Journal of Civil Engineering (IEB), 43 (2) (2015) 115-131

Journal of Civil Engineering IEB

Relationship between standard penetration resistance and strength-compressibility parameters of clay

Md. Jahangir Alam[1], Nandita Rani Shaha[2] and Md. Kamruzzman shohug[1]

[1]*Department of Civil Engineering*
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh
[2]*Executive Engineer*
Public Works Department, Government of Bangladesh

Received 18 May 2015

Abstract

Sometimes, Standard Penetration Test (SPT) is performed as only means of subsoil investigation in Bangladesh. Detail investigation accompanied with laboratory tests are performed for important projects only. Practicing engineers usually rely on SPT field test data and correlations of SPT-N value with various soil parameters for designing 6-10 storied residential building foundation. Sometimes, clients are not convinced to spend more money for detail subsoil investigation. They are only willing to pay for SPT field test. Therefore, it is necessary to study the correlations between SPT-N value and strength and compressibility parameters of clay so that SPT-N value and index properties of soil can be used for designing foundation of less important projects. This paper reports the results of an attempt to find correlations among SPT-N-value, strength, index properties and compressibility parameters.

SPT and undisturbed sampling was done in four sites covering stiff clay and soft clay. In one site, two borings were done; one for SPT and another for undisturbed sampling. Standard Shelby Tubes were used to collect undisturbed samples. Index properties, strength and compressibility parameters of undisturbed soil samples were determined in laboratory.

A linear relation between unconfined compressive strength and SPT-N value was found for all soils, soft or stiff, low or high plasticity. Linear relation between compression index and SPT-N value was found different for different soils. Linear relationship between some index properties (natural moisture content, initial void ratio and dry density) and SPT-N value was found different for different sites. No generalized or normalized relationship was found for these index properties and compressibility parameters.

© 2015 Institution of Engineers, Bangladesh. All rights reserved.

Keywords: Standard penetration test, unconfined compressive strength, compression index.

1. Introduction

Combination of proper sampling, reliable field test data and necessary laboratory test data is needed for geotechnical subsurface investigation. However, due to limited budgets, tight schedules, or lack of concern, most of the subsurface investigation is conducted without necessary laboratory tests and design is done based on the field test data only. Hence establishing reliable correlation between field test data and necessary soil parameters of laboratory test is of enormous importance. It will help to interpret, countercheck, curtail volume of lengthy investigation program or even eliminate undisturbed sampling during sub-soil investigation works. From the various methods of ground investigation currently practiced worldwide, the Standard Penetration Test (SPT) (ASTM D 1586-99, 2006) remains as the most popular widely used in situ testing technique in Bangladesh. That is why it is important to have correlation between SPT-N value and shear strength, compressibility characteristics of soil. However, most of the SPT test in Bangladesh has three major limitations. The first one is uncontrolled height of fall of hammer. Data reported by Kovacs 1994 suggest the energy from rope and cathead-operated safety hammers is 60% of the theoretical free-fall energy, while that of automatic hammers is 90-95% of free-fall. Drumright et al. 1996 stated that SPT-N values using an automatic sampling hammer were approximately 75% of those recorded using the older-style safety hammer. Automatic hammer is used in this study because energy transfer into the drill string is more efficient with the automatic hammer. The second limitation is Non-Standard SPT Spoon. The drawback of locally practiced shoe of SPT Spoon is that the cutting edge is too sharp and it enters into soil more than standard SPT spoon and we get the lower value of SPT. So, SPT-N value obtained is lower than actual value. In Figure 1, angle of driving shoe of standard SPT spoon is 16º to 24º and the cutting edge is not sharp which gives the actual value of SPT. Figure 2 is representing the standard shoe of SPT spoon and locally practiced shoe of SPT spoon. In this research the standard Shoe of SPT spoon is used. The third limitation of local practice of Subsoil Investigation is the use of non-standard shelby tube for undisturbed sampling. Most of the Shelby tube samplers used in Bangladesh have high area ratio, very rough inner and outer surface, irregular cross sections and no specification for cutting edge. Sampler is pushed into soil by impact loading not by static thrust. It has long been recognized that if side friction becomes too high, the sample will jam in the tube.

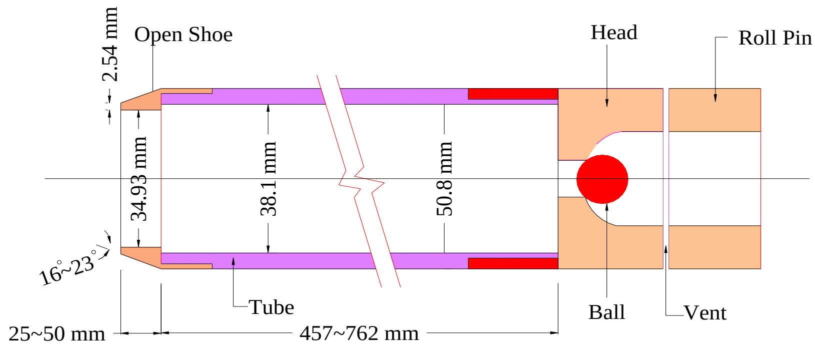

Fig. 1. Standard Dimension of SPT Split-Barrel Sampler (ASTM D 1586-08a).

Apart from the inconvenience of low percentages of recovery, this is associated with very high levels of disturbance (Clayton and Siddique 1999). This type of undisturbed sample may lead to very conservative design of foundations causing more foundation cost. Standard Shelby tubes was fabricated for this study as per recommendations of ISSMFE 1965 having inside diameter 72 mm, wall thickness 1.9 mm, area ratio 10%, inside clearance ratio 0.0%, leading edge taper angle 60^0 up to thickness of 0.3 mm, cutting shoe taper angle 12^0, B/t ratio 38 and smooth inner/outer surface. Figure 3 represents the Standard Shelby tube dimensions.

Therefore, present study was conducted by controlling height of fall, using standard SPT spoon and Standard Shelby tube. In this study, an attempt has been made to establish a reliable correlation between standard penetration resistances (SPT-N value), shear strength and compressibility characteristics of soil.

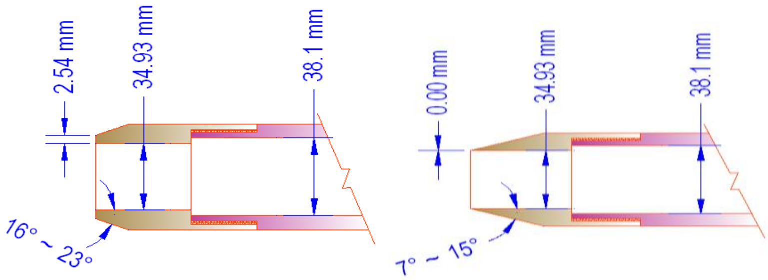

Fig. 2. Comparison of dimension between Standard shoe and Conventional Shoe of SPT spoon.

2. Previous correlations

In engineering applications, the information obtained concerning soil investigation is limited due to the difficulties encountered in sampling, testing, and the time and costs involved. Therefore it is useful to use the correlations by using a small number of soil parameters that can be easily obtained. Numerous numbers of studies have been done so far in establishing this correlation.

2.1 Previous correlation between SPT-N value and unconfined compressive strength

Unconfined compressive strength (q_u) of soil is determined by the means of unconfined compression test. It is useful in determining shear strength and sensitivity of soil. Several works have been done on establishing correlations among SPT-N and Unconfined Compressive Strength (q_u). These correlations are developed to get the Unconfined Compressive Strength directly from the field test. We can generalize the equation by this equation $q_u = kN$. Where, k is the proportionality factor and N is the SPT-N value. Different researchers have proposed different values of k. Several studies have also been done on soils of various locations of Bangladesh by Serajuddin 1996, Bashar 2000, Ferdous 2001, Munshi 2003, Akhter 2010 and many others.

