Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1806-2563
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v36i4.18759

Determination of soil properties from standard penetration test complemented by torque measurement (SPT-T)

Anna Silvia Palcheco Peixoto[1*] and David de Carvalho[2]

*[1]Programa de Pós-graduação em Engenharia Civil e Ambiental, Universidade Estadual Paulista, Av. Engenheiro Luiz Edmundo Carrijo Coube, 14-01, 17033-360, Bauru, São Paulo, Brazil. [2]Programa de Pós-graduação em Engenharia Agrícola, Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas, São Paulo, Brazil. *Author for correspondence. E-mail:anna@feb.unesp.br*

ABSTRACT. The major problem on geotechnical work is to ensure that no settlements occur during the life cycle of the construction. This involves proper design of foundations and their bearing capacity. The Brazilian standard for design and execution of foundations, ABNT (2010) NBR 6122 imposes the utilization of field tests when designing building foundations. The Standard Penetration Test, SPT, ABNT (2001) NBR 6484, is still the most common in-situ test for those purposes. Ranzini (1988) suggested supplementing the conventional SPT with the measurement of the torque (SPT-T) required to turn the split spoon after driving, in order to provide a 'static' component to a 'dynamic' test. The adhesion between the soil and the sampler, obtained by the torque measurement, could be used to calculate the lateral skin friction of piles. This paper describes the SPT-T procedure including both a supplementary equipment and practical aspects. Also it presents an accurate torque measurement, a prediction method to calculate the bearing capacity of piles used in building foundations using the SPT-T test and a comparison between the estimated bearing capacities of building foundations with instrumented load tests in order to validate the method.

Keywords: soil characterization, foundation design, SPT, torque measurement, load tests.

Determinação das propriedades do solo através do ensaio SPT-T

RESUMO. O maior problema relativo à construção de obras geotécnicas é a garantia da não ocorrência de recalques excessivos na vida útil da construção, que envolve o projeto de fundações, o qual depende do conhecimento das propriedades do subsolo . A norma brasileira de projeto e execução de fundações, ABNT (2010) NBR 6122 estabelece que qualquer obra deva ter investigação geotécnica preliminar, no mínimo SPT. Esse é o ensaio mais frequentemente utilizado para caracterização do solo para fins de projeto de fundações e trabalhos geotécnicos. Procurando obter mais informações durante o ensaio, Ranzini (1988) sugeriu adicionar ao ensaio SPT convencional a medida do torque (SPT-T) necessária para rotacionar o amostrador logo após sua cravação. A adesão entre o solo e o amostrador, obtida através do torque, pode ser relacionada com a resistência lateral de estacas. Esse artigo visa descrever o procedimento da medida do torque e apresentar uma nova proposta para prever a capacidade de carga de estacas. As estimativas calculadas foram comparadas aos resultados de provas-de-carga instrumentadas, validando o método.

Palavras-chave: caracterização de solo, projeto de fundações, SPT, medida de torque, provas de carga.

Introduction

In the Brazilian building foundation practice, the SPT test is mainly used to predict geotechnical properties of the soil and the bearing capacity of foundations. The test is standardized by ABNT (2001) NBR 6484.

Ranzini (1988) proposed the Standard Penetration Test with torque measurement (SPT-T), which has been used by some geotechnical engineers in Brazil since 1991. This test is easy to be executed. Basically it supplements the conventional SPT with measurement of the torque required to turn the split spoon after driving (Figure 1). The torque (*T*) provides a 'static' component to a 'dynamic' test. According to Ranzini (1994), the adhesion between the soil and the sampler, obtained by the torque measurement, could be used to calculate the lateral skin friction of piles. equation (1).

$$fT = \frac{T_{\max}}{(41.336h - 0.032)} \quad (1)$$

where:

fT = sampler-soil adhesion, kPa;

T_{max} = maximum torque meter measurement, m.kN;

h = depth of penetration of the sampler, m.

This paper presents the procedure for the torque measurement, a common practice Brazilian engineering, including innovative equipment and practical aspects.

