Correlation of Standard and Cone Penetration Tests: Case Study from Tekirdag (Turkey)

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Abstract. In geotechnical engineering, the Standard Penetration Test (SPT-N value) is often used as an in-situ test. The Cone Penetration Test (CPT) is based on design and cone resistance (qc) and is becoming increasingly widespread. However, there is also a need for a SPT-CPT correlation association that can be used in the basic design. In this study, the values of the SPT-CPT tests applied to the ground were compared and tried to generate a certain statistical data. SPT and CPT experiments were performed side by side to determine the soil properties. Formulas have been developed using various statistical methods and correlation coefficients have been established between the data obtained for "high-medium-low plastic clay" and "sand and sandy clayey soils". The obtained data were compared with the studies in the literature.

1. Introduction

The Standard Penetration Test (SPT) has many disadvantages and influencing factors affecting results, misinterpretation of applications and commenting mistakes. Besides, undisturbed samples pushed into tubes are mostly different from their natural conditions in the area of original stress at certain depth, which must be considered. For this reason, at geotechnical designing, SPT correction should be used while determining engineering properties of soil layers. Cone penetration test (CPT), through continuous measurements without human intervention allows obtaining detailed and the closest to the truth results at the soil profile as well. Engineers in Turkey has gained important experience in the design based on the local SPT correlations. Thus, correct CPT data will complete reliable SPT-CPT correlation.

1.1. Background

There are effective benefits for SPT-N value based on the field performance at the CPT values correlation. For SPT N-value is very important to associate them with static cone resistance q_c, because many empirical relationships SPT-N values and CPT cone tip resistance is established [1]. Many of these studies are as follows in Table 1.

1.2 Determination of Data

The data used here were taken from Tekirdağ city (Turkey) and regions. Unavailable data on location map were not used in this research. Used data, SPT and CPT tests location were taken without distances. Any datum having distance was not used in this study.

Table 1: Previous works for CPT and SPT correlations

Author(s)	Soil Types	Relationship
[2] (De Alencar Velloso D.,1959)	Clay and silty clay	n = qc / N = 0.35
	Sandy clay and silty sand	n = qc / N = 0.2
	Sandy silt	n = qc / N = 0.35
	Fine sand	n = qc / N = 0.6
	Sand	n = qc / N = 1.00
[3] (Meigh & Nixon 1961)	Coarse sand	n = qc / N = 0.2
	Gravelly sand	n = qc / N = 0.3-0.4
[4] (Franki Piles, 1960-from Akça, 2003)	Sand	n = qc / N = 1.00
	Clayey sand	n = qc / N = 0.6
	Silty sand	n = qc / N = 0.5
	Sandy clay	n = qc / N = 0.4
	Silty clay	n = qc / N = 0,3
	Clays	n = qc / N = 0.2
[5] (Schmertmann, 1970)	Silt, sandy silt and silt-sand mix.	n = (qc + fs) / N = 0.2
	Fine to medium sand, silty sand	n = (qc + fs) / N = 0.3-0.4
	Coarse sand, sand with gravel	n = (qc + fs) / N = 0.5-0.6
	Sandy gravel and gravel	n = (qc + fs) / N = 0.8-1.0
[6] (Barata et al., 1978)	Sandy silty clay	n = qc / N * = 1.5-2.5
	Clayey silty sand	n = qc / N * = 2.0-3.5
[7] (Ajayi & Balogun, 1988)	Lateritic sandy clay	n = qc / N * = 3.2
	Residual sandy clay	n = qc / N * = 4.2
[8] (Chang., 1988)	Sandy clayey silt	n = qc / N * = 2.1
	Clayey silt, sandy clayey silt	n = qc / N * = 1.8
[9] (Danziger & de Valleso, 1995)	Silt, sandy silt and silt-sand	n = (qc + fs) / N = 0.2
	Fine to medium sand, silty sand	n = (qc + fs) / N = 0.3-0.4
	Coarse sand, sand with gravel	n = (qc + fs) / N = 0.5-0.6
	Sandy gravel and gravel	n = (qc + fs) / N = 0.8-1.0
	Silt, sandy silt and silt-sand	n = (qc + fs) / N = 0.2
	Silty sand	n = qc / N * = 7.0
[10] (Danziger et al., 1998)	Sand	n = QC / N * = 5.7
	Silty sand, silty clay	n = qc / N * = 5.0-6.4
	Clayey silt	n = qc / N * = 3.1
	Clay, silt and sand mixtures	n = qc / N * = 1.0-3.5
	Clayey sand and silty clayey	n = qc / N * = 4.6-5.3
	Sandy clayey	n = qc / N * = 1.8-3.5
	Clay	n = qc / N * = 4.5
[11] (Emrem et al., 2000)	Turkey soils	n = qc / N = func (D50)
[4] (Akça, 2003)	Sand	n = qc / N = 0.77
	Silty sand	n = qc / N = 0.70
	Sandy silt	n = qc / N = 0.58

