Journal of Geological Resource and Engineering 7 (2019) 105-111
doi:10.17265/2328-2193/2019.03.003

Classification and Friction Angle from CPT in Gneissic Residual Soil of Brazil

Fábio K. Silva[1], César S. Godoi Li[2] and Fernanda S. Schuch[1]

1. Federal Institute of Santa Catarina, Florianopolis 88020-300, Brazil

2. Tractebel Engineering, University of South Santa Catarina, Florianopolis 88015-201, Brazil

Abstract: The current research presents the results of experiment *in situ* and laboratory research with the goal of determining the friction angle in residual soil using the CPT (cone penetration test). This experimental research was completed in an area of study, composed of slopes and plateaus, located in the southern region of Brazil, in the Santo Amaro da Imperatriz municipality. An SPT (standard penetration test) and CPT *in situ* test investigation campaign was conducted and collected from deformed and undeformed samples for physical characterization and triaxial tests. The results made it possible to classify the soils analyzed according to the unified methodology proposed by Robertson that, based on studies provide friction angle values along the hole's depth, and obtained through the CPT. The friction angle values obtained in the CPT indicated a well-defined trend of high values at the surface, which decrease in the middle of the soil mass and increase again near the healthy rock. The friction angles estimated by the CPT were overestimated when compared to laboratory estimations. This occurrence is explained by the fact that the measured resistance of the field tests is embedded in the cementation and suction plots.

Key words: Soil residual, *in situ* tests, friction angle.

1. Introduction

Around the world, researchers are examining residual soils for different purposes. The reliability of the geomechanical properties and prediction of the geotechnical behavior of residual soils are essential for the development of safe and economical projects that use soil as a construction or support material. Due to the intrinsic characteristics of these soils, better understanding of the behavior of tropical and cemented soils provides great contribution to geotechnical engineering.

As such, the current research presents an analysis of the results of CPT (cone penetration test), by obtaining the friction angle in this test and comparing it with the traditional triaxial laboratory results.

Corresponding author: Fábio Krueger da Silva, Ph.D., professor, research fields: soil mechanics, rock mechanics, infrastructure, pavements.

2. Methodology

2.1 Area of Study

The research was carried out in residual soils originating from the Águas Mornas Complex of the municipality of Santo Amaro da Imperatriz. The city of Santo Amaro da Imperatriz is located 30 km (18.6 miles) east of Florianópolis, in the southern region of Brazil.

The area of study is part of the Granite-Gneiss Complex named by Silva [1] of the Águas Mornas Complex. Bittencourt et al. [2] cite that the Águas Mornas Complex mainly comprises of orthogneisses, with subordinate occurrence of paragneisses. Orthogneisses consist of K-feldspar, plagioclase, quartz, biotite and hornblende. The metamorphic-deformational banding is millimetric and well marked by the intercalation of bands rich in quartz and feldspars and biotite-rich levels.

In the soils of the slopes of the area of study, the pedological maps classify the material as an alic Cambisol of the granite-gneiss complex (Cag, gn). It has a very thick profile because the rocky substratum is very fractured. However, its B horizon is poorly developed, superimposed by a 30 cm thick A horizon with a clayey and medium texture, a thick C horizon (up to 20 meters) and non-decomposed minerals.

2.2 In Situ and Laboratory Tests

The studies were carried out in an area composed of five slopes, where several geotechnical investigations have been carried out. The SPT (standard penetration test) and CPT were performed vertically, and close together to represent a single sample. In this way, a battery of tests were performed on the foot, face and crest of the slope, in order to obtain a better representation of the profile of the slopes. Laboratory tests were conducted on samples collected near the *in situ* tests of physical and triaxial characterization.

The site is approximately 60 m above sea level and the cut/slope is about 22 m in height with three formed plateaus as resloping. The representation of the geometrical configuration of the slope was elaborated through topographic surveys before and after the embankment excavation. The section of the slope is shown in Fig. 1.

Four groups of SPT and CPT *in situ* geotechnical tests were conducted in four locations of the research area. For the laboratory tests, samples were collected in an excavation hole dug at three different depths between the holes of the SPT and CPT tests of the group. Fig. 2 shows the configuration of the slope, as well as the location of the tests performed.

