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Comparison between field monitoring and numerical results of a woven geotextile-reinforced soil retaining wall

Résultats du champ et modelage d'un sol retenant renforcé par un geotextile tissé

C.V.S. Benjamim & B.S. Bueno
University of São Paulo, São Carlos, Brazil
J.G. Zornberg
The University of Texas at Austin, USA

ABSTRACT
The use of geotextiles as reinforcements in soil retaining walls may result in significant benefits over the use of other reinforcement with other inclusions such as metallic strips or geogrids. However, the lack of a good understanding of the actual behavior of geotextile-reinforced structures, mainly regarding expected deformations, has prevented widespread utilization of this approach. To contribute for a better understanding of the behavior of geotextile-reinforced soil structures, monitoring of full-scale structures and a further characterization of the materials is needed. Accordingly, eight geotextile-reinforced soil structures were built and instrumented to analyze their behavior. This paper presents the field monitoring results and finite element analyses conducted to analyze the behavior of one of these structures. The results show that current design procedures are conservative, and that the displacements are smaller than expected. The numerical simulation results showed that the Finite Element Method (FEM) is a useful tool to predict the response of structures reinforced with geosynthetics, since the values collected from field instrumentation are very similar to those obtained from numerical simulation.

RÉSUMÉ
Le Sol Retenant Renforcé par un Geotextile peut avoir plusieurs avantages par-dessus les murs renforcés avec les autres inclusions telles que Terre Renforcée. Ceci inclut la facilite de construction, l'opportunité, et une réduction significative des coûts. Cependant, le manque d'une bonne compréhension comme le véritable comportement du geotextile a renforcé des structures, principalement en ce qui concerne les déplacements, a évité une plus grande utilisation de ce genre de solution. Pour contribuer pour une meilleure compréhension du comportement des structures du sol renforcé avec geotextile, l'observation du comportement des structures de grande envergure et une plus ample caractérisation des matériels sont nécessaires. En conséquence, une série de huit structures de sol renforcé avec geotextile a été construite et teste avec des instruments pour analyser le comportement de ce genre de structure. Ce papier présente le champ contrôlant les résultats et les analyses avec des éléments finis, en ce qui concerne le comportement d'une de ces structures. Les résultats montrent à ces méthodes d'équilibre limite sont très conservateurs. La simulation numérique résulte a montrer que le MEF est un outil utile pour prédire la réponse de structures renforcées avec geosynthetics, puisque les valeurs de l'instrumentation étaient très similaires à celles obtenues avec la simulation numérique.

1 INTRODUCTION

The use of geotextiles in reinforced retaining walls may present several advantages in relation to the use of other reinforcement inclusions. This includes ease of construction, expediency, possible lateral drainage, and significant reduction in costs. However, despite these important advantages related to the utilization of geotextiles as reinforcement, most retaining walls around the world use more conventional solutions such as geogrids and metallic reinforcements. The lack of field monitoring data regarding the actual behavior of these structures, mainly in terms of displacements, has certainly prevented a broader use of this reinforced soil technology.

Several aspects related to the behavior of geotextile-reinforced soil structures needs further insight, such as the stress distribution within the backfill, the deformability of reinforcement materials under the confinement of soil, and the actual failure mechanisms.

The difficulty in predicting the behavior of this type of structure using current design methods has been reported in previous studies. A good example is the structure reported by Wu (1992), who collected predictions from several investigators on the behavior of a highly instrumented reinforced soil structure. The predicted results showed a significant dispersion when compared to the monitored response of the prototype. Many factors have contributed to such discrepancy. Among them, the contribution of suction to the shear strength of the soil, the increased stiffness of reinforcement under the confinement of soil, and the contribution of soil arching to the stability of the structure. In summary, field observation of the behavior of prototypes and suitable characterization of the involved materials are still necessary. However, the instrumentation of field prototypes is expensive, and field data often focuses only limited aspects governing the overall behavior of these structures.

To address these shortcomings, eight geotextile-reinforced soil walls were built and instrumented in the vicinity of the University of Sao Paulo at Sao Carlos. The preliminary results from one of these walls, constructed with sandy soil and nonwoven geotextile, can be found in Benjamim et al (2003). This paper presents preliminary information collected from another prototype, constructed using woven geotextiles and the same sandy soil.