qc / N in MPa

* qc / N in bar per blow 0.3m

2. Location and geotechnical assessment

The study area is surrounded by clay sediments, which are mainly consist of alluvial clay and sand lens becomes so rare. Under this clay are shales, siltstone layers of Osmancık strata formation. It is recognized that clay unit is covered mainly in the ground from the data obtained from the SPT borings and CPT at the research area. Lens with loose sand-silt clay mixtures are also included seldom.

On-Site Researches were done

In the research area, 17 m to 24.5 m depth soundings have been applied. Rotary drilling and cone penetration test were applied together. Soil samples was taken as disturbed and undisturbed and were exposure to experiments in Geotechnical Laboratories. Field test data and laboratory results were prepared and evaluated with borehole logs. Cone penetration tests (CPT) were performed by 200 kN capacity machine, at different points of field. Experiments, in each well 2 cm.sec^{-1} procedures were made in the ground and the data obtained were assessed simultaneously and transferred to the computer.

3. Evaluating SPT, CPT results and laboratory studies

This assessment; data obtained from SPT the CPT experiments includes a correlation study. Examination of these data, the creation of soil groups, were made using only when they are closed to SPT and CPT data at the same places. Drillings was made by scratching the ground floor sections and drilling logs were evaluated with the samples of clay (CH, CI, and CL), clayey-silty sand soil were researched. SPT and CPT experiments exposure to assessment tests that can be called from the same location, similar ones taken, the corresponding experiments to test SPT and CPT made within the drilling results were considered at the same depth. Considering the readings made by drilling in the pits with 1.50 m interval of SPT, blows number determined for the last 30 cm of entry in order to eliminate the effects of abuse were taken. In the range of about 1.50 m of drilling, data were taken into consideration for the SPT experiments performed blow counts detected for the last 30 cm of entry to eliminate the effects of abuses.

3.1 Status of Surface and Groundwater

Summers are hot, but not dry, while winters are usually mild and rainy. Precipitations become mostly rain but they sometimes become snow. Average annual rainfall is 649.00 mm. There is more water in the period between December and April. Thus, during this period, the surface flooding may occur. In drilling, groundwater was encountered at an average of 2.50 m. Moreover, in drilling; the ground water level up to 50% of water is higher than the unused punch CPT.

3.2 Data Evaluation

Many variables in SPT value; drilling methods, rod types, sizes and borehole stabilization, sampler type, stroke frequency, mallet type and energy due to reductions affect the validity and usefulness of the test procedure SPT results [12], [13], [14]. Depending on these variables, the measured penetration resistance (SPT-N_{insitu}), can be excessively high or excessively low. Excessive measured SPT-N_{insitu} value, features and bearing capacity of the ground was caused to secure non-predictable. The SPT-N_{insitu} has extremely low measured values, which raises extremely safe but non-economic results.

More usable, useful, and corrections must be applied in order to obtain comparable results. These corrections are:

- CN; geological load correction,
- CE; Energy correction,
- CR; Rod length correction,
- CB; drilling diameter correction,
- CS; Sampler sheath correction,
- CA; Casing head correction,
- CBF; mallet stroke frequency correction,
- CC; mallet pillow correction, [15].

