Evaluation of the Confined Stiffness in the Lateritic Soil-Geotextile Interaction in different Moisture Conditions

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ABSTRACT

In Brazil, there are abundant natural materials known as tropical soils, which are often not used in engineering works due to its low load-bearing capacity. One of the technologies available to control the manifestation of pathologies, increase the service life of the pavement and reduce the thickness of the base layer is the use of geosynthetics as reinforcement. Thus, to study the possibility of the use of local cohesive tropical soils, with fine granulometry, in infrastructure works reinforced with geosynthetics, combined with the drying effect of the soil, constitutes a great attraction from a technical and economic point of view. This work evaluates the increase of stiffness provided by the variation of moisture content (matrix suction) and grain size structure of a cohesive tropical (lateritic clay) soil and a woven geotextile. Monotonic Pullout tests were carried out on a small equipment under three soil condition ("O" Optimum, "S" Dry and "SP" Dry Post-Compaction) and two levels of confining stresses (14 and 28 kPa), in addition Wide Width Tensile tests. The monotonic pullout tests evaluated the soil-geosynthetic interaction under constant displacement, for the calculation of the confined stiffness of the geosynthetic (Jc). The wide width tensile tests were performed to evaluate the unconstrained stiffness of the woven geotextile (Jn). The "S" molding condition, compacted with a higher compaction energy in relation to the other conditions, which consequently altered its soil structure, presented the best performance.

1. INTRODUCTION

The emergence of geosynthetics made possible the use of cohesive materials in infrastructure works. However, an efficient interaction between the geosynthetic and the base material is necessary, which increases the lateral confinement and the stiffness of the system. Thus, the stiffness modulus of the system under low deformation often becomes a more representative parameter of the soil-geosynthetic interaction than the maximum pullout resistance (Chang et al. 1998).

In addition, the search for alternative materials in infrastructure works has been increasing quickly in the recent years. In tropical countries, there are abundant natural materials known as clayey lateritic soils. The tropical climate intensifies the process of leaching and chemical weathering of the soil, which accumulates a considerable amount of oxides providing high load-bearing capacity and low expansibility soils.

This work evaluates the increase in stiffness provided by the variation of moisture content (matrix suction) and the grain size structure at the interface between a cohesive tropical soil (lateritic clay) and a woven geotextile. For this purpose, monotonic pullout tests with soil suction monitoring were performed on small-sized equipment under three scenarios ("O" Optimum, "D" Dry and "DP" Dry Post-Compaction). The Dry Post-Compaction tests were conducted with the same matrix suction of the Dry tests. The monotonic pullout tests evaluated the soil-geosynthetic interaction under constant displacement to calculate the apparent confined stiffness of the geosynthetic (Jc). The Wide Width Tensile tests were conducted to assess the unconfined stiffness of the woven geotextile (Jn). Although there is no general rule in the literature that specifies how best to obtain the complex confined stiffness parameter of a geosynthetics, this paper aims to contribute to making the choice of the most suitable scenario for the studied soil.

2. MATERIALS AND METHODS

2.1 Soil and Geotextile Properties

The soil is a clayey tropical soil, classified as a silt of high plasticity (MH), according to the Unified Soil Classification System (USCS). This material was collected near the city of São Carlos, São Paulo, Brazil.

The predominantly clayey soil has approximately 70% fines, with D_{50} = 0.007 mm and D_{Max} = 0.6 mm. The soil has a California Bearing Ratio (CBR) of 22% and expansion of 0.02%.

The use of local fine soils in their natural or even stabilized condition requires a more detailed study of their geotechnical properties. For this reason, in order to know the applicability of this soil in pavement structures, we used the MCT

(Miniature, Compacted, Tropical) methodology, which addresses a different methodology for tropical soils, proposed by Nogami and Villibor (1981). Based on these results, the soil was classified as a Clayey Lateritic (LG'), which can be used in the base of low cost pavements.

