Sub-Soil Characteristics of Selected Coastal Regions of Bangladesh

Md. Anisuzzaman*, Arifuzzaman, and Ridha

***Abstract*—** Bangladesh is one of the most populated countries in the world having 32% coastal area (47,211 square kilometers). Coastal zone of Bangladesh, with its repeated cycle of floods, cyclones, and storm surges has proved to be one of the most disaster-prone areas of the world. To minimize the impact of cyclones, storm surge and flood in the coast the Government of Bangladesh is mainly limited to build cyclone shelters, earthen embankments, polders, and drainage. To make these structures stable and workable it is essential to essential to know the Sub-soil properties of these coastal regions. It is observed that the top layer coastal soil contains 2 to 33% clay, 50 to 96% silt and 1 to 25% sand. Liquid limit varies from 33 to 53%, plastic limit varies from 22 to 30% and plasticity index varies from 10 to 30%. The untrained shear strength of top soils varies from 15 to 40 kN/m^2. The compressibility ratio varies from 0.140 to 0.180. The selected coastal soils are clays of low plasticity (CL) or silts of low plasticity (ML).

***Keywords*—** Coastal area, disaster, sub-soil property, low plasticity.

I. Introduction

BANGLADESH is one of the most populated countries in the world having 32% coastal area (47,211 square kilometers). The great majority of the people directly or indirectly depend on agriculture for earning a living. The annual growth rate of GDP is greatly dependent on agricultural produce. The coastal regions of Bangladesh are vulnerable by so many natural disasters.

Coastal zone of Bangladesh, with its repeated cycle of floods, cyclones, and storm surges has proved to be one of the most disaster-prone areas of the world. These are recurrent natural hazards, causing loss of lands, agriculture and houses. It also destroys embankments, other hydraulic structures and livelihood along coastlines and estuaries. During the years from 1797 to 2007, Bangladesh has been hit by more than 60 severe cyclones. Bangladesh is a land of rivers and has a largest sea beach in the world. River bank and embankment failure occurs each and every year in our country. About 4000 km of coastal embankments have been constructed to safeguard against inundation, intrusion of saline water and devastation [1]. According to the population census in 2001, some 35 million people live in the coastal region which is 28% of the total population [1]. As the embankments and other hydraulic structures are the first and immediate defense against the storm surge, they face the most severe damages. As for example, cyclone SIDR destroyed fully 362 km and partially 1927 km of coastal embankment, whose damage value is 32 million US$ [2]. It is estimated that due to climate change, 22,000 square kilometer (16% of the total land area) of coastal regions will go under water, which may affect 17 million (15% of the total population) of coastal population [3].

To minimize the impact of cyclones, storm surge and flood in the coast the Government of Bangladesh is mainly limited to build cyclone shelters, earthen embankments, polders, and drainage. A total of 5,695 km of embankments, including 3,433 km in the coastal areas, 1695 flood control/regulating structures, and 4,310 km of drainage canals have been constructed by the Bangladesh Water Development Board (BWDB) during the last several decades. Embankments and polders have reduced floodplain storage capacity during floods, leading to an increase in water levels and discharges in many rivers.

But unfortunately these coastal embankments and other hydraulic structures are damaged each and every year due to the lack of proper design or construction practices. To make these structures stable and workable it is essential to design these structures as an engineered way. As embankments and other hydraulic structures are made with or construct over this coastal soil, it is essential to know the engineering properties of these coastal regions soil for proper design.

To facilitate the Engineers to design properly the main objectives of this research are as follows:

a) To know the soil characteristics of the selected locations of the coastal belt of Bangladesh.
b) To establish correlation between SPT N-value with strength and compressibility properties.

