International Journal of GEOMATE, Jan., 2018 Vol.14, Issue 41, pp.102-110
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2018.41.81190
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

ANALYSIS OF THE UNDRAINED SHEAR STRENGTH THROUGH THE STANDARD PENETRATION TEST WITH TORQUE (SPT-T)

* J.C. Ruge[1], C.C. Mendoza[2], J.E. Colmenares[3], R.P. Cunha[4] and I.F. Otalvaro[5]

[1] Facultad de Ingeniería. Programa de Ingeniería Civil Universidad Católica de Colombia. Bogotá, Colombia
[2] Programa de Ingeniería Civil. Universidad Nacional de Colombia Sede Manizales, Colombia
[3] Departamento de Ingeniería Civil y Agrícola. Universidad Nacional de Colombia, Bogotá D.C
[4] Departamento de Engenharia Civil e Ambiental. Universidade de Brasília, Brasil
[5] Departamento de Ingeniería Civil e Industrial. Pontificia Universidad Javeriana Cali, Colombia.

*Corresponding Author, Received: 17 Oct. 2017, Revised: 14 Nov. 2017, Accepted: 7 Dec. 2017

ABSTRACT: Although in situ tests are very useful for obtaining data on the strength and deformation of a geomaterial, some of these tests have been criticized because of their limitations for identifying certain parameters. This paper presents research into a hitherto little used test here in Colombia, the SPT-T (Standard Penetration Test + Torque). This test combines the advantages of the Standard Penetration Test (SPT) and the Vane Shear Test (VST) to obtain a soil's lateral friction and to correlate its classification and structure by means of the relationship between the N_{SPT} and the torque applied. This study reaffirms the dependent relation between T/N_{SPT} and soil structure found elsewhere in the world and investigates whether parameters governing the undrained condition of soil may be correlated with T/N_{SPT}. Conceptually, a relationship between undrained soil conditions and the way the test is conducted is evidenced. For this reason, this research is an initial approach which open the door to continuing phases of research that may be able to develop appropriate correlations between undrained strengths of soft soils and the T/N_{SPT} parameter used in analyses of this test.

Keywords: Undrained condition, SPT-T, in-situ tests, sedimentary soils, VST

1. INTRODUCTION

The standard penetration test with torque (SPT-T) is a field test that combines SPT-type dynamic measurement methodology with static measurement of torque similar to the Vane Shear Test (VST). Both methodologies are still evolving. Like the SPT, the SPT-T uses a split-spoon sampler which is driven into the soil with a slide-hammer. SPT-T can be used to measure two geotechnical factors, standard penetration resistance and lateral friction (torque), rather than just one factor. Unlike the SPT-T, the VST uses a probe with four orthogonal blades that is driven into the soil. Torque is then applied to the shaft and measured. In the SPT-T, torque is applied to the shaft of the split-spoon sampler and then measured. Test results can be used to derive T/N_{SPT} (torque/number of blows) which can then be used to correlate soil classification and any soil structure which may be present.

This study is based on analysis of lateral friction of the soil-sampler in sedimentary soils of the region under study. Data was first obtained through in-situ testing and then analyzed to demonstrate dependence between T/N_{SPT} and some soil properties. Since appropriate overall correlation for the current context would be premature, this study is limited to a demonstration of the use of SPT-T analysis of parameters obtained directly from the test. Testing methodology based on ASTM D-1586-11 [1], NBR 6484/2001 [2] and INV E-111-13 [3] is explained. The testing method involves removing the head of the scaffolding, placing a centralizer disc onto the guiding tube, fitting a torque wrench, and measuring the torque for an indication of soil adherence to the sampler-soil.

This test indicates soil behavior in terms of the lateral friction between the soil and the soil-sampler and provides an important parameter for deep foundation design that is both cheap and simple. Since SPT-T's first use, researchers in various parts of the world have encouraged other to use it in foundation engineering. Nevertheless, specific studies about the use of this test are needed to determine its real applicability to geotechnical engineering.

2. STATE-OF-THE-ART

Modernization of in-situ testing, first developed as a complement to laboratory tests, has transformed it into a useful and versatile alternative for obtaining geotechnical soil parameters. In-situ testing and laboratory testing each have drawbacks, but these can usually be balanced out by using both types of tests and taking advantages of their reciprocal strengths. For this reason, a subsoil study procedure should

include a combination of the field and lab tests that are ideal for the problem to be addressed [4].