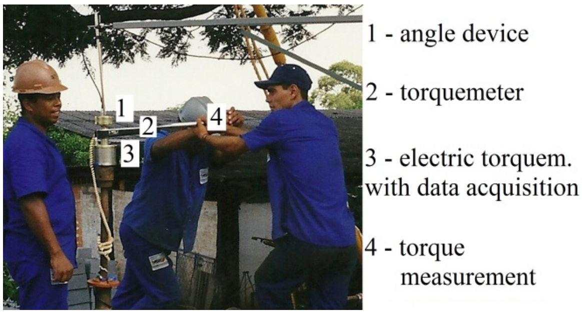

Figure 1. Equipment for the torque measurement test.

According to Kelley and Lutenegger (2004), the skin friction obtained by torque measurement has a good correlation with the Cone Penetration Test (CPT) sleeve measurements, and the N value. This is an interesting data to a preliminary design of building foundations. Likewise, in this research, several SPT-T tests were carried out in six experimental research sites in southeastern Brazil, where many geotechnical test data and building pile load tests were available (Figure 2).

Figure 2. Map of Brazil with the location of the cities and research sites. (no scale)

Therefore, a new instrument for an accurate torque measurement and an innovative method to predict bearing capacity of deep foundations of buildings (piles) are described.

The results were obtained from load tests carried out on different types of piles. After that, other load tests were performed to verify which method has a good prediction.

Material and methods

The conventional SPT test uses a split-barrel sampler to measure the soil resistance to penetration (*N-value*) at each one-meter depth, using a 65-kg hammer falling 0.75 m. In Brazil, the procedure is standardized by ABNT (2001) NBR 6484. In North America, the procedure is standardized by ASTM (2008) D 1586. *N-value* is the number of blows required to penetrate the last 0.3 m of the 0.45 m-depth. In order to get representative soil samples for identification and laboratory tests, a pipe wrench is used to pull the sampler (see Figure 1).

In the SPT-T, basically, the pipe wrench is replaced by a torque meter, and a measurement of the torque is required to break the soil-sampler interaction after penetration.

In this study, in situ tests were carried out firstly in six foundation experimental sites: University of São Paulo, USP (São Carlos and São Paulo Cities); State University of Campinas, Unicamp (Campinas City); State University of São Paulo, Unesp (Bauru and Ilha Solteira Cities) and Federal University of Lavras (UFLA). The types of piles tested in each site are presented in Table 1. In addition, in order to obtain data on peat, a test was also performed between Santos and Guarujá Cities, at the km 79.67 of Cônego Domênico Rangoni highway. These seven sites were chosen because of their different pedological and geomorphological characteristics. Figure 3 shows the USDA soil taxonomy for those soil profiles where SPT-T and load tests were carried out.

The number of SPT-T tests conducted in each site was chosen to enable comparisons among the load tests in foundations of buildings. Thus, a total of 26 SPT-T tests were done with depths ranging from 9 to 28 meters. The water table was considered in all analyses.

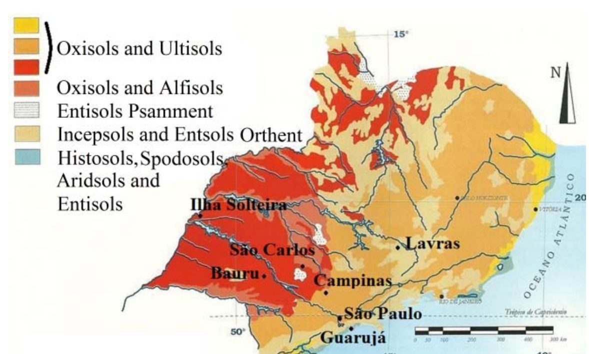

Figure 3. Map of main soils of Southeastern Brazil adapted from Embrapa (1981) and IBGE (2001) apud Lepsch (2002).

The SPT-T test procedure is very simple: after driving the sampler, with the counting of blows, an adapter is placed on the anvil to attach the torque meter (Figure 4a). A centralizing device should be placed either on the mouth of the hole or on the pipe to prevent the rod from shifting while the torque is applied (Figure 4b and c). Afterwards, rotation is applied to the rod-sampler assembly using the torque meter. The maximum torque is measured and the rotation continues without interruption until the torque becomes constant, when the residual torque is obtained.

