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Evaluation of mechanical behavior of a Brazilian marginal soil for reinforced soil structures

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ABSTRACT: Marginal soils are characterized by a large percentage of fine particles and, in general, are not recommended by current standard codes as backfill material for reinforced soil structures because of their poor draining capacity and low shear strength. Notwithstanding, in Brazil, reinforced soil structures are often built using fine soils due to their large availability. Case studies of historical importance in Brazil show a very good long-term performance. This behaviour occurred probably due to the significantly different characteristics of tropical soil compared to similar soils from the northern hemisphere, since tropical soils show excellent shear strength parameters and relatively low compressibilities. To carefully verify the changes in mechanical behavior caused by reinforcing inclusions, an experimental program based on triaxial compression tests was carried out. The tested soils were classified as sandy silty clay (according to the Brazilian Standard Code for grain size analysis-ABNT-NBR 7181) and lateritic soil according to the MCT classification system. Unconsolidated-undrained and consolidated-undrained triaxial tests were carried out on unreinforced and reinforced specimens. The specimens were reinforced with inextensible and impermeable aluminium foil and extensible and permeable nonwoven geotextile as inclusions. A comparison of the results obtained for the unreinforced and reinforced cases confirmed an increase in stiffness for geotextile inclusion reinforced specimens under short and long terms analyses. For the geotextile reinforced soil, the mobilized cohesion parameter was found to increase even for higher values of strain in the two situations analyzed.

1 INTRODUCTION

Soil reinforced structures are an efficient alternative for building steep slopes and retaining walls. Backfill materials for these structures, according to the technical specifications, must predominantly be granular since they present high shear resistance and free drainage capacity. The use of low permeability soils, also called marginal soils, is less recommended, especially for reinforced walls. For reinforced soil slopes, FHWA guidelines (Elias at al., 2001) allow for up to 50% fines with a plastic index (PI) less than 20. However, granular soils are not always accessible in the proximities of construction sites, a situation in which transportation costs may become very high.

It is estimated that 60% of the Brazilian territory is covered by marginal soils, mostly of tropical origin. A case study of instrumented projects of both steep slopes and reinforced walls built with marginal soils in Brazil shows excellent short and long term performance even when reinforced inclusions are of nonwoven geotextiles.

It is believed that the high shear strength and the low compressibility of tropical soils (mainly those of lateritic origin) are due to their unsaturated condition. The main question when analyzing these data is related to the permanence of their unsaturated condition with time. This is certainly related to the low permeability of marginal soils and the high transmissivity of the non woven geotextiles.

To help the understanding of this question, triaxial tests were performed to investigate the efficiency of permeable inclusions in dissipating pore pressure generated during the construction of reinforced embankments. To set the differences, nonwoven geotextile (permeable inclusion) and aluminum foil (impermeable inclusion) were used as soil reinforcement. The use of these two materials showing different shear stress-strain behaviors also permitted the comparison of the magnitude of the vertical deformation.

2 BIBLIOGRAPHIC REVIEW

2.1 *Reinforced soil structures guidelines*

Currently, Brazil does not have any technical specifications for the selection of backfill material for reinforced soil structures.

Therefore, the design of reinforced structures is based mainly on the experience gathered by Brazilian experts in the construction of compacted earth embankments with the intensive use of unsaturated fine tropical soil.

2.1.1 *Poorly drained soils of brazil*

Most of the Brazilian territory is covered with silts and clays, a large percentage of which is of residual origin. Brazilian soils are the product of in-situ weathering of the original rock, which is typical of tropical climate regions. These tropical soils present some pedogenic particularities when compared to soils from the northern hemisphere.

Among various attempts to establish an appropriate system of classification for tropical soils which seems to approach aspects such as the mineralogical and structural peculiarities, there is the MCT classification developed by Nogami and Villibor (1981). Two broad classes according to genesis can be identified: lateritic soils and saprolitic soils.

Lateritic soils constitute the most superficial layer of well drained areas. The clay fraction is made up essentially of low expansion kaolinite clay-mineral. Soils particles are covered and agglutinated by iron and aluminum hydroxides and oxides. The strength of these materials under dry conditions is very high, mainly due to the action of the cements (Cozzolino and Nogami 1993).

Saprolitic soils, on the other hand, often constitute the underlying layers of the lateritic soils. Their mineralogical composition shows a significant number of minerals. These soils present a high percentage of silt-size particles and contain kaolinite micro-cristals and mica which show some plasticity even without the presence of clay-size particles (Cozzolino and Nogami 1993).

In spite of their large amount of fines, tropical soils present shear strength parameters of appreciable magnitude. To illustrate this, Table 1 presents shear strength parameters of soils used in dam constructions in the southern part of Brazil (Cruz, 1996).

Table 1. Residual soil of basalt and diabase origins used in dam construction in the south and southeast regions (Cruz 1996).