The field tests most commonly used are standard penetration tests, vane shear tests, cone penetration tests, penetrometers [5], pressuremeters and dilatometers. However, there is a wide variety of these tests currently in use in geotechnics. Each test tends to be designed for the unique conditions of the soil type (Fig. 1) [6]. Most are not suitable for estimating geotechnical parameters in all types of soil. Each test applies loads differently to measure soil response in order to obtain physical characteristics of the material. Vertical drilling is required for SPT and some versions of PMT and VST. Tests such as CPT and DMT do not require drilling since the direct-push technique is used. This technique does not generate shear within the soil to be tested. However, this type of test is not recommended in hard materials such as cemented soils, rocks, and some gravels that may prevent free penetration.

For this study, SPT-T has the advantage of combining the classic Standard Penetration Test with the Vane Shear Test. SPT-T was created by Ranzini [7], [8] who proposed a slight alteration in the SPT procedure based on the observation that the operator applies torque to the bar with a hand tool at the end of the test. Ranzini thought that the wrench could simply be replaced with a torque to measure the maximum torque needed to overcome the sampler's resistance to rotation.

The test basically uses the same principles as the SPT [1]-[3] in the first step when the split-spoon sampler is inserted into the soil stratum under study. In the second step, a torque wrench attached to the bar, is used to rotate the sampler while it measures the torsion required to overcome the resistance of the soil.

In this manner, the lateral friction of the split-spoon sampler is obtained [9]. Figure 2 shows SPT-T testing equipment: 1. Torque wrench, 2. Adapter, 3. Sampler extension bar, 4. Adjustment disc, 5. Sleeve and 6. Rod.

An advantage of this test is that the momentum measured is not affected by as many variables as in the standard SPT. Factors that influence the meaning of final SPT results, the number of hammer blows required to drive the sampler, include potential errors in counting the number of blows, drop height, weight of hammer, type of sampler, and energy transfer from hammer blows. Through the addition of the torque wrench, the SPT-T also provides a reliable value of lateral friction. Several recent advances in the use of the SPT-T for resolving geotechnical problems are due to introduction of analysis of the correlation of T/N_{SPT} (torque/number of blows) to various geotechnical parameters.

The first part of this study analyzes T/N_{SPT}. The initial idea of using use torque measurement with SPT was presented by Brazilian researchers [11]. They also proposed using the T/N_{SPT} ratio as a way to standardize N_{SPT} apart from any additional geotechnical considerations related to classification of soils. These authors made various measurements using several kinds of torque obtained with manual and electric equipment. They concluded that measurements taken using different means are satisfactory [9]. In addition, suggested the eq. 1 for the estimation of the lateral friction.

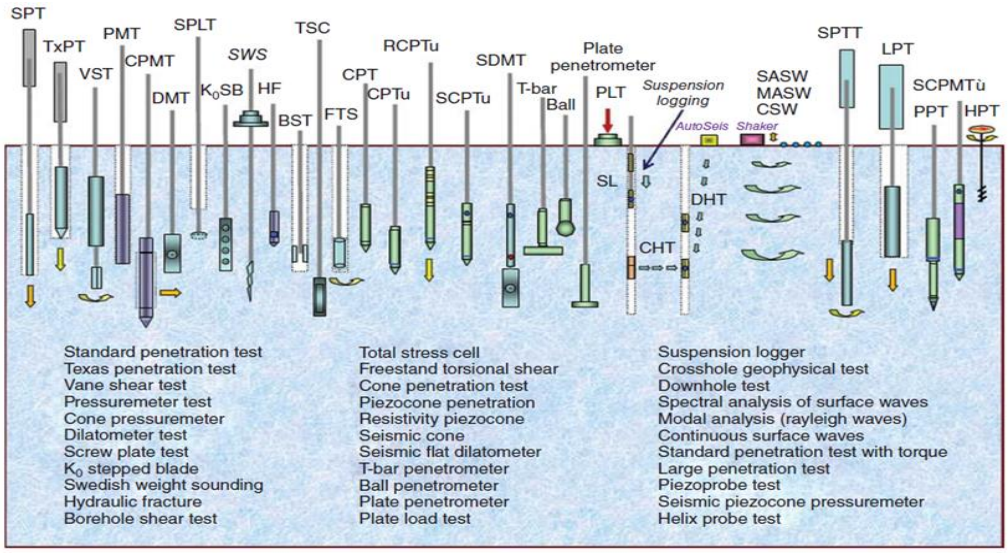


Figure 1. in-situ tests [6]

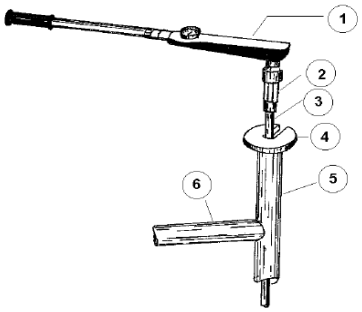


Figure 2. Torque wrench and parts [10]

$$f_T = (2T)/(\pi d^2 L) \quad (1)$$

Where T is the measurement of torque, d is the diameter of the sampler, and L is the length of the sampler.

