Creep behaviour of geotextiles

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ABSTRACT: A generalised nonlinear constitutive relation for creep behaviour of geotextiles is presented in this paper. Suitable testing technique, methods of data analysis and their presentation are suggested. The method of data presentation is based on isochronous load-strain curves and creep isochronous stiffness. Creep behaviour of four generic types of geotextiles is presented and practical significance of the work is discussed.

1 INTRODUCTION

Like all other polymeric materials geotextiles generally exhibit elasto-viscoplastic behaviour. Therefore, where performance data for geotextiles and related products are to be employed in Fundamental Analytical Designs (McGown and Kabir 1983) of permanent reinforced soil systems, creep test data should be used. For this, the development of suitable testing techniques, methods of data analysis and data presentation is of paramount importance. A rapid loading creep test methodology was developed for this purpose. The testing techniques developed are categorized into two main groups; in-isolation and in-soil tests. In-isolation test data may be used to obtain design parameters for those materials which are unaffected by in-soil confinement. However, in-soil tests should be used for obtaining design parameters for those materials whose properties are significantly altered when confined in-soil. The scope of this paper is limited to in-isolation creep behaviour of geotextiles only.

In terms of data analysis, two types of visco-elastic material behaviour, linear and nonlinear visco-elasticity have been taken into account. Many polymeric materials and so geotextiles, behave linearly at low levels of strain but become nonlinear at higher levels, hence the need for a generalised method of data analysis was recognised. A suitable method has been developed which is based on the multiple integral representation as described by Onaran and Findley (1965).

The suggested method of data presentation is based on isochronous load-strain curves and creep isochronous stiffness. To illustrate the load-strain-time behaviour using this technique, data analysis for four basic types of geotextiles are presented. These include a melt bonded non-woven (Terram), a needle-punched non-woven(Bidim), a woven (Lotrak) and a composite geotextile (Propex). Identity and properties of these geotextiles are presented later in Table 1. Finally, practical significance of the work undertaken is briefly discussed.

2 CREEP CHARACTERISTICS OF GEOTEXTILES

2.1 Background research

Little has so far been reported on creep behaviour of geotextiles. As geotextiles are generally made from polymers they are expected to demonstrate behaviour comparable to these when loaded over long periods of time.

Some of the empirical laws proposed to represent the creep behaviour of geotextiles may be described as follows:

$$\varepsilon = \varepsilon_o + A \log t \qquad (1)$$

where ε = total strain, ε_o and A are functions of stress, temperature and nature of material. Finnigan (1977), Van Leeuween (1977), Raumann (1981) reported use of this law for representation of short term creep with limited success.

Paute and Segouin (1977) used the three element rheological model, comprising a spring and a Kelvin model in series to portrary creep behaviour of geotextiles. However, they have presented test data only upto 8 hours duration.

Shrestha and Bell (1982) used the four element Berger model to portrary creep behaviour of geotextiles. They also used the so called "three parameter" equation and found that the rheological model offered a better fit to experimental data.

The main shortcommings of these investigations are that data from short duration tests (often only of several hours) were used. Moreover, these studies failed to present a generalised load-strain-time behaviour of geotextiles.

2.2 Developlment of generalized stress-strain-time behaviour.

It was observed by a number of researchers including Findley and Peterson (1958) that an empirical power function of time could be used to describe the creep of many polymers with reasonable accuracy over a wide span of time, and may be presented as

$$\varepsilon = \varepsilon_o + \varepsilon_t . t^n \qquad (2)$$

where ε_o and ε_t are functions of stress and n is independent of stress and function of material only. Lai and Findley (1973) found n to be nearly independent of temperature and generally less than 1.0.

To compare the suitability of different time functions, (not stress functions), Findley and Peterson, presented the predictions from different equations with results of long time creep of plastic laminates. The data for the first 2000 hours were represented as well as possible by all the equations, then the tests were continued for about 10 years. It was observed by Findley and Peterson and confirmed later by Findley and Tracy (1974) that equation (2) gave a much more satisfactory prediction compared to those by other equations. This is due in part to the fact that creep of plastics, concrete and some metals under moderate stresses starts at a very rapid rate immediately after loading and progresses at a continuously decreasing rate. These are characteristics of equation (2).