Table 1
Correlations between Consistency, N-value and Unconfined Compressive Strength of Cohesive Soils (Terzaghi and Peck 1948 & 1967)

Consistency	N-value	k	Unconfined Compressive Strength, q_u (kPa)*
Very soft	0-2	12.5	<25
Soft	2-4	12.5	25-50
Medium stiff	4-8	12.5	50-100
Stiff	8-15	13.3	100-200
Very stiff	15-30	13.3	200-400
Hard	>30	13.3	>400

**Terzaghi and Peck (1948 and 1967) used the unit in ton/sq. ft which has been converted in this paper to kPa, assuming 1tsf=100kPa.*

Correlation suggested by Terzaghi and Peck (1948 and 1967) are presented in Table 1 gives values of k between 12.5 to 13.3, when q_u is expressed in kPa. The correlations between N and q_u as obtained by Sowers (1953 and 1962) for cohesive soils are presented in Table 2 and the average values of k range from 6.7 to 24 for different soil types. Sanglerat 1972 proposed the following relationships between N and q_u for different soil types with the values of k ranging from 13.3 to 25.0.

Table 2
Correlations between N-value and Unconfined Compressive Strength for different soil types (Sowers 1953 & 1962)

Soil types	Unconfined Compressive Strength in kPa*		
	Minimum	Average	Maximum
Highly plastic clay	14.4N	24N	33.6N
Medium to low plastic clay	9.6N	14.4N	19.2N
Plastic silts, clays with failure planes	4.8N	6.7N	9.6N

** Sowers (1953 & 1962) expressed the strength in 1000 psf which has been converted to kPa in this paper.*

For clay, q_u = 25N kPa,
For silty clay, q_u = 20N kPa,
For silty sandy clay, q_u = 13.3N kPa.

McEarthy 1977 also established following correlations for different types of soil.

q_u = 19.2N kPa for silty clay
q_u = 24N kPa for clay.

Murthy 1993 investigated the relationship between N and q_u for the over consolidated silty clay encountered at Farakka in West Bengal, India. The moisture content of the soil was close to Plastic limit, which varied from 30 to 40 percent. Liquid limit was from 50 to 100 percent with the over consolidation ratio of 5. It was mentioned that there was a considerable scatter of test results and the relation between q_u and N shows q_u = 10 to 20 N (kPa).

Table 3
Correlations between N-value and Unconfined Compressive Strength for different soil types (Sivrikaya and Toğrol 2002)

Soil Type	q_u (kPa)
Highly plastic clay (CH)	9.70Nfield, r=0.83
n=113	13.63N60, r =0.80
Low plastic clay (CL)	6.70Nfield, r =0.76
n=72	9.85N60, r =0.73
Fine-grained soil n=226	8.64Nfield, r =0.80 12.36N60, r =0.78

A study (Serajuddin and Chowdhury 1996) was done on inorganic clay or silty clay layers. They suggested a general correlation as k=16.8 for overall soil. They also divided the soil into three categories on the basis of different range of Plasticity or, Liquid Limit (LL). The correlation factors are as follows:

k = 14.8 for LL $\leq$ 35%;
k = 16.9 for 35 $\leq$ LL $\leq$ 50%;
k = 17.8 for LL $\geq$ 51%.

Sivrikaya and Toğrol (2002) proposed the correlation equations in accordance with soil types and corrections described in table 3. They have performed linear regression analysis with a large number of data (n).

2.2 Previous correlations between SPT-N value and compression index

The compression index (C_c) of compressible clays and silts has some empirical correlations with liquid limit (w_L), initial void ratio (e_0), natural moisture content (w_n) and Plasticity index (I_P). The relationship given by different researchers are listed in the Table 4.

Table 4
Equations used to calculate Cc for inorganic cohesive soil samples

Compression Index, C_c	Comments	Source/Reference
$C_c = 0.009\ (w_L - 10)$	Clay	Terzaghi and Peck (1967)
$C_c = 1.15(e_0 - 0.35)$	All clays	Nishida (1956)
$C_c = 0.009w_n + 0.005w_L$	All clays	Koppula (1986)
$C_c = 0.046 + 0.0104\ I_P$	Best for $I_P < 50\%$	Nakase et al. (1998)
$C_c = 0.37(e_0+0.003w_L+0.0004w_n-0.34)$	678 data points	Azzouz et al. (1976)
$C_c = -0.156+ 0.411e_0 + 0.00058w_L$	62 data points	Al-Khajafi and Andersland (1992)

Serajuddin et al. 1967 correlated C_c with w_L and e_0 of a large number of undisturbed plastic silt and clay soil samples of different areas of Bangladesh and obtained the following empirical relationships:

$$Cc= 0.0078(w_L - 14\%)$$
$$Cc= 0.44(e_0 - 0.30)$$

Another correlation study (Serajuddin and Ahmed 1982) with additional test data from fine-grained soils occurring within about 7 m from the ground surface of different areas of the country suggested the following equation:

$Cc= 0.47(e_0 - 0.46)$ with a correlation coefficient of 0.77.

No such recognized relationship between SPT-N and Compression Index is established yet. One of the main purposes of this study was to correlate SPT-N value with compression index. In addition to that, correlation of SPT-N with natural moisture content, initial void ratio and dry density was also tried.

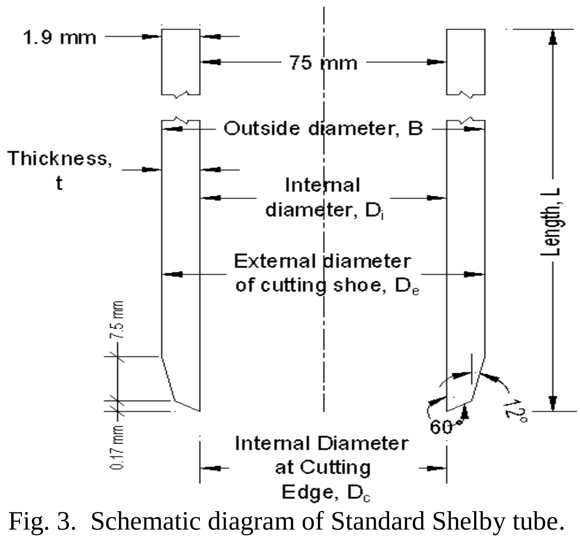

Fig. 3. Schematic diagram of Standard Shelby tube.

3. Instrumentation and test program

Undisturbed soil samples were collected by standard Shelby tubes. Standard penetration resistance was determined at the same place at 1m apart at the same depth of collection of undisturbed samples. Determination of SPT and Sample collection is done at four selected locations i.e. one is at Narayanganj area, the two others are at Khulna city and last one is at Dhaka cantonment. Bhulta of Narayanganj area was selected to have stiff clay soil and Khulna was selected to have soft clay soil so that correlation for both stiff soil and soft soil may be determined.

