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An Initiative to study the Engineering Properties of Coastal Soil: Bangladesh Perspective

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***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 coastal area, 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 know the engineering properties of these coastal region's soil for proper design. It is observed that the top layer coastal soil contains 1 to 32% clay, 50 to 98% silt and 1 to 25% sand. Liquid limit varies from 35 to 54%, plastic limit varies from 24 to 29% and plasticity index varies from 9 to 29%. The untrained shear strength of top soils varies from 14 to 35 kN/m^2. The compressibility ratio varies from 0.134 to 0.175. The selected coastal soils are clays of low plasticity (CL) or silts of low plasticity (ML).*

Keywords: Coastal area, disaster, engineering property, low plasticity.

1. 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 their livelihood. The annual growth rate of GDP is greatly dependent on agricultural product. But, the coastal regions of Bangladesh are vulnerable by so many natural disasters and therefore the agricultural production is not so good. The Figure 1 shows the details flow chart of natural disasters at the coastal zone of Bangladesh.

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 the 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 (BWDB, 1998). According to the population census in 2001, some 35 million people lived in the coastal region which is 28% of the total population (BBS, 2007). As the embankments and other hydraulic

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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$ (DMB, 2008). 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 (Hossain, 2004).

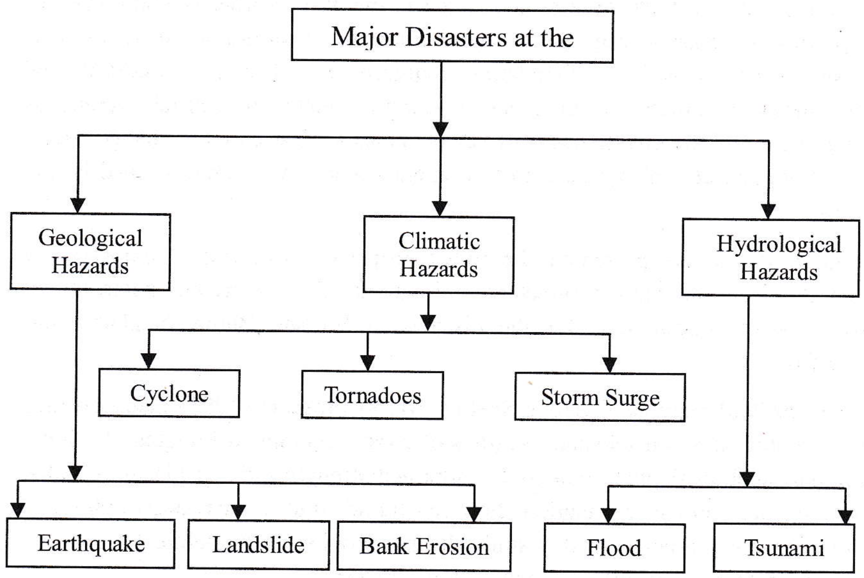

Figure 1: Flow Chart of the Natural Hazards at the Coast of Bangladesh.

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 improper 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 constructed over this coastal soil, it is essential to know the engineering properties of these coastal regions soil for proper design.

The broad 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.

2. Previous Studies

Some research works have been conducted in the past in order to know the soil properties of coastal regions, to 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 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. (1987) 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 (1993) 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 guideline for shallow foundation design for buildings and cyclone shelter.

Hussain (1980) studied the engineering properties of subsoil 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 areas of Bangladesh.

However, the above studied on coastal soils gives some knowledge about the foundation requirements in the coastal regions, but this knowledge are not sufficient to analyze 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 this region.

3. Experimental Program

3.1 Selection of Study Area

Human has little control over natural disasters. We cannot resist cyclone and flood but we can try to minimize the loss due to such hazards. Because of the funnel shaped coast Bangladesh very often becomes the landing ground of cyclones formed in the Bay of Bengal. The Bay cyclones also move towards the eastern coast of India, Myanmar and occasionally towards Sri Lanka. But these cause the maximum damages when they hit Bangladesh, west Bengal and Orissa of India. This is because of the low flat terrain, high density of population and poorly constructed houses, embankments, hydraulic structures etc. In Bangladesh, most of the damages occur 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 prone areas as well as the study areas are shown on the Bangladesh Map in Figure 2. As Khulna, Bagerhat and Patuakhali regions are the most vulnerable to natural hazards; these areas have been selected for this study.

