Creep behavior of geosynthetics using confined-accelerated tests

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ABSTRACT: Creep behavior is an essential parameter in geotechnical structures designed with geosynthetics. Conventional creep tests comprise the measurement of specimen elongation as function of time, after the application of a constant tensile load. Besides, temperature and humidity are kept constant during these tests and the specimens are in-isolation. Due to test time length up to 10,000 h, the determination of creep behavior is time-consuming and expensive. Additionally, these tests may not reproduce field condition, since specimens are not under confining stresses. Time-consuming characteristic may be overcome by conducting accelerated tests at elevated temperature. Field behavior may be reliably approached by performing soil confined creep tests. The purpose of this study is to determine creep behavior of geosynthetics by means of both confined and accelerated creep tests. A new testing machine was developed in order to perform confined-accelerated creep tests on different geosynthetics. Preliminary tests have been performed with the new equipment, which consists of a central box filled with two layers of sand and a load application system on both sides of the machine. During the filling of the test box, geosynthetics specimens were placed between the two layers of sand. After load application, specimen elongation was measured by tell tails and LVDT's. Conventional creep tests were also performed for comparison. Preliminary results show a considerable reduction in both initial and creep strain due to soil confinement. Moreover, one confined-accelerated creep test allowed the plot of a longer master curve, up to 10^6 h.

1 INTRDUCTION

Geosynthetic reinforced soil (GRS) structures are one of the examples where creep characterization of geosynthetics is extremely important. Their design commonly considers reduction factors that decrease geosynthetic tensile strength at its design life. One of those reduction factors is due to creep of the geosynthetic during its service lifetime. The definition of the creep reduction factor is made by means of laboratory tests.

Creep behavior of geosynthetics is commonly determined by in-isolation tests, which are conducted at standard values of temperature and relative humidity. Furthermore, the main standards for geosynthetic creep tests recommend test time length up to 10,000 hours (ASTM D 5262). Consequently, the determination of creep behavior of geosynthetics is time-consuming and expensive. Equally important is that these tests do not reproduce field conditions, since specimens are not under confined stresses. Therefore, conventional creep tests may result in conservative reduction factors, which increase construction costs.

In order to overcome those drawbacks, many studies have suggested different approaches to define geosynthetics creep behavior. With the purpose of reducing test time length, one may accelerate geosynthetic creep by means of tests conducted at elevated temperatures, since creep behavior is highly dependent on this parameter. In addition, the test may be performed under soil confinement, in order to consider soil-geosynthetic interaction, as shown in the pioneer study conducted by McGown at al (1982).

As cited above, the purpose of conducting creep tests at elevated temperature is that one can use this data from an elevated temperature in order to calculate geosynthetic strains at higher values of overlapped time at a reference temperature. This calculation is done by means of time-temperature superposition techniques (TTS), which consists basically in the shifting curves obtained at higher temperature in order to follow the curve obtained at a reference temperature. One of those procedures for shifting data obtained at elevated temperature to a reference temperature was developed by Williams, Landel and Ferry (Ferry 1980) and introduced a time shift factor, a_T, to relate strains at different temperatures (Zornberg et al. 2004). Two constants are considered in this approach, *C1* and *C2*, as one can see in the equation

$$\text{Log } a_T = \frac{-C1\,(T-T_0)}{C2+T-T_0}$$

Where a_T = shift factor,
T_0 = reference temperature,
T = elevated temperature,
C1 and *C2* = empirical constants.

The empirical constants *C1* and *C2* are a function of the polymer type and the reference temperature. However, *C1* and *C2* may assume typical values of 17.4°C and 51.6°C, respectively (Ferry 1980).

This procedure is repeated for several elevated temperatures and results in a longer master curve. ASTM D 5262-07 recommends that creep data should not be extrapolated beyond one order of magnitude. Though, TTS methods allow the designer to be more precise in extrapolation of creep data, since the longer master curve can be used in design. Further information about TTS can be found in Bueno et al. (2005) and Zornberg et al. (2004).

Both measures – confinement and heating – are quite simple when they are considered by themselves. On the other hand, no attempt of using those procedures at the same time, and in the same test, was found in literature. Concerning this, the aim of this paper is to present preliminary results obtained from confined-accelerated creep tests, which were performed with a polyester non-woven geotextile. A new testing machine was developed to conduct such tests in the Laboratory of Geosynthetics of University of São Paulo, at São Carlos.

