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CORRELATION BETWEEN STANDARD PENETRATION RESISTANCE AND UNCONFINED COMPRESSIVE STRENGTH OF BANGLADESH COHESIVE DEPOSITS

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ABSTRACT : Different researchers suggested correlations between consistency, standard penetration resistance (N) and unconfined compressive strength (q_u) of cohesive deposits of different countries/regions. The authors have attempted to establish correlation between N and q_u of cohesive deposits for different areas of Bangladesh and their findings are presented in the paper.

KEY WORDS: Correlation, Standard Penetration Resistance (N), Unconfined Compressive Strength (q_u), and Proportionality Factor (k)

INTRODUCTION

The standard penetration test (SPT) is the most commonly used penetrometer test for subsoil investigation in Bangladesh as well as in U.S.A. and many other countries of the world. The SPT is done as per ASTM D-1586 specification. It is made by dropping a hammer weighing 63.5 kg (140 lb) onto drill rods from a height of 760 mm (30 in). The number of blows N necessary to produce a penetration of 300 mm (1 ft.) into the soil deposit is known as the standard penetration resistance. To avoid seating errors, the blows for the first 150 mm of penetration are not taken into account; those required to increase the penetration from 150 to 450 mm are taken as the N-value. The approximate correlations have been established between N and q_u by different researchers for cohesive soils of their regions/countries. The current practice is to correlate q_u with N as follows,

$q_u = k N$ (kPa), where k is the proportionality factor.

Different literatures indicate that the values of k suggested by the researchers for various types of cohesive soils of different regions/countries vary over a wide range of about 7 to 25, when q_u is expressed in kPa.

The very approximate correlations between consistency, N and q_u for cohesive soils as suggested by Terzaghi and Peck (1948 and 1967) are presented in Table 1. These correlations give the value of k = 12.50 to 13.33.

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

Consistench	N-value	Unconfined compressive strength, q_u (kpa)*
Very soft	0-2	< 25
Soft	2-4	25-50
Medium dtiff	4-8	50-100
Stiff	8-15	100-200
Very stiff	15-30	200-400
Hard	> 30	> 400

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

The correlations between N and q_u as obtained by Sowers (1953 and1962) for choesive soils are presented in Table 2 and the average values of k range from 6.7 to 24 for different soil types.

Table 2. Correlations between N-Value and Unconfined Compressive Strength for Different Soil Types (after Sowers, 1953 & 1962)

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

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

Sanglerat (1972) proposes the following relationships between N and q_u for different soil types with the values of k ranging from 13.33 to 25.

For clay, qu = 25 N kPa

For silty clay, qu = 20 N kPa

For silty sandy soil, qu = 13.33 N kPa

Murthy (1993) investigated the relationship between N and q_u for the preconsolidated silty clay encountered at Farakka in West Bengal, India. The moisture content of the soils was close to the plastic limit which for the soils varied from 30 to 40 percent and the liquid limit from 50 to 100 percent with preconsolidation ratio in the order of 5. It has been mentioned that there was a considerable scatter of test results when values of q_u (kg/cm^2) were plotted as abscissa and $\frac{N}{q_u}$ as ordinate and the trend showed that most of the points were between two parallel lines having values of $\frac{N}{q_u}$ = 5 and 10 and an average value of $\frac{N}{q_u}$ = 7.5 was suggested; and when expressed in kPa, the relationship would be as follows :

$$q_u = \frac{N}{7.5}\ \text{kg/cm}^2 = 13.33\,N\ \text{kPa.}$$

The correlation between N and q_u is quite useful but has to be used according to the soil conditions met in the field. It is, therefore, very much desirable to establish correlations between N and q_u of local cohesive soils instead of depending on correlations established for cohesive deposits of other countries. The authors have attempted in this paper to determine the values of k for the cohesive deposits of Bangladesh so that q_u can be estimated from N-value, when undisturbed sample of a cohesive deposit could not be obtained to determine q_u in the laboratory.

SURFACE GEOLOGY

A brief description of the surface geology of Bangladesh would be helpful to understand the physical and geotechnical characteristics of the soils of different investigated areas covered in this paper.