3.2 Collection of Soil Sample and Sub-soil Investigation Report

Coast of Bangladesh is vulnerable to different kinds of natural disasters. To protect or to construct of coastal structures, it is essential to know the geotechnical characteristics of coastal soils. For this purpose, 24 soil samples were collected from different embankment sections of the study areas.

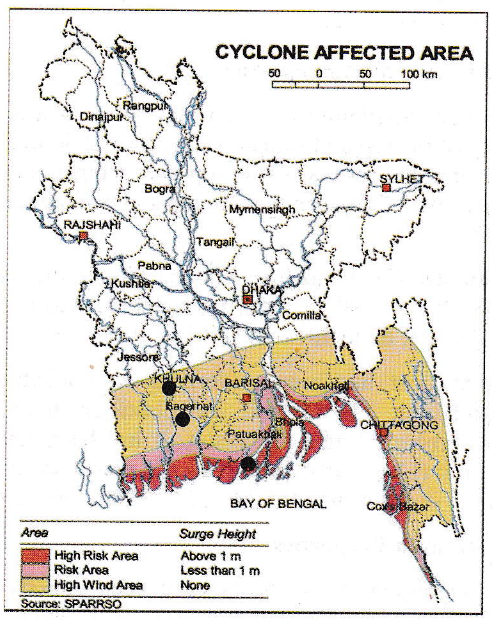

Figure 2: The cyclone affected and study regions on the Bangladesh Map

The depth of collected soil samples for both cases varies from 0.75 to 1.0 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 (33 Nos) of the study areas (Bagerhat, Khulna, Patuakhali) were collected from the Bureau of Research Testing and Consultation (BRTC), BUET for proper understanding of the sub-soil conditions of the study areas.

4. Results and Discussions

4.1 Sub-soil Characteristics of Bagerhat Region

Eight soil samples from Saronkhola thana under Bagerhat district were collected. These samples were collected from the slope of existing embankment and river side of the embankment. The depth of the collected soil sample varies from 0.75 to 1.0 meter. Twelve borelog data of Bagerhat district has been collected from BRTC, BUET. A typical soil profile among these twelve borelogs is shown in Figure 3a. The general soil profile of the top layer (up to 12 m from EGL) is soft to medium stiff to stiff clayey silt or silty clay. And the bottom layer (below 12 m from EGL) is generally dense silty fine sand or sandy silt.

4.1.1 SPT Results

The variations of SPT N-values with depth of the boreholes have been presented in the Figure 4. The uncorrected SPT N-value of soft clayey silt or soft silty clay varies from 1 to 12. The SPT N-value of stiff silty clay, stiff clayey silt and dense sandy silt varies from 8 to 26.

4.1.2 Physical and Index Properties

Typical grain size distributions of top soil samples are shown in Figure 5. Specific gravity of the top soil sample varies from 2.66 to 2.70. Index properties and grain size analysis results of the top soil samples have been presented in Table 1. From Table 1, it is seen that the top soil samples are silty clay or clayey silt (CL or ML).

The mean grain size (D_{50}) and fines content (F_c) of the tested soil varies from 0.009 to 0.048 mm and 90 to 99%, respectively. Again, the top soil samples contain 1 to 32% clay, 65 to 98% silt and 1 to 10% sand.

Atterberg's limits test has been performed on undisturbed soil samples to determine liquid limit, plastic limit and plasticity index. Table 1 shows the summary of Atterberg's limits test result. 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 38 to 54%, 25 to 28% and 15 to 29%, respectively.

4.1.3 Shear Strength Properties

Unconfined compression tests results have been collected for soft silty clay samples which have been collected from Bagerhat region. Detail test results of the samples are presented in Table 2. From this Table, it is seen that dry unit weight and moisture content of the clayey

