# Long-term performance of geosynthetics

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ABSTRACT: Geosynthetics are polymeric products that creep and stress relax during their service lives. Therefore, provisions have to be done in order to predict their long term performance. This paper introduces the questions of creep and of stress relaxation but it mainly focus in creep that is the more dangerous of the two phenomena that occur during the life service of geosynthetics. The paper brings the more important contribution of the geosynthetic research group at the Department of Geotechnical Engineering, School of Engineering at Sao Carlos, University of Sao Paulo, Brazil, that has been involved in questions of creep in isolation, either by using conventional and accelerated creep tests, and also with confined creep tests and more recently with confined accelerated creep tests. This research group not only tried to predict field behavior of geosynthetics based on lab tests, but also tried to measure it in the field. To do this displacement transducers have been imagined, designed and built. The last version of this displacement transducer, called BSB-02, if properly calibrated can also measure the geosynthetic force.

## 1 INTRODUCTION

Geosynthetics creep under loading. This means that the material will deform under constant load with time. If the material is subjected to a long lasting loading, it can even collapse. Of course, the magnitude of creep deformation depends on the type of polymer used to fabricate the geosynthetics, temperature of the environment in which the material is being used and the loading level.

Geosynthetics also stress relaxes when subjected to a loading condition if it cannot deform as it will do if its deformation were not prevented.

Creep and stress relaxation are simultaneous effects that act in any application where the geosynthetics is under loading and buried into the soil to which it interacts. Figure 1 (Costa 2006) illustrates very well both effects.

The figure shows a path OA which corresponds to a short term loading. The inclination of path OA is $\beta_{OA}$, which presents a modulus $J_{OA}$. As the material is loaded at point A, it can further follow path AC where the load is kept constant but the deformation increases with time. This characterizes a creep. The material can also follow path AB, where the deformation is prevented but the load decreases with time. This gives rise to a stress relaxation.

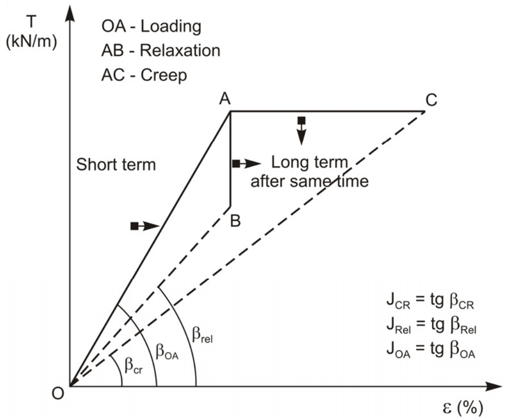


Figure 1: Definition of creep (path AC) and stress relaxation (path AB) after Costa, 2006.

Creep and stress relaxation present paths with inclination of $\beta_{cr}$ and $\beta_{rel}$, for creep and stress relaxation, respectively. These inclinations allow the calculation of modulus for both cases, which will result for creep and stress relaxation, respectively, in $J_{CR}$ and $J_{REL}$. It is important to note that these two modulus are smaller than $J_{OA}$ what allow to conclude that creep and stress relaxation can be regard as problems of softening in a sense that their modulus decrease with time (or with deformation increase and the stress decrease, respectively).

Although they both are important problem in the design, relaxation tests are rarely performed. Creep tests on the other hand have been frequently performed and will be discussed next.

In this paper creep and relaxing stress phenomena will be addressed considering mostly the research at the University of Sao Paulo under the guidance of the author.

## 2 FUNDAMENTAL CONCEPTS

Creep tests can be of two types: deformation and rupture tests. These two types of tests are required to attend limit state of design (Jewell, 1996) of reinforced soil structures that requires:

a) an adequate factor of safety against collapse, which is defined as the ratio between the rupture strength of the reinforcement and the maximum tensile load needed in the design;

b) a maximum tensile elongation of the geosynthetic to ensure that the reinforced structure does not deform beyond acceptable limits;

As said, these two requirements are the basis of the limit state methods of design, namely the ultimate limit state (risk of collapse) and the serviceability limit state (allowable deformation). The design parameters for the reinforcement for the above conditions are preferably obtained from creep tests and are assigned to the end of the design life of the structure, $t_d$.

For the ultimate condition, the tensile design strength, $T_d$, is typically defined from the ultimate value, $T_{ult}$, obtained from rapid tensile tests (ASTM D 4595) as:

$$T_d = \frac{T_{ult}}{RF_{ID}\ x\ RF_{CR}\ x\ RF_{CD}\ x\ RF_{BD}} \qquad [1]$$

Where $RF_{ID}$, $RF_{CR}$, $RF_{CD}$ and $RF_{BD}$ are reduction factors used to account for installation damage, creep and chemical degradation and biological degradation, respectively. Typical values of these factors are provided by Koerner (1994). Default values of $RF_{CR}$ typically range from 2.0 to 7.0, depending on the polymer type and load levels. This means that the design loads, due to creep alone, will vary between 50% and 15% if one of these reduction factors were used.

The parameter $RF_{CR}$ for a given geosynthetic has been typically defined from laboratory test data as a ratio between the ultimate tensile load of the geosynthetic from rapid tensile tests and the failure load obtained from the creep rupture curve for the required design life, $T_{ref}$, as is schematically illustrated in Figure 2. So, $RF_{CR}$ can be expressed by equation [2]:

$$RF_{CR} = \frac{T_{ult}}{T_{ref}} \qquad [2]$$

The creep rupture curve is obtained by subjecting geosynthetic specimens to constant loads (a percentage of the ultimate tensile strength, $T_{ult}$) and recording the time until specimen rupture. The relationship between the sustained loads versus the time of creep rupture has been observed to show a linear response when plotted in a semi logarithmic scale

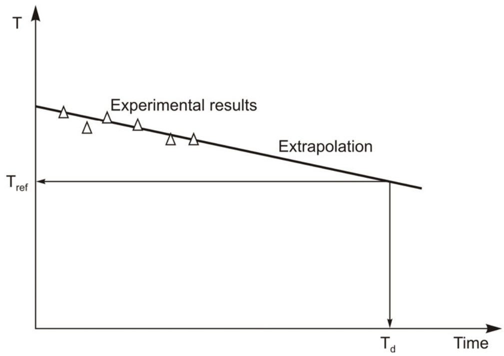


Figure 2: Creep failure curve

To shorten the time required to experimentally obtain creep rupture curve, creep tests have been typically carried out using high load levels (e.g. 70 to 95% of $T_{ult}$). Since only the first part of the creep rupture curve is defined experimentally, extrapolation is used to define the results for comparatively long periods of time. However, good engineering practice requires not extrapolating the properties of a polymer material more than one $\log_{10}$ cycle in time; unless there is other supporting evidences (Jewell, 1996). Consequently, determination of a creep rupture curve for a design life of 100 years requires at least 10 years of creep testing. Many reinforcing materials commercially available have no been tested for such long time and high levels of extrapolation is then required to meet design needs.

The required value of tensile load for the serviceability condition, $T_s$, can be obtained from isochrones (Figure 3), which relate load and creep deformation at a given testing temperature for a specific time of sustained loading. The isochrones are plotted from creep master curves obtained from various geosynthetic specimens submitted to constant loads ranging from 10 to 60% of $T_{ult}$. Value of $T_s$ replaces $T_{ref}$ in equations [2] in the calculation of the tensile design load, $T_d$, for the serviceability condition.