All corrections are used in discrete-grained soils, geological load (CN) and mallet stroke frequency (CBF) correction is not made in practice in fine-grained soils [15].   In this case, fine-grained equations containing fixes for common ground:

$$N_{60}=(CE*CR*CB*CS*CA*CC)N_{insitu} \qquad (1)$$

where:

The basis of their application results in Turkey, SPT correction factors CE=0.75, CB=1, CS=1.2, CA=0.85, CC=1 can be. Turkey also contains all the fixes that are very similar for fine-grained soils;

$$SPT\text{-}N_{60}=0,75*CR.\ N_{insitu} \qquad (2)$$

expression can be used [16]. Depending on the length drill pipe, Cr = 0.75, 0.85, 0.95, 1.00 was accepted [17]. Here drill pipe length effect, depending on the depth is taken as CR = 0.80.

As a result, the equation:
$$SPT\text{-}N_{60}=0.60*N_{insitu} \qquad (3)$$
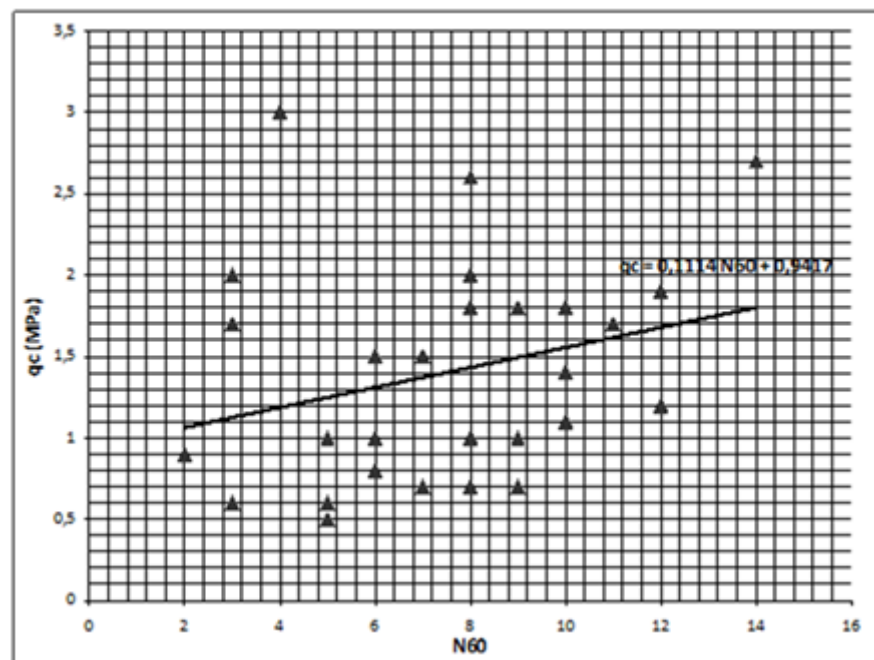
as were measured and evaluated.

Figure 1. CH clay soils for q_c / N_{60} relationship varies

3.2.1 Clayey soils derived from cone resistance q_c and SPT blow count N_{60} was searched.
Existing relationships from, for clay soils q_c / N_{60} ratio of 0.10 to 0.15 (MN / m^2) is known as varies.
   a) Soil group of high plasticity clays (CH) obtained from experiments carried out on the grounds that N_{60} SPT blow counts and CPT q_c end with the relationship between the detected resistance is shown in Figure 1. Here high plasticity clay (CH) obtained for the ground QC / N_{60} = 0.11 value remains between the existing relations (Figure 1).

b) Medium plasticity of clay soil group (CI) made on grounds derived from SPT N_{60} values relationship with CPT are shown in Figure 2 between the detected q-end resistances. Medium plasticity clay (CI) obtained for the ground qc / N_{60} = 0.11 value remains between the existing relations.