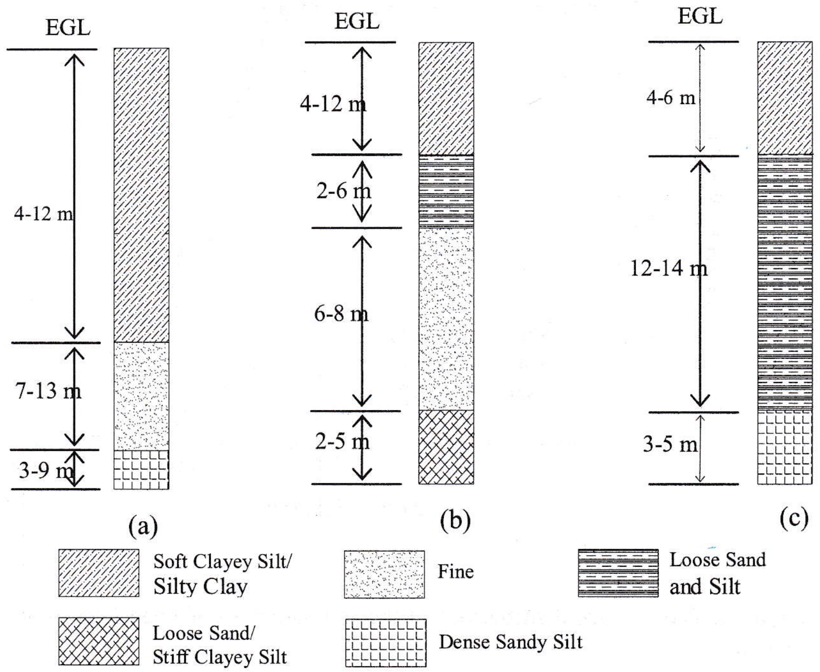

Figure 3: Typical sub-soil profile of coastal regions of Bangladesh: (a) Bagerhat region; (b) Patuakhali region and (c) Khulna region.

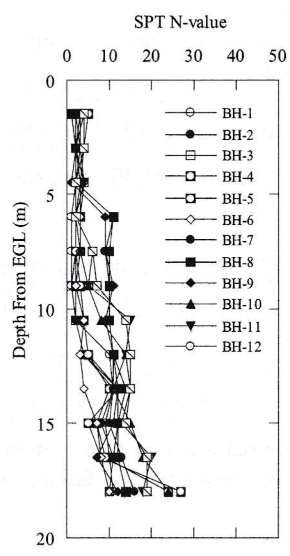

Figure 4: Variation of SPT N-value with depth from Existing Ground Level (EGL) in the Bagerhat region.

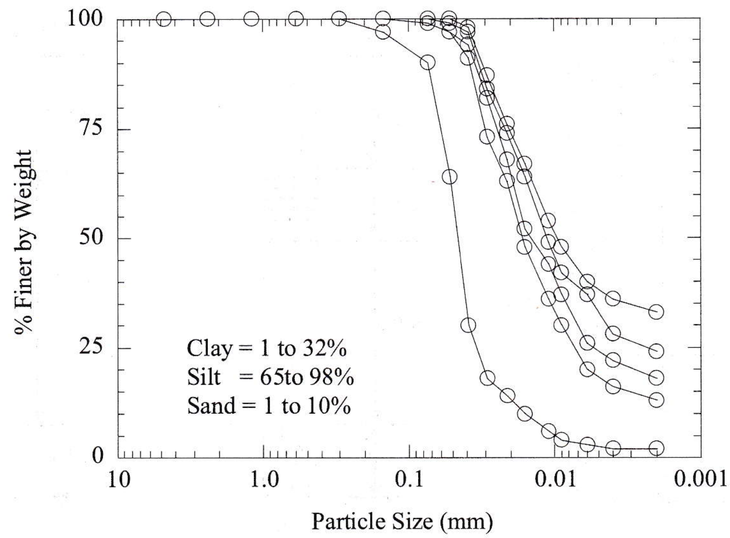

Figure 5: Particle size distributions of the soil samples collected from Bagerhat region.

Table 1: Summary of physical and index properties of Bagerhat region soil

Depth from EGL (m)	Clay (%)	Silt (%)	Sand (%)	LL (%)	PL (%)	PI (%)
0 to 5.0	1~32	65~98	1~10	38~54	25~28	15~29

Note: LL = liquid limit; PL = plastic limit; PI = plasticity index.

Table 2: Summary of shear strength properties of Bagerhat region soil

Depth (m)	w_n (%)	γ_{dry} (kN/m^3)	q_u (kPa)	ε_f (%)	c (kPa)	□ (deg)
0 to 5.0	34~44	12.4~13.5	30.7~57.7	13~15	19~26	11~13

Note: w_n = natural moisture content; γ_{dry} = dry unit weight; q_u = unconfined compressive strength; ε_f = failure strain; c = cohesion; □ = angle of internal friction.

silt or silty clay samples varies from 12.4 to 13.5 kN/m^3 and 34 to 44%, respectively. Cohesion and angle of internal friction of clayey silt or silty clay varies from 19 to 26 kPa and 11 to 13 degree, respectively.