Table 1. Types of piles tested in each site.

Site	Number and Type of Piles Tested
Unicamp Campinas-SP (sandy clay, up to 6m) (sandy silt, up to 20 m)	1 Precast concrete 3 Omega 3 Continuous-Flight-Auger 3 Bored.
USP São Carlos-SP (sandy soil)	3 Bored 1 Root 6 Socketed 2 Small Diameter 1 Strauss
USP São Paulo-SP (silty clay)	1 Precast concrete 3 Continuous-Flight-Auger 1 Auger 2 Franki 1 Steel 1 Strauss
Unesp Ilha Solteira-SP (sandy soil)	3 Precast concrete 3 Bored 1 Socketed
Unesp Bauru-SP (sandy soil)	9 Socketed
Ufla Lavras-MG (clayey silt)	5 Bored-Small Diameter

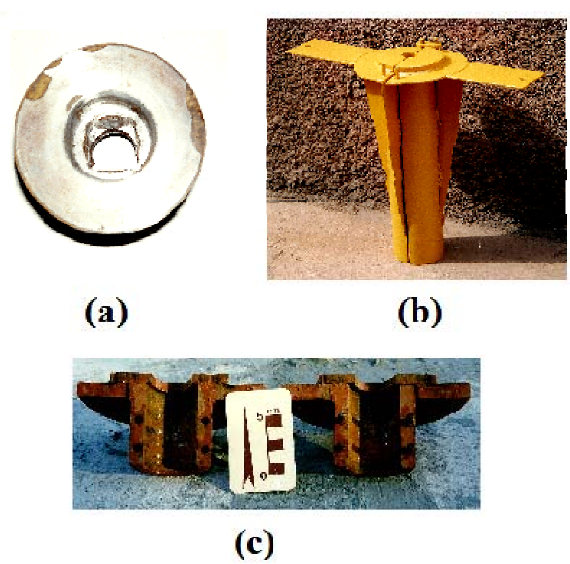

Figure 4. (a) Adaptation made at the anvil; (b) Centralizing device to be placed in the hole; (c) Centralizing device to be placed in the pipe.

Both measurements are logged in the sounding bulletin. The centralizing device and the adapter-torque meter assembly are removed and the soil boring continues to the next meter, where the *N value* and torque values are measured again. This procedure continued until it reached impenetrable SPT sounding or the maximum torque meter capacity. The detailed procedure for implementing this test is described in Peixoto et al. (2007).

Each meter produced the N-value, the torque measurement, the natural moisture and the soil profile. In addition, the 'torque versus rotation degree' curve was also obtained by means of an electric torque meter developed in this research with a data acquisition system (Figure 5).

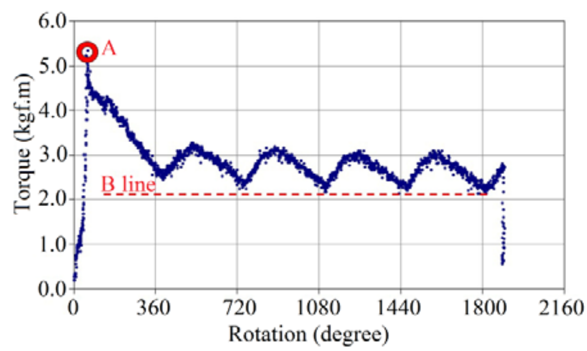

Figure 5. Typical 'torque versus rotation degree' curve.

The results of the tests have been used in two ways: the behavior of the 'torque versus rotation degree' of different soils and finally, a study of a method based on the SPT-T to predict the bearing capacity of foundation piles.

The ultimate bearing capacity of a single pile based on empirical methods using SPT-T test results (*Qu*) can be expressed as the ultimate tip resistance (*Qut*) and ultimate shaft resistance (*Qus*), equation (2).

$$Q_u = Q_{ut} + Q_{us} = x1.(q_c .A_t) + x2 .U.\sum(f_{si}.L_{si}) \qquad (2)$$

where:

x_1 and x_2 = empirical factors;

q_c = tip resistance;

A_t = area of the pile tip;

U = pile perimeter;

f_{si} = shaft or skin resistance within a single soil type, labeled i, penetrated by the pile;

L_{si} = shaft length interfacing with layer i.

