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Correlation of SPT-N & CPT Parameters of Dhaka Soil

Anika Tahsin Nabila[1], Nazifa Sayeed[1], Rifah Karim[1], Dr. Hossain Md. Shahin[1], Md. Shamsul Islam[2]
[1]Department of Civil and Environmental Engineering, Islamic University of Technology
Gazipur, Bangladesh
anikatahsin@iut-dhaka.edu; nazifasayeed@iut-dhaka.edu; rifahkarim@iut-dhaka.edu; shahin@iut-dhaka.edu;
[2]ProSoil Foundation Consultant
Dhaka, Bangladesh
prosoil_9@hotmail.com

Abstract - Standard Penetration Test (SPT) is a very common in-situ test all over the world for its simplicity. Whereas Cone Penetration Test (CPT) is recently getting popular for its better accuracy. Both these tests are necessary for the study of stratigraphy of soil and to find out the important geotechnical properties of subsurface soil. Many empirical studies have been conducted based on the correlations between the parameters of these two in-situ tests. Dhaka soil, which has been considered in this study, is found to be mostly sandy with a mixture of silt and clay. Considering the sleeve friction, cone penetration resistance from CPT and N-value from SPT, the n-ratio for Dhaka soil has been found in this study for four categories of soil along with sand and was compared with those from other studies. Multiple Linear Regression (MLR) Analysis with MATLAB has been used for the N-value prediction by generating multi-linear equations predicting N value for the four soil types. It is expected that the results will provide much better correlations on the addition of fine content as the study soil was mostly sandy.

Keywords**:** SPT, N-value, CPT, Dhaka soil, Correlation, Multiple Linear Regression, MATLAB.

1. Introduction

SPT and CPT are two commonly known in-situ subsurface testing methods. Although CPT has been introduced in Bangladesh somewhere in the last decade, engineers here, due to having more familiarity with using SPT, are more prone towards SPT in geotechnical investigations [1]. But because CPT is more reliable and relatively cost effective than SPT, it has become a common practice to use both CPT and SPT on the same project, especially in large ones.

SPT or Standard Penetration Test is the most used field investigation test around the world including Bangladesh due to its simplicity. It provides information about the resistance and properties of soil. Also, there are many correlations of the SPT-N value with other different soil properties. On the other hand, CPT or Cone Penetration Test is regarded as a more reliable alternative to SPT due to its reliability, repeatability, and standardization [2]. Countless geotechnical researchers have created relationships between these two soil investigation tests which help engineers to adopt empirical methods and analyze soil performance [3]. The study aims to find such correlations in case of Dhaka soil so that in many cases only one in-situ test would do.

2. Description of Study Area

The location of the Mass Rapid Transit (MRT) Project, which is one of the major development projects of Bangladesh, has been selected for the development of correlations of SPT-N and CPT parameters of Dhaka soil. The project locations are specifically on the depot area including phase 1, 2 and 3 of the MRT line 06. For the correct execution of the in-situ testing, the research area was further divided into several study zones. The mentioned in-situ tests were carried out in these areas throughout March and April of 2018.

3. Data Collection

To fulfil the purpose of the subsurface soil exploration, a total of 172 SPT and 110 CPT tests were conducted at the study area. For the SPT test, all the 172 boreholes were made by the rotary drilling method. Auto trip hammer has been

used in the testing procedure where the falling height has been taken as 760mm. During SPT at 1m intervals (ASTM D 1586), disturbed samples of very stiff clay to hard clay and sand layers were collected.

On the other hand, the CPT test has been performed according to ASTM D5778-12. An instrumented cone of 10 cm^2 tip is pushed at a controlled rate (controlled between 1.5 - 2.5 cm/s accepted). Sleeve friction has been recorded through the sensor along a 100 mm length. As the cone goes into the ground, measurements are constantly sent back to the rig and the values of tip resistance (q_c in MPa), sleeve friction (f_s in MPa), pore pressure (u in MPa) and inclination (I in degree) are recorded on the computer. Alongside, data for each of the above parameters have been transported to Excel with 0.01 m data each.