Most of Bangladesh is a flat delta which consists of a large alluvial basin floored primarily with Quaternary sediments deposited by the Ganges-Padma, the Brahmaputra-Jamuna and the Meghna rivers and their numerous tributaries and distributaries.

The Quaternary sediments are divided into two units namely "Old Alluvium" of the Pleistocene age and "Recent alluvium" of the Holocene age. The Tertiary deposits are exposed in the eastern and northeastern part of the country.

The surface geology of Bangladesh may be split into three major geomorphologic zones : (1) Tertiary and Pleistocene Hill Formations, (2) Uplifted Pleistocene Alluvial Terraces, and (3) Recent Floodplain and Piedmont Alluvium of the Holocene age. These are shown on Figure 1. The hill areas include the Chittagong Hill Tracts, and parts of greater Chittagong, Noakhli, Comilla, Sylhet and Mymensingh Districts. The Pleistocene alluvial terraces are restricted to three main regions, namely the Barind, the Madhupur and the Lalmai Hills. The Madhupur terrace areas are in greater Dhaka, Tangail and Mymensingh Districts, the Lalmai Hills are near the Comilla town, and the Barind terrace areas are in greater Rajshahi, Bogra, Rangpur and Dinajpur Districts. Areas of Recent Floodplain and Piedmont Alluvium which cover roughly seventy percent of the total land area of the country include piedmont plains, meander floodplains, tidal floodplains and estuarine floodplains. Piedmont plains cover most of greater Dinajpur District, and a part of greater Rangpur District at the foot of the Himalayas, and also adjacent to the northern and eastern hills. The remainder area of the Recent floodplain alluvium includes meander floodplains, tidal floodplains, estuarine floodplains and basins. Within the above three major geomorphologic zones twenty physiographic units each with fairly uniform physical characteristics have been defined. Meander floodplains include the greater parts of the floodplains of the Teesta, Brahmaputra-Jamuna, Ganges-Padma, Surma-Kushiyara and the middle Meghna rivers. Tidal floodplains exist mainly in the southern region of the Ganges-Padma floodplain and also in some areas of the greater Chittagong coastal plain. Estuarine floodplains occupy most of greater Comilla and Noakhali Districts, and parts of greater Barisal, Patuakhali and Khulna Districts, Sylhet Basin, Arial Bil and Gopalgonj-Khulna peat Basin are also parts of the recent floodplains (Morgan and McIntire, 1959; Bramer, 1971; Hunt, 1976 and Master Plan Organisation Report, 1986).

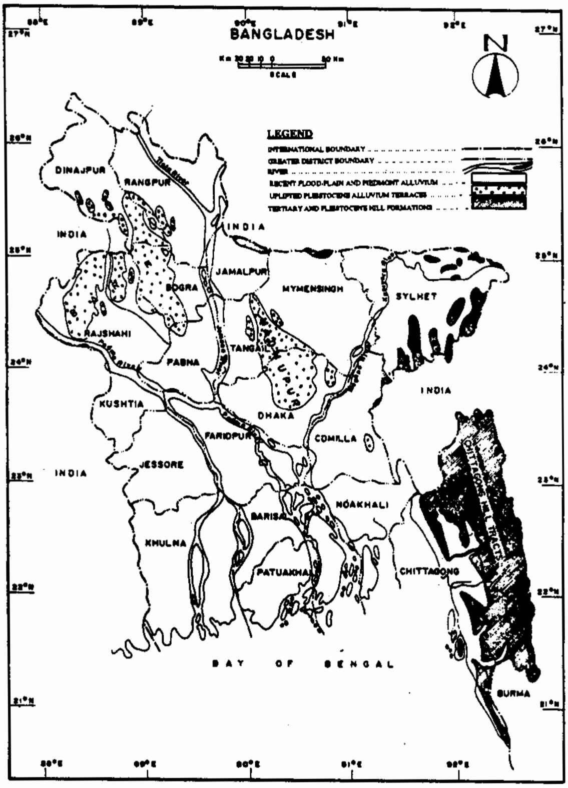

Fig 1. Map Showing Major Geomorphologicaal zones and Greater Districts

In the Geological Map of Bangladesh (1990) the Terrace deposits of the Madhupur Tract and the Lalmai Hills are however described as the Madhupur clay residium (rm) and those of the Barind Tract as the Barind clay residium (rb) under the map units of the Residual deposits; and Recent Floodplain and Piedmont Alluvial deposits have been described under the map units of Coastal, Deltaic, Paludal, Alluvial and Alluvial Fan deposits; and these map units have again been subdivided into numerous soil types, depending on the physical soil characteristics, nature of the areas of the deposits and the condition of environments at the time of deposition, etc.

