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Assessment of Results of CPT Tests in Porous Lateritic Unsaturated Soil from Campinas, Brazil

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ABSTRACT: This work is an analysis of the results obtained by means of mechanical (Begemann Cone) and electric cone penetration tests (CPT) performed in porous, unsaturated lateritic soil from the subsoil of the Experimental Site of Soil Mechanics and Foundations of the University of Campinas (Unicamp), State of São Paulo, Brazil. To this goal, a campaign of three mechanical and three electric CPTs was performed down to the depth of 10 m, which is the limit to get to the rocky massif. The local subsoil is characterized by a 2 m thick surface layer of silty-clayey sand, followed by a layer of silty sand. The average porosity of the local subsoil is approximately 62% and the index of voids is 1.64. Readings of the parameters of both tests indicated low dispersion (q_c, f_s, R_f) in the section between 2 m and 8 m. Variability in the initial section was high. The application of the abacus to classify the soil behavior by means of mechanical cone displayed some dispersion in the results. However, in the electric cone tests, the abacus displayed a good classification. All propositions that were used identified the transition from the surface soil to the residual soil between 7 and 8 m.

1 INTRODUCTION

Over the last few years, the scenario of national engineering, in Brazil, has changed significantly. Expressive investments have been made both in infrastructure works and in civil works. Economic stability and the growing confidence in the Brazilian market led to a massive injection of foreign capital. In this scenario, interchange of methods and technologies has found greater acceptance in the field of engineering, with a strong marketing appeal. This is different from the scenario of some years ago when only the academic community was interested in geotechnical tests, except for SPT.

The presence of foreign companies and investments has led to co-participation of designers and consultants both from Brazil and from abroad. This has brought about technical enrichment and the Brazilian market needed to meet these new expectations. In this context, geotechnical tests such as CPT and particularly CPTU have gained strength nationwide, following the global trend.

In this context, there is lack of information on the possibility of using these tests as safe tools to produce stratigraphic and geotechnical parameters either directly or indirectly by means of correlations, particularly when dealing with tropical lateritic porous unsaturated soils. Pournaghiazar, et al (2013), Collins & Miller (2014) and Yang & Russel (2016) pointed this problem, concerning the suction influence in CPT parameters, specially concerning the correlations with soil parameters.

Therefore, the intent of this work is to analyze the results obtained from mechanical and electric CPT tests conducted at the Experimental Site of Mechanics of Soils and Foundations of the School of Civil Engineering of Unicamp, in Campinas city.

Another purpose of this work is to check, for the Campinas typical tropical lateritic soil, the adequacy of stratigraphic characterization standard methods, despite their potential problems regarding the unsaturated condition, once the methods were created for the saturated and/or dry soil conditions, as noted by Pournaghiazar, et al (2013).

2 GEOTECHNICAL CHARACTERISTICS

The Experimental Site is located within the city of Campinas, State of São Paulo, Brazil. It measures approximately 600 m², being composed of soils in an unsaturated and “porous”, tropical condition with collapsible characteristics. The first studies developed in this site were performed by Gon (2011), followed by Rodriguez (2013), who performed geotechnical characterization tests of the area both in laboratory and in situ tests. Figure 1 shows a simplified geological profile of the Experimental Site obtained from an in situ testing program of Standard Penetration Test (SPT) performed by Rodriguez (2013). This figure shows that the range of results increase below 8 m, perhaps as a function of the proximity of the mother rock strata (with variable depth within the site). This figure briefly summarizes the results from laboratory tests conducted by Gon (2011). The water table level was not found down to the impenetrable lawyer (approximately 10 m). It must be noted that the values of the fraction of sand, silt and clay were obtained by means of joint granulometry tests with no use of defloccculant.

