STUDIES ON THE ENGINEERING PROPERTIES OF SUB-SOIL WITH REFERENCE TO FOUNDATION REQUIREMENTS IN THE COASTAL AREAS OF BANGLADESH

A Thesis

by

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ABSTRACT

This study is aimed at dealing with the dual purpose of, first, providing general understanding of the soil profile in regard to its physical properties and engineering behaviour and second, presenting a general recommendation on the construction of foundation types for various purposes in that coastal region indicating future developments that can reasonably be expected from other investigators in the field.

Useful data on the type of soils encountered for various Government Projects in the region have been collected from various sources like Consulting Firms, Government Departments and others. In addition, it contains test results on some soil samples collected from the locality and tested by the author to ascertain the range of validity with others.

The soil profile of the coastal region contains deposits of cohesive and non-cohesive materials and also a combination of them in varying thickness, texture and drainage characteristics. The upper layers of the deposits are composed of silt clay soils and possess relatively narrow range of particle size. The underlying strata of the deposits are usually silty sand. Organic materials mixed with particles ranging from clay size to sandy size are occassionally present in many locations with relatively higher compressibility and water content. This type of soil material is generally soft and liable to continue settling for a long time due to the weight of the foundation.

In this study, the soil properties such as consistency, natural moisture content, gradation, compressibility and shear strength, have been analysed for their easy identification, and to make general recommendation of the foundation types in the area. Semi-empirical relationships between the parameters like compression index and liquid limit, compression index and natural water content, and compression index and initial void ratio, have been suggested. The value of compression index C_c furnishes the ultimate settlement of any foundation caused due to the primary consolidation of the soil layer. Hence, the use of these semi-empirical equations will be of great importance in the foundation design.

Foundations are usually subjected to attack by the aggressive compounds present in the soils in most of the locations of coastal belt along the shore of Bay of Bengal. Protective measures are desirable against such actions.

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CHAPTER 2

REVIEW OF LITERATURE

2.1 General

Soil is the oldest and undesirable foundation materials which needs elaborate investigations. If the history is traced it will be seen that very little attempts were made to deal with soil problems on a scientific basis until towards the beginning of the 20th Century, when a major contribution was made by a Sweedish soil Scientist, Atterberg(7). He was the first to propose the different stages of consistency in which a clay soil may exist, depending upon its water content.

In 1923, Dr. Karl Terzaghi(8) published his theory of consolidation for determination of the probable settlement under the load. His contribution was universally accepted in the teeth of opposition from engineers who did not then velieve in settlement at all. Later Proctor(9) (1933) made a very important contribution on the principles of soil compaction followed by many other scientists of different countries of the world who contributed significantly to the development of more soil tests in order to measure definite engineering properties tather than theoretical constants whose significance was considered by them somewhat obscure. Their extensive studies have since laid noteworthy landmarks in the determination of physical properties of soils including their engineering properties.

In Bangladesh, many individual studies have recently been made by many government departments, autonomous organisations, and consulting firms on the soil samples collected from different project locations for individual structures, and analysed their physical properties for successful implementation of their engineering projects. Most of these informations and data were collected, and studied for generalisation by the author in the context of this thesis work for the benefit of the foundation engineers so that they can have a generalised picture of the entire area before making a decision on the foundation type suitable in the locality.

2.2 Determination of Physical Properties

The properties of soils that are of primary importance from a practical point of view are gradation, consistency, permeability, compressibility and shear strength.

The various factors on which depend the behaviour of soils are particle size and shape, water content, void ratio, structural arrangement of particles, degree of saturation, degree of compactness, and presence of organic matters. Discussions of these properties and factors affecting them in the context of soils of coastal areas of Bangladesh will comprise the major portion of this thesis.

2.3 Determination of Grain Size Composition

The size of the grains of soil is one of the factors affecting some of its physical properties of direct importance to the engineers, such as cohesion, and permeability. Greater cohesion is caused by small grains and openings in a soil because of their larger total surface of contact between the more numerous small grains. Therefore, identification of their grain property is very important.

Grain size analysis is done for identification and classification of soils. It is done to determine the size of the soil grains and the percentage by weight of soil particles of different particle size comprising a soil sample. Depending on the type of the soil, and the extent of particle size distribution required, either sieve analysis or a combined sieve and sedimentation analysis is done. The distribution curves obtained for fine grained soil are only "approximate" as its accuracy is more questionable[10] than the accuracy of the curves for coarse soil. The soils of coastal areas of Bangladesh are mostly fine grained cohesive soils, and as such much stress could be given on the geological history and structure of the cohesive soil than on particle size.

However, Lamb[10] maintains that the particle size curves, particularly those of sands and silts do have practical values in spite of their serious limitations.

The character of fine grained soils depends chiefly on the finest 20%. The values of effective grain size which is the fine grained soils and Alen Hazen's[11] uniformity co-efficient are utilised to express the grain size characteristics of mixed grained natural soils. A soil having a uniformity coefficient smaller than 2 is considered "uniform", and "graded" if the valua is between 2 and 6. The soil is termed "well graded" if the uniformity co-efficient is greater than 6 for sand and for silty sand. A well graded soil experiences less breakdown than a uniform soil of the same particle size, since there are many interparticle contacts in a well graded soil, and the load per contact is less than in the uniform soil.

2.4 Determination of Soil Consistency

The consistency refers to the relative ease with which the soil aggregate can be deformed or ruptured, and to a large extent it is related to the moisture content. Atterberg[12] first demonstrated the significance of the consistency limits known as the water contents at which the soil passes from the liquid state to the plastic state, and finally to the solid state.

Scott[13] termed the water content of granular soils relatively unimportant. He found that the presence of water except for its influence on the unit weight, affects the behaviour of the soil under stress to a negligible extent.

The soil material when subjected to shear stresses under load undergoes a certain degree of deformation, to all intents and purposes immediately without any further movement, and the deformation continues in time following the application of stress. If the soil material exhibits the first property at any measurable level of stress, it is considered to be solid. On the other hand, it can be called a fluid if, the substance behaves according to the second property.

2.5 Soil Strength as a Measure of Consistency

The soil resistance to deformation changes with the change in soil from one state of consistency to another. The deformation results in the development of stresses in the soil underlying the surface supporting the structure when loaded, but the calculation of stresses developed under varying load conditions is difficult and inacurate.

The resistance to deformation is very important for the design of foundations for buildings and other structures. It has been quantitatively measured in terms of unconfined compressive strength. According to the U.S. Practice(14), the qualitative expressions for denoting consistency of fine grained soils in the undisturbed state and the corresponding unconfined compressive strength are given in Table 2.1.

Table 2.1

Soil consistency and unconfined compressive strength

Consistency	Unconfined compressive strength, Tons/sq. ft.
Soft	0. 25
Medium/stiff	0. 50/1.00
Very stiff	2. 00
Hard	4. 00

and dry strength increases with the plasticity Index, I_p. The soil is said to be organic if the oven dried sample reduced the value of liquid limit by more than 25 percent.

The study of the soils of Bangladesh made by Serajuddin[2] revealed that some of the recently formed soils of south-west regions of Bangladesh are fine grained soils which plot generally above the A-line in the plasticity chart indicating an inorganic character of medium to high plasticity. Soils falling below A-line contain considerable and varying amounts of peat and organic matter. The actual range of value of natural water content, liquid limit, plasticity index and depth of ground water conditions found by him for coastal regions are presented below:

Table 2.2

Range of Values of Natural Water Content, Liquid Limit, Plasticity Index and Ground Water Table.

Test zone	Sample depth(ft.)	Ground water depth(ft.)	N.W.C. %	L_w %	I_p %
Barisal	1 - 36	1 - 6.5	16-83	25-58	10-31
Khulna	1 - 141	0 - 15	13-14	35-121	8-96
Chittagong	1 - 132	1 - 8	14-53	21-95	2-44

The soils of the above regions of Bangladesh consist mostly of fine grained silt and clays whose average liquid limit ranges between 40 and 53. The range of values indicates that the clay soil is of medium to higher compressibility. The clay soil having the same liquid limit shows approximately

2.6 Effect of Liquid Limit and Plasticity Index on Clay Soils

The liquid and plastic limits give a measure of the plasticity of soil, and are both dependent on the amount and type of clay in a soil, but the plasticity index is generally only dependant on the amount of the clay present. The plasticity index are rough measure of the amount of clay in soil, while the study of plasticity index in combination with liquid limit gives information about the type and nature of clay.

Casagrande[18] developed a plasticity chart A-line having the equation $I_p = 0.73\ (L_w - 20)$ and the type of soils are indicated by the various regions in the plasticity chart according to their liquid limits and plasticity Indices.

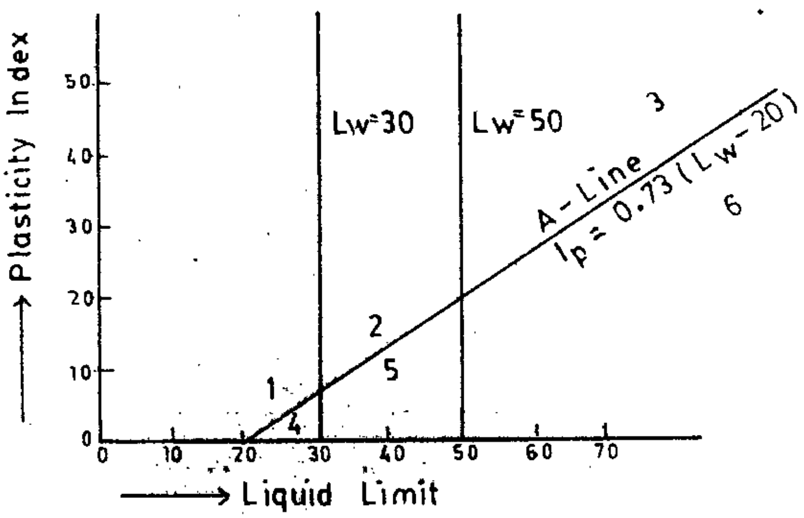

Fig.2-1 Plasticity chart showing variations in characteristics of soils.

According to the chart, the clays are mainly inorganic in character and of medium to high plasticity. Their toughness equal compressibility. Permeability of such clay soils above A-line is very low. According to Indian standard[16], the soils of these regions have medium compressibility with the presence of slightly high compressible character in Khulna soil.

2.7 Relationship of Plasticity Index to Composition of Soil

The Atterberg limits for a soil are related to the amount of water that is attracted to the surfaces of the soil particles. It is expected that the amount of attracted water is largely influenced by the amount of clay that is present in the soil because of the great increase in surface area per mass with decreasing particle size. On the basis of this reasoning Skempton[17] defined this as activity of the soil and classified clays into three groups as follows:

(1) Inactive clay $(A < 0.75)$
(2) Normal clay $(A = 0.75 - 1.25)$
(3) Active clay $(A > 1.25)$

Where A = Colloidal activity of a soil and is defined as the ratio of plasticity index to the percentage of clay fraction in the mixture.

As an example, Montmorillonite is active, Illite is normal and Kaolinite as inactive clay. However, typical values[17] for various clay minerals are given in Table 2.3.

Table 2.3

Typical Colloidal Values for Various Clay Minerals

Clay Mineral	Activity
Muscovite	0.23
Kaolinite	0.40
Illite	0.90
Ca-Montmorillonite	1.50
Na-Montmorillonite	6.00

2.8 Compressibility and its Relationship between Pressure and Void Ratio

The term compressibility is ordinarily used to indicate the susceptibility of soil to decrease in volume under sustained, compressive stress only and is indicated by the change in volume of a soil per unit increase of pressure.

Compression of laterally confined soil specimen under static vertical load starts in the vertical direction resulting in a decrease of specimen thickness. The specimen, in due course of time, attains a certain equilibrium void ratio corresponding to the applied pressure. The relation between applied pressure and the corresponding equilibrium void ratio is represented in the form of a pressure void ratio graph known as virgin compression curve.

Karl Terzaghi[18] developed an empirical equation for the straight line section of the virgin compression curve as under:

$$e = e_o - C_c \log_{10} \frac{P'_o + \Delta p}{P'_o} \qquad (2.1)$$

Where e = void ratio at increased pressure Δp

e_o = void ratio at existing overburden pressure P'_o

C_c = compression index, a dimensionless quantity which represents the slope of the linear portion of the pressure void ratio curve.

2.9 Effect of Liquid Limit and Initial Void Ratio on Compression Index

The settlement due to consolidation of normally loaded clay with void ratio e_o is dependent on the compression index of the clay soil. A typical relationship between void ratio and effective pressure is shown in Fig. 2.2 and between void ratio and the logarithm of effective pressure in figure 2.3.

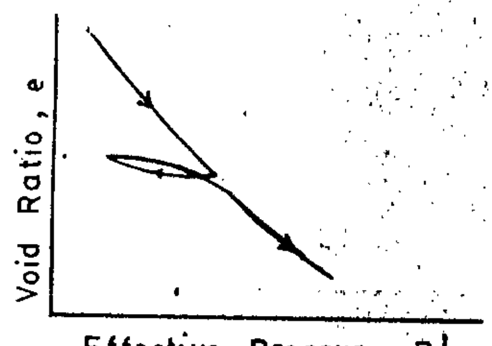

Fig.2-2 Relation between Void ratio and effective pressure

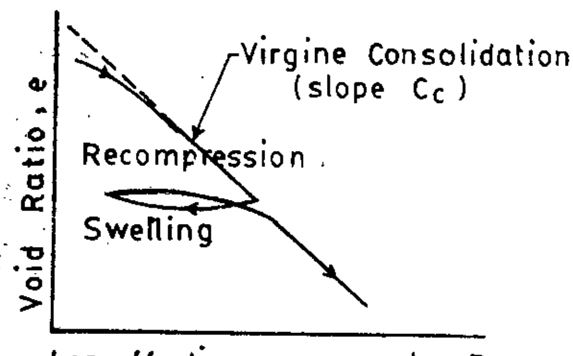

Fig.2-3 Relation between void ratio and the logarithm of effective pressure

Experiment has shown that close relation exists between natural water content and compression ratio $C_c/(1+e_o)$. They are represented approximately by a linear equation in a curve plotted against each other. The graph represents a straight line drawn out of scattered values of compression ratio $C_c/(1+e_o)$ corresponding to the given natural water content. The average value of compression ratio is used directly to compute the final consolidation settlement with the help of the following equation:

$$S = \frac{C_c}{1+e_o} \cdot H. \log_{10} \frac{p'_o + \Delta p}{p'_o} \qquad (2.2)$$

Where S = final settlement of normally loaded clay soil.

H = thickness of the bed.

The compression index C_c is closely related to the liquid limit L_w of normally loaded clay. A.W. Skempton[19] established a relationship between compression index and liquid limit for clays by the following equation:

$$C_{c'} = 0.007\ (L_w - 10) \qquad (2.3)$$

This equation is based on the test results of both ordinary and extra sensitive clays collected from different parts of the world. The equation was later modified by Terzaghi in consideration of the scattering of points to about ± 30 percent. He found the compression index C_c for normally consolidated clays with low or moderate sensitivity corresponding to the field compression curve to be roughly equal to 1.3 $C_{c'}$.

$$\text{Thus, } C_c = 1.3\, C_{c'} = (1.3)\,(0.007 - L_w - 10)$$

$$= 0.009\,(L_w - 10) \qquad (2.4)$$

The compression index C_c for the natural consolidation of a given layer of clay soil can be known without making any tests other than determining its liquid limit. The initial void ratio can be calculated from natural water content. The settlement can then be calculated from Equation 2.91. Equation 2.13 should not be used for extra-sensitive or pre-consolidated soils because the real compressibility of extra-sensitive soils may be several times greater than that obtained by the Equation 2.4.

Serajuddin and Ahmed[31] suggested an empirical relation between compression index and liquid limit for Bangladesh soil as under:

$$C_c = 0.0078\,(L_w - 14) \qquad (2.5)$$

Nishida[20], after a theoretical consideration from some simplifying assumptions derived a relationship between the compression index C_c and the void ratio of soils as follows:

$$C_c = 1.15\,(e_o - 0.35) \qquad (2.6)$$

Where C_c = compression index of a virgin curve at the void ratio e.

e_o = final void ratio after the application of pressure increment.

Expressing the final void ratio e in terms of the initial void ratio e_o, Nishida expressed his above equation in terms of the equation presented by Terzaghi as under:

$$C_c = \frac{1.15\ (e_o - 0.35)}{1 + 1.5\ \log_{10}\frac{P}{P'_o}} \qquad (2.7)$$

When the compression index C_c is determined, it is usual to approximately assume $\log_{10} \frac{P}{P'_o}$ to be equal to unity.

Hence, the above equation is expressed as:

$$C_c = 0.54\ (e_o - 0.35) \qquad (2.8)$$

Earlier, Sowers[21] developed this equation for the clay soil as follows:

$$C_c = 0.75\ (e_o - 0.60) \qquad (2.9)$$

Based on the laboratory tests on clays of Bangladesh Serajuddin and Ahmed (1967) developed the following equation:

$$C_c = 0.44\ (e_o - 0.30) \qquad (2.10)$$

Again Serajuddin[1] established the following empirical relations for soils of coastal embankment areas of Bangladesh as follows:

$$C_c = 0.0135\ (w - 20) \qquad (2.11)$$

$$C_c = 0.50\ (e_o - 0.50) \qquad (2.12)$$

Kabir[22] found out the value of compression index for clay soil of Dacca region as:

$$C_c = 0.44\ (e_o - 0.36) \qquad (2.13)$$

With the help of the above equations, it is possible to determine the value of compression index C_c without performing a consolidation test. According to Nishida, and Serajuddin, their equations agree well with a number of experimental results. Serajuddin's above equations would offer the approximate value of compression index C_c and finally the settlement characteristic of Bangladesh soils, and can be a guide to the current study of this author.

2.10 Relationship between the Shear Strength of Soil, and Effective Shear Strength Parameters

The effective shear strength parameters are cohesion C' and internal friction, Ø. The cohesion is the resistance due to interparticle forces which tend to hold the particles together in a soil mass. The internal friction is the resistance due to interlocking of particles and friction between individual particles at their contact points.

The equation[23] for shear strength of cohesive soil τ_f is correctly represented by the equation :

$$\tau_f = C' + \partial \tan \varnothing$$

$$\tau_f = C'_d + \partial' \tan \varnothing_{d'}$$

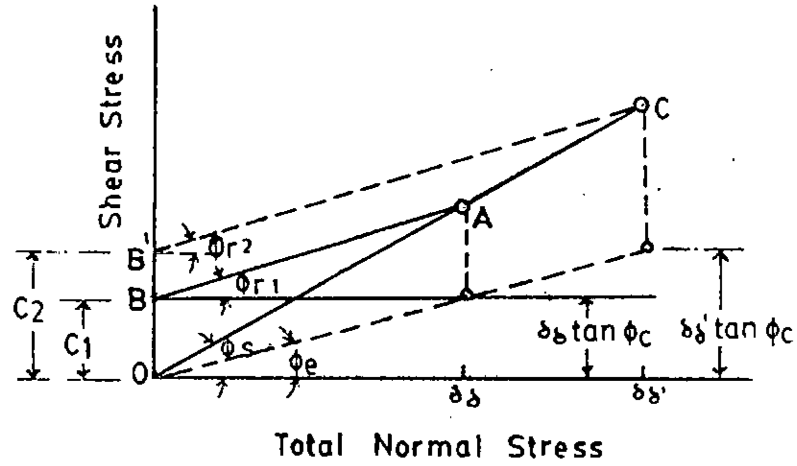

Figure 2-4 Effect of preconsolidation.

Hence the shear strength for normally consolidated clay is given by the equation:

$$\tau_n = \partial' \tan \emptyset_s \qquad (2.12)$$

The shear strength line for the same clay preconsolidated at pressure ∂_d' and having $\emptyset = \emptyset_{r1}$ is represented by the line BA. If the clay is preconsolidated at other pressure, shear strength lines parallel to BA is obtained. This means that cohesion is proportional to ∂_d or ∂

$$C_1' = \partial_d \tan \emptyset_c \qquad (2.13)$$

Therefore, shear strength of the soil after preconsolidation is

$$\tau_p = \partial_d' \tan \emptyset_c + \partial' \tan \emptyset_{r1} \qquad (2.14)$$

This shows the higher values of shear strength due to preconsolidation.

Where σ' = effective stress in a soil equal to the total applied stress σ minus the pore pressure u.

C' = effective cohesion $C_{u'}$ in consolidated undrained test or $C_{d'}$ in drained test.

ϕ = effective angle of shearing resistance ϕ in consolidated undrained test or $\phi_{d'}$ in drained test.

C' is zero for normally consolidated clay. However, they do not always give the same results for undisturbed clays(23). In general, there exists a closer agreement between results obtained for normally consolidated clays than for heavily preconsolidated clays. Drained tests on heavily preconsolidated clays usually yield slightly higher values of C' and ϕ, which is thought due to the work done against volume changes during shear in drained tests and due to the smaller failure strain.

In Figure 2.4, the graphical representation of the above equation is shown. The shear strength line for normally consolidated clay is represented by the line OAC, for which $\phi = \phi_{s'}$ $C' = 0$.

CHAPTER-3

FIELD INVESTIGATIONS AND COLLECTION OF SOIL SAMPLES

3.1 General

Field investigations[24] of the site constitute an essential and important engineering programme which interalia, guide in assessing the general suitability of the site for the proposed works, enables foundation engineer to prepare an economic and safe design. A complete field investigation in general, involves the following operations : (1) preliminary work such as collection of general information and examination of the already existing data about the soil and geological conditions of the site (ii) site reconnaissance (iii) sub-surface exploration and (iv) investigations of the sub-soil materials.

3.2 Scope of the Field Work

Sub-surface exploration comprises a number of field and laboratory works. The field work consists of execution of exploratory borings, standard penetration tests and collection of disturbed and undisturbed soil samples. It provides the information of depth, thickness, extent and composition of each soil stratum, location of hard stratum and ground water conditione strength and compressibility of the various strata.

