Correlation of SPT N and CPT parameters of Dhaka Soil

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PROJECT REPORT APPROVAL

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Hossain Md. Shahin and this work has not been submitted elsewhere for any purpose (except for publication).

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DEDICATION

Our combined thesis work is dedicated to our respective parents. We also express our heartfelt gratitude to our respected supervisor Professor Dr. Hossain Md. Shahin for guiding us throughout the path with utmost sincerity as well as our parents who supported us throughout the journey.

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"In the name of Allah, Most Gracious, Most Merciful."

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ABSTRACT

Keywords: SPT-CPT, Dhaka soil, Correlation, Multiple linear regression.

Standard Penetration Test (SPT) is a very common situ test all over the world for its simplicity. Whereas Cone Penetration Test (CPT) is recently getting popular for its accuracy. Both the tests are necessary for the study of stratigraphy of soil and to find out important geotechnical properties of subsurface soil. Many empirical studies have been conducted based on the correlations of parameters of the two in-situ tests. Dhaka soil is mostly sandy with a mixture of silt and clay. In this study, correlation among the sleeve friction, cone penetration resistance from CPT and N value from SPT. The n ratio for Dhaka soil was compared with those from other literatures. Also, Multiple Linear Regression Analysis has been done with the help of MATLAB for the generation of N-value prediction multi-linear equations for various soil types. Verifications of the N value prediction for sandy Dhaka soil shows that the study requires some improvements that addition of fine content is to be done.

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CHAPTER 1: INTRODUCTION

1.1 General:

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 using SPT in geotechnical field investigations [1]. But considering the fact that CPT is more reliable and relatively cost effective than SPT, it has become a common practice to use both CPT and SPT in the same project, especially in large ones.

SPT or Standard Penetration Test is the most commonly used field investigation test around the world including Bangladesh due to its simplicity. It provides information about the resistance and properties of soil. 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 helps engineers to adopt empirical methods and analyze soil performance [3].

1.2 Study Area:

The development of correlations of SPT-CPT parameters is to be done for Dhaka soil. For the case of Dhaka soil, the correlation is based on the site of the Mass Rapid Transit Project. MRT Line 06 was the first line to get the approval under the mentioned project. This line is from Uttara to Motijheel and runs parallel to the Turag River in the west of Dhaka and curves as it moves south-east following the path of the Buriganga River.

The study area was further divided into a number of study zones for the proper conductance of the in situ tests. All the data from all the sub areas are clustered to fall under a specific area of Line 06 for the development of correlation equations. The mentioned in situ tests were carried out in these areas throughout March and April, 2018. The following Figure 1.2.1 shows the illustration of the study area.

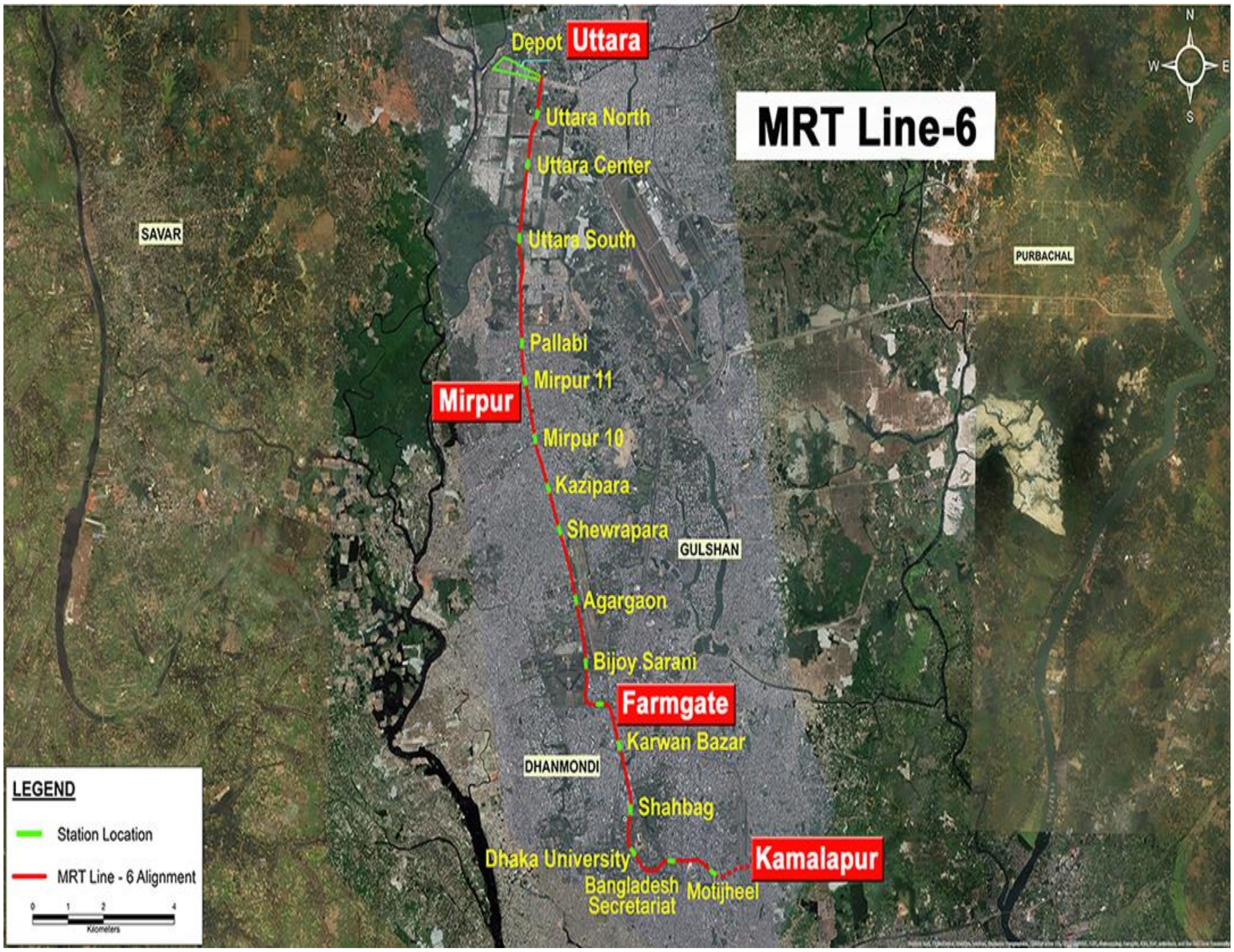


Figure 1.2.1: Illustration of study area (Dhaka MRT Line 06) of Dhaka City
Image Source: journal-of-science-foundation-vol-11-no-1-2013

1.3 Standard Penetration Test:

The Standard Penetration Test was first coined by Terzaghi in 1947 at the Texas Soil Mechanics Conference. It is one of the most common in situ tests since many years in Bangladesh. It is a simple and low cost testing method for determining the relative density and angle of shear resistance of cohesion-less soils along with the unconfined compressive strength of cohesive soil. The test is carried out in a borehole drilled to desirable sampling depth. A split spoon sampler is connected to the drill rod. This type of sampler is used to obtain disturbed samples. In this case, as the soil counters blows, thus becomes disturbed. The split spoon sampler which is penetrated through the layers of soil by specific blows by a hammer from at a height of 76 cm. Usually donut hammers of 63.5 kg are used. Besides, there are uses of other types of hammers as well.

These are based on the differences of operating technique, energy loss or friction. The split spoon is lowered to the bottom of the hole, and is then driven a distance of 450mm (18 in.), and the blows are counted, normally for each 76mm (3 in.) of penetration. At the end of driving the split spoon is pulled from the base of the hole, and the sample is preserved in an airtight container. The penetration resistance (N) is the number of blows required to drive the split spoon for the last 300mm (1ft) of penetration, Penetration resistance during the first 150 mm (6 in.) of penetration is ignored, because the soil is considered to have been disturbed by the action of boring the hole.

1.4 Cone Penetration Test:

Assessment of subsurface stratigraphy in association with soft materials, organic materials like peat, potentially liquefiable materials (silt, sands and granule gravel), and landslides is done by the method of the in situ Cone Penetration Test.

In the Netherlands back in 1932, the very first cone penetration test was conducted by P. Barensten [4]. So, CPT is sometimes referred to as dutch cone test as the current standard is based on that model [5]. Electrical and mechanical cones, those are two types of CPT have been developed.

In the year 1953, Begemann made the improvement of the Dutch cone adding the "friction jacket" from behind the cone. The friction cone aimed for the measurement of local skin friction, f_s, in addition to the cone tip resistance, $q_{c.}$ The test procedure of CPT involves the pushing of a usually 60° cone generally 10 cm^2 through the soil strata at the rate of 1-2 cm/s. The ratio of the total force acting on the cone and the projected area of the cone (10 cm^2) is the tip or point resistance (q_c). The tip force or resistance is measured by load cells located just inside the probe. Theoretically, the tip resistance is said to be related to undrained shear strength of a saturated cohesive material, whereas, the sleeve friction is said to be theoretically related to the friction of the horizon being penetrated [6].

