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CHARACTERIZATION OF UPLIFTED PLEISTOCENE DEPOSITS IN DHAKA CITY

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ABSTRACT : Geotechnical investigations have been carried out extensively in different areas of the city for different building projects during the last several decades. Typical soil profiles and other soil engineering properties upto the explored depths of about 20 to 30 m are presented. 'Activity' of Dhaka clays has been studied. The correlation between standard penetration resistance and unconfined compressive strength has been shown for Dhaka clay. The applicability of several existing compression index correlation equations to Dhaka clays has been studied. The effective preconsolidation pressures for the typical Dhaka clay samples determined by Casagrande method (1936) and by Sridharan, et. al. method (1991) have been presented along with the corresponding overconsolidation ratio

KEY WORDS: Uplifted Pleistocene deposits, Dhaka clay, standard penetration resistance, unconfined compressive strength, compression index, overconsolidation ratio.

INTRODUCTION

Dhaka, the capital city of Bangladesh, stands gracefully on the left bank of river Buriganga, a silent witness of the changes of history over the centuries. What initiated the urbanization of Dhaka in the remote past is shrouded in mystery. The favourable geographical features and geological setting of the place might have been the dominating factors for its urbanization. The Buriganga river provided to Dhaka, the river-transport which was the best mode of communication in the old days. Again, a large area of uplifted land mass in the midst of an extensive low plain was also available at the place in favour of its urbanization. (Alam and Aurangzeb, 1975).

The considerable historical and architectural evidences such as the inscriptions on the tombs and shrines in Dhaka dating to the fourteenth and fifteenth centuries and discovery of Gupta gold imitation coins dating seventh century support the view that Dhaka was in existence much before the Mughal times. (Rizvi, 1975)

After Dhaka became the capital of East Bengal province (renamed as East Pakistan in 1956) of the then Pakistan and administrative centre of about 45 million people in August 1947, expansion of Dhaka city with the old town as its broad base started to meet the needs of the new provincial capital.

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Since the independence of Bangladesh in 1971 Dhaka has grown tremendously and urban developments have been progressing in full swing to meet the requirements of the capital city of independent sovereign Bangladesh.

Systematic geotechnical investigations consisting of different field and laboratory testings have been carried out extensively, particularly during the last three decades in different areas of Dhaka city for small to large scale public and private house building projects, which include mostly high-rise residential, commercial, school, college, university, bank and Govt. and private office buildings.

Available geotechnical investigation results of 249 undisturbed and about 3500 disturbed soil samples from 203 boreholes of varying depths in different investigated areas which remain above the normal flood levels and are formed of Uplifted Pleistocene deposits in Dhaka city have been presented in this paper with evaluation, analysis and discussion of the results to add to the geotechnical data of the city.

SURFACE GEOLOGY

The surface geology of Bangladesh may be divided into three major geomorphologic zones; (1) Tertiary and Pleistocene Hill Formations, (2) Uplifted Pleistocene Alluvial Terraces and (3) Recent Flood-Plain and Piedmont Alluvium. These are shown in Fig.1. The Pleistocene alluvial terraces are restricted to three main regions, namely the Barind Tract (about 9324 sq. kms.), the Madhupur Tract (about 4105 sq. kms.) and the Lalmai Hills (about 34 sq. kms.). (Morgan and McIntire, 1959; Bramer, 1971; Hunt, 1976; and Master Plan Organisation Report, 1986).

Dhaka city is situated on the Dhaka Terrace (DT), which constitutes the southern portion of the Uplifted Pleistocene Madhupur Tract. Dhaka Terrace lies between the Buriganga and Sitalakhya rivers. The area slopes towards the south and the south-east and includes Mirpur, Kurmitola, Dhaka and Demra areas.

This terrace has intensively been dissected by the tributaries of the Turag, the Buriganga and the Balur rivers and formed numerous rounded and elongated hillocks. The elevation of DT ranges from about 6.096 to 11.25 metres above mean sea level (A.M.S.L.). The high lands of DT remain above the normal flood level. The average elevation of the Buriganga and the Sitalakhya flood plains is about 3.048 metres A.M.S.L. The valley floors of these rivers have reached the base level (Alam, 1988).

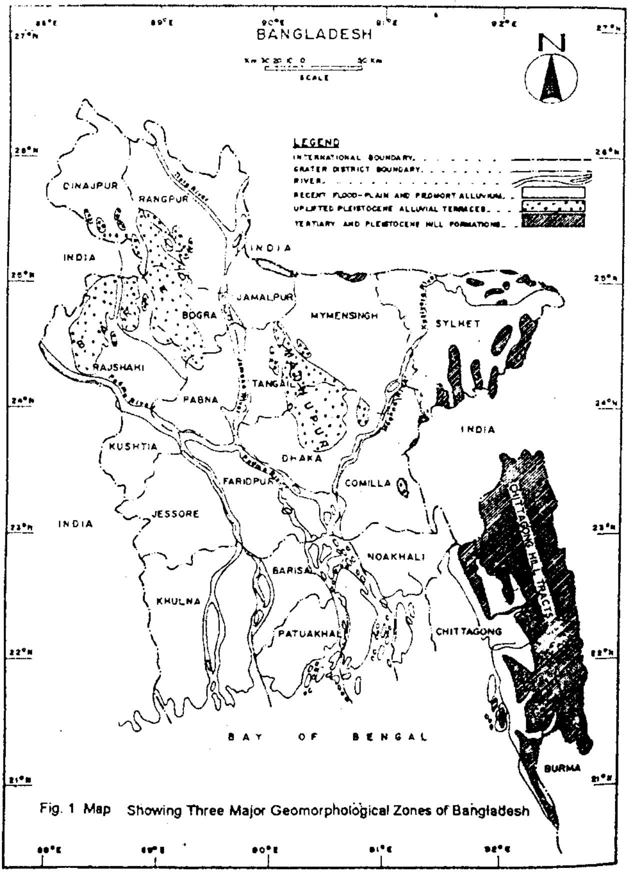


Fig 1. Map showing Three Major Geomorphological Zones of Bangladesh

GEOTECHNICAL INVESTIGATIONS

Field Investigations

The field investigation included the measurement of standard penetration resistance (N) by standard penetration test (SPT) and collection of the SPT spoon sample (disturbed sample) commonly at 1.5 metre interval or at change of strata, collection of the undisturbed sample usually in 75 mm dia thin-walled seamless steel tube from the cohesive soil layer, preparation of the field log of the soil profile, measurement of the ground water table within the borehole and transportation of the disturbed and undisturbed samples for the laboratory tests. Generally 100 mm diameter borehole was sunk by wash boring technique following the standard procedures and extended to the depth mostly of about 20 to 30 metres and occasionally exceeding the 30 metres depth depending on the requirement.

