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SPT-CPT CORRELATIONS FOR RECLAIMED AREAS OF DHAKA

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ABSTRACT

The Standard Penetration Test (SPT) is the most commonly used in-situ test in Bangladesh, while the Cone Penetrations Test (CPT) is becoming popular day by day for using reliable and cost effective design template. Geotechnical Engineers are more familiar with design procedures based on SPT results. As a result, many Engineering projects it is most common to use both CPT and SPT together for subsoil investigation. However, it is not cost effective to perform the both test. It is crucial to identify a correlation between the results of SPT (N) value and CPT test results based on field measurements to convert CPT to SPT result or vice versa. This paper first reviews existing correlations between the results of both SPT and CPT in the literature. The existing correlations depend on grain size, fines content or the soil behaviour type index, I_c. This paper uses the results of soil investigations in Ten (10) major sites in Dhaka city where results of both SPT and CPT, together with grain size distributions are available. The data compiled by the current research of proposed correlations for q_c (cone bearing resistance), N_{60} (N -values corresponding to hammer efficiency of 60%) and others soil parameters shows similar trend as presented by earlier researchers.

Keywords: *Standard Penetration Test (SPT), Cone Penetrations Test (CPT), Correlations, Soil investigations.*

1. INTRODUCTION

At present time, the CPT is becoming increasingly popular in subsoil investigation for its rapid and convenient way to measure continuous soil stratigraphy. On the other hand, the SPT is one of the most commonly used in-situ test procedure for subsoil investigation in many places around the world. However, application of CPT has started in Bangladesh since the last decade for sub-soil exploration and engineering design purpose, but SPT is still the most widespread and economic means for subsoil investigation than any other test.

Due to the lack of soil sampling during CPT, in many engineering projects it is most common to use both CPT and SPT together for subsoil investigation and a combination of obtained soil parameters from these tests is being used for design purpose. The most prominent correlations currently exist for interpretation of soil parameters are primarily Europe and North America based. Besides, CPT equipment developers also used those correlations to develop their own software for CPT data processing and data interpretation. However, soils are natural materials that can, and typically do, vary widely. The available generic correlations may not be applicable to the soils encountered in Bangladesh. Use of the existing correlations, data processing and data interpretation software for local soils without justification may lead to inconsistent results. Therefore, it has been necessary to develop correlations among SPT, CPT and soil parameters, for preparing guideline, specification, cost-effective and reliable design templates based on the proposed correlations depending on different types of soil in different geographic region of Bangladesh.

This study reviews existing correlations between the SPT and CPT available in the literature. Then the uses of results of soil investigations in 10 major sites in Dhaka city have highlighted in this study by the author. The data compiled by the current research for q_c and N_{60} shows similar trend as presented by Robertson *et al*. (1983). Correlations between two parameters for different soil types have established. Figure1 shows the study area and the ten selected locations within Dhaka City.

2. STANDARD PENETRATION TESTS (SPT)

SPT is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. Details of the SPT have explained in the ASTM D 1586. The fact that the name of SPT is Standard Penetration Test with the word 'Standard', it is neither not completely standard equipment wise nor procedure wise resulting in variability and non-repeatability in the results. The influence of the details or procedures of carrying out the test and the equipment used during the test had investigated and reviewed by many investigators (Seed *et al*., 1985; Skempton, 1986; and Robertson and Wride, 1998).

The N values are influenced by; a) borehole diameter, b) using or not using a liner inside the borehole, c) level of water or drilling mud in the borehole as compared to level of ground water, d) diameter of the sampler used in the

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test, e) type of hammer used in the test, f) means of lifting and releasing the hammer, g) depth of the test or length of drilling rods and h) other deficiencies such as verticality of the hammer and rigidity of rods connections. Some of the factors such as level of water or drilling mud in the borehole as compared to level of ground water and other deficiencies such as verticality of the hammer and rigidity of rods connections can be taken care of by direct supervision and good practice.

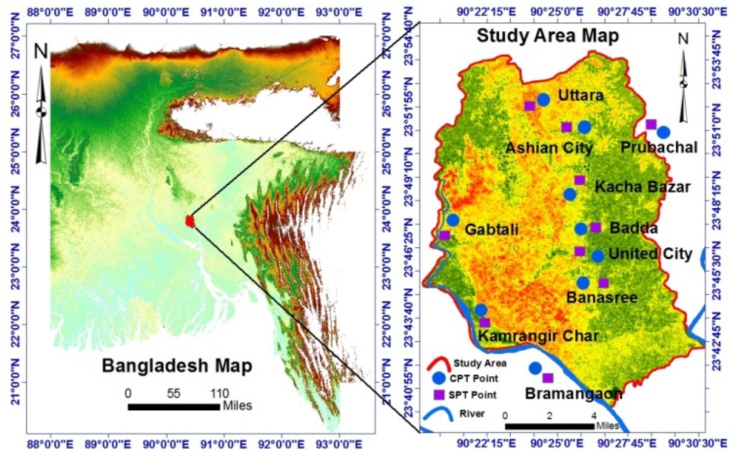


Figure 1: Map showing the study area along with the selected locations.

The most influential and variation factors on reported N values have related to type of hammer and means of lifting and releasing the hammer. The factors that depend on type of hammer and the local practice in each country result are only a portion of intended applied energy reaching the sampler. The ratio of delivered energy to the theoretical applied energy has known as the hammer efficiency. Most of geotechnical engineering practices and correlations have based on N_{60} as suggested by Seed *et al.* (1985). Corrections to N values for hammer efficiencies, as well as for other factors listed above, can be found in Seed *et al*. (1985), Skempton (1986) and Robertson and Wride (1998).