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction:

Several empirical correlations of SPT-N value and CPT data with other parameters are established throughout a few decades in the geotechnical field. The majority of these correlations were developed by regression analysis from the data of Europe and North America. A good number of research papers used Cone tip resistance (q_c), Sleeve friction (f_s) and SPT-N value as a valuable parameter to establish the correlation between CPT and SPT. Some of these correlations may require iteration during applications. In some correlations, the authors of papers used the data for graphical relationship and some of them quantified the correlation in the empirical expressions [7]. Most of the empirical correlations considered a constant value (n) of $n = q_c/N$ and some other researchers proposed $n = (q_c+f_s)/N$ for different soil types. [8]

Here we are summarizing most of the previous work in Table 2.2.1.

2.2 Correlations from Past Research

Table 2.2.1: Existing Correlations

Soil Types	Correlation	Author(s)
Silty Fine Sand (SM)	$q_c = 0.12N + 5.0$	Fauzi Jarushi [3]
Fine Sand (SP)	$q_c = 0.291N + 2.43$	
Fine Sand with Silt (SP-SM)	$q_c = 0.15N + 7.2$	
Clayey Fine Sand (SC)	$q_c = 0.06N + 5.7$	
Silty Clayey Fine Sand (SM/SC)	$q_c = 0.22N + 2.6$	
Clay and silty clay	$n = q_c / N = 0.35$	

Sandy clay and silty sand	$n = q_c / N = 0.2$	De Alencar Velloso 1959 [8]
Sandy silt	$n = q_c / N = 0.35$	
Fine sand	$n = q_c / N = 0.6$	
Sand	$n = q_c / N = 1.00$	
Coarse sand	$n = q_c / N = 0.2$	Meigh & Nixon 1961 [8]
Gravelly sand	$n = q_c / N = 0.3\text{-}0.4$	
Sand	$n = q_c / N = 1.00$	Franki Piles 1960 from Akca 2003 [9]
Clayey sand	$n = q_c / N = 0.6$	
Silty sand	$n = q_c / N = 0.5$	
Sandy clay	$n = q_c / N = 0.4$	
Silty clay	$n = q_c / N = 0.3$	
Silt, sandy silt and silt-sand mix.	$n = (q_c+f_s)/N= 0.2$	Schmertmann 1970 [10]
Fine to medium sand, silty sand	$n = (q_c+f_s)/N= 0.3\text{-}0.4$	
Coarse sand, sand with gravel	$n = (q_c+f_s)/N= 0.5\text{-}0.6$	
Sandy gravel and gravel	$n = (q_c+f_s)/N= 0.8\text{-}1.0$	

Sandy silty clay	$n = q_c / N^* = 1.5\text{-}2.5$	Barata et al. 1978 [9]
Clayey silty sand	$n = q_c / N^* = 2.0\text{-}3.5$	
Lateritic sandy clay	$n = q_c / N^* = 3.2$	Ajayi & Balogun 1988 [9]
Residual sandy clay	$n = q_c / N^* = 4.2$	
Sandy clayey silt	$n = q_c / N^* = 2.1$	Chang 1988 [9]
Clayey silt, sandy clayey silt	$n = q_c / N^* = 1.8$	
Silt, sandy silt and silt-sand	$n = (q_c+f_s)/N = 0.2$	Danziger & de Valleso 1995 [10]
Fine to medium sand, silty sand	$n = (q_c+f_s)/N = 0.3\text{-}0.4$	
Coarse sand, sand with gravel	$n = (q_c+f_s)/N = 0.5\text{-}0.6$	
Sandy gravel and gravel	$n = (q_c+f_s)/N = 0.8\text{-}1.0$	
Silt, sandy silt and silt-sand	$n = (q_c+f_s)/N = 0.2$	
Sand	$n = q_c / N^* = 5.7$	
Silty sand, Silty clay	$n = q_c / N^* = 5.0\text{-}6.4$	
Clayey silt	$n = q_c / N^* = 3.1$	

Clay, silt and sand mixtures	$n = q_c / N^* = 1.0\text{-}3.5$	Danziger et al. 1998 [10]
Clayey sand and silty clay	$n = q_c / N^* = 4.6\text{-}5.3$	
Sandy clay	$n = q_c / N^* = 1.8\text{-}3.5$	
Clay	$n = q_c / N^* = 4.5$	
Turkey soils	$n = q_c/N = \text{func}(D50)$	Emrem et al. 2000 [8]
Sand	$n = q_c / N = 0.77$	Akca 2003 [9]
Silty sand	$n = q_c / N = 0.70$	
Sandy silt	$n = q_c / N = 0.58$	
sand, sandy silt, and silty sand soils	$N = 1.59 + 0.993q_c + 0.069$ effective stress $+ 18.185f_s$	Bashar Tarawneh [8]
Clay	$q_c = 0.2152N^{0.8252}$ (all data) $q_c = 0.1994N^{0.8535}$ (filtered Data)	O. Kara, Z. Gündüz [9]
Silt	$q_c = 0.3993N^{0.7436}$ (all data) $q_c = 0.3755N^{0.7342}$ (filtered Data)	
Sand	$q_c = 0.7094N^{0.7213}$ (all data) $q_c = 0.5334N^{0.809}$(filtered Data)	

All	$q_c = 0.2106N^{0.9513}$ (all data) $q_c = 0.1877N^{0.9894}$(filtered Data)	
High plasticity clays (CH)	$q_c / N_{60} = 0.11$	I. Feda Aral and Ekrem Gunes [10]
Moderate plasticity clays (CI)	$q_c / N_{60} = 0.11$	
Clayey sand-silt-uniform SC, SM and SP sand density	$q_c / N_{60} = 0.39$	
Silty Sand	$q_c = 0.427N$	Mehtab Alam 2018 [11]
Sandy Silt	$q_c = 0.337N$	
Silty Clay	$q_c = 0.319N$	
Lean Clay	$q_c = 0.291N$	
Silty clay	$q_c = 233.2\exp(1.122N)+0.4513\exp(0.02096N)$	M. Asci [12]
Clayey silt	$q_c = 1.228\exp(0.03473N)+0.3193\exp(0.05133N)$	
Clay	$q_c = 233.2\exp(-1.122N)+0.4513\exp(0.02096N)$	

Sandy silt	q_c = 7.187exp(-0.4827N)+1.938exp(0.00989N)	
***q_c/N in bar per blow 0.3m**		

2.3 Highlights from Previous Research:

- **M.M. Shahien and A.H. Albatal (2014)** conducted their research on silty sand deposit in Egypt[7]. Highlights of their research is:
  - The Paper is about correlation of standard penetration test and cone penetration test of silty sand at a place in Egypt. Both SPT and CPT are usually done in a large project. SPT is simple and cost effective. On the other hand, CPT has reliability, repeatability and standardization. This research is based on grain sizes (D_{50}), Fines content (FC%), Soil behavior type index (I_c) and other variables.
  - SPT N value depends on some factors such as borehole diameter, level of water, diameter of the sampler used in the test, type of hammer used in the test, means of lifting and releasing the hammer etc. But here they focused on types and lifting-releasing of hammer. 60% of hammer efficiency is suggested while taking N value.
  - CPT results are based on normalized tip resistance, Q, and normalized friction ratio, F while calculating soil behavior type index (I_c). Here Q and F depends upon total and effective overburden stresses, reference pressure and value of n for cohesiveness.
  - The correlation between SPT and CPT depends upon some factors. They are Types of soil and grain properties, soil density, presence of gravel (affects N value), stratification and non-homogeneity (affects CPT).

- **Md. Monir. Hossain, Nasima Sultana, Ripon Chandro Malo (2020)** conducted their research on correlation between SPT, CPT and soil parameters on Khulna soil.[13] Highlights of their research are:
    - This research is done with local soil (clay to coarse sand) to investigate the relationships of soil parameters with most commonly used soil investigating tools SPT and CPT. CPT is used to determine the details and qualities of soils of the project, where SPT is used to examine the preliminary investigation of soils.
    - This paper is based on the internal angle of friction through SPT obtained from laboratory triaxial test and direct shear test. Grain size, borehole drilling, soil sampling are also observed. An automatic type SPT hammer-release was used for the SPT.
    - Three laboratory tests were done and they are Multi-Stage Triaxial (MST) tests, Direct Shear tests and Sieve Analysis. MST test and direct shear tests were done in order to measure the internal angle of friction from a plot of maximum shear stress versus normal stress. The strength and deformation behavior of soils was also obtained by direct shear tests. Lastly, sieve analysis was performed for soil classification and distribution of soil samples according to their particle size.
    - Some relationships were shown through graphical representation. They are, D_{50} shows a poor relationship with local soils, fine content and $qt_1/(N_1)_{60}$ ratio shows proportional relationship, The correlation between cone tip resistance (qt1) and SPT $(N_1)_{60}$ can serve as a better relationship for sandy soil.

- **Fauzi Jarushi, S. AlKaabim, Paul Cosentino (2015)** analyzed the correlation between SPT and CPT between various soils[3]. The highlights of their paper:
    - This Research is to build up the relationship between SPT and CPT of various sandy soil in Florida, USA. Data for this research were collected from a number of projects sponsored by the Florida Department of Transportation (FDOT). This relationship helps engineers in adopting empirical methods to evaluate and analyze soil performance.