3.3 Sub-surface Exploration

Sub-surface soundings are used for the determination of penetration resistance of soil deposits along vertical lines. They are done to indicate the worst and best spots of the site. Penetrometers are used for making soundings. The standard penetration tests are performed when coarse grained soils are encountered and split tube samples are then collected. Thin wall samplers are used for sampling of fine grained soils.

3.4 Collection of Soil Samples

Of the soil samples collected by the River Research Institute of Bangladesh Water Development Board, Messers Foundation Consultants, Dacca, and Messers Sub-soil Engineers, Dacca from various locations of Barisal, Bhola, Patuakhali, Khulna and Noakhali at various depths ranging 5 feet and below. the results of 213 disturbed and 78 undisturbed soil samples were used for mechanical analysis, determination of natural water content, and consistency. Besides, the test data of 134 undisturbed soil samples collected from the above locations by the above mentioned organisation and consulting firms for unconfined compression test and consolidation test have been in this work.

Thin wall samplers were used by them for collection of these samples. Piston samplers were used for collection of samples especially below the water table. A few soil samples were collected by the author from these organisations for laboratory test in order to use their results in this study.

3.5 Laboratory Investigations

The laboratory investigations on the collected soil samples disclose the general characteristics and their engineering properties. Their physical properties include the natural water content, specific gravity, grain size distribution, and consistency. The soil samples collected by various organisations were tested in their respective soil laboratories, while a few samples were tested by the author in the Bangladesh University of Engineering and Technology soil laboratory. The unconfined compression and Tri-axial tests were done to determine the shearing strength of the sub-soil. The samples were tested in a consolidometer to study the effect of consolidation in consideration of its importance in the study of the effect of compressibility characteristics of the soil samples. These characteristics are vital for determining the period and magnitude of settlement of the foundation.

3.5.1 Test Procedure for Physical Properties

The soil samples collected were duly tested for the determination of natural water content, particle specific gravity, grain size analysis, and consistency according to the standard test procedures.

3.5.2 Consolidation Test

The consolidation test was performed by the author on 4 undisturbed soil samples according to the standard test

Procedure, and the results of the tests performed on 132 undisturbed soil samples by various organisations as already mentioned, have been used in this study.

3.5.3 Unconfined Compression Test

Unconfined compression test was done by the author on 4 undisturbed soil samples for the determination of the shear strength of cohesive soils as per usual test procedure. The shearing strength was measured as half of the unconfined compressive strength at which the specimen had failed along its bearing plane.

3.5.4 Undrained Triaxial Shear Tests

Undrained triaxial shear test was performed on the purely cohesive soils by the various organisations as already mentioned and their results have been used in this study. Consolidated undrained triaxial test was done on the soil samples which appear to have considerable angle of friction as well as cohesion.

CHAPTER-4

LABORATORY TEST RESULTS

4.1 Penetration Resistance and Physical Properties of Soils

Numerous disturbed and undisturbed soils of different regions of coastal areas of Bangladesh that includes Barisal, Bhola, Patuakhali, Khulna and Noakhali collected by the various Government Organisations and consulting firms were tested for the study of their general characteristics and range of natural water content, specific gravity, particle size distribution, liquid and plastic limits, and other engineering properties. Given below is a table indicating the numbers of soil samples collected and tested by organisations and by the author for the above purpose.

Table 4.1

Number of Samples Collected and Tested by Various Organisations and the Author

Organisations/Author	Consistency, N.W.C and Mechanical Analysis	
	Disturbed	Undisturbed
1. Bangladesh Water Development Board	21(Barisal-14 Noakhali-5 Khulna-2	31(Barisal-20 Noakhali-3 Khulna-8)
2. Foundation Consultant	189(Barisal-6 Bhola-75 Patuakhali-91 Khulna - 17)	-
3. Sub-Soil Engineers	-	19(Barisal-5 Bhola - 6 Patuakhali-4 Noakhali-4)
4. Author	-	4 (Patuakhali-4)

Standard penetration test, performed at sites for general exploration of soil profiles,provides depth to hard stratum, and also approximate indication of the strength of the underlying strata. The soil profiles of coastal regions are observed to be generally identical with minor variations in some localities. The S.P.T values for the underlying strata generally vary between 8 and 18 while the upper strata in most of the locations indicate values less than 8.

From the Mechanical analysis, the average clay contents of the specific layers are determined. The values of colloidal activity are also determined in order to classify the clay soils in terms of activity.

Test data are summarised and presented in Tabular form in Appendix A and B. Average and range of values of N.W.C, liquid limit, plasticity index, and grain size analysis are however presented serially in Tables in the following articles.

4.2 Consistency and Natural Water Content

Test results of 213 disturbed and 68 undisturbed soil samples of coastal regions are presented in tabular form in Appendix-A.

The soils are mostly normally consolidated cohesive deposits with their actual range and average values of natural water content, liquid limit, and plasticity index, as summarised in Table 4.2.

Table 4.2

Range and Average Values of Natural Water Content, Liquid Limit, and Plasticity Index

Test zone	Ground water table in feet	RANGE OF VALUES			AVERAGE VALUE OF		
		N.W.C. %	Liquid limit %	Plasticity index %	N.W.C. %	Liquid limit %	Plasticity index %
Barisal	1-11	25.4-42.7	34-50	4-21	36.0	41.0	14.0
Bhola	1-13	24.0-42.1	31-47	5-22	33.0	39.0	12.0
Patuakhali	1-10	24.5-44.0	33-50	3-25	34.0	42.0	16.0
Khulna	1-16	26.1-46.7	32-56	6-29	36.0	42.0	14.0
Noakhali	8-11	34.5-45.0	36-42	12-17	37.0	40.0	13.0

The ground water condition as well as average values of natural water content, liquid limit and plasticity index shown in the above table for different locations in the coastal regions are not in variance, and agree quite well. The liquid limit ranges from 31 to 50 per cent, plasticity index 3 to 29 per cent, natural water content 24 to 47 percent. The ground water table varies between 1 to 16 feet in the locations.

4.3 Grain Size Composition

The soil composition and classification based on grain size analysis on some selected soil samples of different regions of coastal areas are indicated in Table 4.3.

Table 4.3

Average Type of Soil Samples, Specific Gravity Dry Unit Weight and Uniformity Co-efficient

Test Zone	Sample depth in ft.	Average Type of soil sample	AVERAGE VALUE OF Sp. gravity	Dry unit weight	Uniformity co-efficient
Barisal	5-20	Silty clay, silt with fine sand, sandy silt trace clay.	2.67	81.30	6.63
Bhola	5-20	Silty clay, silt with fine sand, trace clay.	2.67	93.13	4.56
Patuakhali	5-25	Clayey silt, little fine sand, silty clay with fine sand.	2.67	88.12	4.46
Khulna	5-15	Silt trace fine sand, sandy silt trace little clay silty clay with peat, trace fine sand.	2.68	87.60	9.07
Noakhali	1-25	Silt with fine sand, trace little clay, fine sand with trace of mica.	2.67	91.33	4.95

From the test results presented in Appendix-B, it is observed that the soils of coastal areas are generally composed of cohesive deposits in the upper stratum underlain by non-cohesive deposits. The cohesive deposits are composed of silt clay soils and possess relatively narrow range of particle size. The non-cohesive deposits are composed of very fine silt to fine sand. Occassional traces mica interculated with silt are encountered at an average depth of below 20 feet from ground level in some very limited areas. The clay fraction (minus 2 micron) generally varies from 3 to 30 percent, the silt fraction varies from 40 to 80 percent, and the sand content is generally less than 10 percent. The uniformity co-efficient for soils of Bhola, Patuakhali and Noakhali regions are found to be less than 6 while for Barisal and Khulna, the value is grater than 6 indicating the soil to be well graded.

4.4 Compressibility

Coastal soil usually varies in compressibility depending on the amount and the character of the fines and the quantity, and graduation of the coarse particles contained by them. Their compressibility depends on their density and moisture content at the time of loading. Test results obtained through a series of testing are presented in Tables in Appendix-C. The range of values of moisture content, dry density, natural void ratio, and compression index for coastal soils are shown in Table 4.4.

The dry density of the soils appears to range from 70.10 to 104.00 and moisture content from 20.30-77.00. Mostly they fall in the ranges of 80.0 to 90.00 and 30.0-45.0 respectively. The values of compression index, for soils of Bhola and Patuakhali, regions show much lower values than Khulna and

Table 4.4

Range of Values of Moisture Contents, Dry Density, Natural Void Ratio, and Compression Index

Test zone	RANGE OF VALUES				
	Sample depth in ft.	Dry density pcf	Moisture content %	Natural void ratio	Compression Index
Barisal	4-25	72.7-94.0	29.0-77.0	0.72-1.27	0.15-0.55
Bhola	4-20	76.5-104	24.0-41.5	0.76-1.34	0.19-0.35
Patuakhali	5-15	70.1-98.5	27.0-50.0	0.65-1.24	0.09-0.42
Khulna	5-35	78.0-104	29.6-58.3	0.65-1.29	0.10-0.53
Noakhali	5-25	87.0-98.2	20.3-40.0	0.67-1.00	0.10-0.30

Barisal regions. It varies from 0.10 to 0.55, in majority of the cases falling in the range of 0.20 to 0.40.

The initial void ratio, e_o ranges from 0.65 to 1.34 in majority of the cases falling in the range of 0.80 to 1.20. It is evident that the higher moisture content results in this compacted soil with more voids, less density and increased plasticity (softness).

The ground water table is very close to the surface of most of the areas of coastal regions. Serajuddin[26] described the degree of saturation for the cohesive deposits found in most of the locations of coastal regions, with a few exceptions, to be about 97 to 100 percent.

4.5 Shear Strength

The shearing strength of both 120 disturbed and 136 undisturbed soil samples collected from different locations of coastal regions has been investigated by means of unconfined compression test as well as Tri-axial test. The factors that control the shear strength of these soil samples are investigated and the results are indicated in the Tables in Appendix-D and E respectively.

In determining the shearing strength through unconfined compression test, the moisture content as well as dry density of the respective soil samples are determined. The normal range and average of these values are indicated in the Table 4.5 and 4.6 respectively.

Table 4.5

Range of Values of Moisture Content, Dry density, and Shear Strength

Test zone	RANGE OF VALUES				
	Sample depth in ft.	Nos	Moisture content %	Dry density (pcf)	Shear strength (psf)
Barisal	0-20	19	21.1-61.7	70.5-108	209-903
Bhola	5-40	75	24.0-42.1	78.0-104	350-1188
Patuakhali	5-40	117	26.5-51.7	81.0-108	310-1296
Khulna	0-45	163	26.0-44.0	78.0-102	340-1288
Noakhali	-	-	-	-	-

Table 4.6

Average Values of Moisture Content, Dry density and Shear Strength

Test zone	Number of samples	AVERAGE VALUES OF Sample depth in ft.	Moisture content %	Dry density pcf	Shear strength psf
Barisal	19	9.30	39.48	83.00	392.20
Bhola	75	4.50	33.84	91.00	752.80
Patuakhali	117	7.80	34.67	89.00	774.40
Khulna	63	11.70	35.85	87.00	713.40
Noakhali	-	-	-	-	-

Based on Triaxial tests carried out on a limited number of undisturbed soil samples, the normal range of values of angle of internal friction, cohesion, failure strain, and water content obtained are indicated in Table 4.7.

Table 4.7

Range of Values of Water Content, Failure Strain, Cohesion, and Angle of Internal Friction

Test zone	Number of samples	RANGE OF VALUES OF Sample depth in ft.	Water content %	Failure strain %	Cohesion psf	Angle of internal friction
Barisal	4	5-10	30.5-49.8	18-20	288-576	$0^{\circ}-6^{\circ}$
Bhola	10	0-15	25.7-32.4	14-20	432-1152	$3^{\circ}-16^{\circ}$
Patuakhali	10	0-10	29.5-38.0	10-20	260-1296	$2^{\circ}-15^{\circ}$
Khulna	5	5-15	26.5-42.4	11-20	250-864	$4^{\circ}-13^{\circ}$
Noakhali	2	10-20	34.6-35.7	9-19	144-1512	$10.5^{\circ}-20^{\circ}$

CHAPTER 5

ANALYSIS AND DISCUSSION OF TEST RESULTS

5.1 Soil Profile and Penetration Resistance of Soils

The soil profiles of coastal regions are generally identical with minor variations in some localities. The non-cohesive deposits (non-plastic), cohesive deposits and combination of these two are predominant in the regions. Mostly the upper surface contains deposits of very soft to soft clay to a varying depths of about 5-20 ft, followed by light to medium stiff silty clay deposits with little trace of sand. The underlying strata generally contains deposits of medium stiff to medium dense silty fine sand with S.P.T values greater than 10. The upper strata containing cohesive deposits shows SPT values not greater than 8, and is generally considered medium to soft in consistency. They are considered suitable for shallow foundations for light to medium loads.

Organic soil materials like peat are occassionally present in the deposits. Their presence is found mostly in the soils of Khulna region within either silt clay or sand silt deposits. They are very loose, and are more compressible. They are identified by the presence of fibrous particles of vegetative matter of dark brown to black colour, and by their characteristic organic odor. The foundation engineer should always determine its depth and extent in the field in order to estimate compressibility effect of the overlying strata.

Serajuddin[26] in his investigations on the soil properties of embankments of coastal areas of Bangladesh observed that the cohesive silt clay soils usually exist in the surface and upper layers in varying thickness of about 6-30 ft in many locations in the coastal area. Even in same places the silty clay is found from the surface down to depths as great as about 60 to 80 feet. In other areas, they are embedded with fine sand silt. The non-plastic silty fine sand of cone resistance in the range of about 20 to about 90 tons/sq.ft. exists at depths greater than 30 feet. The silty clay materials existing in the upper layer possesses a probable average cone resistance of about 5 to 10 tons per sq.ft in the location.

Serajuddin[26] observed that the silt clay materials in some of the areas are too loose with low strength and in other areas it is fairly compact. This variance is shown by the blows on sample spoons being as low as 1 and as high as 17 blows per foot. According to him, the compactness is related to the conditions of tidal or fresh water deposits and to the maximum overburden pressure.

5.2 Consistency and Natural Water Content

The soil materials encountered in the coastal regions are composed of deposits of cohesive and non-cohesive materials and also a mixture of them in varying proportions. The deposits closer to the Bay of Bengal consist of surface sediments duly