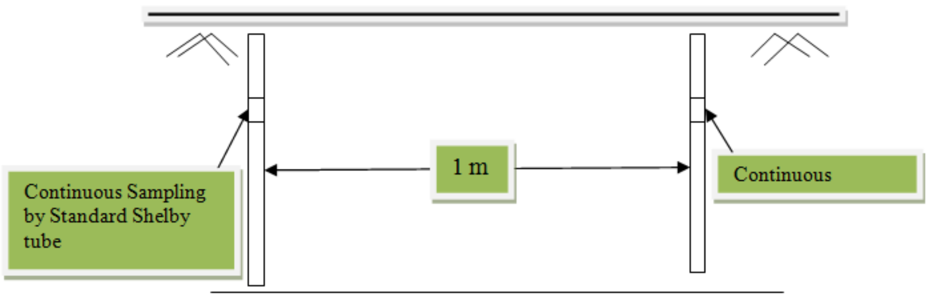

Fig. 4. Schematic diagram of boreholes arranged in the field.

3.1 *Field test and sample collection*

Samples used here are mostly collected from various sites in Bangladesh mainly Bhulta of Narayanganj, Khulna region and the Cantonment of Dhaka. Soft and stiff both soils are included in this study. In order to identify the subsoil stratification and collect disturbed and undisturbed soil samples from different depths and locations four sites were selected for sampling, one site was in Bhulta, Narayanganj, one site was in Atomic Medical Centre, Khulna , the other was in Sheikh Abu Naser Hospital, Khulna and the last one is at cantonment, Dhaka.

Table 5
USCS Classification of soil samples collected from Bhulta, Narayanganj

Sample depth (m)	Sample ID	Sand Fraction (%)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)	USCS Classification
2.90	UD-6	6.5	56	17	39	Brown Fat Clay (CH)
3.81	UD-8	1.8	58	16	42	Brown Fat Clay (CH)
4.73	UD-10	4.0	56	14	42	Brown Fat Clay (CH)
5.18	UD-11	2.5	65	22	43	Brown Fat Clay (CH)
5.64	UD-12	4.0	44	14	40	Brown Lean Clay (CL)
6.55	UD-14	18.0	38	19	19	Brown Lean Clay (CL)
7.01	UD-15	14.4	47	15	32	Brown Lean Clay (CL)
7.93	UD-17	8.8	48	18	30	Brown Lean Clay (CL)
9.30	UD-20	24.8	30	11	19	Brown Lean Clay with Sand (CL)
10.21	UD-22	13.4	45	19	26	Brown Lean Clay (CL)
11.13	UD-24	22.2	44	14	30	Brown Lean Clay with Sand (CL)
11.60	UD-25	8.9	56	25	31	Brown Fat Clay (CH)
12.04	UD-26	6.2	63	23	40	Brown Fat Clay (CH)
12.96	UD-28	38.3	25	11	14	Brown Sandy Lean Clay (CL)

At each site two bore holes were drilled with 1 m spacing between them (as shown in Figure 4). In one bore hole, SPT and disturbed samples were collected by using SPT spoon and another borehole was used to collect undisturbed samples using standard Shelby tube samplers. The SPT and the undisturbed sample were collected at the same level but one meter apart. As the SPT and undisturbed sample was collected at the same level, so the characteristics of soil may be assumed as same. For determination of unconfined compressive strengths, undisturbed soil sample collection is very important because the more the disturbances of sample the more will be the reduction of shear strength. Therefore the relationship between Standard Penetration Resistance (SPT-N value) and the unconfined compressive strength is obtained will be larger or smaller. Undisturbed samples were collected by using standard Shelby tubes.

Table 6
USCS Classification of soil samples collected from AMC Site, Khulna.

Sample depth (m)	Sample ID	Sand Fraction (%)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity index (PI)	USCS Classification
0.46	UD-1	0.8	56	23	33	Dark Gray Fat Clay (CH)
1.83	UD-4	0.3	52	24	28	Dark Gray Lean Clay (CL
3.20	UD-7	0.6	44	22	22	Dark Gray Lean Clay (CL)
4.57	UD-10	1.9	80	38	42	Black Organic Clay (OC)
5.95	UD-13	0.8	57	27	30	Dark Gray Fat Clay (CH)
7.32	UD-16	0.6	32	16	16	Dark Gray Lean Clay (CL)

Initially, boreholes were drilled up to 1.2 m depth by wash boring technique. Then continuous sampling was done in the borehole. After collection of each sample the borehole was widened and cleaned before next sampling to minimize the side friction of sampler. Hot liquid wax was then poured (Figure 5) at the two ends of sampler in a thick layer to keep the sample airtight and was covered by the plastic. The samplers were then brought to the laboratory for testing.

3.2 Laboratory test

For this study, a detailed laboratory investigation was carried out on soil samples collected from the boreholes drilled at the sites. Both types of undisturbed and disturbed samples were taken to laboratory. The laboratory-testing program consisted of carrying out Atterberg limits, particle size analysis, specific gravity test, unconfined compression and one-dimensional consolidation tests. Atterberg limits test and wet sieving was done for soil classification. Unconfined compressive strength tests were performed on undisturbed cohesive soil samples. For determination of the consolidation parameters such as compression index (C_c), coefficient of consolidation (c_v) one-dimensional consolidation tests were performed on undisturbed cohesive soil samples.

4. Test results and discussion

Correlations among index, strength and compressibility parameters were tried to develop from the field and laboratory test results. Test results and correlations are discussed in following subsections.

4.1 USCS classification of soil samples

All the soil samples were classified as per Unified Soil Classification System (USCS). Table 5, 6 and 7 show the USCS classification of samples. It was observed that Fat Clay and Lean Clay both exist in Narayanganj and Khulna. However, percentage of sand in Bhulta, Narayanganj site was more than that in Khulna site. Soft soils of Khulna are mostly Lean Clay. Few organic soils were found in Khulna. Bhulta, Narayanganj soil samples were Fat

Clay, Lean Clay, Lean Clay with Sand and Sandy Lean Clay. At Cantonment, Dhaka, the soil was Fat Clay and Lean Clay.

Fig. 5. Covering after waxing to make the sample airtight.

4.2 Relationship between SPT-N value and unconfined compressive strength

It was tried to find correlation between SPT-N value and Unconfined Compressive Strength (UCS) for each site. Figure 6 and 7 show the correlation for Narayanganj and Dhaka site. Figure 8 shows the correlation by combining data of Narayanganj and Dhaka sites where soil is stiff clay.

Table 7
USCS Classification of soil samples collected from SANH site, Khulna.

Sample depth (m)	Sample ID	Sand Fraction (%)	Liquid Limit (LL)	Plastic Limit (PL)	Plasticity index (PI)	USCS Classification
0.46	UD-1	0.2	53	24	29	Dark Gray Fat Clay (CH)
0.91	UD-2	0.3	58	28	30	Dark Gray Lean Clay (CL)
1.37	UD-3	0.4	30	11	19	Dark Gray Lean Clay (CL)
1.83	UD-4	1.1	45	19	26	Dark Gray Lean Clay (CL)
2.29	UD-5	0.8	44	14	30	Dark Gray Lean Clay (CL)
2.74	UD-6	0.4	89	23	66	Black Organic Lean Clay (CL)

Table 8
Summary of combined relationship between SPT (N) & Unconfined Compressive Strength (q_u) at Khulna, Narayanganj and Dhaka.