Q_{ut} is calculated according to Decourt et al. (1996), where q_c is obtained by equation (3) and Table 2. For Q_{us}, the x_2 factor is a function of the pile type (Table 3), and shaft resistance (f_{si}) calculated by the equation (4).

$$q_c = C \times N \qquad (3)$$

where:

N = *N value*;

C = coefficient, dependent on the type of soil (Table 2).

$$q_s = F_1 . f_{Tmax} \quad (4)$$

where:

F1 = Correction value in function of the pile type and T_{max}(kgf.m)/N ratio (Table 3).

Table 2. *C* coefficient apud Decourt et al. (1996).

Soil texture	*C* (kN m^{-2})
Clay	120
Clayey Silt (C Horizon)	200
Sandy Silt (C Horizon)	250
Sand	400

In addition to Decourt et al (1996) who presented a soil classification according to the degree of structuring through the torque T_{max}/N ratio, this ratio seems to be an interesting index to estimate the behavior of driven piles because it is affected by soil responses to dynamic loads. In this manner, the use of a correction factor based on T_{max}/N ratio appears to be an interesting approach, since it is not a general correlation, once it is obtained directly on the site where the foundation will be built. The T_{max}/N ratio can also be used to indicate the soil laterization.

The x_2 and F_1 values are only a preliminary suggestion and require improvement before being used in building foundation practice.

Table 3. x_2 and F_1 coefficients.

Type of Foundation Pile	x_2	F1	
		T/N < 1	T/N>1
Precast concrete	0.8	1.0	1.0
Omega	3.0	1.0	1.0
Steel	0.3	1.0	1.0
Small Diameter Injected	2.0	1.0	1.0
Root	1.5	1.0	1.0
Strauss	0.8	1.3	0.7
Franki	0.8	0.7	0.5
Socketed	3.5	0.7	0.5
Continuous-Flight-Auger	2.0	1.0*	0.3*
Auger and Bored	1.4	1.3	0.7
Diaphragm Panel Bored	0.7	1.0	1.0

Note: when f_T > 80 kPa, use F_1 = 0.3 to any *T/N*.

Results and discussion

The results of ‘torque versus rotation degree’ were analyzed considering the following factors: shape, rotation speed, N-blow, soil moisture content, equipment capacity and comparison between the mechanical and electrical torques obtained at the same time. The general curve is illustrated in Figure 5. The oscillation shows the difficulty to keep the rod straight inside the hole, even using the centralizing device. Small oscillations indicate the relief caused by the operator’s footsteps.

A total of 469 curves obtained in the seven locations were analyzed. The results of ‘torque versus rotation degree’ allowed the analysis on the behavior of torque versus the rotation degree curve, making possible the definition of the maximum and residual torques and rotation speed.

The definition of maximum and residual torque is shown in Figure 5, where T_{max} corresponds to point A and T_{res} corresponds to the average of line B.

The representative curves of inceptisols showed a maximum torque of 60° before rotation. The residual torque was well defined before the second complete turn.

On the other hand, for oxisols found in Bauru, Ilha Solteira and São Carlos Cities, the residual torque was not well defined before the second curve (720°), while the T_{max} was also obtained before 60°. This can be explained by the high porosity of those soils, and loss of adhesion to the sampler as a function of rotation.

Additionally, the T_{max} was reached almost instantly with the histosols of Guarujá City. The residual torque dropped rapidly and, after the third turn, the value increased slightly, making it difficult to set a correct value.

A comparative study of the empirical method based on the SPT-T results and load tests was developed in six experimental research sites in southeastern Brazil, as shown in Figure 1 and Table 1. Herein, a method is proposed, based on the six experimental research data. The statistical evaluation shown in Table 4 was calculated considering also other data of Brazilian references, as indicated in Peixoto et al. (2000).