- The correlations were established between SPT N (blows/0.3m), CPT tip resistance q_c (MPa) and sleeve resistance f_s (kPa). A positive linear relationship was found between qc, fs and N-value for various sandy soils.
- This study shows that qc/N mostly depends on the grain sizes, fines content, permeability and modification of compressibility of sandy soil. Another important factor that may have an influence on the results is the distance between the SPT and CPT. Various boreholes in close proximity from many sites in this study have shown dissimilarity in strata arrangements and thicknesses.
- As a strength correlation, they proposed a scale where 0 (zero) represents 'no correlation' and it gradually increases and ends at 1 which indicates perfect correlation. There are also some relations: higher the fines content, the higher the fs values; Sandy soils with a high fines content produced higher friction values fs than poorly graded sand.

- **M. Asci, C. Kurtulus, I. Kaplanvural, and M. O. Mataracioglu (2014)** conducted their research on correlation between SPT and CPT data from the subsidence area[12]. The paper highlights are:
  - The SPT and CPT correlations performed in this study are based on the data collected from silty clay, sandy clay, clay and clayey silt soils of Goluck, Turkey.
  - The study area that is Goluck of Turkey is actually a delta having faced earthquakes in the past that caused deformities like liquefaction, collapsing, and lateral spread. A sand band exists along the coastline, and a 20-25 m thick clay layer overlying the sandy-gravely unit was determined in the offshore boreholes. The lateral and vertical gradations of sand, gravel, silt, and sand were observed locally in the boreholes.
  - Begemann Cone Type was used for the CPT, and Pilcon-type hammer and trip release system were used for SPT. The specimens were collected by using a split-barrel (spoon) sampler. The N values measured were normalized to standard rod energy ratio (ERr) given by Skempton[2] using $N_{60}= N_{(ERr/60)}$ Where, N_{60} = SPT

blow count corrected for hammer efficiency, ERr = Rod Energy Ratio and N = uncorrected (raw data) SPT blow count. As ERr = 60% therefore, measured N values were used directly.

  - The n values (q_c /N) were calculated by applying the arithmetic average method. The maximum N values were obtained for sandy silt, and the minimum N values were calculated for clay. A total of 662 data values was used in statistical analysis for the study area soils.
  - SPT values obtained from 23 boreholes and CPT values obtained from 19 boreholes constituted the SPT and CPT data sets. The SPT and CPT correlations were accomplished for silty clay, sandy silt, clay and clayey silt in the study area using statistical analysis.
  - The reading values of CPT were compared with the SPT N values located over the same depth range (along 0.5 m intervals).
  - Correlation functions and coefficients were determined for each soil type. The correlation coefficient values provide a reasonably good correlation for all the soil types. The highest correlation (R^2 = 0.8604) was achieved for clayey silt and the lowest correlation (R^2 = 0.7713) was accomplished for silty clay[12].
  - A table of comparison was made, where it was seen that the correlation coefficient of sandy silt of the study area was greater than other literature values.

- **O. Kara and Z. Gündüz (2010)** conducted a study on correlation between CPT and SPT in Adapazari[9]. The highlights of their study are:
  - Generally, in most of the literature, the correlations between SPT & CPT are found out for homogenous soil. But in this research the study area Adapazarı City, Turkey has a heterogeneous structure in the vertical and horizontal directions.
  - Most of the city is located over deep alluvial sediments. Sands accumulated along bends of the meandering rivers, and the rivers flooded periodically leaving behind predominantly non-plastic silts, silty sands, and clays throughout the city. Clay-rich sediments were deposited in lowland areas where flood waters pounded.

- Four general subsurface site categories of soil types were developed. These were based on comparative ranges of q_c and N values.
- Data were used from 65 boreholes with SPT tests and 47 CPT points in small distance or lesser than 30m. From 65 SPT boreholes and 47 CPT points there are 611 data pairs (N and q_c) available for correlation.
- The cone resistance qc are the average values over a length of 0.3 m where the corresponding N-Values were measured. In this study the same rig and equipment are used on all the SPT tests.
- The N Values used here were corrected to an energy efficiency of 75% (CC=1, CB= 1, CA=0.85, CS=1.2, CE=0.75)[9]
- All data were combined to calculate n-value (q_c/N) for each soil type. Arithmetic average method is used for calculating the n-values. In this study, for clay and silt similar literature n-values have been calculated. Calculated n-value for sand is lower than literature values.
- Total of two statistical analyses were performed with data of clay, silt and sand. The first one included all data and the other one the filtered data. In this case, elimination of data aimed at filtering data situated far from the general trend by statistical approaches related to standard deviation values. After elimination, the same trend was confirmed to be maintained in the N versus qc plot.
- Correlation functions and coefficients were determined for all data groups and filtered data. Power correlation gives the highest correlation coefficient values. Although the correlation coefficients are lower than literature values. The correlation coefficients found from filtered data for all soil types were greater than the data analyses including all data.

- **Bashar Tarawneh (2014)** conducted his study based on sandy and silty sand to sandy silt soil[8]. His research highlights are:

- The paper presented the results of a study that was conducted to assess the use of MLR (Multiple Linear Regression) and SR (Symbolic Regression) to develop models that can accurately predict N-value using CPT data in UAE.
- The geology of the study area had features like dunes, evaporite deposits, gravel plains at mountain bases and the climate dominated by low precipitation, high evaporation and high ambient temperatures by Rahman and Haris (1984).
- The data set consisted of 66 CPT-SPT pairs for sand, sandy silt, and silty sand soils. Distance between each CPT-SPT pair ranged from 3 to 40m for correlating parameters.
- Interpretation of CPT data was performed in terms of Soil behavior type as proposed by Lunne (1997) and Robertson (2009) using SBT charts. It can be noted that all data points have fallen in region five and six. Region five represents silty sand to sandy silt while region six represents clean sand to silty sand.
- CPT readings were taken at every 0.02 m interval but were averaged over 0.5m intervals to be compared with the SPT-N values located over the same depth.
- Standard penetration tests were carried out using a Pilcon-type hammer and trip release system. So based on the rod energy ratio given by Skempton(1986), the SPT-N values were normalized and found to be the same as N_{60} as the 605 ERr ratio.
- The average n-value (=q_c/N) is 0.629. The average friction ratio (R_f%= f_s/q_c*100%) for the collected CPT data is 0.6%. It should be noted that the friction ratio for clean sand is about 0.5% and it increases as soil grains become finer[3].
- A Stepwise Iteration (SI) procedure was used in MLR analysis where the termination of the independent variable elimination process is based on the t-test and F-test outcomes. Elimination of insignificant variables gives more accurate forecasts according to Sonmez and Rowings (1998).
- Model 3 has the highest adjusted R^2 value equal to 0.813, the least standard error of estimate (5.41), and the least mean square error. This model included the variables: tip resistance (q_c), effective vertical stress, and sleeve friction (f_s)[8].
- The R^2 value increases with the addition of terms to the regression model. It can be noted that qc has the highest effect on the adjusted R2 value.

- Symbolic regression (Koza, 1992) is a method for searching the space of mathematical expressions, while minimizing various error metrics. A Genetic Programming (GP) package Eureqa (by Schmidt and H. Lipson 2009) was used to regress functional relationships to predict N-value using q_c, f_s, and effective stress.
- Six models were developed to predict N-value using q_c, f_s, and effective stress. Those models showed some improvement when compared to the developed MLR model. R^2 values for those models ranged from 0.828 to 0.839, a slight improvement is shown when comparing those values to the R^2 value of the MLR model which is 0.813.

- **S. Papamichael and C. Vrettos (2018)** conducted their research on CPT interpretation and correlations to SPT for near-shore marine Mediterranean soils[14]. Their paper highlights are:
  - The main purpose of this paper was 1) to evaluate the applicability of CPT as a site investigation tool and 2) to cross-correlate the relevant values of CPT and SPT. In most projects, only one of these two options is available mainly due to cost control.
  - Data on the soil conditions was derived from fourteen boreholes distributed along the tunnel axis: eight onshore and six offshore. e tunnel axis: eight onshore and six offshore. Exploration depth reached 80 meters below seabed level in the center of the strait[14].
  - SPT testing was carried out at specific depths in the boreholes by recording the blow count number NSPT. Adjacent to each borehole, one CPTu test was performed. Near each onshore borehole an additional CPT was executed to complement the data. The measured NSPT-values correspond to the normalized values at 60% energy N_{60}.
  - CPTu tests on land were conducted using twenty-ton capacity hydraulic penetrometer equipment mounted on a heavy truck ballasted to provide a reaction weight of twenty-three tons.

- The rate of penetration was kept constant at a nominal 2 cm/s except when penetrating very dense or hard layers.
- Due to equipment limitations, the maximum depths investigated by the CPTu were up to 30 m both onshore and offshore.
- Results were recorded in terms of cone end resistance q_c, sleeve friction f_s , and pore water pressure u_2 measured behind the cone.
- Field testing was conducted for all soils including i) grain size distribution with mean grain diameter D_{50}, uniformity coefficient C_u and fines content percentage FC%, and ii) Atterberg limits and organic content for the cohesive soils. Soil classification was made according to the Unified Soil Classification System USCS.
- The collected field data were first transformed to yield the input values for the three different charts suggested by Robertson (1990, 2010), namely the SBT, SBTn and Q_t - B_q charts.