Laboratory Investigations

The classification tests included the determination of the natural water content (W_N), liquid limit (W_L), plastic limit (W_P), plasticity index (I_P), grain size distribution and specific gravity (Gs). The unit weight (γ), initial void ratio (e_o) and the degree of saturation (S) of the undisturbed samples were determined.

The strength tests on the undisturbed cohesive soil included the determination of the unconfined compressive strength (q_u) or occasionally the unconsolidated undrained shear strength (C_u) and the one-dimensional consolidation test properties, namely compression index (C_c), coefficient of consolidation (C_v), present effective overburden pressure (P'_o), past effective pressure or effective preconsolidation pressure (P'_c) and overconsolidation ratio (OCR). Relevant ASTM/BS specifications were followed for all laboratory tests.

RESULTS AND DISCUSSION

Subsoil Profiles

The approximate areas of geotechnical investigation in Dhaka city covered in this paper are described in Table-1 and shown in Fig.2. Some typical subsoil profiles of the different investigated areas are presented in Fig.3

The subsoil profiles show the occurrence of layers of light brown to brown, reddish brown, light red to red clay with grey mottling and trace to considerable amount of fine sands, occasionally mixed with traces of calcareous and/or ferruginous nodules and having low to medium and high plasticity upto different depths of about 4-11m from the existing ground surface in different sites except a site in Area-1, where the site shows the presence of brown, low to medium and high plastic clay layers upto the maximum explored depth of 21m. There could be some sites in some areas in the city where top clay layer of larger depth could be present. Plastic silt and non-plastic silt layers were encountered only at a few locations at some depths. The typical subsoil profiles in Fig.3 generally show the presence of sand strata underlying the upper clay and silt layers in the different investigated areas of the city.

The average N for every 3 m depth of sandy soils strata and the range of the average q_u of the undisturbed cohesive samples taken from the different sites are shown along the sides of the typical soil profiles. The average soil profiles are presented for general information and they are not substitutes of detailed subsoil investigation at any individual site. Unified Soil Classification System (USCS) symbols have been used to describe the soil strata in the average soil profiles. Strata depths are shown with respect to the existing ground level (EGL).

Table-1 Summary of Classification and Strength Tests Parameters of Undisturbed Cohesive Samples

Name of areas	Total bore-hole (No.)	Bore-hole depth (m)	Description of top cohesive layer	Range of classification tests parameters: % Finer than 0.075 (mm)	% Finer than 0.002 (mm)	W_N (%)	W_L (%)	I_p (%)	G_s	Range of unconfined compressive strength and consolidation tests parameters: γ (kN/m^3)	q_u (kPa)	e_o	S (%)	C_c	C_v cm^2/min	P'_o (kPa)	P'_c (kPa)	OCR
Uttara Model Town Area (Area-1)	35	14.0-21.0	Light brown to brown/reddish brown/light red to red CLAY/SILT with grey mottling, trace fine sand, low to high plastic, sometimes mixed with ferruginous concretions	65-99	14-33	20.4-33.7	30-73	8-41	2.67-2.71	16.67-21.19	72.0-366.7	0.626-0.884	74.4-100.0	0.122-0.253	0.026-0.790	21-116	118-240	1.18-4.71
Banani, Gulshan Model Towns & Mahakhali Commercial Area (Area-2)	43	10.0-30.0	Light brown to brown/reddish brown/light red to red CLAY/SILT with grey mottling, trace to considerable fine sand, low to high plastic, sometimes mixed with ferruginous and calcareous nodules	61-99	11-40	19.5-30.0	37-62	12-36	2.67-2.72	16.67-21.28	67.9-399.0	0.542-1.013	74.8-100.0	0.100-0.225	0.030-0.635	21-128	130-235	1.36-4.32
Tejgaon Commercial Area (Area-3)	39	20.0-30.0	Light brown to brown/ reddish brown/ light red to red CLAY/ SILT with grey mottlings, trace to considerable fine sand, low to high plastic	65-99	11-40	18.7-38.6	34-63	10-33	2.67-2.76	17.12-21.03	42.6-456.8	0.603-0.845	84.8-100.0	0.112-0.230	0.100-1.580	22-121	137-225	1.38-4.26
Mohammadpur, Lalmatia & Dhanmondi Residential Areas (Area-4)	20	12.0-25.0	Light brown to brown/ reddish brown/ light red to red CLAY with grey mottling, trace to considerable fine sand, medium to high plastic	61-99	11-30	18.2-29.5	36-63	12-35	2.67-2.70	18.14-20.11	115.9-476.0	0.657-0.864	91.4-100.0	0.110-0.187	0.063-1.010	37-113	129-200	1.47-4.40
Sher-e-Bangla Nagar Area (Area-5)	10	20.0-30.0	Light brown to brown/ reddish brown/ red CLAY with grey mottling, trace to little fine sand, high plastic	89-100	15-23	16.8-25.2	52-65	25-35	2.68-2.70	17.95-20.30	82.2-448.0	0.596-0.700	78.4-100.0	0.134-0.172	0.037-0.057	18-115	153-215	2.14-4.18
Eskaton, Mogbazar & Minto Road Areas (Area-6)	19	15.0-30.0	Brown reddish brown/red CLAY with grey mottling trace to considerable fine sand low to high plastic, sometimes mixed with ferruginous and calcareous nodules	84-99	13-24	18.0-29.2	34-59	12-31	2.68-2.75	17.85-20.89	81.4-462.0	0.652-0.746	84.9-92.9	0.100-0.157	1.033-1.849	48-120	130-235	1.45-2.90
Nilkhet, Palashi & Chankharpul Areas (Area-7)	13	18.0-20.0	Brown reddish brown/ red CLAY with grey mottlings trace to considerable fine sand, high plastic, sometimes mixed with ferruginous and calcareous nodules	80-100	14-29	19.2-26.3	51-66	21-35	2.67-2.71	19.12-20.27	70.9-295.5	0.572-0.740	70.0-100.0	0.098-0.197	0.030-0.296	50-115	152-212	1.84-3.89
Segun Bagicha, Purana Paltan, Topkhana & Abdul Gani Road Areas (Area-8)	10	25.0	Light brown to brown/reddish brown/ red CLAY with grey mottlings trace to considerable fine sand, high plastic, sometimes mixed with ferruginous and calcareous nodules	61-93	13-25	20.5-25.6	38-65	18-31	2.67-2.73	19.11-20.30	98.1-329.0	0.529-0.786	84.3-100.0	0.119-0.240	0.06-0.30	21-115	156-290	1.59-4.71
Motijheel & Dilkusha Commercial Area (Area-9)	8	21.0	Reddish/ reddish brown CLAY with grey mottlings, trace to some fine sand, medium to high plastic sometimes mixed with ferruginous & calcareous nodules	78-91	10-17	22.0-28.6	38-64	14-26	2.67-2.71	18.54-20.26	140.0-428.0	0.579-0.652	96.7-100.0	0.105-0.144	0.079-0.156	22-83	150-170	1.96-2.93
Jatrabari Area (Area-10)	6	21.0	Light brown to brown CLAY, trace fine sand medium to high plastic, sometimes mixed with ferruginous & calcareous nodules	[illegible]	20-22	21.4-34.2	46-60	20-28	2.69	20.04-21.10	59.5-360.9	0.573-0.588	97.9-100.0	0.119-0.203	1.890-2.026	54-121	180-251	1.55-2.07
[illegible]anges :				[illegible]	10-40	16.8-38.5	30-73	8-41	2.6[illegible]-2.7[illegible]	16.57-[illegible]	42.6-476.0	0.529-1.013	70.0-100.0	0.098-0.253	0.026-2.026	18-128	118-290	1.18-4.71