This conclusion became important for the use of torque measurement in engineering practice. [12] also analyzed how to obtain parameters for the design of foundations from SPT-T based on the results of a large-scale trial of the test that they conducted. On the basis of these test, [12], presented some advantages, among others, SPT-T measures static *T* and dynamic *N* strength in a single test. Another is that it provides standardization of the *N* value.

2.1 Correlations for soil classification

[11] were the first to present correlations between the torque obtained from SPT-T and N_{72} in sedimentary soils (Eq. 2) and residual soils (Eq. 3). N_{72} is the *N* value for 72% driven efficiency which corresponds to the average energy required with equipment used in Brazil. Driven efficiency is defined as the energy required to drive the sampler into the soil. According to the recommendation of [13], in Colombia it is possible to use 45%.

$$\boldsymbol{T\,[kg-f.m\,] = 1.10\,N_{72}} \quad (\mathbf{2})$$

$$\boldsymbol{T\,[kg-f.m\,] = 1.84\,N_{72}} \quad (\mathbf{3})$$

For the authors, these correlations can reveal problems found in the values of *N* in the SPT. This is especially true when there are sandy layers containing gravels, a condition which requires more hammer blows to penetrate the sampler than real value. [14] appreciated the great advantage of measuring the torque over the *N* value of SPT since the first measurement is static while the second measurement is dynamic. Another important advantage is that, even though during the SPT the soil structure breaks within the sampler, the torque measures the lateral friction in the region, which, despite the invasion by the sampler, still preserves its original structure. For this reason, structured soils tend to have higher T/N_{SPT} (details in [15]).

The SPT-T test do have the ability to provide an independent assessment of the undrained shear strength of the soil that is generated around the sampler´s body by the measurement of the friction stress mobilized on this region by torque application. In other words, as previously commented, the sampler´s shear resistance to rotation. Likewise, the vane shear presents an independent assessment of the undrained shear strength of the soil by measuring a similar friction stress that is mobilized on both lateral and upper/down sides of a cylindrical element of soil during torque application on the vane´s central bar and blades.

It is possible to assume that both shear resistances might be similar in physical nature, and therefore correlated somehow. This paper advances on this thematic, showing trends between derived SPT torque (expressed in terms of its division by number of blows, or T/N_{SPT}) and the calculated undrained strength variable Su_{λ} by the vane shear test. The comparison will also take on consideration the undrained shear strength values measured on triaxial UU laboratory tests, as expressed on the final overall comparative table.

3. MATERIALS AND METHODS

This section describes the project's characteristics, materials and equipment. The soil will be analyzed in detail on the basis of exploration conducted parallel to the testing with SPT-T.

3.1 Study sites

3.1.1 Geological and geotechnical characteristics

The experimental field is located near the foothills of the Andes on the savanna of Bogotá. Its soil profile is typical of the region: the surface layer is composed of anthropic fill, but is underlain by clays and silts with some sand. Near the bottom end of the boreholes (5.00 meters) gravel is also found. The soil is not strongly resistant to penetration with an SPT of between 4 and 9 blows, has a low bearing capacity and a relatively high content of water. The groundwater level surface is found at 4.00 meters below the soil surface in some places.

Table 1 lists parameters of the top few meters of stratification at the study site. It can be seen that there are clayey soils (CH and CL) suitable for the SPT-T. In Table 1, w denotes the natural water content, LL is the liquid limit and LP is the plastic limit. Additional boreholes were drilled at another site in the south of the city, in order to analyze other types of soft soil with this methodology.

Table 1. Basic characterization parameters

Sample	Depth (m)	w (%)	LL (%)	LP (%)	USC
First site					
S2M1	1.00 – 1.50	37.4	50.6	21.6	CH
S2M2	1.50 – 2.00	32.8	67.9	29.4	CH
S2M3	2.00 –2.50	32.1	48.1	24.5	CL
S2M4	2.50 – 3.00	34.1	45.7	23.0	CL
S2M5	3.00 – 3.50	29.4	25.6	15.7	CL
S3M1	1.10 – 1.18	36.3	65.8	31.6	CH
S3M2	2.40 – 2.90	21.9	58.0	24.9	CH
S4M1	1.30 – 1.90	31.7	58.1	32.8	MH
S4M2	2.30 – 2.90	55.2	69.7	34.5	MH
S4M3	3.20 – 3.80	31.5	40.6	22.1	CL
S5M1	1.40 – 1.90	31.4	53.8	25.7	CH
S5M2	1.90 – 2.40	34.0	48.2	23.0	CL
S5M3	2.40 – 2.90	45.4	59.8	26.9	CH
S5M4	2.90 – 3.40	40.1	48.9	22.1	CL
S5M5	3.40 – 3.90	30.4	30.7	19.2	CL
S8M1	1.50 – 2.00	26.7	37.7	21.7	CL
Second site					
S2M1	1.60 – 2.20	66.45	110.0	46.0	MH
S2M2	2.50 – 3.10	72.89	116.0	61.0	MH
S2M3	3.40 – 4.00	26.40	39.0	18.0	CL
S2M4	4.40 – 5.00	25.42	26.0	14.0	CL

