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A generalized creep model for geosynthetics

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ABSTRACT: In this study, a generalized creep model was developed for simulation of the behavior of geosynthetics. The generalized model simulates creep behavior of geosynthetics by a series of multiple integrals. The effects of stress level and temperature on the creep characteristics are accounted for in the model. It is shown that the model is capable of simulating the creep behavior of different geosynthetics at various stress levels in a accurate and consistent manner.

1. INTRODUCTION

Polymeric geotextiles and geogrids are being used, with increasing popularity, as reinforcing materials (reinforcements) in permanent earth structures, such as geotextile/geogrid reinforced retaining walls. A geosynthetic-reinforced earth structure may "fail" due to excessive long-term deformation of the reinforcement. Hence, the ability to predict long-term creep behavior of geosynthetic reinforcements is critical to safe and economical construction of geosynthetic-reinforced soil structures.

The long-term creep test methods for geotextiles and geogrids can be categorized into two groups; in-isolation and in-soil tests. In-isolation test may be used to obtain design parameters for some geosynthetics of which the creep behavior is unaffected by soil confinement. However, in-soil tests should be used for obtaining design parameters for those geosynthetics whose creep behavior is significantly affected when confined in soil.

In terms of data analysis, two types of viscoelastic material behavior (i.e., linear and nonlinear viscoelasticity) have been used. Most geotextiles and geogrids behave linearly at low levels of stress but become nonlinear at higher levels (with or without tertiary creep). Furthermore, the mechanical properties of these viscoelastic materials are very sensitive to temperature. Hence, the need for a generalized method of data analysis is recognized. In this study, a generalized creep model has been developed based on the multiple integral representation described by Findley, et al (1976).

To illustrate the load-strain-time-temperature behavior of this method, data analysis for two common geosynthetics is presented. The geosynthetics are a polypropylene composite geotextile (Propex 6067) and a polypropylene nonwoven heat-bonded geotextile (Typar 3301).

2. CREEP ANALYSIS FOR POLYMERIC GEOTEXTILES AND GEOGRIDS

A number of analytical methods are available for evaluating the strain versus time characteristics for polymeric materials. The rate process theory using thermodynamic modeling has been used to model creep in textile fibers (Bernard, et al, 1957) and in plastics laminates (Hogan, 1951).

Rheological models, using combinations of springs and dashpots, have been used to model creep in textile fibers (Kumar and Gupta, 1977 and 1978). Shrestha and Bell (1982) used the four elements Burger model to describe creep behavior of geotextiles. They also used the so called "three parameter equation" developed by Singh and Mitchell (1968) and found that the rheological model offered a better fit to experimental data.

The three parameter equation has also been used by Yamaoka and Nishigata (1986) to represent the experimental creep data of woven and nonwoven geotextiles. The reproduction of the experimental creep data, in authors' opinion, was not satisfactory, because of the error at 2000 minutes was as high as 15%. This error is expected to increase substantially with time and render drastically misleading prediction of long term creep behavior.

The main shortcoming of these investigations is that data were derived from short duration tests, often only of several hours. Moreover, these studies failed to model generalized load-strain-time behavior of geotextiles as pointed out by Kabir(1988).

2.1 Generalized Stress-Strain-Time-Temperature Model

Findley, Lai and Onaran (1976) represented the creep behavior of nonlinear viscoelastic materials by using a series of multiple integral. For uniaxial creep, the following expression results:

$$\epsilon(t) = F_1 P + F_2 P^2 + F_3 P^3 \ldots\ldots\ (1)$$

in which,

$\epsilon(t)$: the total strain
p: the applied uniaxial load
F_1, F_2 and F_3: kernel functions.

From equation (1), the following expressions can be written for three uniaxial tension tests at different axial loads, P_a, P_b, and P_c, covering the range of loads of interest,

$$\left.\begin{aligned} \epsilon_a(t) &= F_1 P_a + F_2 P_a^2 + F_3 P_a^3 \\ \epsilon_b(t) &= F_1 P_b + F_2 P_b^2 + F_3 P_b^3 \\ \epsilon_c(t) &= F_1 P_c + F_2 P_c^2 + F_3 P_c^3 \end{aligned}\right\} \quad (2)$$

If the experimental creep strains from the three tests are described as functions of time by appropriate mathematical expressions and introduced on the left-hand side of equation (2), these three equations may be solved simultaneously for the kernel functions F_1, F_2 and F_3.