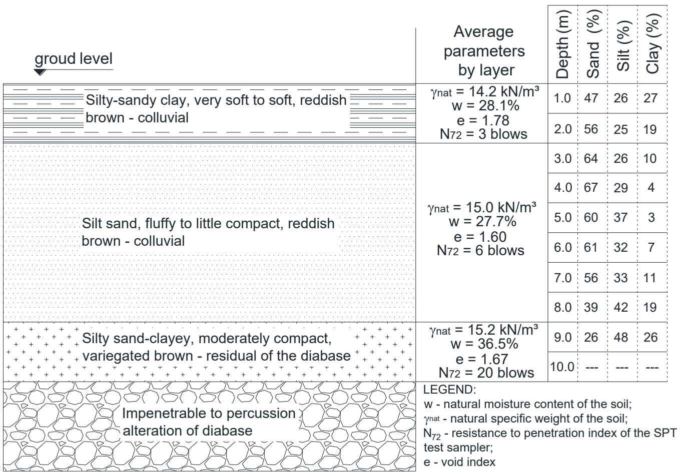

Figure 1. Simplified typical geological profile of the FEC – Unicamp Experimental Site.

2 CPT TESTS

In order to build the database of this work, three CPT-M (mechanical) tests were performed using the Begemann cone per recommendations of ASTM D3441-05 and three CPT-E (electric) tests with the use of Geoprobe instrumented cone per recommendations of ASTM D5778-12. The test site at the Experimental Filed of the School of Civil Engineering, Architecture and Urbanism (FEC) is shown in Figure 2.

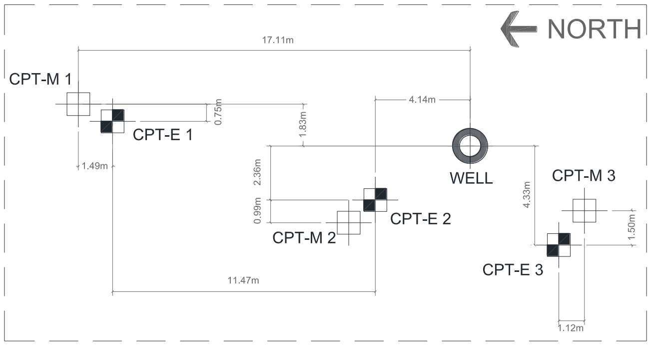

Figure 2. Location of the tests performed in the Experimental Field (Rodriguez, 2013).

2.1 *Results*

Based on the results of the tests, it is possible to observe the variation in resistance of the cone, of lateral friction and of the fact of friction (Figures 3, 4 and 5). The results indicated low dispersion in the readings of the parameters qc, fs and RF (%), particularly at the depths between 2 m and 8 m. The first meter displayed high variability, probably as a function of the dryness of the surface layer. This fact was also observed in the section below 8 m, where the values indicated greater dispersion as a function of the proximity to the rocky top, which had various depths.

Considering that qt = qc (due to u2 = 0), via Figure 3 it is possible to see that the mean values of cone resistance obtained both in mechanical and in electric tests displayed little variation among them. The qc (CPT–M) / qt (CPT – E) ratio was approximately 1.0, with variation coefficient (CV) in the order of 16 %.

As to the values of unit lateral friction, fs, shown in Figure 4, it was noted that the values obtained via CPT–M produced higher values than CPT–E. It must be noted that down to the depth of 6 m, a high value between the fs (CPT–M) / fs (CPT–E) ratio was recorded, i.e., a value in the order of 16, with variation coefficient (CV) of 80%, which indicated high dispersion. From 6 m down to the maximum depth of the tests (9.6 m), the mean value of the ratio was approximately 2.0 with a variation coefficient (CV) of the order of 40%. As the values of lateral friction displayed different trends for each test procedure, the values of RF also varied, as shown in Figure 5.

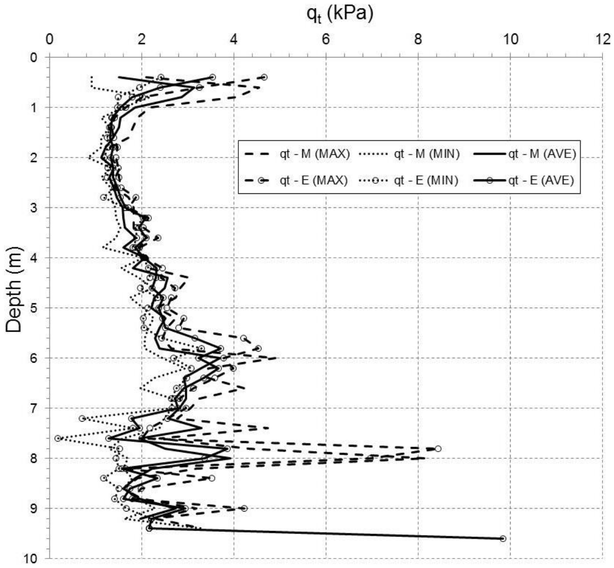

Figure 3. Variation of qt in depth.