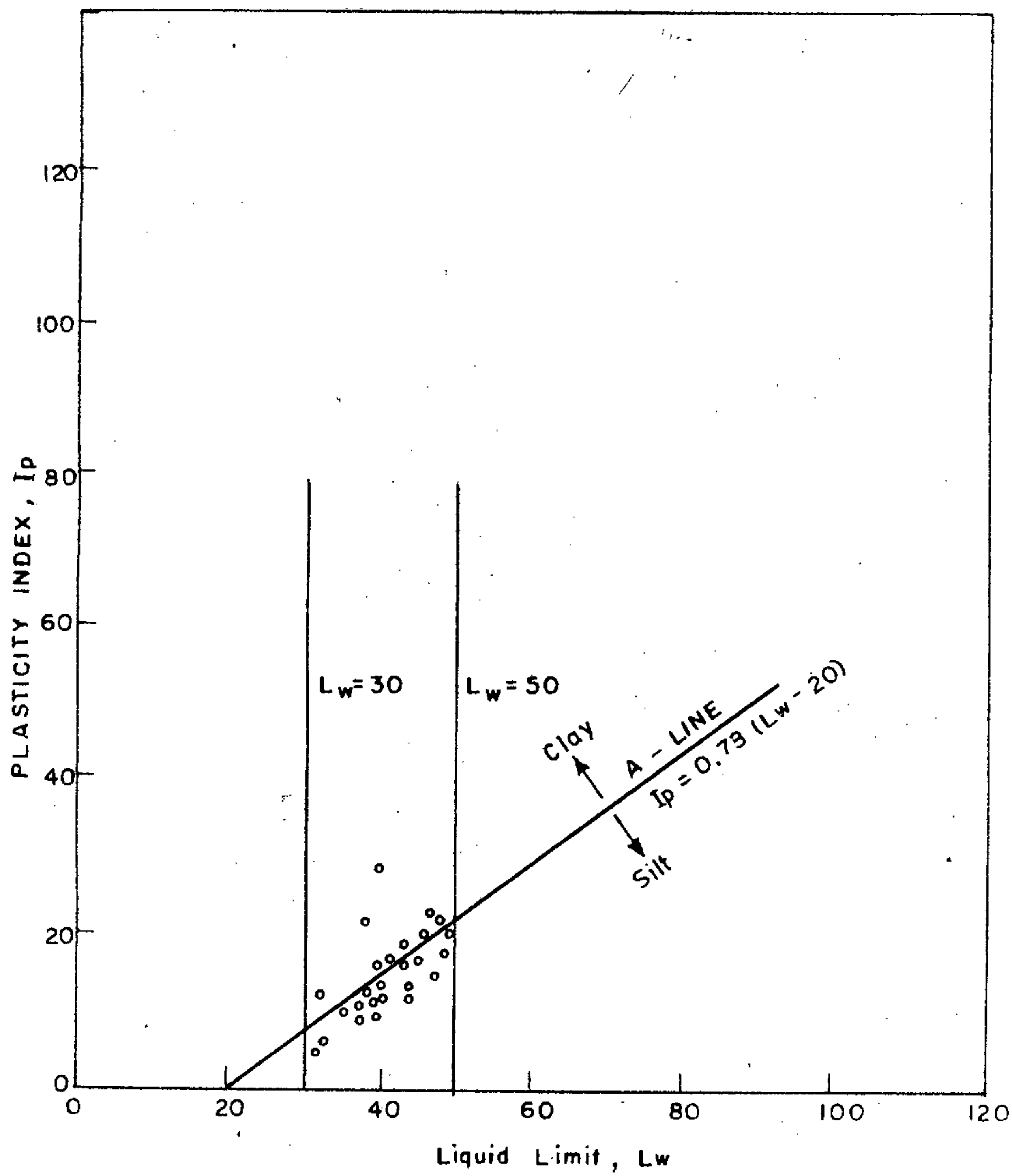

FIG.5.1 PLASTICITY CHART FOR BARISAL SOIL

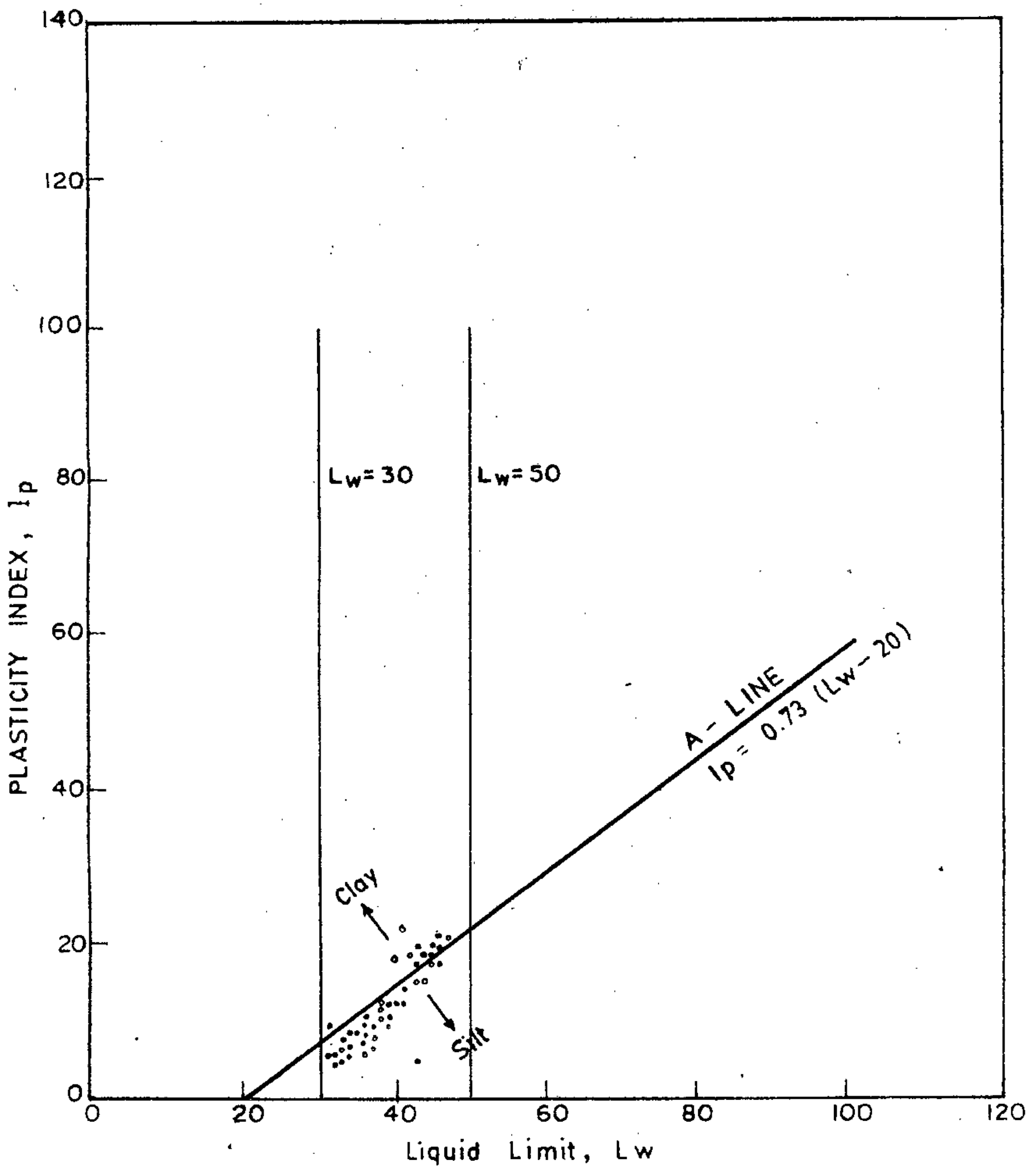

FIG.5.2 PLASTICITY CHART FOR BHOLA SOIL

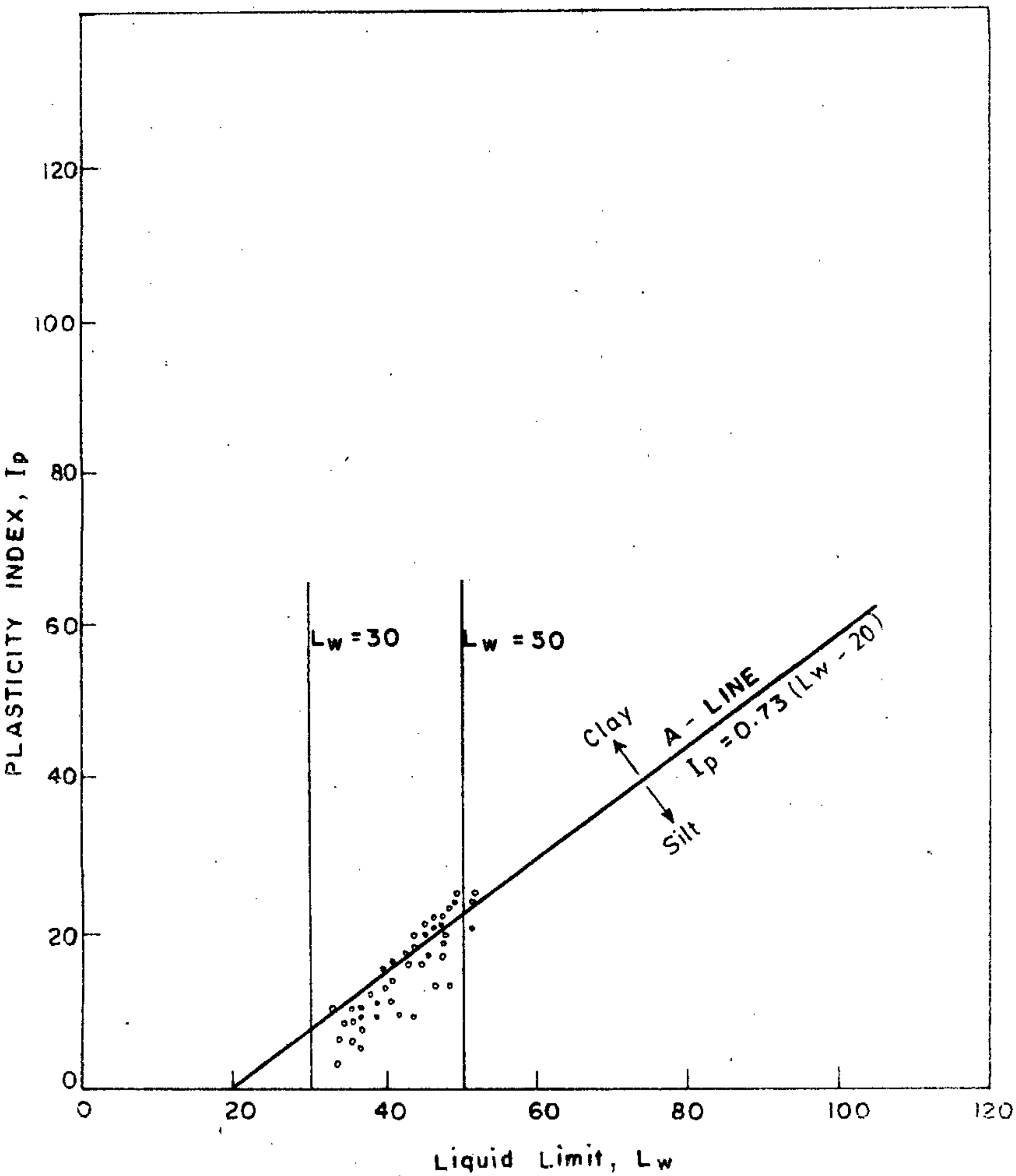

FIG.5.3 PLASTICITY CHART FOR PATUAKHALI SOILS

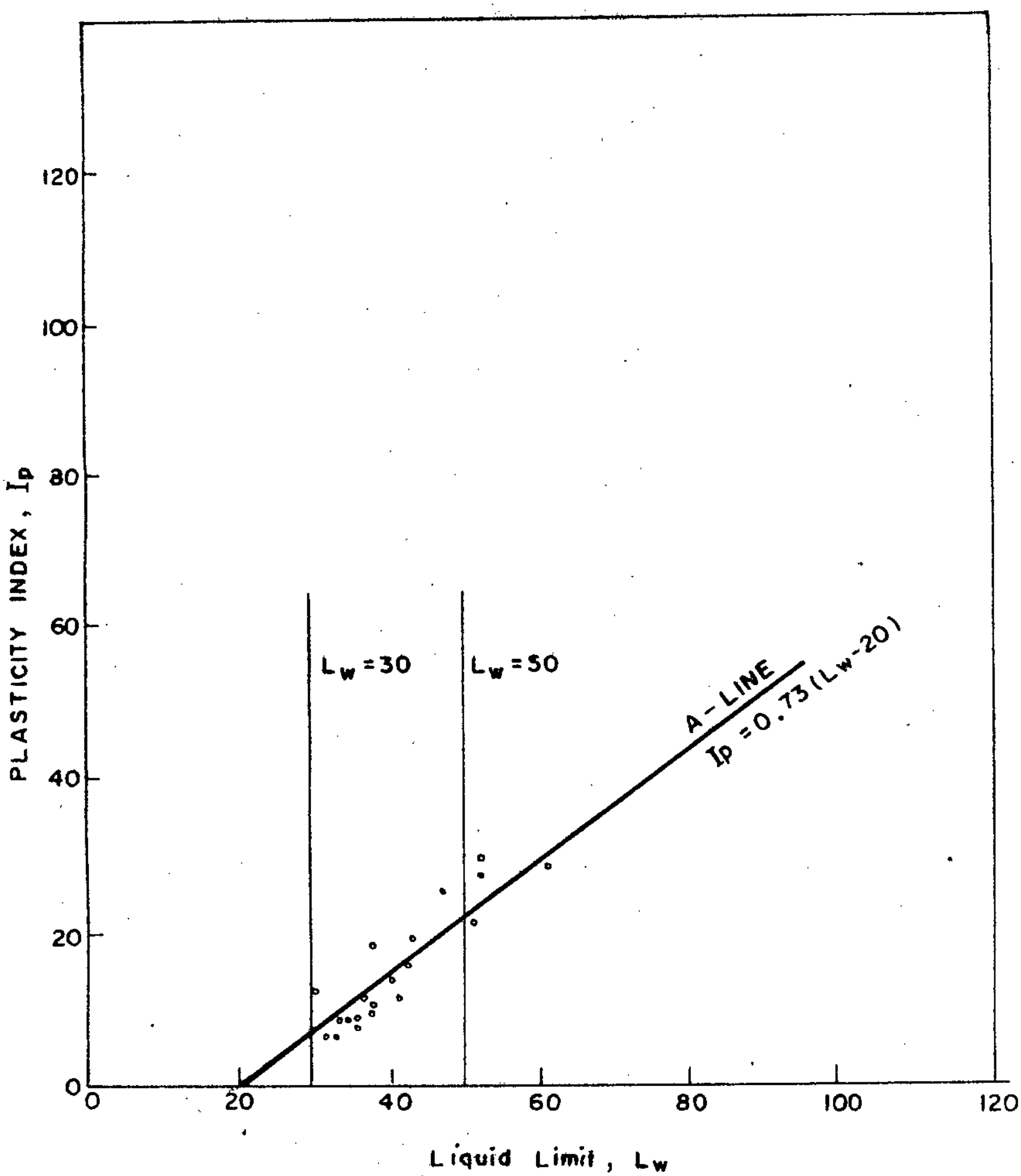

FIG.5.4 PLASTICITY CHART FOR KHULNA SOIL

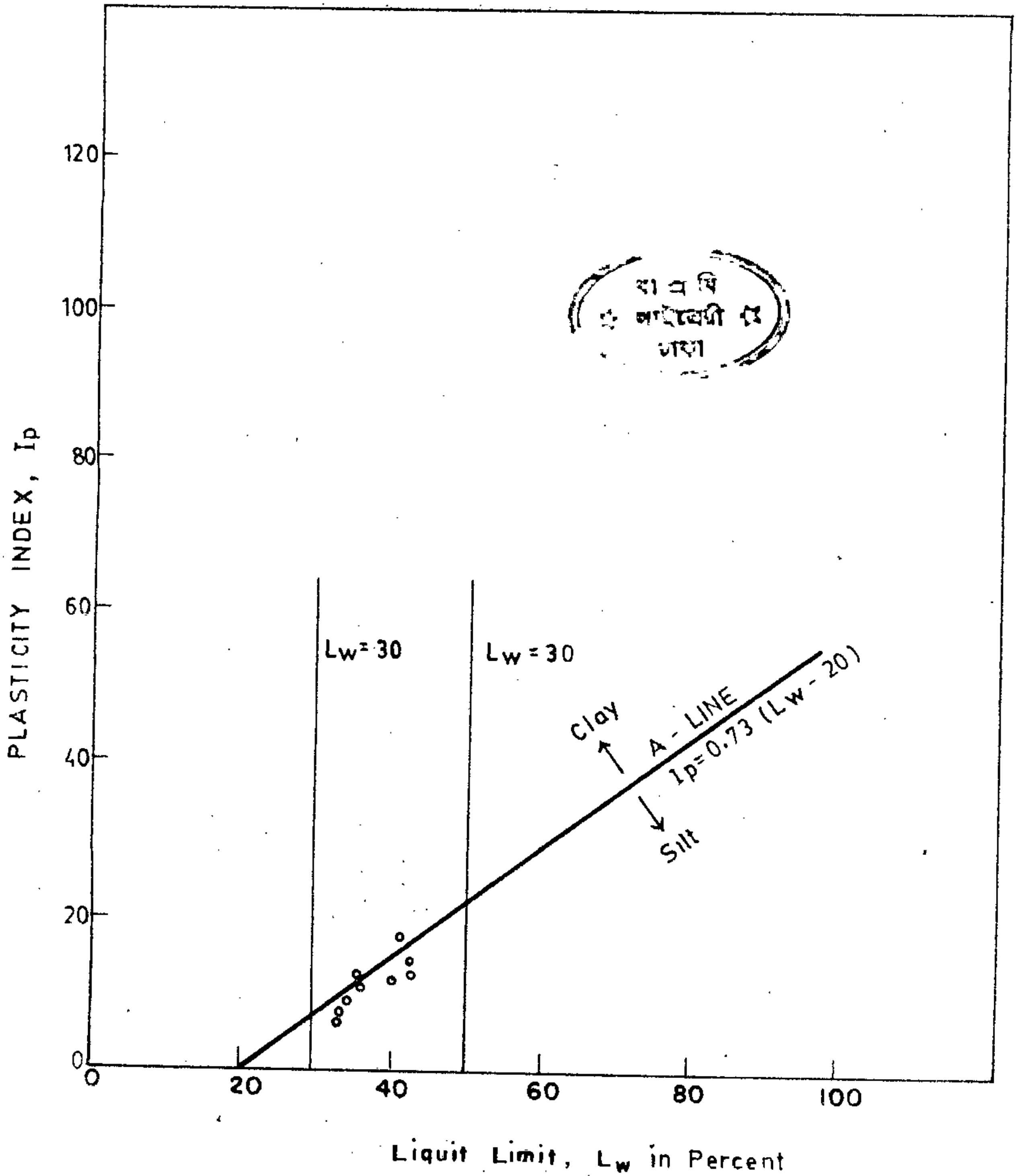

FIG.5.5 PLASTICITY CHART FOR NOAKHALI SOIL

transported by the running water, with occassional presence of organic material in a partly or fully decomposed state. In general, the deposits in the upper surface are soft with natural water content ranging normally between 35 and 42 percent. The ground water table is very close at varying depths to about 1 to 16 feet, in most of the locations of Bhola, Barisal, Patuakhali and Khulna regions. In Noakhali regions, the ground water table exists in between about 8 and 11 feet, where the natural water content varies between 25 to 35 percent. The values of liquid limit for the coastal regions ranges from 31 to 57 percent, plasticity index from 3 to 33 percent, and natural water content from 25 to 44 percent. Their values are plotted separately for different regions in relation to the Casagrande A - line as shown in Figures 5.1 to 5.5. From the plottings, it is observed that the soils plot very close on both above and below the A-line of plasticity chart indicating the type of soils to be inorganic clays of medium plasticity and inorganic silts of medium compressibility. The soil particularly of Barisal, Bhola and Khulna contain appreciable amount of in organic silts as they plot below the A - line within the range of liquid limit 30 and 50.

The coastal clays are moderately plastic. The lower values of liquid limit and plasticity index are indicative of low plasticity and sometimes non-plastic. The presence of Kaoline and mica powder presumably tend to make the soil particles low plastic. The higher values of liquid limits greater than 50 are indicative of the presence of organic matters. The values of plasticity index for some soils of Patuakhali regions show much higher values thereby indicating the likely presence of fat clays which are highly swelling and water absorbant.

The plastic materials with higher values of liquid limits are characterised equally by high moisture content. Samples having a moisture content closer to the plastic limit than to the liquid limit are usually pre-consolidated. The natural water content of most of the plastic clays and silts is found to be less and closer to their liquid limits, thereby indicating that the deposits are normally loaded.

5.3 Grain Size Composition

From the grain size analysis, the gradation of the particles as well as distribution of particle sizes were determined. Clay particles are identified over their colloidal activities which is shown on the Table in Appendix-A.

The plasticity indices and clay contents of a number of samples taken from different stratum vary over a wide range. The range and average values of colloidal activity are shown in Table 5.1 which shows that the activity is as high as 2 to 6.7. The higher values are presumably due to variations in the compositions, within the stratum. Depending on their value, the clay falls in three classes, namely inactive, normal and active clays. Lowest value of 0.75 or less is indicative of inactive clays which show the presence of Kaolinite mineral. Montmorillonite is predominant in the largest number of samples of Patuakhali and Bhola regions as they fall in active group having value of 1.25 or over. The presence of largest number of samples in Montmorillonite group is attributed to the presence of organic matters providing organic colloids.

The co-efficient of uniformity of the silt clay group of some of the soil samples are analysed. The values of D_{60}/D_{10} are found to generally vary between 3.50 and 20. The particles are considered uniformly graded when the value is less than 2, and medium graded for value between 4-6 and well graded for value over 6. The silt-clay particles of Bhola, Patuakhali, and Noakhali are generally medium graded as the value of uniformity co-efficient is less than 6. The soil particles of Khulna and Barisal regions, are generally well graded as their values of uniformity co-efficient are found to be greater than 6.

5.4 Shear Strength of Cohesive Soils

The unconfined compression strength of the cohesive silt and clay soils normally range from about 418 psf to about 2500 psf even upto a depth of 45 ft. from ground surface with only a few occassional results higher than about 2500 psf. Table 5.2 shows the range and average values of shear strength

Table 5.1

Range and Average Values of Colloidal Activity

Sl. No.	Test Zone	Range of Values of Activity						Average values of activity		
		Inactive		Normal		Active		Inactive	Normal	Active
		Value	No. of sample	Value	No. of sample	Value	No. of sample			
1.	Barisal	Nil	Nil	0.82-1.25	4	0.0-4.33	9	Nil	1.036	2.51
2.	Bhola	0.56-0.75	7	0.83-1.25	15	1.36-6.67	58	0.665	1.002	3.048
3.	Patuakhali	0.43-0.75	14	0.76-1.25	31	1.27-6.25	48	0.630	1.0314	2.136
4.	Khulna	0.66	1	0.8-1.22	6	1.43-5.8	10	0.666	0.991[illegible]	3.239
5.	Noakhali	-	-	-	-	-	-	-	-	-

Table 5.2

Range and Average Value of National Water Content, W_o Unit Weight, γd, and Unconfined Compression Strength, q_u

Sl. No.	Test Zone	No. of samples	Range of Value			Average Value of		
			N.W.C.	Dry Density pcf	q_u psf	N.W.C.	Dry density pcf	q_u
1.	Barisal	30	21-61	70-108	418-1806	39	83.11	785
2.	Bhola	101	24-42	78-104	700-2376	34	89.6	1506
3.	Patuakhali	141	26-52	81-108	620-2592	35	88.3	1549
4.	Khulna	82	26-47	78-102	680-2576	36	86.8	1427
5.	Noakhali	8	26-44	-	-	32	-	-

and natural moisture content to give an approximate ideas of shear strength of soils of these regions of coastal areas. The average shearing strength of the soil of Barisal region is comparatively lower than in other regions. The average water content is much higher, and is the likely cause for lower values of shearing resistance which ultimately controls the bearing capacity of the soil.

The values of cohesion is dependent on moisture content. The angle of internal friction for most of the soil samples vary between 0^{o} and 16^{o} as shown in Table 5.3. The angle of friction is quite large for clays of moderate or high plasticity. The higher values of the angle of internal friction indicate that the particles are effectively in contact with clay soils, and the solid body friction persists at the intergranular contacts. The shear strength values are appreciable in that cases. The lower values of cohesion and of angle of internal friction are indicative of the fact that the sub-surface soil consists of a compressible silt clay materials. The lower value of angle of internal friction is indicative of the higher activity of the clay group.

The sub-surface soil in most of the areas are soft, and poorly graded. These characteristics are not favourable for any good foundation material. The foundation engineer will face problem with this type of soils.

Table 5.3

Range of Values of Natural Water Content, W_o Angle of Internal Friction, Ø, and Cohesion C

Sl. No.	Test Zone	Number of samples	Sample depth in ft.	RANGE OF VALUES OF Natural water content %	Angle of internal friction in degree	Cohesion in psf
1.	Barisal	4	5-10	30.53-49.80	0^o-5^o	288-576
2.	Bhola	10	0-15	25.66-32.35	3^o-16^o	432-1152
3.	Patuakhali	10	0-10	29.46-38.00	2^o-15^o	260-1296
4.	Khulna	5	5-15	26.6-42.40	4^o-13^o	250-864
5.	Noakhali	2	10-20	34.60-35.75	10.5^o-20^o	144-1512

5.5 Compressibility of Cohesive Soils

The values of initial void ratio, and compression index, are plotted in Fig. 5.6 to 5.10. . The range and average values of compression index, initial void ratio, N.W.C, liquid limit are shown in Table 5.4. The initial void ratio ranges between 0.65 to 1.34. The larger values of void ratio indicate loose structure of the soil type. The colloidal activity of most of the soils samples shows values greater than 1.25, it can therefore, be concluded that these soil types generally belong to montmorillonite group. They are generally compressible. The compression index ranges from 0.09 to 0.55. The average value of compression index is on the high side which indicates the higher compressible character of the clay soils. The higher values of compression index is indicative of the presence of organic matters like peat.

Degree of saturation for the cohesive deposits is found to be about 97 to 100 percent (Serajuddin 1967). The lowering of water table causes corresponding increase in pressure between the grains of all the soils beneath the original position of water table, and the strain causes ultimate settlement. The coastal areas are almost flat and mostly the soils are partially submerged because the ground water is normally very close to the surface. The degree of saturation is therefore, considered to be 100% for all practical purposes.