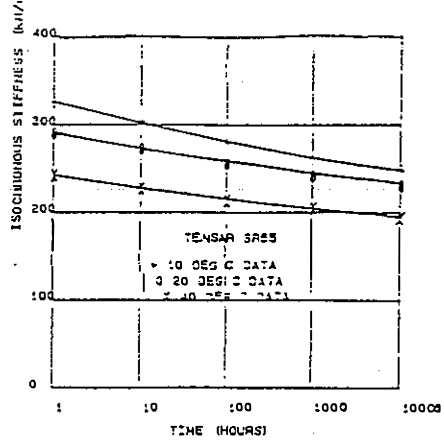

Figure 1 Isochronous stiffness- versus-time curves for 10°C, 20°C and 40°C (after Bush, 1990)

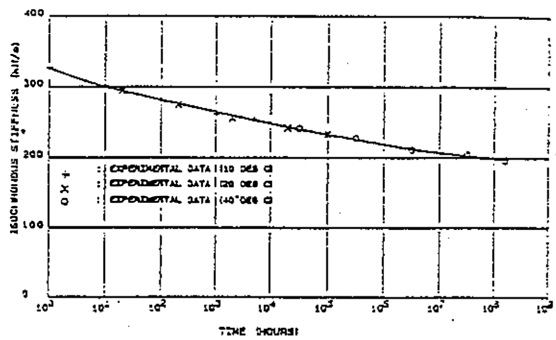

Figure 2 Time-temperature superposition for a HDPE geogrid (after Bush, 1990)

The above method is most suitable when the time-independent strain ϵ_0 is separable form the time-dependent strain, ϵ-ϵ_0, and that the time-dependent strains contain a time function such as t^n which is the same for different loads. Fortunately, the behavior of many polymeric materials can be described within these limitations. Thus, each of the functions F_i in equation (1) has a time-independent part F°_i and a coefficient of time-dependent part F^+_i. The time-independent terms F°_i may be determined separately by means of the procedure described above using equations (2). The time-dependent coefficients may be determined separately in a similar manner.

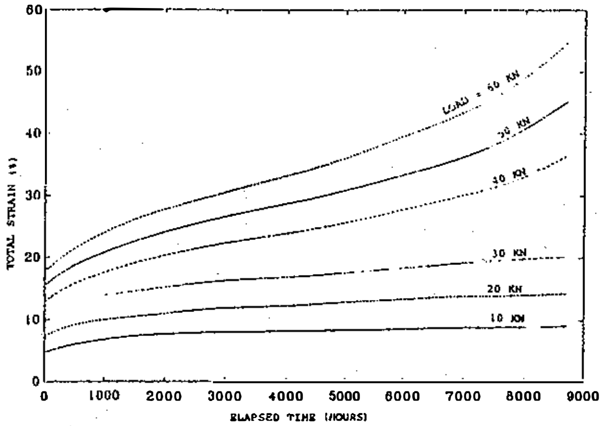

Figure 3 Model performance under six different axial loads, with and without tertiary creep

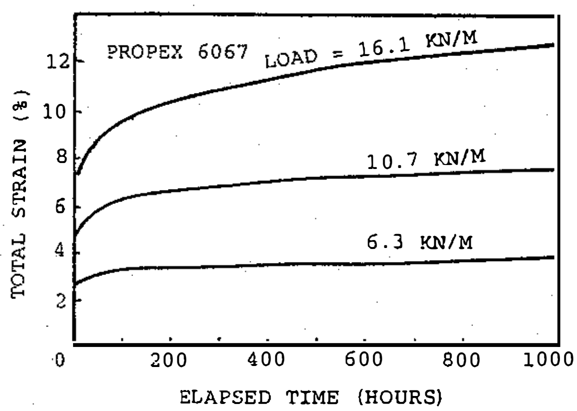

Figure 4 Axial strain versus log-of-time relationship for Propex 6067 (after Kabir, 1988)

An extension of the multiple integral representation discussed above to account for the temperature effect has been described by Findley, et al (1976). Although the most general equation described is capable of accounting for various loading and temperature conditions in principle, the experimental difficulty of characterizing the kernel functions may prevent it from being useful in practice.

It has been found (Morgan and Ward, 1971) that the creep curves for a given stress at different temperatures could be superposed by a simple horizontal shift. Andrawes et al (1986) suggested that time-temperature superposition techniques could be used to improve the confidence in long-term strength predictions. These superposition techniques have been applied by Bush (1990) to the data shown in Figure 1 by time shifting the three temperatures, as shown in Figure 2. Data from the higher temperature tests has been used to accelerate the tests at the lower temperatures, without altering the geogrid behavior.