2 MATERIALS AND METHODS

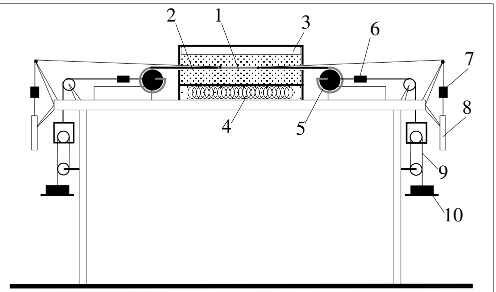
The preliminary tests presented in this paper were performed with one polyester non-woven geotextile. Its mass per unit area (ASTM D 5261) and thickness (ASTM D 5199) are equal to 313 g/m² and 2.59 mm, respectively. Tensile properties of the geotextile used in this research were measured by ASTM D 4595 and are presented Table 1.

Table 1 – Tensile properties of the geotextile used in the tests

	Machine direction	Cross-machine direction
Ultimate tensile strength (kN/m)	7.65	17.24
Strain at break (%)	123.60	90.85

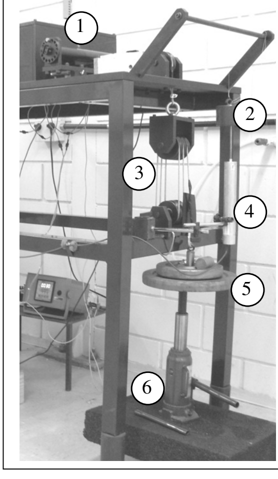
Confined-accelerated creep tests were performed with this geotextile using a new testing machine. Figure 1 schematically presents a view of the equipment, which consists basically of a central metal box filled with sand, in which is placed the geosynthetic specimen. The specimen is clamped outside the box with roller grips and loaded from both sides by means of dead weights. Additionally, a pulley system was used in order to multiply the applied weight. As a result, the tensile load is multiplied by a factor equal to 6.

A pair of load cells was used in order to determine the tensile load on both sides of the specimen precisely. In addition, readings from tell tales installed on the specimen allowed the calculation of geotextile strains during each test. Figure 2 presents a side view of the equipment, just before tensile load application.



1 = Geotextile specimen
2 = Hardened and lubricated portion of the specimen
3 = Pressurized air bag
4 = Heating system
5 = Roller grip
6 = Load cell
7 = Tell tale
8 = LVDT
9 = Pulley system
10 = Dead weights

Figure 1. Layout of the machine developed in this research.



1 = Roller grip
2 = Tell tale weight
3 = Pulley system
4 = LVDT
5 = Dead weight
6 = Hydraulic jack

Figure 2. Lateral view of the machine developed in this research.

The heating system comprises a set of electric resistances and a thermocouple (TC-1). This thermocouple allowed the programming of any heating path. Another thermocouple (TC-2) was placed 20 mm above the geotextile specimen. Specimen temperature were considered equal to the one obtained by TC-2.

Confinement was simulated by means of a pressurized air bag placed over the sand. The pressure inside this bag was kept constant during the whole test. In order to reduce geosynthetic strains outside the test box and soil-specimen friction, the two outermost portions of the geotextile was hardened and lubricated. This procedure prescribed 100 mm of free geotextile length between both hardened portions.

Geotextile strains inside the test box were calculated by means of tell tales readings. The tell tales were tied and glued on the specimen. The distance between both fixation points on the geotextile was measured after each specimen preparation in order to provide its initial length.

The first step of each confined-accelerated creep test presented in this paper is the filling of the test box with sand (D_r = 45%). The geotextile was located between two layers of sand and clamped at each roller grip. Afterwards, the pressurized air bag was placed over the second layer of sand. Both confined tests were performed under an overburden load equal to 40 kPa. The second step consisted in elevating the geotextile temperature by means of the heating system. Temperature near the specimen increased smoothly and reached a constant value during the accelerated test. The last step of each test is the tensile load application. It was performed by means of releasing the dead weights smoothly with a hydraulic jack, which allows a slowly load application.

Two tests were performed with this new equipment, both at 20% of short-term geotextile ultimate tensile strength (UTS) in cross-machine direction, according to data obtained from wide-width tensile tests (ASTM D 4595). These tests were conducted at different temperatures (22°C and 49°C), with the purpose of representing room and elevated temperatures, respectively. In addition, one conventional creep test (ASTM D 5262) was conducted with the same load level in order to assess the influence of the confinement soil during geosynthetic creep. All creep tests were conducted up to 100 h.

3 RESULTS AND DISCUSSION

The results of the creep tests conducted in this research are presented in Figure 3. In conventional creep test, initial strain (t = 1 min) as result of the tensile loading reached 33.3%. Afterwards, the geotextile underwent creep strains, which slightly increased the initial strain up to 35.3% after 100 h. This low level of creep strains is very common due to the low tensile load level (20%). Additionally, one can notice that creep strains increased at a constant rate.

