Field and laboratory time-dependent behaviors of nonwoven geotextiles in reinforced soil walls

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ABSTRACT

Laboratory and field investigation of time-dependent behavior of geotextiles reinforcing a fine-grained soil are evaluated in this paper. The field assessment consisted of analyses of an instrumented section of a nonwoven geotextile reinforced soil wall. In addition, in-soil and in-isolation laboratory creep tests were conducted using the same geosynthetic and soil used in the Geosynthetic-Reinforced Soil (GRS) wall section to better assess time-dependent behaviors in the field. Construction and time-dependent behavior of the full-scale GRS wall proved to be satisfactory over the 4 years of monitoring of both woven and nonwoven geotextile structures. Soil confinement, due to vertical earth pressure on the reinforcement, was found to greatly affect the deformability of the nonwoven geotextile. Time-dependent strain rates were higher when the failure stress state of the soil was reached. Time-dependent behavior was underestimated from in-soil laboratory creep tests and better estimated using in-isolation laboratory tests. However, the GRS wall data did not account for installation damage and wetting-drying processes, which were found to influence time dependent strain predictions.

1. INTRODUCTION

The time-dependent deformation of geosynthetics is an essential property in the design of reinforced soil walls. Geosynthetics are composed of viscous-elastic-plastic materials comprised of compound polymer molecules that undergo time-dependent rearrangement when subjected to an external load or distortion and are expected to creep; this can lead to excessive deformation, or even failure. The time-dependent properties of geosynthetics, soil, and their interactions must be established to accurately predict the mechanical response of geosynthetics under load in a wall. In design analyses, the consideration of geosynthetic time-dependent behavior involves an empirical reduction factor related to the loss of reinforcement strength due to creep, or is typically based on in-isolation creep tests. However, although the long-term behavior of Geosynthetic-Reinforced Soil (GRS) walls is not essentially affected by the creep behavior of geosynthetics, it involves an interaction with backfill soil creep behavior. In-soil characterization of geosynthetic load-strain-time behavior has been conducted in the laboratory using devices that apply load to the geosynthetic through the surrounding soil (Kazimierowicz-Frankowska 2003, 2006; Simonini and Gottardi 2003), as well as devices in which the load is applied to the geosynthetic directly (McGown et al. 1982; Helwany and Shih 1998; França and Bueno 2011). McGown et al. (1982) reported a considerable reduction in the creep deformations of nonwoven geotextiles confined between layers of sand, and a minor effect on woven geotextiles, using a device that allows the load to be applied directly to the reinforcement. Similarly, in-soil creep tests were performed by França and Bueno (2011), in which soil confinement was found to have no significant effect on the creep strains of geogrids and woven geotextiles, but a pronounced effect on the creep behavior of nonwoven geotextiles, while restricting filament movements. However, apart from the initial strain, no soil confinement influences on woven and nonwoven geotextile deformations were reported by Levacher et al. (1994) and Wu and Hong (1994). Wu (1994) and Wu and Helwany (1996) demonstrated that the rheological behavior of confining soils affects geosynthetic creep deformation. If the soil is perfectly bonded to the geosynthetic, implying that there is no relative slippage, the soil and geosynthetic must deform together. Under constant load, the soil restrains geosynthetic deformation when the confining soil exhibits low creep compared to the geosynthetic reinforcement. However, in the case of the confining soil creep rate being higher than that of the geosynthetic, accelerating creep is induced in the reinforcement. Becker and Nunes (2015) also presented a time-dependent study involving a nonwoven geotextile embedded in a compacted sand fill. Contrary to other studies, the creep rates measured were found to be higher in the confined than in the unconfined tests. This behavior was attributed to the relatively low normal stress (10 kPa), which was reported not to be sufficient to prevent structural creep of nonwoven geotextiles. Most of the research studies reported herein reveal the effects of soil confinement on the creep behavior of geosynthetic reinforcements by means of laboratory tests involving confined geosynthetics between soil layers. However, little research has been focused on understanding the in-soil creep behavior of geosynthetic reinforcements in a full-scale GRS wall. Liu et al. (2009) conducted numerical studies and reported a considerable effect of the relative creep between the geosynthetic and soil, not only on the reinforcement strains, but also the tensile loads and soil stresses of a GRS wall. Allen and Bathurst (2002) reported significant deformations of full-scale GRS walls over time, under high surcharge loadings. If the reinforcement strains are sufficiently low to prevent the soil from reaching failure, reinforcement creep will be minimal and the wall will remain stable. Their study also demonstrated that the in-isolation creep rates are the same as or greater than rates measured in full-scale walls, producing conservative creep estimates in walls. More recently, Costa et al. (2016) reported considerable time-dependent deformations of a GRS wall centrifuge model. The sand soil used in this study, which is frequently considered as having negligible creep, was ultimately determined not to have any influence in preventing the development of time dependent deformations. The use of full-scale instrumented GRS walls is an approach that is seldom used to investigate the time-dependent behavior of geosynthetic structures. Furthermore, limited research has been conducted to identify the time-dependent deformations of geosynthetics that are confined by fine-grained soils. This paper contributes to understanding of the time-dependent behavior of geosynthetic reinforcements by conducting a comparison of the responses of two instrumented sections of a full-scale GRS wall with the results from in-soil and in-isolation tests, which allows for establishing the relevance of the results of different laboratory creep tests for the design of GRS walls. The results analyzed in this paper were presented by Placido et al. (2018).