3. CONE PENETRATION TESTS (CPT)

CPT is a method used to determine the geotechnical Engineering properties of soils and delineating soil stratigraphy. Details procedure of the CPT has been contained in ASTM D5778. The cone bearing resistances (q_c) and frictions (f_s) data have been obtained at an interval of 0.01 m by CPT software named PC-mon. PC-mon stands for PC Interface monitor. This unit is the link between the CPTU probes Memocone type II and type III and a portable PC. The portable PC is not included in the delivery. The software PC-mon v 1.0 or later has to be installed in the portable PC. The handling of the PC-Mon is totally menu operated. On the other hand, to classify the soil using CPT results using classification chart (Robertson, 1990) based on the normalized tip resistance, Q, and normalized friction ratio, F, and thus estimate the grain characteristics of soils directly from CPT results by Soil Behaviour Type Index, SBT I_c. The boundaries between different soils in Robertson (1990) chart can be approximated as concentric circles. The radius of these circles, termed the Soil Behaviour Type Index, I_c, is calculated using the following equations (Robertson and Wride, 1998):

$$I_c = [(3.47 - \log Q)^2 + (\log F + 1.22)^2]^{0.5} \quad (1)$$

$$Q = (q_c - \sigma_{vo})/p_a \, (p_a/\sigma'_{vo})^n \quad (2)$$

$$F = [f_s / (q_c - \sigma_{vo})] \, 100\% \quad (3)$$

where σ_{vo} and σ'_{vo} are the total and effective overburden stresses, respectively; P_a is the reference pressure, equal to 100 kPa and n is exponent that is dependent on type of soil. Originally, Robertson (1990) used value of n = 1.0. Robertson and Wride (1998) suggested that n = 0.5 in case of cohesion less soil (sand) and n = 1.0 in case of cohesive soils (clay and silt).

4 SPT-CPT EXISTING CORRELATIONS

4.1 Historical Evolution for Purposes of SPT-CPT Correlations

The evolution of the development and use of SPT-CPT correlations in the literature started as early as mid-fifties of the last century (Shahien and Albatal, 2014). At the present time, the SPT have been the most commonly used field test to determine the geotechnical parameters of granular materials due to both its simplicity and cost in addition to presence of several well-established SPT-based geotechnical design techniques in the literature. Due to its reliability, repeatability and standardization, the CPT, on the other hand, has regarded as an alternative to the SPT. Thus there was a need to convert CPT q_c to SPT N to use SPT N based design procedures (Meyerhof, 1956). Well established correlations between SPT N_{60} and q_c, together with measured N values and q_c, can be used to assess the SPT hammer energy level as suggested by Douglas (1982). Such exercise has been carried out in Egypt by El-Sherbiny and Salem (2013) to assess hammer energy levels of Donut and Safety hammers used in Egypt. Based on the work by El-Sherbiny and Salem (2013) the average energy for the hammers used in Egypt was about 49% for Donut and 60% for Safety hammers.

4.2 Factors Influence the Correlations

The SPT-CPT correlations were reviewed by several investigators in the literature (Schmertmann, 1976; Robertson *et al.,* 1983; and Lunne *et al.,* 1997). The SPT-CPT correlations or relationships depend on several variables that could be grouped in three categories; 1) SPT related variables, 2) CPT related variables and 3) material or soil related variables. Not accounting appropriately for the above mentioned variables contribute significantly to presence of scatter in any developed SPT-CPT correlations.

4.2.1 SPT Related Variables

As discussed earlier, SPT N values are dependent on test procedures and equipment. As N values are dependent on level of energy received by the sampler, the correlation of SPT-CPT is dependent on that level of energy. Thus, correction of N values for received energy is required (Robertson *et al*., 1983 and Lunne *et al*., 1997). Most of recent correlations rely on N-values corrected to hammer efficiency of 60% (N_{60}).

4.2.2 CPT Related Variables

The CPT should be corrected for penetration induced pore water pressure (Campanella *et al*., 1982) and for thin layer effect (Vreugdenhil *et al*., 1994). Other than the case of cohesive layers, pore water pressure correction is not significant. Furthermore, correction for thin layer effect is not commonly used during the development of SPT-CPT correlations, as development of such correlations in non-homogeneous layers with thin layers is difficult.

4.2.3 Soil Related Variables

The SPT-CPT correlation is dependent on type of soil and thus grain properties (Schmertmann, 1970) presence of gravel (Robertson *et al*., 1983), stratification and non-homogeneity (Robertson *et al*., 1983), and soil density (Idriss and Boulanger, 2004). The grain properties can be in the form of median particle size (Robertson *et al*., 1983). Soil type or grain size can be expressed by the SBT index, I_c (Robertson and Wride, 1998). Presence of gravel significantly influences N values, however, percentage of gravel content cannot be accurately sampled during SPT test. The stratification and non-homogeneity in cohessionless deposits can cause abrupt changes in CPT but usually missed by SPT. The ratio of q_c/N is dependent on soil density. The ratio is higher in loose sand as compared to that in dense sand. The SPT is a dynamic test during which penetration- induced pore water pressure might develop. The excess pore water pressure is positive in case of loose sand while it is negative in case of dense sand. Thus, the resulting N value has reduced in case of loose sand while N value is increased in case of dense sand. The CPT, on the other hand, is a static drained test. Such an effect is amplified in presence of silts and fines in the sand.

4.3 Existing Correlations

The existing correlations could be grouped in four categories as summarised in Table 1. The comments in the following paragraph are applicable to the correlations in Table 1. In most of the correlations, with exception of correlations (Hayati and Andrus, 2009), the independent variable is the ratio q_c/P_a/NEr where q_c is the cone tip resistance, Pa is a reference pressure of 100 kPa and NEr is SPT N values with Er is the energy ratio of the hammer used in the test. If Er is missing, this means that the energy ratio is not known. The dependent variables could be median grain size (Category A), fines content (Category B), or SBT index (Category C). In case the correlation has the density of the soil as influential variable, then the correlation has dependent variable of either N (Idriss and Boulanger, 2004) or q_c (Idriss and Boulanger, 2004). Some of these correlations may require iteration during applications. In some correlations, the authors of this paper used the data or the graphical relationship in the original reference and quantified the correlation in the empirical expressions shown in Table 1. In case of using the correlation for estimating SPT N60 from the CPT results, it is important to estimate the fines content for the sake of using the results in liquefaction analysis.