4.2 Sub-soil Characteristics of the Patuakhali Region

Nine soil samples from Kuakata thana under Patuakhali district have been collected for conducting laboratory investigation. The samples are collected from the slope of existing embankment and sea side of the embankment. The depth of collected soil sample varies from 0.5 to 1.0 meter. Eighteen borelog data of Patuakhali district has been collected from BRTC, BUET. Typical soil profiles among these eighteen borelogs are shown in Figure 3b. The general soil profile of the top layer (upto 10 m from EGL) is soft to medium stiff to stiff clayey silt, silty clay or loose to medium dense sandy silt. And the bottom layer (below 10 m from EGL) is generally silty fine sand or sandy silt.

4.2.1 SPT Results

The variations of SPT N-values with depth of the boreholes have been presented in the Figure 6. 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.

4.2.2 Physical and Index Properties

Specific gravity of soil sample varies from 2.66 to 2.70. Typical grain size distributions of nine soil samples are shown in Figure 7. Index properties and grain size analysis results of the top soil samples have been presented in Table 3. From Table 3, it is seen that the top soil samples are silty clay or clayey silt. The mean grain size (D_{50}) and fines content (F_c) of the tested soil varies from 0.014 to 0.049 mm and 90 to 100%, respectively. Again, the top soil samples contain 1 to 24% clay, 51 to 98% silt and 1 to 25% sand.

Atterberg's limits test has been performed on undisturbed soil samples to determine liquid limit, plastic limit and plasticity index. Table 3 shows the summary of Atterberg's limits test result. 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 35 to 51%, 25 to 28% and 09 to 17%, respectively.

4.2.3 Shear strength properties

Unconfined compression tests were conducted on soft clayey silt or soft silty clay samples which have been collected from Patuakhali region. Detail results of samples are presented in Table 4. From the Table 4 it is seen that 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 12.55 to 14.10 kN/m^3 and 30 to 44%, respectively. Cohesion and angle of internal friction of clayey silt or silty clay varies from 18 to 27 kPa and 9 to 13 degree, respectively.

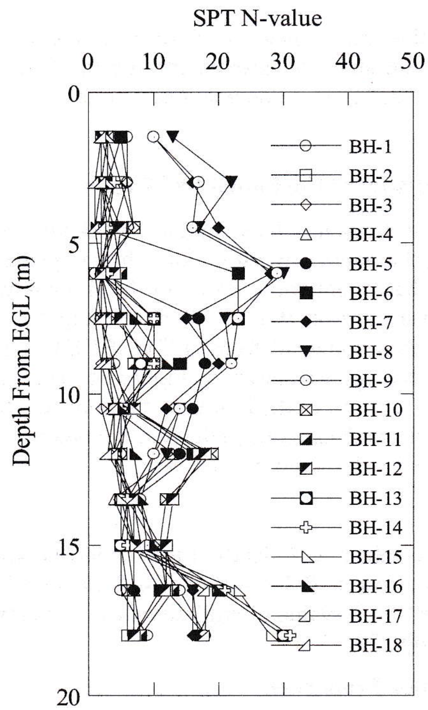

Figure 6: Variation of SPT N-value with depth from Existing Ground Level (EGL) in the Patuakhali region.

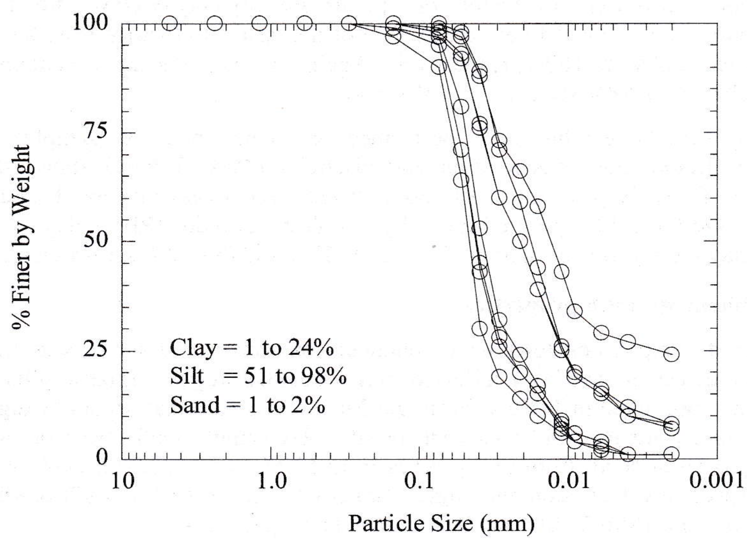

Figure 7: Particle size distributions of the soils collected from Patuakhali region.