Onaran and Findley represented creep of nonlinear visco-elastic materials as a series of multiple integrals. For uniaxial creep, the following expression results:

$$\varepsilon = R(t)P + M(t)P^2 + N(t)P^3 \qquad (3)$$

The Kernel functions R,M,N for constant loading for geotextiles and polymers are expected to take the following form:

$$R(t) = \mu_1 + \omega_1 t^n \qquad (4)$$

$$M(t) = \mu_2 + \omega_2 t^n \qquad (5)$$

$$N(t) = \mu_3 + \omega_3 t^n \qquad (6)$$

where μ's and ω's are material functions and are dependent on temperature (T) and n is a function of material and may or may not be a function of temperature.

Substituting values of R,M and N from equations (4), (5) and (6) in equation (3), the following equation is obtained for constant temperature situation.

$$\varepsilon(t,p) = \varepsilon_o(p) + \varepsilon_t(p).t^n \qquad (7)$$

where $\varepsilon_o = \mu_1.p + \mu_2.p^2 + \mu_3.p^3 \qquad (8)$

and $\varepsilon_t = \omega_1.p + \omega_2.p^2 + \omega_3.p^3 \qquad (9)$

In the case of linear visco-elasticity the coefficients of second and third terms become equal to zero.

The constant μ's, ω's, and n are obtained by curve fitting the results of creep tests for at least three different loads, as described in subsequent sections.

3 TESTING TECHNIQUES

Test apparatuses and procedures developed to study the in-isolation creep behaviour of geotextiles, are described in the following sections.

3.1 Test apparatuses

Test specimens were selected and prepared in much the same way as described by Andrawes, McGown and Kabir (1984). Test set-ups each comprising a basic rig and a loading system, consisting either a direct loading or a lever loading device were designed and constructed to conduct one step, rapid-loading tests. A programmeable data logger capable of logging 100 channels per second, at a minimum logging interval of 0.2 second was used. This system was intended to measure and record loads and displacements under a very rapid loading situation. A schematic diagram of a test set-up developed for in-isolation testing is shown in Figure 1.

3.2 Test procedure

One step loading test using several different loads within the relevant operational range, was used to establish the load-strain-time relationship of the materials. The temperature of these tests was maintained at all times at 20° ± 1°C and the relative humidity at 65 ± 2 percent.

The loads were applied as smoothly as possible and sustained for at least 1000 hours. During the initial part of the tests the loads applied and the resulting extentions of the test specimens were both monitored electronically. The load was measured using a load cell and the extension by the two L.V.D.T.s one on either side of the test specimen (Figure 1). After the rapidly varying initial part of the test, the deformations were measured using mechanical dial gauges.

4 DATA ANALYSES

To obtain the load-strain-time behaviour of geotextiles and to determine the load and time parameters mentioned in equations (7), (8) and (9) which constitute a maximum of seven parameters (for a three degree nonlinearity), the following steps are recommended.

1. Rewrite equation (7) in the form:

$$\log (\varepsilon - \varepsilon_o) = \log \varepsilon_t + n.\log t \qquad (10)$$

and plot log ε vs. log t, using the equivalent zero time (t_o=0), where 2t_o is the time required for the ramped loading. Qualitative