4. Soil Behavior Type (SBT)

The identification of soil stratigraphy and soil type is one of the major applications of CPT. This is done with the linking of the cone penetration resistance with the soil type. Many came forward to introduce charts to relate the use of cone penetration resistance with that of the soil type. But the most popular one was the one by Robertson et al. in 1986 [4, 5]. It is based on cone penetration resistance, q_c with friction ratio, R_f. Here, $R_f = (f_s / q_c)100\%$ and commonly is termed as Soil Behaviour Type (SBT) Chart. SBT Chart basically helps to find out the classification of the soil considering in-situ characteristics. The q_c and the R_f are plotted on the chart to find out the major points plotted on the sectors of different colours. The major soil type has been found out to be sandy for the Dhaka soil, which is the study area, by utilizing the classification of the SBT Chart of Robertson [4,5] in Figure 1.

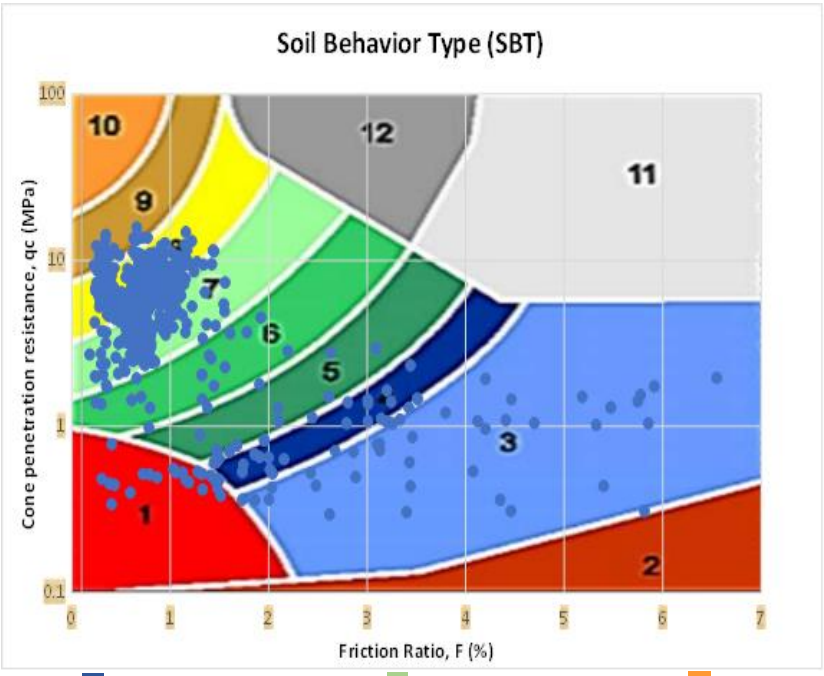

Fig. 1: Plotting q_c and R_f from data of Dhaka soil on Robertson's SBT Chart [4,5] for soil classification of Dhaka.

Sandy soil indicates that there might be a mixture of both coarse grained, and clean or fine sand. This is because of the heterogeneous nature of the soil conditions of Dhaka. Based on the soil types, correlations among SPT-N and CPT

parameters have been developed. The soil types in the SBT chart from the in-situ CPT data do not relate much with the soil classification types from the USCS (Unified Soil Classification System). This is because the latter is based on laboratory results whereas the in-situ test parameters depict actual geotechnical conditions of soil on site.

Considering the results from the CPT test soil classification (B_q) calculations, the SBT chart of Dhaka soil in Figure 1 and the field identification of soil types of SPT, the following categories of soil are selected for development of correlation and related data have been sorted for the multiple linear regression analysis. These categories are:

1. Sandy
2. Mixture of sand and silt
3. Clay
4. Mixture of clay and silt

5. Data Processing

A total of 110 sets of CPT data and 172 sets of SPT data were collected. Parameters of interest are N values of SPT, q_c and fs from CPT test. CPT data have been collected for every 0.01 m while SPT tests are at intervals of every 1m. So, an average depth of 0.5m each was considered for making the data compatible.