Location	q_u (unconfined compressive strength)	R^2
Bhulta, Narayanganj	16.71N	0.78
Dhaka Cantonment	36.45N-270.2	0.81
Combined Correlation of Dhaka Cantonment and Bhulta Narayanganj.	16.76N	0.76
SANH, Khulna	33.88N	0.91
AMC, Khulna	15.57N-16.40	0.93
Combined Correlation of SANH and AMC at Khulna	15.23N	0.16
Summary of combined Relationship at Khulna, Narayanganj and Dhaka	16.50N	0.85

Figures 9 and 10 show the correlation for AMC and SANH, Khulna. Figure 11 shows the correlation by combining data of Khulna sites where soil is soft clay. Figure 12 shows the correlation by combining all data of Dhaka, Narayanganj and Khulna sites. Table 8 summarizes all the correlations between SPT-N value and UCS. It was found that correlation is different for soft and stiff soil. For stiff soil the correlation is more consistent and reliable than that of soft soil. Because shear strength of soft soil is so small that SPT-N value is not good enough to measure it with reasonable accuracy. Plasticity of clay soil has effect on the shear strength. All data were divided into two groups; one for LL<50 and another for LL>50. Figures 13 and 14 show the correlation for LL<50 and LL>50. It is found that correlation for LL>50 is not reasonable. More data needed to find reasonable correlation for LL>50.

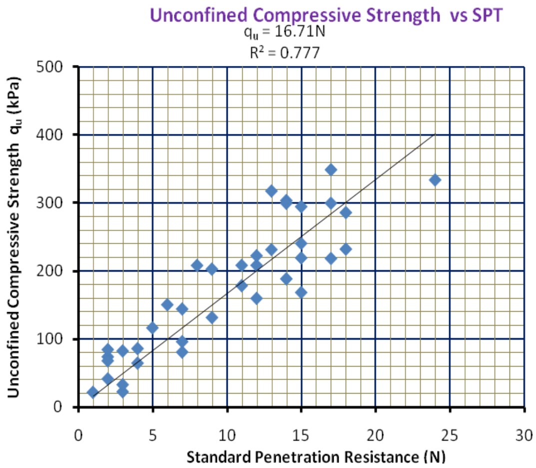

Fig. 6. Correlation between Unconfined Compressive Strength (q_u) & Penetration Resistance (N) at Bhulta, Narayanganj.

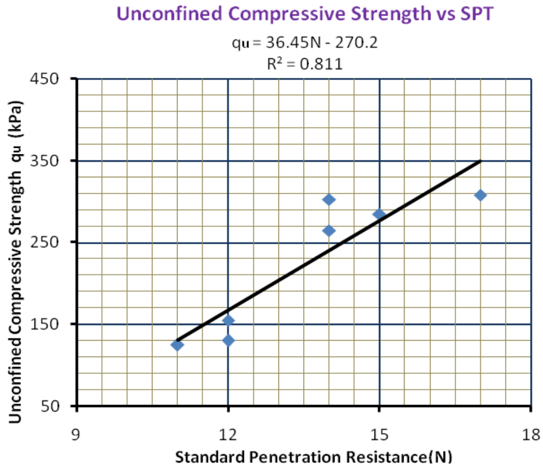

Fig. 7. Correlation between unconfined Compressive Strength (q_u) & Penetration Resistance(N) at Dhaka Cantonment.

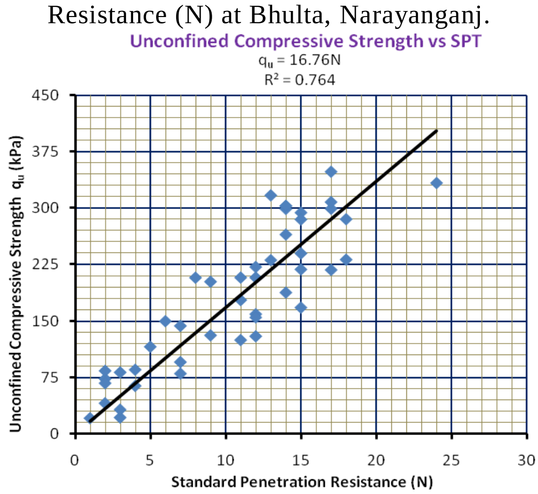

Fig. 8. Combined Correlation between unconfined Compressive Strength (q_u) & Penetration Resistance(N) at Dhaka Cantonment and Bhulta Narayanganj.

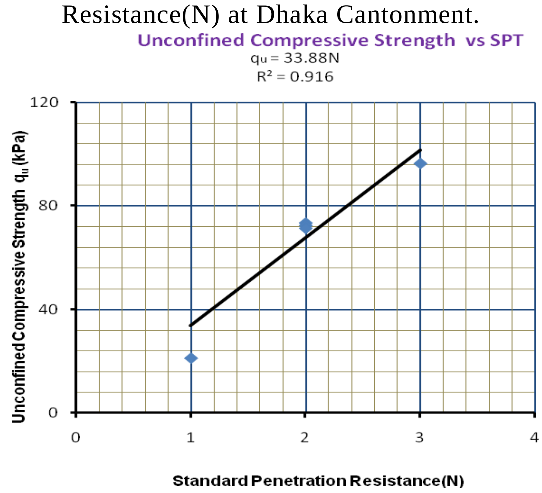

Fig. 9. Correlation between unconfined Compressive Strength (q_u) & Penetration Resistance (N) at SANH, Khulna.

In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. 0 indicates that the model explains none of the variability of the response data around its mean and 1 indicates that the model explains all the variability of the response data around its mean. Value of R^2 1 indicates that the regression line perfectly fits the data. From Table 8, it is observed that R^2 is greater than 0.75 in all location which indicates that the relations developed in this study are reasonable. The average values of q_u range from 9.96 to 17.84 times the SPT-N value for different soil types. These differences could have been caused by soil physical as well as mechanical properties of soil in each region. Therefore, for different regions, it is recommended to use separate relationship.

4.3 Correlation between SPT and compressibility parameters

Typical e-log p curves of soil samples are shown in Figure 15 and 16. The observed compression index, C_c of soil samples at Bhulta, Narayanganj site ranges from 0.090 to 0.229. At Khulna site the observed value of C_c varies from 0.253 to 0.521.As Narayanganj soil is stiff, we observed low value of compression index and soft soil of Khulna has shown high value of compression index. The relationship between SPT-N value and Compression Index are shown in Figures 17 and 18. Compression Index Vs SPT-N value for Bhulta, Narayanganj site can be considered for stiff clay soil only. For soft clay, reliable correlation could not be found. More data is needed to make reliable correlation for soft clay soil. A linear correlation is found between compression index and SPT-N value for each site where compression index decreases with increasing SPT-N value.

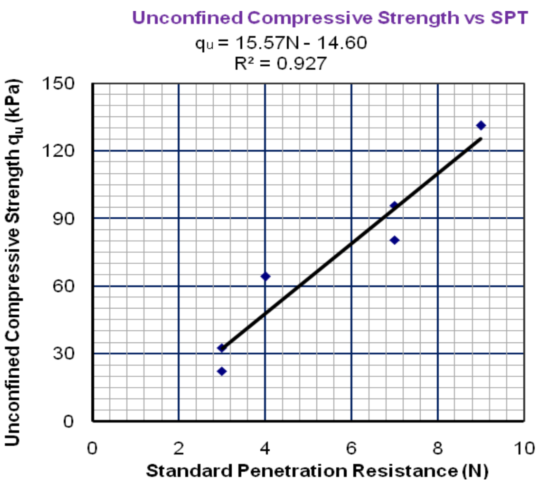

Fig. 10. Correlation between Unconfined Compressive Strength (q_u) & Penetration Resistance (N) at AMC, Khulna.