TESTS AND PRESENTATION OF RESULTS

The field and laboratory test results of 412 undisturbed samples, which were collected as per ASTM D-1587 specification from cohesive soil deposits occurring in different regions/areas of Bangladesh, along with determination of N of the same soil layers as per ASTM D 1586 specification, have been studied to find average values of k cohesive soil deposits of the country.

A good number of the tested samples were from several areas of Dhaka Metropolitan City and Tangail district and these samples belonged to Uplifted Pleistocene Alluvial Terraces of the Madhupur Tract (Madhupur clay residium). Again a considerable number of the tested samples belonged to Uplifted Pleistocene Alluvial Terraces of the Barind Tract (Barind clay residium) in greater Rajshahi district. The remainder of the tested samples were from the several areas of Recent Floodplain Alluvium of the Holocene age.

Natural moisture content (NMC), liquid limit (LL), plastic limit (PL), plasticity index (PI), grain size distribution, unconfined compressive strength (q_u), wet unit weight (γ_{wet}), initial void ratio (eo) and degree of saturation were determined for all these samples. Oedometer consolidation test on the selected undisturbed samples was done to determine their compressibility characteristics. All the tests were performed in the Geotechnical and Material Laboratory of Development Design Consultants (DDC), at Dhaka in different periods. The ranges of some soil test parameters are shown in Table 3.

Table 3. Ranges of Some Soil Test Parameters

Range	NMC %	LL %	PI %	Size distribution (% finer)			N-value	q_u kPa	tWet unit. γwet kN/m3
				0.425 mm	0.075 mm	0.002 mm			
Max.	56	84	57	100	100	52	25	587	23.05
Min.	12	26	3	88	43*	1	1	10	14.81

* About 90 percent of the soil samples contained more than 80% soil fraction finer than 0.075 mm

The cohesive samples of Uplifted Pleistocene Alluvial Terraces were well-oxidized and were reddish, brown or tan, and were mottled. They had generally a low water content resulting in a firmer, more compacted material. They were predominantly medium plastic with LL in range of about 36-50% and there were only a few samples with LL in the range of about 30-35% and 51-60%. Their NMC was close to their PL and some samples had NMC less than PL. They showed over consolidation ratio (OCR) of about 1.5-5 at different areas, and q_u of the most samples ranged from about 40-300 kPa with N from about 2-21 and there were several samples with q_u from about 300-587 kPa and N from about 10-21. The cohesive samples of the Recent Floodplain Alluvium of different areas were mostly light to medium grey, occasionally dark grey, brownish and yellowish. They were generally normally consolidated to slightly preconsolidated with OCR of about 1 to less than 2; and some samples also showed OCR of about 2-3 and only a few samples occasionally had OCR more than about 3-5. The NMC of the most samples was in the range of about 20-50% with only several values below and above this range. These samples had LL in the range of about 26-76% and PI in the range of about 3-42%. The q_u of these Recent deposits was obtained in the range of about 10-240 kPa and mostly in the range of about 1-12.