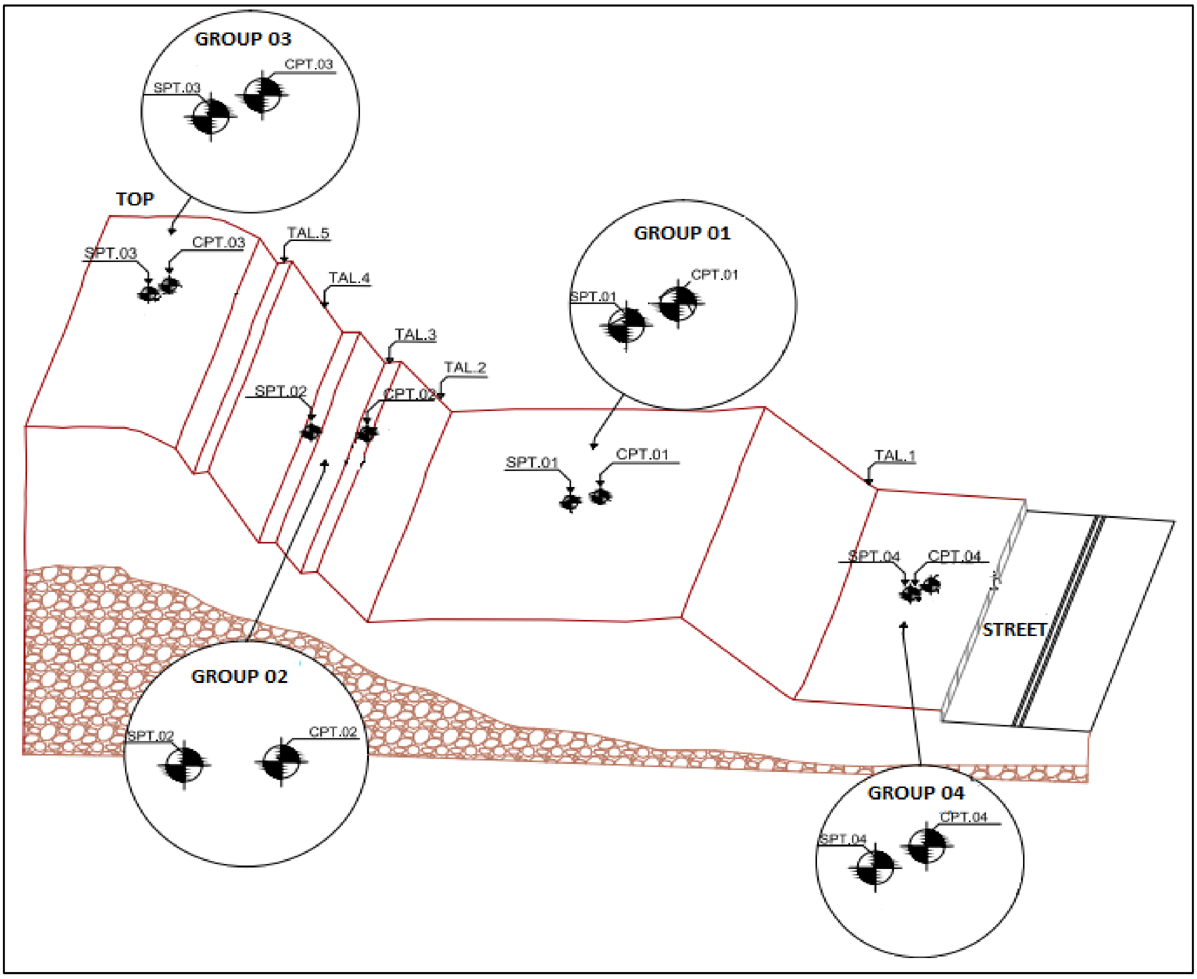

Fig. 1 Location of the *in situ* tests groups (drawing without scale).

Samples collected on the face of slopes 2 and 4 (TAL-2 and TAL-4) and in the inspection hole at each meter of depth (PI-1, PI-2, PI-3) were carried out in the laboratory. Triaxial CIU (consolidated isotropic undrained) and CID (consolidated isotropic drained) tests were performed in five samples, in addition to physical characterization tests.

3. Results

3.1 Physical Characterization

The main results of the physical characterization tests are presented in Table 1. According to the results obtained, the soil is classified as sandy silt to silty sand.