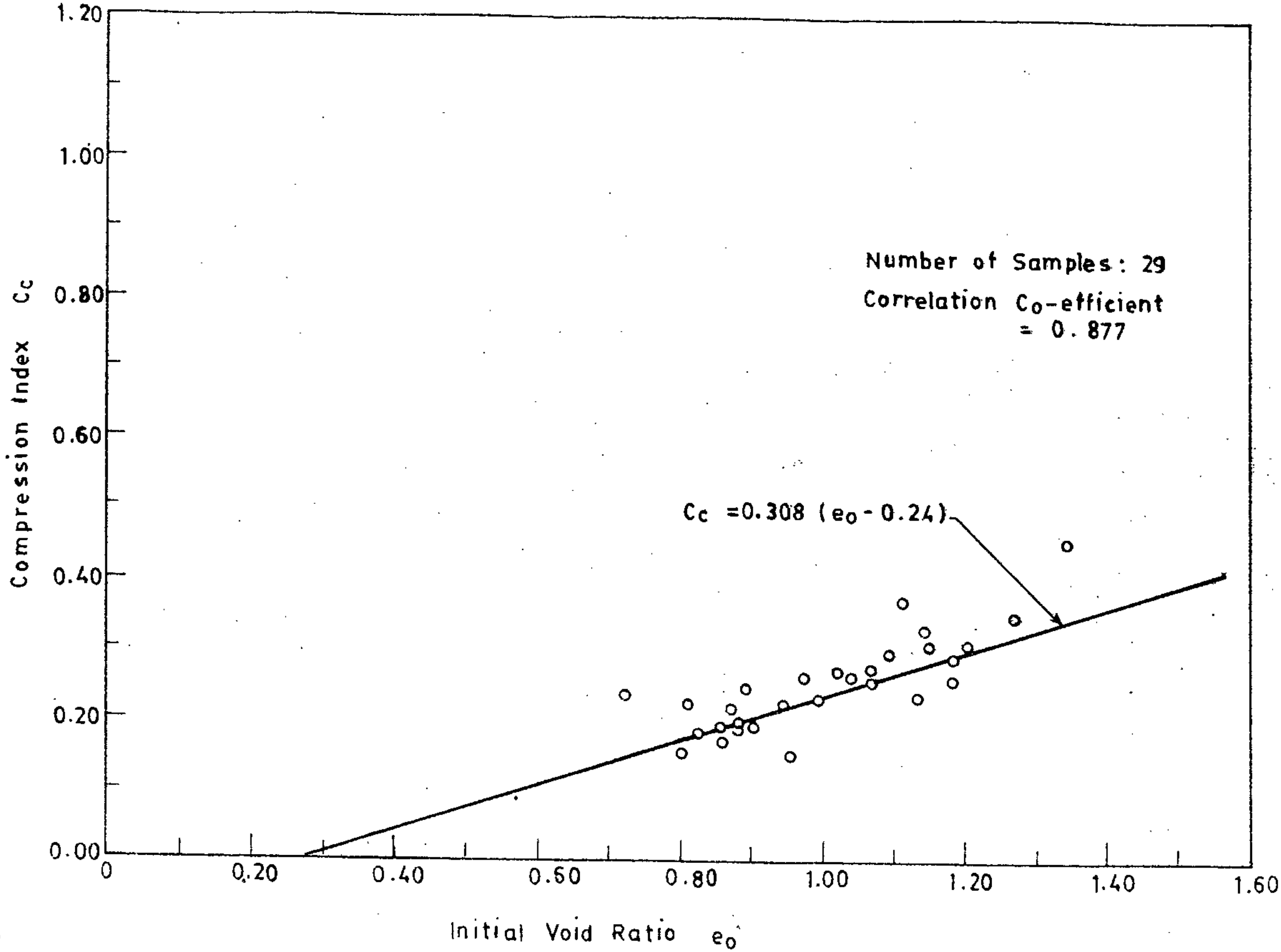

FIG. 5.6 BARISAL ZONE

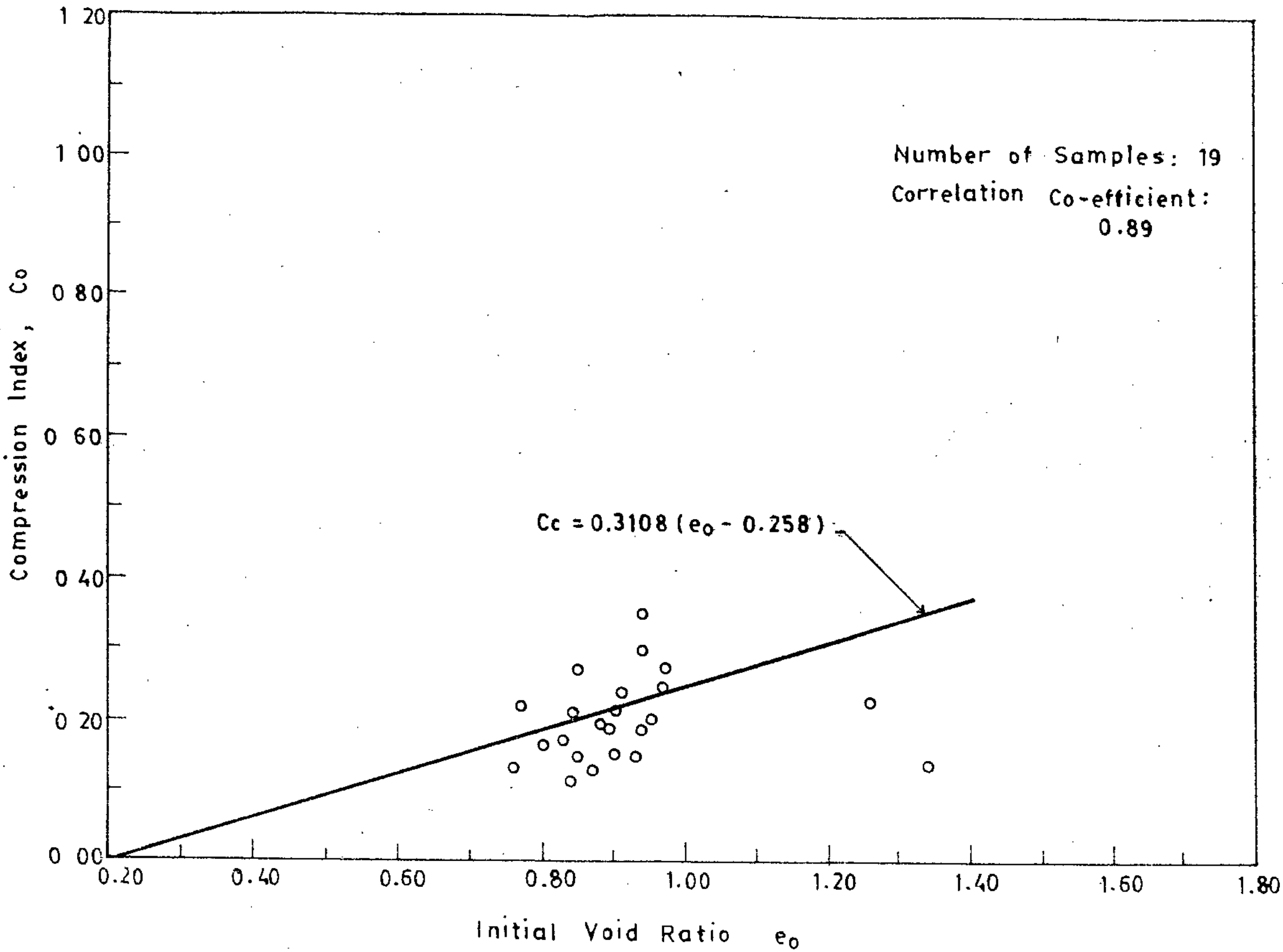

FIG.5.7 BHOLA ZONE

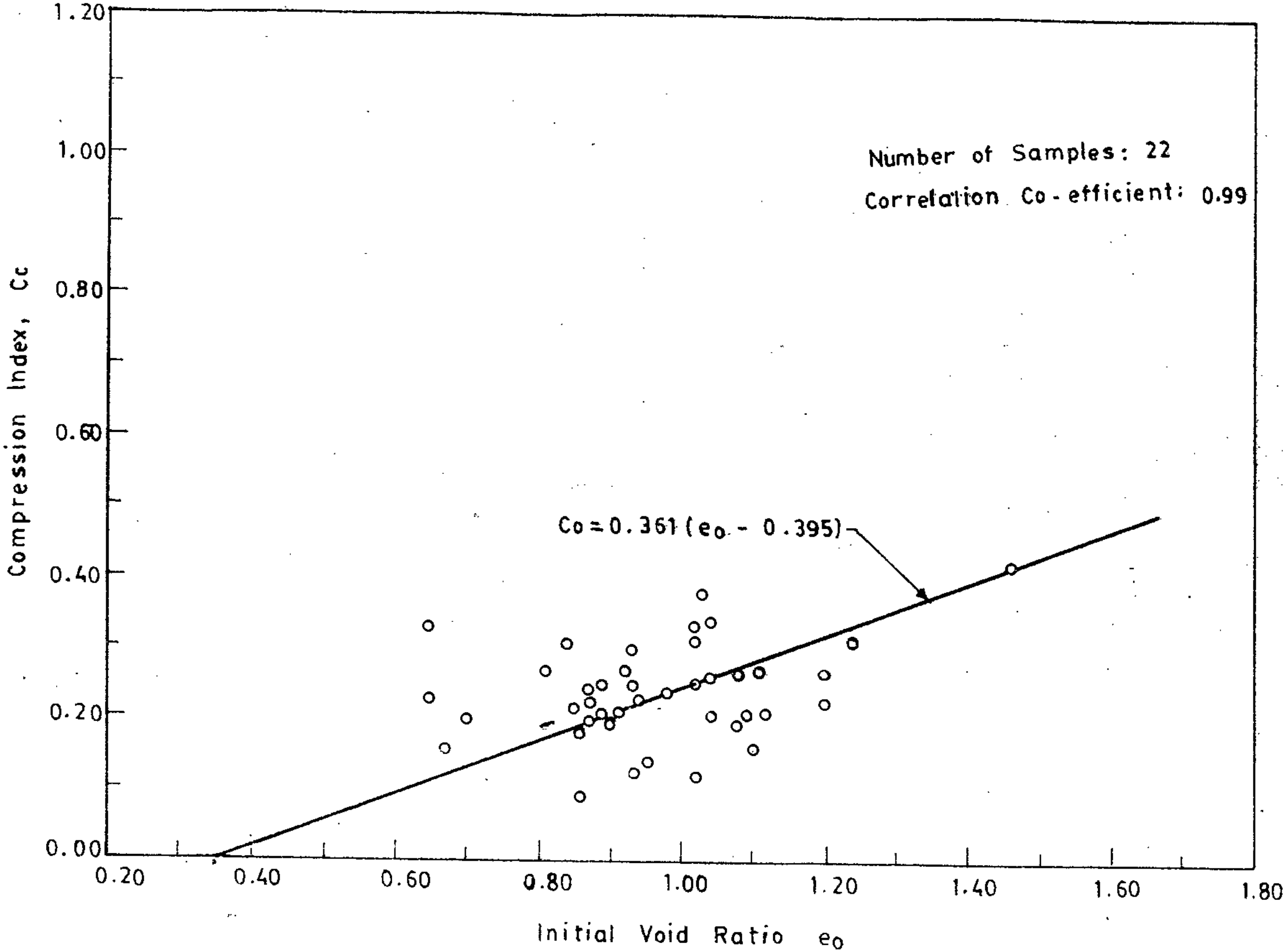

FIG.5.8 PATUAKHALI ZONE

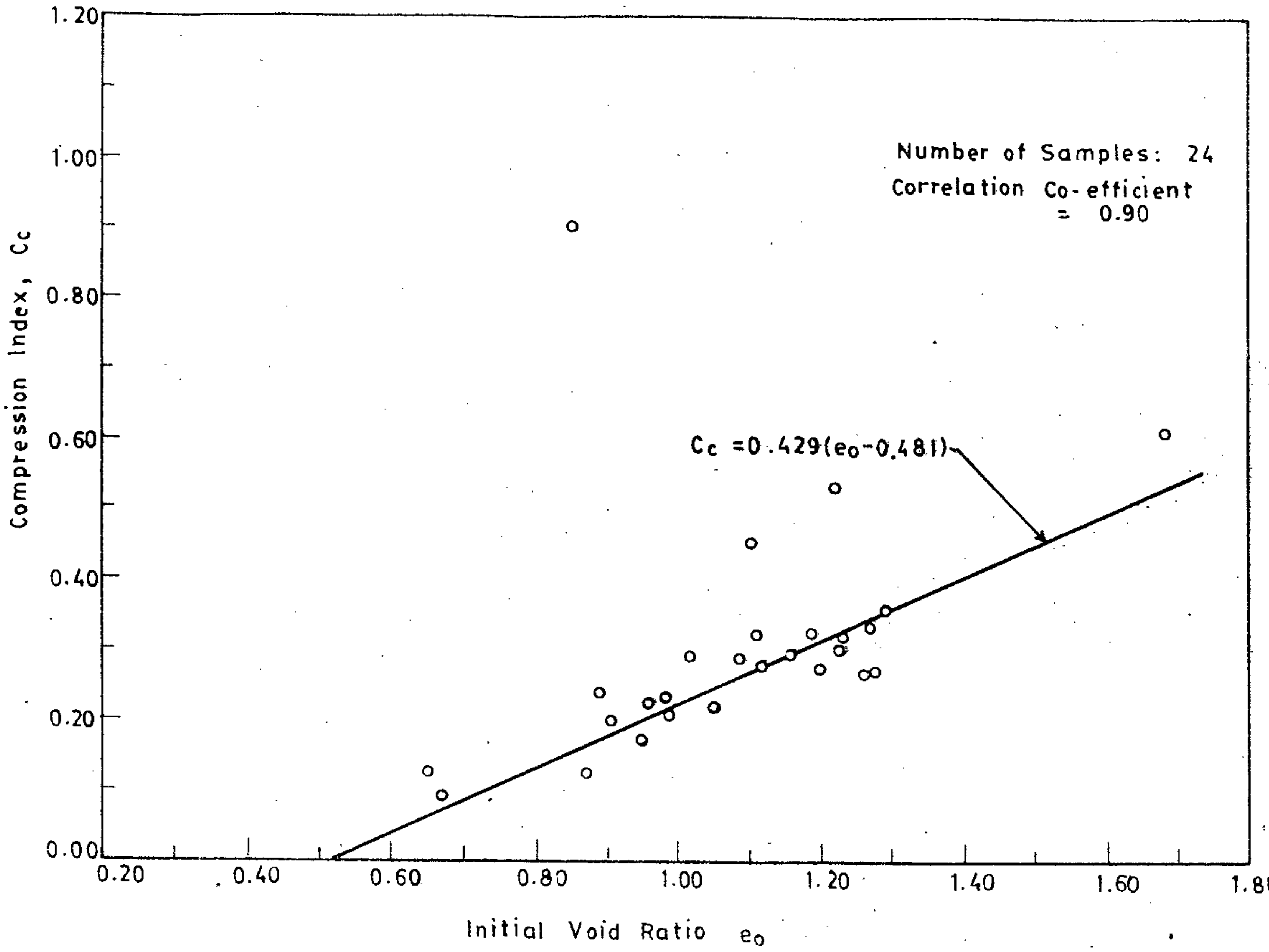

FIG. 5.9 KHULNA ZONE

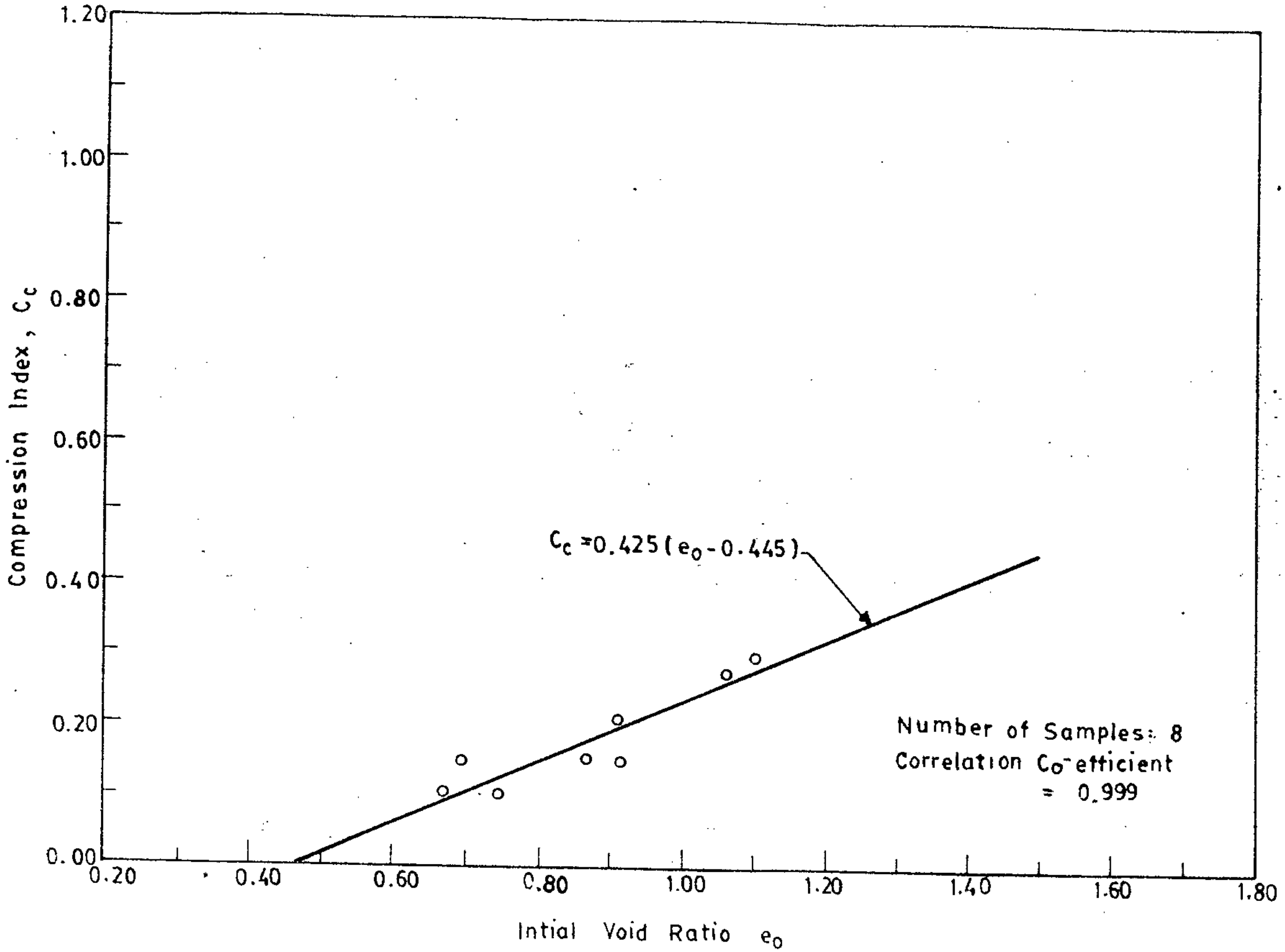

FIG. 5.10 NOAKHALI ZONE

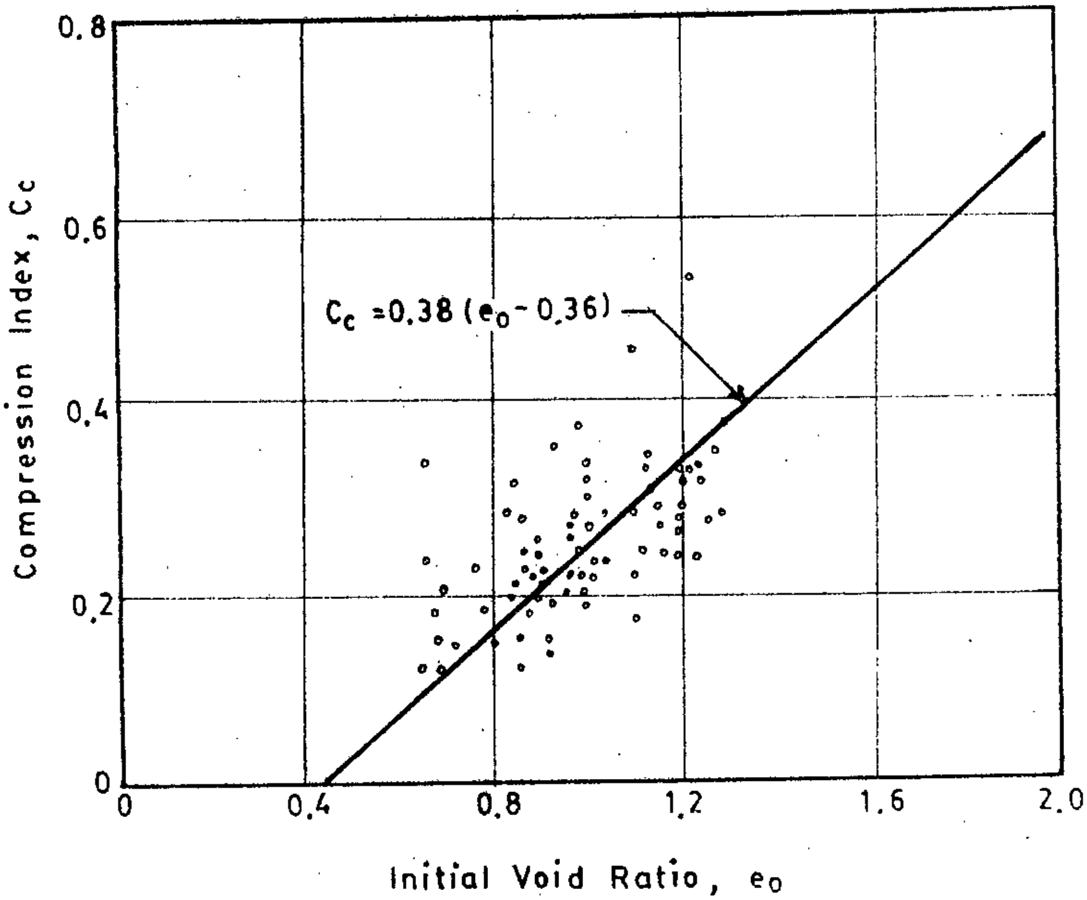

FIG. 5.11 CURVE FOR COMPRESSION INDEX Vs INITIAL VOID RATIO.

Table 5.4

Range and Average Value of Compression Index, C_c Initial Void Ratio e_o, Liquid Limit, L_w and Natural Water Content, W_o

Sl. No.	Test Zone	No. of samples	RANGE OF VALUES OF				AVERAGE VALUES OF			
			Compression index C_c	Initial void ratio e_o	Liquid limit L_w	N.W.C.	C_c	e_o	L_w	N.W.C.
1.	Barisal	27	0.15-0.550	0.72-1.27	31-61	29-77.0	0.246	0.994	42	37
2.	Bhola	23	0.19-0.35	0.76-1.34	31-47	24-42	0.244	0.91	39	33
3.	Patuakhali	44	0.09-0.42	0.65-1.24	33-61	27-50	0.240	0.97	43	34
4.	Khulna	29	0.10-0.53	0.65-1.29	32-61	29-58	0.326	0.78	40	36
5.	Noakhali	8	0.10-0.30	0.67-1.10	33-42	20-40	0.182	0.87	37	32

Consolidation test results support that the soils of coastal areas are normally consolidated with the exceptions of some of the soils which exhibits slight preconsolidation behaviour. It is the belief that the preconsolidated layer was probably at the surface at one time in the geologic past, and may have consolidated due to dessication, and then due to the subsequent subsidence of the soil, the layer was covered with fresh deposits. The preconsolidation of the clay strata could be due to the weight of an overburden which was reduced by increasing the void ratio slightly by swelling until the present state was reached by the effect of erosion due to either tidal waves or some other reasons.

The variations in the values of liquid limits, plastic limits and natural water content shows whether or not a natural clay is preconsolidated. If the value of natural moisture content is closer to the plastic limit than to the liquid limit, the soil is then considered to be preconsolidated. Most of the values of natural water content are thus found to be closer to the liquid limit thereby indicating the soil to be normally consolidated. When the natural water content is considerably lower than the liquid limit, the sensitivity of the clay is likely to be lower. Normally loaded clays are usually soft to a considerable depth below the ground surface.

5.6 Compression Index and its Comparison with Others for Similar Type of Soil Materials.

The settlement of a point on the base of a foundation due to compression S of a thin layer of normally loaded clay soil is computed from the following relation:

$$S = \frac{C_c}{1+e_o} \cdot H. \log_{10} \frac{P_o + \Delta P}{P_o} \qquad (5.1)$$

The values of compression index C_c, and initial void ratio e_o, togetherwith the thickness of the bed of clay H, under pressure P_o and the difference of pressure for an increase of the pressure from P_o to $(P_o + \Delta P)$, provide settlement forecast reliably for the normally loaded clay soil. But in the case of pre-loaded clay soil, the estimation of settlement through the above relation is somewhat less reliable.

