect of temperature on creep behavior was much greater for those made of polypropylene (PP) or high-density polyetholene (HDPE) than for ones made from polyeseter (PET). As for the properties of geotextile fibers, Hoedt found that at similar temperatures geotextiles made of PP or PE fibers exhibited a greater degree of creep than did those made of PET.

3.Load: The creep behavior of geotextiles differs with different load levels. Mikki summed up with the various creep behavior.

In recent years, creep behavior has generally been described using test results. In the early years, Haliburton developed a creep test for which a certain percentage of the geotextile's wide-strip tensile strength was adopted as the fixed load. The unconfined creep test recommended by the ASTM in D5262-92 is largely similar to the above test, stipulating creep loads of 20%, 30%, 40%, and 60% of tensile strength. Chen used the same testing methods, but with creep loads of 20%, 40% and 60% of tensile strength. It is suggested that using the concept of critical stress, the results of these tests be used to establish design loads. The safety factor can be lower than the figure of 4 recommended by the FHWA. The methods and intent of the above creep testing methods are all similar in that they evaluate only the creep properties of the geotextile material. Matichard et al took the confinement factor into consideration from their confined creep testing results. However, no soil interface was used in their experiments, as water pressure alone provided the desired pressure on the geotextile. Although their method disregarded the friction between the soil and the geotextile, their findings did show that geotextile creep reduces under the effect of confinement. Chang et al have also proposed models from the studied tensile behaviors of geotextiles under both confined and unconfined conditions. Taking a similar approach, these also merit further investigation.

3 METHODS AND MATERIALS

Two types of geotextiles were used for this study, one was woven geotextile and the other was nonwoven geotextile. The former type was labelled "A" and the latter "B". The basic properties of each are detailed in Table 1.

Table 1. General properties of geotextiles

Type	Sample A	Sample B
Thickness(mm)	2.97	2.17
Unit weight (g/m^2)	481	380
Tensile strength (kg/7.62cm)	595	160
Elongation at failure(%)	25.38	32.19
Initial modulus (kg/7.62cm)	2820.0	1100.0

In the unconfined creep test program, the ultimate tensile strength (Tu) of each type was measured, then testing was carried out using fixed loads comprising different percentages (10%, 20%, 30%, 40% and 60%) of Tu. This test method was used to determine the creep attenuation of geotextiles at various loads levels.

For the confined creep test, weathered mudstone, a typical geologically hazardous material, was selected as the confinement material. The confining apparatus consisted of upper and lower boxes, each of which measured 22 × 24 × 2.9 cm. The soil sample in the lower box was compacted to a 95% degree of compaction with a moisture content of OMC + 2%. The geotextile was laid on top of it, then the upper box was placed on top and the soil sample was placed in it then compacted. Both ends of the geotextile were protected by an aluminum plate glued firmly in place using EC-30 glue. One end of the specimen was clamped and fixed onto the box, and the other end was also clamped for applying the creep load. Confining pressure was applied normally on the upper soil sample with dead weights. Two confining pressures were used; 1.5 kg/cm^2, and 2 kg/cm^2. Testing was carried out using creep loads of 10%, 20%, 30%, 40% and 60% of Tu. Unconfined creep testing was also used for comparison purposes. Using the models proposed by Chang et al, the method by which stress transfer and distribution occurs in geotextile specimens to which static loads have been applied in a confinement box can be rationally deduced. The analysis can be expressed using the equation 1 below. The values for f_1 and f_2 in this formula should be obtained during pullout and direct shear testing.

$$P = f_1 \times l_{A1} + f_2 \times l_{sg} + P_g \qquad (1)$$

Where:

P =a tensile load carried by the geotixtile with a specified left in the reinforced earth

f_1 =The frictional resistance at the interface between the soil and the aluminum plate.

l_{A1} =The length of the buried portion of the aluminum plate.

f_2 =Frictional resistance at the soil-geotextile interface.

l_{sg} =The length to which the geotextile has been buried in the confinement box.

P_g=Transfered stress onto the geotextile, itself.