Sample/Origin	Classification	Shear parameters c′ (kPa)	Shear parameters ø′(kPa)
Xavantes (SP)	Sandy clay	28	30
São Carlos (SP)	Sandy clay	35	29
Água Vermelha (SP-MG)	Sandy clay	30	23.5
Salto Santiago (PR)	Sandy silty clay	42	29
Itaúba (RS)	Silty clay	65	24

3 EXPERIMENTAL PROGRAM WITH TRIAXIAL COMPRESSION TEST

Triaxial compression tests were performed using 51.1 mm diameter and 126 mm height (diameter/height ratio of 2.47) test specimens. The test specimens were prepared by compacting four layers of the soil at optimum water content and maximum dry density of normal Proctor test.

For the reinforced soil specimens, the inclusions were equally placed along the height of the test specimen (see Figure 1).

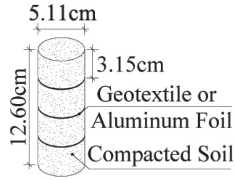

Figure 1. Details of the triaxial test reinforced soil specimen.

Both unconsolidated-undrained (UU) and consolidated-undrained (CU) tests were performed. The UU triaxial tests were carried out using unreinforced soil specimens and aluminum and geotextile reinforced specimens. These tests were, conducted on test specimens at compaction water content to simulate the behavior of the soil at the end of backfill constructions.

The CU triaxial tests were performed only for the unreinforced and geotextile reinforced specimens. In this case, the samples were saturated to obtain information on the soil behaviour under saturated conditions.

3.1 *Materials*

3.1.1 *Soil*

The soil used was mainly a sandy silty clay. The grain size distribution curve is presented in Figure 2. As it can be seen, 80% of the soil particles pass through sieve # 200. Other soil parameters are presented in Table 2.

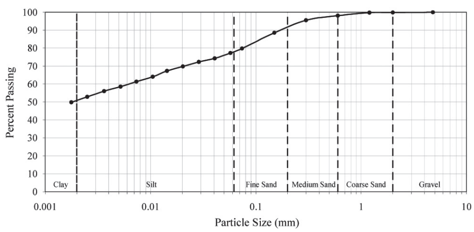

Figure 2. Grain size distribution of tested soil.

Table 2. Main soil parameters.

γ_s (kN/m^3)	w_L (%)	w_P (%)	w_{opt} (%)	$\gamma_{d,max}$ (kN/m^3)	k (m/s)
28.37	41	31	24.50	16.22	2.5E^{-10}

3.1.2 *Reinforcement*

The reinforcement materials used includes aluminum foil – impermeable and inextensible inclusion – and nonwoven geotextile – permeable and extensible inclusion.

The aluminum foil presented an ultimate unconfined tensile strength of 0.90 kN/m and failure strain of 2.0%, according to ASTM D 882, while the unwoven geotextile presented an average thickness of 0.78 mm and ultimate tensile strengths of 4.8 kN/m and 3.34 kN/m in the longitudinal and transverse directions respectively, according to ASTM D 4595. The geotextile failure strains were respectively 32% and 27% in longitudinal and transverse directions. The observed transmissivity (ASTM D 4716) was 1.7 E-6 m^2/s under a hydraulic gradient of 0.1 and vertical confining stress of 100 kPa.

3.2 *Results*

Table 3 presents the deviator stresses and the deformation at failure for both reinforced and unreinforced test specimens.

Table 3. Deviator stresses and deformations at failure for test specimens.

UU test	σ_3 (kPa)	Unreinforced σ_1-σ_3 (kPa)	Unreinforced ε (%)	Aluminum σ_1-σ_3 (kPa)	Aluminum ε (%)	Geotextile σ_1-σ_3 (kPa)	Geotextile ε (%)
	50	299.2	10.1	267.4	3.7	416.9	15.3
	100	361.2	12.8	350.4	7.5	498.1	15.3
	200	461.9	15.8	511.0	15.8	569.5	18.3

CU test	σ_3 (kPa)	Unreinforced σ_1-σ_3 (kPa)	Unreinforced ε (%)	Geotextile σ_1-σ_3 (kPa)	Geotextile ε (%)
	50	210.7	8.3	266.4	14.0
	100	237.5	8.3	362.2	19.1
	200	266.0	8.6	414.8	19.7

Figure 3 presents test specimens after failure. This figure clearly shows the bulging geotextile reinforced specimens in the zones between inclusions (Figure 3 a) while the aluminum inclusions were observed to fail in all triaxial tests carried out (Figure 3 b).

(a) (b)

Figure 3. Specimens after failure. (a) Geotextile. (b) Aluminum.

For short term analysis (UU tests), the deviator stress-strain curves for the unreinforced soil displayed plastic failure while aluminum reinforced soil showed a peak stress for low confining stress values of 50 and 100 kPa at strains of 4% and 7%, respectively.

The geotextile reinforced soil showed a different behavior. It was observed that even under high strains (approximately 20%), neither the peak nor an asymptotic deviator stresses were attained. Instead, the stress was found to increase continuously with strain. This behavior was also observed for geotextile reinforced soil in CU tests while the deviator stress curve of unreinforced soil presented asymptotic values.