Table 1: Summary of Existing SPT-CPT Correlations (Shahien and Albatal, 2014)

No.	Reference	Correlation	Comment
[A] Correlations Based on Median Grain Size, D_{50}			
[1]	Muromachi and Kobayashi (1982)	$(q_c/P_a)/N = 5.48 + 1.36 \log_{10} D_{50}$	
[2]	Robertson *et al*. (1983)	$(q_c/P_a)/N_{55}=7.5(D_{50})^{0.26}$	(a)
[3]	Burland and Burbidge (1985)	$(q_c/P_a)/N=8.0(D_{50})^{0.30}$	(a)
[4]	Seed and DeAlba (1986)	$(q_c/P_a)/N_{60}=6.0(D_{50})^{0.24}$	(a)
[5]	Andrus and Youd (1989)	$(q_c/P_a)/N_{60}=4.95(D_{50})^{0.168}$	(a)
[6]	Kulhawy and Mayne (1990)	$(q_c/P_a)/N=5.44(D_{50})^{0.26}$	
[7]	Suzuki *et al.* (1998)	$(q_c/P_a)/N=11.1(D_{50})^{0.261}$ $(q_c/P_a)/N=8.4(D_{50})^{0.225}$ $(q_c/P_a)/N=6.0(D_{50})^{0.165}$	$0\leq N<10$ (a) $10\leq N<30$ (a) $30\leq N$ (a)
[B] Correlations Based on Fines Content, FC%			
[8]	Jamiolkowski *et al*. (1985)	$(q_c/P_a)/N_{64} = 4.90 - 0.03xFC$ (%)	(a)
[9]	*Chin et al*. (1988)	$(q_c/P_a)/N_{55} = 4.70 - 0.05xFC$ (%)	
[10]	Kulhawy and Mayne (1990)	$(q_c/P_a)/N = 4.25 - 0.024\ FC$ (%)	
[11]	Suzuki *et al*. (1998)	$(q_c/P_a)/N=0.0026FC^2-0.263FC+12.34$ $(q_c/P_a)/N=0.00085FC^2-0.120FC+8.733$ $(q_c/P_a)/N=0.001FC^2-0.059FC+5.59$	$0\leq N<10$ (a) $10\leq N<30$ (a) $30\leq N$, $FC\leq 20$ (a)
[C] Correlations Based on Soil Behaviour Type Index, I_c			
[12]	Jeffries and Davies (1993)	$(q_c/P_a)/N_{60} = 8.5(1-I_c/4.75)$	
[13]	Lunne *et al.* (1997)	$(q_c/P_a)/N_{60} = 8.5(1-I_c/4.6)$	Modified definition of I_c based on Robertson and Wride (1998)
[14]	Robertson (2012)	$(q_c/P_a)/N_{60} = 10^{(1.1268-0.2817Ic)}$	
[15]	Suzuki *et al*. (1998)	$(q_c/P_a)/N = 31.25\exp(-0.68I_c)$ $(q_c/P_a)/N = 18.60\exp(-0.54I_c)$ $(q_c/P_a)/N = 10.21\exp(-0.35I_c)$	$0\leq q_t<5$ (a) $5\leq q_t<15$ (a) $15\leq q_t$ (a)
[D] Correlations Based on Other Variables or Other Forms			
[16]	Idriss and Boulanger (2004)	$(qc1/Pa)/(N1)_{60}=(2.092D_r+2.224)^{3.788}/46(D_r)^2$ $D_r=0.478(qc1/P_a)^{0.264}-1.063$, $(qc1/P_a>21)$ or $D_r=((N1)_{60}/46)^{0.5}$	q_{c1} and $(N1)6_0$ are q_c and N_{60}, respectively, corrected for σ'_{VO}.
[17]	Hayati and Andrus (2009)	$(N_1)60CS=0.356(q_{c1}\text{-}CS)^{0.851}$	Holocene Sand – $FC<20\%$ $I_c<2.25$
[18]	Souza *et al*. (2012)	$q_c/P_a = 10.6\ (N_{60})^{0.71}$	$FC<10\%$

(a)The authors of this paper interpreted data of original reference to come up with the empirical expression.

5. INVESTIGATED SITES AND GEOTECHNICAL DATA

In the laboratory, the following tests were performed for the research**:** Atterberg limit; Specific Gravity and Grain size analysis (especially hydrometer); Static and Cyclic Triaxial test; Direct Shear test; Compaction test; Consolidation test; Density test and Shaking Table test. Comprehensive geotechnical investigation campaigns were carried out in ten sites of major projects. Total ten areas of the Dhaka city have selected for this research. The main targeted areas are the reclaimed lands since some of these lands found susceptible to liquefaction (Ahmed, 2005).

Total ten areas have been selected which almost surrounding the Dhaka city. The reclaimed areas are Bramangaon, Ashian City, Badda, Banasree, Gabtoli, Kawran Bazar, Purbachal, United City, Uttara and Kamrangirchar.

6 EVALUATIONS OF DATA

6.1 Sub-Soil Characteristics

Total ten locations have been selected for developing correlations among CPT, SPT and others soil parameters in Dhaka city in this research. SPT has been conducted and disturbed as well as undisturbed samples have collected from all these locations. Sub-soil characteristics, SPT, CPT test results and laboratory test results of these samples have presented in this section. Besides this CPT test, results have also described. Table 2 shows summary of the statistics of data records collected in 10 sites of this study N value, grain size (d_{50}), fine content (F_c), Cone bearing resistance (q_c), friction (f_s) and friction ratio.

6.1.1 Sub- Soil Characteristics of Bramangaon

This site has situated in southeast part of Dhaka city. It is a private land development project where main filling has done by dredged river sand. The depth of filling of fine sand is 5.0 m from the existing ground surface. The clayey silt layer exists from 5.0 m to 6.5 m from the Elevated Ground Level (EGL). After that, 1.5 m is sandy silt layer. Then 12.0 m is clayey silt. Figure 2 shows a) Depth (m) vs N b) Depth (m) vs Cone Resistance (MPa) c) Depth (m) vs Friction (kPa) d) Depth (m) vs Friction Ratio at different locations.

Table 2: Summary of the statistics of data records collected in this study.