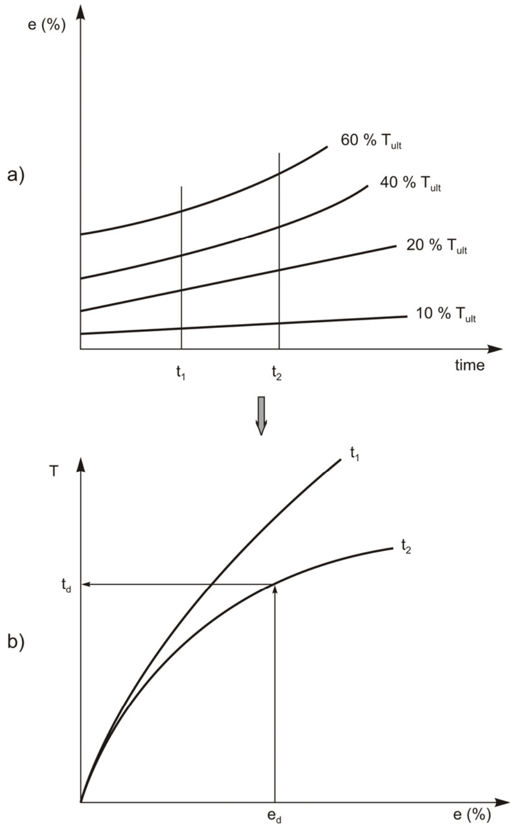


Figure 3: Isochrones for times $t_1$ and $t_2$ (b), obtained from creep master curves (a).

In situations where the deformation of the reinforced structure needs to be smaller than an acceptable limit or when the reinforcement used is prone to large creep deformations, the serviceability condition becomes very important and may govern the design. In any case, current design procedures require that both serviceability and ultimate conditions be checked using creep data from laboratory tests. Therefore creep becomes an important issue in the design of reinforced soil structures and has to be treated, as far as time is concerned, as any other design parameters. Data of temperature accelerated creep tests published so far has shown good comparisons with conventional creep data, indicating that accelerated creep tests are a promising method of predicting creep performance of geosynthetic products.

The magnitude of creep deformation increases with increasing magnitudes of sustained load and temperature. Polymers are comparatively rigid materials at low temperatures and show an essentially elastic response. That is, applied loads are proportional to the strain magnitude, but not to the strain rate. As temperature increases, polymers show viscoelastic deformations and the loads become highly sensitive to the strain rate (Ferry, 1980).

The microstructure of polymers, which are constituted of amorphous and crystalline areas, is partly responsible for the effect of temperature on the creep response of geosynthetics. Specifically, the amorphous zones the polymeric materials include long and flexible threadlike macromolecules that are randomly oriented. The amorphous zones give the main contribution to the creep of geosynthetics. In these areas, occur the orientations along the applied loads of threadlike molecules. On the other hand, the crystalline zones include molecules that are well organized in structural packages similar to a crystal. Creep deformations in these areas will occur if threadlike molecules can slide relatively to each other. Since polymers show both amorphous and crystalline areas they are called semi-crystalline materials. So, orientations and slidings of long polymeric threadlike molecules will occur and the magnitude of the movements will depends of many factors including the relative percentage of the amorphous and crystalline zones of the tested product.

Polymers present transition temperatures that indicate changes in their mechanical behavior. Specifically, the glass transition temperature, $T_g$, marks the transition between glassy and rubbery states. Below $T_g$, the mobility of polymer macromolecules is small and leads to glassy and frequently brittle mechanical behavior. Above $T_g$, the rubbery or state of mobility prevails in which the macromolecules of amorphous zones show higher mobility. Although the material behaves macro structurally as a solid, it is more susceptible to deform as temperature increases (Sperling, 1986). The glass transition temperature, $T_g$, also corresponds to the temperature where the polymer shows a significant change in the coefficient of thermal expansion. The melting temperature, $T_m$, is the transition temperature that marks the passage to the liquid state and is associated with changes in the crystalline zones of the material.

Polypropylene (PP), polyethylene (PE), polyester (PET) and polyamide (PA) are the polymers used in the manufacture of most geosynthetics. These polymers show creep susceptibility on a hierarchal sequence expressed as PP > PE > PA > PET.

The glass transition temperature for PP ranges from -15 to -10 °C, while for PET is approximately 75 °C. Consequently, the PP is well above its $T_g$ at room temperature, while the PET is usually below its $T_g$ value. This partly explains why PET is less susceptible to creep deformations than PP at room temperature.

## 3 ACCELERATED CREEP OF GEOSYNTHETICS

The use of accelerated tests to define the creep behavior of geosynthetics was introduced by Thornton et al. (1997) and Farrag (1997), who tested PET and HDPE geogrids, respectively, in their initial studies.

The principles of accelerated creep testing involve the "free-volume" theory proposed to explain configurational rearrangements of polymer chains (McCrum et all., (1967); Ferry, (1980). The specific free-volume can be expressed as (McCrum et al., 1967):

$$v_f = v - v_0 \qquad [3]$$

where $v_f$ is the free-volume of the polymer, in volume per mass (i.e., the volume of the polymer not occupied by molecules), v is the total volume of the polymer measured at temperature T, and $v_0$ is the actual volume occupied by the polymer molecules (i.e., the volume extrapolated to the temperature $T_0$ = 0 °K). The volume $v_0$ is regarded as a constant value, independent of the temperature. According to this definition the free-volume is zero at T = 0°K and increases with increasing temperature due to thermal expansion.

The basic concept behind the free volume approach to creep is that molecular mobility at any temperature depends on the available free volume at that temperature. The coefficient of thermal expansion becomes larger above the glass transition temperature, $T_g$. Consequently, the free volume increases slowly for temperatures bellow $T_g$, but significantly for temperatures above $T_g$. Therefore, time dependent phenomena such as creep and stress relaxation is also larger above Tg.

Since the free volume increases with temperature, it can be used to describe other polymer properties such as viscosity, η, which according to Doolitttle expression (Ferry(1980), can be given as:

$$\eta = A \exp (B/f) \qquad [4]$$

where $A$ and $B$ are constants and $f$ is the fractional free volume expressed as $v_f/v$.

The dependence of the free volume on temperature can be expressed as:

$$f = f_0 + \alpha_f (T - T_0) \qquad [5]$$

where $\alpha_f$ is the coefficient of expansion of the free volume at temperature T and $f_0$ is the fractional free volume at $T_g$ or other temperature of interest.

