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Field monitoring and numerical prediction of the response of a non-woven geotextile-reinforced wall

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ABSTRACT: This work presents data on the construction and instrumentation of an experimental geotextile-reinforced retaining wall prototype built as part of a research program carried out at the University of Sao Paulo at Sao Carlos. The prototype was built using a fine to medium sand as soil backfill and a non-woven geotextile as reinforcement. The geometry of the prototype was 4 m high, 4 m long and 4 m wide. After construction, the top of the structure became part of a private roadway open to traffic, especially trucks. The instrumentation program consisted of horizontal and vertical displacement transducers made of steel bars and magnetic plates, respectively, placed inside and outside the potential slip surface to investigate the global behavior of the structure. Field measurements showed that the largest horizontal and vertical displacements occurred inside the active zone, close to the wall face. The structure presented large post-construction displacements, attributed especially to the traffic loading on the top of the structure. Numerical simulations with Finite Element Method (FEM) were performed to evaluate a comparison between the simulated and measured results, and to simulate the stresses in the backfill and in the reinforcements. In general, the comparison between the measured and simulated results using FEM showed a very good agreement.

1 INTRODUCTION

The use of geotextiles in small 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 possible important advantages in utilizing geotextiles as reinforcement, most retaining walls around the world use conventional inclusions 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 precluded a broader use of this reinforced soil technology.

Several aspects related to the behavior of geotextile-reinforced soil structures need further investigation, such as stress distribution within the backfill, effect of confinement on the deformability of geotextile materials, and the actual failure mechanisms.

To address these shortcomings, one reinforced soil wall was built and instrumented in the vicinity of the University of Sao Paulo at Sao Carlos, in the backyard of a geotextile plant.

FEM analyses were performed to compare numerical results with field measurements. Furthermore, a stress strain analysis using FEM was carried out to simulate the stresses in the backfill and in the reinforcements.

2 MATERIALS AND METHODS

2.1 *Overview*

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/m^3 and an optimum water content equal to 9.0%.

2.2 *Material characteristics*

A fine to medium sand was used as soil backfill. 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 are summarized in Table 1.

Table 1. Soil shear strength parameters.

	Triaxial tests
Cohesion	9.7 kN/m^2
Internal friction angle	34°

A polyester, short fiber, non-woven geotextile was chosen as reinforcement (Geofort G-400). The main characteristics of the geotextile are listed in Table 2.

Table 2. Geotextile characteristics.

Mass per unit area	400 g/m^2
Thickness	3.8 mm
Ultimate tensile strength	25.7 kN/m
Secant Modulus (5% strain)	40 kN/m

2.3 *Instrumentation*

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 1 presents the geometry of the wall and the instrumentation layout used in the construction of the wall.

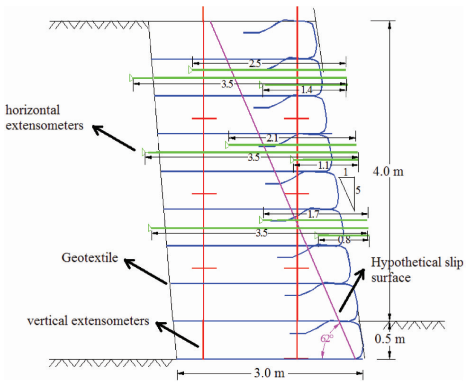

Figure 1. Geometry and instrumentation layout.

3 FIELD MONITORING RESULTS

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 2 and 3 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 3.75 m.

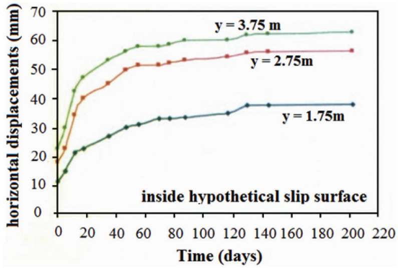

Figure 2. Horizontal displacements measured inside the hypothetical slip surface.