SL	Study Location	Depth (m)	D_{50} (mm)		F_c (%)		N value		q_c (MPa)		f_s (kPa)		Friction ratio	
			Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	BRAMANGAON	0-20	0.046	0.17	20	72	4	8	0.51	16.78	0	120.20	0	4.13
2	ASHIANCITY	0-20	0.002	0.17	20	96	3	42	0.19	7.80	0	233.90	0	6.35
3	BADDA	0-20	0.005	0.19	20	98	1	38	0.17	4.46	0	145.00	0	6.24
4	BANASREE	0-20	0.003	0.17	20	96	1	40	0.17	11.37	0	130.30	0	7.04
5	GABTOLI	0-20	0.003	0.17	19	90	3	15	0.52	7.82	0	70.10	0	9.34
6	KAWRAN BAZAR	0-20	0.001	0.16	30	96	1	35	0.00	18.55	0	226.70	0	7.72
7	PURBACHAL	0-20	0.003	0.17	20	96	1	8	0.35	7.06	0	75.60	0	5.87
8	UNITED CITY	0-20	0.002	0.17	20	95	3	45	0.55	7.17	0	273.20	0	6.39
9	UTTARA	0-20	0.002	0.17	20	96	2	18	0.36	4.85	0	69.10	0	3.10
10	KAMRANGICHAR	0-20	0.003	0.18	20	90	3	28	0.38	9.85	0	96.50	0	5.40

6.1.2 Sub-Soil Characteristics of Ashiancity

This site is situated in Northern part of Dhaka city. The depth of filling of fine sand is about 3.5 m from the existing ground surface. The silty clay layer exists from 3.5 m to 12.5 m from the EGL. After that, 4.5 m is fine sand layer. Then 3.0 m is silty clay.

6.1.3 Sub-Soil Characteristics of Badda

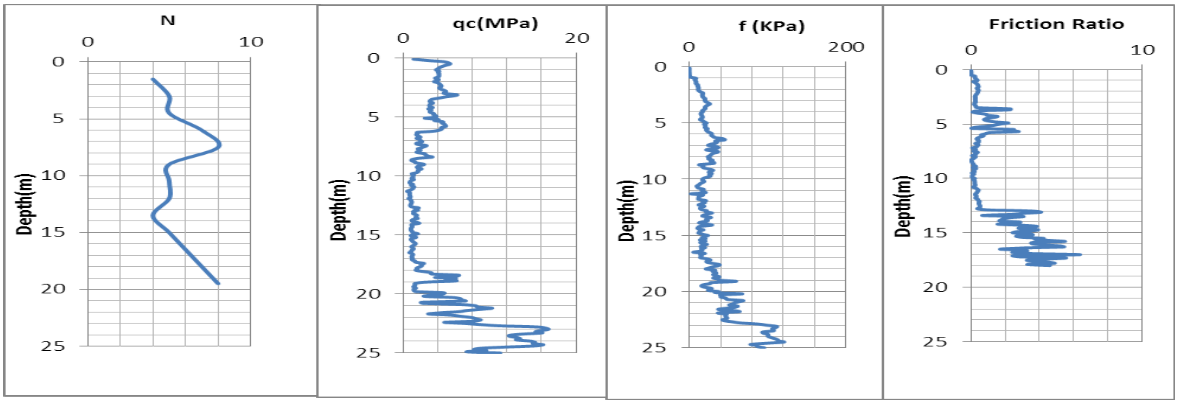
This site is situated in Eastern part of Dhaka city. The depth of filling of fine sand is 5.0 m from the existing ground surface. The organic clay layer exists from 5.0 m to 8.0 m from the EGL. After that, 6.5 m is silty clay layer. Then 4.0 m is sandy silt. Then 1.5 m is fine sand.

6.1.4 Sub–Soil Characteristics of Banasree

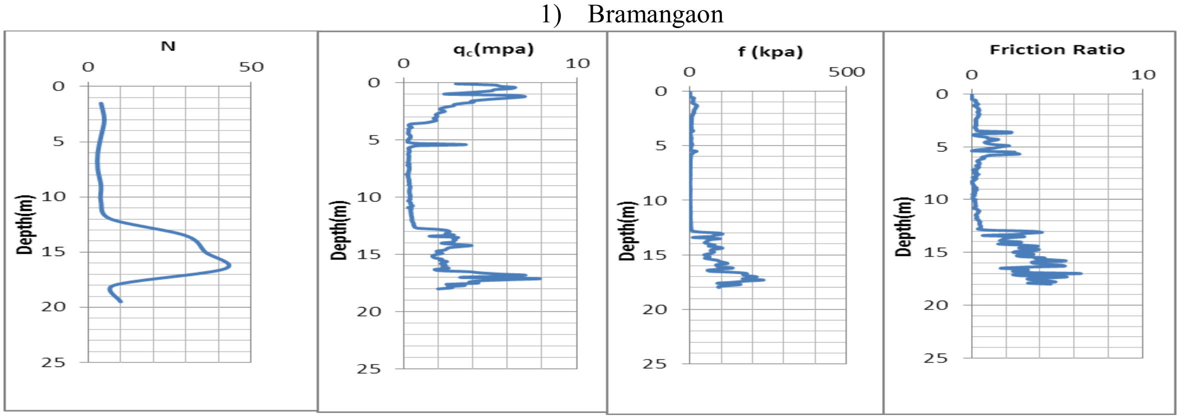
This site is situated in eastern part of Dhaka city. It is a private land development project where main filing has done by dredged river sand. The depth of filling of fine sand is 4.0 m from the existing ground surface. The clay layer exists from 4.0 m to 14.0m from the EGL. After that, 2.0 m is clay layer. Then 4.0 m is silty fine sand.

6.1.5 Sub-Soil Characteristics of Gabtoli

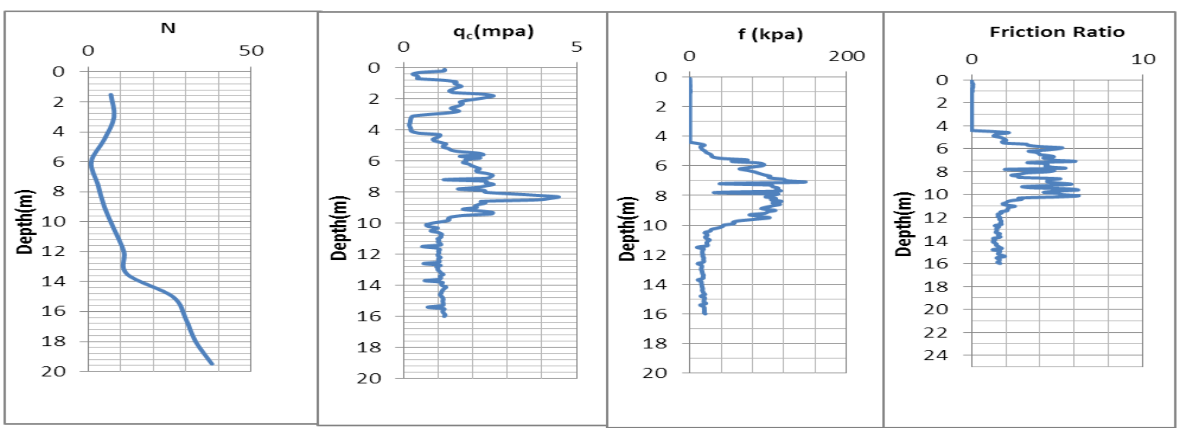
This site is situated in north-west part of Dhaka city. It is a private land development project where main filing is done by dredged river sand. The depth of filling of fine sand is 5.0 m from the existing ground surface. The clay layer exists from 5.0 m to 11.0m from the EGL. After that 7.5 m is sandy silt layer. Then 1.5 m is silty fine sand.