3.2 SPT-T (Standard Penetration Test+Torque)

Testing in the experimental field began with the standard penetration test which was conducted according to [1], [3]. A donut hammer was used which allowed an approximate efficiency of 45% given the configuration used during all testing and the Colombian context for this test [13]. For this study, the N_{SPT} parameter was obtained using methodologies from [13] for correcting the parameter according to confining and energy. N_{145} was obtained when the blows delivered in the field were corrected.

Subsequently, we applied torque to the extension bar of the split-spoon sampler that had been driven into the ground in the first part of the test. Torque was applied through constant 360° rotation which will be called T_{max} in this article. After 30 seconds, residual torque was measured. This new measurement has been named T_{res} (Fig. 3).



Figure 3. Torque wrench used in the SPT-T.

The SPT-T test do however have some major limitations, as those clearly provided by [9] in her PhD Thesis. It lacks standardization and its final results are clearly influenced by the type of equipment, operating crew, level of energy & associated losses, type of driving hammer and the overall physical conditions of the sampler unit. Nevertheless, it is still the most used equipment in South America for field works, geotechnical characterization and foundation design. Hence, its usage is justified in the present study, although it is recognizable that other better techniques to derive the undrained shear strength are available (see [24]).

3.3 VST Test (Vane Shear Test)

For this type of study, it is necessary to have data in order to calibrate the new test to be evaluated. It was decided to conduct the VSTs during the exploration campaign. We decided to follow the guidelines of the [16] and use rectangular and trapezoid vanes to determine undrained shear strength (Su). Even though the *T/N* value of SPT-T has not yet has been directly correlated with Su. This means that these measurements can be important for analysis of the results of this research even though undrained resistance depends on other factors such as anisotropy, OCR and stress paths.

3.4 Laboratory test

As mentioned, the best accepted correlations for the SPT-T are related to soil-sampler adherence estimation from which the soil can be classified and in some cases the soil structure characterized. This is the focus of this study: to use *T/N* for a first approach, within the framework described, both in soil classification and characterization, emphasizing in the undrained condition of the soil.

In addition to VST, for characterization of the soil in terms of its shear strength a series of tests was performed. Under in-situ conditions, it is evident that when there are undrained conditions it will affect the vicinity of the split-spoon sampler because of the speed of execution. For this reason, we decided to perform UU triaxial tests that were consistent with an exposed scenario, related with the obtaining of undrained parameters and the articulation with soil-sampler adherence since this may have an essential connection to the response of undrained soil.

4. RESULTS

4.1 SPT-T

Eight boreholes of four to five meters in depth were drilled to obtain a stratigraphic profile as

described previously. In three boreholes SPT-Ts were conducted. VSTs were performed with rectangular vane (VRTr) and trapezoidal vane (VSTt) in the remaining boreholes.

Table 2 shows the SPT-T results. The first part of the test was based on SPT in accordance with [1], [3], and the torque was applied on the basis of the Brazilian experience with this type of test [9]. T/N_{SPT} was carefully observed. According to the literature found, T/N_{SPT} is the most key factor for correlating the lateral friction and load capacity of piles. It is also important for soil classification purposes as in this article [14]. In accordance with [11] who correlated torque and N_{172} (Eq.1, 2) in sedimentary and residual soils in Brazil, it was observed that at three meters of depth an adequate correlation exists between the number of blows and the torque applied [17]. For Colombia, the correlation was made with N_{145}, according to the recommendation of [11], [13].

From results obtained in field, it was observed that from 3.00 meters deep, the dispersion between the two parameters is high due to the presence of fine gravels. Even though the number of hammer blows do not increase the number, friction between soil and the sampler increases as indicated by measuring torque. The T/N_{SPT} ratio is useful because it combines the measurement of a static parameter (T) and a dynamic one (N). In addition, the measurement of torque indicates lateral friction in around the sampler within the soil that has been only partially altered and still retains its original structure. According to this, structured soils tend to have greater T/N_{SPT}, but the current results reveal that the tested soils are poorly structured, consistent with what is mentioned by [14].