Inspection of expressions [4] and [5] reveals that the viscosity of a polymer depends on temperature and that:

$$\ln \eta(T) = \ln A + B\left(\frac{1}{f_0 + \alpha_f (T - T_0)} - 1\right) \text{ at } T > T_0 \qquad [6]$$

and

$$\ln \eta(T_0) = \ln A + B\left(\frac{1}{f_0} - 1\right) \text{ at } T = T_0 \qquad [7]$$

The change in viscosity which occurs when the temperature is increased from $T_0$ to T can be given as the difference between [6] and [7

$$\log \frac{\eta(T)}{\eta(T_0)} = \log a_T = -\frac{B}{2.303 f_0}\left[\frac{T - T_0}{(f_0/\alpha_f) + T - T_0}\right] \qquad [8]$$

where $a_T$ is a scale factor. Consequently, the time-dependent creep phenomenon such as viscosity depends on the free volume at the testing temperature. Accordingly, a sudden temperature increase from $T_0$ to $T_1$ accelerates molecular motion, which causes a decrease in polymer viscosity and results in increased creep deformation. Mathematically this principle can be expressed as:

$$\eta(T_0,t) = \eta(T_1, t/\alpha_T) \qquad [9]$$

Expression [9] states that the effect of a sudden change in the temperature from $T_0$ to $T_1$ on polymer deformation is equivalent of a multiplicative factor in the time scale.

The time-temperature superposition technique (TTS) is an empirical model of interpretation of creep tests for a material subjected to same loading but conducted at different temperatures. According to TTS deformations registered at temperature $T_1$ can be interpreted as being equivalent to deformations occurring at temperature $T_0$ in a scaled time. This change in time scale can be expressed using the shift factor, $a_T$, which can be defined using Arrhenius equation:

$$\log a_T = \frac{H}{R}\left(\frac{1}{T} - \frac{1}{T_0}\right) \qquad [10]$$

where H is the activation energy (kcal/mol) and R is universal gas constant (1.987 cal/mol,$^o$K). Determination of H from a set of temperature-accelerated tests for HDPE geogrids is reported by Farrag (1987). However, direct determination of $a_T$ using Arrhenius equation is often impractical because of the difficulty in quantifying H. Alternatively, $a_T$ can be calculated using the Landell, Williams and Ferry (LWF) empirical equation, for a temperature change from $T_0$ to $T_1$, as follows:

$$\log a_T = -\frac{C_1 (T_1 - T_0)}{C_2 + (T_1 - T_0)} \qquad [11]$$

where $C_1$ and $C_2$ are polymer universal constants that have being quantified as 17.4 and 51.6 ($^o$K), respectively (Ferry, 1986). Inspections of equations [8] and [11] shows that $C_1 = B/2.03f_0$ and $C_2 = f_0/\alpha_f$ .

Accelerated creep tests at elevated temperatures are performed as conventional creep tests. That is, by subjecting specimens to constant loads and monitoring deformation with time. One of the experimental procedures involves subjecting the test specimens to the same loading but conducting the tests at different temperatures. Figure 4 shows schematically four creep curves plotted in semi-logarithmic scale for four specimens tested under the same load but at temperatures $T_1$, $T_2$, $T_3$ and $T_4$. Next, while keeping the room temperature curve ($T_1$) in its original position the curves obtained at higher temperatures are shifted horizontally until they become aligned with the creep curve $T_1$

The material variability associated with the use of four specimens, as illustrated in Figure 4, may lead to difficulties in defining the creep master curve. To overcome this problem, Thornton et al. (1997) proposed the stepped isothermal method (SIM) in which a single specimen is loaded using the same tensile load throughout the test but several testing temperatures (temperature steps).

To define a master curve that reaches $10^3$ to $10^5$ hours, SIM tests have to be planned taking into account a number, levels and durations of temperature steps. According to Thornton et al. (1998a) a bad planned SIM test, carried out with inadequate temperature or time steps will result in master curves with shorter reach than those conducted with adequate planning..

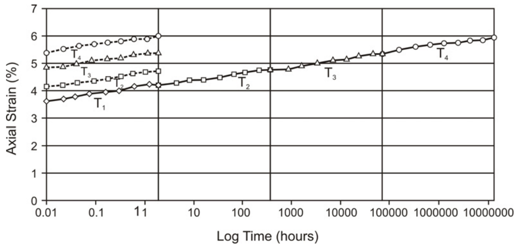

Figure 4: Creep curves showing horizontal displacements at various temperatures according to the STT.

A SIM test is initially conducted as a conventional creep test at the room temperature (curve A in Figure 5). After a certain testing period (e.g. 2 hours), point P in Figure 5, the temperature is rapidly increased to a higher value. This sudden increase in temperature is called a temperature ramp. Additional creep deformations are recorded at this elevated temperature for another period of time (curve B). The same procedure is then repeated for other temperatures (curves C and D).

Each temperature jump of a SIM test is considered as an independent creep test in which time is set to zero every time temperature is raised. Based on Boltzman´s principle of superposition, Point P in Figure 5 is the end point of temperature step A. Also this point is only an intermediary point of temperature step B, which should have origin in $t_0$ from where deformations were to be registered. The value $t_0$ is called virtual time for step B. In a semi-logarithmic plot, point $t_0$ can be estimated if the slope of the creep curves for steps A and B are the same in the vicinity of point P.

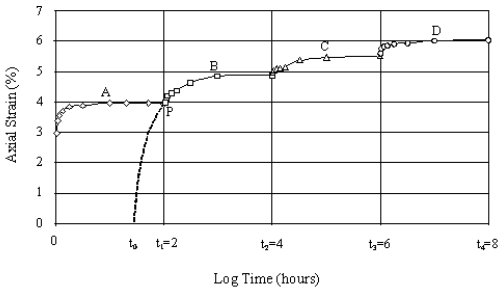

Figure 5: Schematic creep curves showing use of the Boltzman´s superposition principle and the concept of virtual time.

Since each temperature step can be considered as a separated creep test, data can be plotted in a semi logarithmic plane displaced in the horizontal axis by $t_0$. The resulted curves are then shifted horizontally to align with the room temperature curve to obtain a master creep curve of the tested material.

SIM tests have been used worldwide (Allen, 2003) and recently ASTM put forward a testing standard on this subject (ASTM, 2003).

The major difficulty in interpreting SIM data is the definition of virtual time. To overcome this difficulty, Hswan & Ko (2007) presented a procedure to deal with TTS where creep data, when drew in a semi-log plot, is a two segmental curve that presents a change of inclination that occurs exactly at the virtual time. So, to make a TTS translation it is only necessary to eliminate the first part of the curve. Of course, this technique should still be severely tested before it can become a general practice.

Therefore, so far, the accelerated creep tests, specially the SIM tests, are well established technique to overcome the long lasting times of conventional tests. Of course the procedure and the recommendations of Thornton et all. (2001) and of Allen (2002) should be followed in order to well reproduce the conventional tests.

## 4 LABORATORY TESTS AT SAO CARLOS

Although quite simple of performing SIM creep tests are carried out in isolation, i.e. just the geosynthetic is tested without the confinement, and this has received criticism of many engineers. Some professionals say, for example, that the unique confinement dependent materials are those which are compressible, such as nonwoven geotextiles and geomat geocomposites, while others say that all geosynthetic which interact with the soils, and this may include the geogrids, may suffer the confinement effects. In order to answer these questions and also to create in Brazil an infra-structure of creep tests in geosynthetics a research program was initiated second half of the nineties.