In the case of SPT, energy correction of SPT is an important factor, so the calculation of N_{60} was done. N_{60} defines the corrected value for field procedures at 60% energy efficiency. Equation 1 is used by most of the geotechnical engineers for the energy correction, which has been used in this study as well.

$$N_{60} = N_{(field)} \times C_e \quad (1)$$

Here, C_e = Energy correction factor that depends on the way the hammer is lifted and released. Table 1 shows the typical values of C_e.

Table 1: Typical values of C_e [6].

Factor	Equipment Variable	Correction
Energy Ratio	Donut Hammer	0.50 to 1.00
	Safety Hammer	0.70 to 1.20
	Automatic Trip Donut Type Hammer	0.8 to 1.30

As auto trip hammer has been used so, C_e = 1.00 taken from the above stated values against different hammers. So, putting value in equation 1 we get,

$$N_{60} = 1 \times N_{(field)}$$

Therefore, this way N_{60} values have been obtained for use in the analysis. A total of 564 pairs of SPT-N, CPT q_c and f_s values have been taken for the study. The maximum and minimum values of SPT-N, q_c, and f_s for each of the soil categories have been presented in Table 2.

Table 2: Range of SPT-N, q_c, and f_s for Dhaka Soil.

Soil Type	SPT-N		q_c		f_s	
	Max	Min	Max	Min	Max	Min
Sandy	46	4	15.81048	1.021278	0.17128	0.003402
Silt-Sand Mixture	22	3	4.148076	0.437898	0.065218	0.003176
Clay	12	1	3.96238	0.305856	0.071268	0.001382
Clay-Silt Mixture	16	3	1.078046	0.295736	0.022656	0.006718

The results of the calculation of $(q_c+f_s)/N_{60}$ for each of the soil categories have been shown in Table 3. Then the arithmetic mean method is followed for the calculation of the desired n ratio. This n ratio is representative of the correlation among the two concerned parameters of CPT and N value of SPT.

Table 3: Arithmetic Average method results.

Soil Type	**Total No. of Pairs (No. of nf)**	**$\sum$n1 (n1=$(q_c+f_s)/N_{60}$)**	**$\sum$n1/ (No. of nf) n value**
Sand	474	142.8222363	0.3
Silt-Sand Mixture	23	2.956545398	0.13
Clay	58	6.580371294	0.11
Silt-Clay Mixture	9	0.9926646464	0.1

Very few literatures correlated sleeve friction along with N value and cone penetration resistance. So, the comparison of n ratio for Dhaka soil could be compared with the two available literatures in Table 4.

Table 4: Comparison of n ratio of Dhaka Soil with existing literature.

Soil Type	**n = $(q_c+f_s)/N_{60}$**		
	Schmertmann 1970 [11]	**Danziger & de Valleso 1995** [12]	**Dhaka Soil**
Fine to medium sand, silty sand	0.3-0.4	0.3-0.4	0.3
Silt, sandy silt, and silt-sand	0.2	0.2	0.13
Clay	-	-	0.11
Silty-clay to silt-clay	-	-	0.1

A minor variation can be seen in the comparison of n ratios of the two soil types consisting of sand with that of Dhaka soil in Table 4. Besides, since there was no available n ratio for clay and silty-clay to silt-clay type soil, the study of Dhaka soil is successful in introducing n ratios for these two soil categories.

6. MLR Models for Different Soil Types

Four MLR models have been developed for the four categories in soil type of Table 4 using MATLAB. Other soil types found have been marked as insignificant due to the layers being thin because thin layers have somewhat low impact on the measurement of q_c [7]. Much emphasis has been placed on the category of sandy soil as 474 pairs of data from 564 pairs have been found to be sand type. Furthermore, soil type for Dhaka soil, which is the study area, has been found to be mostly sandy by utilizing the classification of the SBT Chart of Robertson [4,5] in Figure 1.