Table 2. Number of blows in field, maximum and residual torque in VST and SPT-T.

Depth (m)	Borehole	N_F	T_{max} [lbf-ft]	T_{res} [lbf-ft]	T/N [kg-f/m]
First Site					
1.00 – 1.50	1 (VSTr)	—	75	25	—
	2 (SPT–T)	4+6	115	85	1.59
	3 (VSTt)	—	60	25	—
	4 (VSTt)	—	60	25	—
	5 (SPT–T)	—	65	20	—
	8 (SPT–T)	—	80	30	—
1.50 – 2.00	1 (VSTr)	—	80	20	—
	2 (SPT–T)	4+5	70	65	1.07
	3 (VSTt)	—	60	20	—
	4 (VSTt)	—	60	27.5	—
	5 (SPT–T)	3+4	82.5	60	1.63
	7 (VSTt)	—	20	5	—
	8 (SPT–T)	5+5	97.5	90	1.35
	9 (VSTt)	—	55	20	—
2.00 – 2.50	1 (VSTr)	—	57.5	30	—
	2 (SPT–T)	5+6	70	65	0.88
	3 (VSTt)	—	72.5	30	—
	4 (VSTt)	—	80	25	—
	5 (SPT–T)	3+4	85	70	1.68
	8 (SPT–T)	8+8	60	52.5	0.52
	9 (VSTt)	—	80	20	—
2.50 – 3.00	2 (SPT–T)	6+5	80	55	1.01
	3 (VSTt)	—	50	20	—
	4 (VSTt)	—	70	30	—
	5 (SPT–T)	3+3	60	52.5	1.39
	7 (VSTt)	—	45	22.5	6.23
	8 (SPT–T)	10+6	77.5	45	0.67
	9 (VSTt)	—	80	20	—
3.00 – 3.50	2 (SPT–T)	1+1	47.5	40	3.29
	3 (VSTt)	—	50	22.5	—
	4 (VSTt)	—	45	15	—
	5 (SPT–T)	1+3	67.5	65	1.34
	7 (VSTt)	—	20	10	2.77
	8 (SPT–T)	1+1	55	47	3.81
	9 (VSTt)	—	80	30	—
3.50 – 4.00	2 (SPT–T)	1+1	30	27.5	2.08
	4 (VSTt)	—	30	10	—
	5 (SPT–T)	3+2	67.5	50	1.87
	7 (VSTt)	—	20	10	2.77
4.00 – 4.50	2 (SPT–T)	1+1	0	0	—
	3 (VSTt)	—	25	5	—
	4 (VSTt)	—	30	10	—
	7 (VSTt)	—	45	25	1.25
Second Site					
1.60 – 2.20	1 (VSTt)	—	70	15	—
	2 (SPT–T)	2+2	65	40	2.25
2.50 – 3.10	1 (VSTt)	—	100	37.5	—
	2	3+3	75	50	1.73
3.40 – 4.00	1 (VSTt)	—	45	25	—
	2	1+2	57.5	35	2.65
4.40 – 5.00	1 (VSTt)	—	—	—	—
	2	2+3	60	30	1.66

Numerous studies [7], [8], [9], [11], [12], [14], [15] have shown that the results of SPT-T are useful for soil classification and analysis of soil structure.

4.2 Unconsolidated Undrained Triaxial Tests

Nevertheless, it is reasonable to think that the undrained soil conditions are related to responses to the soil sampler tests since torque is applied suddenly in soft soil. For this reason, it should eventually be possible to relate torque measurements, and even the T/N_{SPT} value, to an undrained parameter obtained from tests of soils with this drainage characteristic. Table 3 shows the results of UU triaxial tests.

4.3 Comparison of results from SPT-T, VST and TUU laboratory tests

This analysis is oriented toward evaluating SPT-T's usefulness for classifying soils and identifying soil structures. Within this study, T/N_{SPT} determines the incidence of these two parameters.

The values of T/N_{SPT} in the first case study do not reveal any trend related to depth. Instead, they fluctuate, mostly between 1 and 2. According to [14], this type of result implies that these soils are derived from sedimentary deposits. These soils close to the eastern piedmont of the city are formed from deposits that have been weathered over time from the rocks of the eastern hills and then transported by rivers of the savanna. Over time they have formed deeper layers of sediment. For this reason, the value of T/N_{SPT} should, in principle, be close to that based on global experience in this type of characterization.