- **Mahmoud Elbanna, Joseph Quinn and Scott Martens (2011)** did their research on SPT and CPT correlation for Oilsands tailing sands[15]. The highlights of their research are:
  - This paper presents a review of SPT-CPT correlations that enable the direct use of CPT data in flow liquefaction assessments. A site-specific $qt_1/(N_1)_{60}$ ratio of 0.45 is presented that can be useful for the geotechnical engineering community of the oilsands in northern Alberta. Density testing is routinely performed at oilsands tailings dams to confirm that the dyke construction meets the design specifications
  - This paper summarizes the correlations between the CPT and SPT for the MRM tailings sand, and provides an indication of the accuracy of the correlations. Correlations with average grain size (D_{50}), and a comparison with published measurements at other oilsands tailings facilities (namely, the Syncrude Mildred

Lake and J-Pit sites) are also discussed. The MRM is an oilsand mine located in northern Alberta, approximately 70 km north of Ft. McMurray.

- Oilsands tailings gradation :
  - The gradation of the tailings deposits from the three sites considered in this study is generally similar with fines contents ranging between approximately 10 % and 20 %.
  - D_{50} values for the three deposits considered during this paper are 0.19 (standard deviation of 0.09), 0.16 and 0.17 for MRM, Mildred Lake and J-pit respectively[15].
- Description of equipment :
  - The SPTs were carried out through 98 mm diameter boreholes that were advanced using a track mounted, mud-rotary drill rig.
  - The Force-Velocity (FV) method (Sy and Campenella, 1991) was used in the ETR(Energy Transfer Ratio) calculations.
  - The CPT soundings were advanced using a 25 ton track mounted rig with an electrical cone penetrometer that had a cross sectional area of 15 cm2 and a cell capacity of 20 tons.
  - Measurements of dynamic pore water pressure (u), tip resistance (q_t) and sleeve friction (f_s) were made at 10 mm depth increments.
- The Lunne, et al (1997) method has been used for comparison with the qt1/(N1)60 ratio calculated during this study.
- Liquefaction Criteria :

When liquefaction susceptibility is assessed using an $(N_1)_{60}$ derived from CPT data, a greater quantity of liquefiable material is identified than when it is assessed using SPT data directly. This underestimate of liquefiable material from the SPT approach is considered to be due to the wide spacing of SPT measurements missing weak layers that are captured by the close spacing of CPT measurements.

- **T.M. Elkateb and H.E. Ali (2010)** conducted a study on CPT-SPT correlations for calcareous sand in the Persian Gulf area[2]. The highlights of their research are:
  - The main objective of this study is to examine the applicability of various CPT-SPT correlations available in the geotechnical literature to relatively young calcareous sand in the Persian Gulf area.
  - Existing CPT-SPT correlations based on grain size characteristics, such as D_{50} and fine content, are poorly applicable to the UAE sands. This was attributed to many deviations, such as the increased carbonate content and absence of SPT energy measurement, from the existing correlations.
  - Existing CPT-SPT correlations based on soil classification techniques, such as the Soil Behavior Type Index (I_c), showed general agreement with the trend of field data. In addition, the scatter in field data was smaller compared to D_{50} and fine content based correlations.
  - The ratio $(q_c/P_a)/N_{60}$, as determined from field data, for the UAE calcareous fine to medium grained sand was found to be significantly, 40 to 45%, higher than the values predicted using the existing correlations for siliceous sand[2].
  - Risk-based CPT-SPT correlations were developed for the UAE calcareous sand based on the target probability that the actual field value will be higher than the predicted one.
  - There is a need to collect additional high quality CPT and SPT data from the UAE area to verify and refine the finding of this study.

CHAPTER 3: METHODOLOGY

3.1 Data Collection:

To fulfill 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 of the 172 boreholes were made by rotary drilling method. Auto trip hammer has been used in the testing procedure where the falling height has been taken as 760mm, where the mass is released automatically from that height to drive the split spoon sampler into the soil. The N value is defined as the blow-count for 12" (300mm) penetration recorded after the seating drive of 150 mm. In the case of premature refusal conditions, the number of blows for a recorded penetration (including the seating drive) is noted. During SPT at 1 m intervals (ASTM D 1586), disturbed samples of very stiff clay to hard clay and sand layer were collected.

On the other hand, CPT test has been performed by the penetration of a cone into the soil by means of mechanical or electrical energy. Test is performed according to the ASTM D5778-12. An instrumented cone of 10 cm^2 tip is pushed, with the tip facing down, into the ground 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 computer. The graphs of q_c, f_s, u and calculated R_f, estimated N_{60} and B_q have been provided from the data. Alongside, data for each of the above parameters have been transported to Excel with 0.01 m data each.

The following Figure 3.1.1 & Figure 3.1.2 are the setup of CPT instruments in the site of the study area.