The geosynthetic is a biaxial woven geotextile composed by polypropylene (PP). The Wide-width tensile test showed a maximum tensile strength of 31.36 kN/m (catalogue strength of 30 kN/m) and average deformation at rupture of 14.04%. The average stiffness modulus for a deformation of 2 and 5% was 266.36 and 256.50 kN/m, respectively.

2.2 *Scenario Definition*

Table 1 summarizes the initial and final molding conditions during the preparation of the test box prior to testing. All scenarios were tested with a compaction degree (GC) of 98%. The Optimum Scenario "O" has an estimated test suction of 15 kPa, while the Dry Scenario "D" and the Dry Post-compaction Scenario “DP” presented suctions of 75 kPa.

Table 1. Initial and final molding conditions.

Scenario	W Compacted (%)	W tested (%)	Degree of Compaction DC (%)	ρ_{dmax} (g/cm^3)	Estimated Suction (kPa)
O	22.75	22.75	98	1.593	15
D	18.75	18.75	98	1.593	75
DP	22.75	18.75	98	1.593	75

The "O" and "DP" scenarios are compacted at the same point, but only the "O" condition remains at this point for the pull-out tests, whereas the "DP" scenario would lose moisture until it reaches the same moisture content of the "D" scenario. The dry "D" scenario was tested at the same point as "DP", with similar suctions at the time of testing. However, in order to achieve a test condition at the same compaction degree as the "DP" condition, the test had to be subjected to a higher compaction energy, which provided a more flocculated soil structure.

2.3 *Pullout equipment*

The pullout tests were performed for different suctions, which required a more precise control of soil moisture content and the use of a constant soil drying temperature. For this reason, we opted to use a small box. Previous research were carried out using this equipment, emphasizing Teixeira (1999) and Kakuda (2006) who demonstrated a good performance of this box to use cohesive soils in monotonic pullout tests and Ferreira (2007) who compared the confined stiffness between different geogrids. Portelinha et al. (2018) evaluated the pullout resistance of a geogrid under different moisture conditions in this box.

The small-sized equipment consists of a rigid steel box with inner dimensions of 24.5 cm long, 30 cm wide and 14.5 cm high (Figure 1). The upper surface has a reaction cap coupled to a pressure-controlled air bag for the application of the overload. In the rear region, there is a support for the fitting of four tell-tales, which are connected to the geosynthetic by inextensible wires.

There are two holes on the side of the box with a diameter of 7 mm. It was possible to insert a tensiometer to check the interstitial water pressures developed in the cohesive soil during the pullout test. The tensiometer was installed just 1.0 cm below the soil-reinforcement interface.

The displacements of the woven geotextile were measured in four different points nominated D1, D2, D3 and D4. The Geotextile was confined 210 mm long and 260 mm transverse inside the box (Figure 2). All points were spaced 45 mm longitudinally from each other and only the D2 and D3 (central) sensors were used in the present analysis in order to minimize the effects of the edges in the apparent confined stiffness calculations.

Figure 1. Small box and instrumentation.

2.4 Test Procedure

The monotonic pullout test was performed according to the procedures described in ASTM D6706 (2013). The applied loads were 14 and 28 kPa having as a limiting factor the maximum resistance of the woven geotextile in the wide-width tensile test. Larger confining stresses would result in ruptures of the geotextile in the unconfined region before the pullout occurs. These overloads are in the order of values usually found in the literature (Ferreira et al. 2008) which represent the tensions acting on the layers of the base and sub-base of pavements.

In order to simulate the drying effect of the soil in a constant ambient temperature, after the compaction of the soil, the box of the tests in the "DP" scenario was placed inside the oven at a constant temperature of 30 °C. The loss of moisture was controlled through the difference between the initial and final mass of the box. The drying process was finished after the sample reached a moisture content of 18.75%. Then the box was packed with film paper and inserted into two tightly closed plastic bags in order to prevent the exchange of moisture with the environment and to balance the suction of the soil through the box.

2.5 Confined Stiffness

During the pullout test, readings of the tensile load and displacements along the geosynthetic were made by the load cell and the four tell-tales, respectively. The apparent confined deformation was obtained by the displacement difference between two central sensors, whose initial relative distance is 4.5 cm.