Table 3. TUU Tests for σ_3 of 100, 200, 400 (kN/m^2)

Sample	Depth (m)	Su ($\mathbf{kN/m^2}$)
First site		
S2M1	1.00 – 1.50	135
S2M2	1.50 – 2.00	101
S2M3	2.00 –2.50	109
S2M4	2.50 – 3.00	89
S2M5	3.00 – 3.50	71
S5M1	1.40 – 1.90	111
S5M2	1.90 – 2.40	97
S5M3	2.40 – 2.90	105
S5M4	2.90 – 3.40	90
S5M5	3.40 – 3.90	75
Second site		
S2M1	1.60 – 2.20	178
S2M2	2.50 – 3.10	123
S2M3	3.40 – 4.00	93
S2M4	4.40 – 5.00	64

The methodology of [14] also suggests that smaller values of T/N_{SPT} imply less structured soil. This coincides with the soil analyzed in this study which has no structure. VST and UU triaxial results were correlated with SPT-T results for undrained soil conditions. Table 4 shows the undrained resistance of the soil analyzed at the first and second study site obtained from two different pathways. Su_λ is estimated from the VST and corrected with the proposal of [18] that uses the PI as correction parameter. Su_{UU} is the undrained resistance determined by unconsolidated undrained triaxial.

Compatibility of torques measured using different probes can be found by comparing maximum torque and residual torque. In all cases, the materials were found to have sensitivities (T_{max}/T_{res}) of close to two or three times. However, it is logical to think that the structure of a soil tested with a vane probe will suffer greater distortion than the structure of a soil tested with a split-spoon sampler, and this matches the results obtained.

When torque is applied to the vane probe, the movement of the vanes accentuates rupturing of the soil far more than does application of torque to a spoon sampler. Even though it also produces some failure of the material, due to the characteristics of this type of probe the lateral area of the sampler tends to slide more smoothly through the soil, especially in soft soils. The T/N_{SPT} parameter, as at the first study site, shows that soils are poorly structured and tend to be sedimentary. This is consistent with the deposits found at this location. This study validates, in principle, that the variable T/N_{SPT} is compatible with the soil structure using the Brazilian experience as a reference point.

A comparison of the Su corrected by VST with the value obtained in UU triaxial testing shows that the field test tends to produce a more conservative value than that obtained in the laboratory which makes the field test more suitable for any analysis. For the purpose of this research, it is important to clarify that, although there are established precedents for a possible correlation between T/N and undrained soil conditions, a general study is needed to obtain better correlation. This is important because rotation of the split-spoon sampler eventually generates undrained soil conditions at the time of application of the test [19].

This research presents a high level of coincidence with previous studies which indicates that SPT-T is not only novel, but is a promising in-situ test. In fact, it is currently coming into use by consulting firms around the world. Also, is revealed a solid correlation exists between the dynamic measurement N_{SPT} and static measurements. For details see [20]-[22]. Although there is congruence in the simplicity of the analysis and execution of the test in this study, according to [23] this methodology is incapable of providing results that can lead to fully established correlations. This is due to several factors, among which is the fact that the ranges of torque found in diverse types of soil overlap which can generate ambiguous results. Similarly, the Brazilian experience provides valid data for specific sites but these data cannot be extrapolated to any soil classification [24],[25].

5. CONCLUSIONS

The standard penetration test with torque definitively complements conventional research conducted with SPT, and, moreover, it provides a higher technical level. It overcomes many of the technical limitations for which SPT has been strongly criticized, and is emerging as a more reliable field test. The combinations of SPT, VST, and SPT-T or additional tests reduces uncertainty by correctly characterizing a site [26],[27],[28].

Table 4. Number of blows in the field, maximum / residual torque in VST, SPT-T, Su_{λ} and. Su_{UU}