2 MATERIAL AND METHODS

2.1 *Overview*

The prototype was constructed using wrap-around facing. The dimensions of the wall were selected as 4m wide, 4m high and 4m long. The prototypes were built in pairs (two walls were placed in a row back-to-back) and were confined laterally by two longitudinal wooden walls. In addition, plastic greased membranes were placed on the wooden walls in order to minimize lateral friction between the soil and the wood structure. Figure 1 shows a picture of the prototype.

The wall was built using 10 geotextile layers placed with a vertical spacing of 0.40m. The structure was constructed over a 0.40m reinforced base layer of dense sand to increase its external stability. The wrap-around system was constructed using metallic supports and wood boards. The inclination of the facing is 78° to the vertical, which corresponds to a face slope of 1:5. The backfill soil was compacted using a vibratory plate. The relative density used in the construction of the walls was equal to 80%, resulting in a void ratio equal to 0.51 and a dry density equal to 1.77 g/cm^3.

Figure 1 – Geotextile reinforced soil retaining wall

2.2 *Material Characteristics*

A fine to medium well-graded sand was used to construct the soil backfill. Its grain size distribution is presented in Figure 2. The shear strength parameters of the soil were obtained from both direct shear and consolidated-drained triaxial tests, using the same relative density and water content used for field construction. The results of soil tests are listed in Table 1.

A polyester woven geotextile was chosen as reinforcement. The main characteristics of the geotextile are listed in the Table 2.

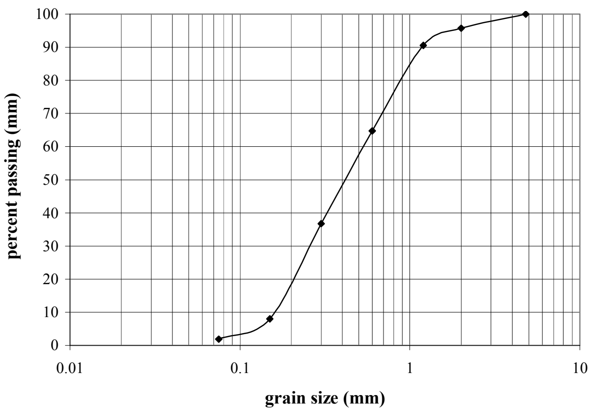

Figure 2 – Grain size distribution

Table 1 – Soil shear strength parameters

	Triaxial	*Direct shear*
Cohesion	16 kN/m^2	15 kN/m^2
Angle of internal friction	33°	32°

Table 2 – Geotextile characteristics

Mass per unit area	204.40 g/m^2
Thickness	1.26 mm
Ultimate tensile strength	13.94 kN/m
Ultimate elongation	22.67 %
Stiffness	61.49 kN/m

2.3 *Instrumentation*

The wall during and after the construction were monitored using three approaches, as follows: surveying to evaluate face displacements, magnetic extensometers to evaluate vertical settlements, and tell tails to monitor horizontal displacements within the reinforcements as well as on the wall facing. The results presented in this paper focus on the internal displacements of the reinforcements and face displacements measured using tell tails.

Tell tails consist of 0.35mm diameter stainless steel inextensible wires, running inside plastic tubes used to reduce friction and to protect the wires. One end of the tell tail is fixed to the geotextile and the free end is attached to a hanging weight, used to facilitate the displacement measurements (Figure 3). The free ends of the tell tails were located in a shaft constructed behind the wall. Measurements were made using a digital caliper with a resolution of 0.01mm. The displacements of the wall face were measured during and after construction by the tell tail attached to the face of the layer.