In fact, the creep tests at Sao Carlos initiated in 1998 with the MSc dissertation of Costa. She performed unconfined and confined creep tests on PP and PET geotextiles. Her data confirmed the international findings showing that PET has smaller creep deformation for the same load level than PP nonwoven geotextiles. Her data also showed that unconfined creep of geosynthetic is dependant on the geotextile structure, as can be shown by Figure 6. As can be seen in this figure, she tested two PP geotextiles from different origin, giving as a result two completely different time deformation curves.

She also showed the influence of confinement of nonwoven geotextiles. Differently of what people generally think with cohesive soils there is no soil penetration in geotextile voids. Figures 6 and 7 show micro-photographies of the geotextile surface after compaction (Figure 7) and after very wet soil had been forced to penetrate geotextile voids (Figure 8).

As can be seen from the analysis of theses figures the strucuture of the geotextile after compaction does not show any soil penetration, only few dirty spots can be seen in the geotextile surface. On the contrary, when prepared with wet soil vigosousl y foced to penetrate geotextile structure the picture show large amount soil particles whithin the geosynthetic structure.

What these result show is that if there is no soil penetration at the geotextile strcuture the action of the confiment is to reduce the geotextile pore space magnifying the interaction between fibres. These effect could be the same if the geotextile was confined with any other product such as a pair of lubricated membranes, for example.

This type of confinement when dealing with creep tests of non woven geotextiles with membranes has been postualted by many important people around the world.

Following the work of Costa (1999) Baras (2001) introduced in Brazil the accelerated creep tests, mainly the SIM tests. He worked with PP and PET non woven geotextiles.

He also introduced the use of digital cameras to measure the deformation. The photographic method he implemented in his work was based on the procedure described by Bueno (1987). Pictures of the specimen, framed by two lateral steel rulers with four reference markers, were taken at the times prescribed by ISO 13431 (ISO, 1998). These times were 0.25, 0.5, 1, 2, 4, 8, 15 and 30 minutes, 1, 2, 4 hours, and so on. Four internal markers were pinned at the top and bottom quarters of each geotextile specimen. The distance between each pair of the four reference markers was measured physically in the laboratory and on the pictures to define scale factors.

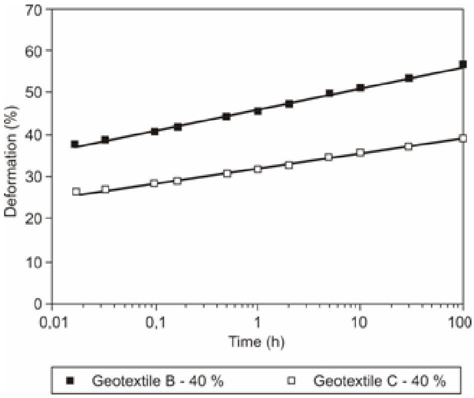


Figure 6: Effect of geotextile structure on creep bahavior (Costa, 2001).

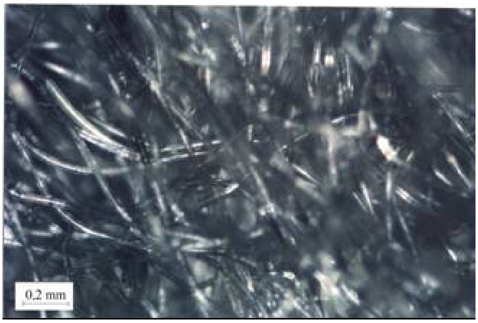


Figure 7 – Compacted soil on geotextile B ( 50x enlargement).

The coordinates of the internal markers are computed by transformation constants calculated using the coordinates of the reference markers both in the global and local systems. Specifically, a system of equations can be defined to find the transformation constants. The general expressions for system of equation are:

$$X = A + B\,x + C\,y + D\,xy \qquad [4]$$

$$Y = A' + B'x + C'y + D'xy. \qquad [5]$$

where X and Y are the coordinates of the global markers, x and y are the corresponding local coordinates (measured at the pictures), and A, A', B, B', C, C′, D, and D′ are the transformation constants from local to global system.

The use of Equations [4] and [5] for the four reference markers leads to a system of eight equations and eight unknowns (the transformation constants of from local to global system). Once the transformation constants are defined, Equations [4] and [5] can be applied to the internal markers to calculate their coordinates in the global system.

An initial picture is taken before loading to allow calculation of the initial distance between any pair of internal markers. Changes of the internal markers relative to their initial positions can then be computed at any time to allow calculation of specimen strains. In other words, since the distances between external makers are known, once the same distances are measured in the picture a scale factor is determined which allows the real distances between internal makers be measured at any time.

Baras (2001) did a large amount of tests in order to get the most from the photographic technique in terms of results. So, he tested the distance from the camera to the specimen, the necessity to work with a fixed camera, etc. He found out, for example, that the best results were obtained if all external and internal markers should be at the same vertical plane, i.e. to be coplanar. He did not use a fixed camera but pictures were taken at a distance of 1.2 m.


Figure 8 – Internal view of geotextile B impregnation (50x enlargement).

Advantages of the photographic technique include its simplicity, the use of conventional digital equipment, minimization of problems associated with specimen slippage at the grips and eliminating the need of using high-resolution displacement transducers. In addition to the conventional axial measurements, this technique allows monitoring of the lateral deformation. The resolution of the photographic technique used in this study is 0.05 mm, which is consistent with the requirements of ISO 13431 (ISO, 1998). Figure 9 shows a view of global and local markers used for displacement monitoring during a conventional creep test.

The accelerated creep tests were carried out using a temperature-control chamber (Figure 9), that houses the specimen. Electric resistances were used to control the temperature within the chamber and fans were used to provide air circulation to achieve uniform temperature within the specimen. Thermocouples attached to the test specimens were connected to an automatic temperature controller. This system controls the electric resistance and fans in order to keep the temperatures at the pre-established level. Temperatures jumps of 10 $^{o}$C were achieved in less than 1 minute using this equipment setup.

The conventional tests were conducted during 1,000 hours (43 days), while the SIM tests were conducted using two hour steps. The temperatures used in the subsequent steps during SIM were room temperature (23 $^{o}$C), 40$^{o}$C, 50$^{o}$C and 60$^{o}$C. This test plan is consistent that used by other investigators (e.g. Thornton & Baker, 2002; Baras et al., 2002). These temperature steps are different from what ASTM D 6692 prescribes.

Figure 9: View of internal and external markers of s creep test.

His apparatus was then inensively used by Costanzi (2003) who performed two sets of tests on PP and PET geotextiles. For each one of the four sets of tests for one of the strress level he used a set of three SIM tests were performed plus a 1000 hours conventional test.

His work was revised and published by Bueno et all. (2007) from were Figure 11 was taken. This Figure show that SIM tests should be used to predcit the behavior of non woven geotextile since the elevated temperatures could reproduce well not only the polymeric but also the structural creep of the tested geotextiles.

The discrepancy between the various curves at the same load level can be attrbuted to the variability of the tension load of gesoynthetic A.

Costa (2006) in her PhD thesis concentrated in confined creep.\howeer, differently from her MSc dissertation she designed an apparatus in which the tensile load in the geosynthetic is applied by the soil, like in the field. Figure 12 shows a picture of the equipment and Figure 13 is a lateral view to help the understanding of how it works.