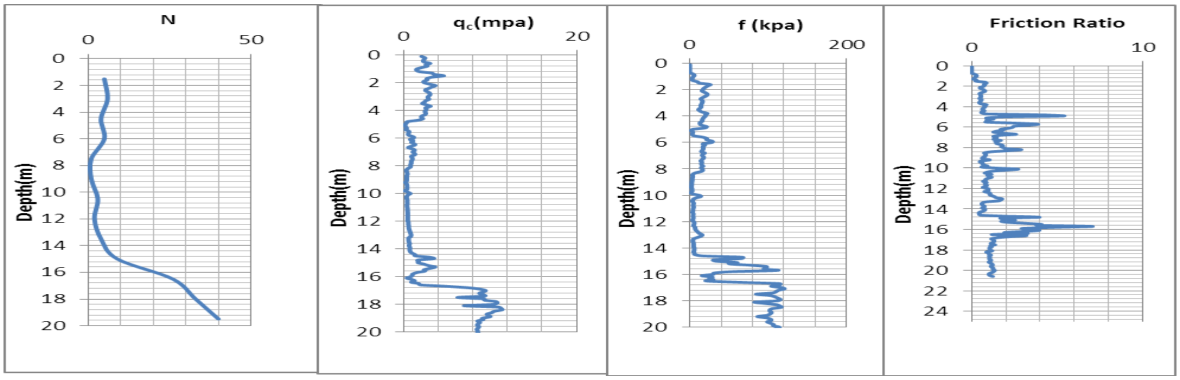
1) Bramangaon



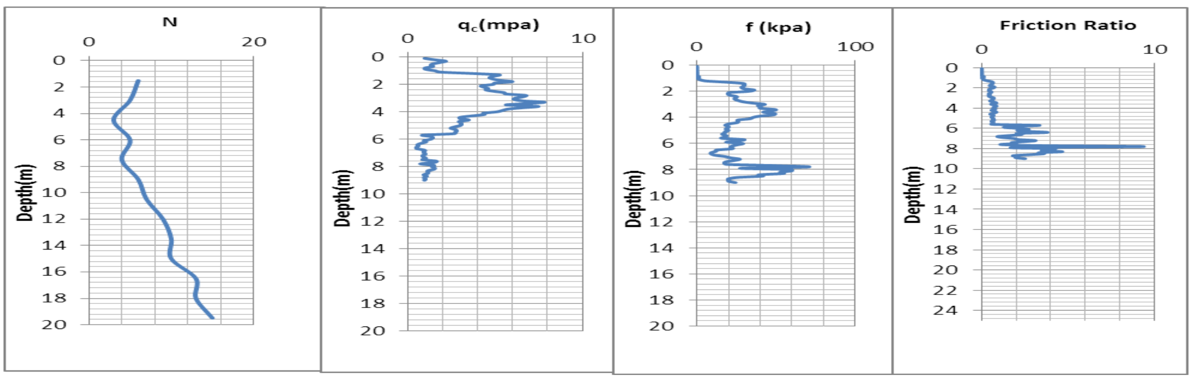
2) Ashian City



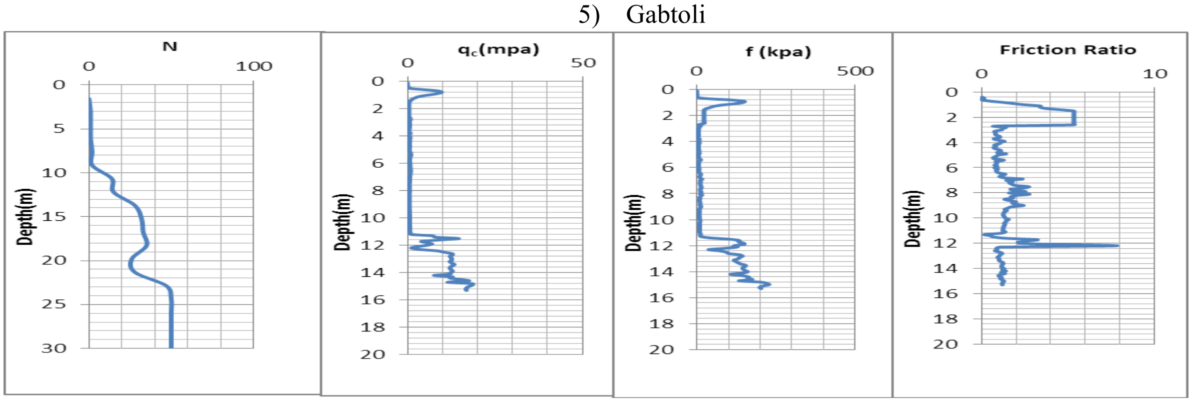
3) Badda



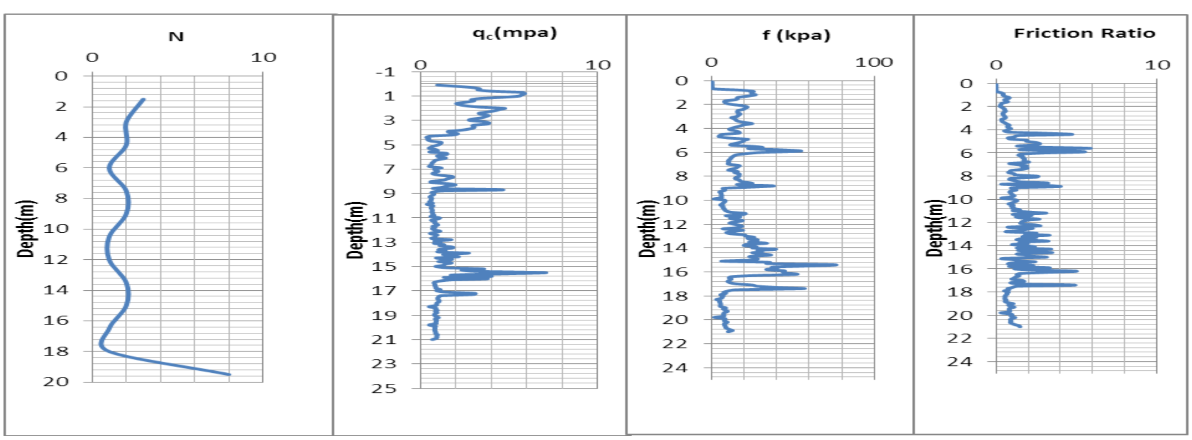
4) Banasree



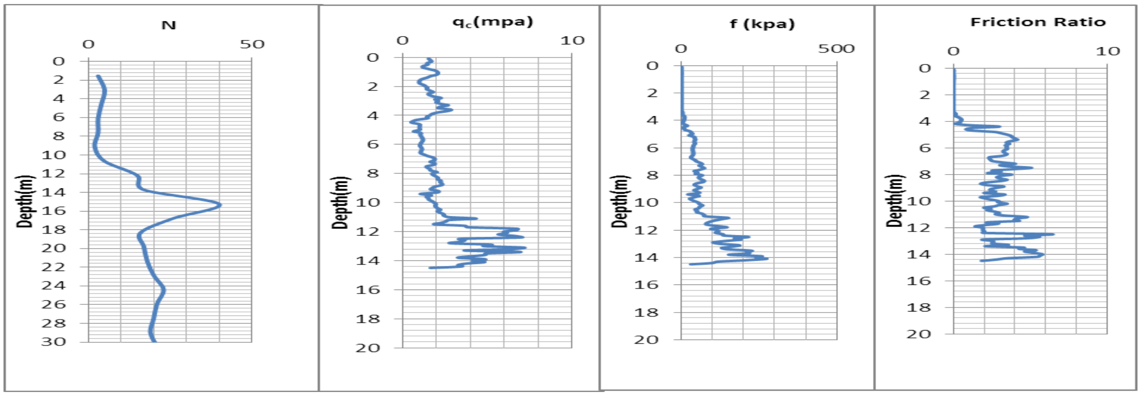
5) Gabtoli



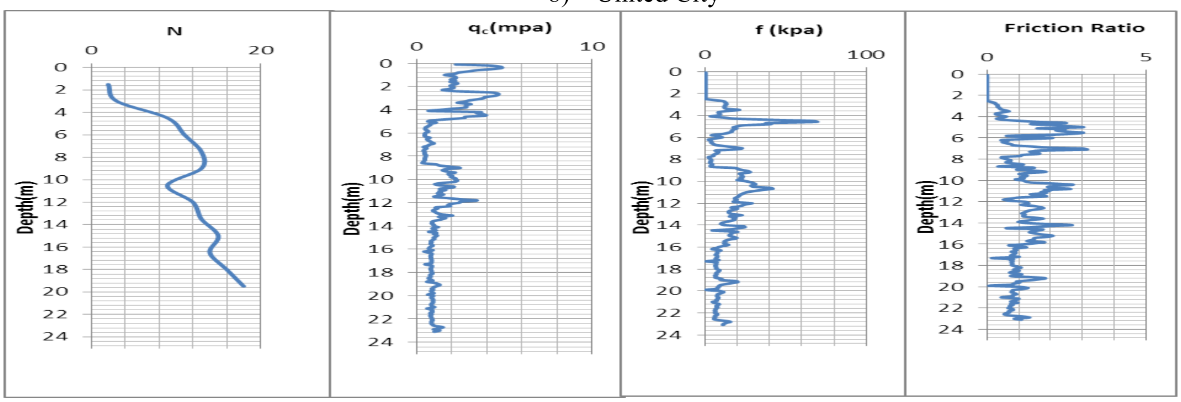
6) Kawran Bazar



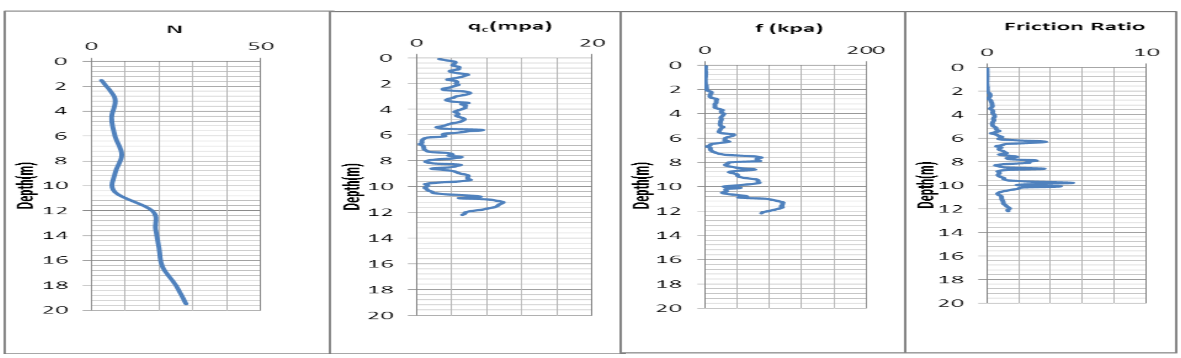
7) Purbachal



8) United City



9) Uttara



10) Kamrangichar

Figure 2: a) Depth (m) vs N b) Depth (m) vs Cone Resistance (MPa) c) Depth (m) vs Friction (kPa) d) Depth (m) vs Friction Ratio at different ten locations.

6.1.6 Sub-Soil Characteristics of Kawran Bazar

This site is situated in northeast part of Dhaka city. The depth of filling of fine sand is 3.5 m from the existing ground surface. The clay layer exists from 3.5 m to 11.0 m from the EGL. After that, 9.0 m is silt layer.