II. Past Researches

Various type of research works have been conducted in the past to know the soil properties of coastal regions, guidelines for restoration of roads and embankments as well as foundation requirements of coastal buildings of Bangladesh. Summary of some past researches related to coastal regions of

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Bangladesh and the effectiveness of vetiver grass against climatic change, slope protection, coastal embankment protection and so on have been described in this section. Amin et al [4] presented the index properties, unconfined compressive strength, shear strength parameters and attempted to correlate geotechnical properties of coastal soils for the districts of Barisal, Bhola, Noakhali and Sandwip. Under the Multipurpose Cyclone Shelter (MCS) Program [5] many borings were conducted in ten selected locations of coastal regions of Bangladesh. Some relations, such as depth versus SPT, undrained strength ratio vs plasticity index and moisture content, correlations between liquid limit, compression index and void ratio are presented in this study. It also provides a guide line for shallow foundation design for buildings and cyclone shelter. Hussain [6] studied the engineering properties of sub-soil in the coast of Bangladesh. He tested many soil samples to know the engineering properties of coastal soils in the districts of Barisal, Bhola, Patuakhali, Khulna and Noakhali. He suggested some empirical relationships between compression index and liquid limit, compression index and natural water content and compression index and initial void ratio. He also provided guide lines on foundation requirements in the coastal area of Bangladesh.

However, the above studied on coastal soils gives some knowledge about the foundation requirements in the coastal regions, but this knowledge on coastal soils are not sufficient to analysis the stability of slopes of the coastal embankments. Therefore, it is essential to investigate the soil properties of coastal soils which are being used for embankment construction. Also, it is essential to make some correlations between different soil parameters of coastal soils for further use.

III. Experimental Program

A. Selection of Study Area

Human has little control over natural disaster. We cannot resist cyclone and flood but we can try to minimize the loss due to natural hazards. Because of the funnel shaped coast of the Bay of Bengal, Bangladesh very often becomes the landing ground of cyclones formed in the Bay of Bengal. In Bangladesh, most of the damage occurs in the coastal regions of Khulna, Patuakhali, Barisal, Noakhali and Chittagong and the offshore islands of Bhola, Hatiya, Sandwip, Manpura, Kutubdia, Maheshkhali, Nijhum Dwip, Urir Char and other newly formed islands. The cyclonic vulnerable areas and the study areas of the coastal regions are shown on the Bangladesh Map in Fig. 1. As the Bhola, Chittagong and Noakhali regions are the most vulnerable to natural hazards; these areas have been selected for this study.

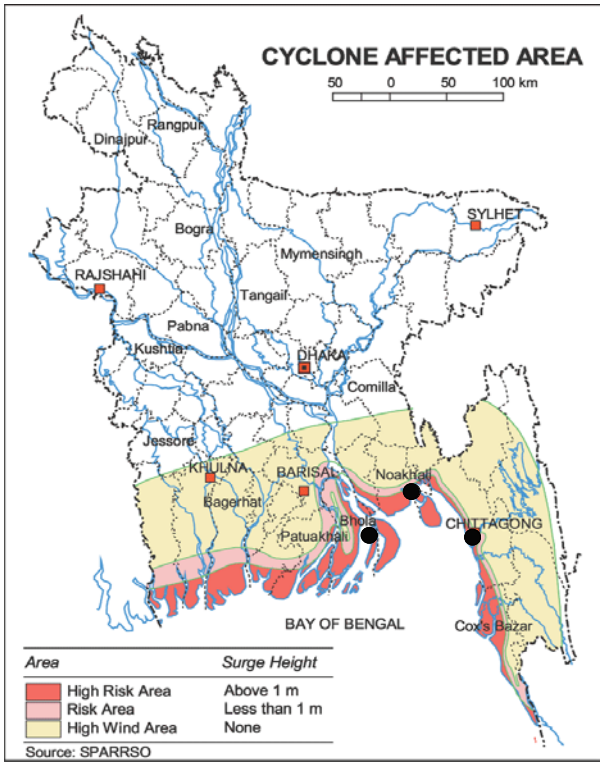

Fig. 1 The cyclone affected and study regions on the Bangladesh Map

B. Collection of Soil Sample and Sub-soil Investigation Report

Coast of Bangladesh is vulnerable for different kinds of natural disasters. To protect or construction of coastal structures it is essential to known the geotechnical characteristics of coastal soils. On this goal, 40 soil samples were collected from different embankment sections Bhola, Chittagong and Noakhali regions. The depth of collected soil ample for both cases varies from 1.0 to 2.0 meter from the Existing Ground Level (EGL). Caritas Bangladesh conducted so many sub-soil investigations at the coastal regions of Bangladesh. They constructed many school buildings, houses and cyclone shelter on the basis of their sub-soil investigation reports. Some of these sub-soil investigation reports (39 Nos) of the study areas (Bhola, Chittagong and Noakhali) were collected from the Bureau of Research Testing and Consultation (BRTC), BUET for proper understanding the sub-soil conditions of the study areas.