Of the many aspects discussed by Costa (2006) is the soil creep potential compared with the geosythetics, i.e., if the soil does not creep and the geosynthetic does, the soil will prevent geosynthetic creep in cases where the strength of the soil increses with deforamation such as for example the increasing stregth of a compacted sand prior to peak. On the other hand, if the soil can also creep the difference between creep curves of confined and unconfined geosynthetic will be the smaller initial deoformation of the confined material. She also mention that the frequnently asserton that real wall creeps very little is the very small loads on the geosynthetics observed in the real structures.

Figure 14 shows data from two confined and wo unconfined creep tests using an woven geotextile. Her equipment allowed the registration of the deformation at different points along the test specimen. The deformation showed in this figure corresponds to the closest point next to the movable wall front face.

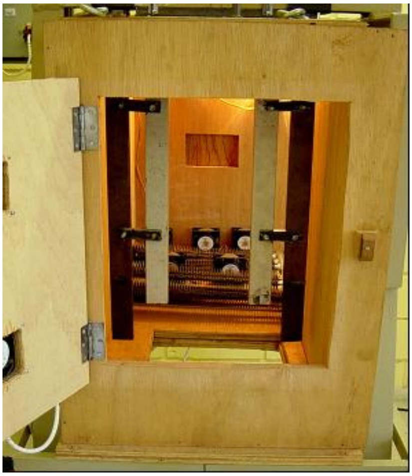

Figure 10: Test chamber used for temperature accelerated creep testing.

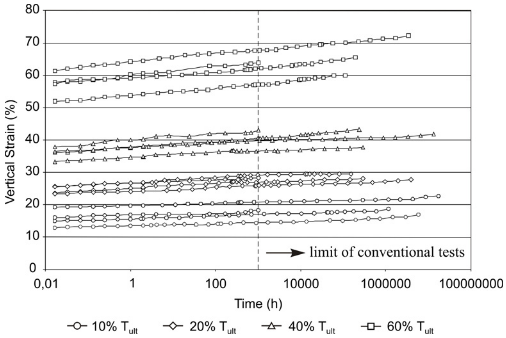


Figure 11: Comparison between creep master curves obtained with conventional and SIM tests for geotextile A.

Costas´equipment was intensively used by Kamije(2005) is her MSc. dissertation. She looked at creep of three types of non wovn geotextiles, four tpes of soils, two degrees of compacton and different load levels. She showed that the confiement really affects the creep behaiour of non woven geotextiles and she also showed that he more deformable the geotextile in isolation, the higher is also the confiend creep.

Figure 15 shows a typical picture of data obtained by Kamije in her MSc dissertation. As ca be seen, the geoextile A is largely affected by confinement

Allthough Costa´s equipment can be regarded as a advance in measuriing creep deformaton and as stated by Costa and Bueno (2006) the equipmen wih very small modificaion can be used to perform accelerated creep tests, besides stress relaxation tests, a new creep apparatus was conceived in order to test confined accelerated creep of geosynthetics.

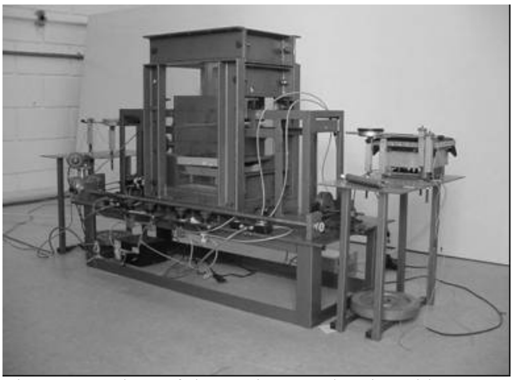

Figure 12: View of the equipment developed by Costa (2004) to study the confined creep of geosynthetics.

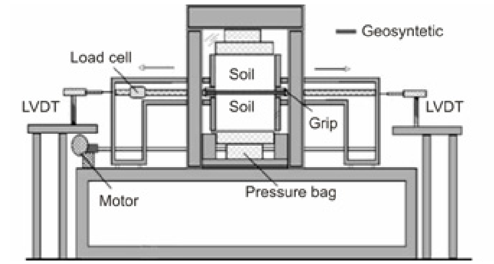


Figure 13: Lateral schematic view of the equipment developed by Costa (2004).

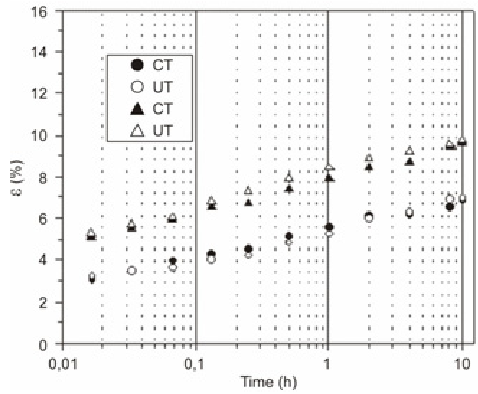


Figure 14: Example of data obtained by Costa (2004).

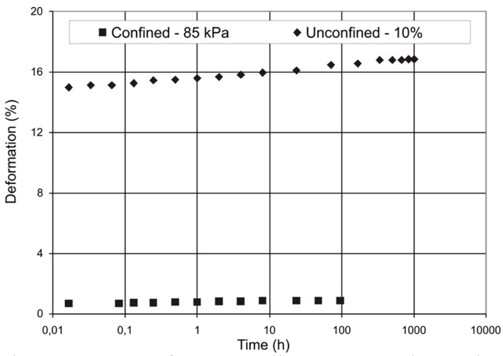


Figure15: Data from Kamije´s MSc. Dissertation showing the confinement effcct in non-woven geoextiles.

This apparatus has been used also to perform confined creep tests and is also prepared to perform relaxation tests (França, 2010). Figure 16 shoes a view of the equipment.

The equipmet has been extensively tested, specially agianst friction on the rigid surfaces of the sample, and all the measurements and physical observations about friction made showed that it is small indeed. Therefore the equipment as planned has been aproved and the test results that had been put forward can be considered of high quality and therefore trustable.

The inconveninces of this type of tests is that one can not perform SIM tests because the time reqired to heat the specimen is far lager than that required by SIM tests, therefore the equipment can only peform convetional confined-accelerated creep tests and the soil used to confine the sample has to be pure sand. On the other hand, the equipment can be used to perform confined tests with any sort of soil, as done by França in his first series of tests.

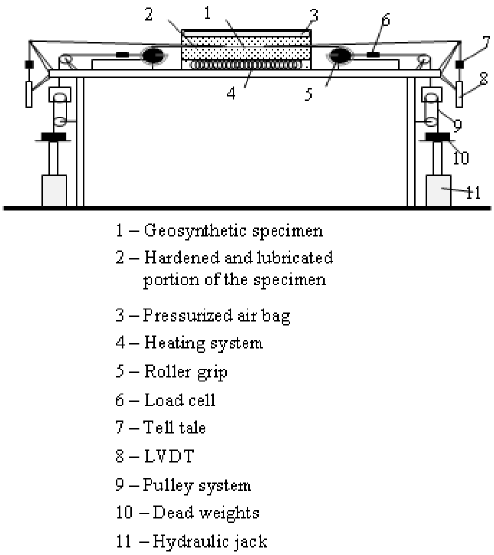


Figure 16: França´s confined-accelerated test equipment.