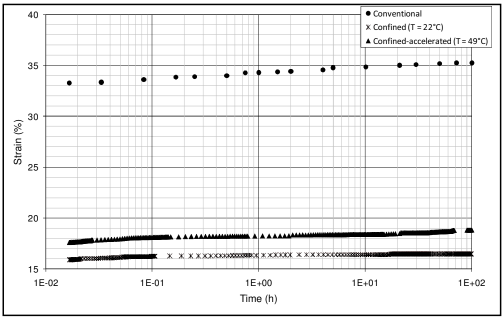


Figure 3. Conventional creep test result at 20% of the geotextile ultimate tensile strength in cross-machine direction.

The first test with the new equipment was conducted at room temperature (22°C). Initial strain was 15.9%, which is considerably smaller than the one found in conventional creep test. This reduction was equal to 52.2% and is due to soil confinement, since it restricts the movements of geotextile filaments. Additionally, soil confinement reduced creep strain in 71.5%, as one can see in Figure 3. Creep strain in conventional creep test was equal to 2.0%, while its value in confined creep test was about 0.57%.

The second test with the new testing machine was conducted at an elevated temperature (49°C). Concerning both confined tests, this one presented the highest value of initial strain (17.6%). Furthermore, it also presented a higher value of creep strain (1.3%). This behavior was expected since temperature increases the creep rate and strains.

The whole set of creep curves were adjusted to logarithmic functions, in which parameter a corresponds to creep strain after one hour and parameter b indicates the rate of creep strain. The function used to adjust creep data relates creep strain, ε, to the overlapped time, t, and can be represented by

$$\varepsilon = a + b \cdot \ln(t)$$

Table 2 shows parameters a and b obtained from each test conducted in this research. As expected, conventional creep tests provided the highest value of parameter b, which indicates its high creep strain rate. In addition, evaluation of parameter a and b of each test clearly indicates the influence of soil confinement on creep strains. Unsurprisingly, both parameters a and b obtained at elevated temperature are greater than those at reference temperature.

Table 2 – Adjustment parameters obtained from in each test

Creep test type	Parameter *a*	Parameter *b*
Conventional	34,24	0,242
Confined	16,29	0,055
Confined-accelerated	18,21	0,106

Despite the lack of data, the TTS technique was used in this research in order to provide a longer master curve. As mentioned above, there are typical values of constants *C1* and *C2*. However, Constanzi et al. (2003) shows that those constants assume different values for a PET geotextile similar to the one used in this research. It is suggested that *C1* and *C2* are equal to 21°C and 100°C, respectively. Thus, these values were considered in this research in order to define the shift factor for the data presented above and produce a master curve. The resulting shift factor is equal to 5.43 x 10^{-5} (Log a_T = - 4.464). Figure 4 presents the master curve obtained by the combination of both confined creep tests performed in the new equipment – at room and elevated temperatures. It is also noticeable that the master curve was plotted up to 2,900,000h, which corresponds to 330 years, approximately. Nonetheless, another confined-accelerated test is necessary to complete the gap between the two portions of master curve.

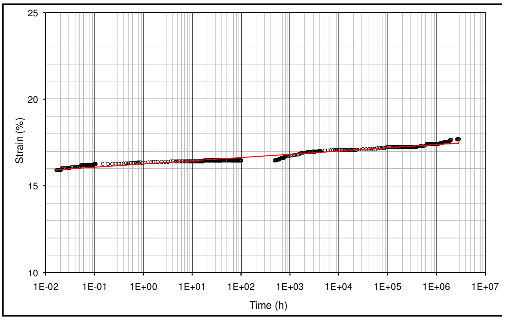


Figure 4. Creep master curve obtained from confined-accelerated creep test at 20% of the geotextile ultimate tensile strength in cross-machine direction.

The creep master curve may be used to predict creep behavior of the geotextile. However, the designer must be aware of using accelerated creep tests to define creep behavior of geosynthetics, since these methods may not be appropriate for high levels of loading (Farrag 1998). Accelerated creep tests conducted at such high load levels may not reproduce the specimen failure noticed in conventional creep tests.

4 CONCLUSION

This paper presented preliminary results of confined-accelerated creep tests on polyester non-woven geotextile. These tests were performed with the new equipment developed in the Laboratory of Geosynthetics of the University of São Paulo, at São Carlos. The following conclusions are drawn from the present study:

- Confined creep tests considerably reduced initial and creep strain of the geotextile. This behavior was predictable, since soil-specimen interaction restricts the movements of the geotextile filaments.
- Confined-accelerated creep test allowed the plot of a longer master curve, which helps the designer to perform the extrapolation to a higher value of elapsed time. However, high load levels need more attention from the designer, since the master curve may not be reliable.
- Further tests are necessary to confirm those preliminary results. Moreover, direct shear tests will be performed in order to measure geotextile-sand shear strength. This procedure will allow the precise calculation of the tensile load applied to the free length of the geotextile.

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