IV. Results and Discussions

A. Sub-soil Characteristics of Selected Coastal Regions

Fig. 2 shows the typical sub-soil profile of coastal regions of Bangladesh. For Bhola region, the uncorrected SPT N-value of soft clayey silt or soft silty clay varies from 1 to 6. The SPT N-value of stiff silty clay, stiff clayey silt and dense sandy silt varies from 7 to 27. Specific gravity of the soil sample varies from 2.61 to 2.71. The mean grain size (D_{50}) and fines content (F_c) of the tested soil varies from 0.010 to 0.047 mm and 88 to

97%, respectively. Again, the top soil samples contain clay 2 to 33%, silt 62 to 96% and sand 1 to 11%. It has been found that for different layers Liquid limit (LL), plastic limit (PL) and plasticity index (PI) of clayey silt or silty clay layer varies from 37 to 55%, 24 to 29% and 14 to 30%, respectively. Again, Dry unit weight and moisture content of the clayey silt or silty clay samples varies from 12.4 to 13.5 kN/m3 and 34 to 45%, respectively. Cohesion and angle of internal friction of clayey silt or silty clay varies from 20 to 28 kPa and 13 to 15 degree, respectively.

For Chittagong region, the uncorrected SPT N-value of soft clayey silt or soft silty clay varies from 1 to 10. The SPT N-value of stiff silty clay, stiff clayey silt and dense sandy silt varies from 10 to 30. Specific gravity of soil sample varies from 2.65 to 2.70. The mean grain size (D50) and fines content (Fc) of the tested soil varies from 0.014 to 0.049 mm and 90 to 100%, respectively. Again, the top soil samples contain clay 2 to 25%, silt 50 to 95% and sand 2 to 12%. It has been found that for different layers Liquid limit (LL), plastic limit (PL) and plasticity index (PI) of clayey silt or silty clay layer varies from 33 to 53%, 24 to 30% and 10 to 20%, respectively. Again, Dry unit weight and moisture content of the clayey silt or silty clay samples collected from top layer (upto 10 m depth from EGL) varies from 12.7 to 14.5 kN/m3 and 30 to 44%, respectively. Unconfined compressive strength of the samples varies between 15 to 32 kPa. Failure strain varies from 11 to 15%. Cohesion and angle of internal friction of clayey silt or silty clay varies from 18 to 27 kPa and 11 to 14 degree, respectively.

Again for the Noakhali region, the uncorrected SPT N-value of soft silty clay varies from 1 to 5. The SPT N-value of loose sand and silt varies from 2 to 14 and dense sandy silt varies from 12 to 20. The specific gravity of soil samples of various depths varies from 2.64 to 2.68. The mean grain size (D50) and fines content (Fc) of tested soil samples varies from 0.018 to 0.0145 mm and 82 to 100%, respectively. Again, the top soil samples contain clay 1 to 23%, silt 50 to 75% and sand 1 to 25%. It has been found that for different layers Liquid limit (LL), plastic limit (PL) and plasticity index (PI) of clayey silt or silty clay layer varies from 41 to 45%, 22 to 28% and 14 to 17%, respectively. Dry unit weight and moisture content of the silty clay samples collected from top layer varies from 10.60 to 12.10 kN/m3 and 45 to 54%, respectively. Unconfined compressive strength of the samples varies between 30 to 40 kPa. Failure strain varies from 13 to 15%. Cohesion and angle of internal friction of clayey silt or silty clay varies from 15 to 22 kPa and 16 to 19 degree, respectively. Summary of the properties of selected coastal soil samples are presented in Table I.