Although the pullout test is not the most suitable test for this calculation, the criterion for obtaining the confined stiffness modulus (Jc) was defined as the ratio between the pullout force and the deformation of the geosynthetic between two sensors as in Ferreira et al. (2008), as an approach for a quantitative analysis (Equation 1).

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$$\boldsymbol{Jc} = \frac{\text{Pullout Force }(\frac{\text{kN}}{\text{m}})}{Deformation\ between\ D3\ and\ D2\ (\%)} \qquad [1]$$

With the pullout test, we intend to study only the load-elongation behavior of the confined geotextile at low deformations, as in geotextile-reinforced pavements, deformation greater than 2% was not observed (Mendes, 2006).

3. RESULTS AND DISCUSSION

Figure 2 shows the pullout test curves with the woven geotextile in the Optimum Scenario (O) with an overload of 14 kPa, as well as its suction measured by the tensiometer. D1, D2, D3 e D4 represents the displacement of the four transducers. The suction showed a high variation in the end of the test.

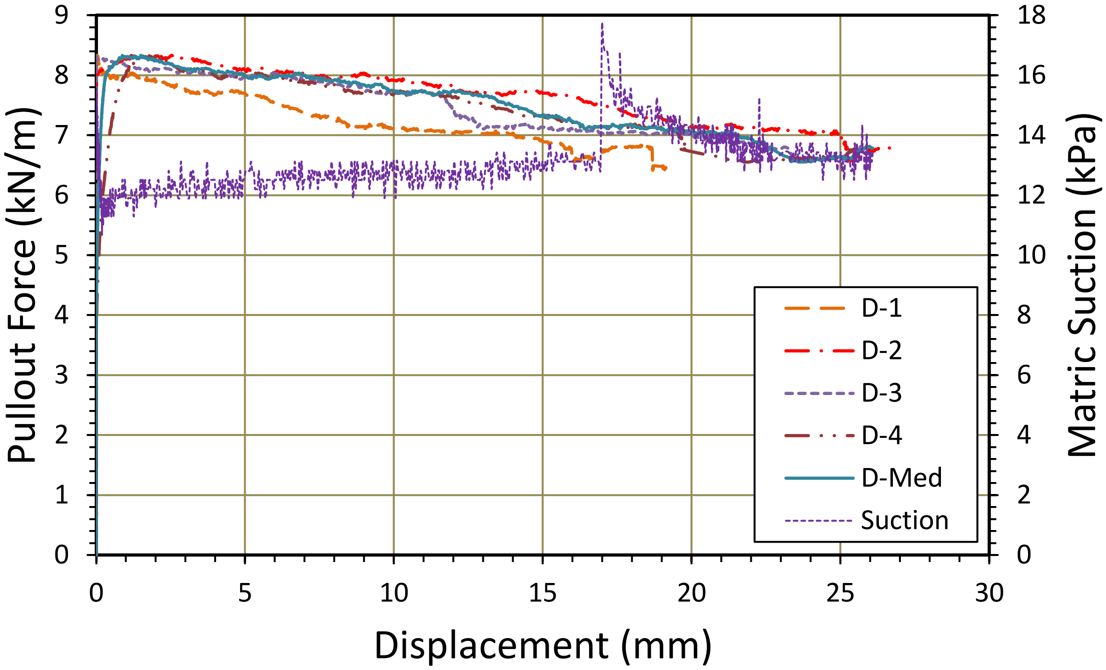

Figure 2. Pullout curves for different points along the geotextile and suction measured by the tensiometer (Scenario O-14).

Figure 3 depicts the comparison between J_N (unconfined stiffness modulus) and J_C (confined stiffness modulus) of the woven geotextile used under different scenarios. The unconfined stiffness was obtained by the ratio of tensile force and deformation between two points known in the wide-width tensile test (ABNT 10319, 2013). The results presented stiffness curves with the same order of magnitude as the curves obtained by Ferreira et al. (2008) tested in the same small scale apparatus, but with granular soil in the upper layers.

