# Time-Dependent Deformations of Geotextile-Reinforced Walls in Reduced-Scale Models

C.M.L. Costa, Federal Center of Technological Education, Maceió, Brazil
J.G. Zornberg, University of Texas at Austin, Austin, USA
B.S. Bueno, University of São Paulo, São Carlos, Brazil
Y.D. Costa, Federal Rural University of Pernambuco, Recife, Brazil
P.C. Lodi, São Paulo State University, Ilha Solteira, Brazil

Costa, C.M.L., Zornberg, J.G., Bueno, B.S., Costa, Y.D., and Lodi, P.C. (2008). "Time-Dependent Deformations of Geotextile-Reinforced Walls in Reduced-Scale Models." Proceedings of *GeoAmericas 2008,* the First PanAmerican Geosynthetics Conference and Exhibition, Cancún, Mexico, 2-5 March, pp. 1434-1439.

ABSTRACT
This paper presents centrifuge tests performed to investigate the time-dependent deformations of geotextile-reinforced soil walls. The models were built using nonwoven fabrics as reinforcement elements and a pure dry sand. Digital image analysis techniques were used to determine the displacement of sand markers placed along reinforcement layers in reduced-scale models. The instrumentation also included one LVDT to monitor the settlement at the top of the models and thermocouples to monitor the temperature inside the centrifuge. Two series of centrifuge tests were performed in this investigation. In some tests, designated herein as "short-term tests", the models were loaded until failure increasing the centrifugal acceleration. In the second series of tests, "long-term tests", the models were subjected to a constant acceleration and the wall deformations were observed with time**.** The results showed that the time-dependent behavior of reinforcement had an adverse effect on wall stability.

RESUMO
Este artigo apresenta ensaios em centrífuga realizados para investigar as deformações ao longo do tempo de muros de solo reforçado com geotêxteis. Os modelos foram construídos utilizando-se mantas não tecidas como elementos de reforço e uma areia pura. Técnicas para análise de imagens digitais foram usadas para determinar o deslocamento de marcos de areia dispostos ao longo das camadas de reforço nos modelos. A instrumentação foi ainda composta por um *LVDT* para monitorar os recalques no topo dos modelos e termopares para registrar a temperatura dentro da centrífuga. Duas séries de ensaios foram realizadas nesse estudo. Em alguns ensaios, designados como "ensaios de curto prazo", os modelos foram carregados até a ruptura, aumentando-se a aceleração centrífuga. Na segunda série, "ensaios de longa duração", os modelos foram submetidos a uma aceleração constante, observando-se a movimentação da estrutura ao longo do tempo. Os resultados mostraram que o comportamento dependente do tempo do reforço afetou a estabilidade do muro.

## 1. INTRODUCTION

Geosynthetic-reinforced soil (GRS) walls have been used worldwide as a result of their technical and economical advantages. However, despite the advantages, the geosynthetics undergo time-dependent deformation under tensile stresses. This behavior is usually taken into account in design by applying a reduction factor to the ultimate strength of the geosynthetic.

Typically, the long-term behavior of the GRS structure is based on reinforcement creep tests without soil confinement. However, the long-term deformation in GRS walls may be affected by the interaction between the reinforcement and the soil. Few studies are available on time-dependent interactive behavior between soil and geosynthetic and this topic has been mainly studied with laboratory performance test (Helwany and Shih 1998, Ketchart and Wu 2002).

Wu and Helwany (1996) conducted laboratory tests to investigate the long-term deformation of geosynthetic-soil composites under a constant applied stress. The study suggests that if the confining soil has a tendency to creep faster than the geosynthetic. Thus, the reinforcement imposes a restraining effect on the deformation of the soil through the adhesion (friction and/or cohesion) between the two materials. On the other hand, if the geosynthetic creeps faster than the confining soil, the soil will restrain the reinforcement deformation. However, there are many uncertainties regarding this interactive behavior to be elucidated.

This paper presents a series of centrifuge model tests performed to investigate the time-dependent interactive behavior between the soil and the geotextile in GRS walls. This investigation attempts to contribute for a better understanding of the long-term behavior of these structures.

