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New equipment to conduct confined-accelerated creep tests on geosynthetics

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ABSTRACT

Creep behavior of geosynthetics is commonly quantified by standard tests conducted using in-isolation specimens. These tests are time-consuming and may not consider the effect of soil confinement. Both concerns have been addressed in the technical literature, but only independently. This paper presents a new device to perform simultaneously confined and accelerated creep tests on geosynthetics. The results of creep tests conducted using both a nonwoven and a woven geotextiles are presented. As expected, creep strains were found to be dependent on the test temperature in both in-isolation and in-soil conditions. On the other hand, the creep behavior of only the nonwoven geotextile was found to be sensitive to soil confinement. Soil confinement was found to have an insignificant effect on the woven geotextile creep response.

PRESENTACIONES TÉCNICAS

El comportamiento de fluencia de geosintéticos es comúnmente cuantificado por las pruebas estándar realizadas con muestras en forma aislada. Estas pruebas requieren mucho tiempo y no se puede considerar el efecto de confinamiento del suelo. Ambos aspectos han sido abordados en la literatura técnica, pero sólo de forma independiente. En este estudio se presenta un nuevo dispositivo para realizar ensayos simultáneamente confinados y acelerados de fluencia en geosintéticos. Los ensayos de fluencia fueron realizados con un geotextil no tejido y un geotextil tejido. Como era de esperar, las deformaciones por fluencia son dependientes de la temperatura de ensayo, tanto en la condicione de aislamiento y en la condicione en el suelo. Por otro lado, el comportamiento de fluencia de sólo el geotextil no tejido se encontró que era sensible al confinamiento del suelo. El confinamiento del suelo se encontró que tenía un efecto insignificante sobre la respuesta de fluencia geotextil tejido.

1 INTRODUCTION

The design tensile strength of geosynthetics used in reinforced soil structures is usually computed by considering different reduction factors to its short-term tensile strength. Among them, the reduction factor due to creep commonly plays the greatest role in reducing geosynthetics design tensile strength. It is quantified based on standard tests (ASTM D 5262), in which in-isolation specimens are submitted to a constant tensile load while their elongation is measured over time. Creep strains obtained from such tests may also be used to evaluate the behavior of geosynthetic-reinforced soil structures reinforced prior to their construction. Thus, the characterization of the creep behavior of geosynthetics plays an important role in defining both the design strength and the behavior of reinforced soil structures.

Despite its widespread use, this type of creep test presents two main deficiencies: it is time-consuming and may not consider the possibly significant effect of soil confinement. These two aspects may lead to expensive tests and conservative results.

Standard creep test may be performed at elevated temperatures to expedite the creep behavior quantification (Bueno et al. 2005). Then, time temperature superposition techniques may be used to infer the creep strains at room temperature from those obtained at elevated temperature. This is completed by performing several in-isolation creep tests at the same load level, yet at different temperatures. As a result, a master curve is produced, which reaches greater values of elapsed time than those in each individual accelerated creep test and represents the creep response of the geosynthetic at the reference temperature. This approach is well established in the technical literature. Several successful studies were published dealing with acceleration of geosynthetics creep response by means of elevation of test temperature (Jeon et al., 2002; Zornberg et al., 2004; Bueno et al., 2005; Jones and Clark, 2007; Tong et al., 2009; Yeo et al., 2009). In addition, ASTM D 6992 presents a test method for evaluating tensile creep behavior of geosynthetics based on the new approach developed by Thornton (1998).

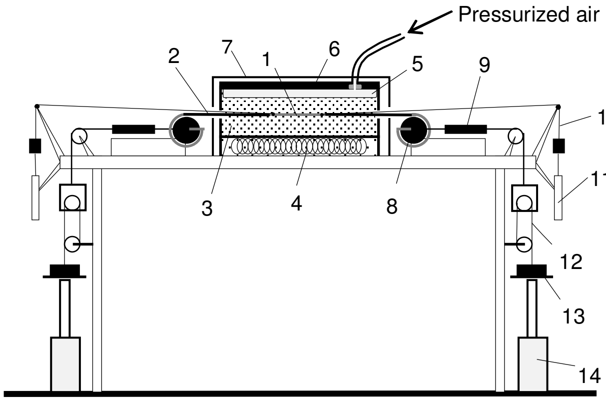
The stress-strain behavior of geosynthetics may be strongly dependent on soil confinement. Elias et al. (1998) suggest three different mechanisms of soil-geosynthetic interaction that may cause it. They are related to restriction in the fibers and yarns movements within the geosynthetic matrix. Therefore, the stress-strain behavior of nonwoven geotextiles might be the most affected by soil confinement due to its structure of filaments. It is followed by the creep response of woven geotextiles and geogrids, which is known to be the least affect by soil confinement. Despite, Elias et al. (1998) still suggest the full characterization of every geosynthetic concerning its confined creep behavior. This statement is based on tests where woven geotextile stress-strain behavior was affected by soil confinement. On the other hand, Boyle et al. (1996) found woven geotextiles stress-strain behavior independent of soil confinement. It emphasizes the suggestion of Elias et al. (1998).