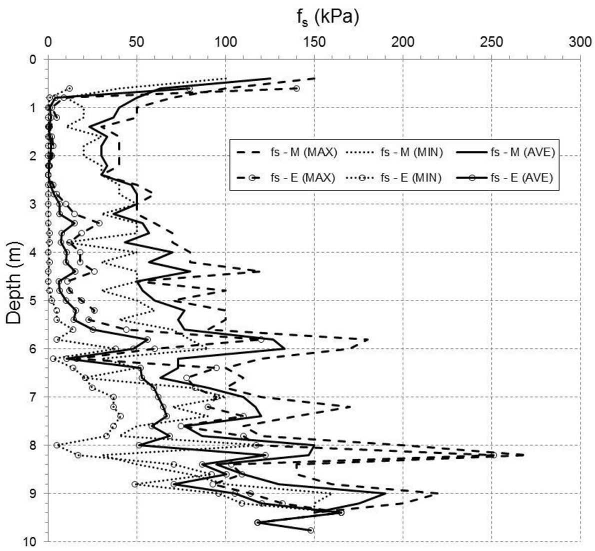

Figure 4. Variation of fs in depth.

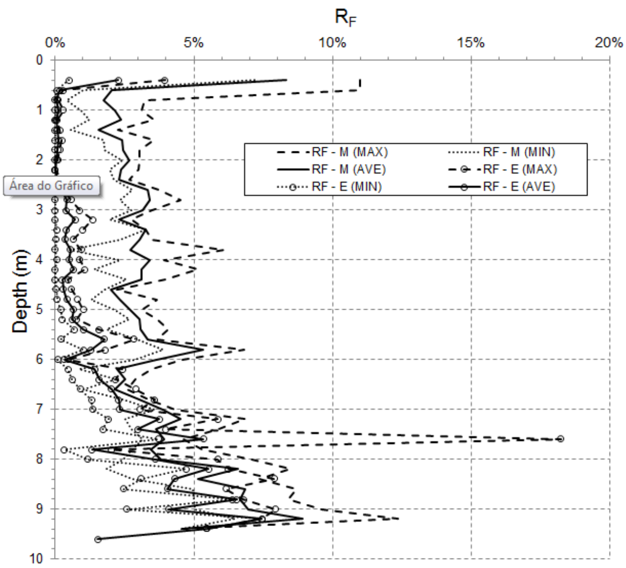

Figure 5. Variation of R_F in depth.

3 SOIL PROFILING

One of the possibilities of the use of CPT tests is to identify the horizons of the stratigraphic profile through the mechanical behavior of the soil when the cone is driven. The proposals of Begemann (1965) and Schmertmann (1969) were used to get the data from CPT-M. The proposals of Douglas & Olsen (1981), Robertson et al. (1986), Eslami & Fellenius (1997) and Robertson (1990) were used to get the data from CPT-E.

Figure 6 shows a summary of the results obtained with the application of the abacus of Begemann (1965). It must be pointed that, when using this abacus, a high concentration of points in the area of low accuracy of the graph was observed and this made it impossible to make the stratigraphic definition of the soil under study.

As to the abacus of Schmertann (1969), it was found that the points were distributed in a manner that made it possible to identify the horizons more clearly and classify the soil. Table 1 shows the results obtained with the use of the abacus of Schmertmann (1969). It was also found that the results showed mostly soil with silty behavior down to the depth of 6 m. Below this depth, the soil displayed clayey characteristics. It was possible to identify the transition of the behavior of the layers in the mean depth of 7-8 m in agreement with the granulometric analyses without Gon defloccculant (2011).