4 ANALYSIS AND DISCUSSION OF RESULTS

4.1 Creep Behavior under Unconfined Conditions

For the unconfined creep test, testing was carried out using the same levels of creep load as that of the confined creep test. However, when 60% of Tu was applied to the "B" specimens (heat-bonded nonwoven), rupture occurred in a short period (less than ten hours). For this reason, the highest creep loading for the "B" geotextile specimens was reduced to 50% of Tu, while that for the "A" samples remained at 60% of Tu, in accordance with the original testing program for the study. According to equation 1, frictional resistance must be taken into consideration for determining the creep loadings required to induce creep in the specimen. In view of this concept, the tensile loads used during testing must be greater than the frictional resistance, so that extra loading is applied to the geotextile specimen. If the tensile load is too small, no extra load is transferred (P_g in equ.1) to the geotextile, rendering the creep test inconclusive. In view of this, appropriate loads for specimen A which exhibited a relatively high Tu(much greater than frictional resistance), would be 10%, 20%, 30%, 40%, and 60% of Tu. For geotextile B which exhibited a very low Tu, the above tensile loads would be too low. Therefore, additional testing was carried out using tensile loads of 90%, 100%, and 110% of Tu.

The results of unconfined creep testing for the "A" geotextiles are depicted using a strain-time diagram in Fig 1.It is evident that the curves flatten out quickly at creep loads of 10% and 20% of Tu. Creep strain attenuation was 4.0% where the creep load was 10% of Tu, and 8.0% where it was 20% of Tu, which is primary creep behavior in terms of the models discussed above. When the creep loads were increased to 30% and 40% of Tu the curves became somewhat irregular, but the creep strain was still attenuated, standing at 13.0% and 20% respectively. The strain-time curve for a creep load of 60% showed a continuous upward trend representing diffused creep, and the creep strain reached approximately 60% after only 30 days. In this condition, 40% of Tu could be the max. creep load to be selected.

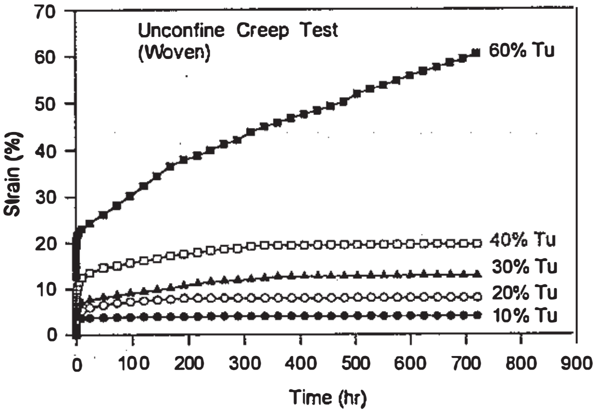

Figure 1. Geotextile A creep strain/time curve

The behavior of the "B" geotextiles is depicted in Fig. 2. The figure shows that the creep strain was attenuated until 40% of Tu, which is classified as attenuating creep. When creep loading reached 50% of Tu, creep strain in the geotextile was quickly dispersed and rupture occurred only for 21 days when creep strain had reached 88%. The max. creep load as 40% of Tu also can be selected.

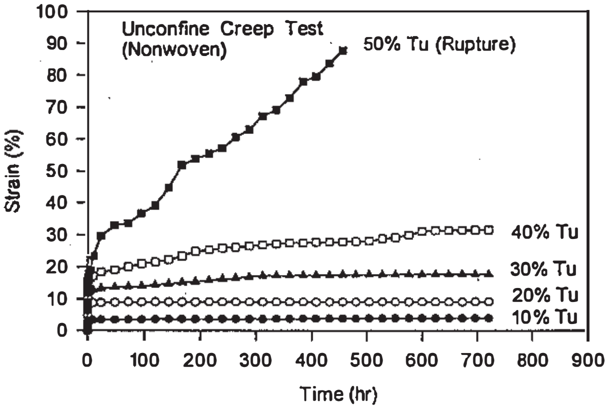

Figure 2. Geotextile B creep strain/time curve

4.2 Creep Behavior under Confined Conditions

Confinement pressures of 1.5 kg/cm^2 and 2.0 kg/cm^2 were adopted for this study. The results of confined creep testing are listed in Tables 2 and 3, and the results of unconfined testing have also been included to facilitate comparison.