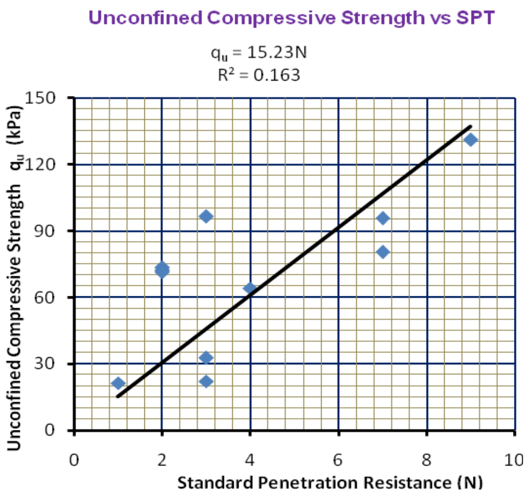

Fig. 11. Combined Correlation between Unconfined Compressive Strength (q_u) & Standard Penetration Resistance (N) at SANH and AMC at Khulna.

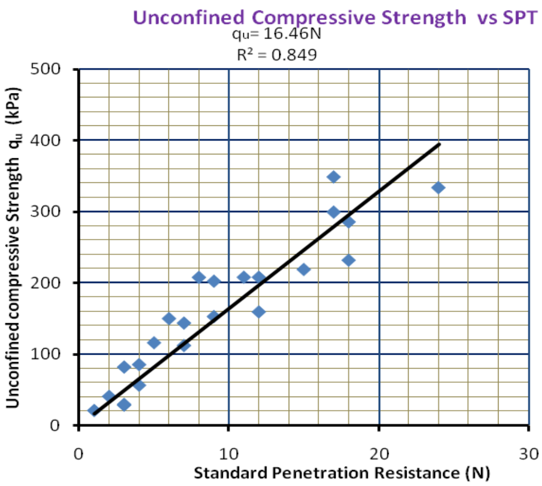

Fig. 12. Summary of combined Relationship between SPT (N) & Unconfined Compressive Strength (qu) at Khulna, Narayanganj and Dhaka.

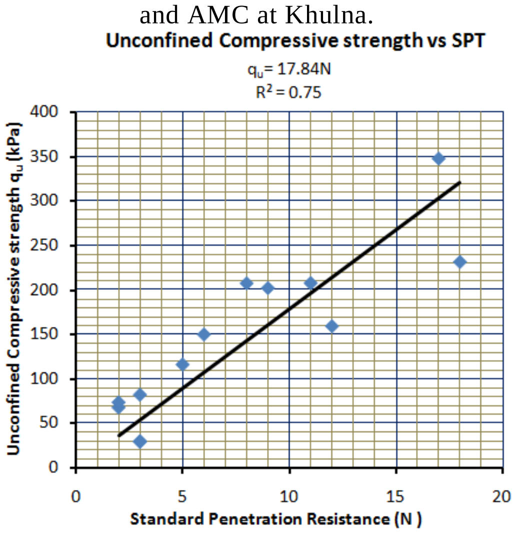

Fig. 13. Correlation between Unconfined Compressive Strength (qu) & Standard Penetration Resistance (N) (for LL ≤ 50)

Initial void ratio is considered as a compressibility parameter of soil. Higher the initial void ratio the more is the compressibility of soil. Initial void ratio vs. SPT-N value was plotted in

Figure 19 and 20. Separate linear relation was found between initial void ration and SPT for each site. SPT-N value increases with decreasing initial void ratio. However, no generalized correlation was found for this parameter. Dry density and SPT-N value has linear relation. Figure 21 and 22 shows that dry density increases with the increasing SPT-N value. Relation between Compression Index and LL are shown in Figure 23 and 24. It was observed that C_c increases with increasing LL. More plastic soils show more compressibility. Figure 25 and 26 show the relation between Cc and Plasticity Index indicating that compressibility increases with plasticity of soil.

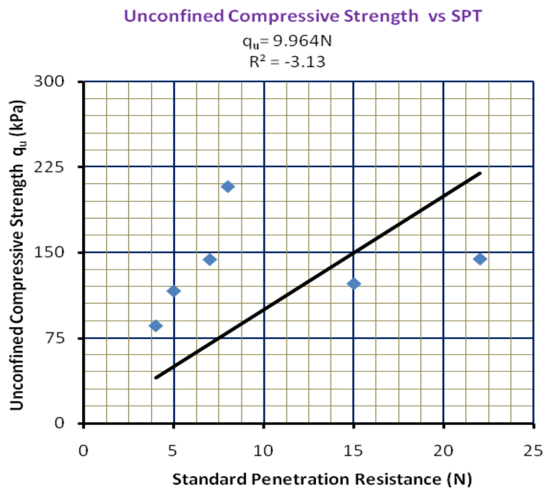

Fig. 14. Correlation between Unconfined Compressive Strength (q_u) & Standard Penetration Resistance (N) (for LL ≥ 50)

Compression Index (Cc) of soil is directly related with initial void ratio. Cc is more for higher initial void ratio as shown in Figure 27 and 28. For saturated soil, void ratio and moisture content are directly related. Higher value of natural moisture content means higher value initial void ratio. Because, in saturated soil, the voids are fully occupied by water. Figure 29 and 30 show the linear relation between Cc and natural moisture content. For all these compressibility parameters, no generalized correlation was found.

4.4 Comparison with existing correlations

From the past relationships given by various authors, it is observed that most of the cases q_u varies from 10 to 20 times of SPT-N value. In this research q_u is equal to 16.5 times of SPT N value. The correlation varies for different types of sample for different locations. The correlations that were developed in different times in this research are linear. The relationship varies with liquid limit, plasticity index, compression index, dry density of soil etc. No normalized relation was found. McEarthy (1977) established the following correlations for silty clay and clay soil.

q_u=N/2.5 ksf = 0.4N ksf for silty clay
q_u=N/2 ksf = 0.5N ksf for clay.

Similar correlation between N and q_u was investigated by Murthy (1993) for the pre-consolidated silty clay encountered at Farakka in West Bengal, India. The moisture content of the soil was close to the Plastic limit, which for the soil varied from 30 to 40 percent, and the liquid limit from 50 to 100 percent with the pre-consolidation ratio in the order of 5. It has been mentioned that there was a considerable scatter of test results and the relation between q_u and N shows q_u = 10-20 N (kPa). Bowels 1988 suggested a correlation q_u = N/4 ksf (12N kPa)

Categorizing by liquid limit, two types of correlation are found in this study which is shown below:

For lean clay q_u = 17.13N Kpa=0.37N ksf;when LL < 50 %

For fat clay q_u = 9.97N Kpa=0.21N ksf; when LL ≥ 50 %

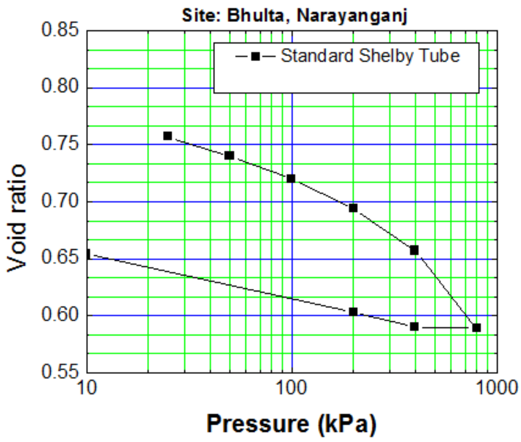

Fig. 15. Typical e-log p curve of samples collected from Bhulta, Narayanganj.