## 2. CARACTERISTICS OF CENTRIFUGE MODELS

The centrifuge tests were performed using the 15 g-ton geotechnical centrifuge at the University of Colorado at Boulder. The models were built using a pure sand and commercially available interfacing fabrics were used to simulate the reinforcements in centrifuge tests. A box with inside dimensions of 419 mm x 203 mm in plan, and 300 mm in height was used to house the models. A transparent Plexiglas plate lined with a Mylar sheet was used as one of the side walls of the box to enable in-flight visualization of the models during testing. The other walls of the box were aluminum plates lined with Teflon to minimize side friction.

Figure 1 shows the basic geometry of the models. The model walls were built with a height of 229 mm on a 25.4-mm thick foundation. The facing was extensible (i.e. wrapped-around reinforcements) and inclined at an angle of $85^0$ to the horizontal. Air dried Monterey No. 30 sand was used as backfill material and foundation soil. The sand was pluviated though air under controlled condition to give a relative density of 70% (wall) and 100% (foundation layer). Twelve layers of reinforcement were used in the models, which corresponds to reinforcement spacing of 19 mm. All models were built using a reinforcement length of 203 mm. The layer designation adopted herein is also showed in Figure 1. Layer 1 corresponds to the bottom layer, while layer 12 indicates the top reinforcement layer.

Regarding sand and reinforcement properties, the Monterey n. 30 sand is uniformly graded sand, classified as SP in the Unified System. The friction peak angle obtained from triaxial compression tests for the relative density of 70% is about $36^0$. The nonwoven interfacing fabric used as reinforcement is manufactured by *Pellon Division of Freudenberg Nonwovens* and it is commercially designated as Pellon Sew-in. This material is a 100% polyester fabric with a mass per unit area of 23 g/m$^2$, and an unconfined ultimate tensile strength of 0.033 kN/m, measured from wide-width strip tensile tests (ASTM D4595).

The instrumentation of the models included one linear variable displacement transducer (LVDT) used to observe vertical settlement at the top of the model (Fig. 1) and thermocouples to monitor the temperature inside the models.
Black colored sand markers were placed along the Plexiglas wall at each reinforcement layer. The movement of the markers was monitored using a digital image acquisition system and it is used in this investigation to determine the strain distributions along the reinforcement layers.

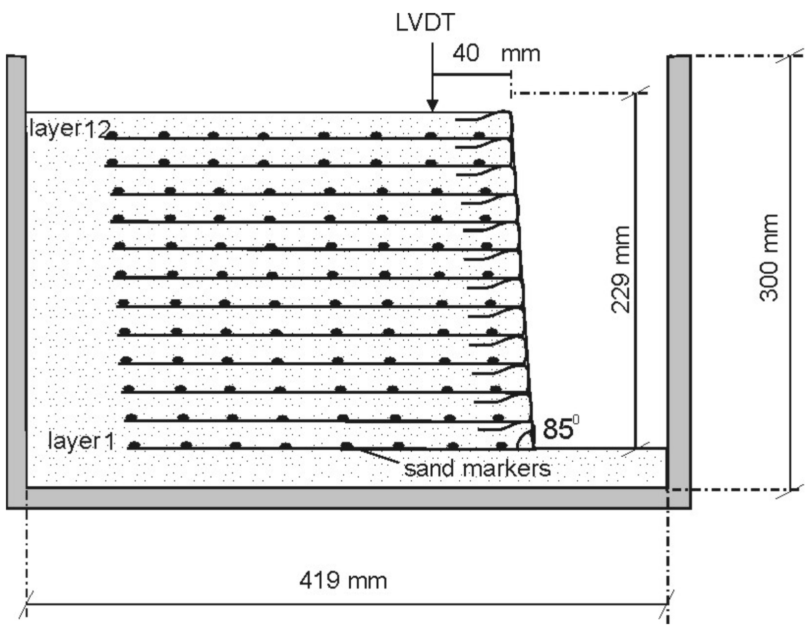


Figure 1. Layout of the models.

## 3. CENTRIFUGE TESTING PROGRAM

Two series of centrifuge tests were performed in this investigation. Model F1 (see Table 1), designated herein as “short-term test” was loaded until failure increasing the centrifugal acceleration. The main purpose of the short-term test was to identify the short-term strength and failure mechanism of the structure. Two additional tests (F2 and F3) were conducted to evaluate the repeatability of the test results.

In the second series of tests (model C1 to C4) the models were subjected to a constant acceleration of 25, 40, 60 and 80% of acceleration at failure based on previous short-term tests. For most tests, the deformation behavior of the model under a constant centrifugal acceleration was observed for 10 hours. These tests were conducted to evaluate the long-term behavior of the structure.