2. FULL-SCALE INSTRUMENTED GRS WALL

2.1 Overview

The GRS wall was constructed using a local lateritic fine-grained (tropical) soil, which includes sections reinforced with nonwoven and woven geotextiles. The project involves retaining structures that were constructed as part of a development in the Bairro Novo residential condominium in Campinas, Sao Paulo, Brazil. The structure is a 9 m-high wrap-around reinforced soil wall with 1 H:10 V batter. The retaining structure was constructed along 300 m of a natural slope. A 4.5 m-high sloped embankment (1.5 H:1.0 V) was constructed on top of the retaining wall to achieve the required design elevation. Figure 1 illustrates the GRS wall. Details regarding the construction and monitoring program of the instrumented full-scale GRS wall used in this study are described by Portelinha et al. (2014). An interesting aspect of this study is that the nonwoven reinforcement had a tensile strength of only 40% of that of the woven geotextile, as well as an unconfined tensile stiffness (at 5% strain) that was 7.5 times smaller. The purpose of this selection was to examine the effects of soil confinement on geotextile deformations under operational conditions. Both instrumented sections were constructed with identical geometry, with reinforcement vertical spacing of 0.4 m and a reinforcement length of 7.0 m. A cross section of the wall is illustrated in Figure 1. The GRS wall is expected to be extremely stable in terms of pullout resistance, as the ratio between the reinforcement length and wall height is 1.25, which is a great deal higher than the usual value of 0.6 adopted for design. Portelinha et al. (2014) also discuss the design aspects of this GRS wall.

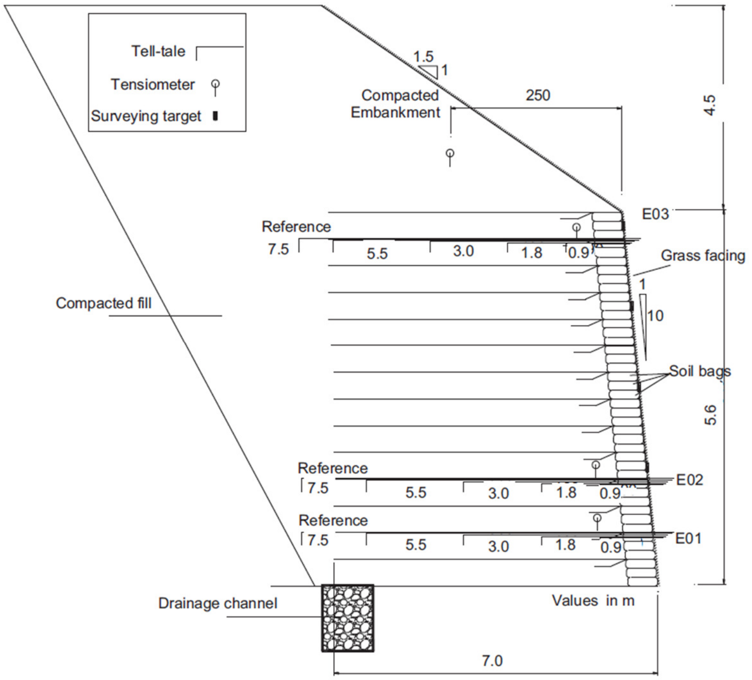

Figure 1. Cross-section and instrumentation layout of the full-scale GRS walls (Portelinha et al. 2014).

2.2 Geosynthetics

A nonwoven geotextile with an ultimate tensile strength of 25 kN/m and in-isolation stiffness of 20 kN/m was selected for the project. The geotextile weight per unit area was 396 g/m^2 and deformation at failure was 78%.