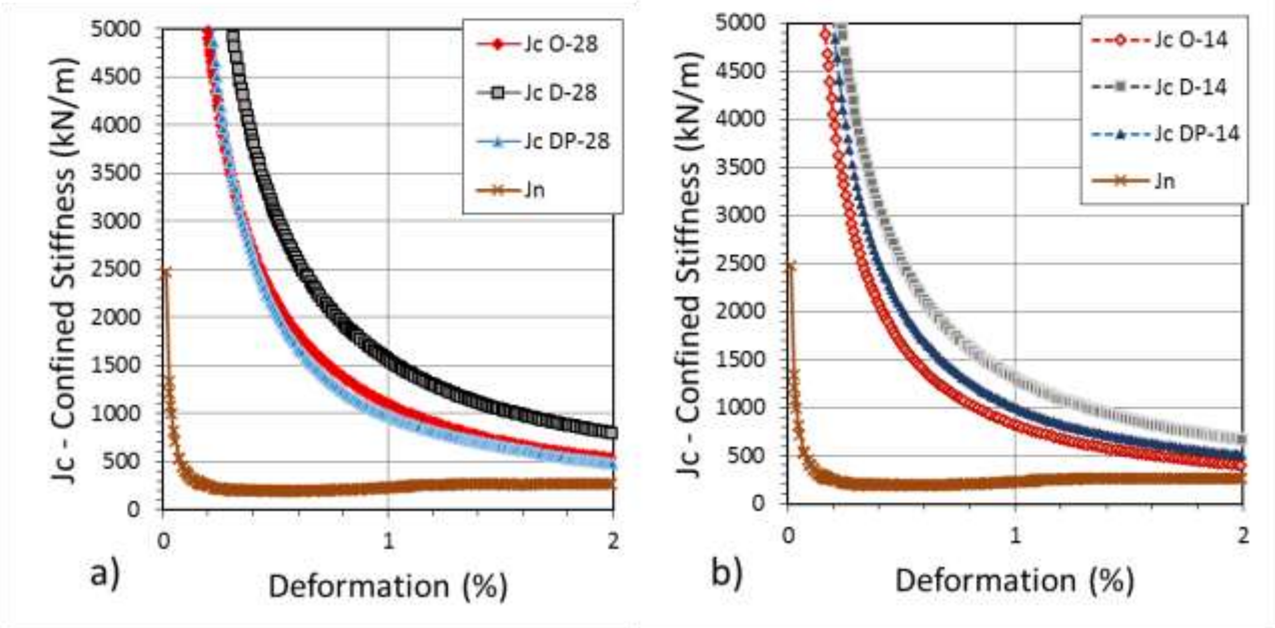

Figure 3. Comparison between confined and unconfined stiffness under different scenarios for the overload of: (a) 28 kPa and (b) 14 kPa.

The tests in the "D" Scenario presented the greatest increase of stiffness caused by the overload, which agrees with the results obtained by Portelinha et al. (2018), where the tests directly compacted at a moisture content lower than the optimum moisture content presented better performances than the tests in the Optimum Scenario.

The "DP" and “O” scenarios presented a similar stiffness curve behavior for the two overloads. However, greater confined stiffness curves were expected in the “DP” Scenario, since it has a higher matrix suction than “O” Scenario due to the drying process and the same suction as "S" Scenario. This may indicate the existence of other parameters involved in woven soil-geotextile interaction, such as soil structure or compaction energy, which may influence interface resistance even more than soil matrix suction itself. The quantification of these parameters requires a parametric statistical analysis of the pullout tests, which does not contemplate the main objectives of this work.

Based on the secant stiffness modulus for a 2% deformation depicted in Figure 4 (a), usually required for designs, we observe that all scenarios (O, D, and DP) presented a stiffness modulus above the unconfined stiffness, whose representation is given by the dashed horizontal line (266.36 kN/m). The increase in the overload provided an increase in the confined stiffness in all scenarios. The penetration of fine soil particles in the woven geotextile small openings are factors that may also have contributed to the increase in the tensile strength.