Table 2. Geotextile A under identical creep load and creep strain

	10%Tu	20%Tu	30%Tu	40%Tu	60%Tu
σ_3=0	3.93	7.93	12.84	19.56	60.30
σ_3=1.5 kg/cm^2	1.98	3.93	6.86	13.15	20.02
σ_3=2.0 kg/cm^2	1.02	2.03	3.95	10.68	18.49

Note:Tu=595kg/7.62cm

Table 3. Geotextile B under identical creep load and creep strain

	10%Tu	20%Tu	30%Tu	40%Tu	60%Tu	90%Tu	100%Tu	110%Tu
σ_3=0	3.98	9.058	17.65	31.507	85.574	--	--	--
σ_3=1.5 kg/cm^2	0.828	1.139	1.455	1.85	2.34	10.23	17.94	32.56
σ_3=2.0 kg/cm^2	0.489	0.821	1.165	1.426	1.83	4.05	10.15	16.50

Note:Tu=160kg/7.62cm

To ascertain the frictional resistance between the soil and the aluminum plat during the testing process, a pullout test was conducted on the latter. Following the ASTM direct shear testing , the results are provided for reference and comparison in Table 4, so that the P_g value can be ascertained from frictional resistance between the soil and the aluminum plate. In this table, the methods used to obtain the frictional resistance between the aluminum plate and the weathered mudstone were the same as those used for confined creep testing of the geotextile. Additional testing was carried out with the geotextile clamped between two sheets of aluminum plate.It should be noted that these results differ from those obtained using a single sheet of aluminum plate. It can be deduced from the results that frictional resistance has a greater influence for wovens than for nonwovens. This is because the "c" values and "ϕ" angles are greater for the interface between soil and nonwoven geotextiles, and because the relatively small loads used were partially sustained by frictional resistance.

Table 4. Comparison of direct shear test results for geotextile/mudstone, aluminum sheet/mudstone

	C (kg/cm^2)	ϕ (°)
Geotextile A/mudstone	0.265	20
Geotextile B/mudstone	0.367	23
Aluminum/ mudstone	0.014	1.4

*Friction resistance between geotextile and mudstone "A $\times$(C+σtanϕ)"

Geotextile A/mudstone	σ=1.5kg/cm^2	125.56
	σ=2.0kg/cm^2	153.74
Geotextile B/mudstone	σ=1.5kg/cm^2	155.4
	σ=2.0kg/cm^2	188.27
Aluminum/ mudstone	σ=1.5kg/cm^2	7.72
	σ=2.0kg/cm^2	9.58

Creep strain only became readily apparent when the load exceeded 90% of Tu and began to be transferred to the geotextile itself. The results of confined creep testing show that even if frictional resistance is greater than the creep loading being applied, a small amount of creep still occurs in the geotextile. The recorded data indicate that a small amount of creep occurs at the moment creep loading is applied, and then almost no further elongation occurs for a short period. The reason for this is probably that as creep loading is first applied, the frictional resistance between the geotextile and the soil has not yet developed to the predicted value, so some creep occurs. But as soon as the frictional resistance between the soil and the geotextile is fully developed, it begins to restrict elongation in the geotextile. Comparing the results with those from unconfined creep testing shows that frictional behavior during the confined creep process cannot be fully described using only the "c" and "ϕ" values obtained through direct shear testing. Furthermore, after exceeding the peak static friction, the geotextile and the soil together begin to undergo creep. Actual creep behavior in this situation will be slightly different than what was expected because the friction effect in this situation is unlike that outlined earlier.

Taking the distribution of forces applied to the geotextile into consideration, when tensile load is gradually applied to the confined specimen, the strain (i.e. stress) is gradually distributed in a triangular pattern from the point at which the load is being applied, and spreads down toward the fixed end. Therefore, all the creep loads used in this study could be expected to cause an independent triangular pattern of strain (i.e. stress) distribution in the specimen. The lighter the load is as a percentage of Tu (for example the case of 10% of Tu for the "B" geotextiles) and the smaller it is in proportion to frictional resistance.And more likely it is that the strain resulting from its transfer to the geotextile will take on a triangular distribution on the load end. Although stress transfer P_g, has not full developed along the specimen to the fixed-end, local resistance closing to the loaded-end has already been overcome to some extent and is being transmitted to the geotextile itself. This hypothesis should provide a rational interpretation of frictional resistance and stress transfer.

4.3 Design Requirements and Considerations

From the results of unconfined creep testing it was mentioned previously, that the maximum attenuated creep load for the "A" geotextiles was 238.0 kg/7.62 cm(40% of Tu) and the creep attenuation value was about 20.0%. For the "B" geotextiles, the maximum attenuated creep loading was 64.0 kg/7.62 cm (approximately 40.8% of Tu) and the creep attenuation value was 32.0%.