Table 1. Centrifuge tests

| Model | Type of test | Centrifugal acceleration level for long-term tests (% $N_f$) |
|---|---|---|
| F1 | Short-term | - |
| F2 | (failure) | - |
| F3 | | - |
| C1 | Long-Term | 25 |
| C2 | (creep) | 40 |
| C3 | | 60 |
| C4 | | 80 |

## 4. PROCEDURE TO OBTAIN REINFORCEMENT STRAIN DISTRIBUTIONS

The images collected from the acquisition system were analyzed using the same procedure described by Zornberg and Arriaga (2003). The analysis of the digital images involved the determination of the spatial coordinates of the sand markers for each desired image in centrifuge test. Relative displacements between sand markers were defined using the database of marker coordinates obtained throughout the test. For each reinforcement layer, the marker closest to the face was considered the reference point for determination of relative distances between markers. The displacement distribution data was fitted to same sigmoid curve used by Zornberg (1994). The expression [1] shows the sigmoid function used to fit the displacements.

$$d = \frac{1}{a + b \cdot e^{-cx}} \qquad [1]$$

where d is the marker displacement at a given image, x is the distance between the marker and the corresponding reference marker, "e" is the natural logarithm base, and a, b, and c are parameters defined by fitting the displacement data to the sigmoid curve using least squares techniques.

The geotextile strain distribution was then calculated as the derivative of the displacement distribution function. The strain distribution calculated adopting this procedure shows zero strain values at the face of the wall and at the embedded end of the reinforcement. This trend is consistent with the behavior of geosynthetic-reinforced strucutures with extensible facing. Further details can be found in Zornberg and Arriaga (2003).

## 5. TEST RESULTS

Table 2 presents the g-level at failure for the short-term tests and demonstrates the good repeatability of the results. The average value was adopted to calculate the centrifugal acceleration for the long-term tests. Figures 2 shows the displacement data and the sigmoid curve fitted for Model F3, layer 10. Figure 3 presents the strain distribution for the same model and reinforcement layer. As shown in the Figure 2, displacement data can be fitted reasonably well by the sigmoid function. Displacement information obtained for all models is provided by Costa (2004).

Table 2. G-level at failure for short-term tests

| Model | g-level at failure for short-term tests ($N_f$) |
|---|---|
| F1 | 20 |
| F2 | 19 |
| F3 | 21 |

Figure 4 shows the time-dependent settlement for the models subjected to constant centrifugal acceleration (long-tem tests). Settlements with time occurred for all models. The greater settlement rates were observed for the centrifugal acceleration equal to 80% of the acceleration at failure ($N_f$). For model C4, the wall failed after 4.3h. The thermocouples inside the models indicated only slight temperature variations that were considered insignificants for the purpose of this study.

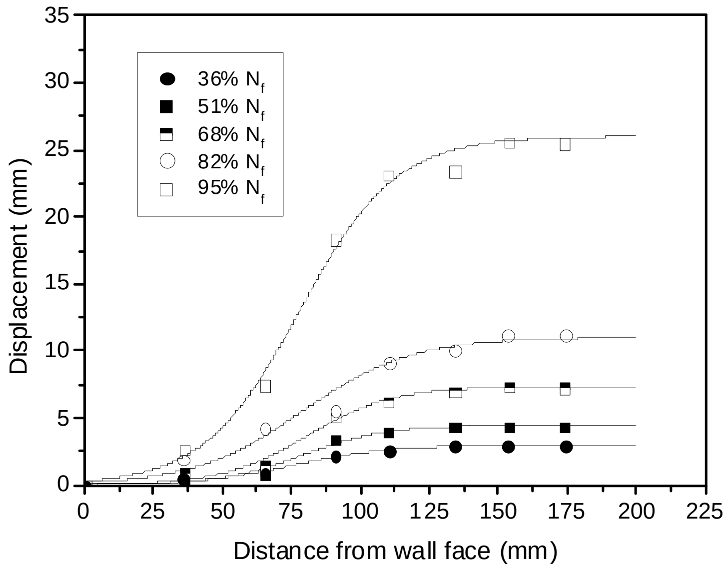


Figure 2. Displacement data and sigmoid curve for model F3, layer 10.