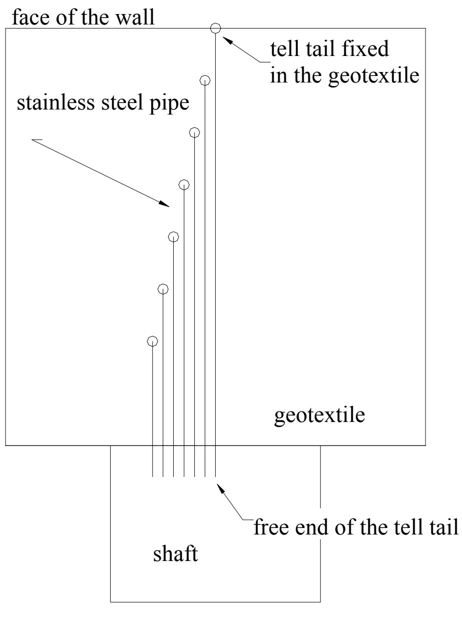

Figure 3 – Top view of the wall showing the distribution of the tell tails

3 FIELD MONITORING RESULTS

Geotextile strain values were obtained by calculating the relative movements between tell tail points and dividing them by the distance between these measuring points. Face and internal horizontal displacements were measured during and after the construction. Post-construction monitoring presented here is extend until 200 days after construction. Some of the collected field monitoring results is presented below.

3.1 *Horizontal strains within the reinforcements*

The horizontal reinforcement strains were generally very small during construction. The largest horizontal strains occurred near the face (Figure 4). The horizontal strains induced near the face took place mainly during construction, as soil rearrangement was observed after removing the wooden face supports.

The walls were subjected to a rainy season during the post-construction period. A decrease in soil suction and an increase in the weight of the wedge were expected during this period. However post-construction strains did not increase as expected and the results presented show that they were very small. The use of polyester geotextile, with comparatively high stiffness and low creep potential, may have contributed to the small magnitude of the recorded horizontal displacements. Figure 5 present the strain of the reinforcements after 200 days. The rows of points of maximum strain suggest the development of a possible active zone (Figure 5).

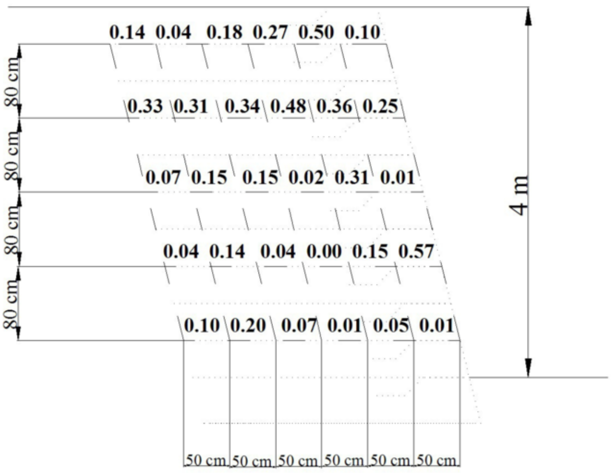

Figure 4 – Geotextile strains at the end of the construction (%)

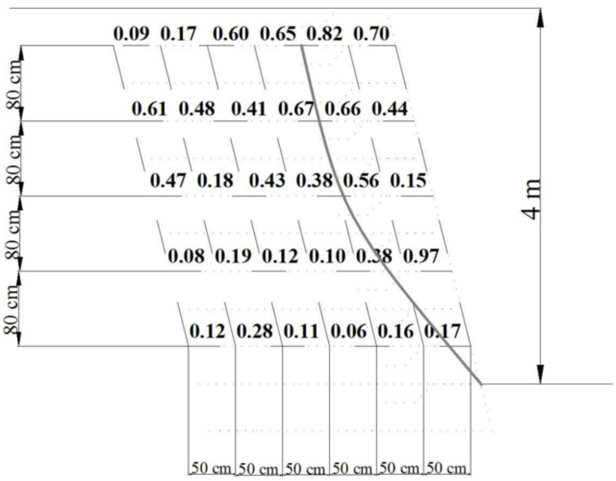

Figure 5 – Geotextile strains after 200 days of construction (%)

3.2 *Face displacements*

As expected, the horizontal displacements measured at the face were larger than those measured in the interior of the structure. However, most of these displacements are expected to be the result of accommodation of each layer during construction. External measurements were made in the middle of each layer (Figure 6).

Face displacements presented results varying from 0.5 to 2.0 cm, with the largest face displacements at approximately 2/3 of the height of the wall. Even though post-construction face displacement did occur, their magnitude is considered to be significantly small for this type of structure (less than 2.0 cm).