B. Consistency of Selected Coastal Soil

Correlation between C_c and e_o

Attempts have been made to correlate compression index (C_c) and initial void ratio (e_o) obtained from this study of coastal soils of Bangladesh. The relation between C_c and e_o has been compared with other relationships provided for other coastal soils of Bangladesh (Amin et al., 1987; Nishida, 1956; Serajuddin and Ahmed, 1967). A plot of C_c versus e_o is shown in Fig. 3. The best fit relationship, obtained in this study is presented in Equation 1. Correlations provided by Amin et al. (1987), Nishida (1956) and Serajuddin and Ahmed (1967) are presented in Equations 2, 3 and 4, respectively. The relationship proposed by Nishaida (1956) is for undisturbed clays and that for Serajuddin and Ahmed (1967) is for fine-grained soils of Bangladesh.

$$C_c = 0.45(e_o - 0.44) \quad (1)$$

$$C_c = 0.42(e_o - 0.34) \quad (2)$$

$$C_c = 0.33(e_o - 0.35) \quad (3)$$

$$C_c = 0.54(e_o - 0.35) \quad (4)$$

Where, C_c is compression index and e_o is initial void ratio.

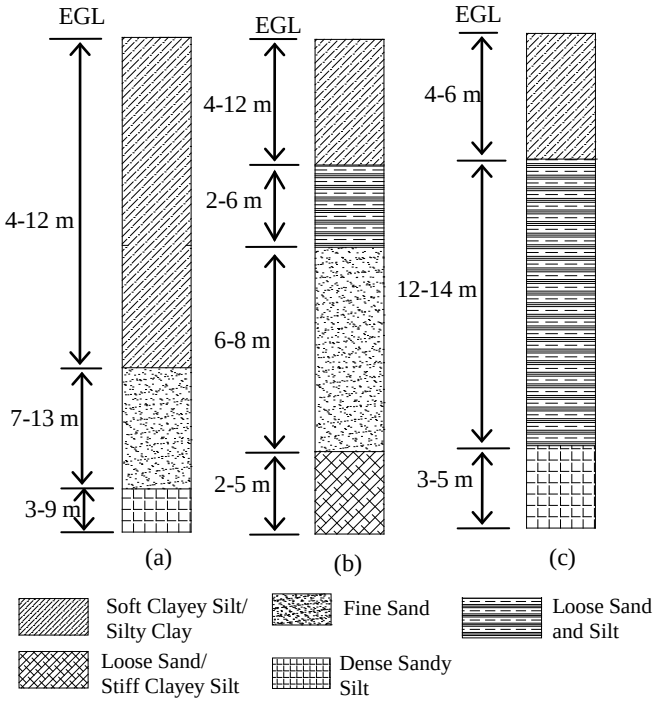

Fig. 2 Typical sub-soil profile of coastal regions of Bangladesh: (a) Bhola region; (b) Chittagong region and (c) Noakhali region

Correlation between C_c and w_n

The settlement of a point on the base of a foundation due to compressions of a thin layer(s) of normally loaded clay soil is computed from the following relation:

$$S = \frac{C_c H}{1 + e_o} \log_{10} \frac{P_0 + \Delta P}{P_0} \quad (5)$$

The compression ratio is closely related to the natural water content, and as such the values of compression index

TABLE I
SUMMARY OF THE PROPERTIES OF TOP COASTAL SOIL

Properties	Location		
	Bhola	Chittagong	Noakhali
Physical Properties			
Liquid limit, LL (%)	37~55	33~53	41~45
Plastic limit, PL (%)	24~29	24~30	22~28
Natural moisture content, w_n (%)	34~45	30~44	45~54
Plasticity index, PI (%)	14~30	10~20	14~17
Clay content (%)	2~33	2~25	1~23
Silt content (%)	62~96	50~95	50~75
Sand content (%)	1~11	2~12	1~25
Engineering Properties			
Cohesion, c (kPa)	20~28	18~27	15~22
Angle of Internal Friction, ϕ (degree)	13~15	11~14	16~19
Undrained shear strength, c_u (kN/m^2)	15~29	15~19	14~35
Compressibility ratio, $C_c/(1+e_o)$	0.14~0.16	0.13~0.17	0.14~0.18