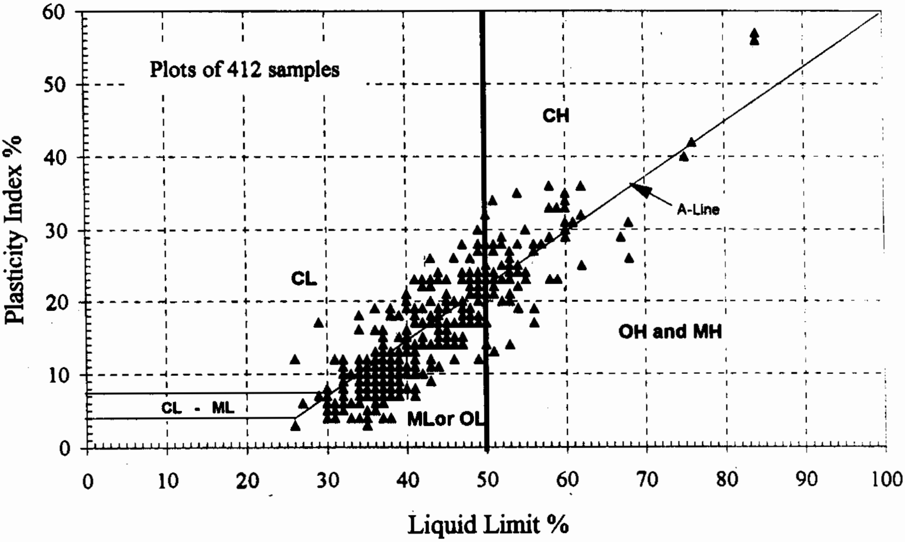

Fig 2. Position of the Tested Cohesive Soil Samples on Casagrande Plasticity Chart.

The values of LL and PI of all the soil samples are plotted on Soil Classification Plasticity Chart in Fig. 2. Plots of N as abscissa and q_u as ordinate of all 412 samples are shown on Fig. 3. Ninety two percent of these samples had degree of saturation from about 80 to 100 percent and the remaining about 8 percent had degree of saturation less than 80 percent. The samples were obtained from various depths above and below ground water table (GWT) at the time of sampling. Of the 412 samples 225 had degree of saturation from about 95-100 percent and plots of N vs q_u for these 225 samples are presented on Fig. 4. Again, 156 of the 412 samples had 100 percent saturation and 130 of these 156 samples existed below GWT at the time of collecting the samples; and plots of N vs q_u of these 156 samples are shown on Fig. 5. Plots of N vs q_u of the cohesive soils having different degrees of saturation and with liquid limits ≤35% (grouped as low plastic soils), 36 to 50% (grouped as medium plastic soils) and ≥ 51% (grouped as high plastic soils) are shown on Figs. 6(a), 6(b) and 6(c) respectively. Average values of k as obtained in Figs. 3 through 6 are shown in Table 4.

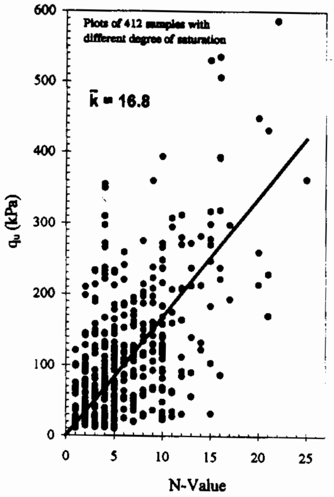

Fig 3. Correlation between N-Value and qu (412 Samples with Different Degree of Saturation

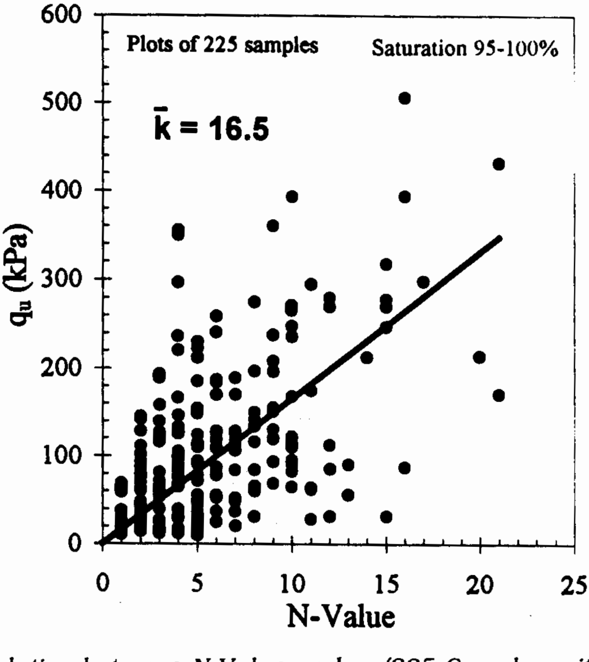

Fig 4. Correlation between N-Value and q_u (225 Samples with 95-100% Degree of Saturation)

