Estimation Analysis of Lateritic Soils Properties from SPT and DMT

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ABSTRACT: The use of field tests correlations in order to obtain geotechnical properties of the soil is a common practice in geotechnical engineering. Although, it is necessary to utilize correlations with care, since those are designated for specific types of soils. This paper aims to evaluate the geotechnical properties estimates of a lateritic soil from SPT and DMT tests. The investigation field tests were performed in Brasília, Brazil. In order to analyze the geotechnical properties of this lateritic soil, five SPT and one DMT tests were performed. In addition, laboratory tests such as triaxial tests were carried out to obtain shear strength and deformability parameters. Geotechnical properties were estimated from SPT and DMT results, and then compared with laboratory test results. DMT tests are shown to provide a reasonable means of assessing the shear strength and deformability parameters of this particular soil.

Keywords: DMT; SPT; Lateritic soils; Field tests; Soil properties.

1. Introduction

Brasília was a pre-designed city built in the early 60's to house the main Governmental administrative institutions and its public employees, but it has increased more than it was initially forecasted, allowing the establishment of several engineering working sites within the Federal District. The city is located in an area of Brazil with highly weathered residual tropical soils made up of laterites or "latosoil" (Mendoza et al, 2016). This soil has high aluminum and iron content due to processes of lixiviation of the upper soil layers. As a consequence, this soil has a porous cemented structure. Tropical soils are mostly derived of geological and pedological processes typical of tropical wet regions. Those soil types are generally composed of a highly weathered layer, followed by a deep layer of residual soil with relict structures from parent rock, which is called saprolites (Rocha and Giacheti, 2018). This latosoil has been extensively subjected to a laterization process and it presents a variable thickness throughout the District, varying from few centimeters to around 40 meters. There is a predominance of the clay mineral caulinite, and oxides and hydroxides of iron and aluminum. The variability of the characteristics of this latosoil depend on several factors, such as the topography, the vegetal cover, and the parent rock. In localized points of the Federal District the top latosoil overlays a saprolitic/residual soil with a strong anisotropic mechanical behavior and high (SPT) penetration resistance, which originated from a weathered, folded and foliate slate, the typical parent rock of the region (Cunha and Camapum de Carvalho, 1997).

The principal purpose of site characterization is to describe the stratigraphical profile, which consists in identifying the soil layers, thickness, soil type, groundwater level and physical and mechanical properties. For this purpose, in situ and laboratory tests can be used (Rocha *et al*, 2016; Rocha and Giacheti, 2018). Some field testing methods (e.g., SPT and DMT) can be employed as an alternative to the traditional laboratory testing approach.

Lateritic soil properties estimation and characterization has been evaluated by many researchers (Cunha *et al*, 1999; Almeida *et al*, 2011; Schnaid *et al*, 2016; Rocha *et al*, 2016; Wang *et al*, 2018; Rocha and Giacheti, 2018).

This paper aims to present and discuss geotechnical properties estimates of a lateritic soil from SPT and DMT tests performed at one relatively well-studied unsaturated tropical soil profile at Solotrat research site, in the Federal District, Brazil. SPT and DMT test data were interpreted and compared to available reference soil parameters determined based on laboratory tests.

2. Research Site

The research site is located at the brazilian central plateau on the Solotrat experimental site. This site is located in the outskirts of Brasilia near the town of Guará. The approximate coordinates of the site are 15°48′59″ S; 47°57′58″ W, and the main elevation is 1,084 m. Fig. 1 shows the location of the experimental site. One particular characteristic of this site is the abundant presence of Brasilia's porous, soft clay in the upper layer of the soil.

Figure 1. Research site location

Within the Federal District, the occurrence of extensive areas (more than 80 % of the total area) covered by a weathered laterite of the tertiary-quaternary age is regular. It is essentially a red residual soil developed in humid, tropical and subtropical regions of good drainage. It is leached of silica and it presents a particular concentration of iron oxides and hydroxides and aluminum hydroxides. It also has a predominance of the clay mineral caulinite and, in localized points of the Federal District, it overlays a saprolitic/residual soil with a strong anisotropic mechanical behavior and high standard penetration resistance, which is originated from a weathered slate, a typical parent rock of the region. The superficial latosoil has a dark reddish coloration, and displays a much lower resistance and a much higher permeability than the bottom saprolitic/residual soil. The studied latosoil constitutes into a "collapsible" sandy clay with traces of silt, with a high void ratio and coefficient of collapse. Its coefficient of permeability is also high for a typical clay, being close to those found for fine to silty sands. This soil is the so called "porous" clay of Brasília, which major geotechnical parameters are displayed in Table 1.