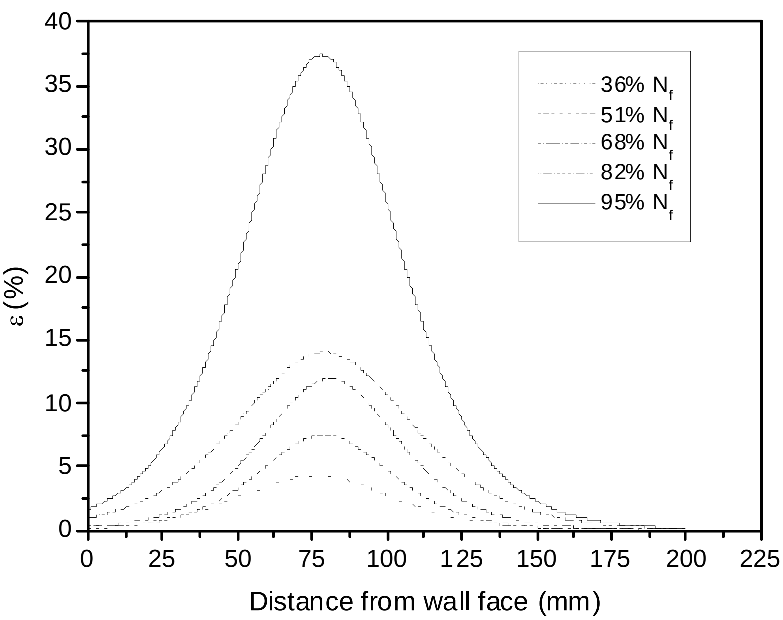


Figure 3. Strain distribution for model F3, layer 10

The maximum strain for reinforcement layers in Model C4 is shown in Figure 5. The values shown in the Figure for layers 5 to 12 were identified based on strain distribution curve obtained for each reinforcement layer. This figure also presents results of two conventional creep tests in accordance to ASTM 5262 for the fabrics used in this investigation. The applied load corresponds to 80% of the ultimate short-strength of the geotextile.

As shown in the figure, the models strains are inside the interval observed for the conventional tests and the strain rates were very similar for both conditions. This agreement was also obtained in terms of time to failure. The time for creep failure ranged from 1 to 5 hours for conventional tests (ASTM D5262) while the time for the model C4 to fail was about 4 hours.

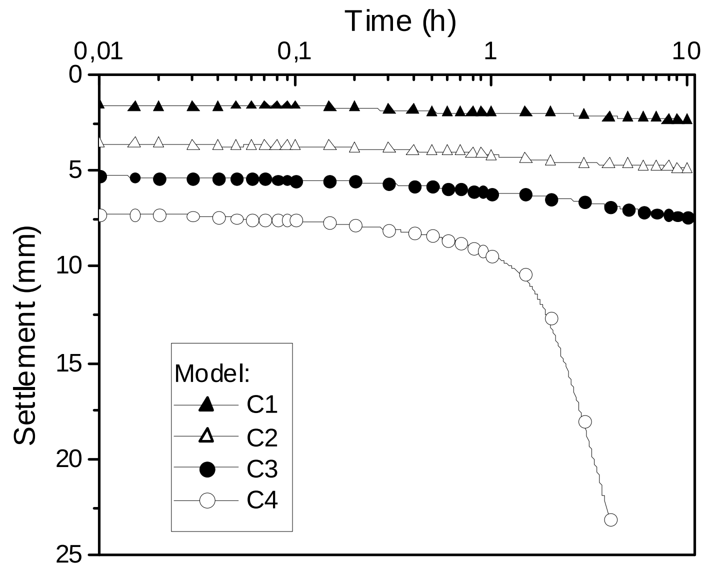


Figure 4. Settlement with time for long-term tests.