3.2 Triaxial Tests

Further details of the test preparation procedures, saturation, consolidation and shear stages, as well as the analysis of stress-strain curves can be obtained in the works of Godoi [3] and Krueger [4]. Table 2 shows the values of the resistance parameters obtained for residual gneiss soil.

3.3 In Situ Tests

The results of the interpretation of the data obtained by the SPT and CPT tests are presented below. The friction angle deductions are also presented according to the methodology used.

3.3.1 Geotechnical Profile

The geotechnical profile of the soil section was determined by the lateral extrapolation of the information collected in a vertical hole with the results of others of adjacent surveys. The geotechnical profile, based on the CPT results, was obtained after behavioral interpretation based on the results of the force measured in the load cell for tip crimping and its respective correlations with the tip area and lateral area. These relationships define the tip resistance and lateral friction of the CPT test. Profile of the soil of the studied region is seen in Fig. 2.

3.4 SPT and CPT Results

Fig. 3 presents the results of the substrate profile, the number of strokes of the SPT, the values of tip resistance and lateral friction for the four groups of *in situ* tests. It should be noted that the CPT group 2 test starts its measurements from 4.0 m so that the appropriate layers could be evaluated at the same depth as the SPT test. This was because the CPT trials were performed at slope 2 plateau, while SPT was performed at slope 3 plateau. The difference in height of the slopes

Table 1 Summary of the physical characterization tests.

Sample	Depth (m)	Particle soil density	Atterberg limits			Granulometry				
		G_s	LL (%)	PL (%)	IP (%)	% Clay	% Silt	% Sand	% Gravel	U.S.C*
TAL-4-AM-1	0.5	2.73	52	43	9	6.3	45.1	48.7	0	ML
TAL-2-AM-1	0.5	2.66	52	34	18	5.9	54.4	37.1	2.6	ML
PI-1-AM-1	1.00	2.68	39	33	6	5.7	34.4	58.0	1.8	SM
PI-1-AM-2	2.00	2.67	43	30	13	5.3	30.4	56.1	8.3	SM
PI-1-AM-3	3.00	2.72	38	30	8	3.6	31.2	61.3	3.9	SM

*L: Low, M: Mo, S: Sand.

Table 2 Summary of the triaxial tests in gneiss residual soil (resistance parameters).

Sample	C' (kPa)	Φ' (º)	c (kPa)	φ (º)
Tal. 4-AM. 1	37.0	25.4	40.0	16.3
Tal. 2-AM. 1	31.0	24.5	31.0	24.5
PI 1-AM. 1	18.0	30.0	40.0	25.0
PI 1-AM. 2	45.0	29.0	45.0	29.0
PI 1-AM. 3	37.0	27.0	61.0	14.5

