Performance of a block-faced geogrid wall using fine-grained tropical soils

Performance d'un mur de sol renforcé par des géogrilles et face à des blocs utilisant des sols fins tropicaux

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ABSTRACT

This paper presents the results of an instrumented block-faced geogrid wall built in São José dos Campos, SP, Brazil. Fine-grained tropical soils were used as a backfill for the wall construction. The performance of the wall was good. Laboratory tests were carried out to determine the parameters. The wall height at the instrumented section was 4.2m. Monitoring was carried out for two months, including during the construction period. Reinforcement tension was measured through load cells at different locations in four different layers. A specific device was designed and used for monitoring vertical and horizontal internal loads on the blocks that composed the wall face. Topography, inclinometers and magnetic settlement plates were used for the measurement of internal and external movement. Total pressure cells at five different locations near the foundation level measured vertical stress. Comparisons between theoretical and measured values of tension in the reinforcement are also presented.

RÉSUMÉ

Cet article présente les résultats du monitorage d'un mur de sol renforcé par des géogrilles, face à des blocs préformés, construit à São José dos Campos (état de Sao Paulo, Brésil). Des sols fins tropicaux ont été utilisés comme matériaux d'atterrissement lors de la construction de ce mur. Le mur présente une bonne performance mécanique. Des tests de laboratoires ont été réalisés afin de déterminer les paramètres. La hauteur du mur dans la section instrumentée est de 4,2 m. Le monitorage a été effectué pendant deux mois incluant la période constructive. La tension des renforts a été mesurée au moyen de cellules de charge à différents endroits des quatre couches. Un équipement spécifique a été projeté et utilisé pour monitorer les efforts verticaux et horizontaux dans les blocs qui composent la face du mur. La topographie, l'inclinomètre et les plaques magnétiques de compression ont été utilisés pour mesurer les mouvements internes et externes. Des cellules de pression totale, placées à cinq endroits différents a proximité du niveau de fondation, ont permis de mesurer les tensions verticales. Enfin, une comparaison entre les valeurs théoriques et les mesures de tension du renfort est présentée.

Keywords: instrumentation, segmental geogrid wall, soil compaction, analysis, fine-grained tropical soil.

1 INTRODUCTION

Fine-grained residual soils have been widely used as a backfill for reinforced soil wall construction in Brazil. Good performances of these walls have been verified (Carvalho et al. 1986; Ehrlich et al. 1994; Bruno & Ehrlich, 1997; Ehrlich et al. 1997). Mori et al. (1979) discuss the properties of some typical compacted Brazilian saprolites. Tropical saprolites, no matter what their percentage of fines, generally show good compaction and workability characteristics. The compacted soil has high strength, low compressibility and low permeability, even when compacted with water content well above or below the Proctor optimum water content. This paper presents the results of an intensive monitoring program of a reinforced soil wall built with residual fine-grained soils located in São José dos Campos, Brasil (Riccio Filho, 2007). The wall is part of a link between Carvalho Pinto and Presidente Dutra highways. External and internal movements, stress on blocks that compose the wall face and tension in the reinforcements were monitored.

2 MATERIALS AND METHODS

2.1 *Materials*

The wall facing is composed of segmental pre-cast concrete blocks (TERRAE W type block) with geogrids being used as reinforcement (FORTRAC 55/30-20 & FORTRAC 35/20-20).

A deep soft clay deposit is found in the area. The wall was constructed on a piled concrete platform. The backfill material consisted of residual clayey silty sand. Two soil types were used as backfill: a yellow sandy clay (soil A), used from the top of the wall to 3.2m depth, and a red sandy clay (soil B), used from 3.2m to bottom of the wall at 4.2m depth. Table 1 presents the results of grain-size distribution and Atterberg limits for those soils. Dynapac CA 250 PD roller was used for soil compaction.

Table 1 – Soil characteristics.