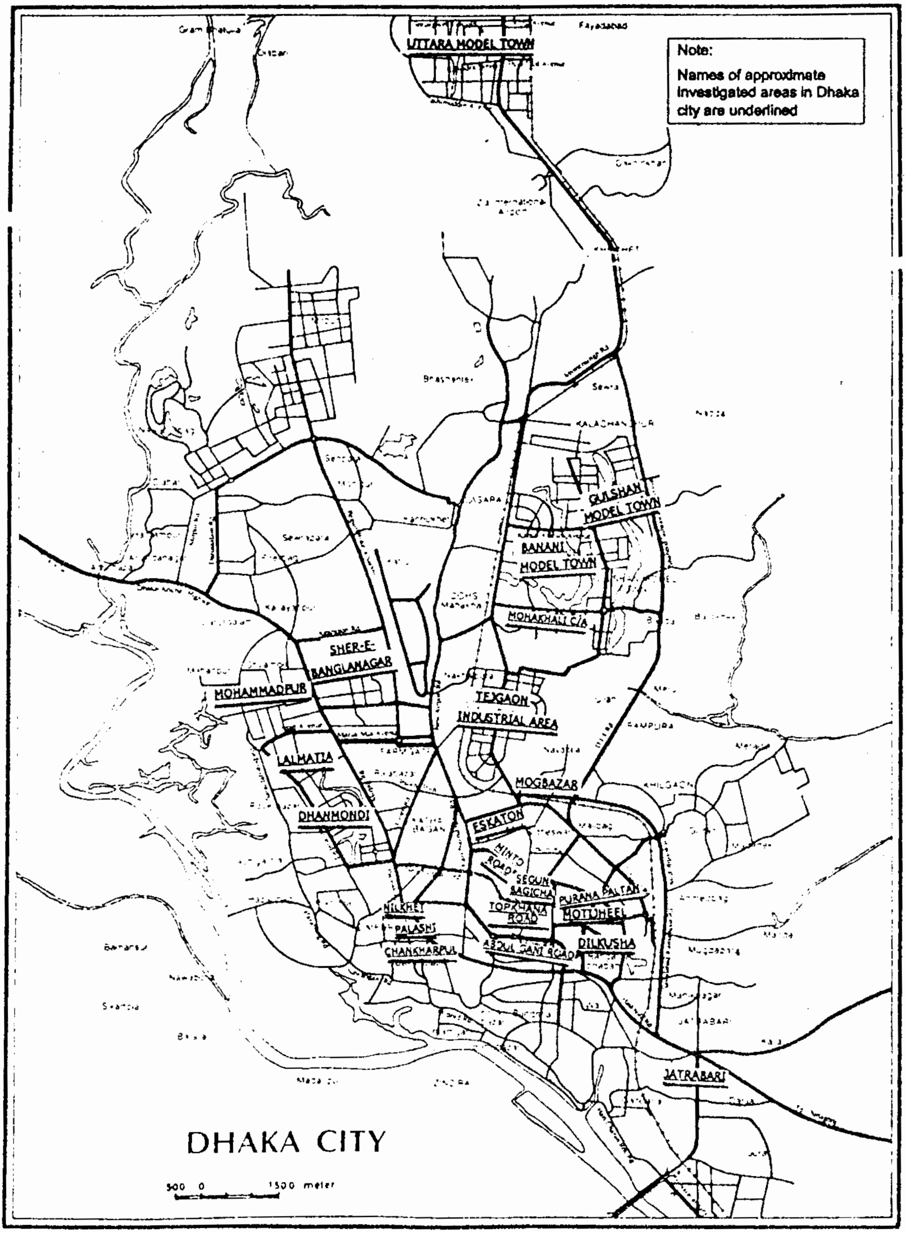
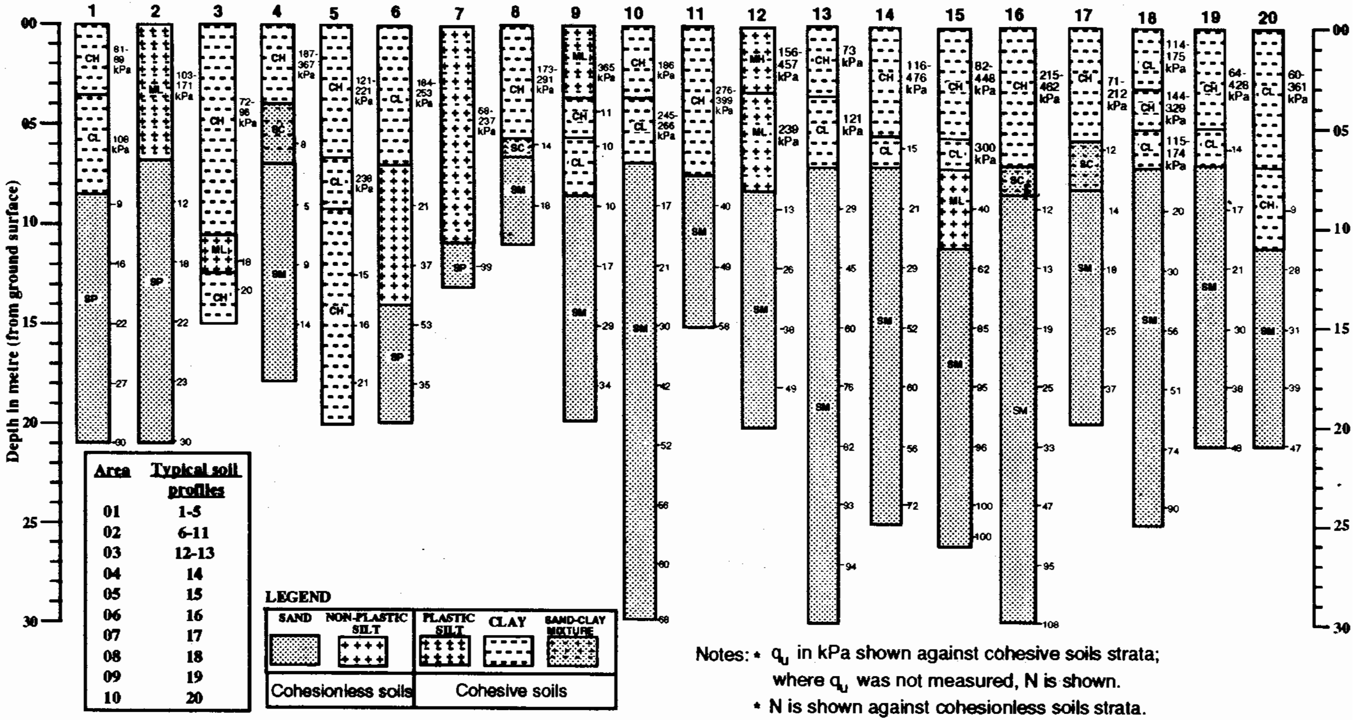


Fig 2. Map showing Approximate Investigated Areas in Dhaka City

Fig. 3 Some Typical Soil Profiles in Dhaka City



Notes: * q_u in kPa shown against cohesive soils strata; where q_u was not measured, N is shown.
* N is shown against cohesionless soils strata.