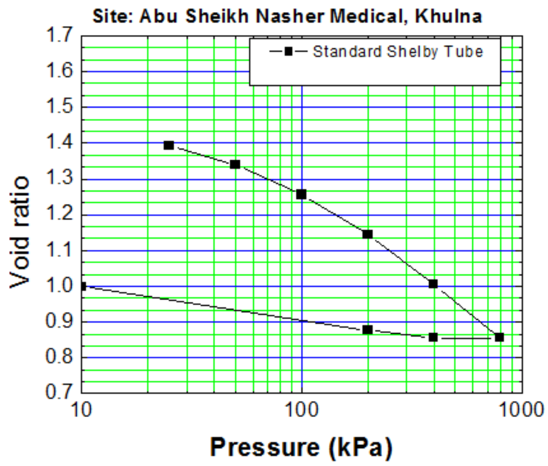

Fig. 16. Typical e-log p curve of samples collected from SANH site, Khulna.

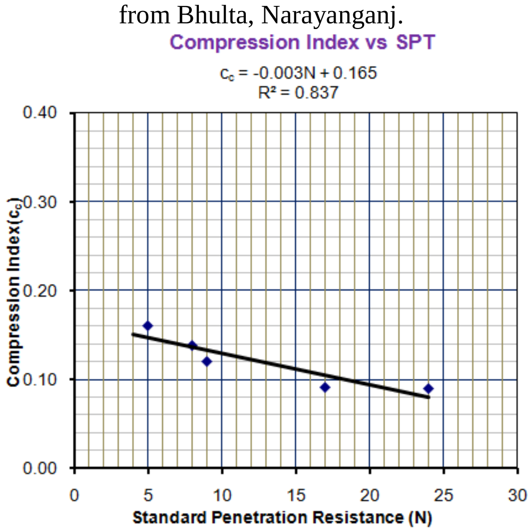

Fig. 17. Relationship between SPT & Compression Index at Bhulta, Narayanganj.

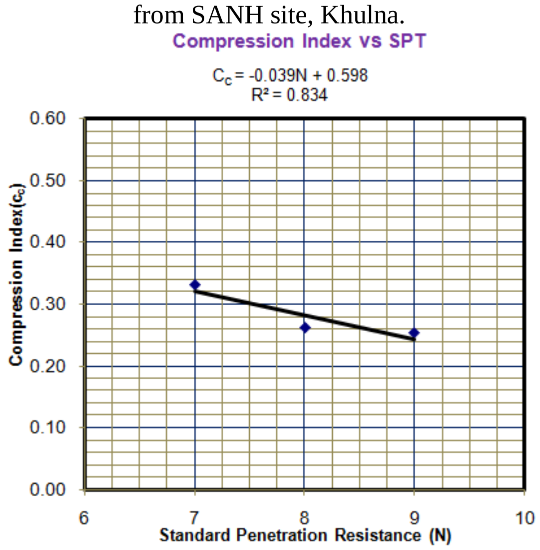

Fig. 18. Relationship between SPT & Compression Index at AMC, Khulna.

In this study, the plastic Limit varies from10 to 23 and Liquid limit varies from 17 to 57. It has been found that the test result is scattered and the average value of q_u=16.5 N kPa in Bhulta, Narayanganj area. But in Khulna region the soil is too soft and the data which was found from the test result is very scattered. So in combination of soft and stiff soil, low or high plasticity the value of unconfined compressive strength is q_u=16.5 N kPa = 0.34N ksf. Comparing the new relationship between q_u and N-value with previous correlations done by other authors, it is observed that correlation is not unique. It varies for different type of soils for different locations. It is more or less similar to the other authors. Azzouz et al. 1976 introduced several correlations between Compression Index and Initial Void Ratio for different types of soil.

$C_c = 1.21+1.055(e_0-1.87)$; for Motley clays from Sao Paulo city

$C_c = 0.208e_0+0.0083$; for Chicago clays

But the correlations which are found in this study are given below:

$C_c = 0.295e_0 - 0.028$ for stiff clay at Bhulta, Narayanganj
$C_c = 0.651e_0 - 0.310$ for soft clay at AMC, Khulna

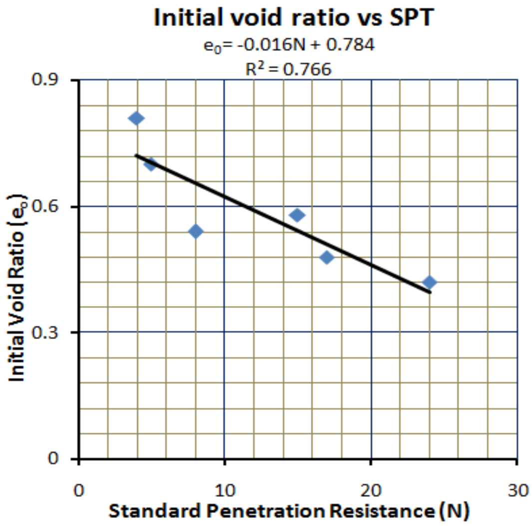

Fig. 19. Relationship between Initial Void ratio & SPT at Bhulta, Narayanganj.

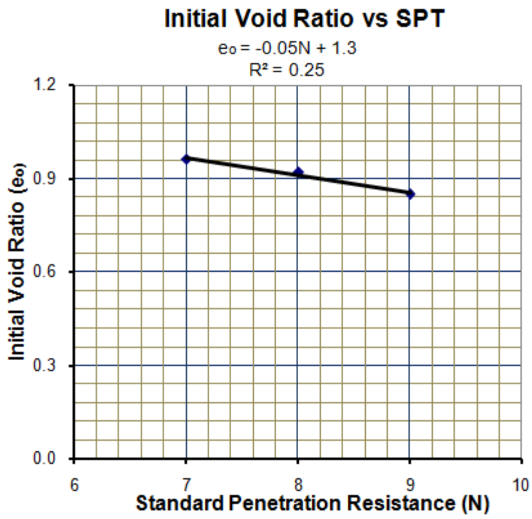

Fig. 20. Relationship between Initial Void ratio & SPT at AMC, Khulna.

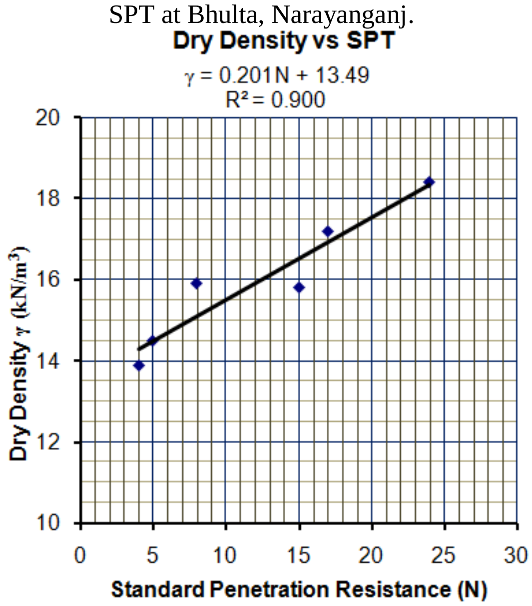

Fig. 21. Relationship between Dry Density &SPT at Bhulta, Narayanganj.

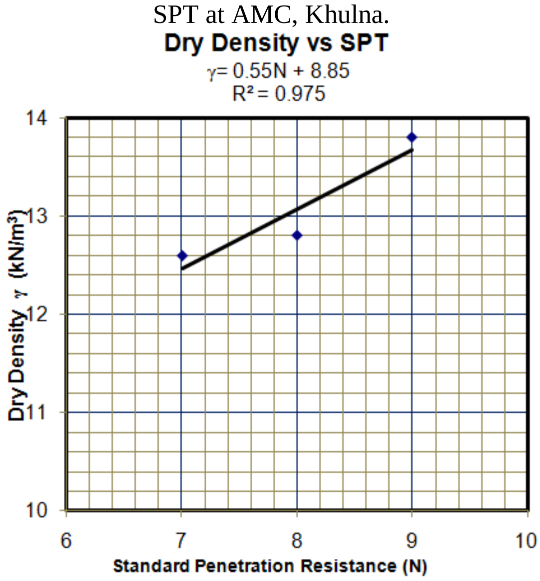

Fig. 22. Relationship between Dry Density & SPT at AMC, Khulna.