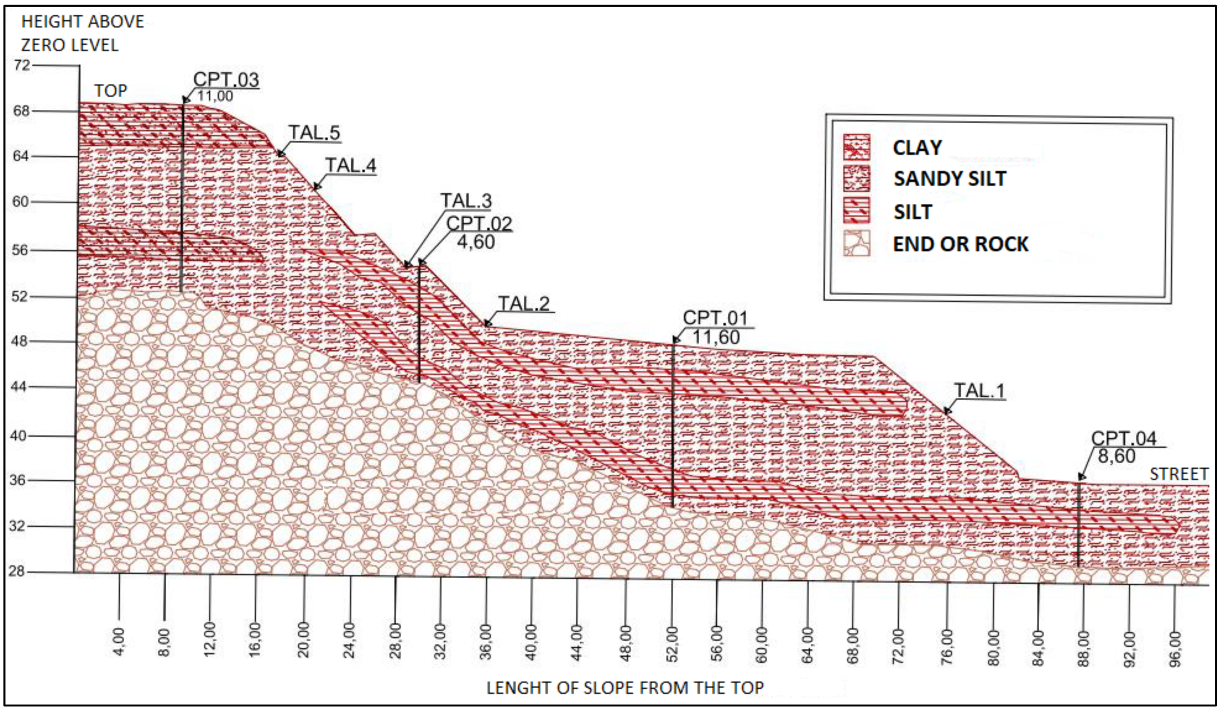

Fig. 2 Geotechnical profile obtained by the CPT test on gneiss residual soil.

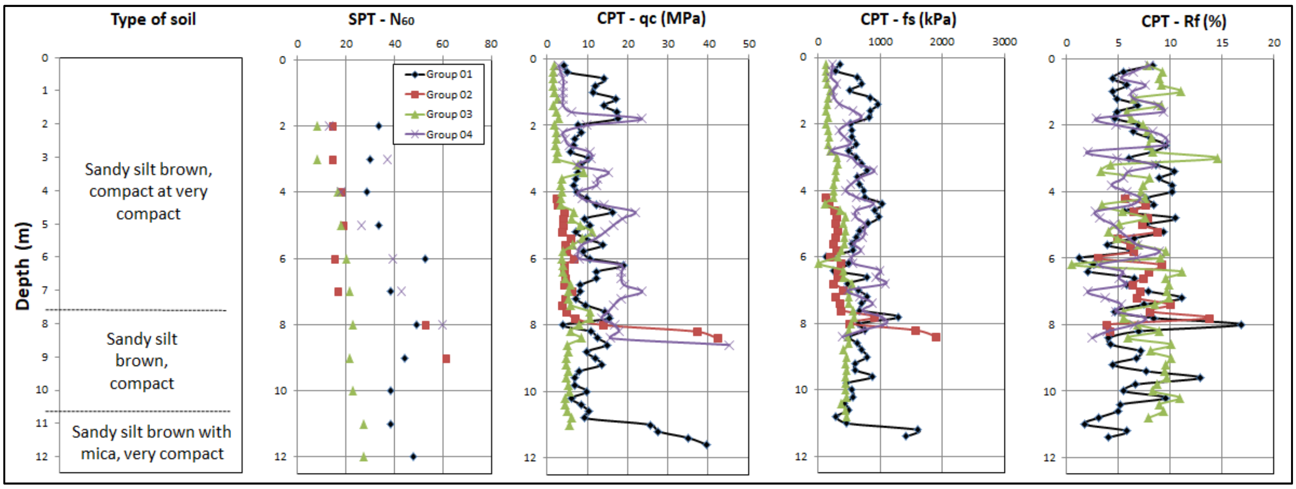

Fig. 3 Stratigraphy of the profile and values of N_{60}, q_c, f_s and R_f for the SPT and CPT obtained on gneiss residual soil.

was 4.0 m. The presented layer profile was obtained through the visual-tactile classification made in the SPT test. The information collected by the SPT and CPT tests along the depth can be seen in Fig. 3.

3.5 Classification of the Soil via CPT

The graphic proposed by Robertson [5] and adapted by Jefferies and Davies [6] identifies soil behavior based on unified methodology. This graphic was developed for electric cones so, based on studies by De Ruiter [7], the lateral friction records of the mechanical cone of this research were corrected (divided by 2) to be applied in the classification chart of soils. Fig. 4 presents the classification of the soils obtained in this work based on the charter proposed by Robertson [5].