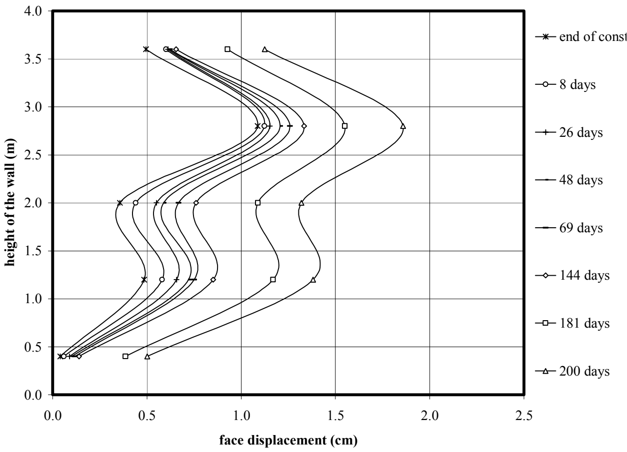

Figure 6 – Displacement of the wall face

4 NUMERICAL ANALYSES

Numerical simulations were performed in order to obtain additional information on the behavior of the prototype and to allow comparisons with instrumentation data. The simulations were performed using Plaxis (version 7.2). Figure 7 shows the mesh used in the analyses. The finite element method technique allows performing parametric studies to explore the sensitivity of the wall behavior to variables such as soil types, inclusions, layout and inclusions stiffness. Tables 3 and 4 list the material properties adopted for the analyses.

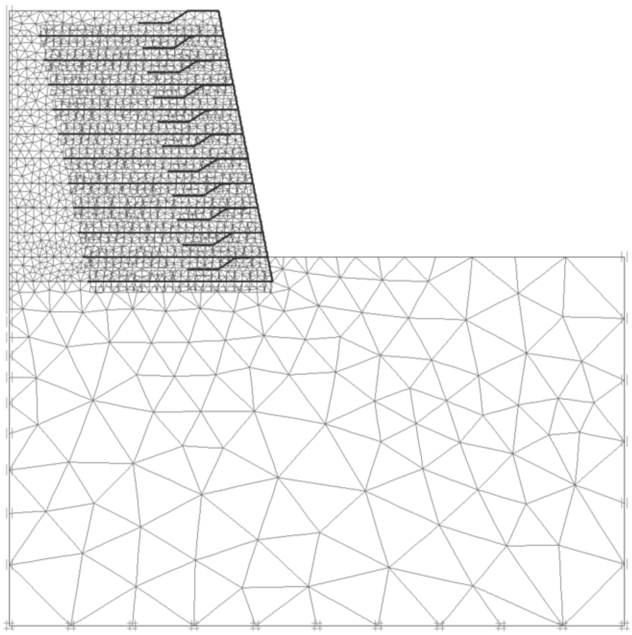

Figure 7 – FE Mesh of reinforced soil structure

The soil properties were adopted based on the results of laboratory triaxial tests conducted using soil specimens, with the same water content and unit weight of backfill soil used in wall construction. These backfill soil parameters are considered to be suitable for the numerical analyses, conducted to evaluate the wall movements at the end of the construction. However, the water content of the backfill soil, and consequently its suction and shear strength will be affected during the rainy season.

Table 3 – Parameters adopted for the soil

Model	hardening soil model
Condition	drained
Young's modulus	$5x10^4$ kN/m^2
Unit weight of the soil	18 kN/m^3
Cohesion	15 kN/m^2
Angle of internal friction	32^o
Dilantancy angle	10^o

Table 4 - Parameters adopted for the geotextile reinforcements

Stiffness	61.5 kN/m
Coefficient of soil-reinforcement interaction	0.65

Consequently, prediction of the post-construction behavior is more difficult to predict using FEM. it is harder to make a good prediction. The post-construction displacements were attributed to the rearrangement of the soil particles after the rainy season.