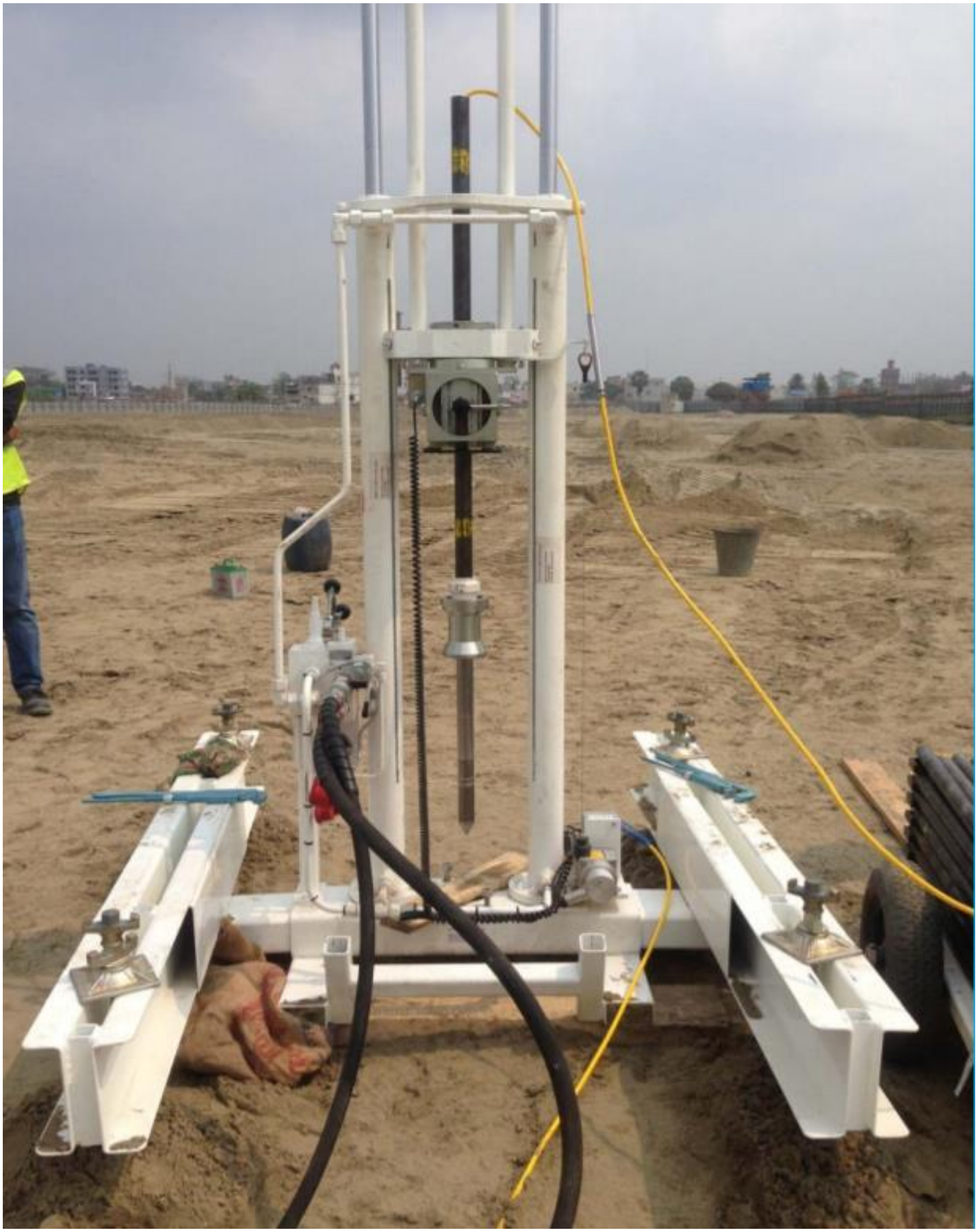


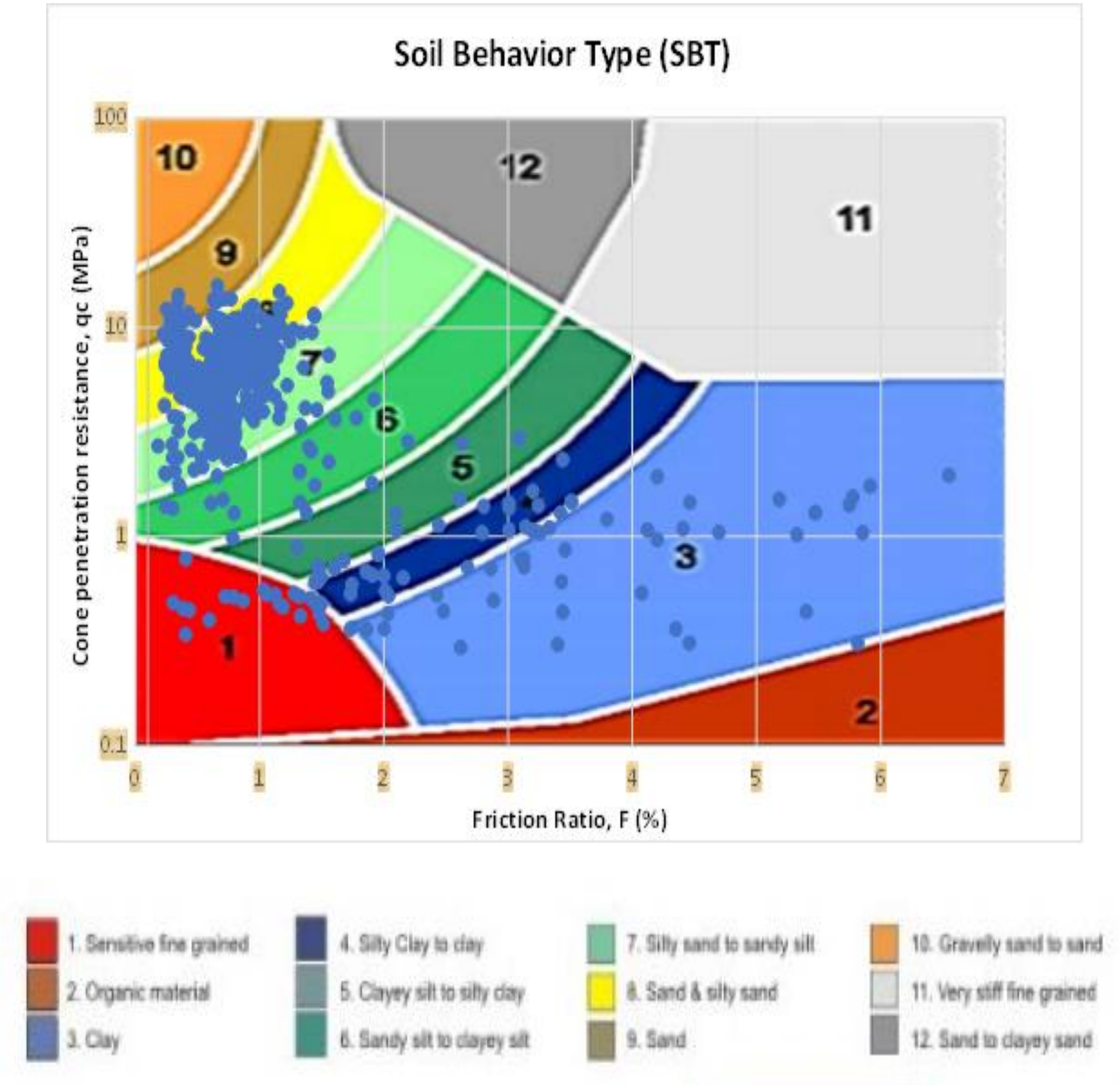
Figure 3.1.1: Field Setup of Geomil Equipment Fox 100 CPTU
Image Source: Prosoil Foundation Consultant

Figure 3.1.2: Field Setup of Geomil Equipment Fox 100 CPTU
Image Source: Prosoil Foundation Consultant

3.2 Soil Behavior Type (SBT):

The identification of soil stratigraphy and the soil type are 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 the soil type. But the most popular one was the one by Robertson et al. in 1986 [4, 16]. It is based on cone penetration resistance, q_c with friction ratio, R_f. Here, $R_f = (f_s / q_c)$ 100% and commonly termed as Soil Behavior Type (SBT) Chart.

From the CPT Data of q_c and f_s calculated R_f are taken for use in the SBT chart and performed in Microsoft Excel.



Robertson el et 1986

Figure 3.2.1: Soil Behavior Type Chart for Dhaka Soil

The chart shows the majority of the soil type falls in the zones of 7, 8 and 9 where 7 is silty sand to sandy silt, 8 is sand and silty sand and 9 is sand. This is because Dhaka soil is sandy. Other minor amounts are seen to be in zones 3 and 4 where 3 is clay and 4 is silty clay to clay.

Mainly the focus is on the development of correlation for sandy soil of Dhaka as far as major soil types from SPT-N and CPT data interpretation leads to this finding. Other than this, considering the results from the CPT test soil classification Bq calculations, the SBT chart 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

Sandy soil indicates here might be the mixture of both coarse, clean or fine sand. This is because of the heterogeneous nature of soil conditions of Dhaka.

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

3.3 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 test at interval of every 1m. So, an average of 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 N60 was done. N60 defines the corrected value for field procedures and 60% energy efficiency. The following equation is used by most of the geotechnical engineers:

$$\mathbf{N60 = N_{field} \times C_e}$$

Here,

C_e = Energy correction factor that depends on the way the hammer is lifted and released

Table 3.3.1: Typical values of C_e[21]

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.

Now,

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

Therefore, this way N_{60} values have been obtained for use in the analysis.

Combining the data of SPT N values and CPT parameters based on 4 major soil types was identified through field identification and calculation of B_q respectively, total 566 pairs of SPT-N, CPT q_c and f_s values have been taken.

A total of 566 pairs of SPT-N, CPT q_c and f_s values have been taken combining the data of SPT N values and CPT parameters based on Dhaka sand soil and other 3 soil types that have been selected on the basis of field identification and calculation of Bq respectively.

The maximum and minimum values of SPPT-N, q_c and f_s for each of the soil categories are tabulated below:

Table 3.3.2: 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

Table 3.3.3: 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

The above table is the result of the calculation of $(q_c+f_s)/N_{60}$ for each of the soil categories. Then arithmetic mean method is followed for the calculation of desired n ratio. This n ratio is representative of the correlation among the two concerned parameters of CPT and N-value of SPT.

Table 3.3.4: Comparison of n ratio of Dhaka Soil with existing literature

Soil Type	$n = (q_c+f_s)/N_{60}$		
	Schmertmann 1970	Danziger & de Valleso 1995	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	-	-	0.12
Silty-clay to silt-clay	-	-	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 available two literatures. A minor variation can be seen in the comparison which is almost negligible. Besides, there was no available n ratio for clay or silty-clay to silt-clay soil. Therefore, the study is successful in introducing n ratios for the mentioned two categories along with the introduction of n ratios for Dhaka soil.

3.4 Multi-linear Equation for Prediction of N value

In case of statistical analysis, regression analysis is a statistical method that determines the relationship between one dependent variable with one or more independent variables. It measures the strength of effects of independent variables on the dependent variables. Here, the independent variables are usually termed as regressors. The study deals basically with Multiple Linear Regression (MLR) models.

N_{60} as the dependent variable

&

Independent variables = q_c and f_s

$$\mathbf{N_{60} = \beta_0+\beta_1 q_c+\beta_2 f_s}$$

For the four categories of soil type, four MLR models have been developed. Therefore, in this case, goodness of fit is not much concerned as the value range of the variables in each of the models would not be much varying. In this study, the development of an equation for predicting the N value is the approach. N-value prediction equations would reflect the correlation between the SPT, CPT parameters for the different categories of soil.

For the purpose of the MLR analysis, MATLAB has been used. Alongside, to check the validity of the results from MATLAB, multiple linear regression analysis in Microsoft EXCEL has been used. This is because MATLAB sometimes might show some minor errors in functioning.

CHAPTER 4: DATA ANALYSIS: RESULT

4.1 General

The results that were obtained throughout the whole investigation is summarized in this chapter. The study was based on the relations of q_c and f_s with N_{60}, though q_c is deemed to be more consistent than the value of fs. A total of 17 areas were tested for qc and fs and 4 different types of soils were found which includes sandy, sandy silt-silty sand, clayey and silty-clay. Multiple linear regressions have been applied in order to find the relationship between the three variables with the help of MATLAB.

4.2 MLR Models of Different Soil Types

The four soil types found in the seventeen test locations in the current research are presented in the following section. Other soil types found have been marked as insignificant due to the layers being thin because thin layer effects on the measurement of q_c [17]. Much emphasis has been placed on the sandy categorized soil as 474 pairs of obtained data from 566 pairs have been found to be sand type. The Soil Behavior Type Chart also should be the same thing that major soil is sandy.

The four models with the scatter plots, N-value prediction equations and R squared values are explained below respectively.