Similarly to short-term stress-strain performance, the creep behavior of geosynthetics may also be affected by soil confinement. Accordingly, creep tests with in-soil specimens may be performed in order to overcome the second drawback of standard creep tests. These tests are more likely to consider the overall effect of soil confinement in the creep response of geosynthetics. The pioneer approach to consider the effect of soil confinement in the creep behavior of geosynthetics was conducted by McGown et al. (1982). Several recent studies on confined creep tests where other types of equipment were used have been conducted by Costa (2004), Mendes et al. (2007), Ding, et al. (2009) and Kamiji et al. (2009). Despite the number of successful attempts, there is not a standard procedure to conduct in-soil creep tests.

As previously presented, both approaches have been successfully published in the technical literature. However, no attempt of using both procedures simultaneously in one test has been conducted so far. Therefore, this paper presents a new device that allows confined and accelerated creep tests to be conducted simultaneously. The new creep testing equipment was developed in the Laboratory of Geosynthetics of the School of Engineering of University of São Paulo at São Carlos. The components of the new device are briefly described. In addition, results of four different types of creep tests (conventional, confined, accelerated and confined-accelerated) using both a nonwoven polyester geotextile and a woven polypropylene geotextile are presented.

2 NEW CREEP TEST EQUIPMENT

The new creep test equipment was developed in order to perform both confined and accelerated creep tests on geosynthetics, either simultaneously or not. Accordingly, it is equipped with five different systems, which are required for loading the specimen, measuring its elongation, reproducing soil confinement, elevating the test temperature and acquiring data readings from both temperature controller and elongation measurement. A schematic representation of the new creep testing equipment and its systems is presented in Figure 1. Each system is composed by different elements portrayed in Figure 1 (Loading – 8, 9, 10, 12, 13 and 14; Elongation measurement – 10 and 11; Confinement – 3, 5 and 6; Heating – 4 and 7) and will be described further in the following sub-sections, together with the specimen preparation methodology. The data acquisition system is not shown in Figure 1.



1 – Geosynthetic specimen
2 – Reinforced-lubricated portion of the specimen
3 – Upper part of testing chamber
(confining medium and specimen)
4 – Lower portion of testing chamber
(heating system)
5 – Pressurized air bag
6 – Testing chamber lid
7 – Expanded polystyrene cover
8 – Roller grip
9 – Load cell
10 – Telltale inextensible wire
11 – LVDT
12 – Pulley system
13 – Dead weight
14 – Hydraulic jack

Figure 1. Layout of the new creep testing equipment.

Creep tests where both issues are addressed are conducted both under soil confinement and at elevated temperatures. The geosynthetic specimen is placed into the upper portion of a metallic chamber (400 x 400 x 250 mm, B x B x H; 12.5 mm thick walls) filled with a confining medium. A normal confining pressure is applied by means of a pressurized air bag placed over the confining medium. Moreover, the heating chamber located in the lower portion of the metallic chamber, underneath the geosynthetic specimen, is used to increase the test temperature to a constant value. Then, the specimen is attached to two roller grips, on both sides, and subjected to a known constant load while its elongation is measured over time by means of telltales attached to the specimen. The desired condition can be controlled by combining the effects of both temperature and soil confinement. Four different creep tests may be ultimately performed (conventional, confined, accelerated and confined-accelerated).