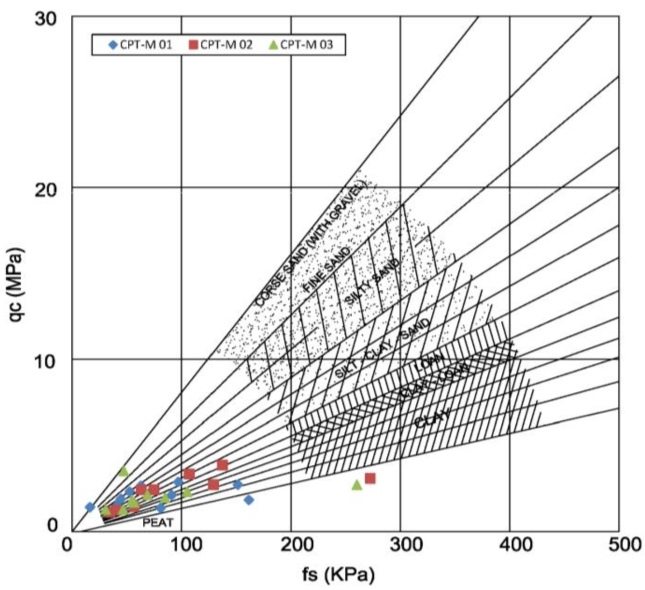

Figure 6. Soil classification by Begemann (1965).

Table 1. Soil classification by Schmertmann (1969).

Depth (m)	CPT-M 1	CPT-M 2	CPT-M 3
1	3	3	1
2	3	2	3
3	3	2	2
4	2	2	2
5	4	3	2
6	3	2	2
7	2	2	2
8	1	3	1
9	1	-	1
10	-	-	-
SBT	Description		
1	Clay		
2	Sandy and Silty Clay		
3	Clayey Sand and Silt		
4	Sand		

Using the data of the CPT-E tests, it was possible to apply the abacus of Doulgas & Olsen (1981), Robertson et al. (1986), Eslami & Fellenius (1997) and Robertson (1990) (Tables 2, 3, 4 and 5).

Table 2. Soil classification by Doulgas & Olsen (1981)

Depth (m)	CPT-E 1	CPT-E 2	CPT-E 3
1	3	3	3-2
2	3	3	3
3	3	3	3
4	3	3	3-2
5	3	3	3
6	3-2	3	3
7	3-2	3	3-2
8	2-1	2	3-2
9	3-2	2-1	2-1
10	-	1	2
SBT	Description		
1	Clay		
2	Silt		
3	Sand		

Table 3. Soil classification by Robertson et al. (1986)

Depth (m)	CPT-E 1	CPT-E 2	CPT-E 3
1	7	7	7
2	6	7-6	7-6
3	7-6	6	6
4	7-6	7-6	6
5	7	7	7-6
6	7-6	7	7-6
7	7-5	7-6	7-6
8	5-4	6-4	6-5
9	8-7	3	6-3
10	-	3	3
SBT	Description		
3	Clay		
4	Clay to Silty Clays		
5	Silty Clays to Clayey Silt		
6	Clayey Silt to Sandy Silt		
7	Sandy Silt to Silty Sand		
8	Silty Sand to Sand		

According to the abacus proposed by Douglas & Olsen (1981), CPT-E 1 found two different layers: one from 0 to 5 m with sandy behavior and the second one 6 m down with sandy silty behavior. CPT-E 2 found three layers: the first one from 0 to 7 m with sandy behavior; the second one from 8 to 9 meters with silty to silty-clayey behavior, and the third one 10 m down with clayey behavior. The CPT-E 3 test found two layers: the first one from 0 to 8 m with sandy to silty sandy behavior and the second from 9 m down with silty behavior. The proposition of Douglas & Olsen (1981) led to identification of the behavior of sandy to silty-clayed layers at the mean depth of 7 to 8 m in CPTE-02 and CPTE-03 tests in agreement with the granulometric analyses without Gon deflocculant (2011). In the CPTE-01 test, the interface of the layers was seen at 5 m. The behavior of the second layer detected by the proposition was dispersed among the tests, and the result of the application of CPT-E 1 and CPT-E 3 was closer to the one obtained by Gon (2011).