2.3 Backfill soil

The local soil used for the reinforced fill was obtained from a natural slope, and consists of non-plastic silty sand with 33% fines (i.e. passing sieve no. 200). The laboratory compaction characteristics of the soil were obtained from modified Proctor tests (ASTM D1557). The foundation soil, to a depth of 3 m, is the same as the backfill soil. The shear strength parameters were obtained using consolidated drained (CD) tests performed on unsaturated soil specimens (ASTM D7181) and compacted at the optimum water content. The CD tests for unsaturated specimens gave a cohesion intercept of 40 kPa and friction angle of 37°.

2.4 GRS wall instrumentation

Instruments were installed on a 5.6 m-high section with woven geotextile. For comparison, an experimental section with nonwoven geotextile, and the same reinforcement layout and height, was also fully instrumented. Instrumentation was used to monitor the wall performance during and after construction. Mechanical extensometers (tell-tales) with smooth jacketed steel rods were installed along the reinforcement length to monitor internal displacements, and facing displacements were monitored using topographic surveys. Figure 1 details the instrumentation layout used to evaluate the wall performance. The tell-tale points were attached to the geotextile at distances of 0.90, 1.80, 3.00, and 5.50 m from the facing. The instruments were placed in three rows at heights of 0.8, 1.6, and 5.2 m from the base of the wall (sets E01, E02, and E03, respectively), as illustrated in Figure 1. Survey targets were attached to the exposed wrap-around facing at 1.6, 2.8, 4.0, and 5.2 m from the base of the wall to measure facing displacements. Portelinha et al. (2014) provide further details regarding the GRS wall instrumentation program.

3. LABORATORY TIME-DEPENDENT TENSILE TESTS

3.1 In-isolation creep tests

The in-isolation creep tests for the geotextiles were conducted following the ASTM D5262 testing procedure. The tests involved the nonwoven geotextile specimens being subjected to sustained loads of 5% (1 kN/m), 10% (2 kN/m), and 20% (4 kN/m) of the ultimate tensile strength of each material.

3.2 In-soil creep tests

Specific details regarding the novel in-soil time-dependent apparatus are described by Costa (2004). Figure 3 illustrates the in-soil apparatus. The reinforced soil system is located within a rigid metal box, with one side forming a transparent glass wall. The reinforced soil system exhibits a symmetric geometry and basically involves geosynthetic reinforcement between two compacted soil layers. The other two lateral steel plates, which are perpendicular to the glass wall, are free to move in the horizontal direction by using small wheels running along rails that are fixed at the bottom of the metallic container. The reinforced soil is compacted over two cars (plates with wheels) and is also free to move horizontally. The cars run internally along rails of which the spacing between both cars imposes a potential failure surface. The wheel system allows the cars to run over the rails without friction. The geotextile ends are fixed to two opposite clamps located internally to the moving walls, but connected to an external frame by means of a rod with a load cell between the clamps and walls. The frame is also free to move, and the relative displacements between the frame and moving front wall allow for measurement of the mobilized tensile loads during testing. Vertical stress is applied over a rigid plate on top of the reinforced soil unit by using dead loads and a lever arm, as shown in Figure 3. For the tests, the geosynthetic sample (200 × 200 mm) was embedded between two 100 mm-thick soil layers. To ensure a plane strain condition throughout the test, the adhesion between the sidewalls and soil was reduced by creating a lubrication layer at the interface, which consists of a transparent latex sheet and thin layer of silicon grease. The working principle of this equipment consists of applying vertical stress on the top of the reinforced soil unit, resulting in horizontal forces being transferred to the moving walls and external frame. While the geosynthetic is strained, the internal clamp tends to restrict the wall movement, resulting in a reaction force between the clamp and frame. This force consists of the tensile load mobilized by the reinforcement. In this apparatus, the soil stress path is similar to the active earth pressure condition. Instruments were used to monitor tensile loads and internal displacements. A load cell located between the external frame and clamps allowed for measurement of the horizontal loads mobilized by the geosynthetic reinforcements. Furthermore, internal displacements were obtained by using wire extensometers. This technique involved one end of the inextensible wires being attached to different points along the geotextile length, while the other end was attached to positioning sensors (potentiometers) with 0.001 mm precision. The relative displacements between two wire extensometers allowed for the calculation of reinforcement strains.