Table 4. Statistical evaluation of methods dispersion using SPT-Tdata.

Pile Foundation Type	Qu_{cal}/Qul_{meas} ratio mean	sd	cv (%)
Precast Concrete	1.02	0.16	15.3
Auger	1.05	0.31	28.9
Continuous Flight Auger	0.86	0.33	38,5
Bored	0.91	0.14	15.9
Socketed	1.01	0.18	17.4

Note: Q_{ul} is the ultimate load determined by the load tests; sd is the standard deviation and cv is the coefficient of variation.

For precast concrete pile, the methods using SPT-T data appear to be interesting, since this *in situ* test simulates pile execution. For auger and continuous flight auger piles, the *ratio* Qu_{cal}/Qul_{meas} based on SPT-T methods achieved to satisfactory results. On the other hand, the results of bored piles were acceptable, which means that the behavior of the continuous flight auger piles can be influenced by a scale factor (compared with SPT sampler diameter) or execution type. Again, the results for the socketed pile were smaller than those expected in foundation practice.

Conclusion

The equipment developed for torque measurement during the SPT test allows obtaining the maximum and residual torque, rotation versus torque and identification of susceptible soils to vibration. In this way, the tests showed that in certain soils it is difficult to infer a procedure to obtain the residual torque. Otherwise, this value shows the loss of resistance when the soil is subjected to driven load.

The results of the proposed method probably can be explained by the use of the factor, x_2, which depends on T_{max}/N and represents type and structure of the soil on which the foundation was executed.

Acknowledgements

The authors gratefully acknowledge FAPESP (São Paulo State Foundation for Research Support) for the financial support.

References

ABNT-Associação Brasileira de Normas Técnicas - **NBR 6484**. Execução de Sondagens de Simples Reconhecimento dos Solos. Rio de Janeiro: ABNT, 2001.

ABNT-Associação Brasileira de Normas Técnicas - **NBR 6122**: Projeto e Execução de Fundações. Rio de Janeiro: ABNT, 2010.

ASTM-American Society of Technical Materials. **ASTM D 1586**. Standard test method for standard penetration test (SPT) and split barrel sampling of soils. Vf United States: ASTM, 2008.

DECOURT, L.; ALBIERO, J. H.; CINTRA, J. C. A. Análise e projeto de fundações profundas. In: HACHICH, W.; FALCONI, F. F.; SAES, J. L.; FROTA, R. G. Q.; CARVALHO, C. S.; NIYAMA, S. (Ed.). **Fundações teoria e prática**. São Paulo: Ed. Pini, 1996. p. 265-327.

EMBRAPA-Empresa Brasileira de Pesquisa Agropecuária. Serviço Nacional de Levantamento e Conservação de Solos. **Mapa de solos do Brasil**. Rio de Janeiro: Ministério da Agricultura, 1981. (Mapa escala: 1:5000000).

KELLEY, S. P.; LUTENEGGER, A. J. Unit skin friction from the standard penetration test supplemented with the measurement of torque. **Journal of Geotechnical and Geoenvironmental Engineering**, v. 130, n. 5, p. 540-543, 2004.

LEPSCH, I. F. **Formação e conservação dos solos**. São Paulo: Oficina de Textos, 2002.

PEIXOTO, A. S. P.; ALBUQUERQUE, P. J. R.; CARVALHO, D. **Utilization of SPT-T, CPT and DMT tests to predict the ultimate bearing capacity of precast concrete pile in brazilian unsaturated soil**. Denver: ASCE, 2000.

PEIXOTO, A. S. P.; ANTENOR, V. B.; RAMOS, T. M.; DAVID, R. **Rod length influence in torque measurements of SPT-T Test**. Denver: ASCE, 2007. p. 1-14.

RANZINI, S. M. T. SPT-F. **Solos e Rochas**, v. 11, n. único, p. 29-30, 1988.

RANZINI, S. M. T. SPTF: 2ª parte. **Solos e Rochas**, v. 17, n. 3, p. 189-190, 1994.

Received on October 4, 2012.
Accepted on April 22, 2014.