6.1.7 Sub-Soil Characteristics of Purbachal

This site is situated in north-west part of Dhaka city. It is a Government land development project where main filing is done by dredged river sand. The depth of filling of fine sand is 6.5 m from the existing ground surface. The clay layer exists from 6.5 m to 13.5 m from the EGL.

6.1.8 Sub-Soil Characteristics of United City

This site is situated in Eastern part of Dhaka city. The depth of filling fine sand is 5.0 m from the existing ground surface. The clay layer exists from 5.0 m to 11.0m from the EGL. After that, 7.5 m is sandy silt layer. Then 1.5 m is silty fine sand.

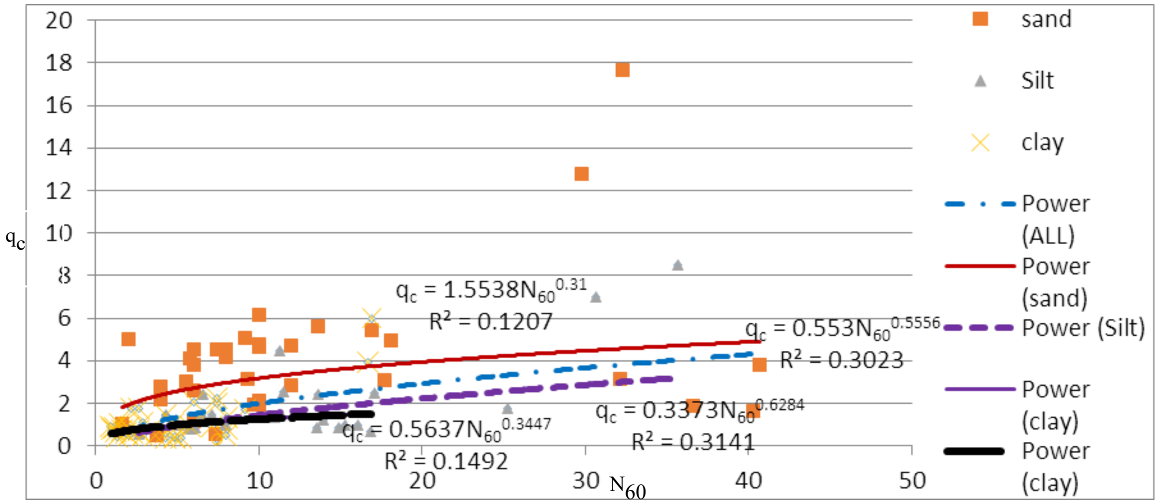


Figure 3: q_c vs N_{60} curve.

6.1.9 Sub-Soil Characteristics of Uttara

This site is situated in north of Dhaka city. It is a Government land development project. The depth of filling fine sand is 3.5 m from the existing ground surface. The clay layer exists from 3.5 m to 8.0m from the EGL. After that, 12 m is silt layer.

6.1.10 Sub-soil characteristics of Kamrangichar

This site is in southeast part of Dhaka city. It is an island surrounded by river Buriganga. It is connected to main land by two bailey bridges and there is quite dense population in the area. The depth of filling fine sand is 3.5 m from the existing ground surface. The clay layer exists from 8.0 m to 9.5 m from the EGL. After that, 10.5 m is fine sand layer.

7. PROPOSED CORRELATIONS

Many empirical correlations have been created between the SPT N-value, and other engineering properties of soils as can be seen from Table 1. Although SPT has disadvantages such as discrete strength measurement and dependence on operator and apparatus, but it is still the most popular and economic mean for subsurface investigation. On the other hand, the CPT is becoming progressively popular for its high ability to delineate stratigraphy of soil and assess soil properties rapidly and continuously. For many geotechnical projects, it is common to determine that the preliminary design based on soil parameters obtained from standard penetration tests, whereas the final design is based on cone penetration test results, or vice versa. Thus, it is very valuable to find reliable CPT-SPT correlations so that available database of the test sites performances and property correlation with SPT N-value could be effectively used. Three different curves for the different types of soil (sand, silt and clay) have been shown in Figure 3. The three different equations have been developed for finding the q_c value from N_{60} and vice versa. Considering the all types of soil data another curve has also been developed for finding the q_c value from N_{60} and vice versa. The compiled by the current research similar trend as proposed by Robertson *et al.* (1983).

Table 3: Correlation between q_c and N_{60}.

Soil type	Proposed correlations	
Sand	$q_c = 1.5538*N_{60}^{0.31}$	$R^2 = 0.120$
Silt	$q_c = 0.3373*N_{60}^{0.6284}$	$R^2 = 0.314$
Clay	$q_c = 0.5637*N_{60}^{0.3447}$	$R^2 = 0.149$
Combined sample (Sand, Silt and Clay)	$q_c = 0.553*N_{60}^{0.5556}$	$R^2 = 0.302$

In this research, q_c and f_s of soil up to about 20 m depth have been determined by CPT test in ten selected areas of

Dhaka city. These cone resistances and frictions data have been obtained at an interval of 0.01 m by CPT software. Again, at the same ten locations SPT has been conducted up to 25 m depth. The data compiled by the current research for q_c and N_{60} shows similar trend as presented by Robertson *et al.* (1983). Correlation between the two parameters for different soil types have been shown in Table 3.

Due to lack of adequate soil grain size data, use Robertson (1990) soil classification chart to define soil behaviour type index. Here build up a correlation between $(q_c/p_a)/N_{(60)}$ and I_c. For doing this job, firstly find out I_c value. Table 4 describes the procedure to find out I_c value. Then a graph have been drawn between $(q_c/p_a)/N_{(60)}$ and I_c curve has been shown in Figure 4. From this figure a linear curve has been drawn. By this curve a straight-line equation has been formed which shown in equation 4. When adequate soil grain size data are not available, N_{60} at a specific location has been converted to q_c or vice versa by using the equation. The curve is also similar trend as proposed by Robertson (1990).

$$(q_c/p_a)/N_{(60)} = -3.095 * I_c + 9.898 \tag{4}$$

Where, q_c = cone resistance (MPa); N_{60}= corrected N value; I_c= Soil behaviour type Index.