The values of compression index, and initial void ratio obtained on the basis of experimental test results on the undisturbed clay soil samples collected from different locations of Barisal, Bhola, Patuakhali, Khulna and Noakhali regions are plotted against each other in Figures 5.6 to 5.10 which on statistical analysis give linear relations for all the regions as:

Barisal region : $C_c = 0.308\ (e_o - 0.240)$ (5.2)

Bhola region : $C_c = 0.3108\ (e_o - 0.258)$ (5.3)

Patuakhali region: $C_c = 0.361\ (e_o - 0.395)$ (5.4)

Khulna region : $C_c = 0.429\ (e_o - 0.48)$ (5.5)

Noakhali region: $C_c = 0.425\ (e_o - 0.445)$ (5.6)

Statistical analysis of their combined plotted points in Figure 5.11 gives a linear equation for clay soil of coastal region as a whole, having a correlation co-efficient of + 0.938 as:

$$C_c = 0.38\ (e_o - 0.36) \tag{5.7}$$

The compression ratio $\frac{C_c}{(1+e_o)}$ is closely related to the natural water content, and as such the values of compression index and natural water content computed for all the regions of coastal areas are plotted separately in Figures 5.12 to 5.16 which gives identical linear relations as:

Barisal region : $C_c = 0.0113\ (W_o - 16)$ (5.8)

Bhola region : $C_c = 0.0117\ (W_o -16)$ (5.9)

Patuakhali region: $C_c = 0.0129\ (W_o - 16)$ (5.10)

Khulna region : $C_c = 0.0132\ (W_o-16)$ (5.11)

Noakhali region : $C_c = 0.0116\ (W_o - 16)$ (5.12)

Statistical analysis on their combined plotted points in Figure 5.17 gives a linear relation having correlation co-efficient of + 0.839 as:

$$C_c = 0.0147\ (W_o - 16) \tag{5.13}$$

Using the relation $e_o = \frac{G_s \cdot W_o}{S}$ where G_s = specific gravity of the soil grains, W_o = natural water content, and S = degree of saturation, the empirical relation 5.7 can be