Table 4. Soil classification by Eslami & Fellenius (1997)

Depth (m)	CPT-E 1	CPT-E 2	CPT-E 3
1	5-3	5-4	5-4
2	5	5-4	5-4
3	5	4	5-4
4	5	4	4-3
5	5	4	4
6	5-4	4	4
7	4-3	4	4
8	3	4-3	4
9	4	3-2	3
10	-	3	3
SBT	Description		
2	Soft Clay - Soft Silt		
3	Silty Clay - Hard Clay		
4	Silty Sand - Sandy Silt		
5	Sand - Gravel		

Table 5. Soil classification by Robertson (1990)

Depth (m)	CPT-E 1	CPT-E 2	CPT-E 3
1	6	7	8-6
2	-	6	6
3	-	6-5	6-5
4	-	5	5
5	6	5	5
6	5-4	5	5
7	5-4	5	5
8	4-3	4-3	4-3
9	5-4	3	4-3
10	-	3	3

SBT	DESCRIPTION
3	Clays to Silty Clays
4	Clayey Silts to Silty Clays
5	Silty Sand to Sandy Silt
6	Clean Sand to Silty Sand
7	Stony Sand to Sand

Table 5 is a summary of the classifications produced by the application of the abacus of Robertson et al. (1986). According to the methodology proposed by the authors, CPT-E 1 displayed three different layers: the first one from 0 to 7 m with silty behavior, the second one at 8 m with clayey to silty-clayey behavior, and the third one from 9 m down, with sandy behavior. CPT-E 2 displayed three layers: the first one from 0 to 7 m with silty behavior, the second from 8 to 9 m with silty to clayey behavior and the third one from 10 m down, with clayey behavior. CPT-E 3 displayed three layers: the first one from 0 to 7 m with silty behavior, the second one from 8 to 9 m with silty to clayey behavior, and the layer from 10 m down with clayey behavior. With the use of the abacus of Robertson et al. (1986), it was possible to differentiate the behavior of two layers interfacing at 7 m, in agreement with the indications of Gon (2011) in the granulometric analyses without deflocculant. The behavior of the first layer was that of sandy-silty to silty soils and the second layer was classified as silty-clayey to clayey soils.

Table 6 shows the results obtained according to the abacus of Eslami & Fellenius (1997). It was found that the CPT-E 1 test detected two different layers: the first one from 0 to 6 m with sandy to silty-sandy behavior, and the second one from 7 m down, with silty-sandy to silty clayey behavior. CPT-E 2 test displayed two layers: the first one from 0 to 7 m with sandy to silty sandy behavior, and the second one from 8 m down with silty-clayey to clayey behavior. CPT-E 3 test displayed two layers: the first one from 0 to 8 m with sandy to silty sandy behavior, and the second one from 9 m down, with silty clayey to clayey behavior. In general, the method of Eslami & Fellenius (1997) detected behaviors close to the one obtained by Gon (2011). It also distinguished the behavior of two layers, with interface at 7 m in average.

Table 7 shows the results of the application of the abacus of Robertson (1990). It was possible to observe that it was difficult for CPT-E 1 test to classify between 0 and 4 m due to the low values of RF obtained; silty and clayey behavior was seen from 6 to 9 m. In the CPT-E 2 test, the analyses indicated two layers: the first one from 0 to 7 m with sandy to silty behavior, and the second one from 8 m down, with silty to clayey behavior. CPT-E 3 test found two layers: the first one from 0 to 7 m with sandy to silty behavior, and the second one from 8 m down, with silty to clayey behavior. In general, the first layer, as characterized by the proposition of Robertson (1990), was similar to the results obtained by Gon (2011); however, the lower layers displayed clayey soils, contrary to the results of Gon (2011), same as the methodology of Robertson et al. (1986). It must be pointed out that these two methods presented the SBT (Soil Behavior Type) of the soils under analysis. It is advisable to assess several aspects such as soil fractions, clay contents, LL, LP, among other aspects to produce a more accurate diagnosis of the behavior of the material.

5 CONCLUSION

No differences were detected among the values found in the mechanical and electric tests for the values obtained via cone resistance (qt). This demonstrates the reliability of both methods.