Figure 17 shows two sets of creep tests performed in a nowoven geotextile. The solid line are the results of unconfined creep test. As can be seen, the material presented a creep master curve with a measured value of angular or creep coefficient. On the other hand, the dashed lines are results of confined tests. Allthough the lines present some paralelism indicating that the confimement was unable to reduce or even to nulify completely the creep behavor of he material, one can see that it was able to minimize very efficiently the initial deformation of the geotextile. These results are similar to Kamije´s data. As clearly shown by this author, the level of condinement can affect the value of the deformation measured.

Figure 18 presents data of confined and unconfined geogrid using sand. As can be seen the unconfined test shows a creep curve with some inclination while the confined creep curve is completely horizontal. This test shows that a geogrid confined into a sand interacts with the soil that restrics the creep behavior. When the test was finished and the top sand was carefuly removed it was possible to see the importance of the interaction geogrid-soil, specially the effect of transversal members.

Figure 19 shows results of unconfied test (solid line) and a confined test (dashed line) of a geogrid. In this case, the soil was a clayed sand, Figure 20. Allthough the the initial deformations of both tests were very close, the creep of the unconfined test was significantly greater than the confined geogrid test which was horizontal. The difference in the initial deformaton could be attributed to the varaibilty of samples as far as ultimate tension stress are concerned.

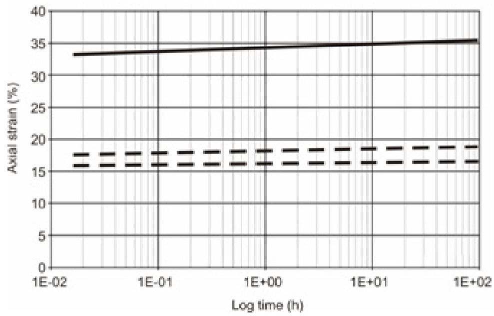


Figure 17: Unconfined (solid line) and confined tests (dashed lines) on nonwoven geotextile

## Field prototypes

Besides laboratory tests, the geosynthetics group at Sao Carlos tried to mesure the creep behavour of geotextile renforced walls. The main corern of this research group was to built walls with reiforced material fabricated in Brazil and to use local soils.

Therefore the first prototype was part of Pedroso´s MSc. dissertation. The reinforced wall was built in a cut performed in a natural slope. After construction it became part of a private unpaved roadway open to traffic, especially trucks. The prototype was constructed using wraparound facing.

The wall was built with dimensions of 4 m wide, 4 m high and 4 m long. The wall was reinforced using

9 geotextile layers with a vertical spacing of 0.5 m. The structure was constructed resting on a 0.5 m reinforced layer of dense sand. The inclination of wall face was 78° to the vertical, which corresponds to a face slope of 1H:5V. The backfill soil was compacted using a vibratory plate. The target compaction degree used in the walls was 95%, resulting in a dry unit weight of 17.8 kN/m³ and optimum water content.

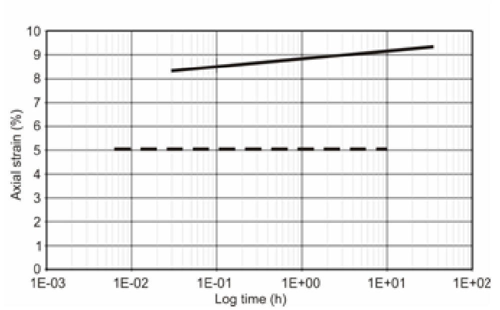


Figure 18: Unconfined (solid line) and confined tests (dashed lines) on geogrid buried into pure sand.

equal to 9.0%.

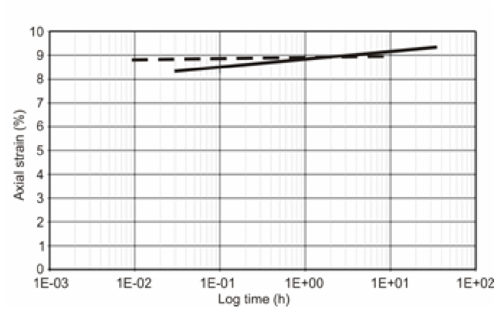


Figure 19: Unconfined (solid line) and confined tests (dashed lines) on geogrid buried into clayed sand.

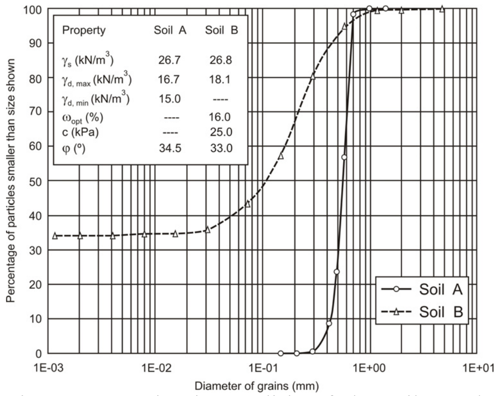


Figure 20: Grain size analisis of the soils used in França´s tests.

The soil used as backfill was a fine to medium sand with 10 % of clay. The shear strength parameters were obtained from consolidated-drained triaxial tests, using specimens prepared with the same relative density and water content used in field construction. The soil shear strength parameters were cohesion of 9.7 kN/m$^2$ and an internal friction angle of 34$^o$.

A polypropylene, short fiber, non-woven geotextile was chosen as reinforcement (Geofort G-400). The main characteristics of the geotextile are listed in Table 1, bellow.

Table 1: Characteristics of the used geotextile.

| Geotextile property | Value |
|---|---|
| Mass per unit area | 400 g/m$^2$ |
| Thickness | 3.8 mm |
| Ultimate tensile strength | 26 kN/m |
| Secant Modulus (5% strain) | 40 kN/m |

The wall was monitored using magnetic extensometers to evaluate vertical settlements, and horizontal extensometers (steel bars) to monitor horizontal displacements within the reinforcements, placed inside and outside the potential slip surface, in order to investigate the global behavior of the structure. Both measurements allowed a resolution of 1mm. Figure 21 presents the geometry of the wall and the instrumentation layout used in the construction of the all.

Internal horizontal and vertical displacements were measured during and after the wall construction. Post-construction monitoring presented here was conducted until 202 days after construction.

The results show that the largest horizontal and vertical displacements during construction occurred within the active zone, close to the wall face, indicating a potential logarithmic spiral slip surface.

Figures 22 and 23 present the horizontal displacements referring to the extensometers placed within and outside the hypothetical slip surface, respectively, from the end of the construction until 202 days later. The steel bars were placed at three different heights: y=1.75 m, 2.75 m and 3.75m.

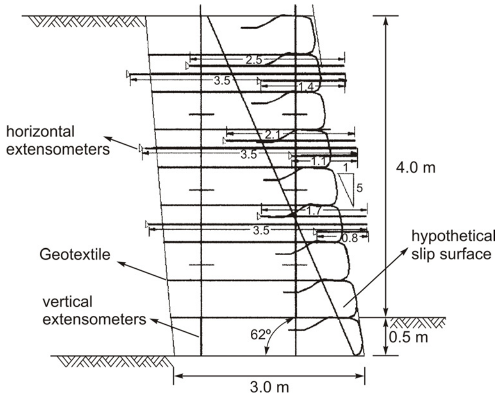


Figure 21: View of Pedroso´s prototype.