c) Relations between the cone resistances qc with SPT N_{60} values obtained from clay soils qc/N_{60} ratio from 0.10 to 0.15 MN / m^2 is designated as (Figure 3), where clayey soils obtained for qc / N_{60} = 0.11 value remains in the literature value.
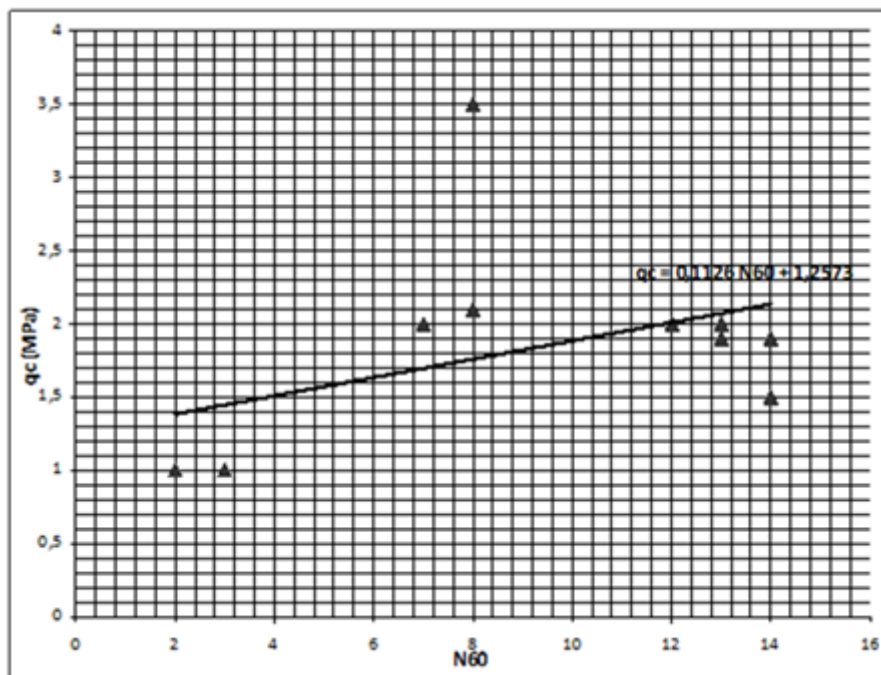

Figure 2. CI clay soils for qc / N_{60} relationship varies

3.2.2 Clay-silt-uniform sand obtained from the soils, has researched the relationship between CPT cone resistance qc and N_{60}.
Existing correlation of, clay-silty sand-uniform soils for qc / N_{60} ratio from 0.20 to 0.55 MN / m^2 is known varies.
Clay-silty-uniform sand (SC, SM, SP); the N_{60} obtained in return for SPT on the CPT tests detected by qc-cone resistance; qc / N_{60} = 0.39 MN / m^2 is determined to be between (Figure 3).

3.2.3 The CPT cone resistance in the soils, depending on the analysed data obtained (qc) N_{60} rate was compared with the surrounding frictional force fs.
The CPT parameter values qc and fs depending on the test method at preparation   can be determined frequently and accurately. With these corrections, errors in the number of N_{60} can be reduced as well. Besides, SPT and CPT data are seen massed ground point closer to each other. Therefore, qc / N_{60}-fs comparison seem to support for right to results (Figure 4).
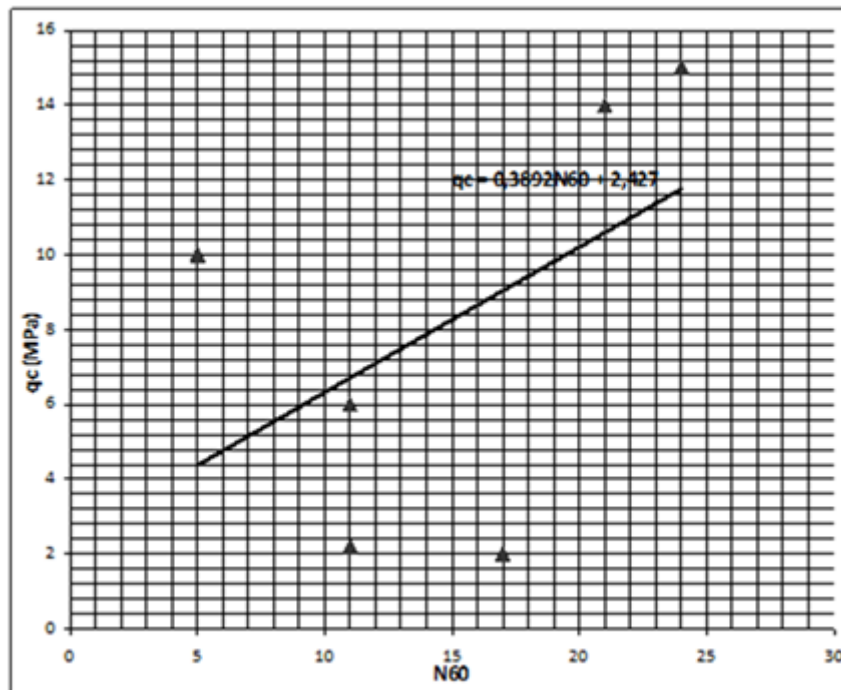
Figure 3. qc/N_{60} for sand density for soils (SC SM and SP)

3.2.4 N_{60} the numbers of blows were investigated to research relationship between the ratio of surface and abrasion resistance (Figure 5).