Depth (m)	Borehole	N_F	T_{max} [lbf-ft]	T_{res} [lbf-ft]	Su_{λ} $[kN/m^2]$	T/N [kg-f/m]	Su_{UU} $[kN/m^2]$
First Site							
1.00 – 1.50	1 (VSTr)	—	75	25	196.88	—	—
	2 (SPT–T)	4+6	115	85	—	1.59	135
	3 (VSTt)	—	60	25	152.25	—	—
	4 (VSTt)	—	60	25	164.5	—	—
	5 (SPT–T)	—	65	20	—	—	—
	8 (SPT–T)	—	80	30	—	—	—
1.50 – 2.00	1 (VSTr)	—	80	20	196.0	—	—
	2 (SPT–T)	4+5	70	65	—	1.07	101
	3 (VSTt)	—	60	20	152.25	—	—
	4 (VSTt)	—	60	27.5	164.5	—	—
	5 (SPT–T)	3+4	82.5	60	—	1.63	111
	7 (VSTt)	1+1	20	5	61.25	—	—
	8 (SPT–T)	5+5	97.5	90	—	1.35	—
	9 (VSTt)	—	55	20	168.43	—	—
2.00 – 2.50	1 (VSTr)	—	57.5	30	161.0	—	—
	2 (SPT–T)	5+6	70	65	—	0.88	109
	3 (VSTt)	—	72.5	30	186.08	—	—
	4 (VSTt)	—	80	25	210.0	—	—
	5 (SPT–T)	3+4	85	70	—	1.68	97
	8 (SPT–T)	8+8	60	52.5	—	0.52	—
	9 (VSTt)	—	80	20	219.33	—	—
2.50 – 3.00	2 (SPT–T)	6+5	80	55	—	1.01	89
	3 (VSTt)	—	50	20	128.33	—	—
	4 (VSTt)	—	70	30	177.63	—	—
	5 (SPT–T)	3+3	60	52.5	—	1.39	105
	7 (VSTt)	—	45	22.5	118.13	—	—
	8 (SPT–T)	10+6	77.5	45	—	0.67	—
	9 (VSTt)	—	80	20	210.0	—	—
3.00 – 3.50	2 (SPT–T)	1+1	47.5	40	—	3.29	71
	3 (VSTt)	—	50	22.5	131.25	—	—
	4 (VSTt)	—	45	15	133.87	—	—
	5 (SPT–T)	1+3	67.5	65	—	1.34	90
	7 (VSTt)	—	20	10	52.5	—	—
	8 (SPT–T)	1+1	55	47	—	3.81	—
	9 (VSTt)	—	80	30	210.0	—	—
3.50 – 4.00	2 (SPT–T)	1+1	30	27.5	—	2.08	—
	4 (VSTt)	—	30	10	89.25	—	—
	5 (SPT–T)	3+2	67.5	50	—	1.87	75
	7 (VSTt)	—	20	10	52.5	—	—
4.00 – 4.50	2 (SPT–T)	1+1	0	0	—	—	—
	3 (VSTt)	—	25	5	65.63	—	—
	4 (VSTt)	—	30	10	78.75	—	—
	7 (VSTt)	—	45	25	118.13	—	—
Second Site							
1.60 – 2.20	1 (VSTt)	----	70	15	149.04	----	----
	2 (SPT–T)	2+2	65	40	----	2.25	178
2.50 – 3.10	1 (VSTt)	----	100	37.5	221.66	----	----
	2 (SPT–T)	3+3	75	50	----	1.73	123
3.40 – 4.00	1 (VSTt)	----	45	25	130.94	----	----
	2 (SPT–T)	1+2	57.5	35	----	2.65	93
4.40 – 5.00	1 (VSTt)	----	----	----	----	----	----
	2 (SPT–T)	2+3	60	30	----	1.66	64

According to the state-of-the-art on this topic, the best accepted correlations are related to identification of soil structure using T/N_{SPT} as the main variable in the analysis of the test. This study has confirmed what has been found in other studies that when soils which are poorly structured are tested, they present a low value of T/N_{SPT} low which implies that they are sedimentary deposit soils as has been shown by [14]. Similarly, [29] have shown that large test values of N_{SPT} reveal great difficulty in the application of torque due to the strong adherence between the soil and sampler. Conceptually, a relationship between undrained soil conditions and the way the test is conducted is evidenced. For this reason, this research is an initial approach which open the door to continuing phases of research that may be able to develop appropriate correlations between undrained strengths of soft soils and the T/N_{SPT} used in analyses of this test.

6. REFERENCES

[1] ASTM-American Society of Technical Materials. ASTM D 1586. Standard test method for standard penetration test (SPT) and split barrel sampling of soils. 2008. United States.

[2] ABNT-Associação Brasileira de Normas Técnicas. NBR 6484. Execução de Sondagens de Simples Reconhecimento dos Solos. 2001. Rio de Janeiro.

[3] INVIAS. INV-111-13, Ensayo Normal de Penetración (SPT) y Muestreo de Suelos con Tubo Partido. Espec. Generales de Construcción y Normas de Ensayo para Mat. de Carreteras. 2014.

[4] Briaud, J. Geotechnical Engineering: Unsaturated and Saturated Soils. Ed. Wiley, 2013. pp 15-56.

[5] Villavicencio, G., Breil, P., Espinace, R. and Valenzuela, P. Control de compactación con penetrómetro ligero en relaves, considerando su variabilidad material y estructural. Rev. de la Constr. Pontificia Univ. Católica de Chile. 6(2). 2007.