A significant difference was observed in the behavior of lateral friction (fs) of the cone when the two types of tests (mechanical and electrical) are assessed. Down to the depth of 6 m (the layer with the highest index of voids and also with marked laterization), the differences were of the order of 16 times, whereas in the lower section, the differences were of the order of 2 times. This shows that this parameter is sensitive to the type of soil formation found. Therefore, attention must be paid to indiscriminate use of this parameter.

As for the data obtained from the mechanical cone test, it was difficult to use the abacus of Begemann (1965). This fact was not observed in the abacus of Schmertmann (1969). However, these abacuses were used only so that the results obtained with the mechanical cone could be applied, thus making it possible to make a comparison with those obtained with the electric cone.

The use of the CPT test to identify horizons of the stratigraphic profile by means of the mechanical behavior of the soil when the cone is driven proved to be appropriate when the electric cone was used. The stratigraphic profiles obtained were very close to those obtained by means of the joint granulometric test without use of deflocculant. As the massif is composed of unsaturated porous lateritic soil, the test without the use of deflocculant is the most suitable method to indicate the soil behavior. The only point to be noted is the abacus of Robertson (1990) in which stratigraphic discretization of values of Rf is very impacted, as pointed out in CPT-E 1.

Despite the most popular abacus, and/or charts, used for soil characterization were developed for saturated and/or dry conditions, it presented good relation with the laboratory results for the unsaturated lateritic Campinas soil. The results obtained made it possible to clearly identify the transition of layers between the depths of 7 m and 8 m.

It's necessary to extend this research, using a calibration chamber, to check if the suction would affect the soil characterization using the abacus (or charts) used here in.

6 REFERENCES

ASTM-D3441. 2005. *Standard test method for mechanical cone penetration tests of soil*

ASTM-D5778. 2012. *Standard test method for electronic friction cone and piezocone penetration testing of soils*

Begemann, H.K.S.P. 1965. The friction Jacket Cone as an aid in determining the soil profile. *6th International Conference of Soil Mechanics and Foundation Engineering, Proc., Montreal, Quebec, Canada*, v.1, 17-20.

Collins, R., & Miller, G.A. 2014. Cone penetration testing in unsaturated soils at two Instrumented test sites. In Proceedings of the 6th international conference on unsaturated soils, UNSAT, Sydney, Australia, Balkema, Lisse, Vol. 2, 1489-1494.

Douglas, B.J. & Olsen, R.S. 1981. Soil classification using electric cone penetrometer. *Symposium of Cone Penetration Testing and Experience, Proc., ASCE. New York*, 209-227

Eslami, A. & Fellenius, B. H. 1997. Pile capacity by direct CPT and CPTu methods applied to 102 case histories. *Canadian Geotechnical Journal*, 34 (6), 880 - 898.

Gon, F.S. 2011. *Caracterização Geotécnica Através de Ensaios de Laboratório de um Solo de Diabásio da Região de Campinas*. FEC-UNICAMP. Dissertação de Mestrado, 153pp.

Pournaghiazar, M., Russell, A.R., & Khalili, N. 2013. The cone penetration test in unsaturated sands. Geotechnique 63(14): 1209-1220.

Robertson, P.K, Campanella, R.G., Gillespie. D. & Greig, J. 1986. Use of piezometer cone data". *In-Situ 86, Specialty Conference, Proc., ASCE, Blacksburg*, 1263-1280.

Robertson, P.K. 1990. Soil classification using the cone penetration test. *Canadian Geotechnical Journal*, 27, 151-158.

Rodriguez, T.G. 2013. *Caracterização geotécnica de um solo de diabásio por meio de ensaios de SPT e CPT*. FEC-UNICAMP. Dissertação de Mestrado, 167pp.

Schmertmann J. H. 1969. *Dutch Friction Cone Penetration Exploration of Research Area at Field 5, Eglin Air Force Base, Florida, US Army Waterways Experimental Station, Vicksburg, Mississippi*, Contract Report S-69-4

Yang, H. & Russell, A.R. 2016. The cone penetration test in an unsaturated silty sand. Canadian Geotechnical Journal. 53(3): 431-444.