2.1 Loading System

Two roller grips are used to load the geosynthetic specimens. They are located on both sides of the new creep testing equipment and are placed over rails in order to allow a low friction horizontal motion. Steel cables (3.2 mm in diameter and nominal strength equal to 4.45 kN) connect the grips to dead weights. Despite the stability of the dead weights loading systems, it is quite challenging to apply high loads using this approach. Therefore, a pulley set is provided in the new equipment to multiply the load applied by dead weights. In addition, two load cells (maximum capacity equal to 4.90 kN) are used to determine the actual load that has been applied to the specimen during each test. Figure 2 presents a detailed view of some items of the loading system placed on one side in the upper part of the equipment.

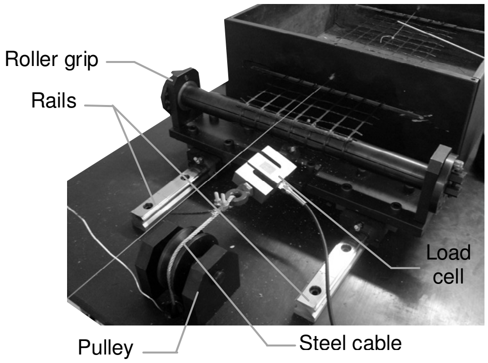


Figure 2. Main components of the loading system of the new creep testing device.

The use of the pulley set required a calibration of the loading system in order to determine the relationship between the dead weight and the load applied to the geosynthetic specimen. Several different dead weights were used while the response of each load cell was registered and the data was interpreted by a linear regression. Since both load cells responses were quite similar, an average linear function was computed. The difference between the average linear function and those obtained for each load cell is less than 2% in the tests presented in this paper. Hence, the initial amount of dead weights to be used in each test was estimated by this average linear function. Then, minor weight corrections were performed immediately after the load application and during the test in order to keep the load within a strict range. As a result, the coefficient of variation calculated using all readings taken during the tests was less than 3.5%.

2.2 Elongation Measurement System

Two telltales were used to register the displacement of two points of the specimen within the test chamber during each test. The length between both points (about 85 mm) is measured before the test setup and considered as the initial length. Calibrated LVDTs provide the displacement of both points during the tests. Finally, specimen strain is computed by the ratio between the sum of displacements A and B and the initial length (L_0), as presented in Equation 1. Figure 3 presents a view of one side of the new creep testing equipment where both a telltale and a LVDT can be located. In addition, two components of the loading system (pulley set and dead weights) are shown in Figure 3.

$$\varepsilon = (A + B) / L_0 \qquad [1]$$

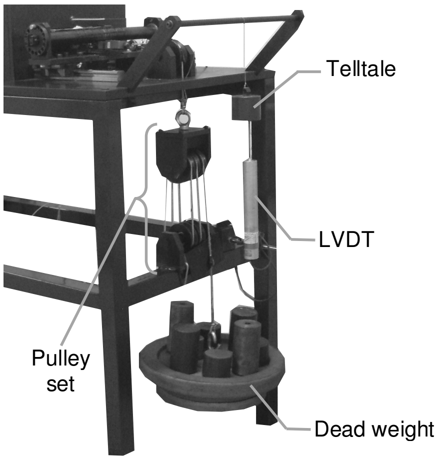


Figure 3. View of one side of the new creep test equipment.

The stability of the elongation measurement system was assessed regarding the extension of the wire at elevated temperature values. Then, a sample of the wire was submitted to an average temperature of 81.9°C for more than 30 hours. No extension in the wire was noticed after it reached the desired temperature.

2.3 Confinement System

The upper portion of the test chamber was filled with dry sand in order to reproduce the confining medium. Then, a normal stress is applied with a pressurized air bag placed over the soil. The air pressure was kept constant during each test. In addition, a piece of a polyester nonwoven geotextile (313 g/m² and 2.59 mm thick) was placed between the sand and the bag to prevent the air pressure bag from being damaged by sand grains. Finally, a lid is screwed to the test chamber and works as a reaction to the applied air pressure. A control panel connects the pressurized air bag and the pressurized air system of the laboratory and allowed the application of a constant pressure (50 kPa) in in-soil creep tests.

2.4 Heating System

A heating system was implemented in the new creep testing equipment in order to conduct tests at elevated temperature. It is located in the lower portion of the test chamber and consist of three electrical resistances (1,500 w each), two thermocouples, a controller with computational interface and a polystyrene cover. The electrical resistances are located in the lower portion of the testing chamber, which is filled with loose sand. The lower portion of the test chamber also houses one of the thermocouples (TC-1). TC-1 controls the temperature of the electrical resistances. The second thermocouple (TC-2) is placed 20 mm above the specimen, in the upper portion of the test chamber. While TC-1 is used to measure the temperature near the electrical resistances and program it, TC-2 registers the temperature near the specimen. Accordingly, the specimen temperature was considered equal to the readings in TC-2 in every test.