A large concentration of points is observed in zones 5 and 6. According to the chart, the material can be classified as silty sand and sandy silt, with I_C an value between 1.31 and 2.60. Thus, the classification of the soil through *Qtn* (normalized tip resistance) × *Fr* (normalized

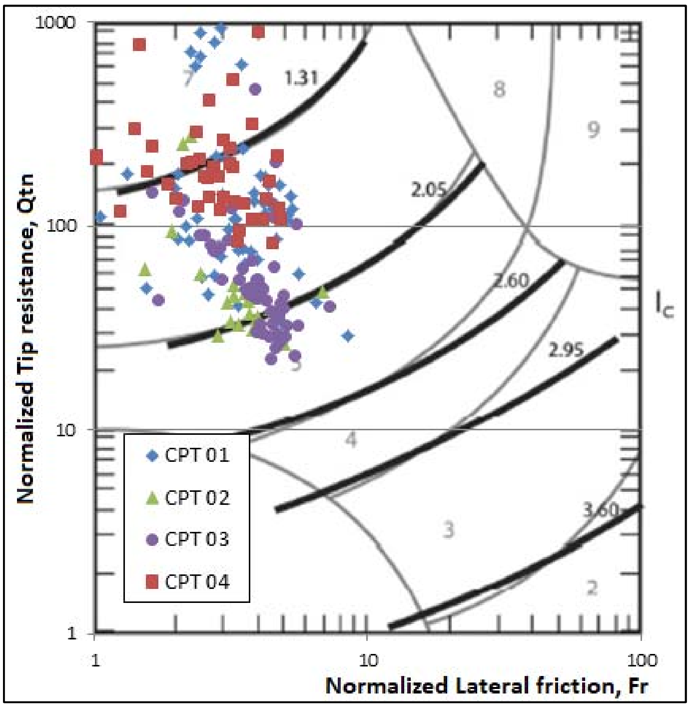

Fig. 4 Classification of the material.

lateral friction) confirms the results obtained by other *in situ* and laboratory tests.

3.6 Relation between Tip Resistance and N_{60} (q_c/N_{60})

Some research has sought to evaluate the relationships between the CPT tip resistance and the penetration index of the SPT. This relationship is influenced by the granulometry of the material. Different types of source rocks produce different grain sizes due to heterogeneity associated with the formation of residual soils.

An example of influence of particle diameter on the relationship between CPT tip resistance and SPT penetration index is shown in the studies of Viana da Fonseca and Coutinho [8] in residual soils of Portugal. The residual soil of Guarda granite presents larger particle sizes and higher values of the q_c/N_{60} ratio when compared to Porto saprolitic soil (CEFEUP), which has finer grains. In research on Brazilian and Portuguese soils, characterized by finer soils, they lead to values of the ratio q_c/N_{60} smaller than those proposed by Robertson & Campanella [9]. The results of these authors and the current research on residual soils of gneiss can be seen in Fig. 5.

It is also noticed that the results of this research confirm the data of other researches in residual soils and tend to be below the average line proposed by Robertson & Campanella [9]. It is concluded that the behavior of residual soils is not dominated by granulometry, but by factors associated with the degree of alteration suffered.

3.7 Friction Angle Estimated from CPT (φ_{CPT})

The friction angle was evaluated based on the CPT, similarly performed by Viana da Fonseca and Coutinho [8]. Fig. 6 presents the values of friction angle estimated in this research. The drawn line also demonstrates a growth in depth and displays high values for low vertical tensions. The friction angle ranges from 32º to 46º with a virtual friction angle value of 38º. These results confirm the cohesive-frictional behavior of these materials where, for low stress levels, cohesion is the dominant component and, for high stress levels, the friction component prevails.