Soil	≤ 2μm (%)	≤ 20μm (%)	≤ 2mm (%)	wL (%)	PI (%)
A	42	49	99	38	22
B	42	47	99	49	29

Table 2 shows the results of triaxial tests (CW – constant water content) carried out under conventional (axi-symmetric) and plane strain boundary conditions. The soil samples were compacted statically with a representative field moisture content and density. Tests were performed with constant water content and controlled air pressure inside the soil sample (atmospheric pressure). Pore-water pressure was measured during these tests. In Table 2 C_{eq} is the equivalent soil cohesion that includes the effect of pore-water suction on shear resistance.

doi:10.3233/978-1-60750-031-5-1877

Table 2. Triaxial tests results.

Soil	Boundary Condition	γ (kN/m³)	W (%)	ϕ' (°)	c_{eq} (kPa)
A	Plane Strain	16.7	20	36	60
	Axi-symmetric	16.5	21	25	42
B	Plane Strain	16.7	20	38	50
	Axi-symmetric	16.5	21	26	52

2.2 *Instrumentation*

The locations of monitoring instruments are shown in Figures 1 and 2. Load cells for the measurement of tension in the reinforcements were located in five different reinforcement layers (main section, P) with a redundancy section (12th layer, 1.8m depth, R2A set on main section and R2B set on the redundancy section). Each instrumented geogrid layer was monitored at four different points throughout its length. A specific device was designed and used for monitoring vertical and horizontal internal loads on blocks that composed the wall face. Total pressure cells at five different locations near foundation level measured vertical stresses; two of them represent measurement redundancy. Topography, inclinometers and magnetic settlement plates were used for the measurement of internal and external movements.

In Figure 1, P1 to P10 assign the location of the magnetic settlement plates and I1a, I1b and I2 the positions of the inclinometer measurements.

Monitoring was carried out for two months, including the construction period.

3 FIELD RESULTS

3.1 *Reinforcement Tension*

In Figure 3 shows the tension distributions measured in the reinforcements at the end of construction period.

Figure 4 shows the relationship between maximum reinforcement tension values and depth. Note that the measured values exhibit a tendency to be constant in relation to depth, in accordance with the predictions of Ehrlich & Mitchell (1994). High induced horizontal stress values due to compaction and low stiffness reinforcements lead to this behavior.

Figure 5 shows the results of tension measurements in reinforcement R4 (above the 17th soil layer) before, during and after compaction operations. An increase in peak stress may be seen in the reinforcement tension induced by the equipment operation, followed by an unloading to a residual tension value at the end. The residual value is much higher than the value found before soil compaction. The observed behavior is also in accordance with Ehrlich & Mitchell's (1994) predictions. It is interesting to note that the residual stress is not uniform along the length of the reinforcement. The final value for load cell set 3 was higher than the others.

3.2 *Instrumented Block Loads*

Figure 6 shows the measured verticals and horizontal internal loads acting on the instrumented block at different stages of wall construction. Vertical loads were measured at the frontal (V1) and rear (V2) parts of the block and horizontal forces (H) at the centre. At the end of construction, the measured horizontal force was equal to 41% of the vertical force acting on the block (V1 + V2).

In Figure 6 the dashed line indicates the calculated vertical loads corresponding to the self weight of the blocks full of gravel assuming the vertical piling of these blocks. Note that the actual facing inclination is not vertical but 1H:10V. Measured values were always higher than the ones calculated in Figure 6. These results indicate that there was friction mobilization at the soil block interface and backfill vertical stress transference to blocks.

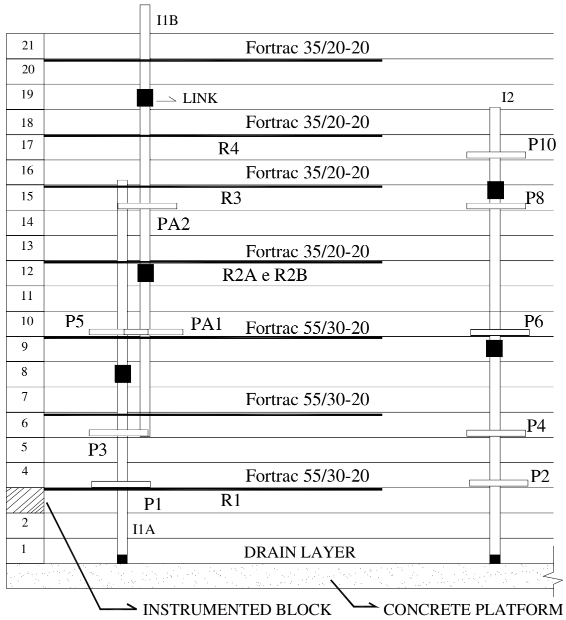

Figure 1. Position of Instruments – cross view.