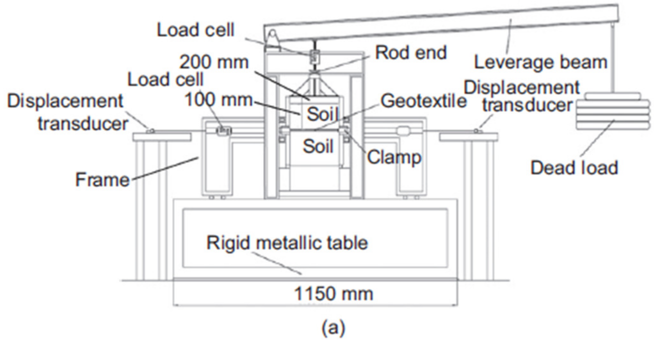

Figure 3. In-soil laboratory time-dependent test apparatus (Costa 2004).

3.3 Scope of laboratory testing program

As summarized in Table 1, in-isolation and in-soil time dependent tests were performed as part of this investigation. The same soil and geosynthetics used in the full-scale GRS wall were used in the laboratory program. In-soil time-dependent tests were performed to simulate the geosynthetic-reinforced layers of the instrumented GRS sections described previously. Accordingly, in-soil tests were conducted with constant vertical stress of 140, 200, 300, and 400 kPa to reproduce the vertical stresses expected to occur in the three monitored layers of the GRS wall (see Figure 1). All tests were performed with soil compacted at the optimum water content (11%) and at 98% of standard Proctor compaction density.

Table 1. Properties of the soil used as backfill material

Designation	Testing program	Geosynthetic	σ1 (kPa) or T (kN/m)	σ3 (kPa)
NW In-isolation	In-isolation creep tests	Nonwoven geotextile	5% to 20% of Tult	0
NW In-soil In-soil	time dependent tests	Nonwoven geotextile	140 to 400	—

4. RESULTS AND DISCUSSIONS

The results of the in-isolation creep tests for the nonwoven geotextiles are illustrated in Figure 4. In-isolation creep tests were conducted using 5, 10, and 20% of the tensile strength of the geosynthetic material. The load level is also indicated in the figure.

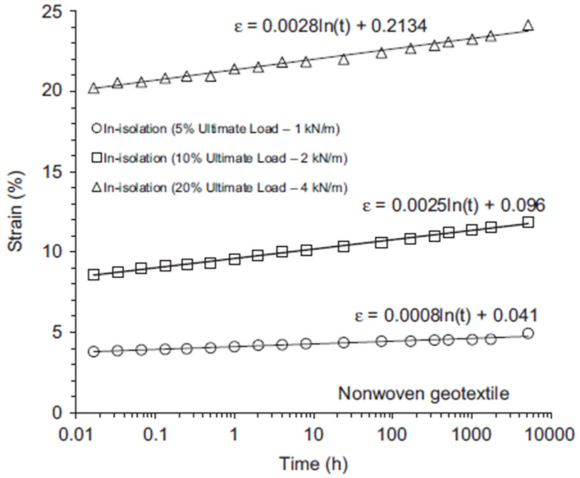

Figure 4. Results of in-isolation creep tests for nonwoven geotextiles.

Results of the laboratory in-soil time-dependent tests using nonwoven geotextiles are presented in Figures 5. The figure shows the progression of strains with time for the in-soil tests conducted with nonwoven geotextiles. For the nonwoven geotextiles, the total strains obtained after 120 h of testing were 0.9%, 1.8%, 5.4%, and 6.5% for normal stresses of 140, 200, 300, and 400 kPa, respectively. In general, strain rates are observed to be higher when high vertical stresses are applied. This fact can be attributed to the stress state being close to that of soil failure with 300 and 400 kPa of vertical stress.

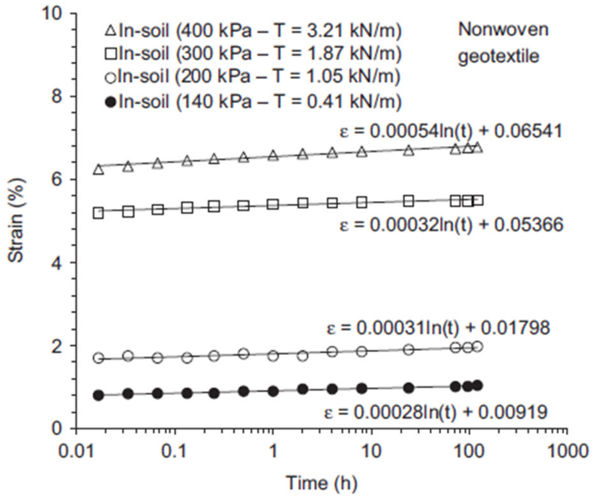

Figure 5. Results of in-soil creep tests for nonwoven geotextiles.