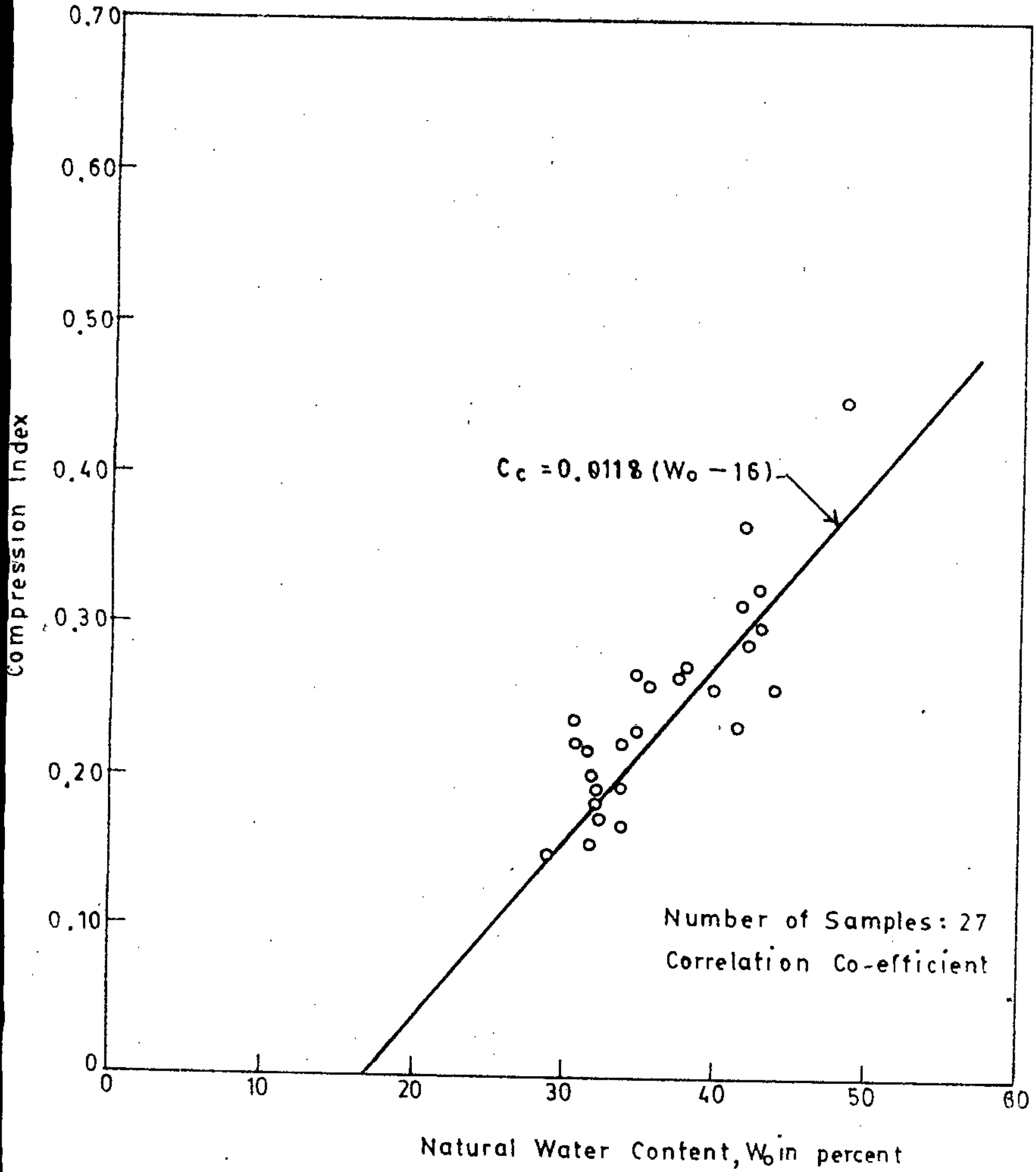

FIG.5.12 COMPRESSION INDEX Vs NATURAL WATER CONTENT BARISAL ZONE

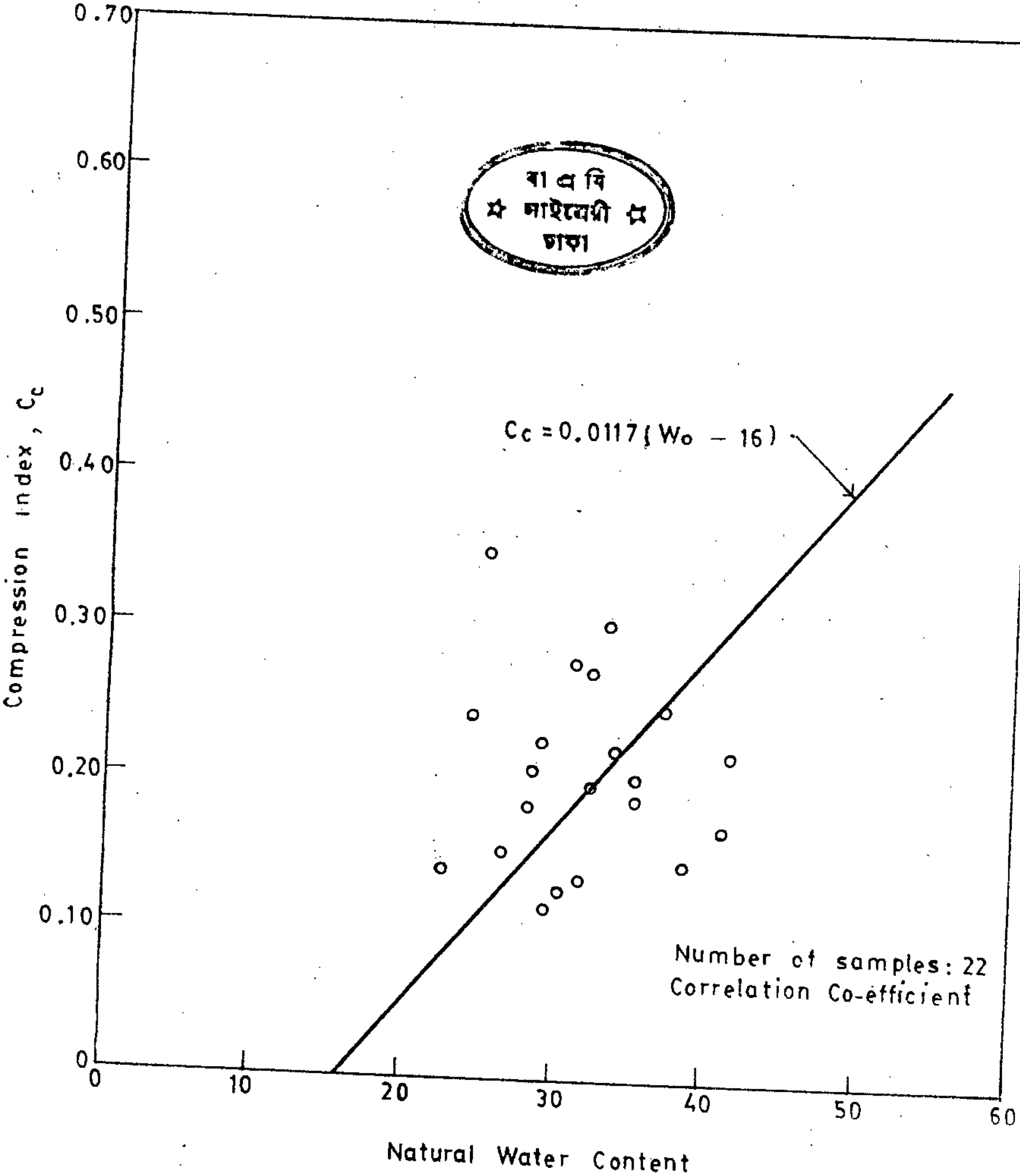

FIG. 5.13 COMPRESSION INDEX Vs NATURAL WATER CONTENT BHOLA ZONE

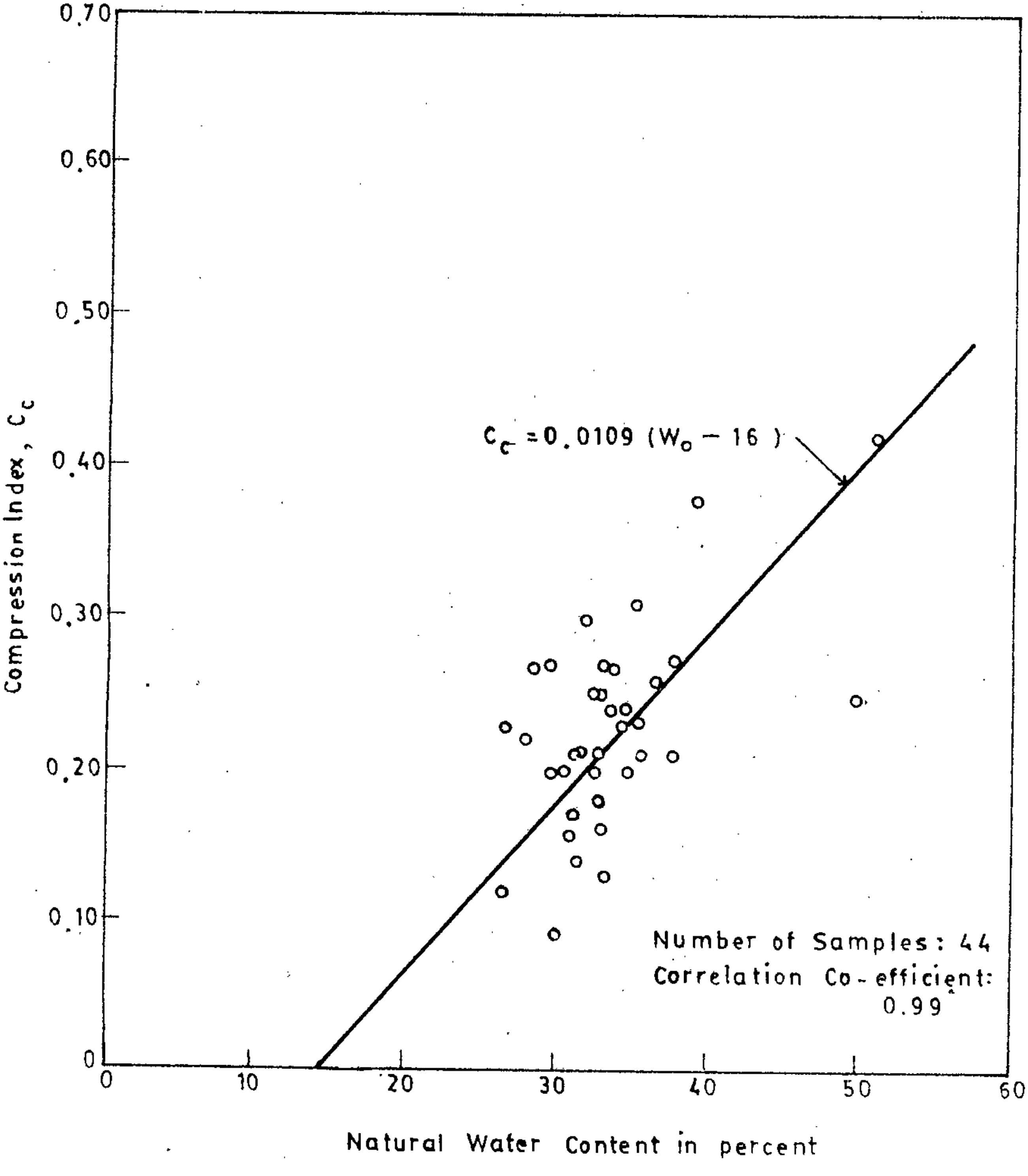

FIG. 5.14 COMPRESSION INDEX Vs NATURAL WATER CONTENT PATUAKHALI ZONE

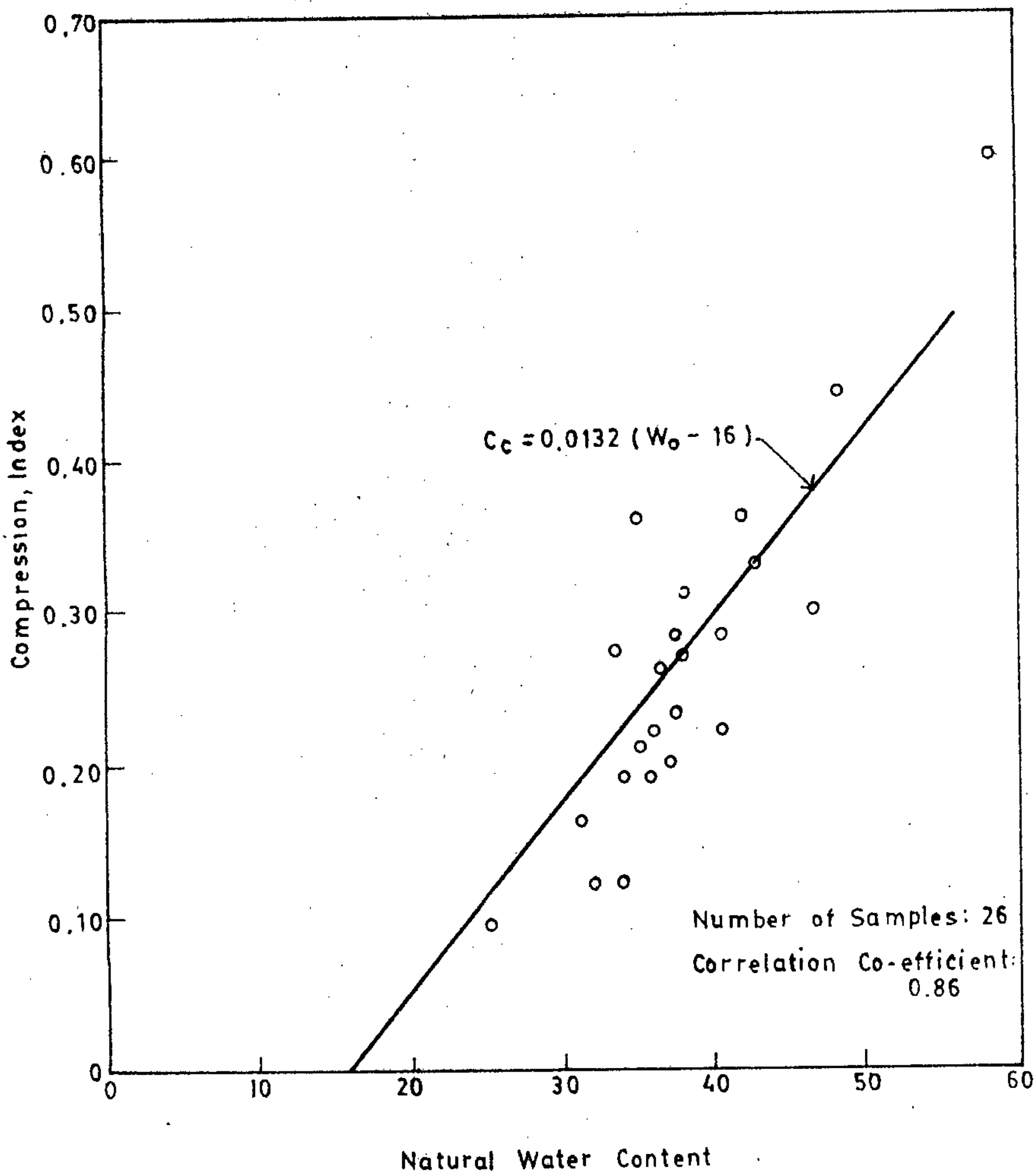

FIG. 5.15 COMPRESSION INDEX Vs NATURAL WATER CONTENT
KHULNA ZONE

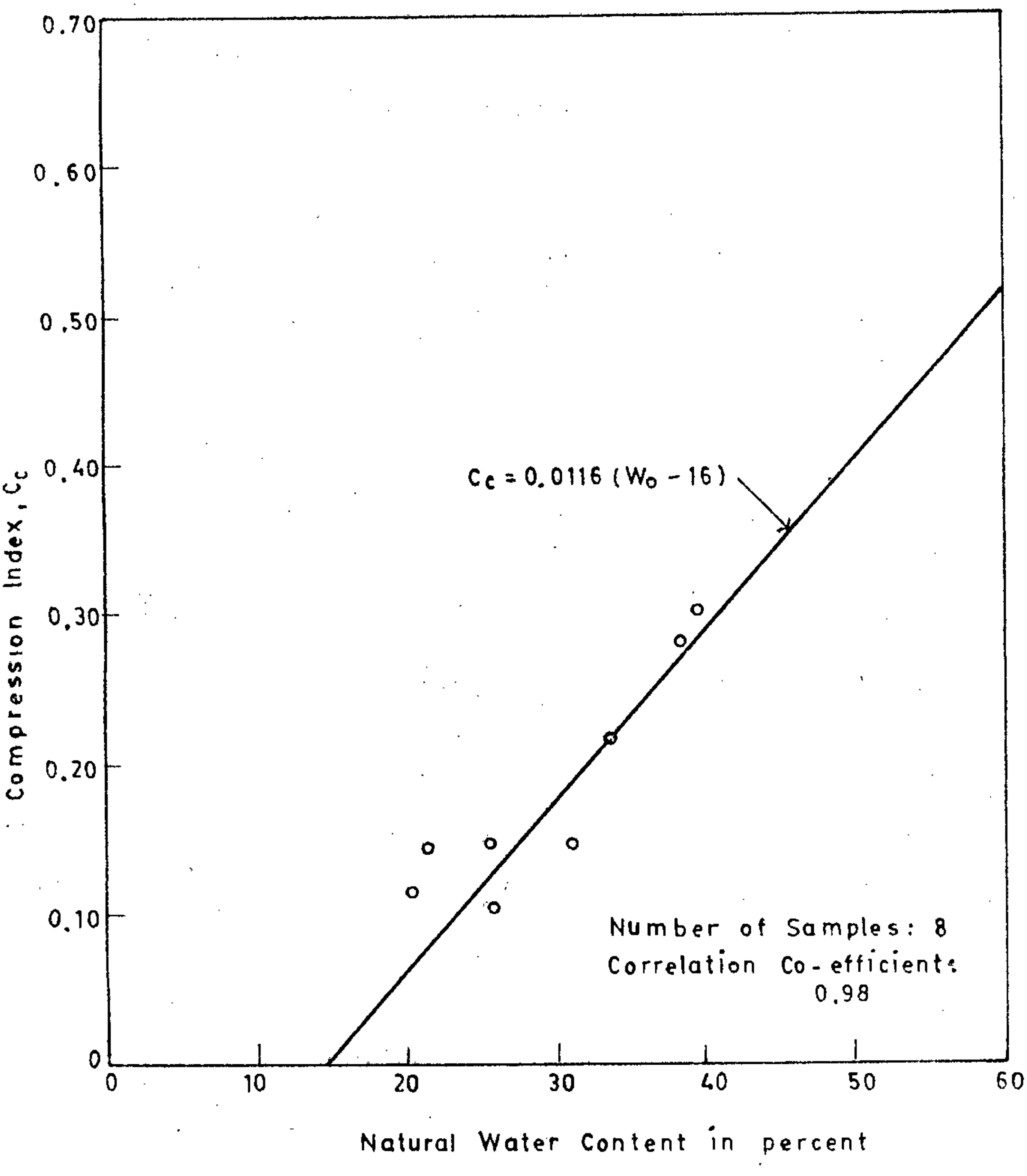

FIG. 5.16 COMPRESSION INDEX Vs NATURAL WATER CONTENT NOAKHALI ZONE

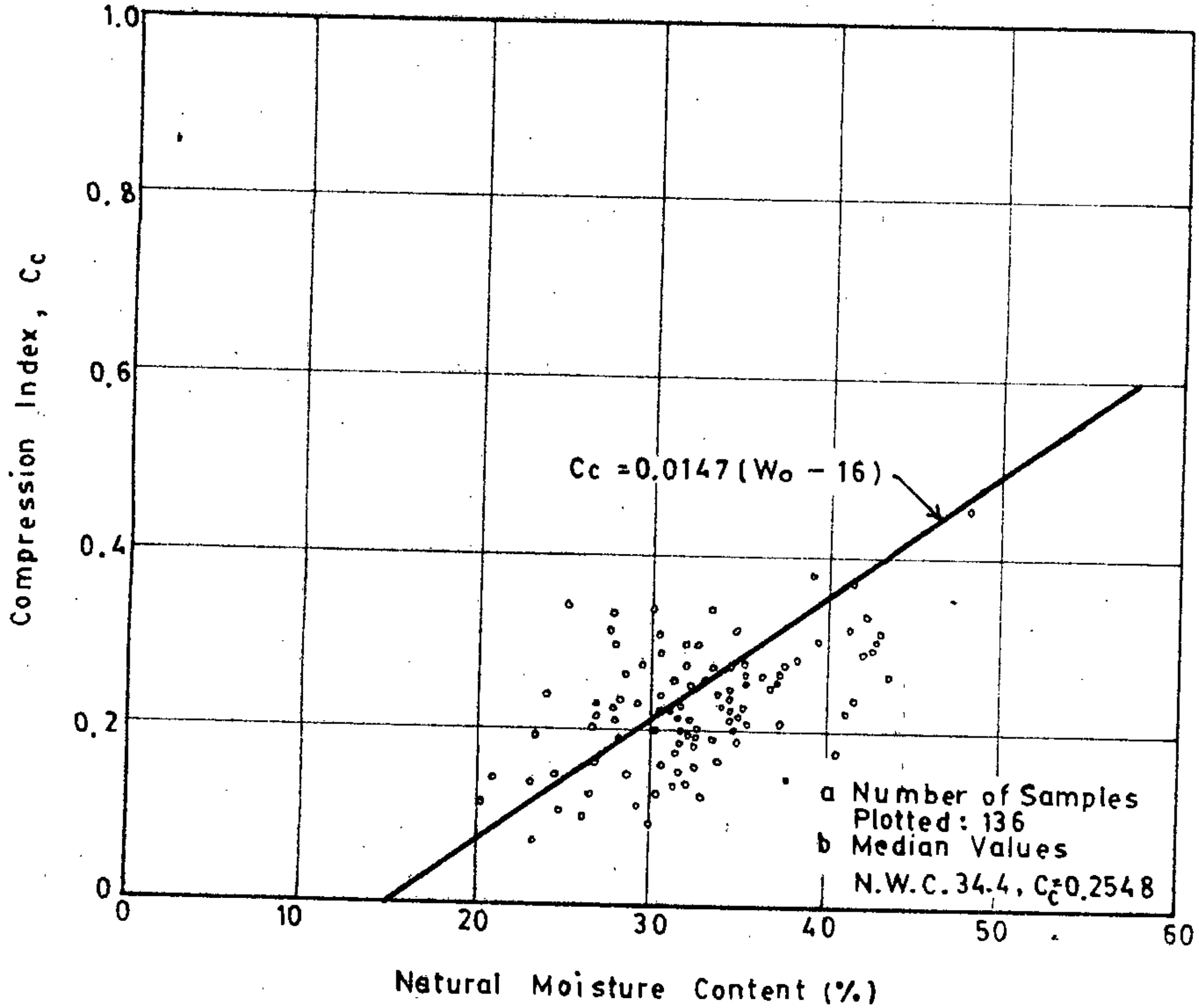

FIG. 5.17 COMRRESSION INDEX Vs NATURAL WATER CONTENT

rewritten as:

$$C_c = 0.38\ (G_s . W_o - 0.36) \tag{5.14}$$

The specific gravity of the soil grains of coastal regions is found to be in the range between 2.67 to 2.74. Taking the average value of specific gravity 2.70, the above empirical relation becomes:

$$C_c = 0.0157\ (W_o - 16) \tag{5.15}$$

According to Terzaghi and Peck, the compression index is closely related with liquid limit as represented by the equation:

$$C_c = 0.009\ (L_w - 10) \tag{5.16}$$

Based on the plotted points in Figures 5.18 to 5.22 for normally loaded clay soils of Barisal, Bhola, Patuakhali, Khulna, and Noakhali regions of coastal areas, the following empirical relations are obtained:

Barisal region : $C_c = 0.0088\ (L_w - 14)$ (5.17)

Bhola region : $C_c = 0.0078\ (L_w - 14)$ (5.18)

Patuakhali region: $C_c = 0.0083\ (L_w - 14)$ (5.19)

Khulna region : $C_c = 0.0075\ (L_w - 14)$ (5.20)

Noakhali region : $C_c = 0.0145\ (L_w - 14)$ (5.21)

Statistical analysis of their combined plotted points in Figure 5.23 gives a linear relation with co-efficient of