The climate of the region is subtropical with rainfall concentration during the summer (between November to March). Total annual average rainfall in Brasilia, varies in range from 5 to 242 mm. Figure 2 presents the average month water precipitation between 1981 and 2010. It is also possible to observe that the months of May, June, July, August and September present low average month precipitation values when compared to other months.

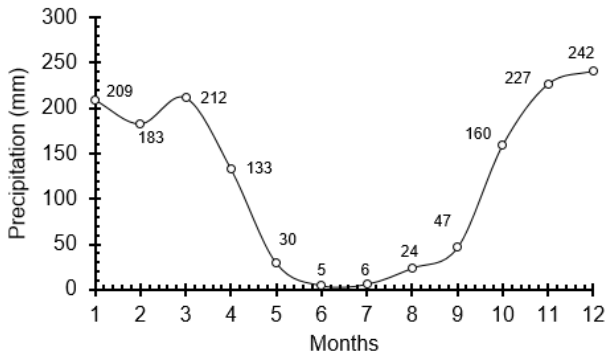

Figure 2. Average monthly precipitation: 1981 -2010 (INMET, 2019)

Table 1. Geotechnical parameters of Brasília porous clay

Parameter	Unit	Range
Sand percentage	%	12-27
Silt percentage	%	8-36
Clay percentage	%	80-37
Dry unit weight	kN/m^3	10-17
Natural unit weight	kN/m^3	17-19
Moisture content	%	20-34
Degree of saturation	%	50-86
Void ratio	--	1.0-2.0
Liquid limit	%	25-78
Plasticity limit	%	20-34
Plasticity index	%	5-44
Drained cohesion[a]	kPa	10-34
Drained Friction angle[a]	degress	26-34
Young`s Modulus [b]	MPa	1-8
Coefficient of Collapse	%	0-12
Coeff. Earth Pressure (K_0)	--	0.44-0.54
Coeff. Permeability	m/s	10^{-8} - 10^{-5}

3. Site Characterization

SPT, DMT and different types of laboratory test were carried out to obtain reference values for defining geotechnical soil parameters for the research site. Geotechnical characteristics are presented in Fig. 3. Drained triaxial tests were performed at 3 m depth.

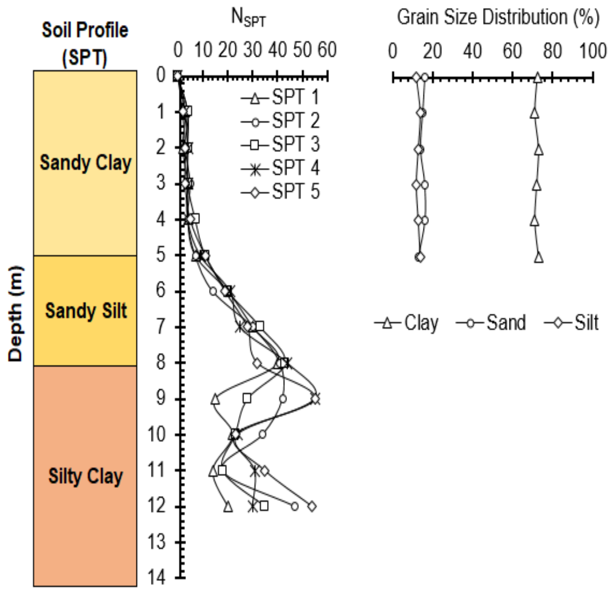

Figure 3. Field and laboratory tests

Disturbed samples also retrieved from the SPT thick-walled standard tube helped in the visual and tactile assessment of the distinct soil layers. All tests were performed in accordance with the Brazilian ABNT-6484 (ABNT, 2001) standard. Also, a flat Marchetti dilatometer test was carried out in accordance with the ASTM-

D6635-01 (ASTM, 2007) U.S. standard. Unfortunately, only one sounding with this test was possible because the blade became stuck at a depth of about 8 m and the rods were damaged. It was also possible to define a general division of soil layers at the site on the basis of both in-situ techniques and retrieved samples. From top to bottom, these layers consist of a sandy clay down to 5 m depth, followed by a 3 m thick sandy silt layer and finally, a silty clay layer down to 12 m depth presenting N_{SPT} values higher than 20.