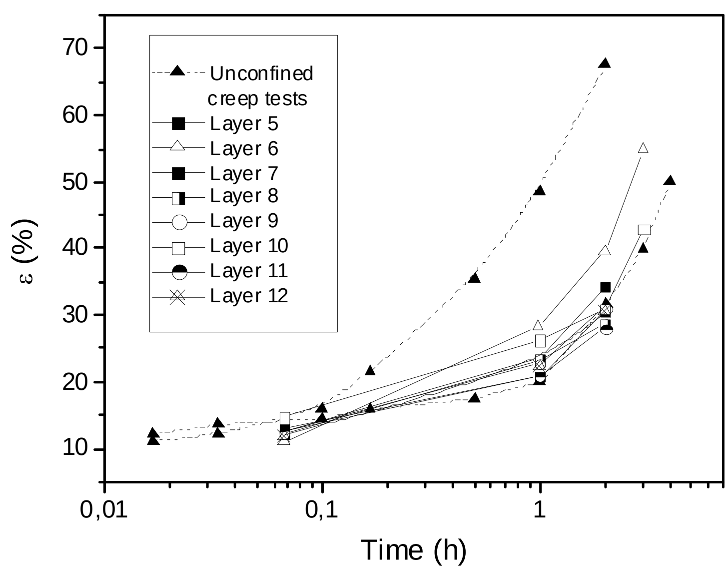


Figure 5. Strain with time for model C4 and for conventional creep tests.

It is important to highlight that the level of acceleration for long-term tests in respect to g-level at failure for short-term tests ($N_f$) does not imply that the reinforcements are subjected to the same load level in respect to material tensile strength. However this can be particularly true for the model C4 considering stress redistribution between reinforcement layers, i.e, at this level of centrifugal acceleration, all reinforcement layers are equally loaded. The stress redistribution was previously reported in the literature for geosynthetic-reinforced structure in centrifuge test (Jaber, 1989; Arriaga, 2003). This hypothesis is also very consistent since that confined tensile strength of the fabric used is independent of confinement stress level as shown by Zornberg et al. (1998). Thus, although the reinforcement layers are subjected to distinct confining stress it is possible to assume that similar strain between reinforcement layers implies similar loads.

The testing program carried out in this study revealed important aspects of the soil reinforcement interaction. Of particular relevance for the results is that the supposed lower ability of the sand to creep could not prevent the long-term deformation for the model C4.

## 5. CONCLUSIONS

This study was undertaken to investigate the time-dependent deformations of geotextiles considering the long-term interactive behavior between the reinforcement and the confining soil. The following conclusions can be drawn from the analysis of the results:

- Time-dependent deformations were observed in all long-term tests performed in this study. The reinforcement strains with time for the model subjected to the higher centrifugal acceleration were very similar to strains measured in conventional creep tests for the reinforcement.
- The results clearly indicate the interference of the time-dependent behavior of the geotextiles in wall stability. The model subjected to the higher centrifugal acceleration failed after few hour of test.
- The soil used in the models, typically considered as a soil with negligible creep, could not prevent the deformation and the long-term rupture of the model C4.

## REFERENCES

ASTM D5262 - Standard test method for evaluating the unconfined tension creep behavior of geosynthetics. *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA.

Arriaga, F. (2003). Response of geosynthetic-reinforced structures under working stress and failure conditions. Boulder, Ph.D. Thesis, University of Colorado at Boulder, 205p..

Costa, C. M. L. (2004). Time-dependent deformations in geotextile reinforced soil walls, Ph.D. Thesis, School of Engineering at Sao Carlos, University of Sao Paulo, Sao Carlos, 330p.

Helwany, S. M. B. and Shin, S. (1998). Creep and stress relaxation of geotextile-reinforced soils, *Geosynthetics International*, 5: 425-434.

Jaber, M. B. (1989). Behavior of reinforced soil walls in centrifuge model tests. Berkeley, Ph.D. Thesis, University of California, Berkeley, 239p.

Ketchart, K. and Wu, J.T.H. (2002). A modified soil-geosynthetic interactive performance test for evaluating deformation behavior of GRS structures, *Geotechnical Testing Journal*, 25: 1-9.

Wu, J. T. H. and Helwany, S. M. B. (1996). A performance test for assessment of long-term creep behavior of soil-geosynthetic composites, *Geosynthetics International*, 3: 107-124.

Zornberg, J. G. (1994). Performance of geotextile-reinforced soil structures. Ph.D. Thesis, University of California, Berkeley.

Zornberg, J. G., Sitar, N., and Mitchell, J. K. (1998). Limit equilibrium as basis for design of geosynthetic-reinforced slopes, *Journal of Geotechnical and Geoenvironmental Engineering*, 124: 684-698.

Zornberg, J. G. and Arriaga, F (2003). Strain Distribution within Geosynthetic-Reinforced Slopes, *Journal of Geotechnical and Geoenvironmental Engineering*, 129: 32-45.