So, different type of soil shows different correlation. No generalized correlation is found. In this study, the empirical relationship is found between Compression Index and initial void ratio which is shown in Figure20 and 21. It is found that all empirical relations including present study are more or less followed the same trend.

Therefore, relation from this study can be used for clay soils of Bangladesh. Azzouz et al. 1976 gave several correlations for the compression index and natural moisture content:

$C_c = 0.01w_n$ (for Chicago clays)
$C_c = 0.0115\ w_n$ (for organic soil, peats etc.)

The correlations of C_c and natural moisture content w_n for both type of stiff and soft soil at Narayanganj and Khulna are:

$C_c = 0.006w_n - 0.016$ Bhulta, Narayanganj
$C_c = 0.021w_n - 0.527$ AMC, Khulna

It was observed that the correlations between C_c and w_n are similar but not same. So, no generalized correlation was found for this parameter. Some correlations were given by Terzaghi and Peck (1967) for the compression index and liquid limit.

$C_c = 0.009\ (w_L-10)$ for the soil where the sensitivity ratio is less than 4
$C_c = 0.007(w_L-10)$ for remolded soil

Serajuddin et al. 1967 correlated C_c with w_L of a large number of undisturbed plastic silt and clay soil samples of different areas of Bangladesh and obtained the following empirical relationships:

$C_c = 0.0078(w_L - 14)$

In this study, the correlation with C_c & w_L which are found:

$C_c = 0.002w_L + 0.003$ Bhulta, Narayanganj
$C_c = 0.013w_L - 0.3691$ AMC, Khulna

Similar correlations were found for compression index and liquid limit. The linear correlations were developed for different types of soils. But no generalized relation is observed. This correlation is different for different types of soil.

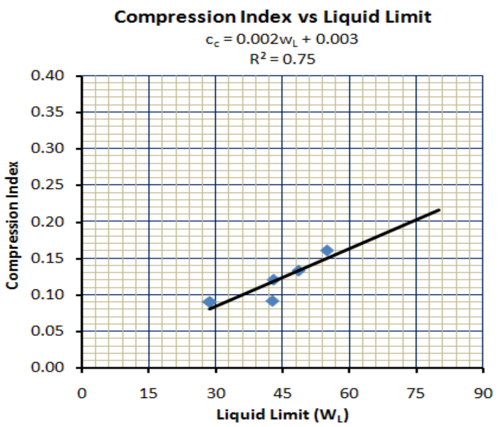

Fig. 23. Correlation between Compression Index & Liquid Limit at Bhulta, Narayanganj.

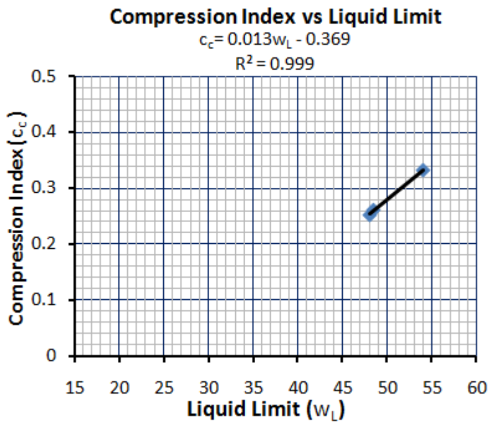

Fig. 24. Correlation between Compression Index & Liquid Limit at AMC, Khulna.

Nacci et al. 1975 tested some natural deep ocean soil samples and correlate with compression index and plasticity index.

$C_c = 0.02+0.014\ I_P$

Similarly, Nakase et al. 1998 correlated with compression index. But there is a limitation of this relation, that this correlation is applicable when Plasticity index is $I_P < 50\%$ and showed a relation:

$C_c = 0.046 + 0.0104\ I_P$

By testing a large number of undisturbed soils collected from Narayanganj and Khulna, several correlations are found that are as follows:

$C_c = 0.004I_p + 0.021$ Bhulta, Narayanganj
$C_c = 0.018I_p - 0.169$ AMC, Khulna

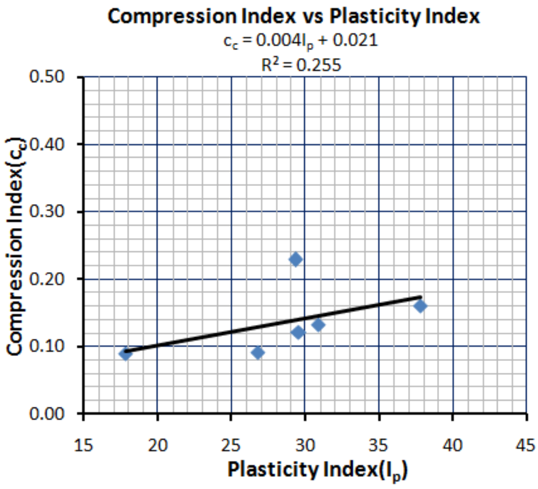

Fig. 25. Correlation between Compression Index & Plasticity Index at Bhulta, Narayanganj.

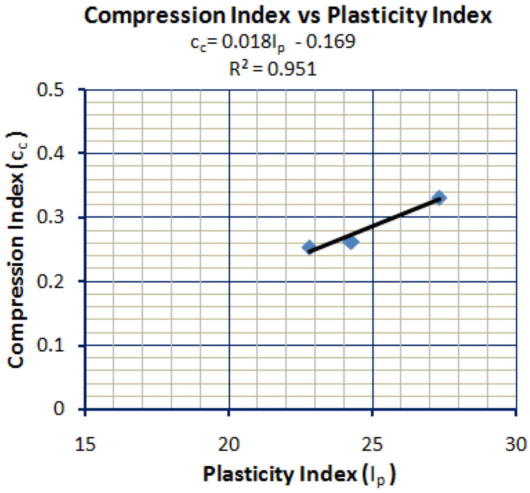

Fig. 26. Correlation between Compression Index & Plasticity Index at AMC, Khulna.

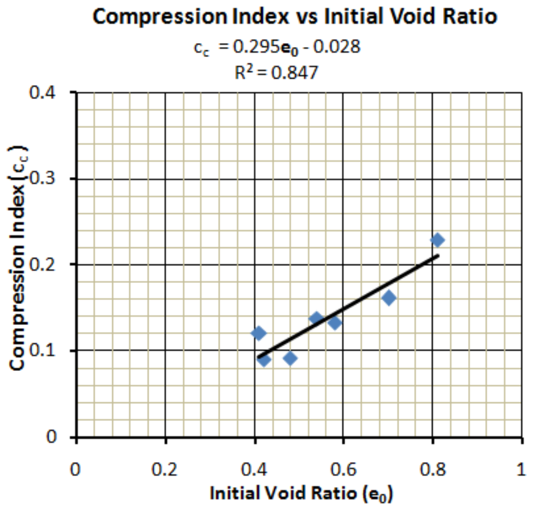

Fig. 27. Correlation between Compression Index & Initial Void Ratio at Bhulta, Narayanganj.