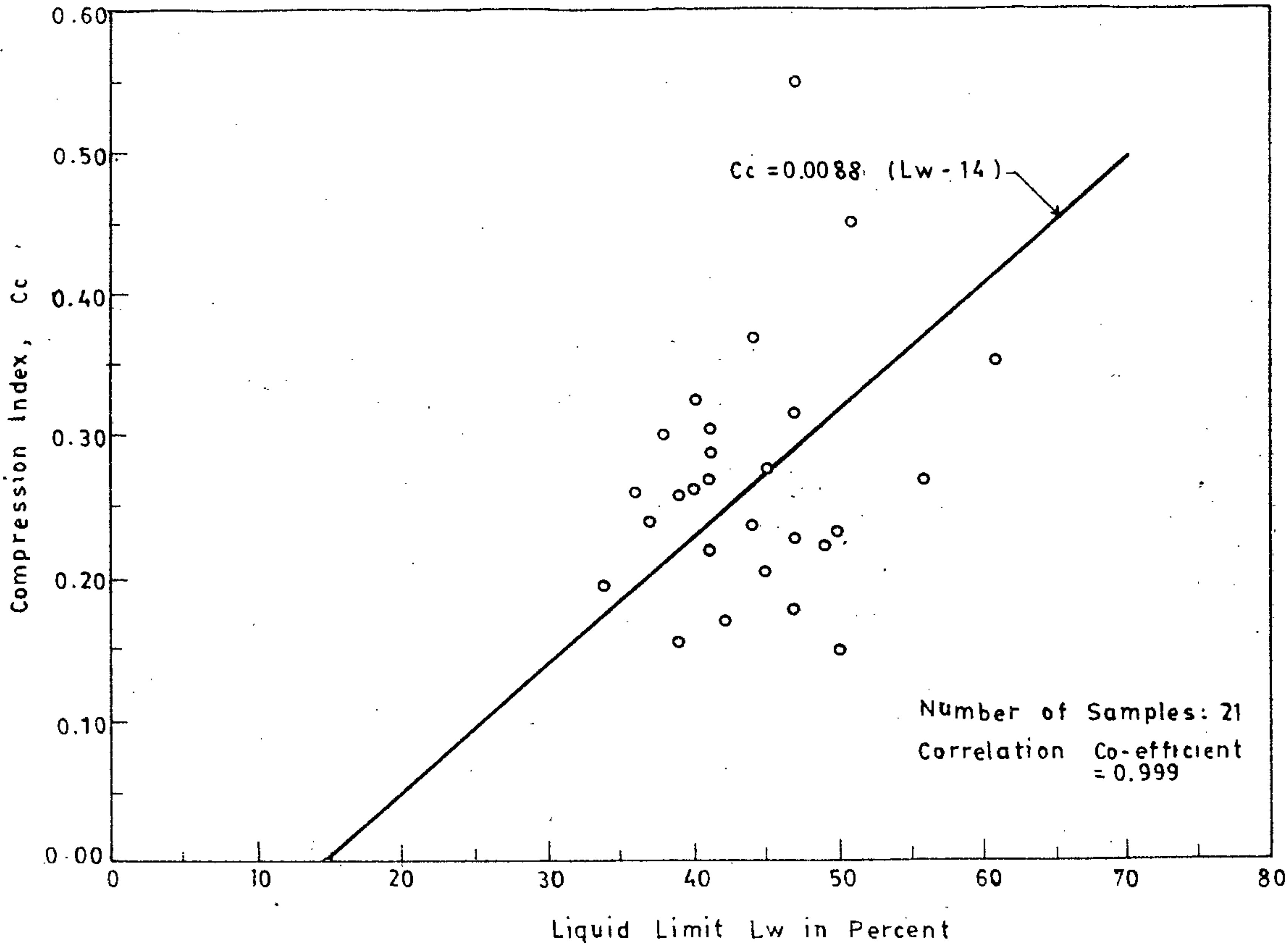

FIG.5.18 BARISAL ZONE

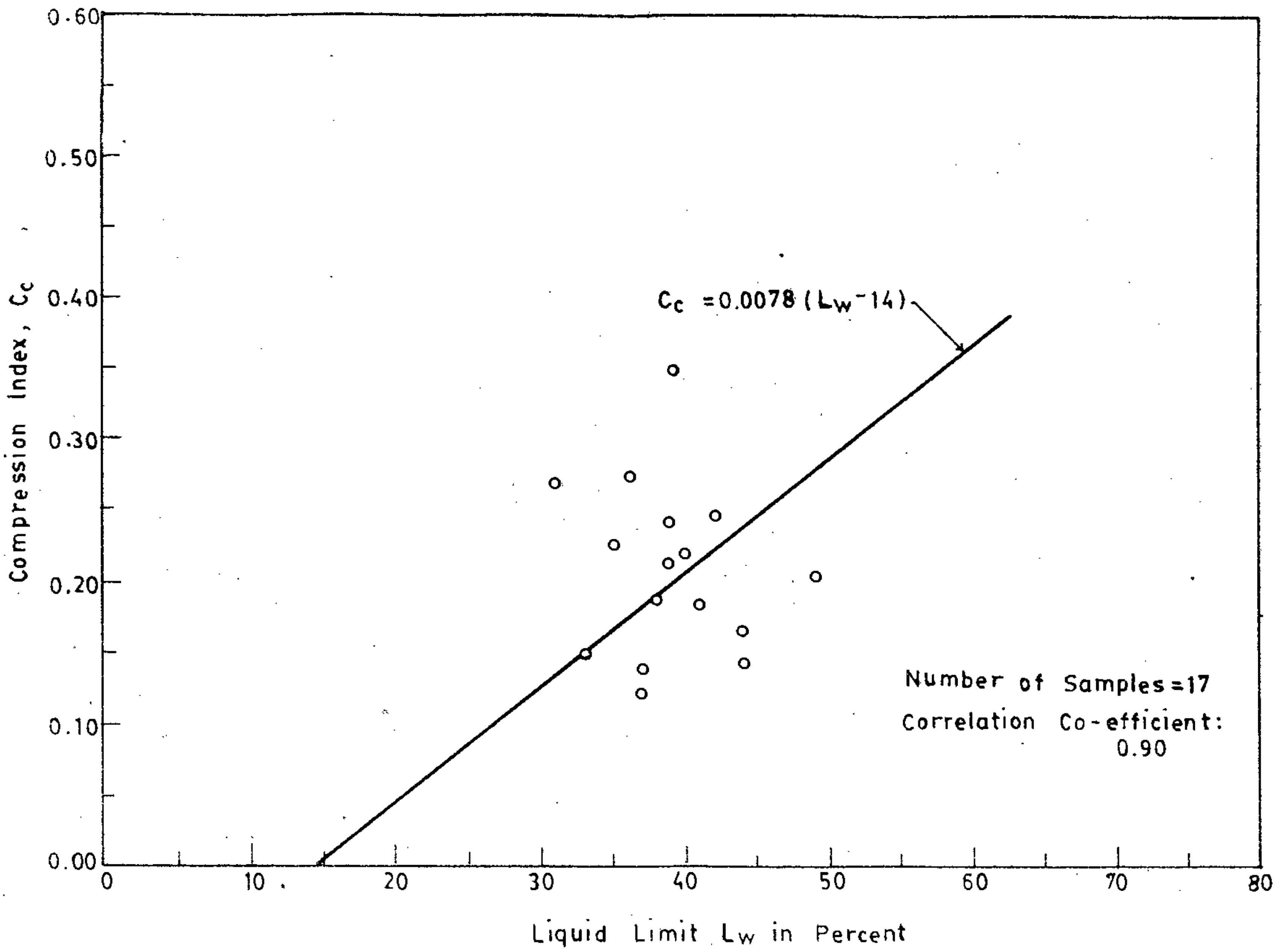

FIG. 5.19 BHOLA ZONE

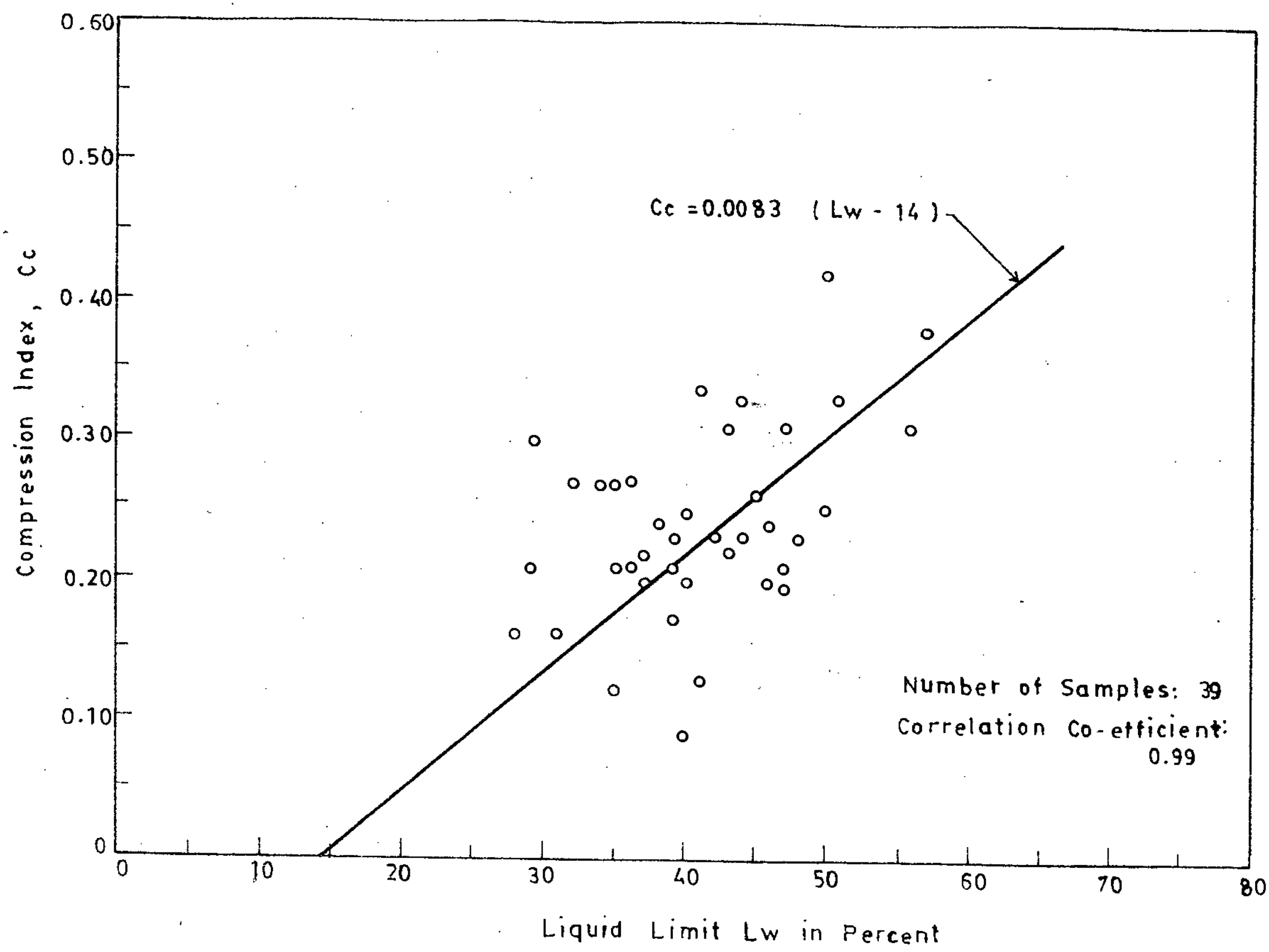

FIG.5.20 PATUAKHALI ZONE

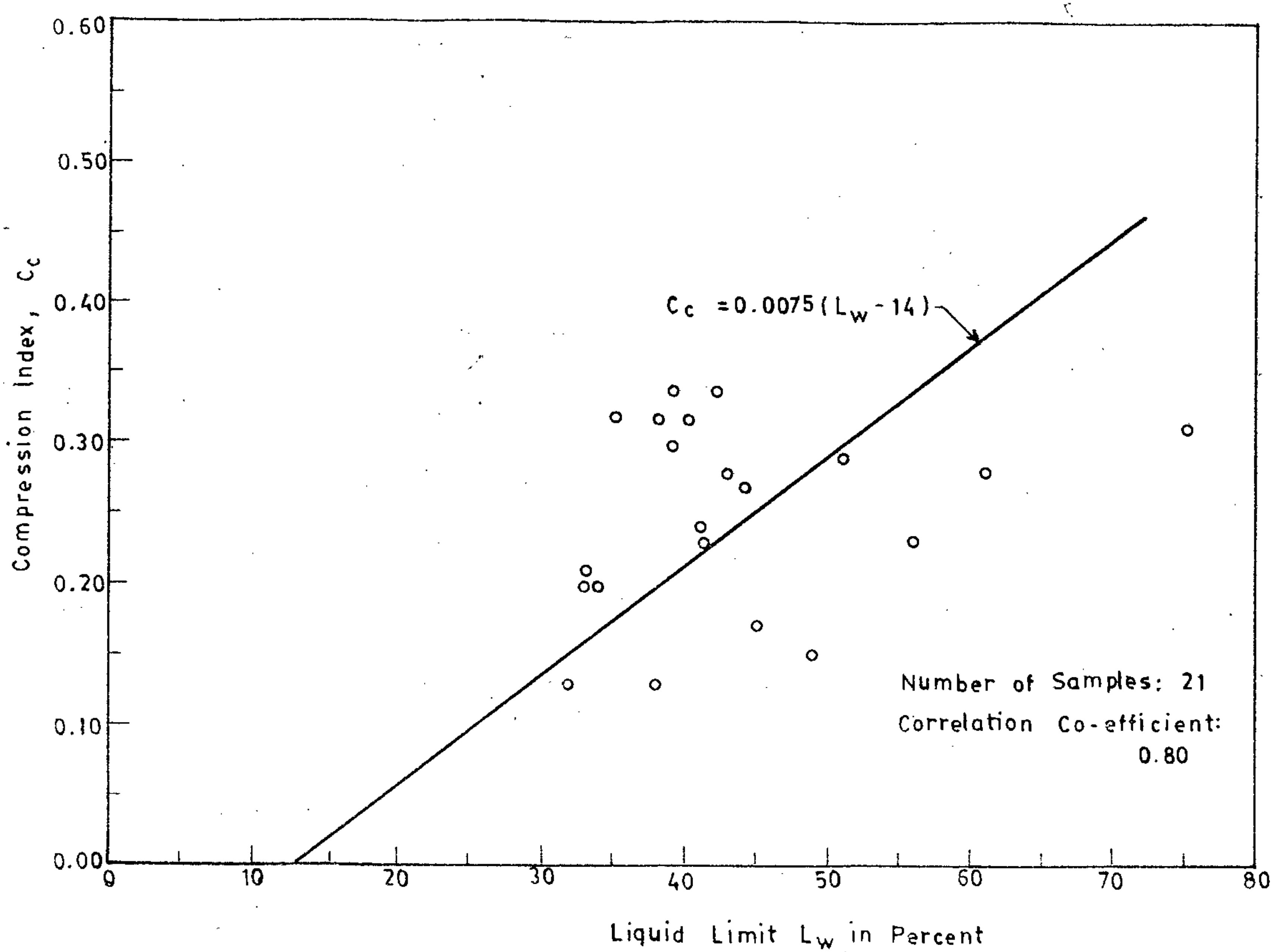

FIG.5.21 KHULNA ZONE

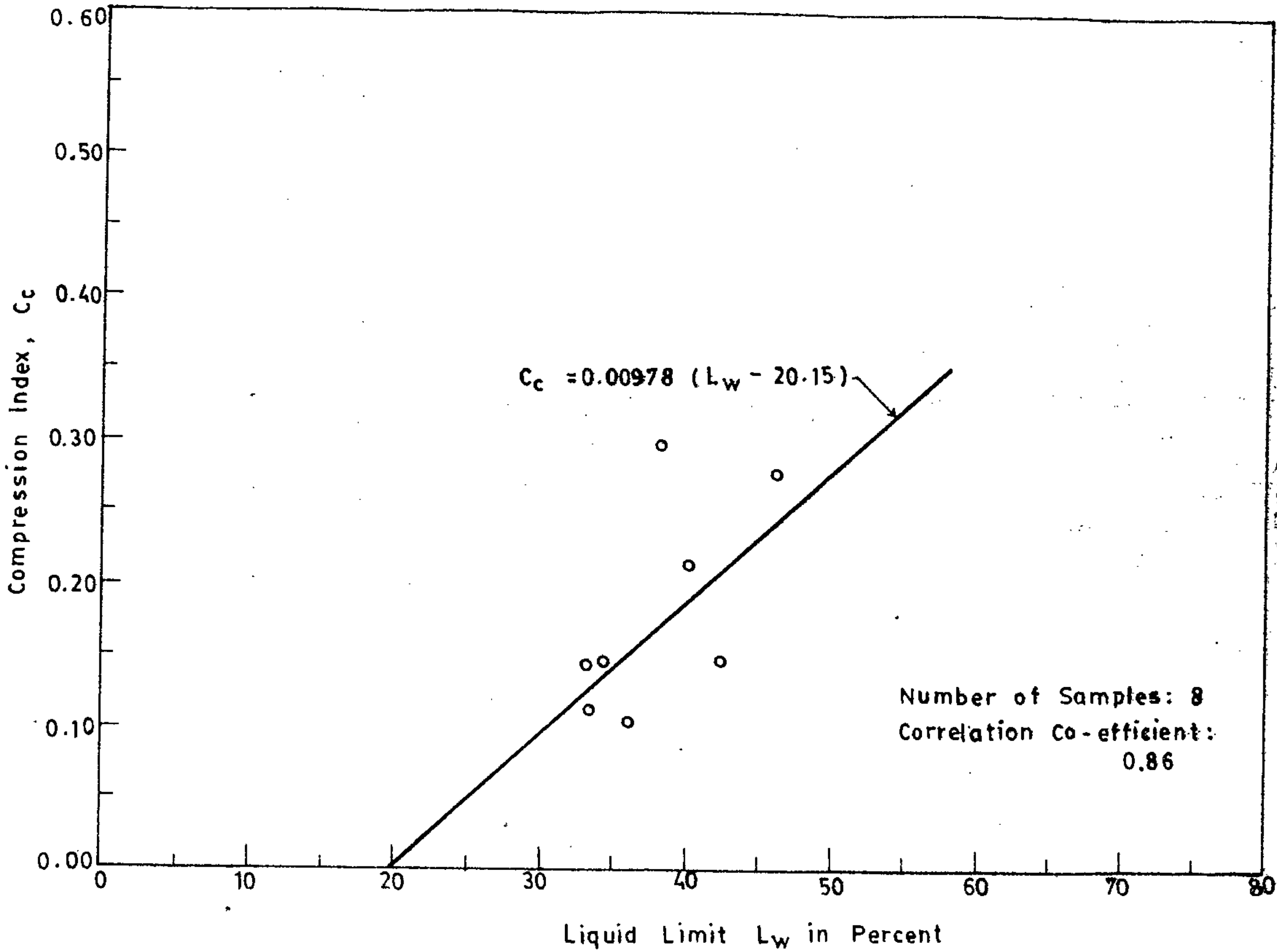

FIG.5.22 NOAKHALI ZONE

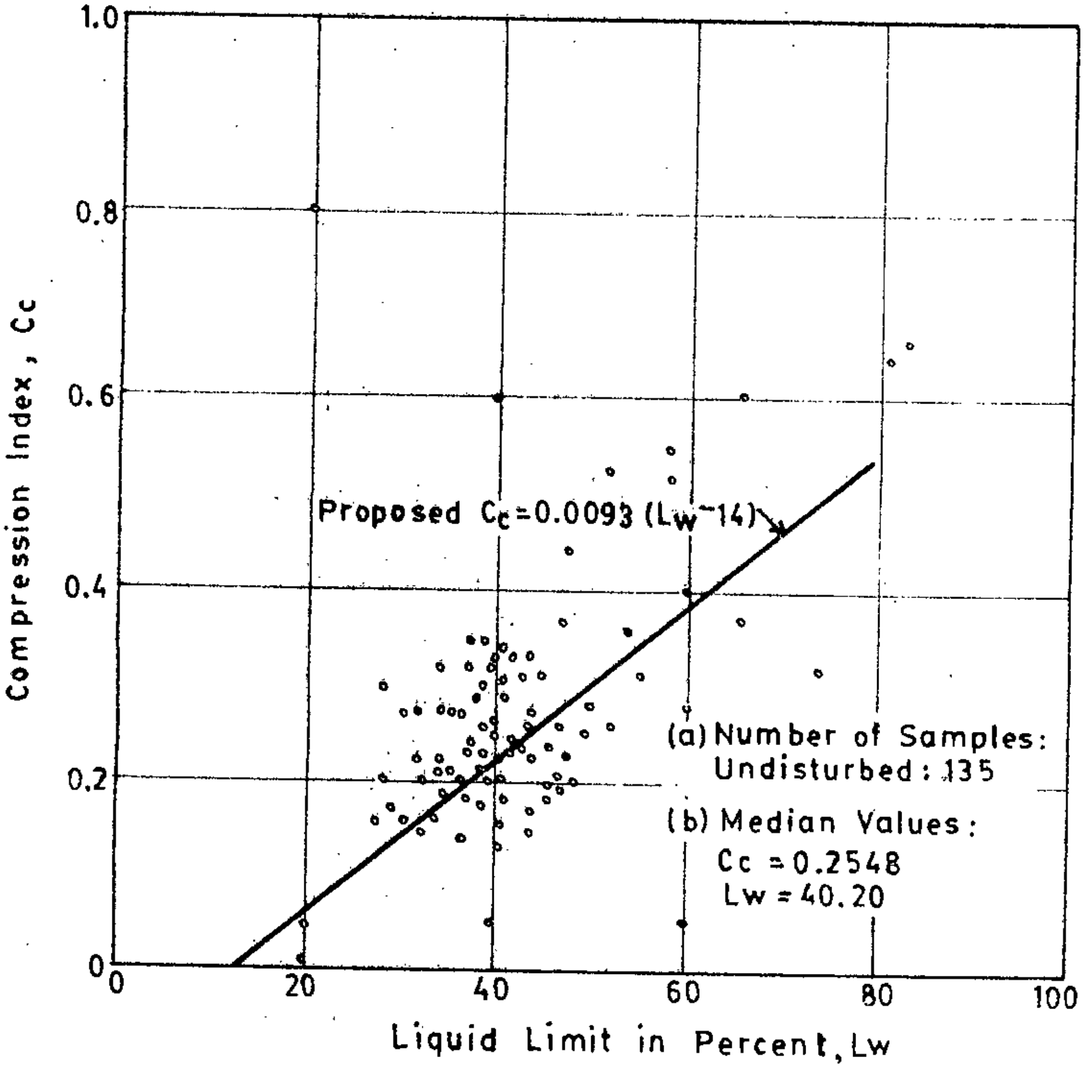

FIG. 5.23 COMPRESSION INDEX VS LIQUID LIMIT

correlation + 0.999 as:

$$C_c = 0.0093\ (L_w - 14) \tag{5.22}$$

These empirical equations can conveniently be used to estimate the compressibility characteristics of fine grained soils of coastal regions of Bangladesh from the simple test of natural water content and liquid limit without undertaking time consuming consolidation tests. The results obtained through these empirical equations may be misleading in case of heavy structures to be built on such fine grained soils. In that event, a consolidation test is desirable.

A comparative study of these linear relations as shown in Figures 5.24 to 5.27 and their relationship with that of Skempton, and Serajuddin has been made. The results show very little variations. An illustration showing experimental values of compression index from initial void ratio and from liquid limit, and comparison of their values estimated from empirical relations already suggested in this work and with others are presented in Table 5.5. It appears that the values of compression index in most cases agree quite well with a number of experimental results.

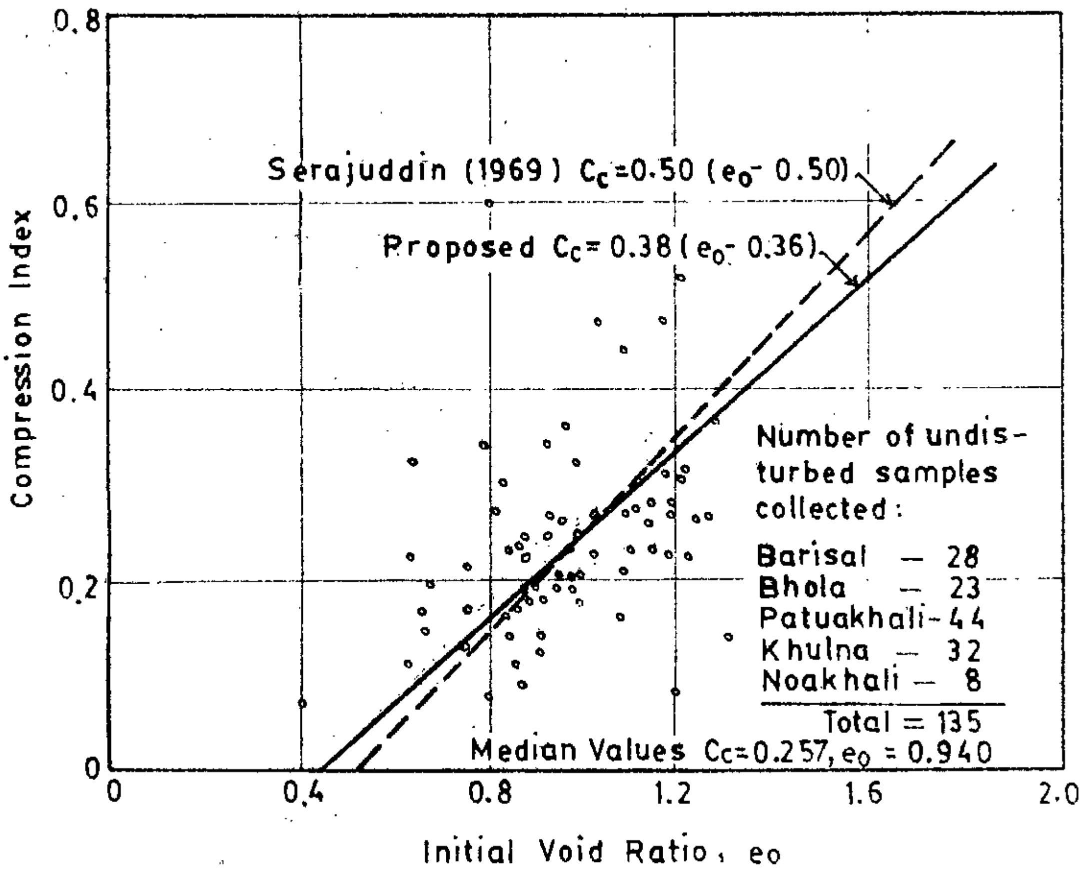

FIG. 5.24 LABORATORY COMPRESSION INDEX Vs INITIAL VOID RATIO

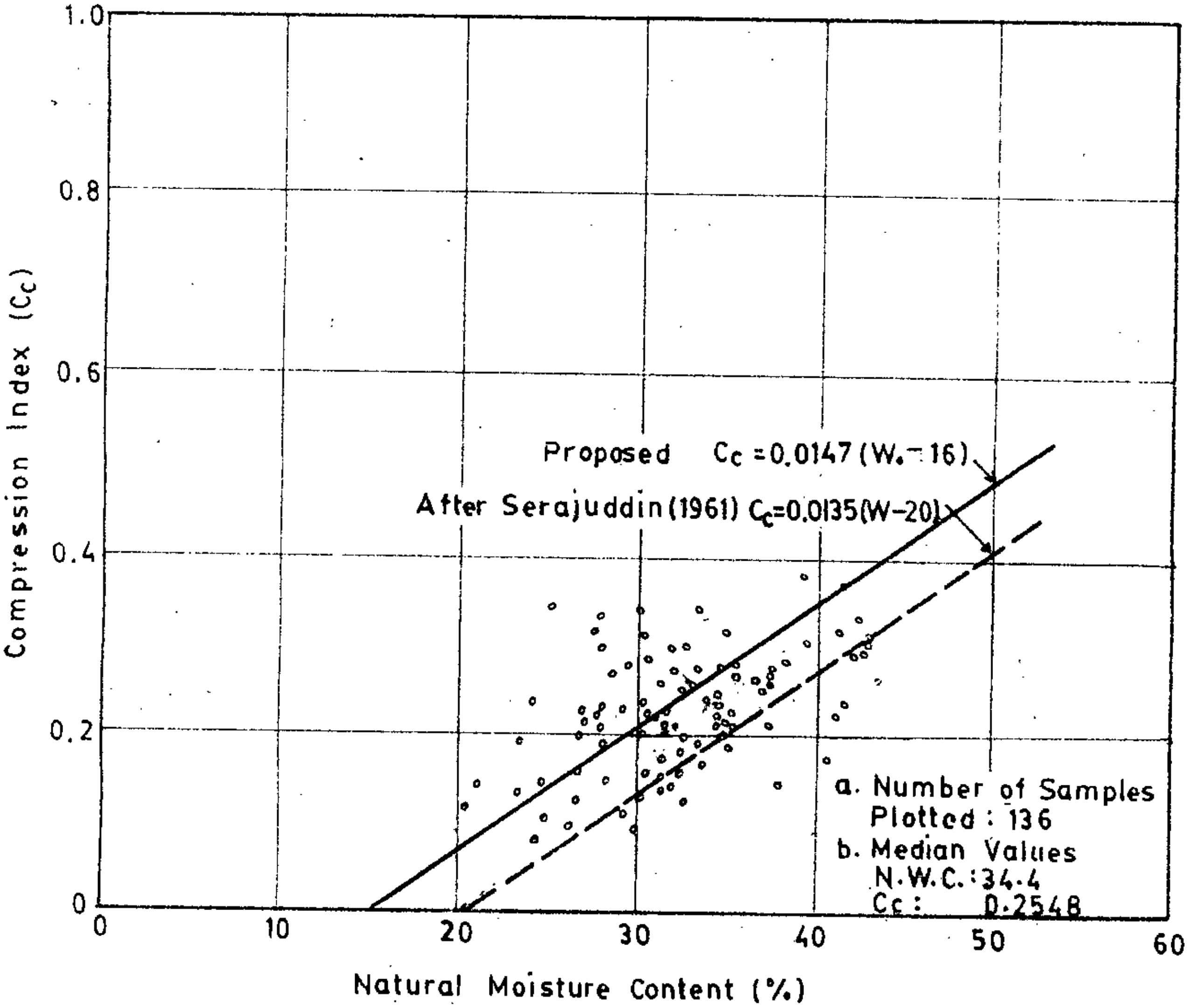

FIG. 5.25 COMPRESSION INDEX Vs NATURAL WATER CONTENT

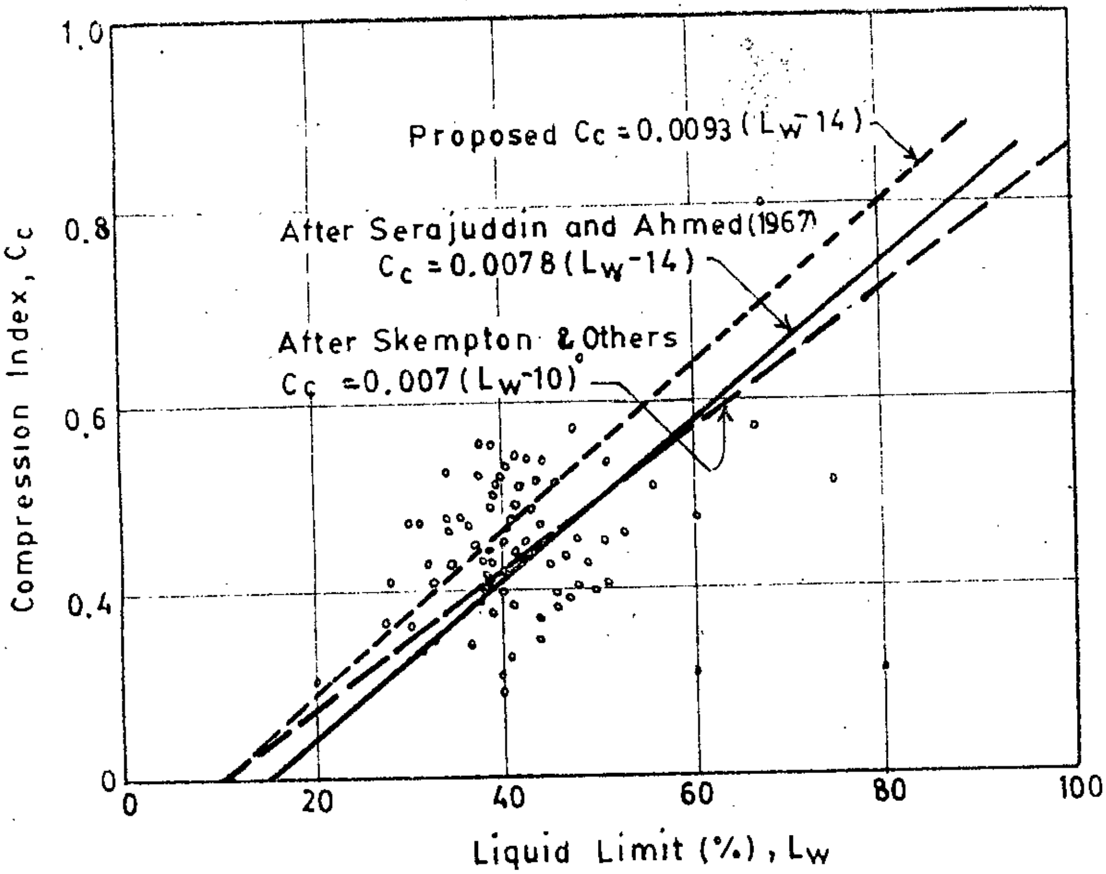

FIG.5.26 COMPARISON OF CURVES FOR COMPRESSION INDEX Vs LIQUID LIMIT

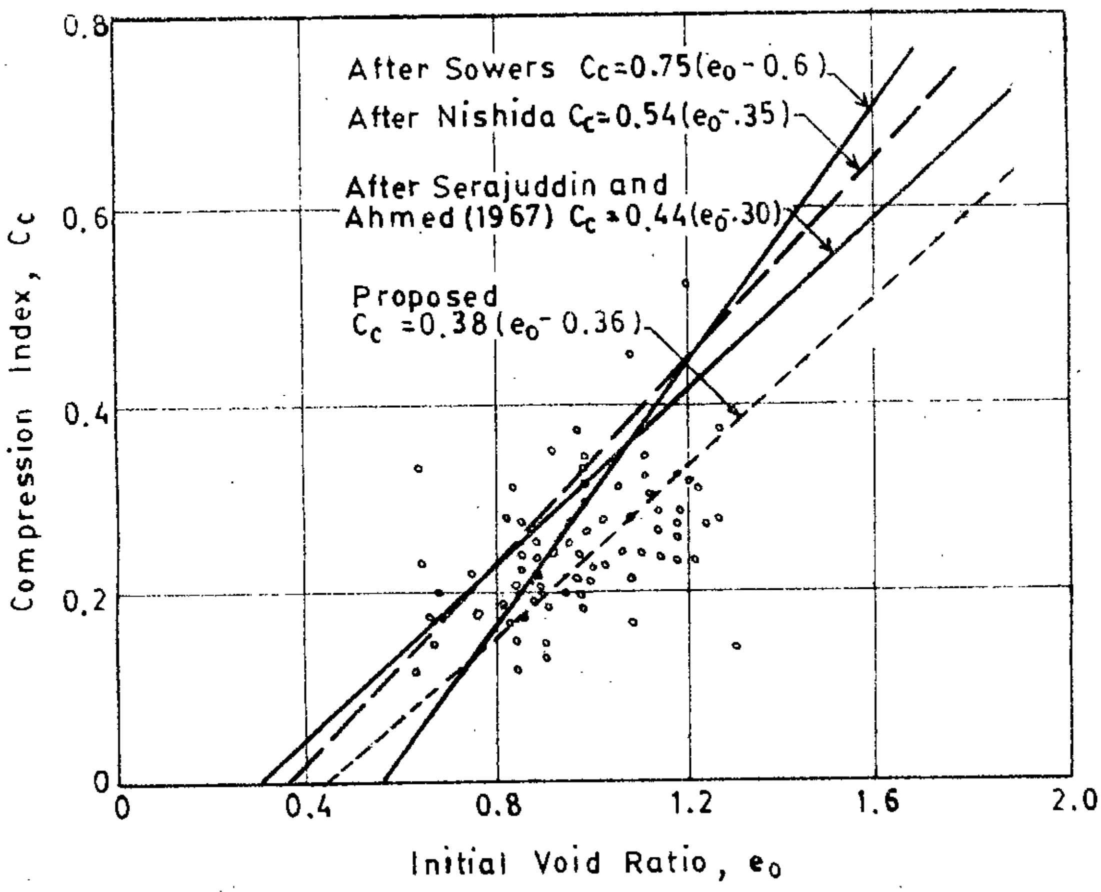

FIG.5.27 COMPARISON OF CURVE FOR COMPRESSION INDEX Vs INITIAL VOID RATIO

Table 5.5

Experimental Values of Compression Index from Initial Void Ratio and from Liquid Limit and Values Estimated from Emprical Equations developed by Various Authors

Liquid limit L_w	Natural void ratio e_o	Compression index C_c (actual)	C_c from e_o				C_c from L_w		
			Sowers	Serajuddin	Nishida	Author	Serajuddin	Skempton	Author
33	0.85	0.15	0.187	0.242	0.270	0.186	0.148	0.161	0.181
34	1.20	0.27	0.450	0.396	0.459	0.319	0.156	0.168	0.190
36	0.91	0.21	0.232	0.268	0.302	0.209	0.172	0.182	0.209
37	0.72	0.24	0.090	0.185	0.199	0.137	0.179	0.189	0.207
38	1.09	0.30	0.371	0.349	0.402	0.279	0.187	0.196	0.228
39	1.18	0.26	0.435	0.387	0.448	0.312	0.195	0.203	0.237
40	0.77	0.22	0.127	0.206	0.227	0.156	0.203	0.210	0.247
42	0.97	0.24	0.278	0.295	0.335	0.232	0.218	0.217	0.266
43	0.84	0.31	0.180	0.238	0.265	0.182	0.226	0.231	0.276
44	1.02	0.33	0.315	0.317	0.362	0.251	0.234	0.238	0.285
45	1.04	0.26	0.330	0.326	0.373	0.258	0.242	0.245	0.294
47	1.24	0.31	0.480	0.414	0.480	0.334	0.257	0.259	0.313
50	1.46	0.42	0.645	0.510	0.599	0.418	0.280	0.280	0.342

CHAPTER-6

TYPES OF FOUNDATION FOR DIFFERENT KINDS OF STRUCTURES

6.1 Introduction

Foundation of a structure always needs a base either just below the surface of the ground or at certain depth in order to transmit the entire load of the structure to the ground. The type of foundation depends mainly on the nature of the structure, the loads it must carry, the type of bearing stratum, and the cost of the foundation in comparison with the cost of the super structure. A foundation normally fails structurally due to failure of the bearing stratum and its unusual compressibility characteristics. Often cracks are observed in structures resulting from the failure of the foundation due to settlement and low shearing strength. Eventually, settlement may cause ultimate collapse of a structure even though the factor of safety against shear failure in the foundation may be adequate. These two characteristics govern the stability of the foundation, and call for a thorough investigation of the sub-soil conditions.