Fig. 4 presents the lift off (p_0) and 1.1 mm membrane expansion (p_1) DMT pressures, that were further used to calculate the standard I_D, K_D and E_D, DMT parameters widely used on empirical correlations that furnish the geotechnical design values.

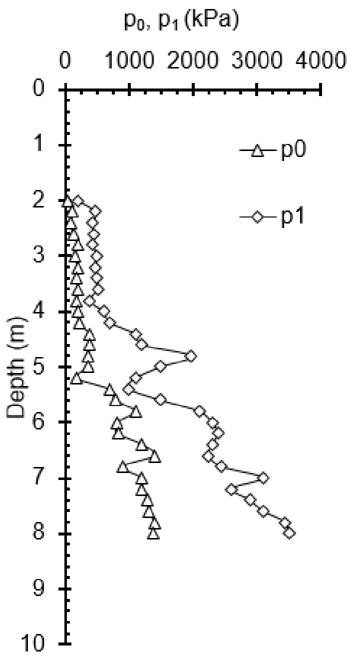

Figure 4. p_0 and p_1 in DMT tests

4. Test Results and Analysis

A DMT test was carried out at the research site and Fig. 5 presents the tests data in terms of ID, KD and ED where ID, KD and ED calculated by Marchetti's (1980) equations.

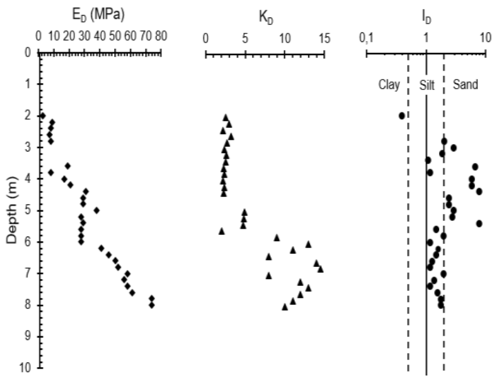

Figure 5. DMT test data for the research site

The design geotechnical parameters of interest, those associated to soil strength and deformability, can be acquired from published empirical solutions. For Instance, Lunne et al. (1989) presents a comprehensive state of the art on the existing DMT correlations of that time. SPT correlations in Brazil were introduced by Décourt (1995) and Teixeira (1996). Most of them, however, are still used nowadays, with minor modifications on the input variables to accommodate distinct characteristics for each region. The derived geotechnical parameters were then compared to reference laboratory once obtained from tests with undisturbed block samples.

Despite the limited laboratory data (Triaxial test data at a single depth), this comparison permitted preliminary interpretation of this in situ device in this tropical, unsaturated porous clay of the Federal District. Given the high void ratio and permeability of this clay, and its unsaturated condition, the correlations for drained material were preferentially adopted herein for most of the derived parameters, as will be presented next.

Fig. 6 presents the comparison between the Young modulus obtained from the DMT and SPT using diverse correlations and the laboratory values from drained triaxial tests (Baldi et al., 1986; Robertson et al., 1989; Décourt, 1995; Poulos, 1998). The laboratory reference values were related to both the initial (Ei, tangent) and the intermediate (E_{50}, secant at 50% of failure load) Young moduli levels. In order to use N_{SPT} values for correlation applications, an average N_{SPT} value was employed at each depth.

The DMT Young moduli were obtained by adopting distinct correlation factors F (multiplied by E_D) suggested for drained soils. Both procedures of F = 2 (Robertson *et al.*, 1989), and F = 0.85 and 3.5 (Baldi *et al.*, 1986) respectively for normally and overconsolidated sands, were tried out. SPT Young moduli were acquired by using correlations factors (multiplied by N_{SPT}) proposed by Décourt (1995) and Poulos (1998), where F = 3.5 and 3.0, respectively.