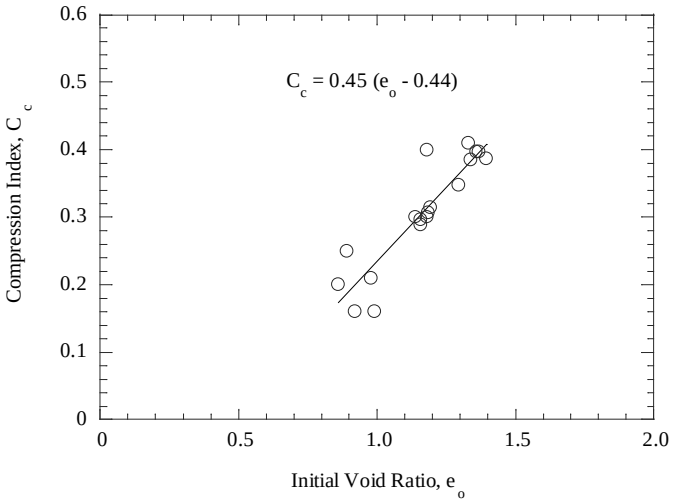

Fig. 3 Compression index versus initial void ratio of coastal soil

And natural water content for selected coastal areas is plotted in Fig. 4. From the plot a linear relation between C_c and w_n is obtained and can be shown by the equation:

$$C_c = 0.008(w_n - 3) \quad (6)$$

Correlation between C_c and LL

According to Terzaghi and Peck (1967), the compression index of undisturbed clays is closely related with liquid limit as represented by the equation:

$$C_c = 0.009(LL - 10) \quad (7)$$

The values of compression index and liquid limit for selected coastal areas are plotted in Fig. 5. From the plot it is observed that a valid linear relation exists between the compression index and liquid limit for selected coastal regions soil as represented by the equation:

$$C_c = 0.009(LL - 13) \quad (8)$$

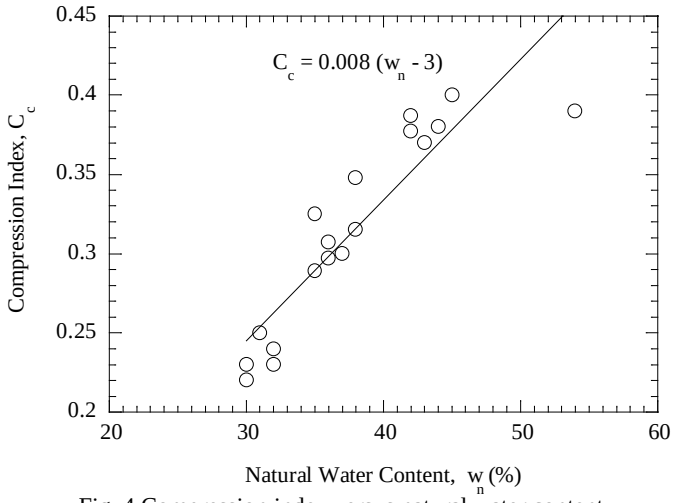

Fig. 4 Compression index versus natural water content

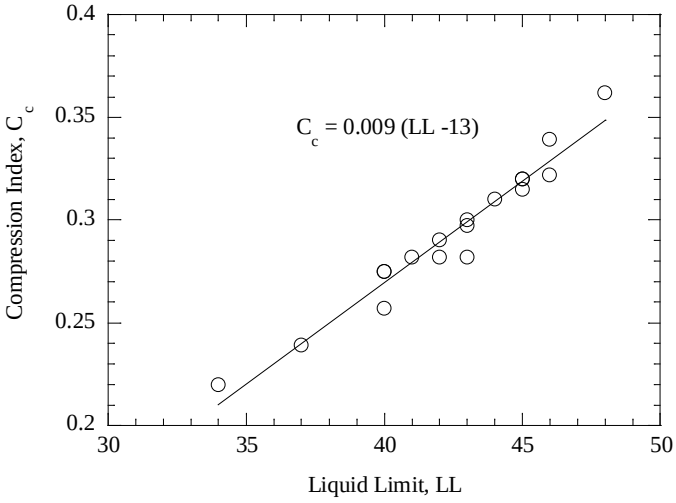

Fig. 5 Compression index versus liquid limit

ACKNOWLEDGMENT

The authors would like to express their special gratitude and appreciation to Caritas, Bangladesh for their extreme co-operation during the field survey and field tests. The author would also like to express his special gratitude and appreciation to BRTC, BUET for providing the sub-soil investigation reports.

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