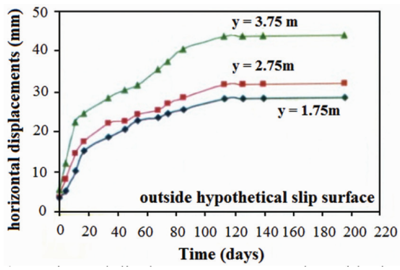

Figure 3. Horizontal displacements measured outside the hypothetical slip surface.

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. 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%.

Figures 4 and 5 present the vertical displacements referring to the extensometers placed within and outside the hypothetical slip surface, respectively, since the end of the construction until 202 days after construction. These magnetic extensometers were

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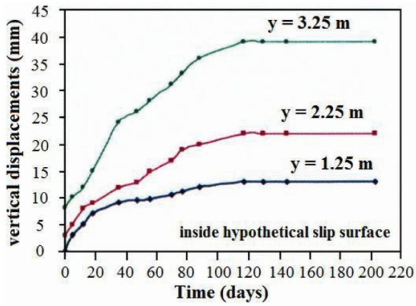

Figure 4. Vertical displacements measured inside the hypothetical slip surface.

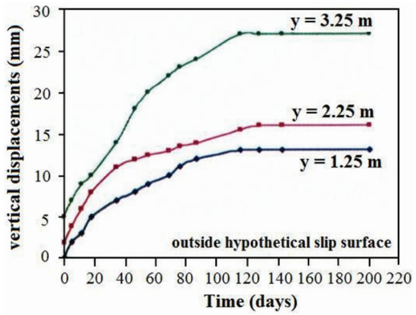

Figure 5. Vertical displacements measured outside the hypothetical slip surface.

placed at three different heights: 1.25 m, 2.25 m and 3.25 m.

In general, the vertical displacements were smaller than the horizontal measurements. The maximum vertical displacements during construction and 202 days after that, measured inside the hypothetical slip surface, reached 8 mm and 38 mm, respectively, at 3.25 m high.

The results for the extensometers placed outside the hypothetical slip surface reached 5 mm and 27 mm, respectively for the of construction and 202 days after that. At the same way that occurred for the horizontal displacements, the vertical displacements stopped after 120 days.

4 NUMERICAL ANALYSES

Numeric simulations were performed in order to obtain additional insight on the behavior of the prototype and to allow comparisons with instrumentation data. The simulations were performed using SSCOMPPC code, a Finite Element Analysis Program of Soil Structure Interaction and Compaction Effects (Boulanger et al., 1991).

A non linear hyperbolic soil model was used to model the soil (Duncan & Chang, 1970), and a linear elastic model was used to model the reinforcements. A manual procedure to correct the FEM mesh due to the displacements, which occurred at the end of each compacted layer, was implemented. This allowed following very closely the wall construction sequence. Soil parameters adopted for the numerical analyses are summarized in Table 4. Geotextile properties used in the analyses are the same as presented in Table 2. Figure 6 shows the mesh used in the analyses.

Table 4. Parameters adopted for the soil.

γ kN/m^3	K	n	Rf	Kb	m	c kPa	ϕ (°)	K_o	K_{ur}
17.8	963	0.42	1.0	212.4	0.0	9.7	34	0.44	1445

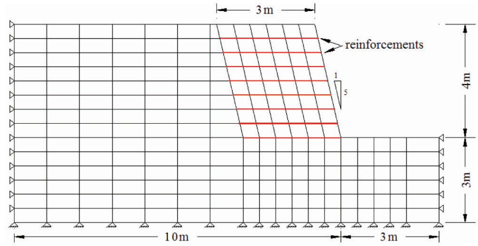

Figure 6. Mesh of reinforced soil.

The measured and simulated results using FEM showed a very good agreement. The comparison between the results from numerical simulations and field measurements at the end of constructions are presented in Figure 7, respectively for horizontal and vertical displacements.