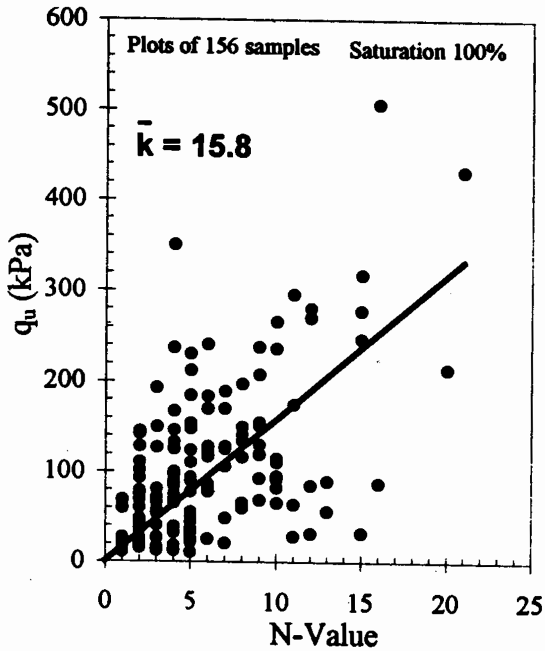

Fig 5. Correlation between N-Value and q_u (156 Samples with 100% Degree Saturation)

Table 4. Approximate Proportionality Factor, k for Cohesive Soils of Different Liquid Limit Range and Different Degree of Saturation.

Soil Type	USCS * Symbol	Number of Samples	Range of LL	Degree of Saturation	Proportionality Factor, k
Clays and Silts of low to medium to high plasticity	CL, ML, CH & MH	412	26-84%	About 92% samples between 80-100% saturation and about 8% samples below 80% saturation	16.8 (Fig. 3)
As above	CL, ML, CH & MH	225	-	95-100%	16.5 (Fig. 4)
As above	CL, ML, CH & MH	156	-	100%	15.8 (Fig. 5)
Clays and Silts of low plasticity	CL & ML	86	≤ 35%	Different degree of saturation	14.3 (Fig. 6a)
Clays and Silts of medium plasticity	CL & ML	254	36 -50%	As above	16.9 (Fig. 6b)
Silts and Clays of high plasticity	CH & MH	72	≥ 51%	As above	17.8 (Fig. 6c)

* USCS = Unified Soil Classification System.