The consistency of the upper cohesive soil strata in Dhaka city is predominantly medium, stiff and very stiff and occasionally hard as indicated by q_u and N of the cohesive soil layers. The relative density of the underlying sand strata is predominantly medium and dense having the N in the range of about 9-10 to about 30-50 with increasing depth, and occasionally very dense at greater depths with N more than 50 and reaching about 90-100 in some areas.

Classification and Index Properties

The classification and index properties are summarised in Table-1 along with the strength properties showing the ranges of the different soil parameters for each area and then at the bottom of the table the ranges of the test parameters covering all the areas to give an idea about the general characteristics of the soils in Dhaka city.

Granular characteristics

The composite grain size distribution curves for the cohesive and cohesionless soils of the Uplifted Pleistocene areas in Dhaka city are shown in Figs. 4(a) and 4(b) respectively.

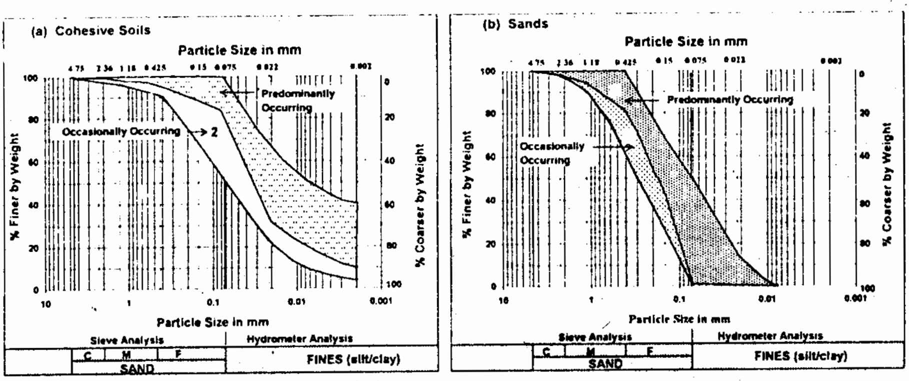


Fig 4. Composite Grain Size Curves of Uplifted Pleistocene Soils

Unit Weight

The unit weight (γ) measured on 249 undisturbed cohesive samples was found in the range of 16 kN/m^3 to 21 kN/m^3 with majority between 18 kN/m^3 and 21 kN/m^3. The cohesive soil layers were generally quite firm and compacted and were characterised by low water content.

Degree of Saturation

The degree of saturation of 81 typical cohesive samples of Dhaka city was obtained in the range of 70 to 100 percent with majority between 90 and 100 percent.

Specific Gravity

The specific gravity of the cohesive deposits in Dhaka city lies in the range of 2.67 to 2.76.

Natural Water Content, Liquid Limit and Plastic Limit

The natural water content of the cohesive deposits in Dhaka city is generally low and mostly very close to or less than the plastic limit. The values of W_N, W_L and W_P for 160 cohesive samples of the different areas in Dhaka city indicate that W_N is less than W_P for about 69 percent samples, W_N is equal to W_P for only about 7 percent samples and W_N is larger than but mostly closer to W_P for about 24 percent samples.

Position of Dhaka Clays on the Plasticity Chart

The liquid limit and plasticity index of 366 cohesive soil samples of Dhaka city are plotted on the Plasticity Chart in Fig. 5. As only about 10 percent samples are plastic silts (ML and MH), for all practical purposes the Uplifted Pleistocene cohesive deposits in Dhaka city can be called *Dhaka clays*, like *London clays*, *Bangkok clays*, *Leda clays*, etc. Plots of Dhaka clays in Fig.5 have given a linear regression equation of $I_p = 0.74\ (W_L - 19)$ almost parallel and very close to the A-line of the Plasticity Chart having the equation of $I_p = 0.73(W_L - 20)$.

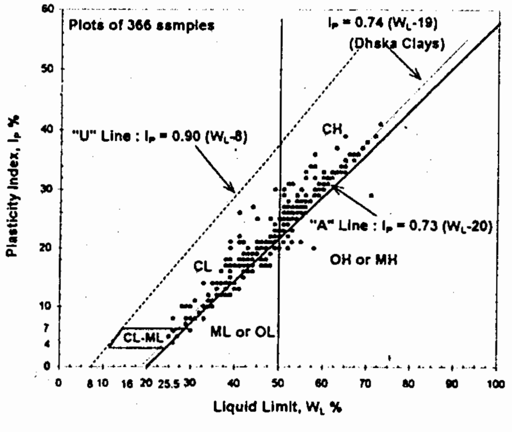


Fig 5. Position of Dhaka Clays on Plasticity Chart

Fig.5 also shows that about 50 percent of these cohesive samples have $W_L \leq 50$, and about 50 percent cohesive samples have $W_L > 50$.

Eusufzai (1970) plotted the values of W_L and Ip of 22 representative clay samples of the 25 boreholes on the Plasticity Chart and found that all the clay samples of Dhaka city of his study were above the A-line of the chart within a band, and suggested that except a few clay samples of a certain area all the clay samples of Dhaka city fell remarkably within or very close to the band for glacial clays of Boston, Detroit, Chicago and Canada as identified by A. Casagrande. A great majority of the plotted points in Fig. 5 of the present paper support the above view of Eusufzai on Dhaka clays.

Sensitivity

Dhaka clays are insensitive. A selected number of the undisturbed clay samples from different areas were tested for q_u in the natural state and in the remoulded state. No reduction of the q_u was obtained in the remoulded state of the clay samples.

Activity

'Activity' is defined as the ratio of plasticity index (Ip) to clay fraction content (Cp) and related to mineralogy (Skempton 1950). The clay fraction content is expressed in percentage by weight of particles finer than 2 microns.

Skempton and Northey (1952) have shown that mineral assemblage of illite, kaolinite, montmorillonite, calcite, quartz, mica, etc. in different order of predominance may give different values of clay fraction, activity, undrained shear strength and sensitivity.