Thermal losses are likely to occur during the tests. Thus, the test chamber is sheltered by an expanded polystyrene cover. Besides, the difference in readings from both TC-1 and TC-2 was calibrated over a wide range of values. As a result, the temperature registered in TC-2 for a given temperature in TC-1 can be determined before the beginning of the test, which allows the selection of the initial set point to be programmed in TC-1.

2.5 Data Acquisition System

The data acquisition system of the new creep testing equipment was designed to register readings from LVDTs, load cells and the heating system (temperature in both TC-1 and TC-2). It comprises two different devices. Firstly, a data acquisition device, model P3, manufactured by Vishay Instruments® records the readings from LVDTs and load cells. In addition, temperature readings are registered by the temperature controller mentioned in sub-section 2.4. Both devices have computational interfaces which allow their operation and programming.

2.6 Specimen Preparation

The new creep testing equipment requires 200 mm wide and 1100 mm long geosynthetic specimens. Despite they are comparatively long, the length of interest is located in the central segment of the specimens and is 100 mm long. Thus, the width-length ratio is equal to that recommended in both tensile and creep standards. Two hardened regions limit the length of interest, in both side of the specimen. They were reinforced with a bi-component adhesive and a sheet of polyester in order to reduce both their strains and friction with the confining medium. Besides, these regions were lubricated with vaseline and are surrounded by two rigid geomembranes, which have a texturized side and a smooth one. The smooth sides are placed in contact with the geosynthetic specimen while the texturized ones positioned in contact with the sand. Finally, the geosynthetic specimen is covered by the final layer of sand and the chamber is closed. Figure 4 schematically illustrates the final aspect of the geosynthetic specimen.

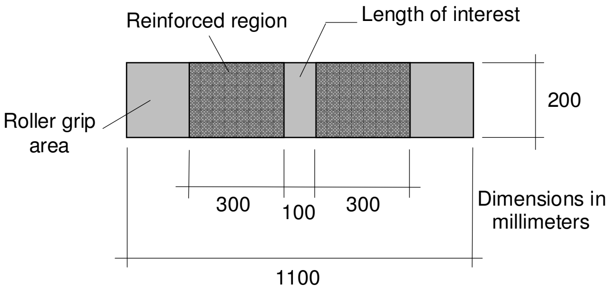


Figure 4. Dimensions of geosynthetic specimens.

3 CREEP TESTS

Three different types of creep tests were used to evaluate the new creep testing equipment: confined, accelerated and confined-accelerated. Confined creep tests refer to those where the specimen is embedded in sand and subjected to a normal stress during the test. Accelerated creep tests designate those conducted at elevated temperature using in-isolation specimens. Finally, confined-accelerated creep tests present both characteristics simultaneously. Besides, standard creep tests (ASTM D 5262) were used to characterize the creep behavior of the geosynthetics. The following sections present a brief description of both the materials used (geotextiles and sand) and the tests performed. Additionally, the results of such tests are presented and discussed.

3.1 Materials used

Two different geotextiles were used to evaluate the new creep testing equipment. Firstly, the four types of creep tests were performed using a nonwoven polyester geotextile manufactured with continuous fibers. Then, a similar set of creep tests were conducted with a polypropylene woven geotextile. Both materials were tested in machine direction only. Table 1 summarizes the characteristic of tested geosynthetics.

Table 1. Characteristics of tested geosynthetics.

Characteristics	Nonwoven geotextile	Woven geotextile
Nominal thickness (mm) (ASTM D 5199)	2.36 (9.0%)[1]	0.94 (4.2%)
Mass per unit area (g/m) (ASTM D 5261)	254 (0.1%)	276 (3.0%)
Tensile strength (kN/m) (ASTM D 4595)	13.87 (11.2%)	50.93 (4.2%)
Elongation at rupture (%) (ASTM D 4595)	59.57 (5.0%)	14.84 (10.9%)

[1] the numbers in parenthesis indicate the coefficient of variation of each characteristic.