6.1 MLR Model for Sand Soil

Sandy soil is dry, nutrient-deficient, and fast draining with little or no ability to transport water from deep layers through capillary transport. They also have good shearing strength and compressibility in both compaction and saturation [8]. A total of 474 data were used to form a correlation between the three variables q_c, f_s and N_{60} using MATLAB, the regression model of which is shown in Figure 2.

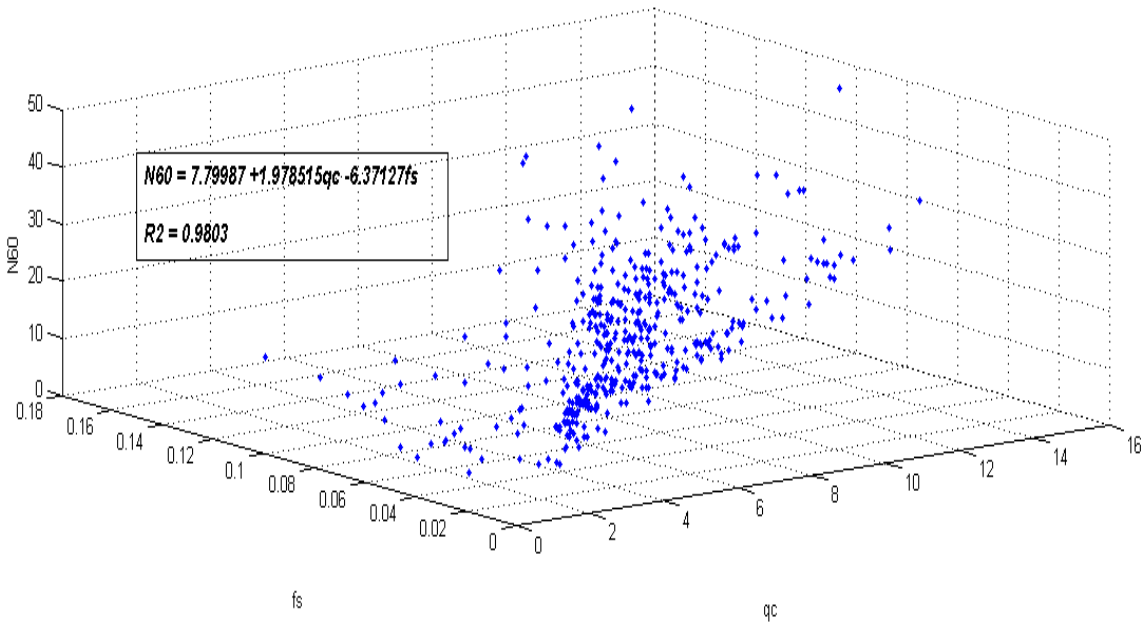

Fig. 2: Correlation between q_c, f_s and N_{60} of sand soil.

6.2 MLR Model for Silty-Sand Soil

Silty-sand soil has a coarse-grained skeleton with reduced undrained shear strength due to the small amount of fine [9]. A total of 23 data were used to form the correlation using MATLAB, the regression model of which is shown in Figure 3.