SPT blow count N_{60} in the experiment, has increased in proportion to the fs skin friction resistance. In this case, the increase of the number of pulses of the fs skin friction as expected which means that increase (Figure 5).
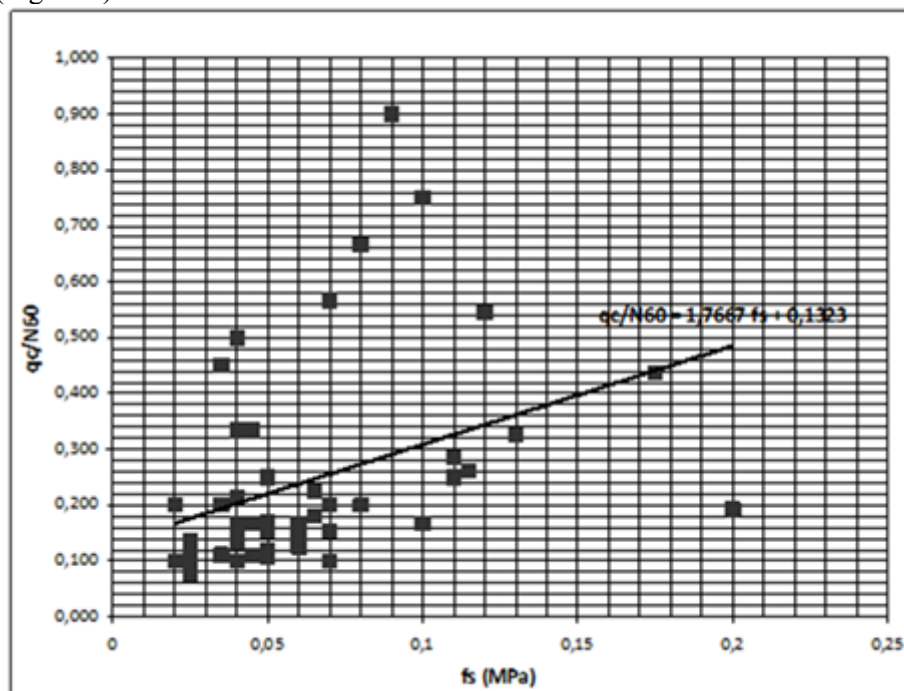

Figure 4. qc / N_{60}-fs relationship

3.2.5 CPT terminating resistor structures formed in the ground were searched   the relationship between the surface and   abrasion resistance and were shown in Figure 6.
When q_c terminating resistor with *fs*, superficial linear abrasion resistance increased and surface frictional resistance also increased as expected (Figure 6).
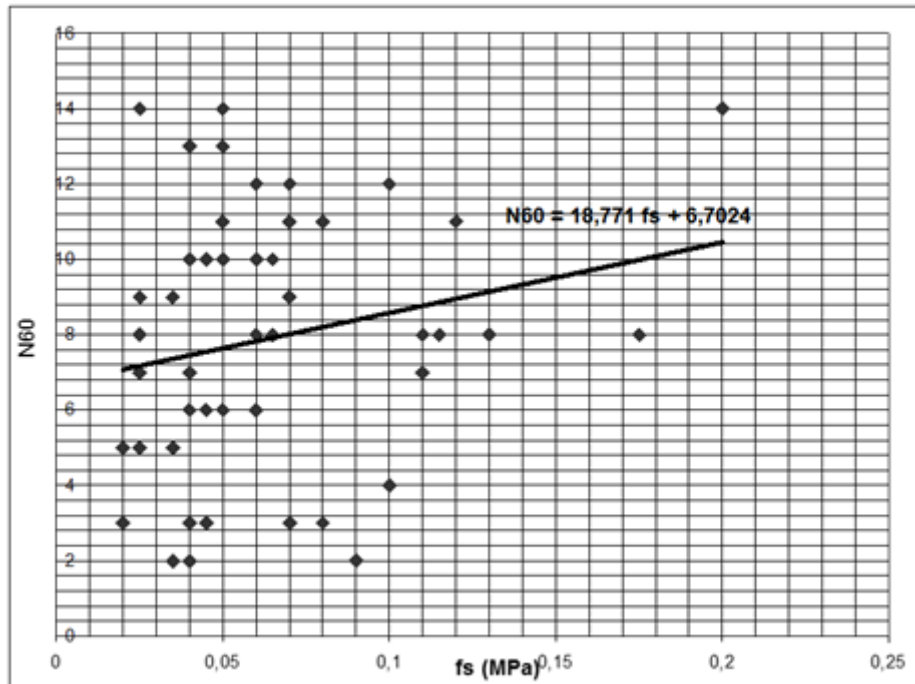