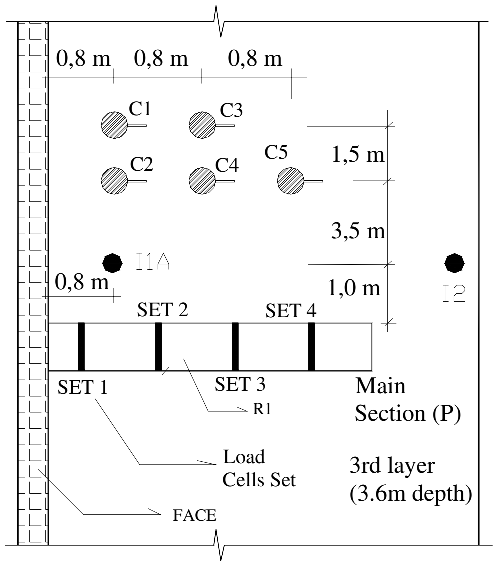

Figure 2. Position of Instruments in 3rd layer, 3.6m depth.

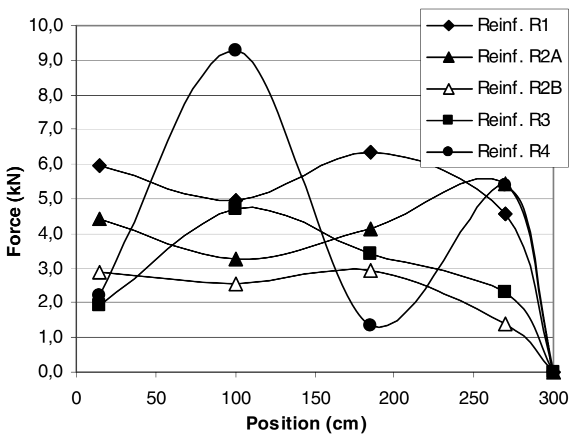

Figure 3. Reinforcement Tension, end of construction.

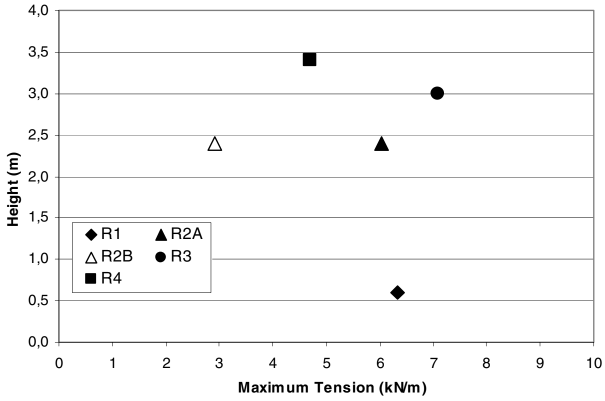

Figure 4. Maximum reinforcement tension vs. depth.

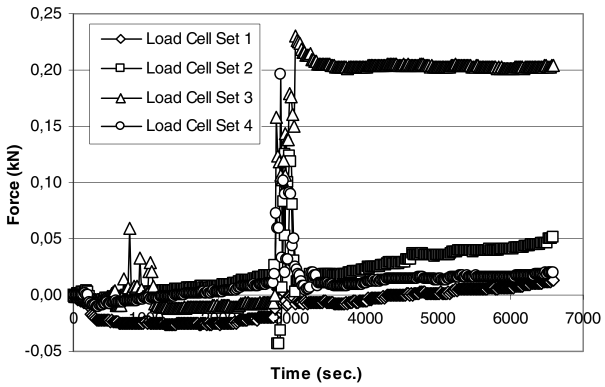

Figure 5. Measured tension in reinforcement R4 – before, during and after compaction operations.