Table 3: Summary of physical and index properties of soils collected from Patuakhali region

Depth from EGL (m)	Clay (%)	Silt (%)	Sand (%)	LL (%)	PL (%)	PI (%)
0 to 5.0	1~24	51~98	1~2	35~51	25~28	9~17

Note: LL = liquid limit; PL = plastic limit; PI = plasticity index.

Table 4: Summary of shear strength properties of soils collected from Patuakhali region

Depth (m)	w_n (%)	γ_{dry} (kN/m^3)	q_u (kPa)	ε_f (%)	c (kPa)	□ (deg)
0 to 5.0	30~44	12.6~14.1	29.1~69.2	13~15	18~27	9~13

Note: w_n = natural moisture content; γ_{dry} = dry unit weight; q_u = unconfined compressive strength; ε_f = failure strain; c = cohesion; □ = angle of internal friction.

4.3 Sub-Soil Characteristics of the Khulna Region

Three borelog data of Khulna district has been collected from BRTC, BUET. Typical soil profile of three boreholes is shown in Figure 3c. The general soil profile of the top layer is soft silty clay. And the bottom layer is generally silty fine sand or sandy silt. And the bottom layer is generally loose sand and silt or dense sandy silt.

4.3.1 SPT Results

The variations of SPT N-values with depth of the boreholes have been shown in the Figure 8. The uncorrected SPT N-value of soft silty clay varies from 1 to 3. The SPT N-value of loose sand and silt varies from 2 to 14 and dense sandy silt varies from 12 to 20.

4.3.2 Physical and Index Properties

The specific gravity of soil samples of various depths varies from 2.66 to 2.67. Index properties and grain size analysis results of the top soil samples have been presented in Table 4.5. The mean grain size (D_{50}) and fines content (F_c) of tested soil samples varies from 0.018 to 0.0145 mm and 82 to 100%, respectively. Again, the top soil samples contain 1 to 23% clay, 50 to 75% silt and 1 to 25% sand.

Atterberg's limits test has been performed on undisturbed soil samples to determine liquid limit, plastic limit and plasticity index. Table 5 shows the summary of Atterberg's limits test result. 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%, 27 to 28% and 14 to 17%, respectively.

4.3.3 Shear strength properties

Unconfined compression tests results have been collected for soft silty clay samples which have been collected from Khulna region. Detail results of tested soil samples are presented in Table 6. From the Table 6 it is seen that dry unit weight and moisture content of the silty clay

samples collected from top layer varies from 10.82 to 11.70 kN/m^3 and 45 to 54%, respectively. Unconfined compressive strength of the samples varies between 32.26 to 38.26 kPa. Failure shear strain varies from 13 to 15%.

4.4 Summary of Selected Coastal Soil Properties

The general sub-soil profiles of 18 m depth from the Existing Ground Level of the selected coastal areas are presented in the Figure 3a, 3b and 3c. From these Figures it is observed that the top layer soil of the coast is generally silty clay or clayey silt. The thickness varies from 4 to 12 meter. Below this layer, soil is generally loose sand or silt, silt with trace clay and fine sand or silty fine sand. The thickness varies from 2 to 13 meter.

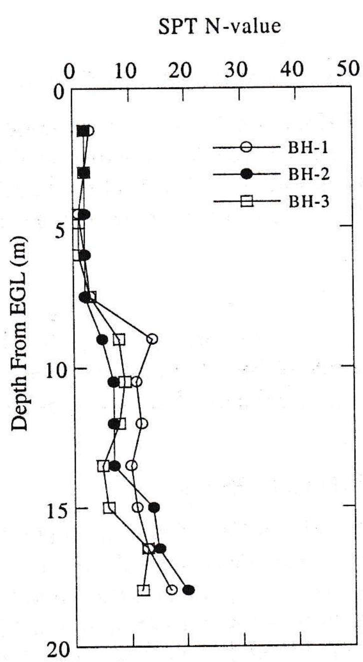

Figure 8: Variation of SPT N-value with depth from Existing Ground Level (EGL) in the Khulna region.