2.2 Numerical Solution of Kernel Functions

In this study, a numerical method was used to solve equations (2). The measured creep strains ϵ_a, ϵ_b and ϵ_c at the end of each time increment were introduced successively into equations (2) and the kernel functions F_1, F_2, and F_3 at the end of each time increment were evaluated by solving equations (2) simultaneously. A natural cubic spline function was then established for each kernel function. Creep strains under a specified load (P) were then calculated by using equation (1). Obviously; three creep curves under three different sustained loads are needed to evaluate the kernel functions. Therefore, these three creep curves are the "input" required for this model.

The time-temperature superposition principle cited above was utilized in this study to simulate the temperature effect on the behavior of polymers by stretching (or shrinking) the real time for temperature above (or below) the reference temperature. In other words, the behavior of polymers at a high temperature and a high strain rate is assumed to be similar to that at a low temperature and a low strain rate. Materials exhibiting this behavior are called "thermorheologically simple" (Findley, et al, 1976). Thus, determination of the temperature shift factor α_T as a function of temperature will provide the necessary information for determination of the reduced time.

3. EVALUATION OF PROPOSED TECHNIQUE

The generalized stress-strain-time-temperature model for polymers described above is capable of predicting the creep behavior of nonlinear viscoelastic materials in its most general case. This includes primary, secondary, and/or tertiary creep under any specified stress level taking into consideration the effect of temperature changes.

Figure 3 illustrates qualitatively the perfor-

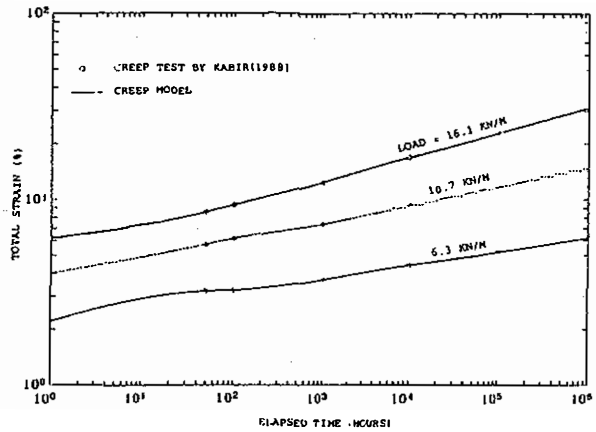

Figure 5 Comparison of creep model performance and creep test results on Propex 6067--logarithmic scale

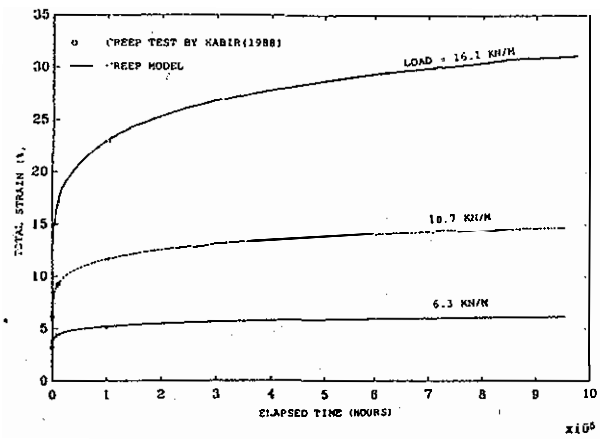

Figure 6 Comparison of creep model performance and creep test results on Propex 6067--arithmetic scale

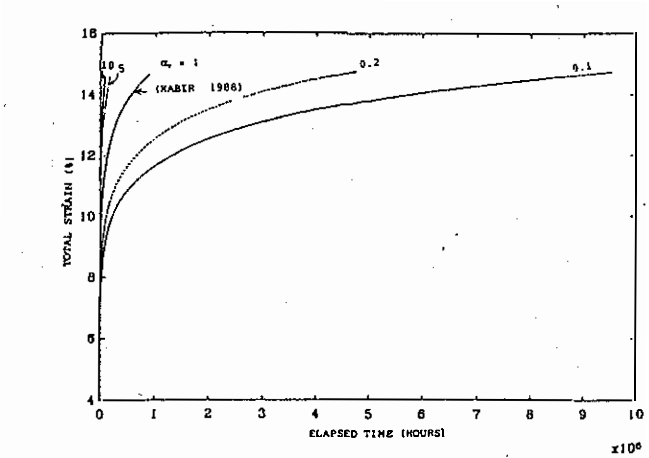

Figure 7 Time shifts due to temperature changes--arithmetic scale

mance of the generalized stress-strain-time-temperature model. Six isothermal creep curves under six different axial loads are plotted as ϵ(strain) vs. t(time). The ability of the model to describe tertiary creep is clear at higher axial loads (40, 50 and 60 KN). At lower axial loads (10, 20, and 30 KN) no tertiary creep is observed.