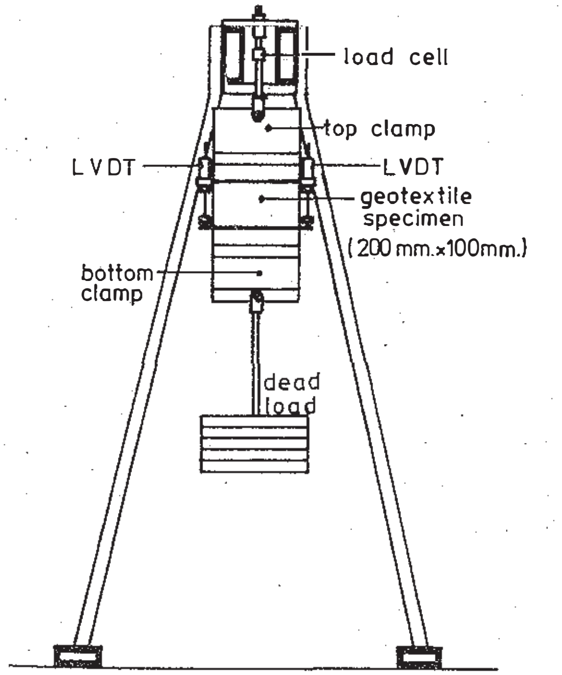

Fig. 1 The creep test rig

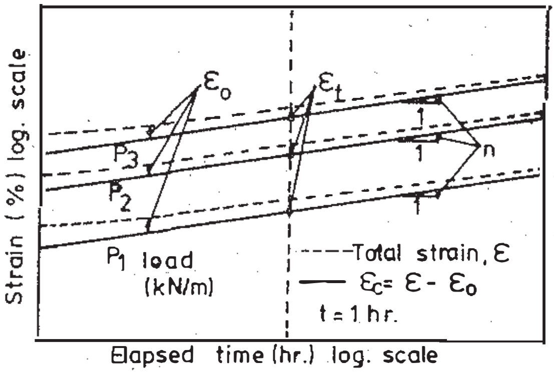

Fig. 2 Curve fitting for creep parameters

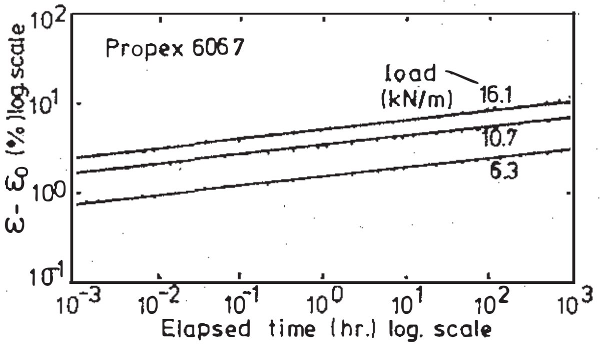

Fig. 3 Curve fitting for Propex

plots for different loadings (P) are shown by dotted lines in Figure 2. If for example it is assumed that ε_o = 0 in equation (10) then the plot will yield a straight line. However, this is not the case for most polymers and geotextiles. When a selected value of ε_o is subtracted from ε and the resulting reduced data ($\varepsilon - \varepsilon_o$) is again plotted against time, the lower set of curves result which are shown in Figure 2 as sharp lines. These ε_o values are not necessarily the equivalent of instantaneous strains, being only the values of strain required to make the straight lines fit the test data. The relevent plots for the composite geotextile Propex are presented in Figure 3.

2. The parameter n (equation (7)) is the common slope of the three sharp lines in Figure 2.

3. The three values of ε_o are then plotted against load and polynomials upto three degrees are fitted to obtain the parameters μ_1, μ_2 and μ_3 (equation (8)).

4. The three values ε_t (($\varepsilon - \varepsilon_o$) values at t = 1 hour) from Figure 2 are plotted against load P and polynomials upto three degrees are fitted to obtain the parameters ω_1, ω_2 and ω_3 (equation (9)).

The plots described in items 3 and 4 above appropriate for the geotextile Propex is presented in Figure 4. The value of n is also shown on this figure.

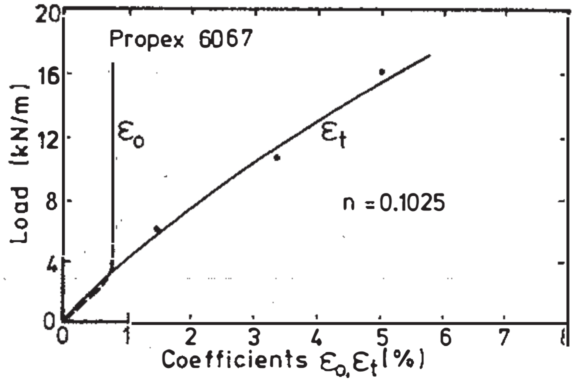

Fig. 4 Creep parameters of Propex

5 TEST RESULTS

5.1 Presentation of creep properties

It is suggested that the data obtained from the foregoing analyses should be presented in the form of three plots described as follows:

PLOT (A): This is a plot of total strain (ε) vs. time (t) for 1000 hours or more.