From Figure 3 and Table 3, it can be observed that besides the restriction of soil movement due to geotextile, the reinforcement permitted larger specimen strains thus improving its shear strength. However, the aluminum reinforcement was shown not to improve the soil behavior during rupture especially for low confining pressures (50 and 100 kPa).

Figure 4 shows the secant modulus of the unreinforced and reinforced (aluminum and geotextile) soils used in the UU triaxial tests. From the figure, it can be observed that soil stiffness decreases with an increase in specimen deformation. For a specific deformation, the secant modulus is shown to increase with an increase in confining stress. As a general pattern, for strain levels above 2.0%, the nonwoven geotextile reinforced specimens were stiffer than the unreinforced soil. At low confining stresses, the aluminum foil reinforced test specimens presented lower stiffness than the unreinforced specimen. However, a progressive increase in the secant modulus was observed with an increase in confining stress.

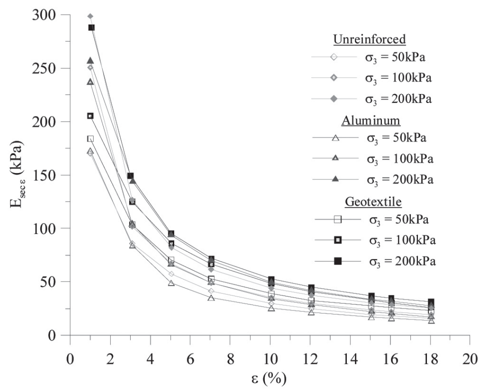

Figure 4. Stiffness versus strain curves from UU triaxial tests.

Figure 5 shows the secant modulus-strain curves for the CU triaxial tests for both unreinforced and geotextile reinforced specimens.

It is easy to observe that the behavior pattern is similar to that shown in Figure 4, i. e., the reinforced

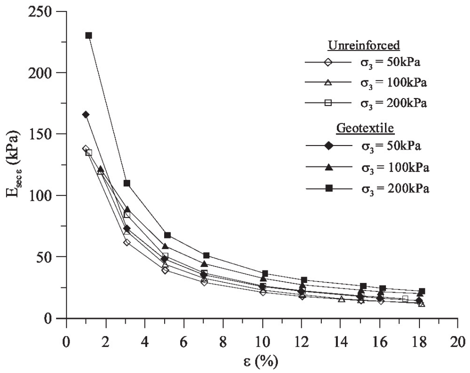

Figure 5. Stiffness versus strain curves from CU triaxial tests.

soil showed a gradual increase in secant module with the increase of the confining stress.

Data from Figure 5 showed that the values of secant modulus for the geotextile reinforced specimens are larger compared to those of the unreinforced soil especially under low strains. This behavior is not however, observed for the short term analysis (Figure 4).

Figures 6 and 7 show the variation in shear strength parameters for different strain levels (2.0, 5.0, 10.0 and 15.0%).

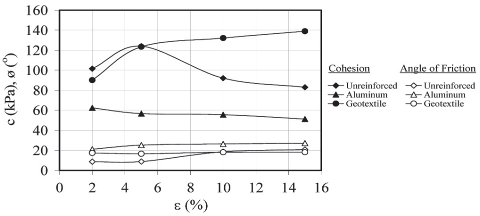

Figure 6. Shear strength parameters (c e ø) for different strain.

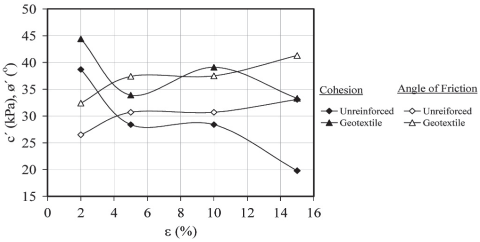

Figure 7. Shear strength parameters (c′ e ø′) for different strain values – CU tests.

The analysis carried out and shown in Figures 6 and 7 demonstrate improvements in shear strength parameters of the soil due to the inclusion of geotextile. Contrary to the short term analysis it can be seen in Figure 7 that for long term analysis, the reinforced soil shows an increment in both strength parameters related to strain. Notwithstanding, the mobilized angle of friction of the soil is observed to increase. This behavior suggests that the use of permeable inclusions can enhance soil behavior regarding stability and shear strength because reinforcements permit higher rates of drainage and consequently of consolidation of the soil layers.

4 CONCLUSIONS

Based on the results exposed above, the following conclusions were reached:

- Under both short and long term conditions, clayey lateritic soils show an excellent behavior when reinforced with nonwoven geotextile. Under long term analysis, soil improvement is due to drainage by transmissivity which occurs along the porous inclusions;
- Geotextiles modify failure modes of the test specimens thus conferring a higher stiffness in both cases analyzed;
- For geotextile reinforced soil, the mobilized shear strength parameters was found to increase even for higher values of strain in the two situations analyzed;
- The comparison between permeable and impermeable reinforcements allowed the verification of the importance of using permeable reinforcement in reinforced soil structures composed by marginal soils, with regards to increase in stability due to higher rates soil drainage.

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