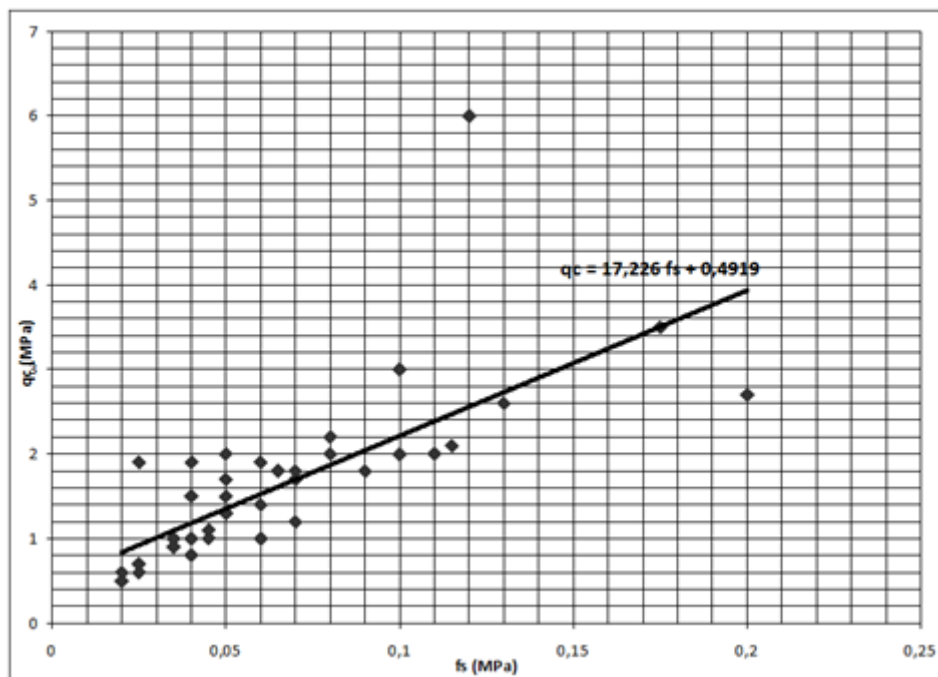**Figure 5.** fs / N_{60} relationship variety

Figure 6. qc/fs relationship variety

4. Conclusions

Only SPT and CPT data received from the same points were used to organize for Tekirdag East Crossing Interchange arrangement. As it can be noticed within the research the correlations established between the SPT and CPT, that is found compatible with the values obtained from the correlation made on the ground, it made clay and sand content group literature.

1. Relations between clay ground made in the literature accessed from cone resistance qc and SPT blow count from 0.10 to 0.15 (MN / m^2) unless otherwise stated. Made obtained in these studies; High plasticity clays (CH) for qc / N_{60} = 0.11 value,
   Moderate plasticity clays (CI) for q c/ N_{60} = 0.11 value,
   For intersections CH, CI and CL obtained from clayey soils and cone resistance qc and the relationship varies SPT blow count N_{60},
   qc / N_{60} = 0.11 value was found.
2. Clayey sand-silt-uniform cone resistance obtained from ground qc and between SPT blow count, relationship made 0.20 to 0.55 in the literature (MN / m^2) unless otherwise stated. Earned in these studies; Clayey sand-silt-uniform SC, SM and SP sand density for soils qc / N_{60} = 0.39 MN / m^2 remained between previous studies.
3. qc / N_{60}, compared with the surrounding frictional force fs. CPT parameters depending on the assay method of preparation and can be often determined accurately. N60 in the number of errors can be reduced by adjustments. It is observed that clusters of points closer to the ground. Therefore, qc / N_{60} - fs comparison results can be reported to the near right. SPT blow count N_{60} with the FS superficial abrasion resistance where a linear effect, this means increased friction with the surface of the FS as the expected increase in the number of pulses.
4. N60 with which a linear effect between fs, N_{60} increase as expected in this case means an increase by fs.
5. When qc with fs surface friction resistance is linear, depth and terminating resistors increases, it is determined that skin friction resistance (fs) also increases as predicted.