In terms of activity, clays have been classified by Skempton (1953) as *inactive clays* (activity <0.75), *normal clays* (activity 0.75-1.25) and *active clays* (activity >1.25)

From the information of the 27 clays of different locations, Skempton (1953) has deduced that there is some degree of correlation between activity and the mineralogy and geological history of a clay.

Skempton (1953) has farther shown that if the plasticity index is plotted against the clay fraction content of a number of samples taken from 'any particular clay stratum' then the points lie about a straight line which extrapolates back to the origin, although there is generally a quite wide range in the numerical values for both properties. The relationship as shown by him for the four natural clays is reproduced in Fig. 6 for convenience of comparing the activity characteristics of Dhaka clays.

In order to classify Dhaka clays in terms of *activity*, plasticity indexes of a large number of inorganic cohesive samples of different investigated areas of Dhaka city are plotted against corresponding 2 micron clay fraction in Fig. 7. Majority samples are found in the 'normal clay group' and a lesser number of samples are in the 'inactive clay group'. No inorganic clay in the 'active clay group' was found in the different sites of the investigated areas in Dhaka city. The scattering of

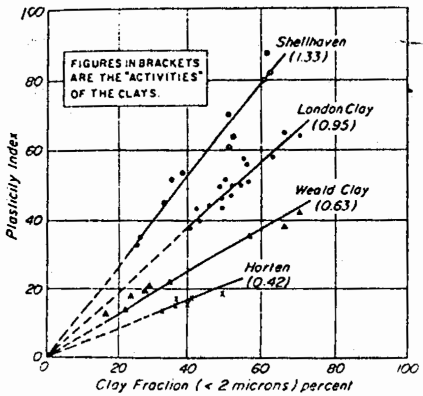


Fig 6. Relationship between Plasticity Index and Clay Fraction (Reproduced from Skemption, 1953)

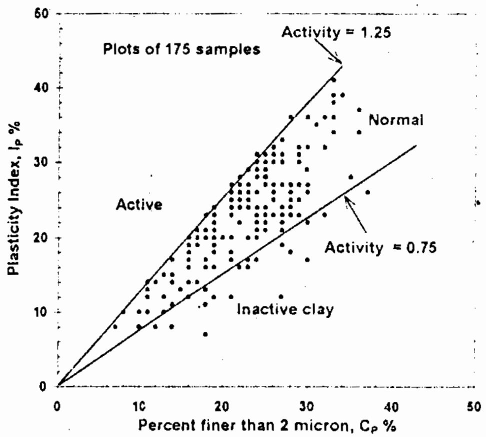


Fig 7. Classification of Dhaka Clays according to Activity

the plots of the clay samples may be due to the difference in the mineral assemblage in the clay samples of different sites.

Again, ten individual sites, each of which had at least five tested clay samples, were selected. Plasticity indexes were plotted against clay contents of the tested samples of each of the ten sites separately. It was observed that the average straight lines around the plotted points for different sites had different slopes, some of them extrapolated back to the origin and the others did not. Then the plasticity indexes and the clay contents of all the 119 clay samples of the said ten sites were plotted and the slope of the average straight line around the plotted points did not exactly pass through the origin on extrapolation and gave the following linear relation with wide scattering of plotted points:

$Ip = 1.0093Cp + 0.5238$,

and $r = 0.812$, where r is coefficient of correlatin.

As 'activity' of a clay sample is a ratio of Ip to Cp any small experimental error in Ip and/or Cp may appreciably change the activity value of a sample. During the preparation of this paper a site in Dhaka city was investigated and 23 clay samples from 9 boreholes of the site were tested with special care to find Ip and Cp as accurately as possible. The Ip and Cp for this 23 samples were in the range of about 13 to 28 percent and 10 to 27 percent respectively. The Ip plotted against the Cp gave the following linear correlation with plotted points fairly closed to the linear regression line:

$Ip = 0.8348\ Cp + 5.882$ and

$r = 0.8964$,

This linear equation indicates that when Cp approaches zero then also there may be a small amount of plasticity in Dhaka clays in some sites. This means that the soil fraction between 0.075mm and 0.002mm of Dhaka clays also probably contributes slight plasticity to the soil. However, this impression would need further studies on 'activity' of Dhaka clay of more individual sites before any conclusion. Hoque (1983) obtained the following linear relation for 16 alluvial soils of Bangladesh :

$Ip = 0.658\ Cp + 2.71$ and $r = 0.928$.

Seed, et. al. (1962) have suggested the following formula for 'activity';

$$\text{Activity} = \frac{\text{Plasticity Index}}{\text{Clay content - 10}}$$

and with a reference to Casagrande (1958) have farther added that above difference from Skemption's equation may be attributed in large measure to (1) difference in the characteristics of liquid limit devices used in Great Britain (by Skempton) and the United States (by Seed, et. al.) and (2) the relatively poorer grading of artificially prepared soils (used by Seed et. al) as compared with natural soils (used by Skempton).

It is mentioned here that British liquid limit device was used for measuring the liquid limits of Dhaka clay samples considered in the present paper.

Seed, et. al. (1964a) studied on liquid limit, plastic limit, plasticity index, and 2 micron clay fraction content of a large number of artificial clay samples containing mixtures, in pairs of kaolinite, illite and bentonite clay minerals, or these individual clay minerals and showed that activity relationships for these artificial soils did not pass through the origin and the relationships were found to be linear with the plasticity index being zero at a 2-micron clay content of about 9% and it was suggested for those artificial soils the following formula :

$$\text{Activity} = \frac{\text{Plasticity Index}}{\text{Clay content - 9}}$$

Seed, et al. (1964b) have suggested 'that at clay content greater than approximately 40%, the plasticity indices of soils containing a given type of clay will be directly proportional to the clay content but this relationship will not be true at lower clay content'; and 'thus, definitions of the activity of clays based on simple linear relationships should be used with caution'.

The 2-micron clay content of the Dhaka clay samples studied in this paper did not exceed 40 percent as may be seen in Fig.7.

SHEAR STRENGTH CHARACTERISTICS

Unconfined Compression Test Results

The ranges of q_u for the 227 undisturbed cohesive samples are presented areawise in Table 1. The numbers of cohesive samples lying in the different ranges of q_u are shown in Fig.8. There were only a few soft cohesive samples of small depths with q_u between 25 and 50 kPa and also some medium samples occasionally at some sites, generally at small depths with q_u between 50 and 100 kPa. A great majority of cohesive samples gave q_u between 100 and 300 kPa. Again, some cohesive samples occurring occasionally at some sites, generally at greater depths, gave q_u between 300 and 500 kPa.