The model requires experimental data of three isothermal creep tests under three different axial loads covering the load range of interest. It is recommended in the design of geosynthetic-reinforced-earth structures to avoid high axial loads which may cause tertiary creep in the geosynthetic reinforcement. Nevertheless, if high axial loads are expected, the model requires experimental data of three isothermal creep tests (with tertiary creep) under three different axial loads higher than the critical load which causes tertiary creep.

To evaluate the model performance, experimental creep results on Propex 6607 given by Kabir (1988) were used. Propex 6607 is a composite (woven and needle punched), 100% polypropylene geotextile with a unit weight of 650 gsm. Creep test results on Propex 6607 under three different axial loads are shown in Figure 4. For purposes of extrapolation, Figure 4 was reproduced on a log-log scale as depicted by the data points in Figure 5.

The generalized stress-strain-time-temperature model was then used to simulate the experimental creep test results. An excellent simulation of the experimental curves is noted in Figures 5 and 6.

The authors believe that the model is capable of describing the most general case of creep as shown in Figure 3. Unfortunately, experimental data of creep tests with tertiary creep are not available to the authors at this time to verify this assertion.

The performance of this creep model at different temperatures is qualitatively shown in Figures 7 and 8 for shift factors of 0.1, 0.2, 1, 5, and 10. The shift factor of 1 corresponds to the creep test at reference temperature and 10.7 KN/m axial load as given in Figure 4.

Laboratory creep tests on geotextiles at different temperatures are being conducted at the

University of Colorado at Denver. The results of these tests will be used to verify the performance of the creep model at different temperatures.

To further evaluate the performance of the creep model, the model was used to simulate the experimental creep data of Typar 3301 geotextile. Figure 9 illustrates the experimental data simulation by the use of the creep model.

It is of a great importance to evaluate the performance of the creep model under different load history such as simple axial tension. If the stress-strain-strain-rate relationship is unique for a particular material, then the proposed generalized creep model should be able to predict the performance of this material when subjected to a different load history such as simple axial tension under different strain rates. To accomplish this, the generalized creep model was incorporated into a finite element program with a time-marching scheme. The finite element program was then used to predict the performance of the geotextile in simple axial tension under two different strain rates, 2% and 0.2% per minute. The prediction is compared with the experimental data under the same strain rates as shown in Figure 10. The comparison is quite satisfactory, which further assert the validity of the generalized creep model.

More simple axial tension experiments for different geosynthetics under different strain rates are being conducted at the University of Colorado at Denver by the authors to prove the uniqueness of the stress-strain-strain-rate relationship of each geosynthetic material. The uniqueness of this relationship will make it possible to extract creep curves from simple axial tension curves of the same material under different strain rates.

4. CONCLUSIONS

From the findings of this study, the following conclusions may be drawn:

(1) The method of data analysis derived from the multiple integral representation of viscoelastic material behavior is a versatile technique which proved suitable for different types of creep, namely; creep with or without tertiary stage.