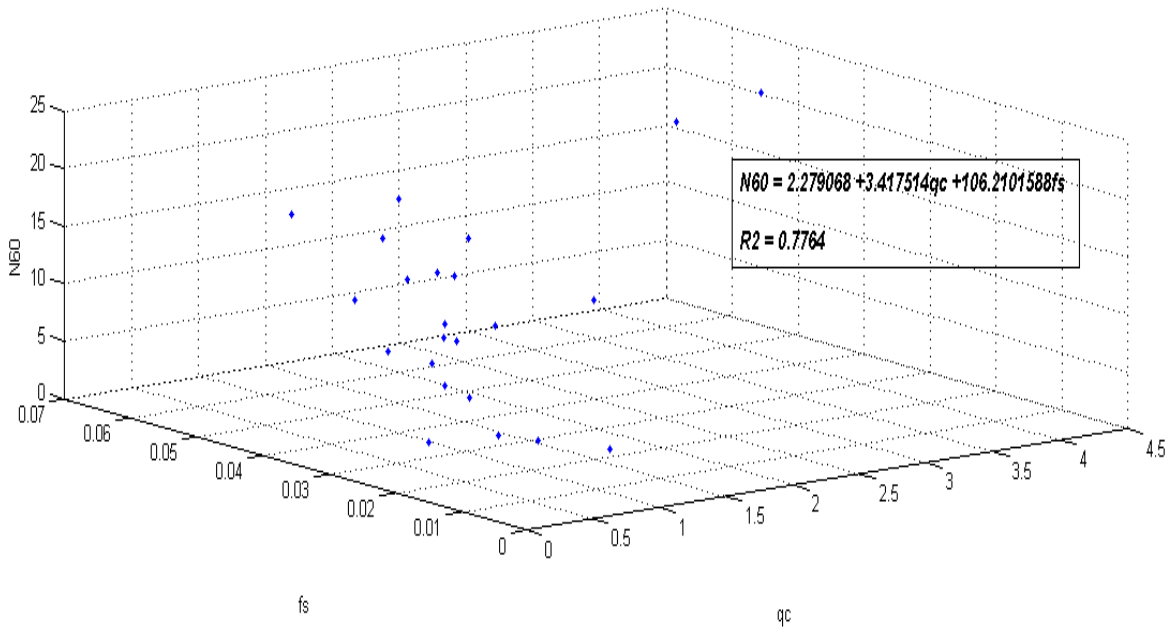

Fig. 3: Correlation between q_c, f_s and N_{60} of silty-sand soil.

6.3 MLR Model for Clay Soil

Clay soils are heavy, contain high nutrients and can hold water. They can be both highly compressible and low compressibility. A total of 58 data were used to form the correlation using MATLAB, the regression model of which is shown in Figure 4.

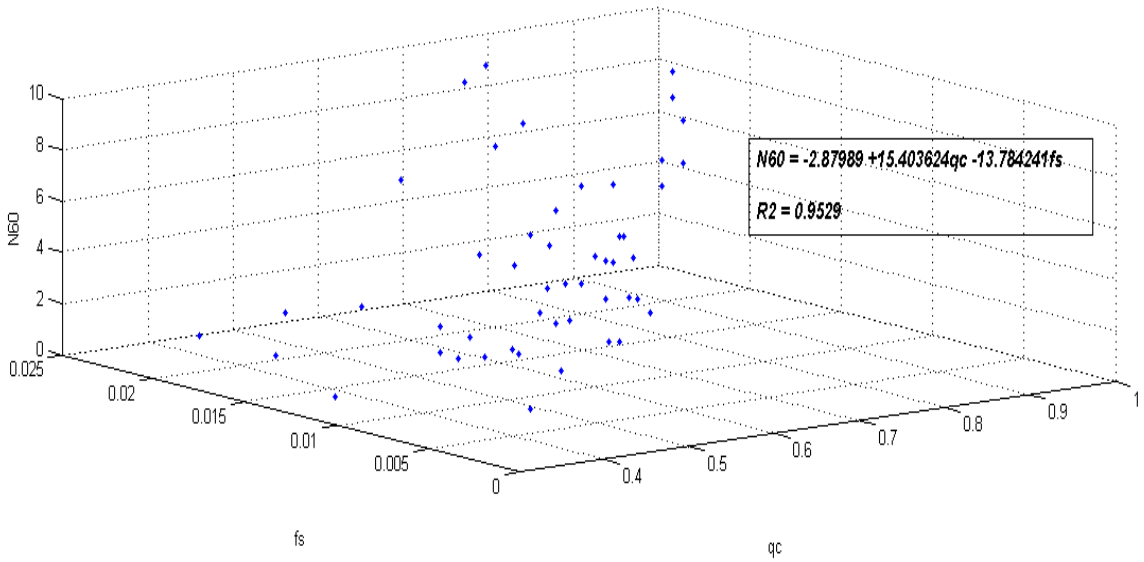

Fig. 4: Correlation between q_c, f_s and N_{60} of clay soil.