[6] Mayne, P., Coop, M., Springman, S., Huang, A. and Zornberg, J. Geomaterial Behavior and Testing. Proc. of the 17th Int. Conf. on Soil Mechanics and Geot. Eng. London: ISSMGE. 2009. pp. 2777-2872.

[7] Ranzini, S. SPT-F. Solos e Rochas, 11, 1988, pp. 29-30.

[8] Ranzini, S. SPT-F: 2ª parte. Solos e Rochas, 17 (3), 1994, pp. 189-190.

[9] Peixoto, A. Estudo do ensaio SPT-T e sua aplicação na pratica de engenharia de fundações. PhD. Thesis. Unicamp. 2001.

[10] Alonso, U. Correlação Entre o Atrito lateral medido com o Torque e o SPT. Solos e Rochas. 3, 1994, pp. 191-194.

[11] Décourt, L. and Quaresma, F. Practical Applications of the SPT Complemented by torque measurements, SPT-T; Present Stage and Future Trends. Proc. ISSMGE, 1994, pp. 143-146.

[12] Soares, J. Emprego do SPT-T e Pressiometro Ménard em um Deposito Arenoso da Região Litorânea de Joao Pessoa. Dissertação (Mestrado), Univ. Fed. da Paraíba. Dep. de Eng. Civil. Campina Grande. 1999.

[13] González, A. Estimativos de parámetros efectivos de resistencia con el SPT. X Jornadas Geot. de la Ingeniería colombiana.1999.

[14] Décourt, L. SPT in non-classical materials. U.S. Brazil Geotechnical Workshop on applicability of classical soil mechanics principles of structured soils, 1992, pp. 64-100.

[15] Décourt, L. A More Rational Utilization of Some Old in-situ Tests. Proc. of the 1st international conf. on site characterization, 1998, pp. 913-918.

[16] INVIAS. INV E-170-13 Ensayo de corte en suelos cohesivos usando veleta de campo. Espec. Generales de Construcción y Normas de Ensayo para Materiales de Carreteras. 2014.

[17] Carmona, J. and Ruge, J.C. Analysis of the existing correlations of effective friction angle for eastern piedmont soils of Bogota from in situ tests. Tecno-Logicas, 18 (35), 2014, pp. 93-104.

[18] Bjerrum, L. Embankments on soft ground. Proc. of the Specialty Conf. ASCE, 2(12), 1972, pp. 1-64.

[19] Cangie, B. and Dipova, N. Estimation of Undrained Shear Strength of Konyaaltu Silty Clays. Indian Journal of GeoMarine Sciences. 46 (03), 2017, pp 513-520.

[20] Kelley, S. and Lutenegger, A. Unit Skin Friction from the Standard Penetration Test Supplemented with the Measurement of Torque. Journal Geotechnical and Geoenvironmetal Engineering ASCE, 2004, 130:540-543.

[21] Heydarzadeh, A., Fakher, A. and Moradi, M. A feasibility study of Standard Penetration Test with Torque measurement (SPT-T) in Iran. Geotech. and Geoph. Site Characterization 4, 2013.

[22] Lutenegger, A. and Kelley, S. Standard Penetration Tests with Torque Measurement. Geotec. Site Charact. Proc. Balkema. USA, 1998, pp. 939-945

[23] Scheilz, S. Development of SPT-torque test correlations for glacial till. MS Thesis. Purdue Univ. 2012.

[24] Peixoto, A., Albuquerque, P. and de Carvalho, D. Utilization of SPT-T, CPT and DMT tests to predict the ultimate bearing capacity of precast concrete pile in Brazilian unsaturated soil. Advances in unsaturated geotechnics. ASCE, 2000, pp.32-39

[25] Peixoto, A., Antenor, V., Rams, T. and David, R. Rod length influence in torque measurements of SPT-T. ASCE, 2007, p. 1-14.

[26] Peixoto, A. and de Carvalho, D. Determination of soil properties from standard penetration test complemented by torque measurement. Acta

Scientiarum Technology, 36 (4), 2014, pp. 617-621.

[27] Schnaid, F., Lourenco, D. and Odebrecht, E. Interpretation of static and dynamic penetration tests in coarse-grained soils. Geotechnique Letters 7. 2017.

[28] Hafez, D., Mahgoub, A., and Kief, M. General regression neural network modeling of soil characteristics from field tests. Int. Journal of GEOMATE, Jan., 2017, Vol. 12, 29, pp. 132 - 139

[29] Piovan, T. and Peixoto, A. Influence of angular trust in the measurement of torque in the SPT-T. Fundamentals to application in geotechnics. Manzanal and Sfriso (eds). 2015.

Copyright © Int. J. of GEOMATE. All rights reserved, including the making of copies unless permission is obtained from the copyright proprietors.