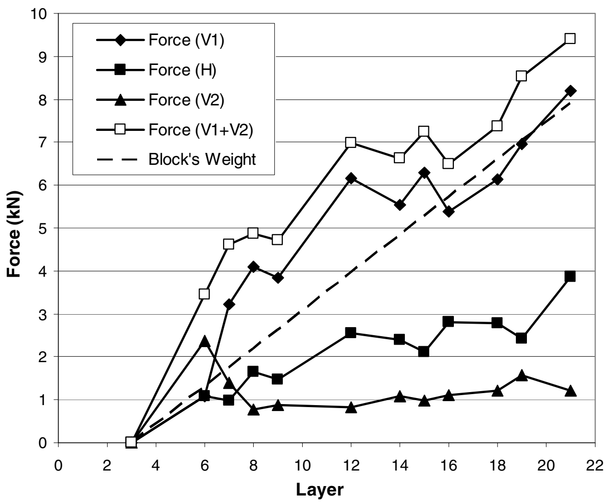

Figure 6. Vertical and horizontal forces on instrumented block.

3.3 *Vertical Displacements*

The vertical displacements were significant (maximum 20 mm) during the placement and compaction of the soil layer just above the settlement plate. Some small movements may have occurred during construction of the next layer (maximum 2 mm). No other displacements were measured after this. In general, the behavior for all layers was similar, including measurements near the bottom of the wall. Note that the vertical stress induced by compaction operations were much higher than geostatic ones. Therefore, significant movements may be expected only during the placement of each soil layer and compaction, as has consistently been measured in the field.

3.4 *Horizontal displacements*

Figure 7 shows that the horizontal displacements measured by inclinometers at the end of wall construction. As expected, lateral movements near the face (I1) were greater than those observed in the unreinforced zone (I2). The displacements occurred exclusively towards the face. Displacements at the top of the wall were greater than those at the base and the maximum deflection (δ/H) observed was 1.5%.

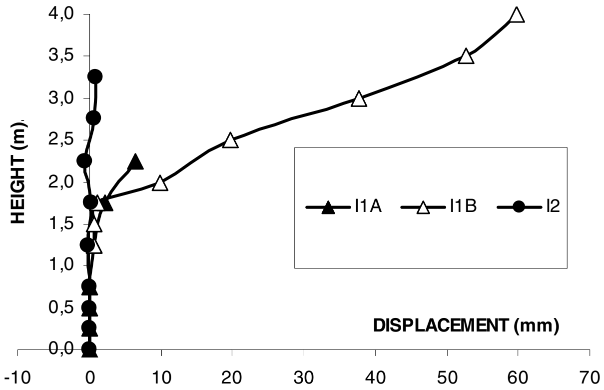

Figure 7. Horizontal displacements at end of construction.

3.5 *Vertical Stress*

Figure 8 compares measured and calculated vertical stress values. Vertical stress determination took into account: (a) the one-dimensional condition ($\sigma_v = \gamma' \cdot z$) and (b) Meyerhof's (1955) method, which accounts for eccentricity of the resultant force on the wall base. The calculations considered the equilibrium of the reinforced soil mass under the effect of its own weight and the active earth pressure, based on Rankine's theory, exerted by the embankment on the wall. Soil shear strength parameters (Table 2) under plane strain and axi-symmetric conditions were used for this determination. The values measured showed no uniform vertical stress distribution at the wall base, with increasing values towards the face. Note that the measured values are higher than the calculated ones.

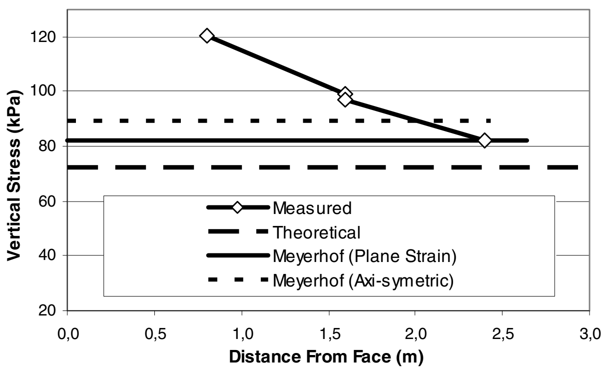

Figure 8. Vertical stress distribution in the wall foundation.