Table 5: Summary of physical and index properties of soil collected from Khulna region

Depth from EGL (m)	Clay (%)	Silt (%)	Sand (%)	LL (%)	PL (%)	PI (%)
0 to 5.0	1~23	50~75	1~25	41~45	27~28	9~17

Note: LL = liquid limit; PL = plastic limit; PI = plasticity index

Table 6: Summary of shear strength properties of of soil collected from Khulna region

Depth (m)	w_n (%)	γ_{dry} (kN/m^3)	q_u (kPa)	ε_f (%)	c (kPa)	□ (deg)
0 to 5.0	42~54	10.6~11.7	29.2~38.3	13~15	12~17	9~13

Note: w_n = natural moisture content; γ_{dry} = dry unit weight; q_u = unconfined compressive strength; ε_f = failure strain; c = cohesion; □ = angle of internal friction

Finally, soil is generally dense sandy silt, stiff clayey silt or silty fine sand of thickness varies from 2 to 9 m. The uncorrected SPT N-value of soft clayey silt or soft silty clay varies from 1 to 12. The SPT N-value of stiff silty clay or dense sandy silt varies from 8 to 30.

The grain size distributions of the selected coastal soils are presented in the Figure 9. From the Figure 9 it is observed that the selected top layer coastal soil contain 1 to 32% clay, 50 to 98% silt and 1 to 25% sand. Liquid limit varies from 35 to 54%, plastic limit varies from 24 to 29% and plasticity index varies from 9 to 29%.

Figure 9 shows the plot of plasticity chart of the selected top layer coastal soil. The important feature of the plasticity chart is the empirical A-line. An A-line separates the inorganic clays from the inorganic silts. Inorganic clay values lie above the A-line, and values for inorganic silts lie below A-line. Plot shows that the selected coastal soils are clays of low plasticity (CL) or silts of low plasticity (ML). Safiullah (1994) present the plasticity chart for coastal soils of Bangladesh collecting from ten locations which is close to the plasticity chart in Figure 9.

The undrained shear strength of top soils varies from 14 to 35 kN/m^2. The compressibility ratio varies from 0.134 to 0.175. Summary of selected coastal soil samples are presented in Table 7.

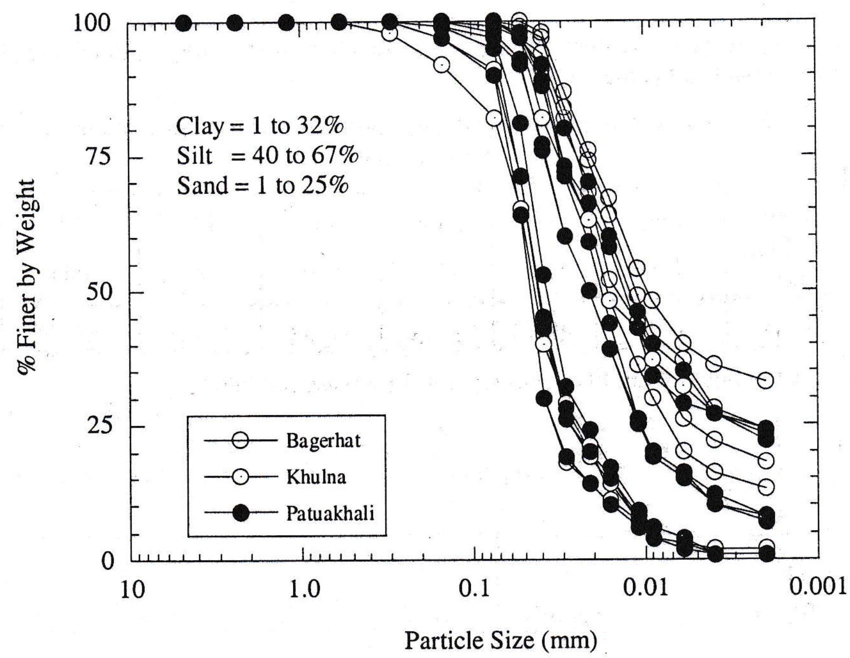

Figure 9: Particle size distributions of selected coastal regions soil.