The maximum horizontal displacements during construction, measured within the hypothetic slip surface, reached 22 mm at the height of 3.75 m. The structure presented large post-construction displacements, attributed especially to traffic loading.

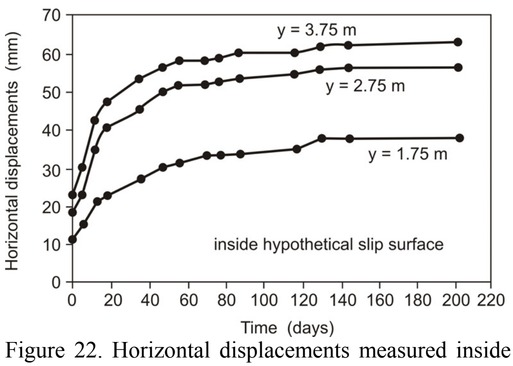


Figure 22. Horizontal displacements measured inside the hypothetical slip surface.

This long term displacements stopped 120 days after the end of the construction, reaching 62 mm. The maximum displacement measured outside the hypothetical slip surface at the end of construction was equal to 5 mm at 3.75 m, and 44 mm after 202 days, at same elevation. The relation between the maximum displacement at the end o the construction and the total height of the structure (δ/H) was 1.5%.

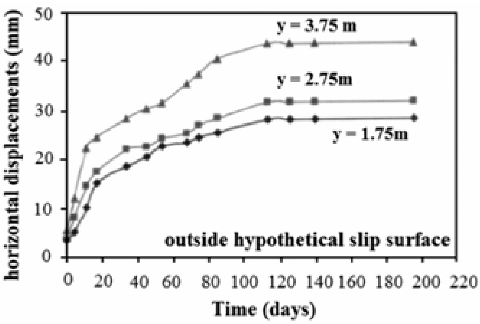


Figure 23. Horizontal displacements measured outside the hypothetical slip surface.

Following Pedroso´s wall, and supported by FAPESP, a series of eight prototypes was built by Benjamin (2006) as part of his PhD thesis. He used pure sand and local soils as backfill (sandy and clayey soils) In this way he could look at the effect of soil type, taking into account the effect of cohesion and the drainage capacity of the bakfill. All his prototypes, with exception of wall 7, presented very small post-construction deformations, therefore creep, even during the raining period. During this period the soil absorbs water, becoming havier and therefore incresing the required force on the reinforcement. Besides that, the water that occupies the gesynthetics voids may cause an increase of pore water pressue which is responsile for soil shear strength reduction. So, because of the load increase and soil shear srength decrease, it was expected that during the rainnig period the creep deformation increase. The instrumentation readings lasted for, at least, two years.

Figure 24 shows the geomery of Benjamim´s experiments. The walls were built in pairs such that in the unreiforced zone, exactly in the middle part of the walls a instrumentaion well was buit to serve both structures.

The wall 7 was designed with very small safety of factor, and therefore, was built in order to creep. It was observed that in this wall the unconfined creep could reproduce quite well what happened in the field since the confinement could only reduce the initial deformation but not the field creep that was due to a polymeric effect.

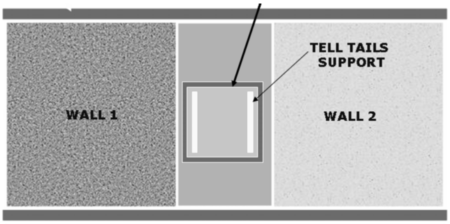


Figure 24: Geometry of Benjamim´s experiments

Figure 25 shows a view of the creep deformation experienced by wall 7. The deformation were high and the internal zone of the reinforced area was bounded by a nearly linear Rankine surface.

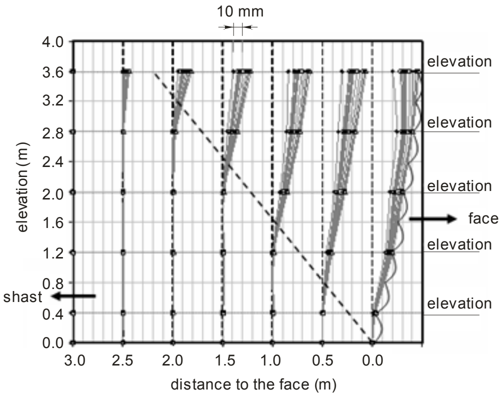


Figure 25: Creep deformation of Benjamim´s wall 7.

**Field instrumentation.**

The type of field instrumentation used to register long term performance of geosynthetics depends on the function the material will have during the design life. For example, earth pressure cells can be used to register horizontal and vertical stresses of the soil beneath or above geosynthetics to measure soil arching or creep under compressive loads or piezometers to measure the pore pressures at points of interest.

The registers of geosynthetics displacements have been used using tell tales as in the research work of Benjamim (2006) or even rigid bars as in the research of Pedroso (2000).

An electric measuring unit of geosynthetics displacements, aiming the calculation of geosynthetics deformations in reinforcements, has been devised by Marques et al. (1985). This unit consists of a metal plate connected to a spring fixed to a sliding cap of the unit case, Figure 27. The strain gages are fixed to the metal plate and work in tension. As the geosynthetic deforms it pulls the spring which apply a load to the measuring unit. If the system is properly calibrated it can also give the load between the points where the unit is connected to the geosynthetic. One can get the same stiffness if, for example, the system is connected to a geogrid member. The geogrid cut member must have approximately the same stiffness as the spring plus the measuring unit.

However, any strain gauge instrumentation that works in tension, such as this measuring device, may present a small output signal and therefore a small sensitivity. Therefore, caution must be exercised in order to obtain the required output signal. Aspects such as the use of semiconductor strain gauge with a gage factor of about 50 larger than the conventional one and a special selection of the sensitive material and its geometry are very important to increase the output sensitivity.

An improved unit of the device BSB-01 was devised by Bueno (2009) and works on flexure, Figure 28. The unit allows also registering the difference of displacement between two points that allows the calculation of reinforcement deformation. This system can be also calibrated to measure geosynthetic force. At the present the device BSB-02 has been used to register creep of reinforced retaining structures and also as laboratory equipment to register the deformation of geosynthetics under creep tests.

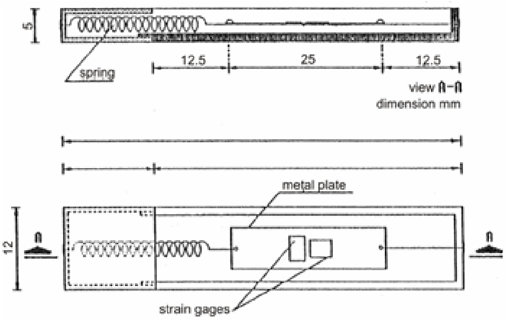


Figure 27: A view of the first device used to register the internal deformation of working geosynthetics (BSB - 01)

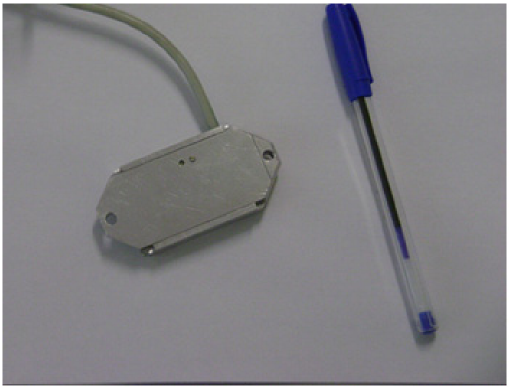

Figure 28: A view of the second device (BSB-02) used to register the internal deformation of working geosynthetics.