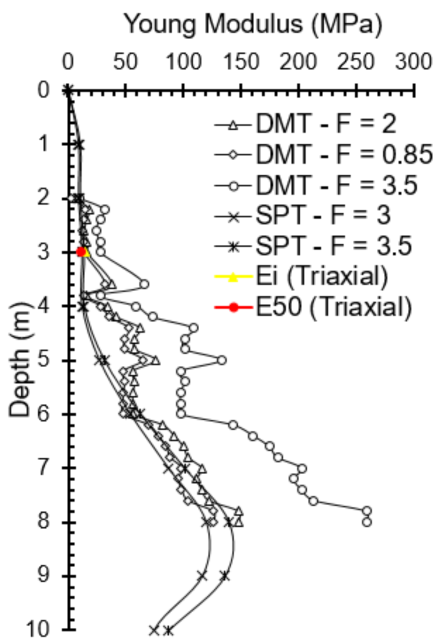

Figure 6. Young moduli comparison

The comparisons of Fig. 6 indicate that for the tangent Ei and secant E_{50} values an F of 0.85 and 2 would reasonably represent the laboratory results, as well as for the

SPT estimates at a 3 m depth. SPT and DMT Young moduli estimates present a reasonable convergence from 2 to 3 m and 6 to 8 m depth.

The reference friction angle of this particular clay was obtained via drained triaxial tests, with samples isotropically consolidated. In order to obtain the drained strength of this clay, a correlation proposed by Marchetti (1997) was used for the DMT test data. Although these correlations were developed for purely frictional materials (without effective cohesion, which is not the case of the Brasilia porous clay), they were used herein as a start point for a preliminary evaluation of this clay's drained frictional strength. A SPT correlation proposed by Teixeira (1996) was adopted to evaluate friction angle estimates based on the SPT.

Fig. 7, therefore, presents the comparison of reference and predicted DMT and SPT friction angles. It can be readily seen that the SPT methodology fails to accurately predict this parameter, but rather yield values that are respectively lower reference one. However, the DMT estimate presents a reasonable friction angle prediction, despite the limited laboratory reference data Hence, the SPT (Teixeira, 1996) values would have to be multiplied by a factor close to 1.6 to exactly match the reference value.

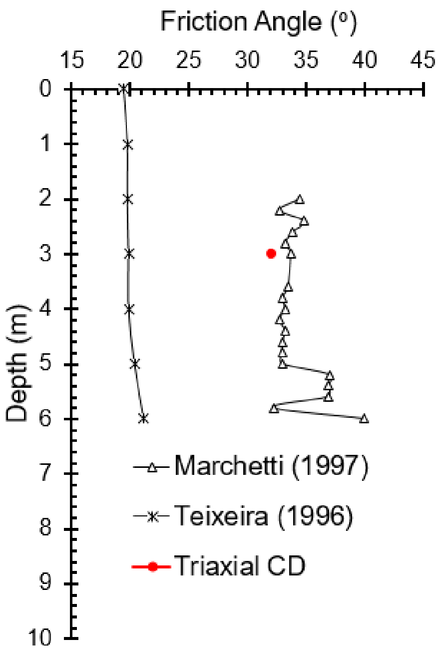

Figure 7. Young moduli comparison

Cunha et al., (1999) presented a preliminary interpretation of DMT results on the Brasília porous clay. It was possible to verify that the material herein analyzed present similar characteristics to the material studied by Cunha et al., (1999). Therefore, it was possible to observe that similar estimates for strength and deformability parameters were obtained using the DMT test data.

5. Conclusions

This paper presents an inceptive experience and interpretation on the Marchetti dilatometer with a tropical geotechnical material, the Brasília unsaturated and porous clay. It also shows SPT estimates for strength and deformability parameters, which is the most employed field technique in Brazil for earthworks design. Despite of the limited laboratory data, this paper presented a preliminary comparison between empirically predicted and reference laboratory values. These tests were carried out as a part of ongoing research of the Geotechnical Graduation Program of the University of Brasília and its results, although limited and preliminary, are of practical interest. The standard DMT and SPT correlations employed were developed for drained quaternary (predominantly) sandy deposits. The use of those correlations are justified due to the material high permeability and site unsaturated condition. Such characteristics allow this clayey material to shear in a drained manner when external loads are applied. General conclusions of the comparisons together with possible adjustments coefficients are presented. Such preliminary results can serve as an inceptive evaluation of strength and deformability estimates for these types of soils, which are now conceived for practical local engineering use. It is also important to note that this research presented similar estimates compared to previous preliminary studies.

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