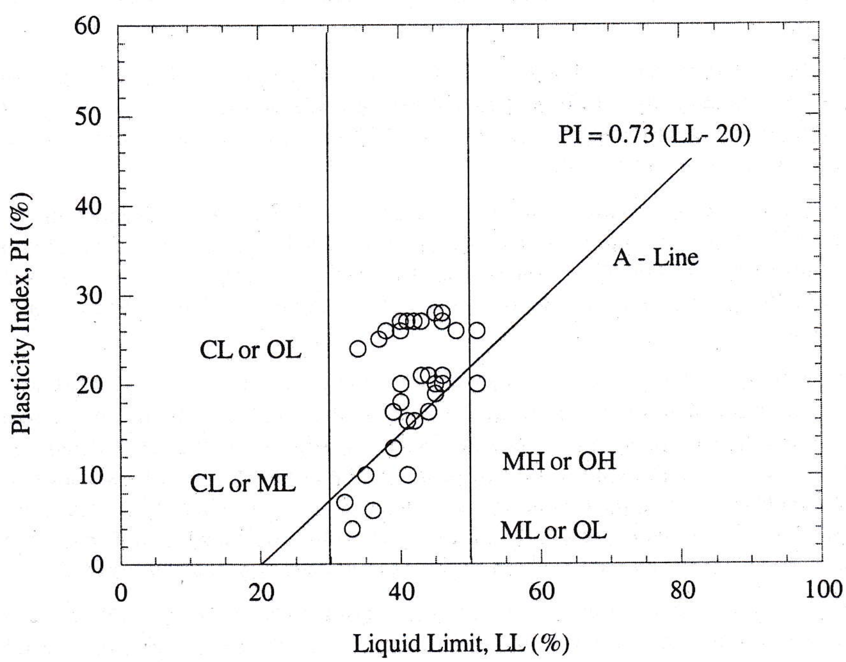

Figure 10: Plot of plasticity index of coastal soils of Bangladesh on plasticity chart.

Table 7: Summary of the properties of top layer coastal soil

Properties	Location		
	Bagerhat	Khulna	Patuakhali
Physical Propertie			
Liquid limit, LL (%)	38~54	38~45	35~51
Plastic limit, PL (%)	25~28	24~28	24~29
Natural moisture content, w_n (%)	34~44	42~54	30~44
Plasticity index, PI (%)	15~29	9~17	8~18
Clay content (%)	1~32	1~23	1~24
Silt content (%)	65~98	50~75	51~98
Sand content (%)	1~10	1~25	1~2
Engineering Properties			
Undrained shear strength, c_u (kN/m^2)	15~29	15~19	14~35
Compressibility ratio, $C_c/(1+e_o)$	0.141~0.162	0.134~0.168	0.143~0.175

4.5 Consistency of Selected Coastal Soil

4.5.1 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 Figure 11. 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, on the other hand Serajuddin and Ahmed (1967) is for fine-grained soils of Bangladesh, respectively. Amin et al. (1987) proposed the relationships for coastal soils of Bangladesh.

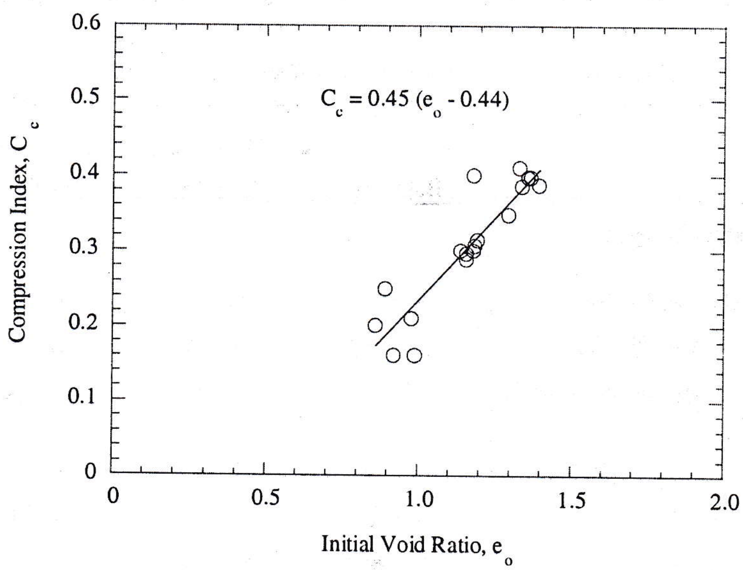

Figure 11: Compression index versus initial void ratio of coastal soil.