## 5 FINAL REMARKS

Creep is an important and complex design parameter for any geosynthetic which is loaded in tension or in compression in the field.

Conventional creep tests (those run at a constant temperature) are time consuming and therefore expensive. Besides that because of the time required to run a complete test, creep became a special property.

The use of a temperature accelerated creep tests is a common practice around the world, specially the SIM procedure, since there are good comparisons between data obtained by both tests. More important is the fact that accelerated creep tests allow creep be considered as a normal design parameter such as any other that has a determination procedure described by technical standards. The procedures must be easy to be understood by any people involved with geotechnical tests and must also give quick answers.

Although most of creep test are performed with the geosynthetic in isolation (without the soil) it is important to say that even non compressible materials which strongly interacts with the soil, such as geogrids, can be affected by soil confinement

## ACKNOWLEDGEMENTS

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## REFERENCES

Allen, S.R (2003) Considerations on the Stepped Isothermal Method – a Breather on the Way of Widespread Use, Proceedings of the GRI-17 Conference on Hot Topics in Geosynthetics, Folson, PA, pp.292-311.

Allen, T. M. (1991).Determination of Long-Term Tensile Strength of Geosynthetics: a State-of-the-Art Review, Proceeding of the Geosyntheics´91, Atlanta, vol.1, pp.351-379.

ASTM D 6992. Standard Test Method for Accelerated Tensile Creep and Creep-Rupture of Geosynthetic Materials Based on Time-Temperature Superposition Using the Stepped Isothermal Method, ASTM International, West Conshohocken, Pa.

Baras, L. C. S. (2001). Geotextile Creep Study Using Conventional and Accelerated Tests. MSc. Dissertation. School of Engineering at Sao Carlos, University of Sao Paulo, 82p. (in Portuguese).

Baras, L. C. S.; Bueno, B. S.; Costa, C. M. L. (2002). On the Evaluation of Stepped Isothermal Method for Characterizing Creep Properties of Geotextiles. Geosynthetics – 7th ICG, Nice, France, vol. 4, pp. 1515-1518.

Benjamim, C.V.S. (2006) Experimental evaluation of prototypes of geotextile reinforced soil walls. PhD thesis. School of Engineering at Sao Carlos, University of Sao Paulo, 330 p. (in Portuguese).

Bueno. B.S. (1987) The behavior of thin walled pipes in trenches, PhD thesis, University of Leeds, 325p.

Bueno, B.S. (2009) BSB-02: A measuring device to register deformation and load of geosynthetics, LG, Special Publications 07p. (in Portuguese).

Bueno, B. S., Costanzi, M. A. & Zornberg, J. G. (2005) Conventional and accelerated creep tests on nonwoven needle-punched geotextiles. Geosynthetics International, v. 12:6, p. 288-298.

Bush, D. I. (1990).Variations of Long Term Design Strength of Geosynthetics in Temperatures up to 40°C, Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products, The Hague, Netherlands, vol. 2, pp. 673-676.

Costanzi, M. A. (2003) The use of SIM method to obtain the isochrones and the creep rupture curve of geotextiles. MSc. Dissertation. School of Engineering at Sao Carlos, University of Sao Paulo, 82p. (in Portuguese).

Costa, C. M. L. (1999). Creep of goetextiles. MSc. Dissertation. School of Engineering at Sao Carlos, University of Sao Paulo, 97 p. (in Portuguese).

Costa, C .M. L. & Bueno, B. S. (2006). Construction of na Equipment for Evaluating the Long Term Behavior of Soil-Geosynthetics Composites, Soils and Rocks, 29 (3):350-370.

Costa, C. M. L. (2004) Time dependant deformation of geotextile reinforced walls. PhD thesis. School of Engineering at Sao Carlos, University of Sao Paulo, 330 p. (in Portuguese).

Farrag, K. (1987) Prediction o Long Term Strains of Geosynthetics from Accelerated Creep Tests, IFAI, Geosynthetics´97, Long Beach California, vol. 1, pp. 267-275.

Ferry, J. D. (1980). Viscoelastic Properties of Polymers. 3rd Edition, John and Sons, New York, NY,USA.

França, F. (2010) Confined and Accerated Creep of Geosynthetics. Forthcoming PhD Thesis. School of Engineering at Sao Carlos, University of Sao Paulo, (in Portuguese).

Kamiji, T. S. M. M. (2006). Confined creep of non-woven geotextiles. MSc. Dissertation. School of Engineering at Sao Carlos, University of Sao Paulo, 103p. (in Portuguese).

Koerner, R. M. (1994). Designing with geosynthetics, Englewood Cliffs, New Jersey, Prentice Hall, 3rd Ed

Jewell, R. A. (1996) Soil reinforcement with geotextiles. London, CIRIA, 332p.

Marques, G. L. O., Bueno, B. S., Lima, D. C. and Minnitte, E. (1995). Measurements of internal and external displacements of reinforced soil walls. Proceedings of the 2nd Brazilian Symposium on Geosynthetics, Sao Paulo, pp. 61-70. (in Portuguese).

McCrum, N,G., Read, B.E. and Williams, G (1967) Anelastic and Dielectric Effects in Polymeric Solids, Dover Publication, Inc, New York, 617p.

Pedroso, E. O. (2000) Geotextile reinforced soil walls. MSc. Dissertation. School of Engineering at Sao Carlos, University of Sao Paulo, 82p. (in Portuguese).

Thornton, J. S. & Baker, T.L. (2002) Comparison of SIM and Conventional Methods for Determining Creep-Rupture Behaviour of a Polypropylene Geotextile, 7th ICG. Nice, France, vol. 4., pp.1545-1552.

Thornton, J. S.; Allen, S. R.; Thomas, R. W. (1997). Approaches for the Prediction of Long Term Viscoelastic Properties of Geosynthetics from Short Term Tests. In: Geosynthetics ’97. Proceedings. California. v.1. ,p.277-291.

Thornton, J. S.; Allen, S. R.; Thomas, R. W.; Sandri, D. (1998a). The Stepped Isothermal Method for Time-Temperature Superposition and Its Aplication to Creep Data on Polyester Yarn. In: Sixth International Conference on Geosynthetics, Conference Proceedings. v.2, p.699-706

Thornton, J. S.; Paulson J.N.; Sandri D. (1998b). Conventional and Stepped Isothermal Method for Characterizing Long Term Creep Strength of Polyester Geogrids. In: Sixth International Conference on Geosynthetics. Conference Proceedings. v.2, p.25-29