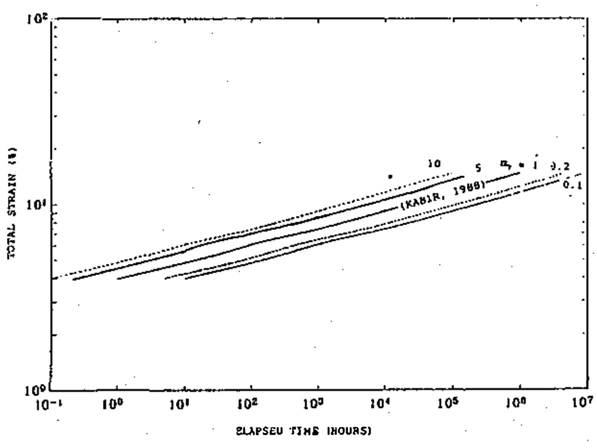

Figure 8 Time shifts due to temperature changes--logarithmic scale

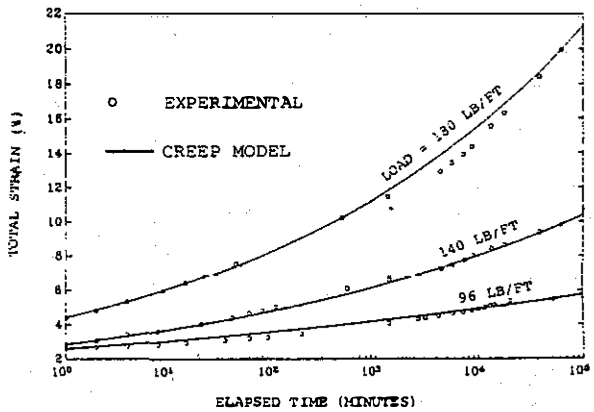

Figure 9 Comparison of creep model performance and creep tests results on Typar 3301

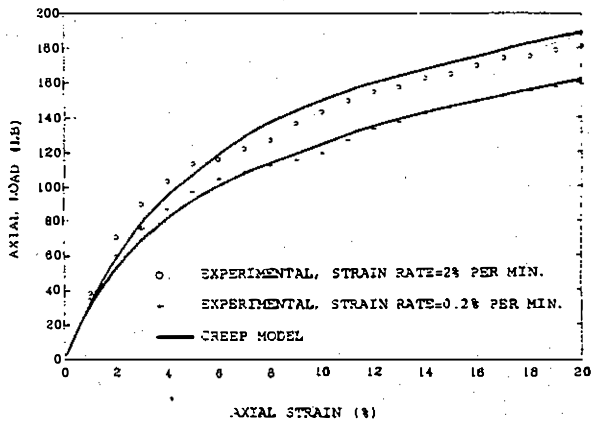

Figure 10 Comparison of Creep model performance and experimental results on Typar 3301 in simple axial tension under different strain rates

(2) The successive time increment technique to evaluate the kernel functions is versatile and suitable for different types of creep. Furthermore, the use of the natural cubic spline function to describe the time dependency of the strains and kernel functions is very satisfactory, providing an excellent prediction of creep under different axial loads.

(3) The generalized creep model is capable of predicting the behavior of a heat-bonded, nonwoven geotextile in simple axial tension under different strain rates.

REFERENCES

Andrawes, K.Z. McGown, A., and Murray, R.T., 1986 "The Load-Strain-Time-Temperature Behavior Of Geotextiles And Geogrids" Proc. 3rd Int. Conf. on Geotextiles, Vienna, Volume 3:pp 707-712.

Bernard D. Coleman and Andrew G. Knox (1957), "The Interpretation of Creep Failure In Textile Fibers Of A Rate Process"

Bush, D.I., 1990 "Variation Of Long Term Design Strengths Of Geosynthetics in Temperatures Up To 40°C" Geotextiles, Geomembranes and Related Products, Den Hoedt, Balkema, Rotterdam

Findley, Lai, and Onaran (1976) "The Engineering Application Of The Absolute Rate Theory To Plastics: I-Laminates," Bulletin of the University of Utah, Volume 42, Number 6, pp 1-147

Kabir, M.H. (1988), "Creep Behavior of Geotextiles," Int. Geotech Sym. on Theory and Practice of Earth Reinforcement/Fukuoka Japan/ 5-7 October 1988

Kumar, S. and Gupta V.B., (1977), "A Model For Nonlinear Creep Of Textile Fibers."

Kumar, S. and G. Bupta, V.B. (1978), "A Nonlinear Viscoelastic Model for Textile Fibers."

Morgan, C.J. and Ward, I.M. (1971) "The Temperature Dependence of Non-Linear Creep and Recovery in Oriented Polypropylene." J. Mech. Phys. Solids, 1971, Vol. 19, pp 165-198. Fergamon Press, Great Britain

Shrestha, S.C. and Bell, J.R. (1982), "Creep Behavior of Geotextiles Under Sustained Loads." Proc. of Sec. Int. Conf. on Geotextiles, Las Vegas, USA, 3:769-774

Singh, A. and Mitchell, J.K. (1968), "Creep Potential And Creep Rupture Of Soils."

Yamaoka, I. and Nishigata, T. (1986), "Creep Characteristics of Geotextiles." The second Soil Engineering Research Conference, Sapporo, Japan. (in Japanese)