PLOT (B): After calculation, the isochronous load-strain relations may be plotted. Using equation (7), the data may be extrapolated up to 10^6 hours.

PLOT (C): From the isochronous load-strain plot, secant slopes at appropriate strain levels may be computed for different times. These values of secant slopes known as the Creep Isochronous Stiffnesses (I_{sc}), may be plotted against time (to a log scale) up to 10^6 hours.

Typical equivalents of Plots (A), (B), and (C) for the composite geotextile Propex are presented in Figures 5,6 and 7 respectively.

5.2 Typical results

To illustrate the applicability of the method of data analyses, the load-strain-time behaviour of the four types of geotextiles are presented here. In all cases two creep tests were performed for each load level and the average was reported.

The results of creep parameters (μ, ω and n in Figure 4), the isochronous load-strain diagrams (Figure 6) and the diagrams showing variation of Creep Isochronous Stiffness, I_{sc} (at 5 and 10 percent strain levels) with time for the composite geotextile Propex were presented earlier. The relevant plots for the other three geotextiles, Terram, Bidim and Lotrak are presented in Figures 8,9 and 10. The values of n and the expressions for ε_o and ε_t obtained for all the four geotextiles are also presented in Table 1.

The agreement between test data and results from the mathematical model, in case of all the four geotextiles possessing different structural and mechanical behaviour, may be termed as very satisfactory. This depict the versatility of the mathematical model to portrary the load-strain-time behaviour of these geotextiles.

6 DISCUSSION AND CONCLUSIONS

In Fundamental Analytical Designs of geotextile reinforced soil systems, data from