However, this model is applied to purely distracting

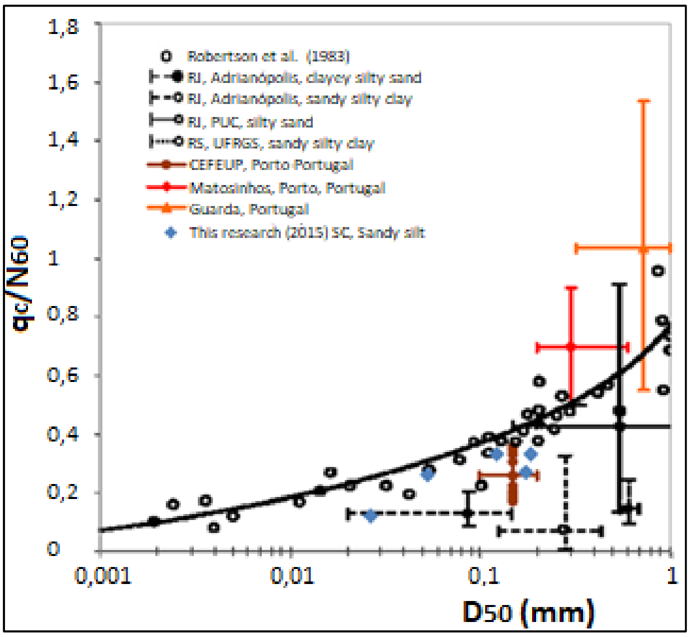

Fig. 5 **Interval of the ratio q_c/N_{60} in Brazilian and Portuguese residual soils.**

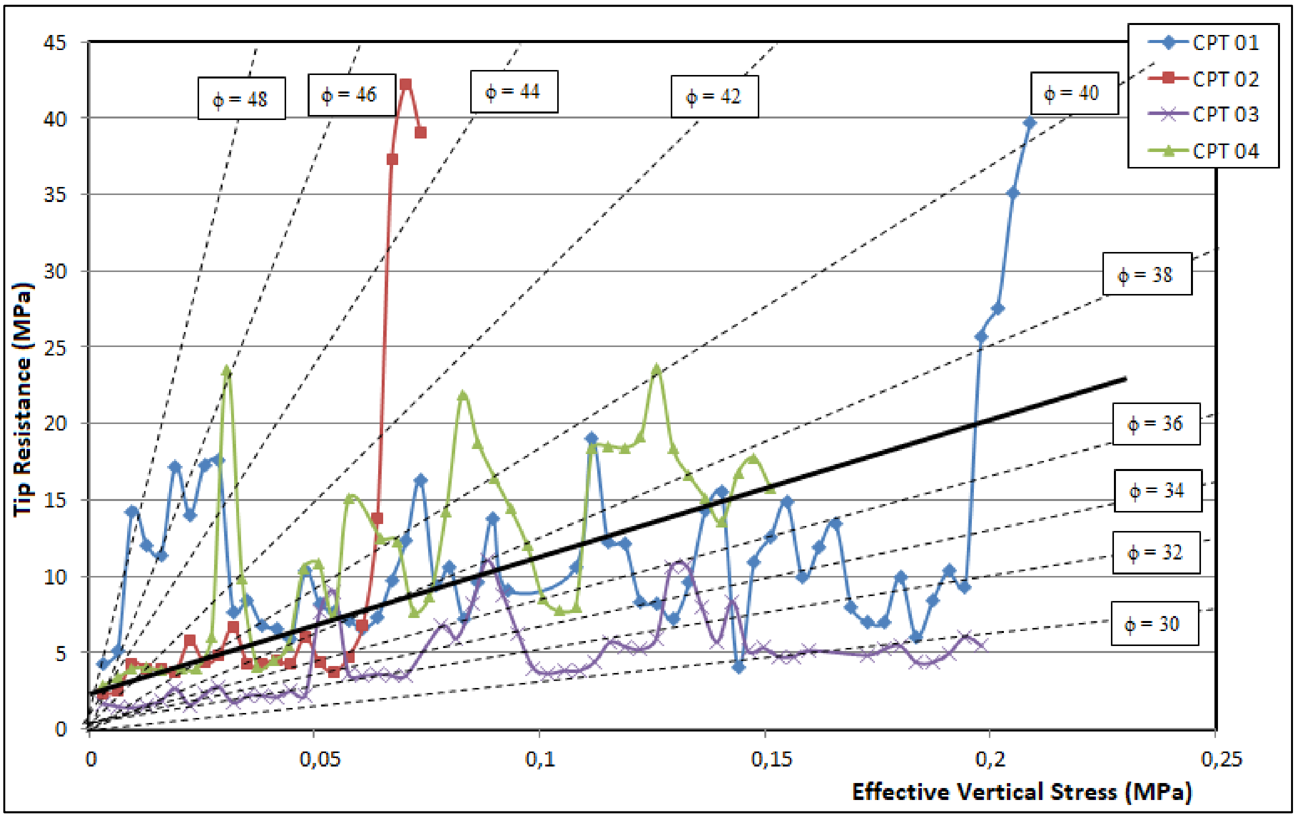

Fig. 6 **Results of friction angle via CPT in sandy silt gneiss residual soil.**

soils evaluated in the Robertson and Campanella [9] surveys developed in clean and non-cemented sand. However, in the absence of a specific cohesive-frictional model it is used to determine the friction angle of the soil. However, this figure represents the contribution of some cohesion.