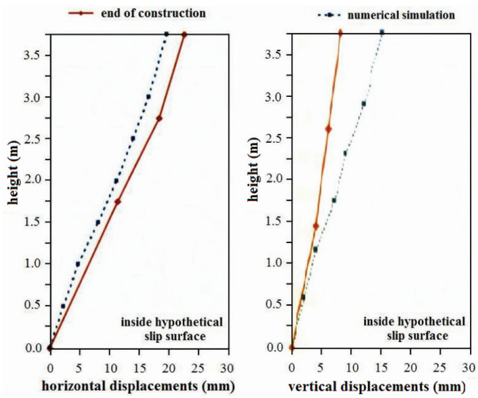

Figure 7. Displacements comparison between measured and simulated results.

The maximum horizontal displacement within the potential slip surface, obtained by the numerical simulation, was equal to 18 mm. The difference between the measured and the simulated results was equal to 13%

In relation to the vertical displacements, the simulated results were larger than those obtained by the field measurements.

Many factors can have contributed to this discrepancy, which were not taken into account in the design. Among them, the contribution of suction to the shear strength of the soil and its permanence with time, the increase of reinforcement stiffness with confinement and the arching effect that occurs in the backfill soil as relative movements between soil zones take place.

Figure 8 presents the maximum tensile load distribution obtained from the numerical analyses for each reinforcement layer. Although small, these tensile loads show a small evidence of the formation of a slip surface starting at the foot of the slope and propagating into the soil mass. A log spiral curve fitted very well to the numerical data differing substantially from a Rankine's (45° + ϕ/), indicated by the straight line in the figure.

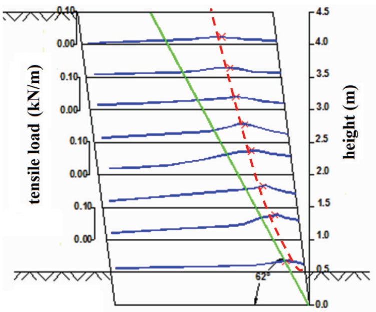

Figure 8. Indication of hypothetical slip surface.

Figure 9 presents the vertical stresses simulated by the FEM analysis. The results show that the stresses close to the face are smaller than the results calculated by the soil unit weight. After half of the reinforcement length, the vertical stresses became constant. This stress reduction is due to the backfill yielding close to the wall face.

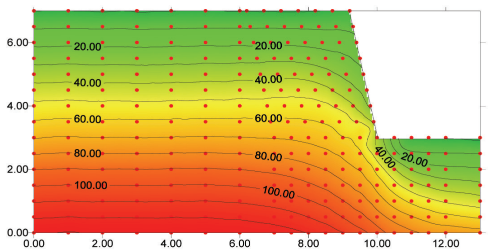

Figure 9. Vertical stresses in the reinforced backfill.

It was observed in the prototype results a rotation passing by the toe of the wall, as presented by the maximum shear strains of the backfill in Figure 10,

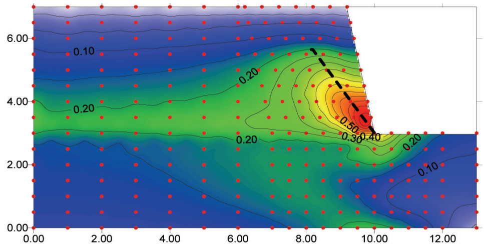

Figure 10. Maximum shear strains in the structure.

where occurred a shear strain concentration. The shear strain contours indicate a potential slip surface close to the wall, as shown by the dashed line.

5 SUMMARY AND CONCLUSIONS

A non-woven geotextile-reinforced wall was constructed to evaluate its deformation and provide confidence on the use of geotextiles for reinforced soil structures. An extensive field monitoring program was conducted to measure horizontal and vertical displacements inside and outside of the reinforced backfill.

The displacements at end of construction were very small; however the structure presented large post-construction displacements, especially due to traffic loading, stopping 120 days after the end of the construction.

The measured and simulated results using FEM showed a very good agreement, especially to the horizontal displacements. Besides that the Finite Element Method results showed peculiar vertical stress pattern with stress reduction close to the face of the wall.

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