3.6 *External lateral movements*

At the end of construction the lateral displacements of the face blocks measured by topography were 4.0mm and 22.0mm at a depth of 2.60m and a depth of 1.60m from the top of the wall, respectively. Note that measured values are of the same magnitude as the inclinometer measurements, as shown in Figure 7.

4 MEASURED AND PREDICTED TENSIONS IN THE REINFORCEMENTS

The relationship between the measured and predicted summation of maximum reinforcement tensions is shown in Figure 9. The methods used in the analysis were Bathurst et al. (2003), Ehrlich & Mitchell (1994), Leshchinsky & Boedeker (1989) and Rankine's Theory. The calculations were made considering soil strength parameters determined from plane-strain triaxial tests (Table 2) and the measured forces mobilized at the block facing (Figure 6). In order to verify the significance of results, calculations with and without soil cohesion were carried out.

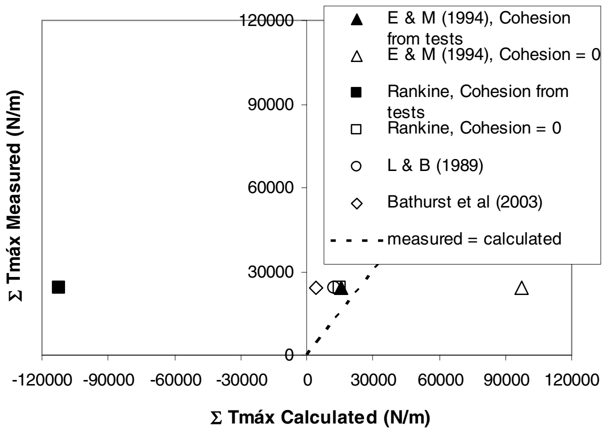

Figure 9. Measured and predicted summation of maximum tension in the reinforcements R1, R2A, R3 and R4.

Ehrlich & Mitchell (1994) presented the best fit between measurement and prediction. Note that with this method compaction stress, soil cohesion and reinforcement and soil-stiffness properties can be explicitly taken into account. Leshchinsky & Boedeker (1989) presented good results, although this results from error compensation. Note that Leshchinsky & Boedeker's (1989) method does not take into account soil cohesion (which may lead to a reduction in reinforcement tension) nor the stress induced by backfill compaction (which may lead to an increase in reinforcement tension). For the no cohesion condition Rankine's active and Leshchinsky & Boedeker (1989) lead to similar reinforcement tension values. Nevertheless, Rankine's active condition leads to negative reinforcement tension values when cohesion is considered. That means that in this case reinforcements are not necessary for equilibrium. Bathurst et al.'s (2003) method provided a tension value significantly smaller than the measured one. The difference of results occurs even though this method does not take into account soil cohesion in the analysis.

5 CONCLUSIONS

A block-faced geogrid wall using fine-grained tropical soils as a backfill was monitored. External and internal movements, stress on the facing blocks and tension in the reinforcements were measured. Analyses of the measured values lead to the conclusions as follows.

Maximum tension in the reinforcement exhibited a tendency to be constant in relation to depth due to compaction stress, in accordance with Ehrlich & Mitchell (1994). Measurements showed vertical and lateral wall movements and an increase in tension in the reinforcements due to compaction operations. Residual values were much higher than the values verified before soil compaction.

At the end of construction forces acting on facing blocks showed horizontal values equal to 41% of the vertical ones. Vertical loads were always higher than the calculated values considering the blocks' own weight. The results indicated friction mobilization at the soil block interface and backfill vertical stress transference to blocks.

Lateral movements measured by inclinometers indicated that displacements increased from the bottom of the wall to the top; the maximum deflection was 1.5% at end of construction. No uniform vertical stress was measured at the base of the wall; increasing values were verified towards the face.

Ehrlich & Mitchell (1994) presented the best predictions for tension in the reinforcements. The results show that compaction stress, soil cohesion and reinforcement and soil-stiffness properties cannot be neglected in this type of analysis.

ACKNOWLEDGMENTS

The authors would like to thank HUESKER Synthetics Co., the Brazilian Research Council (CNPq) and the José Bonifácio University Foundation (FUJB) for the financial support. The authors also thank Andrade Gutierrez Co., TERRAE Co. and Agrogeo Co. constructors of the project for providing logistic support in the field.

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