Since in-soil tests were planned, a poorly graded clean sand was used as a confining medium. Basic characterization tests were performed with the sand (ASTM D 422; ASTM D 854; ASTM D 4253; ASTM D 4254; ASTM D 2487) and resulted in specific density equal to 26.7 kN/m³; maximum index dry unit weight equal to 16.7 kN/m³; and minimum index dry unit weight equal to 15.0 kN/m³. Besides, it is classified as SP. Its coefficient of curvature and of uniformity were computed from grain size distribution curve and resulted in 1.01 and 0.72, respectively. The sand was compacted with 45% of relative density in every creep test performed under in-soil condition (confined and confined accelerated creep tests). Peak and residual friction angles of the sand were determined by direct shear tests (ASTM D 3080) at the same relative density and resulted in 34.4° and 27.5°, respectively.

3.2 Tests performed

Firstly, the creep behavior of the geotextiles was characterized by means of a standard creep test (ASTM D 5262), which is referred as conventional creep test. Then, accelerated creep tests were performed followed by confined ones, under 50 kPa of normal stress. Lastly, the confined-accelerated creep tests, under 50 kPa, were conducted with both geotextiles. All tests were conducted under different conditions and with different durations (Table 2). Despite the recommendations regarding duration of each test, creep tests performed in the new creep testing machine did not last 1,000 h. Nonetheless, they were used to evaluate the differences between in-soil and in-isolation creep behavior of both geotextiles.

Table 2. Characteristics of creep tests performed in this study.

Type of creep test	Nonwoven geotextile	Woven geotextile
Conventional	60.0% UTS 1300 h 21.6°C	30.0% UTS 10 h 25.6°C
Accelerated	61.2% UTS 90 h 38.6°C	29.2% UTS 25 h 28.2°C
Confined (50 kPa)[1]	59.9% UTS 36 h 23.9°C	29.9% UTS 168 h 22.8°C
Confined-accelerated (50 kPa)[1]	60.8% UTS 206 h 38.2°C	29.9% UTS 143 h 38.6°C

[1] confining pressure applied during the test.

3.3 Results

The results from eight creep tests are presented in this sub-section; six of them were performed with the new creep testing machine developed during this study. As expected, the creep behavior of the nonwoven geotextile was interpreted by means of a logarithmic regression. On the other hand, the creep response (time versus creep strain) of the woven geotextile was found to have a different relation. Its creep behavior was represented by a power function regression. In both cases, the comparison between the regression equations allowed the evaluation of the influence of test temperature and soil confinement.

3.3.1 Nonwoven geotextile

Figures 5a and 5b present the creep test results of the nonwoven geotextile at room and elevated temperatures, respectively.

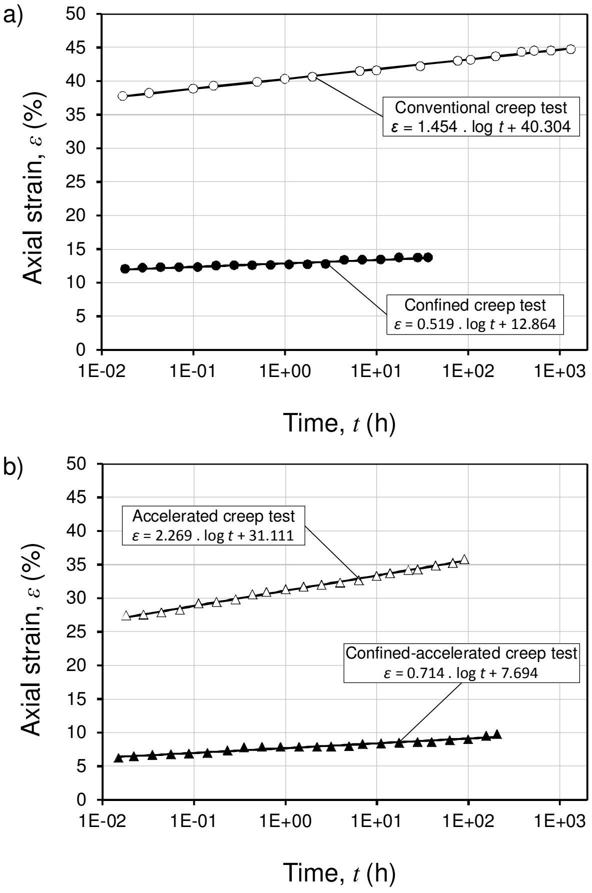


Figure 5. Effect of soil confinement in the creep behaviour of the nonwoven geotextile at room temperature (a) and at elevated temperature (b).