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

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

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

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

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

4.5.2 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 and natural water content for selected coastal areas is plotted in Figure 12.

From the plot a linear relation between C_c and w_n is obtained, which can be shown by the equation:

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

4.5.3 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:

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

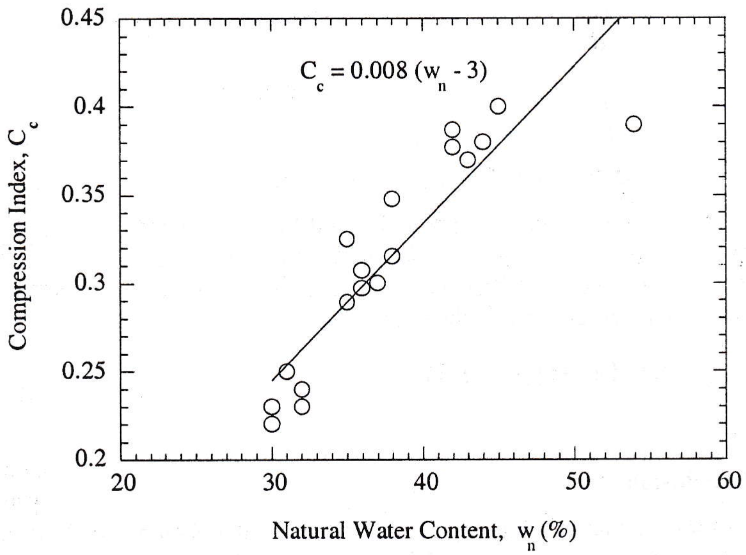

Figure 12: Compression index versus natural water content.

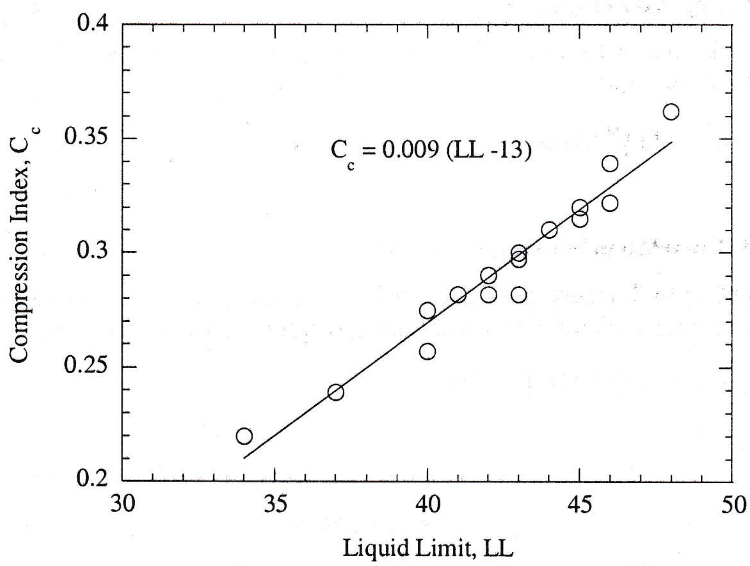

Figure 13: Compression index versus liquid limit.

The values of compression index and liquid limit for selected coastal areas are plotted in Figure 13. From this 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:

$$C_c = 0.009(LL - 13) \tag{8}$$

5. Conclusions

It is observed that the top layer soil of the coastal regions of Bangladesh is generally silty clay or clayey silt. The thickness varies from 4 to 12 meter. Below this layer soil is generally loose sand or silt, silt with trace clay and fine sand or silty fine sand. The thickness varies from 2 to 13 meter. Finally, soil is generally dense sandy silt, stiff clayey silt or silty fine sand of thickness varies from 2 to 9 m.

The uncorrected SPT N-value of soft clayey silt or soft silty clay varies from 1 to 12. The SPT N-value of stiff silty clay or dense sandy silt varies from 8 to 30.

The top layer coastal soil contains 1 to 32% clay, 50 to 98% silt and 1 to 25% sand. Liquid limit varies from 35 to 54%, plastic limit varies from 24 to 29% and plasticity index varies from 9 to 29%. The undrained shear strength of top soils varies from 14 to 35 kN/m^2. The compressibility ratio varies from 0.134 to 0.175. The selected coastal soils are clays of low plasticity (CL) or silts of low plasticity (ML).

Acknowledgement

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