These categories based on the classification of in-situ data are:

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

Sand:

This type of soil is dry, nutrient-deficient, 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 compaction and saturation both [18]. A total of 474 data were used in order to form a correlation between the three variables q_c, f_s and N_{60} which has been shown in Fig. 4.2.1

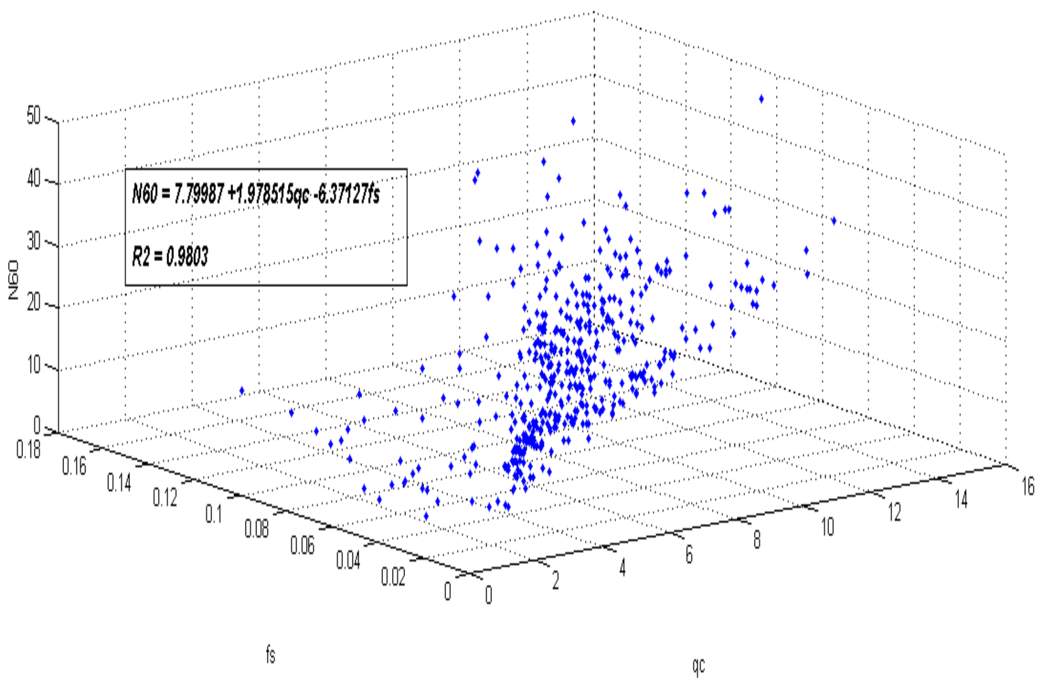


Fig 4.2.1 Correlation between q_c, f_s and N_{60} of sand

Here, in case of sand

N_{60} = 7.79987 +1.978515*q_c -6.37127*f_s

R squared = 0.9803

Silt-Sand Mixture Soil:

This type of soil has a coarse grained skeleton with reduced undrained shear strength due to the small amount of fine [19]. This has been made a category by the SBT and SPT data analysis. This is actually a mixture of sand-silt, not basically silty-sand. A total of 23 data were used in order to form the following correlation.

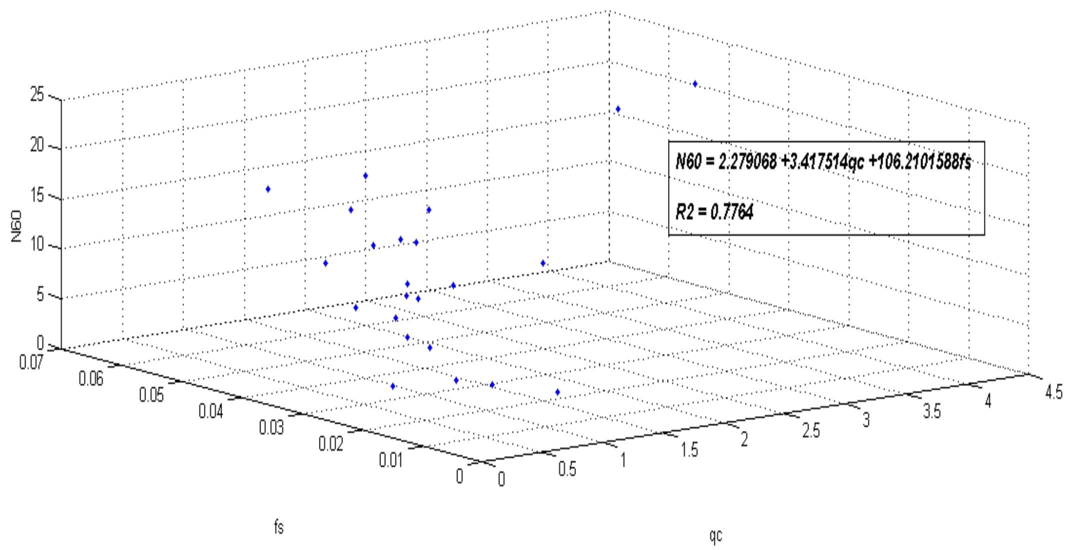


Fig 4.2.2 Correlation between q_c, f_s and N_{60} of silt-sand mixed soil

Here, in case of silt-sand mixed soil

N_{60} = 2.279068+3.417514*q_c+106.2101588*f_s

R squared= 0.7764

Clay Soil:

Clayey soils are heavy, contain high nutrients and can hold water. They can be both highly compressible and of low compressibility. To find the correlation of the three variables of clayey soil a total number of 58 data were used which is shown in Fig. 4.2.3

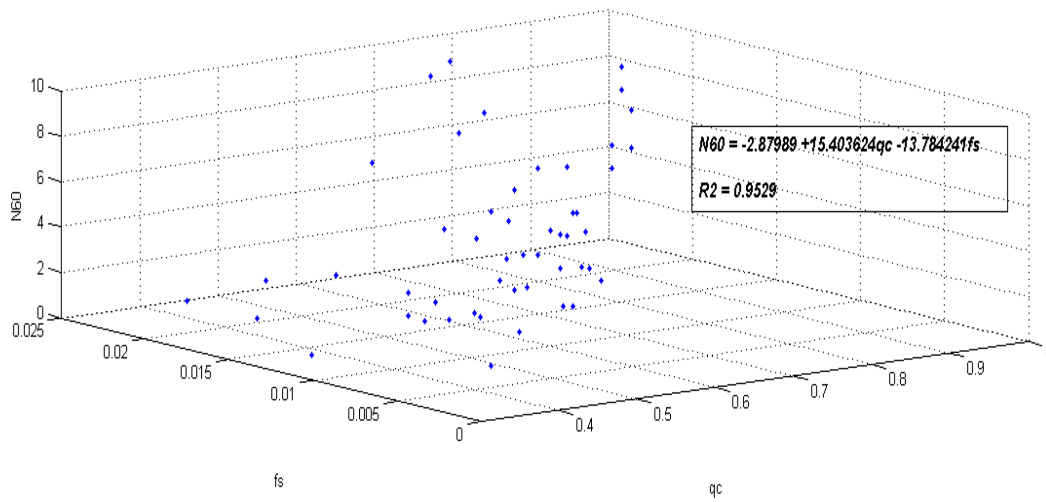


Fig 4.2.3 Correlation between q_c, f_s and N_{60} of clay soil

Here, in case of clay soil

N_{60} = -2.87989+15.403624*q_c-13.784241*f_s

R squared = 0.9529

Silt-Clay Mixture Soil:

Silty clay is generally brownish gray, with soft and creamy texture, flow shape, rich in organic matter, and with clay content more than 50% [20]. A total of 9 data were used in order to form the correlation shown in Fig.

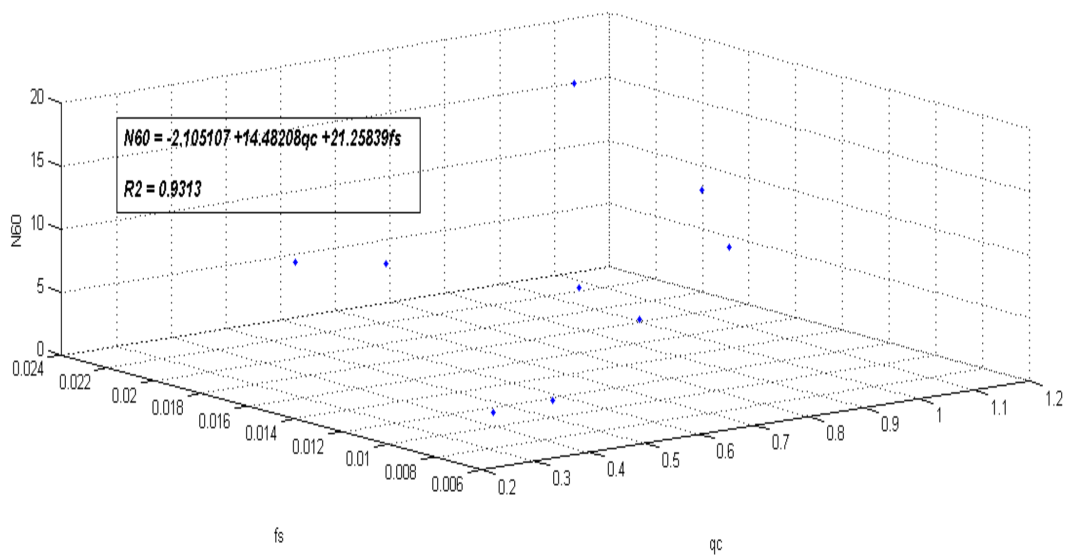


Fig 4.2.4 Correlation between q_c, f_s and N_{60} of silt-clay mixed soil

Here, for this case of silt-clay mixed soil,

N_{60} = -2.105107+14.48208*q_c+21.25839*f_s

R squared = 0.9313

CHAPTER 5: DATA ANALYSIS: DISCUSSION

From the analysis of the data using MLR models it has been found that the predicted N_{60} equations for each type of soil can be determined through the following equations in Table 5.0