Table 4: Estimation of Soil behaviour type Index for BRAMANGAON site

Depth (m)	q (MPa)	$N_{(60)}$	$(q_c/p_a/)N_{(60)}$	I_c
1.5	4.16	8.00	5.20	1.44
3.0	4.75	10.00	4.75	1.65
4.5	3.14	9.28	3.39	1.74
6.0	4.48	11.25	3.98	1.78
7.5	2.54	11.50	2.21	2.07
9.0	2.4	6.56	3.66	2.01
10.5	0.83	6.07	1.37	2.51
12.0	0.87	5.68	1.52	2.58
13.5	1.48	4.28	3.46	2.38
15.0	0.97	5.08	1.91	2.65
16.5	0.78	5.81	1.33	2.77
18.0	1.51	6.49	2.31	2.48
19.5	1.48	7.13	2.08	2.51

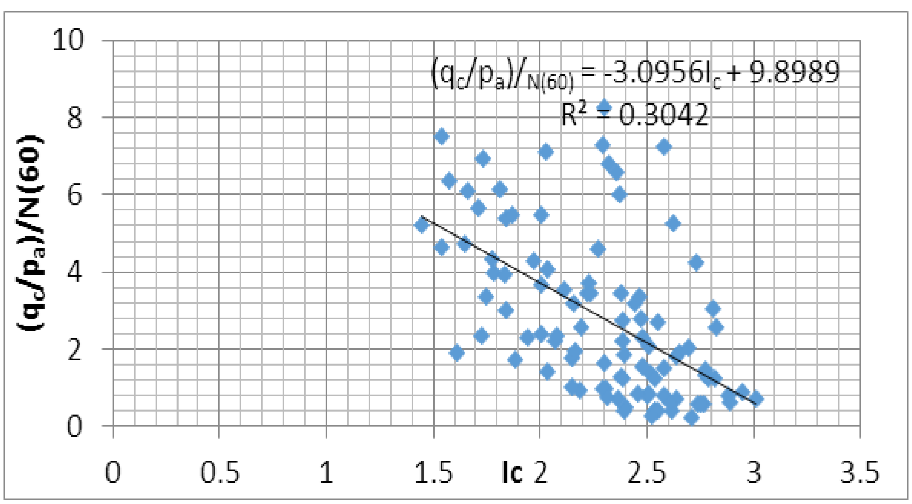


Figure 4: $(q_c/p_a)/N_{(60)}$ vs I_c

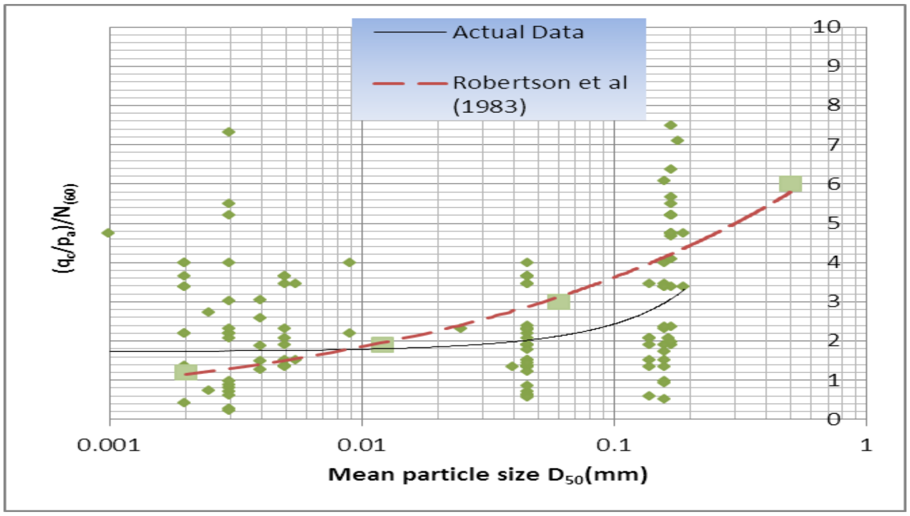


Figure 5: $(q_c/p_a)/N_{(60)}$ vs d_{50}

A considerable number of studies have been taken place over the years to quantify the relationship between SPT N values and CPT cone bearing resistance, q_c. A wide range of q_c/N ratios have been published leading to much confusion. The variations in published q_c/N ratio can be rationalized somewhat by reviewing the derived q_c/N ratios as a function of mean grain size (d_{50}). It is clear that the q_c/N ratio increases with increasing grain size. The scatter in results appears to increase with increasing grain size. This is not surprising since penetration in gravelly sand (d_{50}=1.0 mm) has been significantly influenced by the larger gravel sized particles, not to mention the variability of delivered energy in the SPT data. In addition, sand deposits in general have been usually stratified or non-homogeneous causing rapid variations in CPT tip resistance. A correlation between $(q_c/p_a)/N_{(60)}$ vs $d_{(50)}$ have been proposed by Robertson and Campanella (1983). The data compiled by the current research also shown similar trend as shown in Figure 5.

Correlation between $(q_c/p_a)/N_{(60)}$ vs I_c and $(q_c/p_a)/N_{(60)}$ vs d_{50} has been obtained for those data. In the research, work used only ten locations of CPT and SPT data. However, more reliable and cost effective design template are needed to develop correlations that are more reliable.

8. CONCLUSIONS

Different correlations regarding different types of soil properties have been proposed based on the soil of Dhaka, Bangladesh. CPT, SPT and laboratory test has been done separated ten locations of Dhaka city. From the CPT test, the cone resistance varies from 0.17 to 16.78 MPa. From the SPT test, the N value varies from 1 to 42. Friction ratio varies from 0 to 9.34 kPa. Grain size (d_{50}) and Fine content (F_c) varies 0.001 to 0.19 and 18.7 to 98 respectively. Proposed correlation between q_c vs N_{60}, $(q_c/p_a)/N_{(60)}$ vs I_c and $(q_c/p_a)/N_{(60)}$ vs d_{50} has been obtained for ten selected reclaimed areas of different locations of Dhaka. q_c and $N_{(60)}$ has been correlated based on different soil types (sand, silt and clay). It has also been derived q_c/N ratios as a function of mean grain size (d_{50}). It is clear that the q_c/N ratio increases with increasing grain size. The scatter in results appears to increase with increasing grain size. These proposed correlations are similar to other existing correlations developed for soils deposits of other countries. Addition of more future SPT, CPT and Soil data will increase the accuracy of the proposed correlations.

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