6.4 MLR Model for Silty-Clay Soil

Silty clay is generally brownish gray, with soft and creamy texture, flow shape, and with clay content more than 50% [10]. A total of 9 data were used to form the correlation using MATLAB, the regression model is shown in Figure 5.

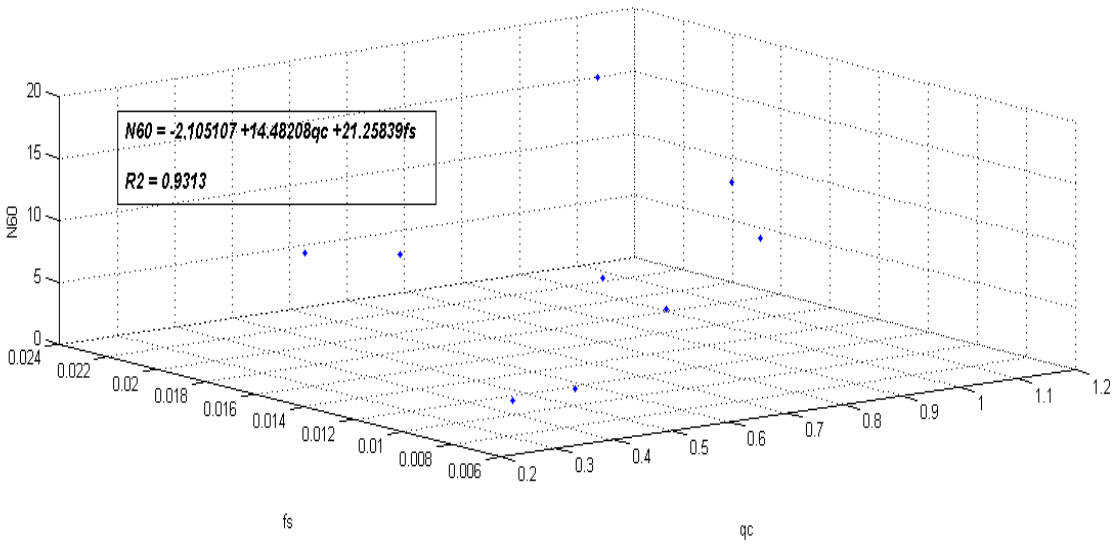

Fig. 5: Correlation between q_c, f_s and N_{60} of silty-clay soil.

7. Results

From the analysis of the data through MLR models using MATLAB, it has been found that the predicted N_{60} values for each type of soil can be determined through the generated equations in Table 5.

Table 5: Summary of Relationship Between q_c, f_s And N_{60}.

Soil Description	$n = (q_c+f_s)/N$ ratio	Correlation Equation	Correlation Coefficient R^2
Sand	0.3	$N_{60} = 7.79987 + 1.978515q_c - 6.37127f_s$	0.9803
Silty-Sand	0.13	$N_{60} = 2.279068 + 3.417514q_c + 106.2101588f_s$	0.7764
Clay	0.11	$N_{60} = -2.87989 + 15.403624q_c - 13.784241f_s$	0.9529
Silty-Clay	0.1	$N_{60} = -2.105107 + 14.48208q_c + 21.25839f_s$	0.9313

R^2 measures the proportion of variation in the N_{60} which can be attributed to q_c and f_s. Here, silty sand has the lowest value for $R^{2,}$ and sandy soil has the highest R^2 value. It merely indicates that the soil has mixed properties (contains silt, clay etc.) [3].

Conclusion

In-situ data is of more importance in case of any subsurface investigation as it denotes the actual soil properties at the site. As only field data have been emphasized, the study successfully dealt with the in-situ soil behavior for the required correlations. As samples show, a major part of Dhaka soil being coarse grained needs the addition of an ample amount of fine grain soil. In this case, there is a need to introduce laboratory data using laboratory tests for consideration of grain size along with in-situ data so that we can introduce the USCS classification. The addition of fine content mixed soil data to the existing data of sandy soil is necessary for the development of a modified equation, which is suggested for future study.

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