Table 5.0 SUMMARY OF RELATIONSHIP BETWEEN q_c, f_s AND N_{60}

Soil Description	Correlation Equation	Correlation Coefficient R^2
Sandy Soil	N_{60} = 7.79987 +1.978515*q_c -6.37127*f_s	0.9803
Silt- Sand mixed Soil	N_{60} = 2.279068+3.417514*q_c+106.2101588*f_s	0.7764
Clay Soil	N_{60} = -2.87989+15.403624*q_c-13.784241*f_s	0.9529
Silt-Clay mixed Soil	N_{60} = -2.105107+14.48208*q_c+21.25839*f_s	0.9313

5.1 Explanation on R^2

R-squared is a statistical measure of how close the data are to the fitted regression line or how well the data is fitting the model. It is known as the correlation coefficient or in multiple linear regressions, it is called the coefficient of multiple determinations and it can range from 0 to 1. Or when expressed in percentage it can range from 0% to a 100% where a 100% indicates that the model explains all the variability of the response data around its mean. R-squared is supposed to reflect the percentage of the dependent variable variation with accuracy that the linear model explains.

From Table 1, the value of R^2 for sandy soil is found to be 0.9803. R^2 measures the proportion of variation in the N_{60} which can be attributed to q_c and f_s. A R^2 of 0.9803 means that (0.9803*100) or 98.03% of the observed variance can be explained through the model outputs. And it's the same for all the other soils that have a R^2 value of 77.64%, 95.29% and 93.13% accordingly. Here, silty sand has the lowest value for R squared. It merely indicates that the soil has mixed properties (contains silt, clay etc.) [3].

5.2 Data Validation

After finding out the equations for the correlations a data validation check was done for all the four different categories of soil with sample data. It is found out for all the categories that all the predicted N-values are similar. Expect, very few with only difference of one blow which is not much of a difference.

The following tables show the comparison between the actual and predicted values for the four types of soil.

Sandy Soil:

Table 5.2.1 Predicted N value comparison for sandy soil

q_c	f_s	N_{60} (Actual)	N_{60}(Predicted)
13.67602	0.085772	33	34
9.800446	0.066552	27	27
14.87708	0.17128	35	36
7.243007	0.018552	22	22
6.004918	0.053968	20	19
11.41123	0.039272	30	30
3.334216	0.015792	15	14

Except for two values, all the other N values have been predicted correctly with the developed equation.

Silt- Sand Mixed Soil:

Table 5.2.2 Predicted N value comparison for silt-sand mixed soil

q_c	f_s	N_{60} (Actual)	N_{60}(Predicted)
1.07751	0.0324	9	9
1.116822	0.035068	10	10
3.057432	0.023886	14	15
0.780786	0.003176	5	5

Therefore, it is seen all the predicted N values are similar to the actual ones.

Clay Soil:

Table 5.2.3 Predicted N value comparison for clay soil

q_c	f_s	N_{60} (Actual)	N_{60}(Predicted)
0.822789	0.016176	10	10
0.76831	0.01288	9	9
0.5234519	0.00406	5	6
0.460352	0.005476	3	5
0.52895	0.005938	6	6

Here, there are minor variations but considerable to some extent.

Silt-Clay Mixture:

Table 5.2.4 Predicted N value comparison for silt-clay mixed soil

q_c	f_s	N_{60} (Actual)	N_{60}(Predicted)
0.644958	0.009662	7	7
0.888966	0.011572	10	11
0.65462	0.012474	8	8
0.536976	0.02188	6	6
0.295736	0.007746	3	2

So, except for only one N value, rest values have been predicted correctly with the help of the developed equation.

5.3 Residual Plots:

The residual plots have been used to check the assumptions of the MLR model for each of the four categories of soil taken.

Sandy Soil:

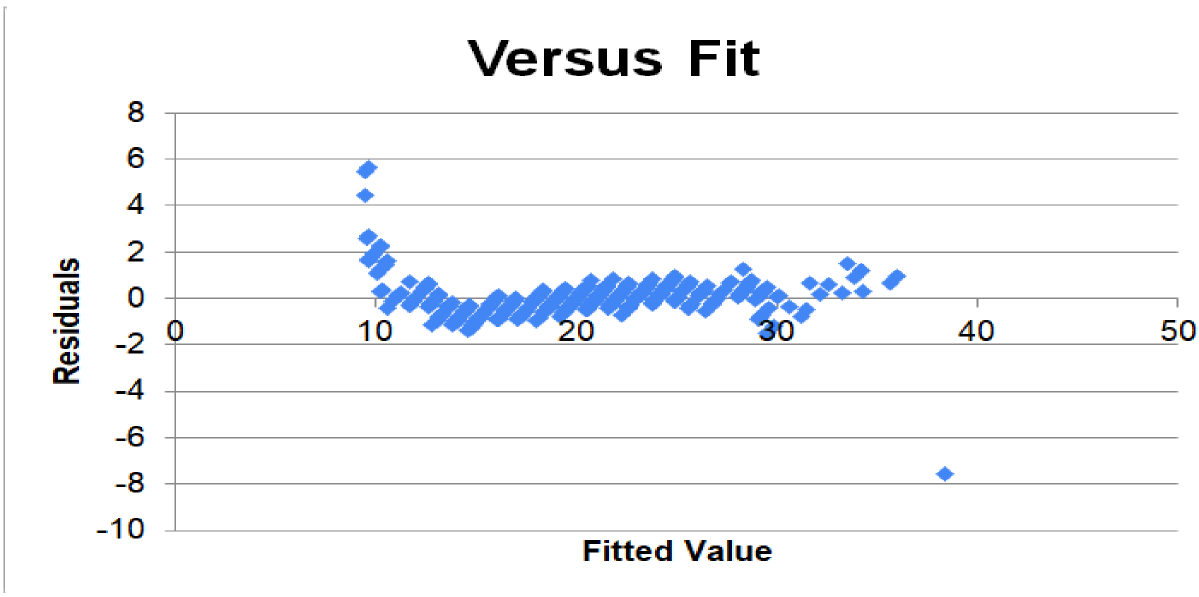


Figure 5.3.1: Residual plot for sandy soil

The residuals scattered around zero indicate that the predictions of the N_{60} values are correct on an average. Whereas the few dotted points that can be seen scattered further away from the average are highs and lows in terms of difference from the actual values.

Silt-Sand Mixed Soil:

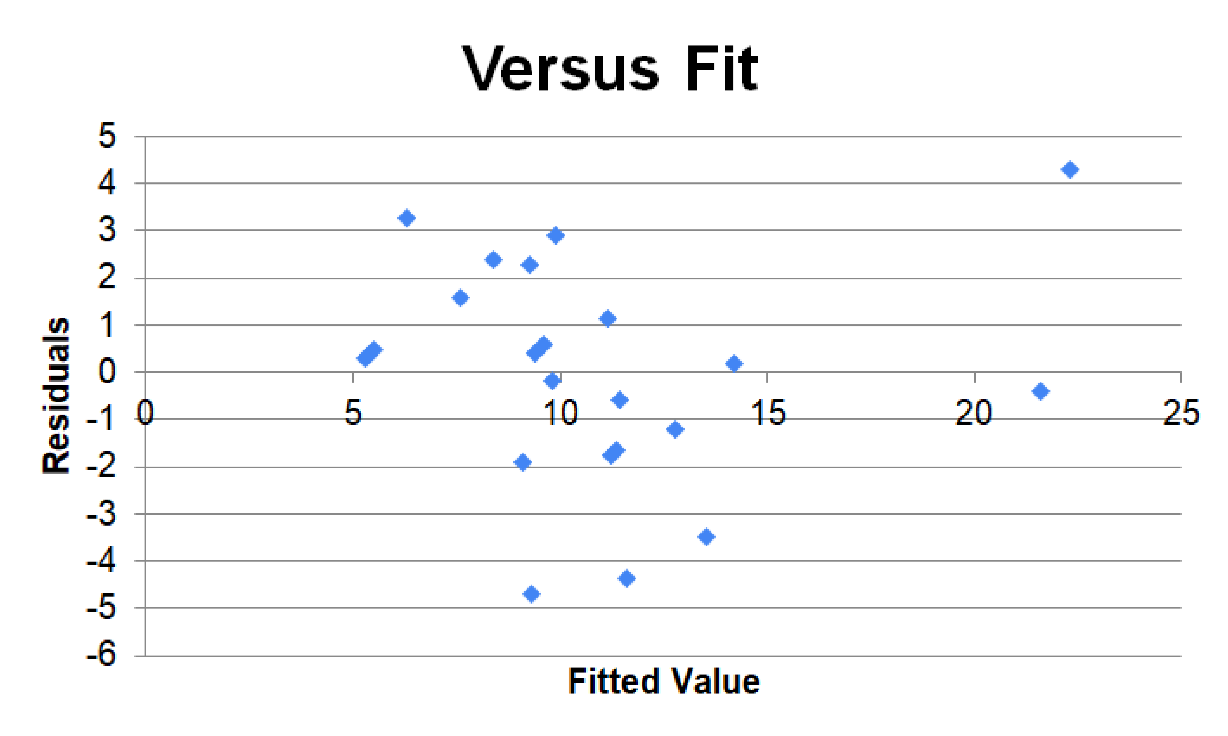


Figure 5.3.2: Residual plots for silt -sand mixed soil

The residuals here are more scattered than the previous soil. This indicates that there are no patterns in the data meaning the value of one point can't be predicted from other. The residuals are not exactly scattered all around zero. This indicates that there are higher numbers of variances between the actual and predicted values. This can be due to the lower number of data.

Clay Soil:

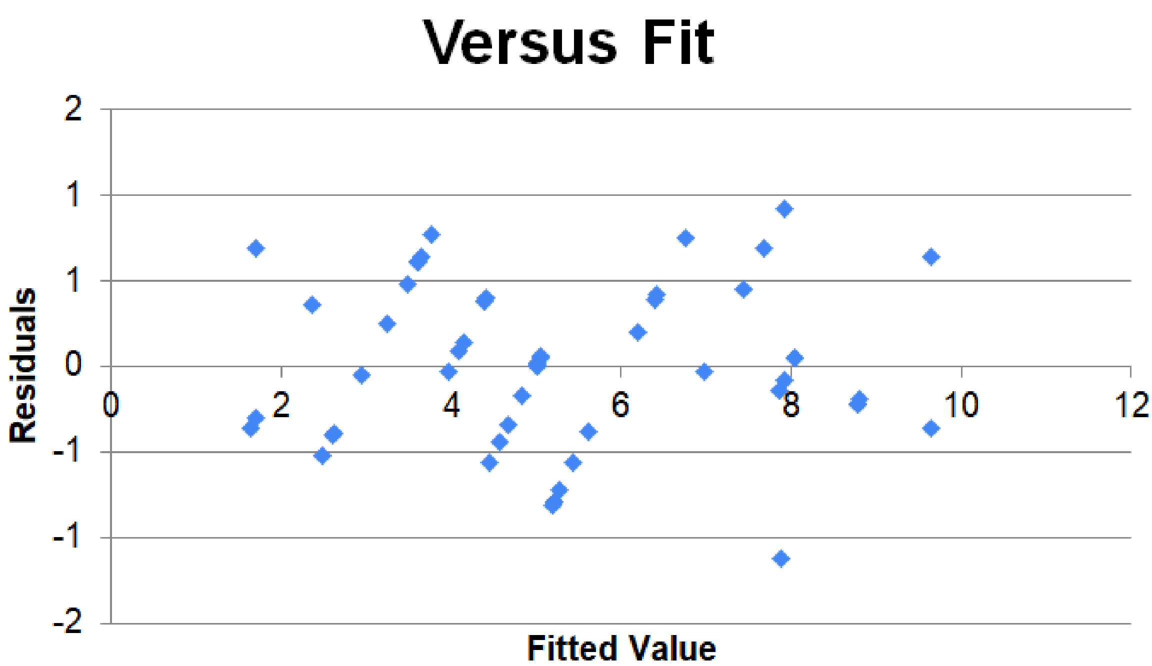


Figure 5.3.3: Residual plot for clay soil

The residuals for this soil shows some scattered further away from the zero of the x axis while most of the data can be seen scattered around the entire length of the fitted values.

Silt-Clay Mixed Soil:

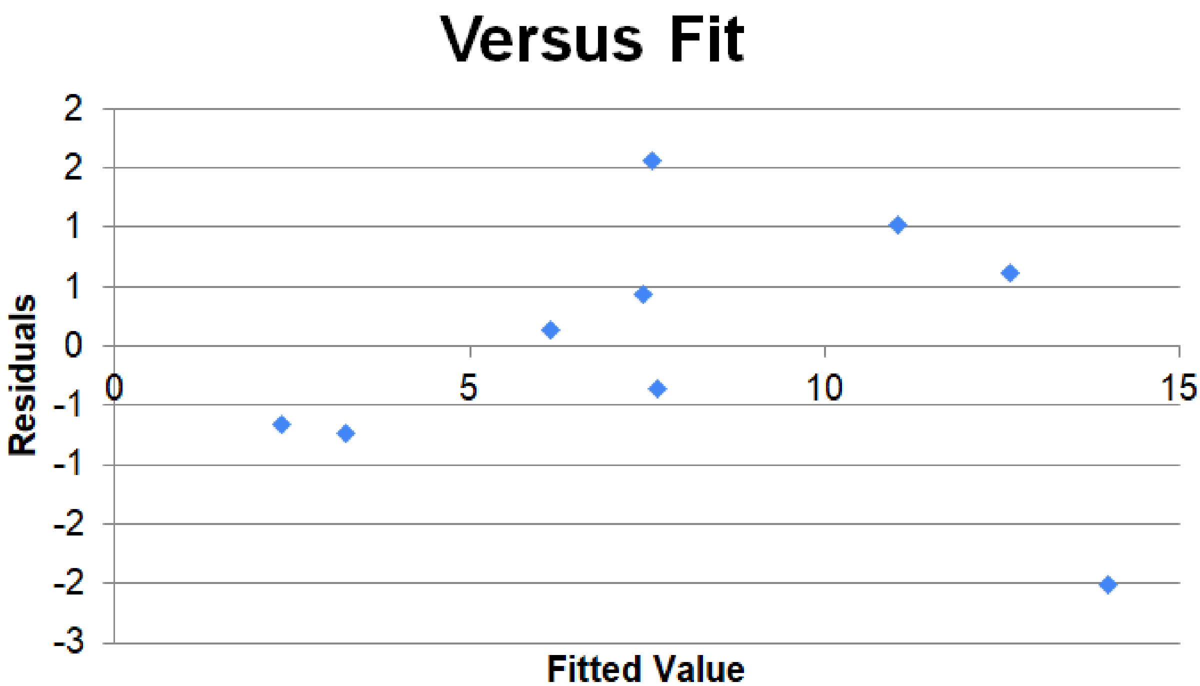


Figure 5.3.4: Residual plot for silt-clay mixed soil

The scatters in the above diagram indicate that there are no unwanted patterns. The ones that are scattered closer to zero indicate that the model predictions are correct on an average whereas the ones further away indicate a high or low.

CHAPTER 6: CONCLUSION

6.1 General

This Chapter includes the summary and overview of the study. Here, we discussed our established equations and further studies. We used almost 564 data for four different types of soil to conduct this research. We had some limitations in this research and we tried to discuss recommendations in this chapter.

6.2 Findings

This study examines the results of a study where correlation of SPT N-value, cone tip resistance and sleeve friction from Dhaka soil has been established. This study is done for mostly sandy soil, still it shows some knowledge about silty sand, clay and silty clay.

- The ratio, n= $(q_c+f_s)/N$ of sandy soil, silty sand, clay and silt clay are 0.3, 0.13, 0.12 and 0.1 respectively.
- The correlation equation of sandy soil is $N_{60}= 7.799 + 1.979*q_c - 6.371*f_s$; where $R^2=0.9803$
- The correlation equation of silt-sand mixed soil is $N_{60}= 2.279 + 3.417514*q_c + 106.210*f_s$; where $R^2=0.7764$
- The correlation equation of clayey soil is $N_{60}= - 2.879 + 15.404*q_c - 13.784*f_s$; where $R^2=0.9529$
- The correlation equation of silt-clay mixed soil is $N_{60}= - 2.105 + 14.482*q_c + 21.258*f_s$; where $R^2=0.9313$

6.3 Recommendations

This research has been done under in-situ soil data. If we use laboratory data for this analysis, there will be more diversity in results. We will be able to get empirical correlation equations based on Unified Soil Classification System (UCSC) classified soils.

But if we consider in-situ condition only, our result is totally fine and acceptable for research studies and further uses.

6.4 Further Study

In-situ data is of more importance in case of any subsurface investigations. As, only field data have been emphasized on this study, so the study successfully could deal with the in-situ soil behavior for the required correlations.

The major part of Dhaka soil being coarse grained needs addition of ample amount of fine grained soil in situ data. In this case, laboratory data can be used for consideration of grain size along with in situ data so that we can use the USCS classification. Nevertheless, the study is successful considering the in situ data.

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