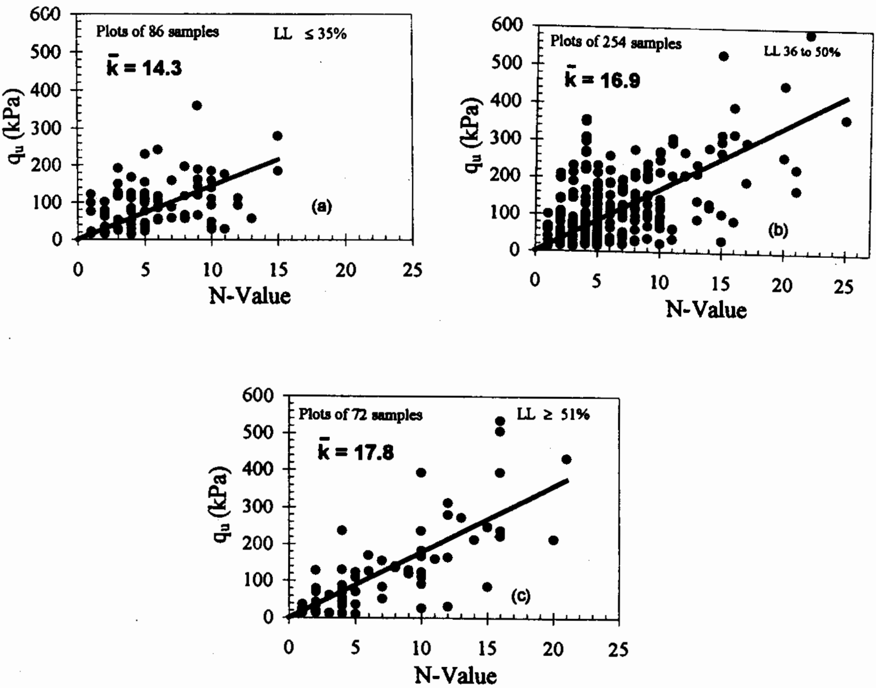

Fig 6. Correlation between N-Value and q_u (Samples with Different Liquid Limit Range

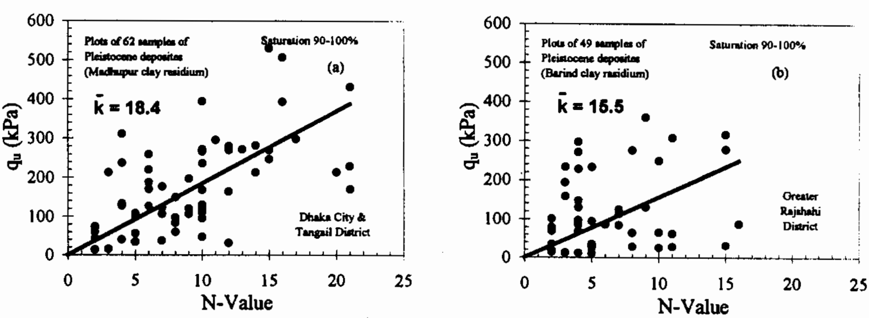

Fig 7. Correlation between N-Value and q_u (Samples of Terrace Deposits (a) Dhaka Metropolitan City and Tangail District and (b) Greater Rajshahi District)

Because such correlations are mostly site -or area - oriented, the plots (not shown in the paper) of N vs q_u of the cohesive soil samples of different areas were made separately to observe the variation in the

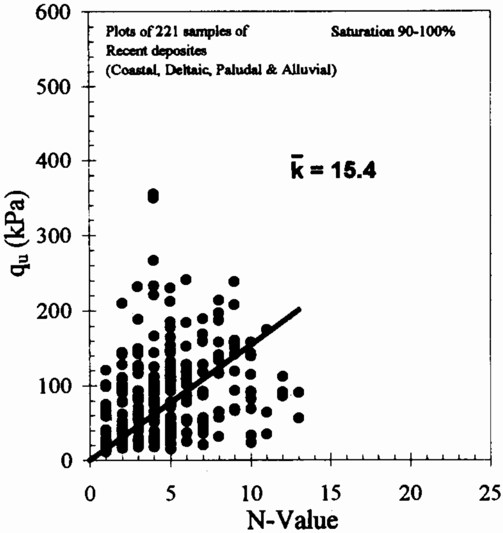

Fig 8. Correlation between N-Value vs q_u (Samples of Recent Floodplain Deposites)

average values of k for samples of different areas. The samples of different areas were partially to fully saturated as indicated in Table 4. There were wide scatter in the plots on N vs q_u of the samples and the very approximate values of k as were obtained for samples of different areas are presented in Table 5.

Again the plots of N vs q_u of the cohesive soil samples with 90-100 percent saturation of the Uplifted Pleistocene Terrace deposits (Madhupur clay residium) of some areas of Dhaka Metropolitan City and Tangail district and of those (Barind clay residium) of greater Rajshahi district are presented on Figs. 7a and 7b respectively. Plots on N vs q_u of the cohesive samples of the Recent deposits with 90-100 percent saturation of different areas of the country are shown on Fig. 8 The plots in Figs. 7a and 7b were made to study if the samples with 90-100 percent saturation of Madhupur clay residium and Barind clay residium gave the same or different values of k for the two regions on the two sides of the present Brahmaputra-Jamuna river. The plots on Fig. 8 were made to obtain the average value of k for the samples of the Recent cohesive deposits with 90-100 percent saturation and also to see the difference in the values of k for the Uplifted Pleistocene and Recent deposits.