4. Conclusions

With the completed research, one can infer the following conclusions:

(1) Laboratory Tests

• The density value of the particles is between 2.67 and 2.73, the liquidity limits varied between 38% and 52% and the plasticity limit between 6% and 18%;

• A considerable variation of the physical indexes can be emphasized. However, it is noted that the variation of the void index along the hole's depth is a characteristic feature of residual soils;

• In the triaxial tests, the drained resistance parameters vary from 31k Pa to 45 kPa of effective cohesion and 24.5º to 29º of effective friction angle. The non-drained triaxial tests determined total cohesion values between 40 kPa and 61 kPa, while the friction angle is between 14.5º and 25º and effective cohesion values between 18 kPa and 37 kPa and effective friction angle between 25.4º and 30º.

(2) *In Situ* Tests

• The SPT and CPT *in situ* tests identified a similar geotechnical profile, classifying the soil as a sandy silt.

• The ratio q_c/N_{60} is within the range suggested by other researchers who conducted on residual soils.

• The current classification abacus proposed by the CPT [5, 6] interpreted a type of soil behavior that was included in the same type of material inspected in the SPT samples.

• Through the results of the CPT tests used in the charter for determination of φ proposed by Robertson & Campanella [9] it was possible to estimate a virtual friction angle of 38° for the residual gneiss soil.

• The results obtained in the field indicated higher values than those determined in the laboratory tests. In partially saturated soils the resistance is governed by two components: one cohesive and the other friction. In the absence of a model that contemplates these two plots, the analyses are usually made considering only the friction plot. Cohesion is the predominant part of the most superficial layers with low stress levels, possibly because they are influenced by suction, which results in higher estimates of friction angles from the field tests. While in depth, with high levels of stresses, the friction component prevails. In this sense, a relationship between the friction angle differences estimated by the CPT and DMT was proposed, where the contribution of the cementation and suction and the values determined by the triaxial, and where the resistance refers only to the frictional nature, are included. This difference correlated with effective cohesion seems to give some sense to the understanding and interpretation of the friction angle estimates made from *in situ* tests.

References

[1] Silva, L. C., and Bortoluzzi, C. A. 1987. "Texto Explicativo para o Mapa Geológico do Estado de Santa Catarina." Escala 1:500.000. Florianópolis. DNPM/Secretaria Ciências Tecnológicas.

[2] Bittencourt, M. F., Bongiolo, E. M., Philipp, R. P., Morales, L. F. G., Rubert, R. R., Melo, C. L., and Luft, J. R. J. L. 2008. "Estratigrafia do Batólito Florianópolis, Cinturão Dom Feliciano, na região de Garopaba-Paulo Lopes, SC." *Revista Pesquisa em Geociências*. Instituto de Geociências, UFRGS.

[3] Godoi, C. S. 2014. "Caracterização Geomecânica de um Solo Residual de Gnaisse—Santo Amaro da Imperatriz, Santa Catarina." Universidade Federal de Santa Carina.

[4] Krueger, F. S. 2015. "Caracterização física e mecânica de solo residual de gnaisse por meio de ensaios de campo e laboratório em Santa Amaro da Imperatriz, Santa Catarina." Universidade Federal de Santa Carina.

[5] Robertson, P. K. 1990. "Soil Classification Using the Cone Penetration Test." *Canadian.Geotech. J.* 27: 151-8.

[6] Jefferies, M. G., and Davies, M. P. 1993. "Use of CPTU to Estimate Equivalent SPT N_{60}." *Geotech. Test. J.* 164: 458-68.

[7] De Ruiter, J. 1971. "Electronic Penetrometer for Site Investigations." *Journal of the Soil Mechanics and Foundations Division* 97: 457-62.

[8] Viana da Fonseca, A., and Coutinho, R. Q. 2008. "Characterization of Residual Soils." In *Geotechnical and Geophysical Site Characterization*, edited by Huang e Mayne, London.

[9] Robertson, P. K., and Campanella, R. G. 1983. "Interpretation of Cone Penetration Tests Part I: Sand." *Canadian Geotech. J.* 20 (4): 718-33.