Figure 4 (b) illustrates the increase of secant stiffness in a 2% deformation in relation to the unconfined stiffness values "Jn". The "D" scenario in an overload of 28 kPa presented a stiffness increase of 198%. Even under low overloads, the lowest increase of stiffness presented was of 51%, which attests a better performance of the woven geotextile under confined conditions.

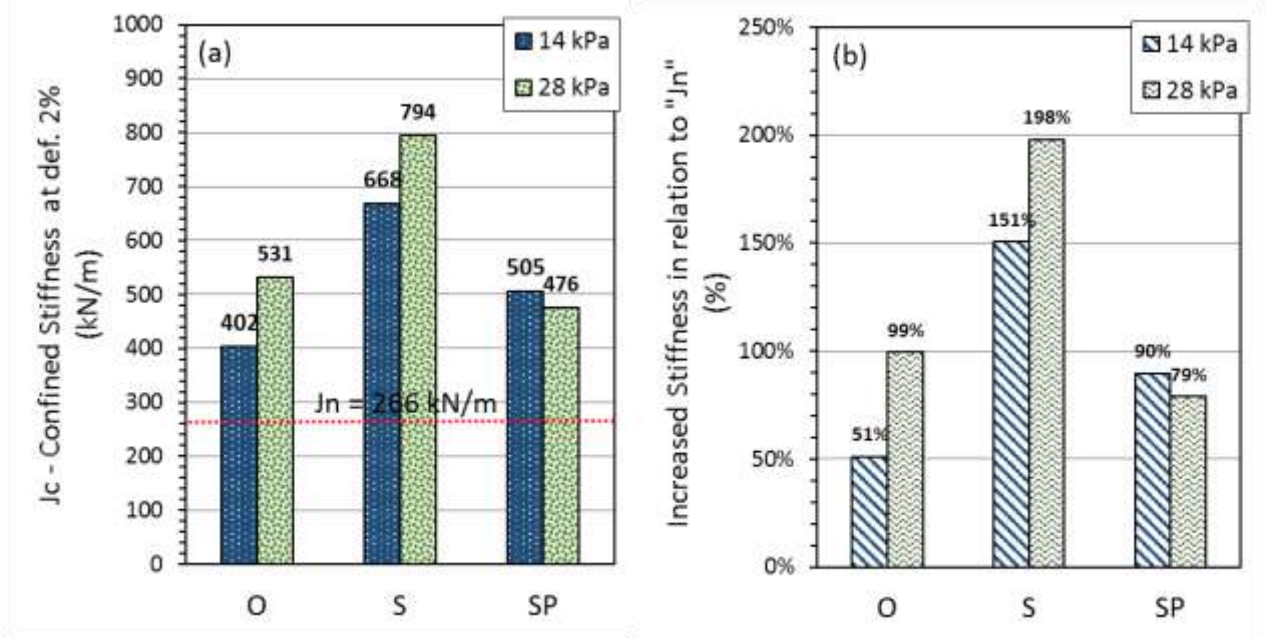

Figure 4. **(a)** Secant stiffness modulus obtained for a deformation of 2% **(b)** Increase of stiffness to a deformation of 2% in relation to unconfined stiffness.

4. CONCLUSION

The work evaluated the confined stiffness of a woven geotextile, under different scenarios of suction and soil structure , using monotonic pullout tests. After comparing these results with the unconfined stiffness, we observed that:

The "D" Scenario had a stiffness 49% and 57% higher than the "DP" and “O” Scenarios, respectively. As the “D” and “DP” scenarios were tested with the same suction of 75 kPa, it indicates that other parameters may be influencing the interaction between the soil and the geosynthetic, such as soil structure or changes in lateritic soil properties caused by the increase of compaction energy.

Although woven geotextiles are usually considered materials with lower stiffness than biaxial geogrids for pavement purposes, this geotextile presented a favorable stiffness behavior when confined. However, a larger number of tests as well as additional analyses in real case studies are needed to validate this statement in the field. In any case, the use of unconfined stiffness of geotextiles in projects can be considered a conservative attitude.

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