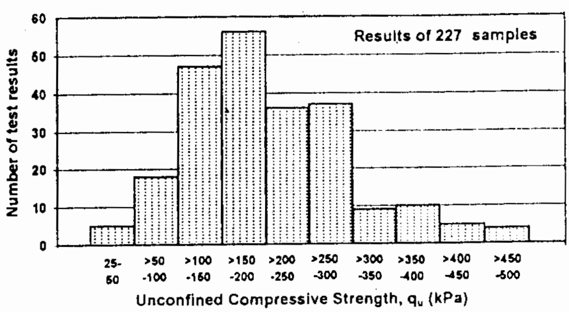


Fig 8. Range of Unconfined Compressive Strength

Correlation between q_u and N

The values of N are plotted against those of q_u in Fig.9 to establish a correlation between q_u and N. In spite of wide scattering of plots, following relationship is suggested:

q_u = 16 N (kPa), where 16 is the value of the proportionality factor(f) for saturated Dhaka Clays as shown in Fig.9(a). This value of f=16 obtained in the present paper appears to be in good agreement with the earlier recommended value of 'f ' for Uplifted Pleistocene Madhupur clay residuum which included also some Dhaka city clays. (Serajuddin and Chowdhury, 1996). In the present correlation the test results obtained after 1996 from many new sites of Dhaka city have been considered.

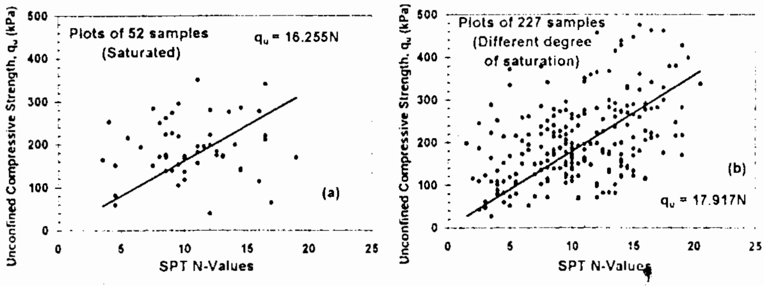


Fig 9. Correlation between Unconfined Compressive Strength and SPT N-Value

The relationship is better applicable to saturated cohesive soils than the than the highly unsaturated ones because a strong soil with a high air content may have a lower N-value than an equally strong saturated soil in which the voids having water can not collapse as the SPT sampler advances (Peck, et. al. 1974).

COMPRESSIBILITY CHARACTERISTICS

Presentation of Consolidation Test Parameters

The ranges of C_C, C_V, P'_O, P'_C, OCR, γ, e_O, S and G_S of the eighty-one consolidation test samples are presented areawise in Table-1. It can be seen from Fig.10 and Fig.11 that majority of the Dhaka cohesive samples have Cc between about 0.100 and 0.200 and OCR between about 1.50 and 3.00. According to Bowles (1997) OCRs of 1 to 3 are obtained for lightly overconsolidated soils and heavily overconsolidated soils might have OCRs> 6 to 8.

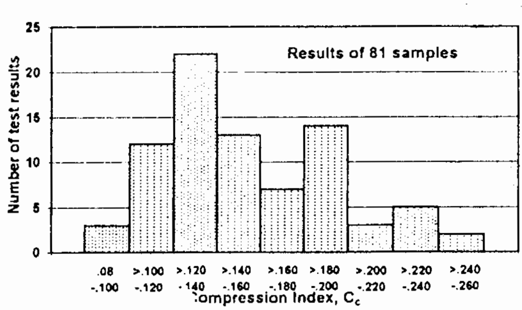


Fig 10. Range of Compression Index

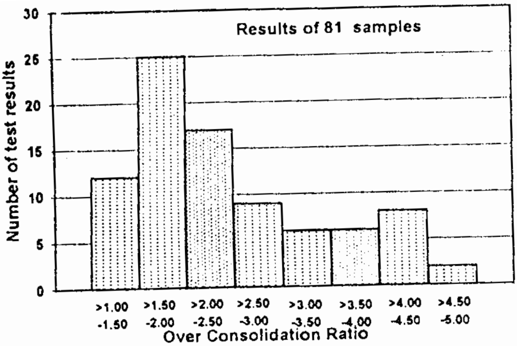


Fig 11. Range of Over Consolidation Ratio

Compression Index Correlations

A good number of empirical equations, that might be used to make estimates of compression indexes, were developed by different researchers for different regional and local soils. The Cc of thirty-one saturated Dhaka clay samples computed by the following ten selected empirical equations and actual Cc were compared:

Compression Index Equations used	**Source/ Reference**	**Equations**
$C_c = 0.009\,(W_L - 10)$	Terzaghi and Peck (1967)	Eq.-1 *
$C_c = 0.0078\,(W_L - 14)$	Serajuddin and Ahmed (1967)	Eq.-2
$C_c = 0.009W_N + 0.005W_L$	Kappula (1986)	Eq.- 3 *
$C_c = -0.0997 + 0.009W_L + 0.0014\,I_P + 0.0036W_N + 0.1165e_o + 0.0025Cp$	Kappula (1981)	Eq.-4 *
$C_c = 0.37(e_o + 0.003W_L + 0.0004W_N - 0.34)$	Azzouz et.al (1976)	Eq.-5 *
$C_c = -0.156 + 0.411e_o + 0.00058W_L$	Al-Khafaji & Andersland (1992)	Eq.-6*
$C_c = 0.30(e_o - 0.27)$	Azzouz et. al (1976)	Eq.-7
$C_c = 0.44(e_o - 0.30)$	Serajuddin and Ahmed (1967)	Eq.-8
$C_c = 0.4049(e_o - 0.3216)$	Serajuddin (1987)	Eq.-9
$C_c = 0.2765[G_s\{(1+e_o)/Gs\}^2 - 0.5171]$	Serajuddin (1987)	Eq.-10

Note : The equations marked with * are taken from Table 2-5 of Bowles (1997)

The values of Cc computed from the equations 1, 2, 3 and 4 were very high compared to the actual values of Cc for Dhaka clay samples. So, these four equations do not appear to be applicable to Dhaka clays.

The actual C_c and the C_c computed from Eq. (5) to Eq. (10) for the thirty-one clay samples presented in Table 2 are comparable.

The Eq. (8), Eq. (9) and Eq. (10), which do not contain liquid limit and water content parameters and are established by using the laboratory tests data of Bangladesh clays and plastic silts, gave computed C_c very close to the actual C_c for Dhaka clays.