Table 5. Approximate Proportionality Factor, k for Cohesive Soils of Different Areas

Areas	Number of samples	Plasticity Characteris -tics	Degree of Saturat on	Range of N-value	Range of q_u (kPa)	Approximate value of k
Some areas in Dhaka Metropolitan City and Tangail district (Madhupur clay residium)	113	LL=30-62% PI=4-36%	Partially to fully saturated	2-22	14-587	18.2
Some areas in Greater Rajshahi district (Barind clay residium)	59	LL=26-68% PI=6-35%	As above	2-25	10-360	15.4
Greater districts of Chittagong including islands, Noakhali including islands and Comilla (Recent deposits)	175	LL=30-62% PI=4-29%	As above	1-15	14-355	15.5
Greater Sylhet district (Recent deposits)	17	LL=26-75% PI=3-40%	As above	1-10	20-155	13.5
Greater districts of Bankerganj and Faridpur (Recent deposits)	25	Ll=27-76% PI=5-42%	As above	1-11	17-230	14.1
Greater Khulna district (Recent deposits)	23	LL=35-60% PI=8-29%	As above	1-4	11-67	16.8
Some areas in Dhaka Metropolitan City and Tanganil district (Madhupur clay residum)	62	Low, medium and high plastic	90-100%	2-21	10-530	18.4 (Fig. 7a)
Some areas in Greater Rajshahi district (Barind clay residium)	49	As above	90-100%	2-16	5-360	15.5 (Fig. 7b)
Recent deposits of different areas combined (Coastal, Deltaic, Paludal and Alluvial deposits)	221	As above	90-100%	1-13	10-36	15.4 (Fig. 8)

OBSERVATIONS

Fig. 2. indicates that the cohesive soil samples of different areas of the country plot very closely on both sides of the A-line of the Plasticity Chart and there are more plastic silts than clays; and silts and clays of low to medium plasticity (CL and ML) occur more frequently than those of high plasticity (CH and MH) in the different investigated areas.

Figs. 3 through 6 and Table 4 demonstrate that the average values of k or the different soil types with different degree of saturation lie in the range of about 14.3 to 17.8.

Table 4 and Fig. 5 also show that the average value of k f the cohesive soils with 100% saturation for different investigated areas of the country is about 15.8. It is also observed in Table 4 and Fig. 6 that the average value of k has a trend to increase generally with increase of plasticity of the soils, that is about 14.3, 16.9 and 17.8 for low plastic, medium plastic and high plastic soils respectively.

Fig. 7a shows that the average value of k of the samples with 90-100% saturation from Madhupur clay residium of Dhaka Metropolitan City and Tangail district is about 18.4. Fig. 7b shows that the average value of k of the samples with 90-100% saturation from Barind clay residium of greater Rajshahi district is about 15.5. Fig. 8 indicates that the average value of k of the samples with 90-100% saturation of the Recent cohesive deposits of greater districts of Chittagong, Noakhali, Comilla, Sylhet, Bakerganj, Faridpur and Khulna is about 15.4.

DISCUSSION

Generally the undisturbed cohesive silt and clay samples are taken by means of seamless thinwalled steel tubes (commonly known as Shelby tubes) from the cohesive strata in only a portion of the depth of total test holes for economy and N is measured in all other depths of the test holes at frequent intervals for the full depth. In such case, N is used hand in hand with q_u, although the latter is considered more reliable. In order to extend the results of limited detailed testing in the laboratory to the more extensive exploratory work, various correlations are made and so is the attempt made in this paper.

It has been observed that although very low N-values of about 2 to 4 were obtained in some cohesive soil strata in some areas, thereby indicating the soil layers to be very soft to soft in consistency, while the laboratory measured q_u-values of about 100 to 200 kPa for the tube samples from the same layers indicated the deposits to be quite strong. This was predominantly observed in the reddish, brown or tan coloured compact cohesive silt/clay samples belonging to the Uplifted Pleistocene terrace deposits of Dhaka Metropolitan City areas, Tangail district and greater Rajshahi district.