The logarithmic equations presented for each set of data points were compared to evaluate the influence of soil confinement in the creep response of the nonwoven geotextile. As expected, soil confinement was found to be extremely effective in reducing both creep and initial strains in this material. Additionally, the reduction of the creep strain rate is also noticed, as can be seen in the reduction of the slope of the lines presented. A reduction of about 65% can be noticed in the slope of the regression lines due to soil confinement.

In regarding to the test temperature, the increase in this parameter causes an increase in both initial strains and creep strain rate. This behavior was expected as this approach (elevation of test temperature) is used to expedite the quantification of geosynthetics creep response.

3.3.2 Woven geotextile

The same set of creep tests was performed using the woven geotextile. Figures 6a and 6b present the results obtained from this set of tests at room and elevated temperature, respectively.

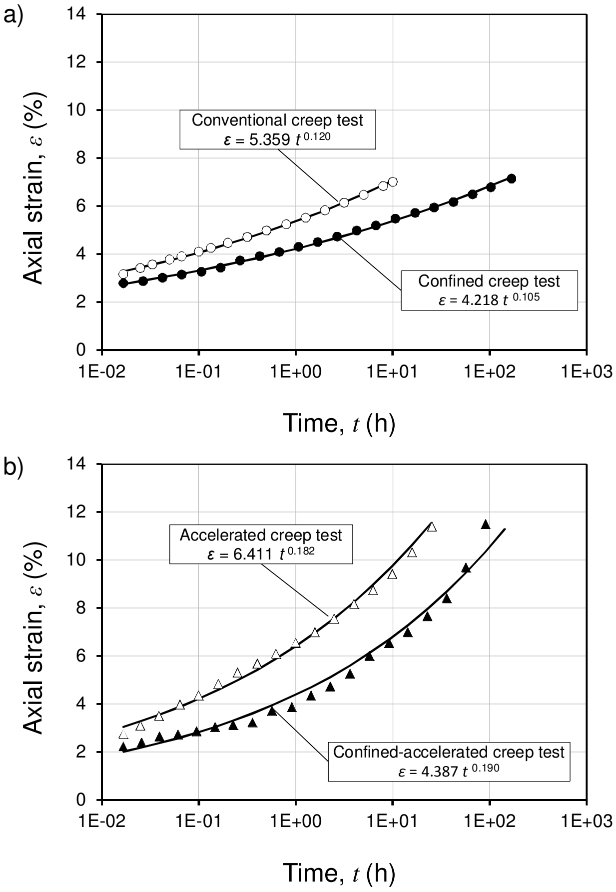


Figure 6. Effect of soil confinement in the creep behavior of the woven geotextile at room temperature (a) and at elevated temperature (b).

As observed in Figure 6, the exponents found in both cases (room and elevated temperature) are quite similar in both in-isolation and in-soil conditions. It shows that the creep behaviour of the woven geotextile tested in this study is reasonably independent of soil confinement. On the other hand, initial strains are somewhat different. It may be caused by the loading application method. The load is applied manually in each test, which may result in some different loading rate. Further improvements are still necessary in the new creep testing equipment. However, it successfully accomplishes its purpose of conducting simultaneously confined and accelerated creep tests.

4 CONCLUSIONS

This paper described the new creep testing equipment developed to perform simultaneously, or not, confined and accelerated creep tests. Two geotextiles (nonwoven and woven) were tested in four different conditions. The tests conducted with the new equipment were compared with those performed using standard procedures (ASTM D 5262). The following conclusions are drawn from the present study:

- The new creep testing equipment was successfully developed and is capable of conducting three different types of creep tests, namely confined, accelerated and confined-accelerated.
- The soil confinement effect was found to be highly effective in reducing both creep strain rate and initial strains of the nonwoven geotextile. As a result of confined and confined-accelerated creep test, it can be seen a reduction of 65% of the regression equation slope.
- The effect of soil confinement was barely noticed in the creep tests performed with the woven geotextile.
- The effect of the temperature on the creep behavior of both geotextiles was showed in this study. As expected, the increase in test temperature leads to an increase in creep strain rate values.
- Further improvements to the new creep testing machine are predicted regarding the load application system in order to make it operator independent. Furthermore, additional creep tests will be conducted in order to develop a larger data base concerning in-soil creep behavior of different types of geosynthetics.

5 ACKNOWLEDGEMENTS

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