Stress-strain curves after 30 days(72 hrs) for geotextiles under various creep loads are depicted in Figs. 3 and 4. Referring to Fig. 3 for design considerations, it can be seen that where the design requires a 5% creep strain and stress at 25% of Tu. The design stress for the "A" (woven) geotextiles would be 148.8 kg/7.62 cm; under unconfined conditions the corresponding creep strain would be 11%. Under a confining pressure of 1.5 kg/ cm^2 it would be 5%; and under a force of 2 kg/ cm^2 it would be only 2.58%. This shows that under confined conditions, the soil helps keep creep within the required limits. For a design loading that required the maximum attenuated load of 238.0 kg/7.62 cm, the creep strains corresponding to confining forces of 1.5 kg/ cm^2 and 2.0 kg/ cm^2 would be 13.0% and 11.0% respectively (see Fig. 3). These figures are well below the creep attenuation value of 20.0% (Fig. 1), and would be achieved during or soon after construction of the reinforced soil structure. Hence the safety factor can be reduced from 4 down to 2.50(40% of Tu), so that the strength of the geotextile can be more fully utilized.

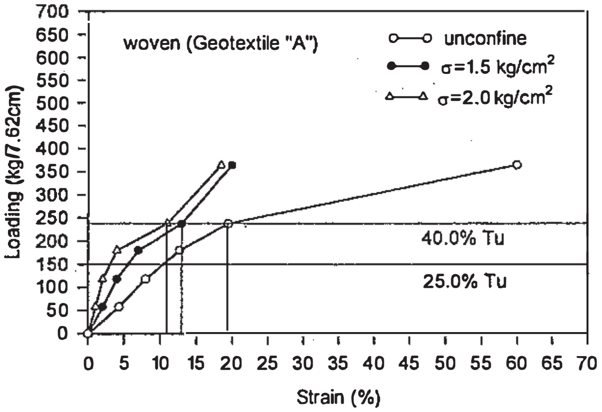

Figure 3. Creep test results for 30 days stress-strain curve (sample"A")

The ultimate tensile strength (Tu) of the "B" geotextiles is lower than for the "A" samples and the "c" values and ϕ values between the former samples and the soil are higher than for the latter, so frictional resistance has a significant influence on the "B" geotextile, as seen in Fig 4.

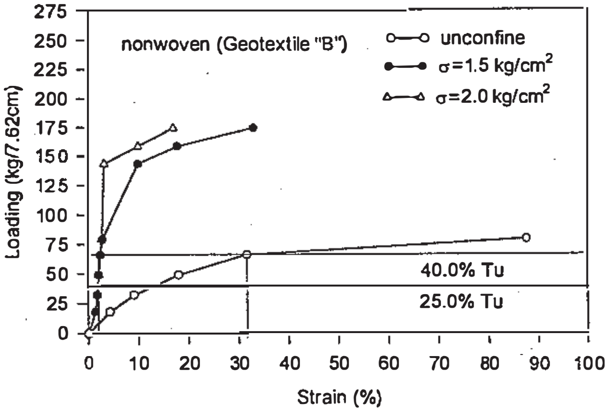

Figure 4. Creep test results for 30 days stress-strain curve (sample"B")

For a creep strain of 5% and stress at 25% of Tu, the design strength would be 40 kg/7.62

cm^2. Creep strain in all cases is less than 5%, with the exception of unconfined creep strain, which reaches 14%. For a design loading requiring a maximum attenuated creep loading of 64.0 kg/7.62 cm^2, the corresponding strain values would be well below 5%. Therefore the safety factor of 4, also can be reduced to 2.5(40% of Tu).

5 CONCLUSIONS

The experimental results and analysis presented in this study can be summed up as follows.

1.Under the same confining pressure, the amount of creep increases as the creep load rises; and where the creep load is the same, increases in confining pressure decrease the amount of creep, which may even be reduced to nil.

2.The results of this study indicate that the safety factor can be justifiably lowered, and that this would be safe overall.

3.The process by which strain is transferred and distributed when creep occurs during confined testing of geotextiles can further verify the phenomena observed and the conclusions drawn in this study.

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