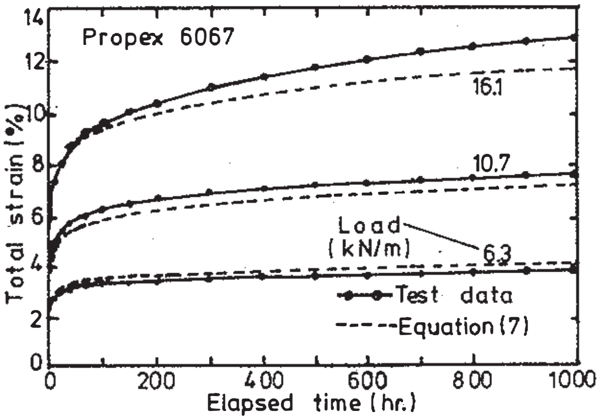

Fig. 5 ε-log t plot for Propex

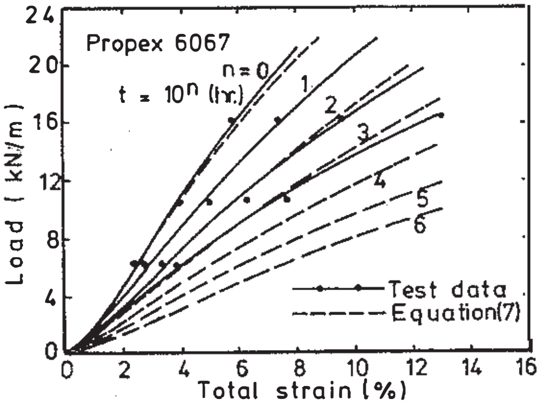

Fig. 6 Isochronous load-strain plots for Propex

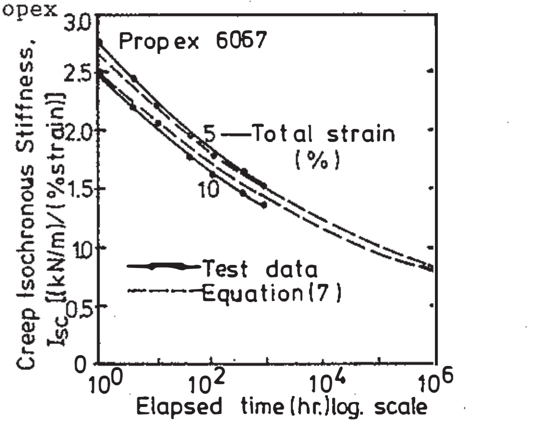

Fig. 7 Creep isochronous stiffness for Prope

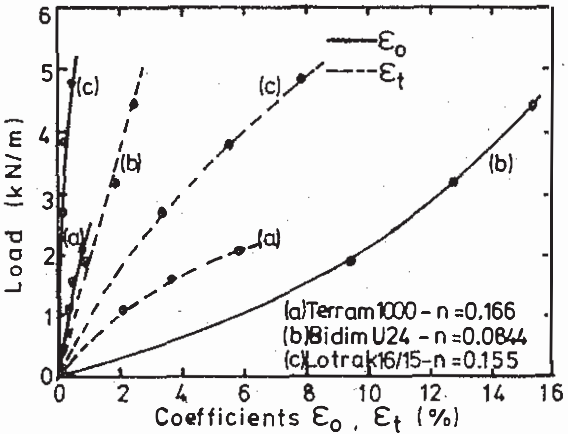

Fig. 8 Creep parameters of three geotextile

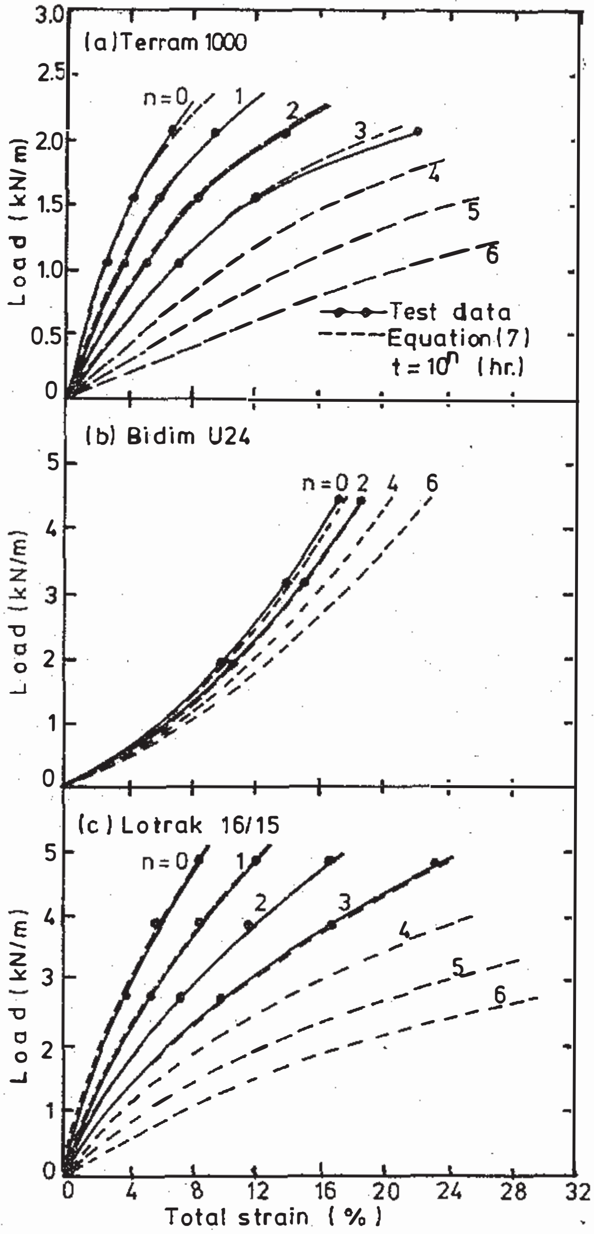

Fig. 9 Isochronous load-strain plots for three geotextiles

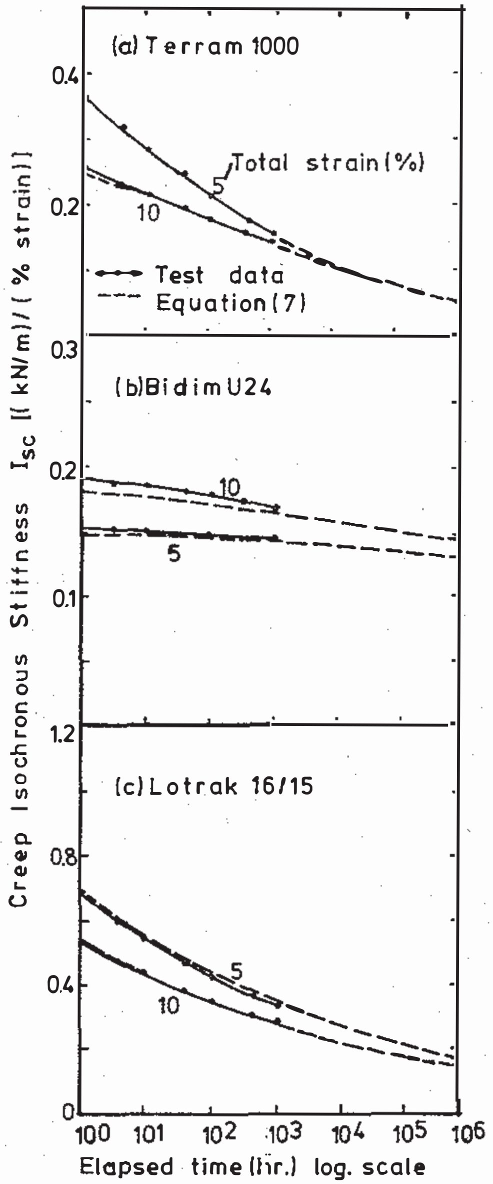

Fig. 10 Creep isochronous stiffnesses for three geotextiles

load-strain-time behaviour (using creep isochronous stiffness) of geotextiles must be used to evaluate the long term safety margins of the constituent soil and reinforcement. A soil which may have adequate safety margin under short term loading may loose that due to shedding of load by the reinforcement, undergoing long term deformation and vice versa. Therefore, an elaborate design should take into account the exact sharing of the load between soil and the reinforcement, throughout the design life of the structure. Apart from stability considerations, use of creep parameters is of vital importance in calculating deformations. Excessive deformations may impair the serviceability condition of the reinforced soil

Table 1. Identity and creep properties of geotextiles

Characteristics / Geotextile	Method of constr.	Polymer compos.	Unit wt. (gsm)	Creep parameters		
				n	ε_o	ε_t
Terram 1000	Non-woven melt-bonded	*PP 67% PE 33%	140	0.166	$0.407P-0.218P^2 + 0.087P^3$	$2.296P-0.894P^2 + 0.553P^3$