Table 2 Comparison of Values of Actual C_C and Computed C_C

Sl. No.	Soil properties							Actual C_C	Computed C_C by different empirical equations					
	W_N (%)	W_L (%)	W_P (%)	I_P (%)	C_P (%)	e_o	G_S		$0.37(e_o+0.003W_L+0.0004W_N-0.34)$ Eq. (5)	$-0.156+0.411e_o+0.00058W_L$ Eq. (6)	$0.3(e_o-0.27)$ Eq. (7)	$0.44(e_o-0.30)$ Eq. (8)	$0.4049(e_o-0.3216)$ Eq. (9)	$0.2765[Gs((1+e_o)/Gs)^2-0.5171]$ Eq. (10)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	25.4	67	31	36	33	0.700	2.710	0.129	0.2113	0.1706	0.129	0.176	0.1532	0.1519
2	23.9	59	29	30	26	0.632	2.680	0.150	0.1771	0.1380	0.109	0.146	0.1257	0.1318
3	22.3	59	29	30	25	0.626	2.690	0.188	0.1746	0.1355	0.107	0.143	0.1233	0.1288
4	28.7	55	28	27	22	0.765	2.685	0.150	0.2225	0.1903	0.149	0.205	0.1795	0.1778
5	24.5	53	28	25	16	0.648	2.680	0.122	0.1764	0.1411	0.113	0.153	0.1322	0.1372
6	19.6	54	28	26	24	0.542	2.700	0.100	0.1376	0.0981	0.082	0.106	0.0892	0.1005
7	24.7	54	28	26	30	0.729	2.678	0.172	0.2075	0.1749	0.138	0.189	0.1650	0.1657
8	20.2	51	26	25	28	0.580	2.681	0.210	0.1484	0.1120	0.093	0.123	0.1046	0.1145
9	24.5	58	28	30	21	0.705	2.701	0.135	0.2031	0.1674	0.131	0.178	0.1552	0.1546
10	26.4	59	29	30	19	0.740	2.710	0.130	0.2174	0.1824	0.141	0.194	0.1694	0.1659
11	28.0	49	27	22	25	0.752	2.700	0.150	0.2110	0.1815	0.145	0.199	0.1743	0.1714
12	22.0	44	26	18	23	0.622	2.700	0.195	0.1564	0.1252	0.106	0.142	0.1216	0.1264
13	23.5	53	28	25	22	0.624	2.680	0.122	0.1674	0.1312	0.106	0.143	0.1224	0.1291
14	23.1	44	26	18	16	0.633	2.670	0.119	0.1607	0.1297	0.109	0.147	0.1261	0.1332
15	22.8	51	28	23	21	0.642	2.667	0.225	0.1717	0.1374	0.112	0.150	0.1297	0.1365
16	24.8	49	25	24	14	0.710	2.708	0.136	0.1950	0.1642	0.132	0.180	0.1573	0.1556
17	26.2	45	25	20	16	0.679	2.697	0.162	0.1793	0.1492	0.123	0.167	0.1447	0.1460
18	26.0	55	25	30	27	0.728	2.690	0.144	0.2085	0.1751	0.137	0.188	0.1646	0.1639
19	25.1	59	29	30	21	0.640	2.698	0.183	0.1802	0.1413	0.111	0.150	0.1289	0.1327
20	23.7	56	28	28	19	0.660	2.700	0.102	0.1841	0.1477	0.117	0.158	0.1370	0.1392
21	23.2	58	29	29	22	0.647	2.690	0.125	0.1814	0.1436	0.113	0.153	0.1318	0.1358
22	21.7	55	28	27	19	0.572	2.688	0.185	0.1501	0.1110	0.091	0.120	0.1014	0.1112
23	23.1	55	28	27	16	0.624	2.678	0.135	0.1695	0.1324	0.106	0.143	0.1224	0.1293
24	24.8	54	21	33	22	0.702	2.650	0.119	0.1976	0.1638	0.130	0.177	0.1540	0.1593
25	25.6	59	28	31	20	0.686	2.702	0.188	0.1973	0.1602	0.125	0.170	0.1475	0.1479
26	24.1	44	25	19	13	0.644	2.692	0.157	0.1649	0.1342	0.112	0.151	0.1305	0.1346
27	21.1	55	28	27	21	0.529	2.702	0.125	0.1341	0.0933	0.078	0.101	0.0840	0.0963
28	25.8	51	28	23	17	0.579	2.699	0.105	0.1489	0.1115	0.093	0.123	0.1042	0.1124
29	24.1	53	28	25	14	0.609	2.673	0.144	0.1619	0.1250	0.102	0.136	0.1164	0.1248
30	23.4	50	28	22	14	0.652	2.695	0.129	0.1744	0.1410	0.115	0.155	0.1338	0.1370
31	22.1	54	25	29	20	0.573	2.692	0.203	0.1494	0.1108	0.091	0.120	0.1018	0.1112
MAX	28.7	67	31	36	33	0.765	2.710	0.225	0.223	0.190	0.149	0.205	0.180	0.178
MIN	19.6	44	21	18	13	0.529	2.650	0.100	0.134	0.093	0.078	0.101	0.084	0.096
MEAN	24.0	54	27	26	21	0.651	2.690	0.150	0.178	0.143	0.114	0.154	0.133	0.138
S. D.	2.05	5.19	1.89	4.34	4.9	0.061	0.014	0.033	0.024	0.026	0.018	0.027	0.025	0.021

In Fig.12 the e_o is plotted against the actual C_c of the eighty-one clay samples and the slopes obtained from Eqs. (7), (8) and (9) are superimposed on Fig.12 for comparison. In spite of wide scattering of plotted points, Eq. (8) by Serajuddin and Ahmed(1967) and Eq. (9) by Serajuddin(1987) appear to give better fitting than Eq. (7) by Azzouz, et. al. (1976), probably because the Eqs. (8) and (9) were established on the test results of the cohesive soils of Bangladesh.

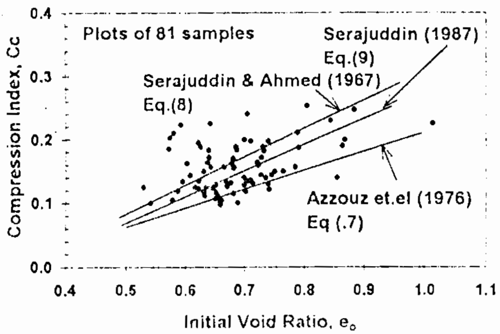


Fig 12. Compression Index versus Initial Void Ratio

Comparison of P'c Determined by Two Methods

The P'c for all the consolidation test samples was determined by the void ratio - log pressure (e-log p) method suggested by Casagrande (1936). The method is very popular because it is easy to use compared to several other methods.

However, the log e-log p method proposed by Sridharan et. al. (1991) and demonstrated in Figure 2-20 of Bowles (1997) was used to determine P'c for twenty Dhaka clay samples, two samples from each investigated area in Dhaka city. The P'c and OCR obtained by the two methods as presented in Table 3 appear to be reasonably close to each other.

CONCLUSION

The paper is expected to give the engineers and engineering profession dealing with planning, design and construction of structures on or in or by means of the soils in Dhaka city some basic geotechnical data of Dhaka soils occurring in different areas of the city.

The information included in the paper may have particular value in preliminary site studies before extensive subsoil exploration and testing is undertaken for final design and construction.