The average value of k ends to be site dependent; and that consistency correlations are very poor anyway because of variations in OCR, aging, sample water content, presence or absence of drilling fluid, location of ground water table, and generally variability of soil deposits (Bowels, 1988). In the present study also variations of k were observed for Older and Recent deposits in different areas of the country and due to variation in the degree of saturation of the samples (Tables 4 and 5).

According to Peck et al. (1974) the SPT may lead to a gross misconception of the consistency in highly sensitive clays and moreover, it is far too crude a test to justify its use for even approximating numerical values representing the strength of soft or very soft saturated clays; and the ease of penetration of the sampler depends not only on the strength of soil but also on its compressibility and thus a strong cohesive soil with a high air content may have a substantially lower N-value than an equally strong saturated soil in which the voids can not collapse as the sampler advances.

Highly sensitive clays may be rare and are not commonly encountered in Bangladesh. The sensitivity of Bangladesh clays was found to vary from low to medium (sensitivity 1 to 5) and most soils had sensitivity less than 4 (Serajuddin and Islam, 1982). According to Peck et al. (1974) natural soils having values of sensitivity greater than 4 are known as sensitive clays, and, if sensitivity exceeds 8, as extra sensitive clays. Therefore, the very low values of N against quite high values of q_u as observed in some cohesive soils of this study might have been due to presence of high air contents and low saturation, and not due to high sensitivity of the samples. However, more studies in this respect would be necessary to confirm the reasons for quite high values of q_u against very low values of N of some cohesive deposits as observed in this study.

The recent researchers have suggested for correction of energy ratio, E_r, for drilling rigs and as there is a wide scatter in E_r for different drilling rigs it has been further suggested that the drill system dependent E_r be referenced to a standard energy ratio value E_{rb} (Bowels, 1988). In Bangladesh no such study has yet been done to authors' knowledge on energy ratio and standard energy ratio for drilling rigs, which are mostly manufactured locally as per ASTM D 1586 specifications, and are operated manually by labourers who raise the drop hammer by pulling the rope of the drop hammer over the pulley and suddenly release the same to allow the hammer to drop through 760 mm approximately. It is not exactly known what may be the approximate energy ratio of the local drilling equipment under this local operating condition.

The authors of this paper are of the opinion that as the average values to k for Bangladesh cohesive soils have been determined from the values of N measured mostly by locally manufactured drilling equipment and operated under local manual operation system (without any auto-drop hammer), the average values of k as obtained and presented in this paper would be well applicable to Bangladesh cohesive soils till the local drilling equipment and operation system would be standardised according to the current practices of the advanced countries of the world.

CONCLUSION

As there is a considerable scatter in points of plots, slightly lower values of k than the different average values of k obtained in this correlation study should be used to conservatively estimate q_u of a saturated cohesive soil layer from N-value of the layer, when no undisturbed sample has been taken from the layer to determine q_u in the laboratory.

The following values of k are suggested to estimate q_u of saturated cohesive silt and clay layers of Uplifted Pleistocene deposits from N-values of the layers :

i) k = 16 for reddish, brown or tan coloured Uplifted Pleistocene silt and clay deposits (Madhupur clay residium) of medium to high plasticity of Dhaka Metropolitan City areas and Tangail district.

ii) k = 14 for reddish, brown or tan coloured Uplifted Pleistocene silt and clay deposits (Barind clay residium) of medium to high plasticity of greater Rajshahi district.

Again, based only on the plasticity characteristics of the cohesive silt and clay deposits occurring in different areas of the country, the following values of k are suggested to estimate q_u of saturated cohesive silt and clay layers from N-values of the layers :

i) k = 16 for clays and silts of high plasticity with LL $\geq$ 51%.

ii) k =15 for clays and silts of medium plasticity with LL = 36- 50%.

iii) k = 13 for clays and silts of low plasticity with LL $\leq$ 35%.

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NOTATIONS

GWT = Ground Water Table

LL = Liquid Limit

N = Standard Penetration Resistance

NMC = Natural Moisture Content

OCR = Over Consolidation Ratio

PL = Plastic Limit

PI = Plasticity Index

eo = Initial Void Ratio

K = Proportionality Factor

q_u = Unconfined Compressive Strength

γ_{wet} = Wet Unit Weight