As mentioned previously, laboratory creep tests were conducted using the same geotextile reinforcements and fill materials as the full-scale GRS wall, which allows for comparison between the two approaches. The time dependent data of both instrumented full-scale walls are compared to the results of the laboratory creep tests in Figure 6. In this figure, the creep results from in-soil and in-isolation tests of the nonwoven geotextile reinforcement are compared to the time-dependent field behavior of the nonwoven geotextile section. The instrumented layers E02 and E03 were used for the comparisons. To make fair comparisons, the geosynthetic strains obtained from the GRS walls were converted to load by using the reinforcement stiffness from in-isolation isochronous creep curves as reported by Walters et al. (2002). Considering the loading time of 1000 h at 5% strain, the stiffness from the in-isolation creep isochronous approach corresponds to values of 25 kN/m for the nonwoven geotextiles. However, the study by Walters et al. (2002) is accurate for geogrid and woven geotextile reinforcements. Accordingly, the estimated field tensile load of the nonwoven geotextile may be higher than expected, as the effect of soil confinement is not considered in the in-isolation tests. The results indicate that the time dependent strains are underestimated by the in-soil laboratory creep tests, because the values of parameter α were generally lower than those observed in the GRS wall. The creep rates in the nonwoven geotextile section were five to seven times higher than those from the in-soil laboratory tests. However, the results obtained from the in-isolation creep tests demonstrate strains rates that are more consistent with those resulting from the GRS sections. The creep strain rates from the in-isolation laboratory tests were significantly lower than those obtained in the GRS wall, thus underestimating the creep behavior. However, the GRS wall creep behaviors were compared to the laboratory tests without considering potential chemical degradation (which was minimal in all cases) and installation damage, which can significantly affect reinforcement creep behavior. Furthermore, the wetting and drying process during the design life influences the soil strength and stiffness, which was not considered in the laboratory tests.

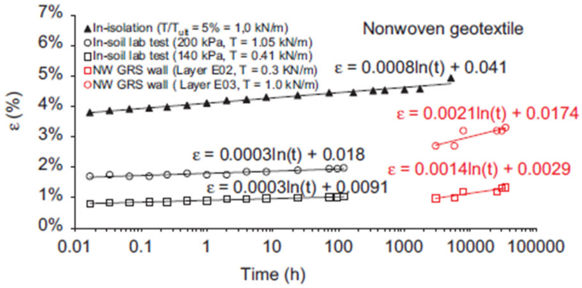

Figure 6. Comparison of time-dependent strains between laboratory tests and the instrumented GRS full-scale wall responses.

5. CONCLUSIONS

Specific important conclusions and discussion points from this study are summarized as follows:

- In-soil versus in-isolation laboratory tests: The in-soil apparatus used in this study allows for geotextile tensile load and strain monitoring during the tests. With this apparatus, a load is applied to the geosynthetic through the surrounding soil. The in-soil test data demonstrate that the mobilized tensile loads of both geotextiles were quite similar for different soil vertical stresses. In general, the strains rates were observed to be higher when high vertical stresses were applied. This can be attributed to the stress state being close to that of soil failure when higher vertical stresses are applied. A combination of stress relaxation and creep occurs during the test, as neither the loads nor strains are constant. In the beginning of the test, stress relaxation is predominant; after this period, creep is predominant. Stress relaxation appears to be greater in the tests conducted with woven than with nonwoven geotextiles. Under lower vertical stresses, the time-dependent behavior is observed to be similar, which is attributed to the stress state not reaching that of soil failure. The creep rates of the in-isolation nonwoven geotextile are found to be five times higher than the in-soil creep rates.
- Full-scale GRS wall versus laboratory time-dependent behaviors: The study allows us to conclude that the time-dependent behavior was underestimated from the results of in-soil laboratory creep tests, since creep rates were generally lower than those observed in the GRS wall. On the other hand, the results obtained from the in-isolation creep tests show more consistent creep strain rates than those from the GRS sections. However, the GRS wall time-dependent behaviors were compared to laboratory tests without considering potential chemical degradation (which was minimal in all cases) and installation damage, which can significantly affect the creep behavior of reinforcements. Additionally, wetting and drying processes during design life influences soil strength and stiffness, which was not considered in laboratory tests. All these variables led to increasing creep behavior in the GRS wall sections. Accordingly, it was found that in-isolation creep tests are sufficiently accurate to estimate the time-dependent behavior of geotextile reinforced soil walls.

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