The horizontal displacements obtained from the numerical simulation are very similar to the results of the prototype instrumentation in the end of the construction. Consistent with the field monitoring results, the reinforcement strains obtained from numerical simulation were very small. Figure 8 shows the geotextile strains obtained from the numerical analysis. While small, the location of maximum reinforcement strains show an evidence of the development of a slip surface starting at the foot of the slope and propagating into the soil mass. Figure 9 shows an illustration of the output of Plaxis, showing the horizontal displacements of the backfill.

Comparing the results from the prototype field monitoring at the end of the construction, with the results from the numerical analysis using MEF, it can be observed the geotextile strains obtained from the field monitoring are slightly larger than the numerical analysis, mainly close to the face. Inside the soil backfill, these strains are more similar. That happened because the numerical analysis cannot consider the movements induced during construction near the face, which took place after removing the wooden face supports.

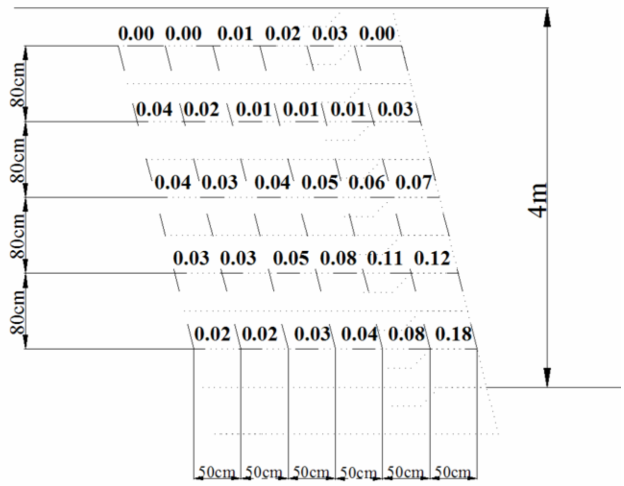

Figure 8 – Geotextile strains obtained by FEM (%)

5 SUMMARY AND CONCLUSIONS

A woven geotextile-reinforced wall was constructed to evaluate its deformation and provide confidence on the use of these reinforced soil structures. An extensive field monitoring program was conducted to measure horizontal internal reinforcement strains and face displacements. The horizontal reinforcement strains were very small (less than 1% after 200 days). The largest horizontal displacements occurred near the face, approximately at 2/3 of the height of the wall. Internal displacements occurred mainly during construction. As the internal horizontal displacements, face displacements are mainly due to the rearrangement of each layer that happened during the construction, since these external measurements were made in the middle of layers.

Although a decrease in shear strength was anticipated during the rainy season due to a decrease in soil suction and an increase in the weight of the wedge, post-construction strains did not increase as expected and the results presented show that they were very small. The use of polyester geotextile, with comparatively high stiffness and low creep potential, may have contributed to the small magnitude of the recorded horizontal displacements. The results of the numerical analyses showed that FEM is a useful tool to predict the behavior of structures reinforced with geosynthetics, since the field instrumentation results were very similar to those obtained with numerical simulations.

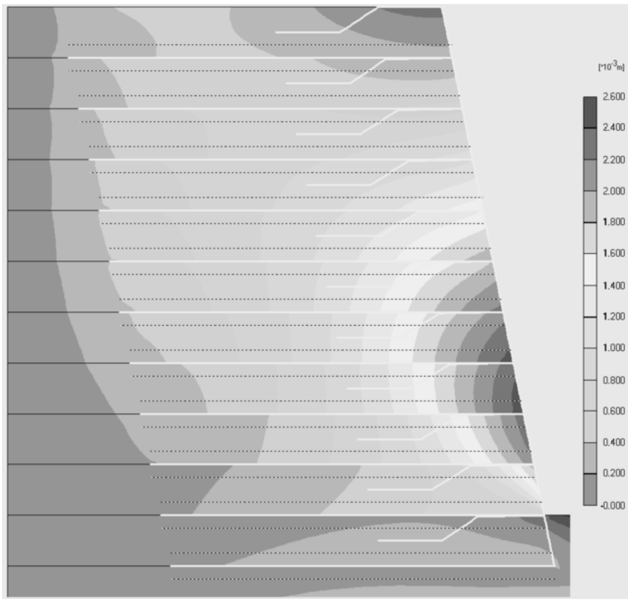

Figure 9 – Horizontal displacement of the backfill (mm)

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