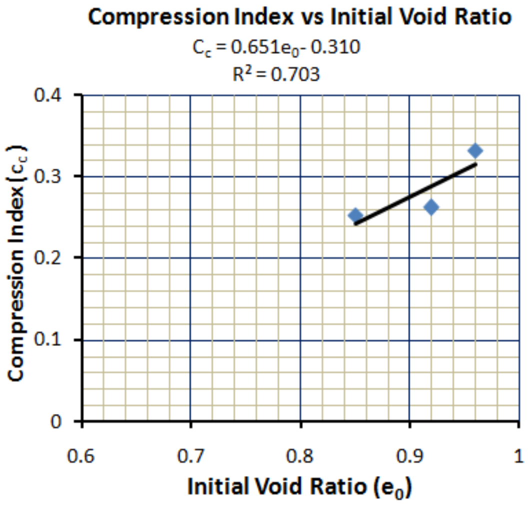

Fig. 28. Correlation between Compression Index & Initial Void Ratio at AMC, Khulna.

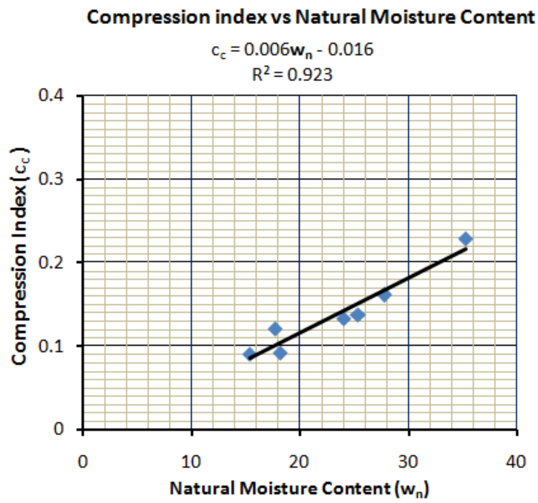

Fig. 29. Correlation between Compression Index &Natural Moisture Content at Bhulta, Narayanganj.

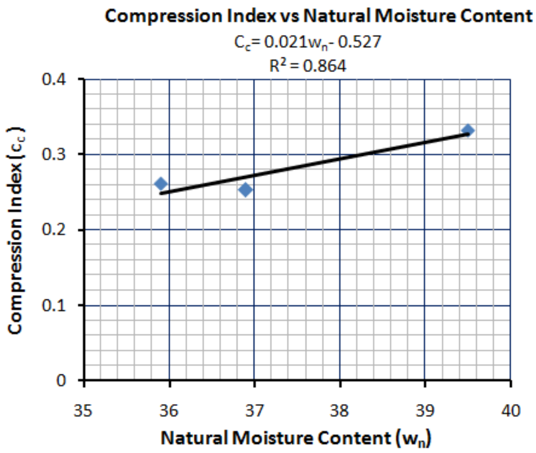

Fig. 30. Correlation between Compression Index & Natural Moisture Content at AMC, Khulna.

The relationship between compression index and plastic limit was found different for different soils. The relationships that are developed for soft and stiff soil is followed the similar trend.

5. Conclusion

SPT and undisturbed sampling was done in four sites covering stiff soil and soft soil. From the test results following conclusions may be drawn.

- A linear relation between Unconfined Compressive Strength (UCS) and SPT-N value was found for all soils, soft or stiff, low or high plasticity. The relation is q_u = 16.5 N in kPa. Comparing the new relationship between q_u and N-value with previous correlations done by other authors, it is observed that correlation is not unique. It varies for different type of soils for different locations.
- Linear relation between compression index and SPT-N value was found different for different soils.
- Reliable linear relationship between compressibility parameters (initial void ratio, dry density and natural moisture content) and SPT-N value was found different for different sites. All empirical relations including present and previous study are more or less followed the same trend. Therefore relation from this study can be used for clay soils of Bangladesh.
- The linear correlations were found between index properties (Liquid Limit, Plasticity Index) and compression index for different types of soils. No generalized relationship was observed.

References

Akhter, S. (2010) “Comparison of Sample Disturbance between Standard Sampling and Current Practices in Bangladesh”.

Al-Khafaji, A.W. and Anderson, O.B. (1992) “Equation for Compression Index Approximation”, JGED, ASCE, Vol. 118, No.1, Jan., pp.148-153.

Azzouz, A.S. (1976) “Regression Analysis of Soil Compressibility”, Soils and Foundations, Tokyo, Vol. 16, No. 2, pp. 19-29.

Bashar A. (2000), “Geotechnical Characterization of Dhaka Metropolitan Area”, M. Engineering Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka

Bjerrum, L. (1973) “Problems of Soil Mechanics and Construction on Soft Clays and Structurally Unstable Soils (Collapsible, Expansive and Others)”, State-of-the-Art Report, Session IV, Proc., 8th Tnt. Conf Soil Mech. and Found. Engg., Moscow, Vol. 3, pp. 109-159. Reported by Siddique (1990)

Bowles, J.E. (1997) “Foundation Analysis and Design,” 5th Ed., McGraw-Hill, New York, pp.15-165.

Clayton, C.R.I and Siddique, A. (1999), “ Tube Sampling Disturbance-Forgotten Truths and New Perspectives” Geotechnical Engineering Journal, Proceeding of the Institution Civil Engineers, London, Vol. 137, pp 127-135

Drumright, E.E., Pfinsten, C.W., Lukas, R.G. (1996), “Influence on Hammer Type on SPT Result”, Journal of Geotechnical Engineering, ASCE, Vol. 122, pp 588-589.

Ferdous S.M. (2001), Geotechnical Characterization of Khulna City Corporation (KCC) Area, M. Engineering thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

Hvorslev, M.J. (1949) “Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes”, Waterways Experimental Station, Vicksburg, U.S.A. Repotted by Siddique (1990).

ISSMFE (1965). “Report of the Subcommittee on Problems and Practices of Soil sampling”, Proceedings of the 6th International Conference on Soil Mechanics and Foundation engineering, Montreal, Vol. 3, Appendix II, pp. 64-71.

McEarthy, D.F. (1977) “Essentials of Soil Mechanics and Foundation” Prentice-Hall Company, Reston, Virgin.

Murthy, V.N.S. (1993) “A Textbook of Soil Mechanics and Foundation Engineering”, SaiKripa Technical Consultants, India.

Nishida, Y. (1956) “A Brief Note on Compression index of Soils”, JSMFD, ASCE, Vol. 82, SM 3, July, pp. 1-14.

Peck, R.B., Hanson, W.E., and Thornburn, T.H. (1974) “Foundation Engineering”, John Wiley and Sons, New York.

Sanglerat, G. (1972) “The Penetrometer and Soil Exploration”, Elsivier Publishing Co., Amsterdam.

Serajuddin, M. (1998) “Some Geotechnical Studies on Bangladesh Soil: A Summary of Papers between 1957-96”, Journal of Civil Engineering, the Institution of Engineers, Bangladesh, Vol. CE 26, No.2, 1998. Pp. 101-125.

Siddique, A., Farooq, S.M and Clayton, C.R.I. (2000), “ Disturbances Due to Tube Sampling in Coastal soils”, Jornal of Geotechnical and Geoenvironmental Engineering, American Society of Civil Engineers(ASCE), Vol. 126, No. 6, pp 568-575.

Sowers, G.F. (1953 and 1962) “Modern Procedures for Underground Investigation”, Proceedings, ASCE.

Terzaghi, K. and Peck, R.B. (1967) “Soil Mechanics in Engineering Practice”, 2nd Ed. John Wiley and Sons, New York, pp. 729.