Table 3. Comparison of Values of Effective Preconsolidation Pressure and Overconsolidation Ratio Determined by e-log p and log e-log p Methods

Name of Area	Sample No.	Sample Depth (m)	γ kN/m^3	Soil Type	P'_o (kPa)	e-log p method		log e-log p method	
						P'_c (kPa)	OCR	P'_c (kPa)	OCR
Uttara Model Town Area	1	5.45-5.85	19.6	CH	111	150	1.35	150	1.35
	2	5.47-5.85	19.7	CH	112	210	1.88	260	2.32
Banani, Gulshan Model Towns and Mohakhali Commercial Area	1	3.90-4.30	19.2	CH	79	182	2.30	182	2.30
	2	2.40-2.80	20.4	CH	53	170	3.21	200	3.77
Tejgaon Commercial Area	1	5.45-5.85	19.9	CL	112	163	1.46	185	1.65
	2	5.45-5.85	19.4	CL	110	163	1.48	190	1.73
Mohammadpur, Lalmatia and Dhanmondi Residential Areas	1	3.97-4.35	19.7	CH	82	150	1.83	230	2.80
	2	5.47-5.85	18.5	CL	105	200	1.90	240	2.29
Sher-e-Bangla Nagar Area	1	3.80-4.20	19.5	CH	78	210	2.69	185	2.37
	2	2.40-2.80	19.7	CH	51	150	2.94	180	3.53
Eskaton, Mogbazar and Minto Road Areas	1	3.95-4.35	19.2	CL	80	225	2.81	220	2.75
	2	5.45-5.85	20.9	CL	118	130	1.10	180	1.53
Nilkhet, Palashi and Chankharpul Areas	1	3.90-4.18	19.6	CH	79	163	2.06	170	2.15
	2	3.95-4.35	20.4	CH	85	200	2.35	150	1.76
Segun Bagicha, Topkhana, Purana Paltan and Abdul Gani Road Areas	1	5.37-5.77	19.9	CL	111	180	1.62	260	2.34
	2	2.95-3.35	20.3	CH	64	190	2.97	180	2.81
Motijheel and Dilkusha Commercial Areas	1	3.95-4.35	19.5	CL	81	170	2.10	210	2.59
	2	2.40-2.80	19.1	CH	50	150	3.00	150	3.00
Jatrabari, Area	1	5.45-5.85	20.3	CH	115	251	2.18	260	2.26
	2	5.45-5.85	20.1	CL	114	180	1.58	200	1.75

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REFERENCE

Alam, M.K. and Aurangzeb, M.M. (1975), 'Geological Environment for Greater Dacca City', Conference Issue of The Third Annual Conference of Bangladesh Geological Society, pp. 34-37.

Alam, M.K. (1988), 'Geology of Madhupur Tract and its Adjoining Areas in Bangladesh', Government of the People's Republic of Bangladesh, Records of the Geological Survey of Bangladesh, Vol.5, Part 3.

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

Al-Khafaji, A. W., and O.B. Andersland (1992), 'Equations for Compression Index Approximation', JGED, ASCE, Vol. 118, No.1, January, pp. 148-153.

Bramer, H. (1971), 'Soil Survey Project, Bangladesh Soil Resources', UNDP/FAO, Rome.

Bowles, J.E. (1997), 'Foundation Analysis and Design', Fifth Edition, McGraw-Hill Companies, Inc.

Casagrande, A. (1936), ' The Determination of the Preconsolidation Load and Its Practical Significance', 1st ICSMFE, Vol. 3, pp. 60-64.

Casagrande, A. (1958), 'Notes on the Design of the Liquid Limit Device', Geotechnique, ICE.

Eusufzai, S.H.K. (1970), 'Soil profile across Dacca the capital city of East Pakistan', Proc. the Second Southeast Asian Conference on Soil Engineering, held at Singapore.

Hoque, A.M. (1983), 'An Examination of the Engineering Properties of Alluvial Soils of Bangladesh in Relation to their Mineralogical Composition', Journel of the I.E.B., Vol.11, No.3, July, pp.23-32.

Hunt, T. (1976), 'Some geotechnical aspects of road construction in Bangladesh', Geotechnical Engineering, Vol. 7(1), 1-33.

Morgan, J.P. and McIntire, W.G. (1959), 'Quaternary Geology of Bengal Basin, East Pakistan and India', Bulletin of the Geological Society of America, Vol.70, No.3, pp.319-341.

Master Plan Organisation (1986), 'Geology of Bangladesh', Technical Report No. 4.

Peck, R.B., Hanson, W.E. and Thornburn, T.H. (1974), Foundation Engineering, Wiley International Edition, John Wiley and Sons.

Rizvi, S.N.H. (1975), Government of the People's Republic of Bangladesh, Ministry of Cabinet Affairs, Establishment Division, 'Bangladesh District Gazetteers, Dacca'.

Skempton, A.W. (1950), 'Soil Mechanics in relation to geology', Proc. Yorkshire Geological Society.

Skempton, A.W. and Northey, R.D. (1952), 'The Sensitivity of Clays', Geotechnique Vol.3, pp. 30-53, I.C.E.

Skempton, A.W. (1953), 'The colloidal "Activity" of clays', Third ICSMFE, Zurich, Switzerland, pp. 57-61.

Seed, H.B., Woodward, R.J. and Lundgren, R (1962), 'Prediction of Swelling Potential for Compacted Clays', JSMFD, ASCE, SM3, June, 53-87.

Seed, H.B., Woodward, R.J. and Lundgren, R (1964a), 'Clay Mineralogical Aspects of the Atterberg Limits' JSMFD, ASCE, SM4, July, pp. 107-131.

Seed, H.B., Woodward, R.J. and Lundgren, R (1964b), 'Fundamental Aspects of the Atterberg Limits', JSMFD, ASCE, SM6, 75-105.

Serajuddin, M. and Ahmed, A. (1967), 'Studies on Engineering Properties of East Pakistan Soils', Proc. First Southeast Asian Regional Conference on Soil Engineering, Bangkok, Thailand, pp. 9-12.

Serajuddin, M. (1987), 'Universal Compression Index Equation and Bangladesh Soils', Proc. Ninth Southeast Asian Geotechnical Conference, Vol.1, pp. 5-61 to 5-72.

Sridharan, A., et. al. (1991), 'Improved Method for Estimation of Preconsolidation Pressure', Geotechnique, Vol.41(2), June, 263-268.

NOTATIONS :

C_p	=	Clay fraction content
C_c	=	Compression index
C_v	=	Coefficient of consolidation
e_o	=	Initial void ratio
f	=	Proportionality factor
Gs	=	Specific gravity
Ip	=	Plasticity index
N	=	Standard penetration resistance
OCR	=	Over Consolidation Ratio
P'_o	=	Present effective overburden pressure
P'_c	=	Past effective overburden pressure or effective preconsolidation pressure
q_u	=	Unconfined compressive strength
r	=	Coefficient of correlation
S	=	Degree of saturation in percentage
USCS	=	Unified Soil Classification System
W_N	=	Natural water content
W_L	=	Liquid limit
Wp	=	Plastic limit
γ	=	Unit weight