References

[1]   Robertson, P. K., R. G. Campanella and A. Wightman; "SPT-CPT correlations" Journal of the Geotechnical Engineering Division, ASCE, 109(11), 1449-1459, ISSN. 0733-9410. New York, 1983.
[2]   De Alencar Velloso D., O ensaio de diepsondeering e a determinacao da capacidade de cargo do solo. Rodovia, 29, 1959.
[3]   Meigh, A.Ç. ve Nixon, I.K. Granüler zeminlerin yerinde testlerin karşılaştırılması. Zemin Mekaniği ve Temel Mühendisliği 5. International Konferansı. Paris, 1961.
[4]   Akça, N., Correlation of SPT-CPT data from tha United Arab Emirates, Enginering Geology. V.67, 219-231, 2003.
[5]   Schmertmann, J.H., Static Cone to Compute Static Settlement Over Sand. ASCE, J-SM and FID, Vol:96, SM3, pp 1011-1043, 1970.
[6]   Barata at all., Uplift Tests on Drilled Piers and Footing Built in Residual Soil. Proc. VI Congresso Brasileiro de Mecânica dos e Solos Engenharia de Fundações. Rio de Janeiro. v 3. pp. 1-37, 1978.
[7]   Ajayi, L.A., Balogun, L.A., Penetration Testing in Tropical Laterictic and Residual Soils-Nigerian Experience, Proceedings of the First İnternational Symposion on Penetration Testing, Vol. 1,   315-328. Orlando, 1988.
[8]   Chang, M.F., In-Sıtu Testing of residual soils in Singapore. Proceedings 2ND International Conference Geomechanics in Tropical Soils. VI. 97-108, Singapore, 1988.
[9]   Danziger, B.R., and D.A. Velloso, "Correlations between the CPT and the SPT for some Brazilian

soils", Proc. CPT'95, Linkoping, V:2, pp;155-160, 1995.

[10] Danziger, F.A.B., M.S.S. Almeida, E.N. Paiva , L. G.F.S. Mello and Danziger, B.R., The piezocone as a tool for soil stratification and classication", Proc. XI Cobramseg, Brasilia, 1998.

[11] Emrem, C. ve Durgunoğlu, H.T., Türkiye CPT veri tabanı ve mevcut amprik bağıntılar ile karşılaştırma. Zemin Mekaniği ve Temel Mühendisliği 8. Ulusal Kongresi, 2000.

[12] Sağlamer, A., Standart Penetrasyon Deneyi Nedir-Ne Değildir?, Zemin Mekaniği ve Temel Mühendisliği Türk Milli Komitesi Bülteni, 1(4), 267-271, 1979.

[13] Nixon, I.K., Standard penetration test: State-of-the-art report, Proceeding of the 2nd Europen Symposium on Penetration Testing, pp.,3-21, Amsterdam, May 1982.

[14] Coduto, D.P., Foundation Design Principles and Practices, Prentice Hall, Englewood Cliffs, New Jersey, 1994.

[15] McGregor, J.A. and Duncan, J.M., 1998. Performance and use of the standard penetration test in geotechnical engineering practice, A Report of a study performed by Virginia Tech Center for Geotechnical Practice and Research, Virginia Polytechnic Institute and State University, October 1998.

[16] Sivrikaya, O. ve Toğrol, E. Ince daneli zeminlerde SPT sonuçlarının düzeltilmesi üzerine bir çalışma, İTÜ. dergisi (Mühendislik), Vol.2, No.6, s.59-67, 2003.

[17] Skempton, A.W., Standard penetration test procedures and the effects in sands of overburden pressure, relative dencity, particle size, aging and overconsolidation, Geotechnique, 36(3), 425-447, 1986.