Bidim U24	Non-woven	PES 100%	210	0.0844	$7.084P-1.373P^2 + 0.125P^3$	$0.527P$
Lotrak 16/15	Woven tapes	PP 100%	120	0.155	$0.046P-0.0118P^2 + 0.004P^3$	$0.436P+0.346P^2 - 0.0215P^3$
Propex 6067	Composite wov+needl	PP 100%	650	0.1025	0.8 for $P > 0$	$0.2079P+0.0103P^2 - 0.000161P^3$

*PP-Polypropylene, PE-Polyethylene, PES-Polyester.

structure itself or any structure supported by it.

On the basis of the work presented here, the following conclusions may be drawn.

1. The method of data analysis synthesised from the multiple integral representation of visco-elastic meterial behaviour was found to be a versatile technique which proved suitable for the four different types of geotextile tested.
2. The curve fitting technique to obtain the time dependent and load dependent parameters was also found to be versatile and suitable for the four types of geotextile.
3. The power function law of time dependency with the polynomial form of load dependency, were found to portray linear and nonlinear visco-elastic behaviour of geotextiles with reasonable accuracy.
4. The use of stiffness values from short term tests may be misleading, often unsafe, in the selection of geotextiles for long term use under load.
5. The creep isochronous stiffness (I_{sc}) should be used in design to obtain safe and allowable loads as well as limiting deformations in geotextiles used for reinforcement.

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