The important criterion governing the selection of the type of foundations in coastal areas is essentially to have information on the geologic past of the sub-surface conditions, and the behaviour of sub-soil under the existing conditions to ascertain as to the capability of the proposed foundation of carrying the required loads, and whether they might experience detrimental settlement.

The foundation engineer on assumption that the construction of a given type of foundation is possible in most of the locations of coastal regions, should judge the probable performance of the foundation with respect to two types of unsatisfactory behaviour like failure of the ground to support the foundation, and uneven settlement of the foundation which may cause cracks and damage to the superstructure. Soil characteristics already analysed can provide information against these two types of unsatisfactory behaviours.

6.2 Zoning of Coastal Regions

Based on the geologic origin as well as physical properties of the coastal soil already analysed, the coastal areas may be divided into three zones for recommendation of the type of foundations feasible in their respective zones:

I. Zone of Deltaic, meander and swamp deposits - Barisal region.

II. Zone of Deltaic and Tidal deposits - Bhola, Patuakhali and Khulna region.

III. Zone of Tidal and swamp deposits - Noakhali region.

In the zone of Deltaic and meander and swamp deposits, the ground water depth varies from 0 to 10 feet. The upper sourface upto a depth of about 10 to 20 ft is composed of soft to medium silt clay with S.P.T. values varying between 4 and 8 only and is underlain by medium compact sandy soil. The organic soils are also occassionally present. The deposits are generally normally consolidated with higher compressibility and lower shearing strengths.

In the other two zones of Tidal and swamp deposits as well as Déltaic and tidal deposits, the upper surface upto a depth of about 10 to 20 feet comprises soft to medium silty clay deposits of medium plasticity and of medium compressibility. The deposits in most of the locations exhibit slight precon-solidation behaviour due to the loss of overburden by dessication. Organic materials like fine fibrous fragments of decayed vegetable matter, black in colour mixed with particles ranging from clay size to sandy size are occassionally present. They are predominant especially in most of the locations of Khulna region. They are soft with relatively higher compressibility and water content. The water contents in some locations of Khulna region are found to be as high as 68 percent.

The deposits along the shore of Bay of Bengal consists of surface sediments and are normally attributable to slumping due to wave action on the shore materials. The deposits possess relatively narrow particle range, and contain appreciable quantities of soluble salts which are considered highly unfavourable for use as foundation materials. The colloidal activity of the soil deposits encountered in most of the locations in the region shows values greater than 1.50 indicating the soils to be in the active group. The sodium and calcium sulphates are highly deleterious to contacting concrete.

6.3 Problem of Salinity and Foundation Remedy

The coastal belt along the shore of Bay of Bengal can be regarded as salinity zone where foundations are usually subjected to attack by the aggressive compounds present in the soil. Concrete foundations exposed to sea water are mostly affected by the sulphate attack in the ground. Their deterioration is visible due to spalling of the concrete which in turn is caused as a result of corrosion of the reinforcement. Steel structures are subject to corrosion. Protective measures can only provide immunity against such deterioration. It is therefore, important to investigate the possibility of corrosion in the salinity zone. A full chemical analysis of sea water samples against the worst conditions of salinity is required. The use of sulphate resisting cement and high alumina cement in the construction of concrete foundation will be useful to give greater resistance against deterioration to a varying degree. Pre-cast members such as concrete piles may be used for structures like Buildings, Bridges, Dams, Water Tower, Jetty, etc. with medium to heavy loads suitably in the region. The concrete piles may, in that case, be impregnated with hot asphalt under low pressure before their use.

6.4 Bearing Capacity Range

The performance of any foundation depends on the bearing capacity as well as on the stress deformation characteristics of the supporting soil. The bearing capacity depends primarily on the shearing resistance of the sub-soil which is taken as one-half the unconfined compressive strengths. The bearing capacity of the clay sub-soil is approximately taken 3 q_u. Its range alongwith the relative density of different locations are worked out and presented in Table 6.1.

The bearing capacity of the sub-soil of most localities of Barisal region normally varies between 0.57 and 2.46 Tons/sq.ft at 5 ft depths with some major exceptions in Kawkhali and Jhalakati where it shows higher values varying between 1.8 Tons/sq.ft and above. The bearing capacity of the sub-soil in most of the locations of Bhola, Patuakhali and Khulna region generally ranges between 0.85 Tons/sq.ft and 2.5 Tons/sq.ft. In some localities the values at depths ranging 10 to 25 feet are found to be higher than 2.5 Tons/sq.ft having higher values of dry density. This type of soil is highly suitable for any good foundation consisting of footings,piles or piers. The loose sub-soil having lower bearing capacity needs consolidation. The use of footings, rafts, piles and piers resting on this type of soil should be proportioned in such a way to provide a factor of safety of 3 against a bearing capacity failure.

6.5 Settlement Characteristics

The settlement of footings on clay soil depends primarily on its compressibility which is intimately related to its

Table 6.1

Range of Bearing Capacity of Sub-soil of Different Locations

Locations	Number of samples	Sample depth in feet	Range of Values of Dry density pcf	Range of Values of Bearing capacity q_d, Tons/sq.ft
A. BARISAL REGION				
Babuganj	2	10	70.5-81.7	0.27-0.70
Hularhat	2	5	78.3-80	0.38-0.46
Riverbank	3	5	77-88.3	0.60-1.52
Amanatganj	3	10	79.0-86.3	0.49-1.23
Amanatganj	2	20	79.0-79.7	0.30-0.61
Pirojpur	4	5	76.5-93.0	0.46-0.76
Banaripara	2	5	-	0.43-0.49
B. BHOLA REGION				
Charfession	2	5	90.0-99.0	1.94-1.14
Kachuakhali	2	5	88.5-88.5	1.72-2.94
Chanchra	2	5	86.0-95.0	1.72-2.19
Kulgazir Taluk	2	5	90.0-97.0	0.97-1.84
Bhola Town	4	5	88.6-93.7	0.95-1.49
Bhola Town	3	15	79.6-89.1	0.74-1.42
C. PATUAKHALI REGION				
Ichadi	2	5	83.0-89.0	1.75-2.71
Kharizzama	2	5	93.5-94.0	1.57-2.90
Kharizzama	3	10	80.5-93.5	0.78-2.95

Amkhul Hat	2	10	86.5-95.0	1.65-2.78
Naluabagi	3	5	83.0-94.5	0.78-2.68
Chandpura	2	5	84.0-95.0	2.28-3.42
Chandpura	2	10	84.0-96.00	1.57-2.75
Moudubi	2	15	82.0-88.0	0.96-1.09
Golachipa	2	5	85.5-91.5	1.29-2.63
Serajpur	2	5	87.0-87.5	0.79-1.78
Serajpur	2	10	72.0-80.0	0.78-1.18
Pathargata	3	5	70.1-87.5	0.70-1.14
Pathargata	3	10	84.0-84.50	0.85-1.20

D. KHULNA REGION

Sheikpara	6	5	82.0-91.00	0.91-3.11
Khan Jahan Road	3	10	84.0-87.50	1.74-2.45
Khan Jahan Road	4	25	78.0-84.00	0.92-1.98
Khulna Town	2	15	85.0-89.00	1.53-2.78
Jessore Road	2	25	85.0-90.00	1.55-1.74
Goalpara Power Station	2	5	84.0-94.0	1.54-2.84
Bagerhat	5	5	73.0-89.6	1.08-2.48
Mangla	3	5	88.5-93.5	0.81-2.43
Shiromoni	2	5	77.1-78.1	0.76-0.93

history of loading. It is important to make a reliable estimate of the amount of the differential settlement that may be experienced by the structures resting on it in order to determine whether or not the foundation layout under consideration is satisfactory. Based on the compressible characteristics of the normally loaded clay soils of the coastal region, settlement forecasts for particular type of foundations of particular locations have been made by means of computating settlement at different elevations on the base of structures in order to give the designer a satisfactory basis for deciding the foundation type. The detailed settlement calculations are however, presented in Appendix-F.

It is observed that the footings for the column foundation of a 4 storey building if constructed in Barisal region with compressibility characteristics as already analysed will ultimately settle 4.26 inches due to the primary consolidation of the clay layer. Likewise the computation of settlement of a raft foundation for identical building structure if constructed in Bhola Town with almost identical compressibility characteristics will show a settlement of approximately 2.05 inches. This settlement of the raft foundation can be reduced by lowering the elevation of its base through excavation. Alternatively, friction piles may be used to support the footings depending on the practicability and economy of the construction at sites.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 Conclusions

The conclusions arrived at in this study is tentative, and can serve only as a general guide to the foundation engineers in the preliminary planning and design work of foundations of various structures in the coastal areas. Correlation suggested in this study should serve as an aid to them to have a first hand information of local soil conditions. They are cautioned not to substitute the results obtained by using these correlations for proper tests where a detailed investigation of compressibility characteristics as well as mineral composition and their likely effects on the structures, is absolutely necessary.

From the limited investigations performed in this study the following tentative conclusions may be drawn:

(i) On the basis of geologic origin and the type of soils identified in this study, the coastal areas of Bangladesh may be divided into three different zones (Reference Fig. 7.1). These are

I. Barisal region: Zone of deltaic meander and swamp deposits.

II. Bhola, Patuakhali and Khulna region: Zone of deltatic and tidal deposits.

III. Noakhali region: Zone of tidal and swamp deposits.

The sub-soils of these three zones are predominantly composed of three types of deposits such as cohesive deposits, non-cohesive deposits and a mixture of them in varying proportions. Organic soils like peat are occassionally present. The soil formations are stratified, and have the following distinctive physical characteristics:

(2) The type of soils encountered in the zone of deltatic, meander and swamp deposits are mostly inorganic silts of medium plasticity. (Reference Fig. 5.1).

In the zone of deltaic and tidal deposits, the soils are mostly composed of inorganic silts of medium plasticity with exceptions of Patuakhali region where the deposits are mostly mixtures of inorganic silt and clay of medium plasticity. In Khulna region, presence of organic silts and clays of higher plasticity is prominent. (Reference Figures 5.2, 5.3 and 5.4).

In the zone of tidal and swamp deposits, the type of soil encountered is mostly composed of mixtures of inorganic silt and clay of medium plasticity. (Reference Fig. 5.5).

(3) The soil deposits mostly contain flocculated structures with low density and higher compressibility. The presence of sulphate salts are an indication of their presence. (Reference Table 5.1).

(4) The soil deposits are mostly normally loaded. The values of compression index varies normally in the range between 0.20 to 0.30 (Reference Figures 5.12 to 5.16).

Some of the soil deposits exhibit slight pre-consolidation behaviour.

Semi-empirical relationships between the parameters like compression index and liquid limit, compression index and natural water content, and compression index and initial void ratio, have been suggested as follows:

$$C_c = 0.0093\ (L_w - 14)$$
$$C_c = 0.0147\ (W_o - 16)$$
$$C_c = 0.38\ (e_o - 0.36)$$

Where C_c = Compression index

L_w = Liquid limit

W_o = Natural water content

e_o = Initial void ratio

The value of compression index C_c furnishes the ultimate settlement of any foundation caused due to the primary consolidation of the soil layer. (Reference Figures 5.11, 5.17 and 5.23).

(5) The soils of deltaic and swamp deposits are generally soft and possess relatively low shear strength normally ranging between 200 to 900 psf. On the otherhand, the soils of deltatic and tidal zones

possess a little higher value of shear strength normally ranging between 300 to 1300 psf. (Reference Table 4.4).

The bearing capacity of the soils of deltaic and swamp deposits is low, and normally varies in a range between 0.57 to 2.46 Tons/sq.ft while their normal range in the deltaic and tidal deposits varies between 0.85 to 3.50 tons/sq.ft. This indicates that the soils of the latter regions are comparatively more consolidated.(Reference Table 5.2).

(6) The ground water table in the deltaic zones of Barisal, Bhola, Patuakhali and Khulna varies between 0 to 16 feet while in Noakhali zone, it varies between 8 to 11 feet.(Reference Table A in Appendix).

(7) The clay properties of most of the locations are influenced by their mineral composition. Appreciable amount of colloidal activity results due to the increase in the plasticity index. (Reference Table A in Appendix).

(8) Aggressive compounds like sodium sulphates and calcium sulphates are present in the soils of coastal areas especially in the areas very close to the sea, and their presence are likely to

cause deterioration of the foundation. Calcium and sodium sulphates of Montmorrilonite group are predominant in the soil of Patuakhali and Bhola regions.

(9) An appreciable amount of soluble salts is present in the soil deposits along the shore of Bay of Bengal. These salts are highly deleterious to contacting concrete. The concrete foundations exposed to sea water are likely to be affected by the salt attack in the ground causing spalling of the concrete. Adequate remedial measures must be adopted in the design, construction and maintenance stages for such foundations.

(10) Footings for building structures with light to medium loads are more suitable in areas where the silty clay soils are generally soft. Pile foundations for structures of medium to heavy loads are more suitable in areas where the compression index value is in the range of 0.15 and above. In order to avoid excessive differential settlement of individual footings for medium to heavy structures due to the presence of soft layers beneath the base of the footing, the use of piles or raft is desirable. For framed structures, the use of raft foundation is considered more suitable.

7.2 Recommendation for Future Study

The investigations into the behaviours and characteristics of the soils of coastal regions of Bangladesh is no doubt a painstaking exercise. Short duration study and laboratory research is definitely insufficient to look into its different aspects including chemical analysis of the mineral composition characteristics because of its nearness to the sea. More extensive study by taking more representative soil samples of the regions is very much needed because the data base in the present study was not sufficiently extensive. In the present study, the number of soils samples collected especially from Barisal, Khulna and Noakhali regions is not enough to have a full generalised pictures of the soil conditions in the context of foundation requirements in the locality.

In order to present a generalised picture of the engineering properties of sub-soil of coastal region, the author, suggests further study in future on the following:

(i) More data based study on the behaviour and engineering properties of sub-soil of entire coastal region including the areas of Sunderban, Hatiya, Sandwip, Maheskhali, Kutubdia, and Cox's Bazar may be undertaken in order to suggest improvement on the correlations already suggested in this study.

(ii) Study may be made on the mineral composition characteristics of clay soils of coastal regions and its likely effect on the structures in the locality.

(iii) Observation may be undertaken by the investigators on the behaviour of the structures built in this coastal region, in order to study the long term effect and its likely deterioration for being nearer to the sea. Study may be made on the causes of failure of some structures which may have already failed or are showing signs of failure.

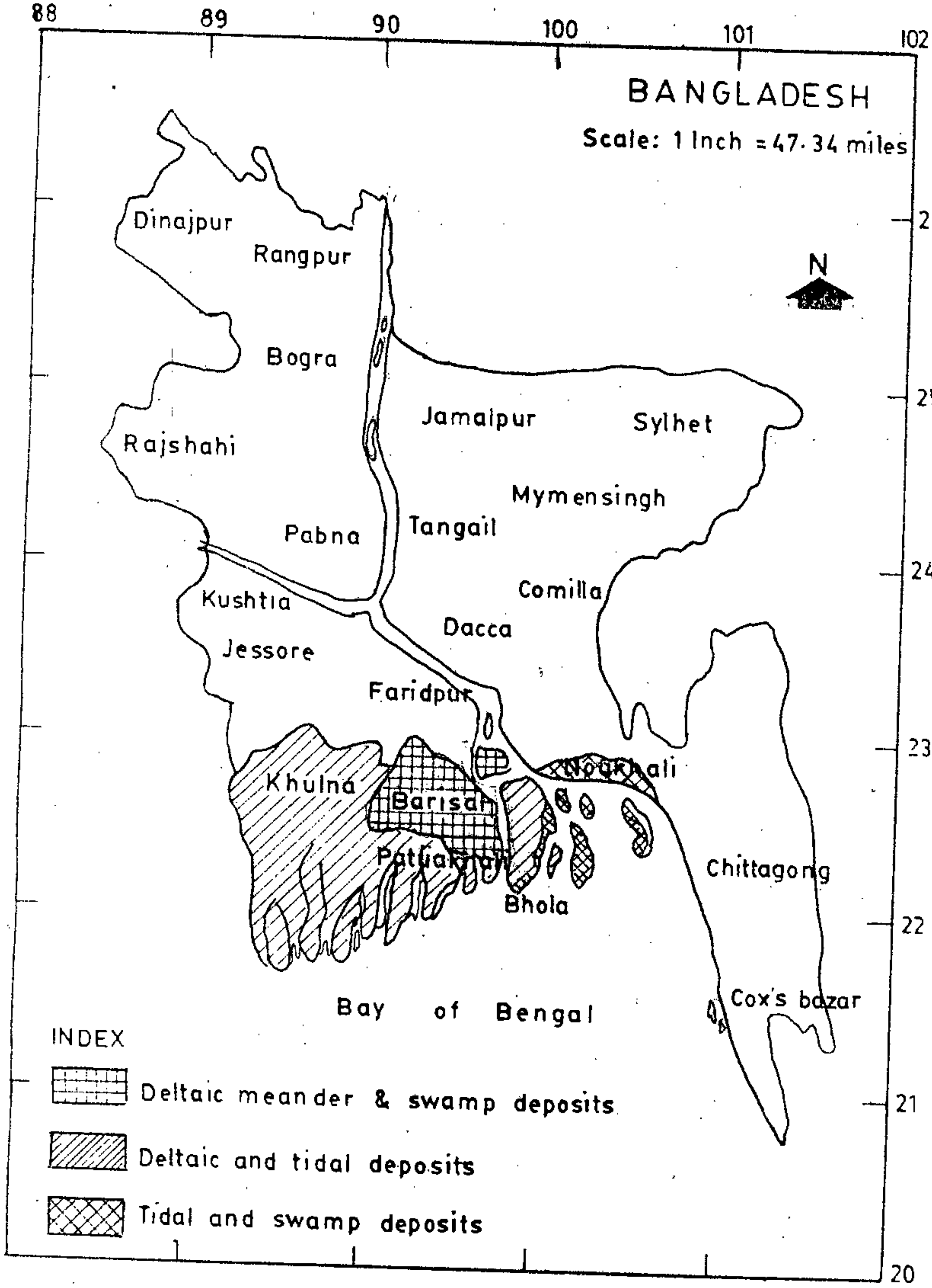

FIG. 7.1 MAP OF BANGLADESH SHOWING THE ZONING OF COASTAL AREAS

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26. See Reference 3, pp. 614.

APPENDIX-A

PHYSICAL PROPERTIES OF SOIL SAMPLES

A. TEST ZONE: BARISAL

Sl. No.	Location	Bore hole No.	Sample No.	Ground Water depth in ft.	Sp.gr.	N.W.C. %	Liquid limit Lw %	Plasticity Index Ip, %	Clay content %	Colloidal activity
1	2	3	4	5	6	7	8	9	10	11
1	Babuganj	1	D1(FC)	0'0"	2.69	39.0	45	19	23	0.82
2	River Bank(IWTA)	1	U1(SS)	4'4"	2.675	35.2	41	12	6	2.00
3	"	2	U1(SS)	6'0"	2.67	34.1	42	15	7	2.14
4	"	3	U1(SS)	6'0"	2.68	42.1	44	16	8	2.00
5	Jhalakati	1	UI(HR)	1'5"	2.68	26.6	37	8	-	-
6	Jhalakati	2	U2(HR)	3'7"	2.68	27.0	41	14	-	-
7	Jhalakati	2	U5(HR)	3'7"	2.70	31.5	41	11	-	-
8	Jhalakati	3	U2(HR)	5'6"	2.68	36.4	40	9	-	-
9	River Bank	1	D1(HR)	2'10"	2.67	37.7	39	8	-	-
10	River Bank	2	D1(HR)	3'4"	2.67	35.0	31	4	-	-
11	River Bank	2	U1(HR)	3'4"	2.72	31.3	39	11	-	-
12	River Bank	3	D4(HR)	3'0"	2.67	38.6	45	19	-	-
13	River Bank	3	D5(HR)	3'0"	2.68	36.8	36	11	-	-
14	Kawkhali	1	D1(FC)	10'0"	2.69	21.1	54	27	26	1.04
15	Kawkhali	2	D1(FC)	10'0"	2.68	25.4	48	21	10	2.1
16	Keyabunia	1	U1(HR)	1'7"	2.66	25.5	49	17	-	-

1	2	3	4	5	6	7	8	9	10	11
17	Keybunia	1	U2(HR)	1'7"	2.67	41.1	44	19	-	-
18	Keyabunia	1	U2(HR)	1'7"	2.67	31.5	41	12	-	-
19	Keyabunia	1	D6(HR)	1'7"	2.66	34.0	38	12	-	-
20	Keyabunia	2	U1(HR)	9'1"	2.67	37.2	50	18	-	-
21	Keyabunia	2	U2(HR)	9'1"	2.67	30.7	44	12	-	-
22	Keyabunia	3	U2(HR)	1'11"	2.66	35.9	44	11	-	-
23	Keyabunia	3	U4(HR)	1'11"	2.67	35.1	47	14	-	-
24	Hularhat	1	U1(SS)*	4'0"	2.70	50.3	32	11	9	1.22
25	Hularhat	2	U1(SS)	4'3"	2.71	43.5	38	21	10	2.10
26	Monoharpur	1	D1(HR)	4'0"	2.70	35.8	41	13	-	-
27	Monoharpur	1	D2(HR)	4'0"	2.70	32.0	34	10	-	-
28	Monoharpur	2	U2(HR)	10'0"	2.71	34.5	47	20	-	-
29	Monoharpur	2	D6(HR)	10'0"	2.71	38.4	36	9	-	-
30	Monoharpur	3	D7(HR)	1'9"	2.73	39.9	37	12	-	-
31	Monoharpur	3	U1(HR)	1'9"	2.73	41.3	47	22	-	-
32	Kachikata	1	U1(HR)	1'11"	2.67	36.4	44	19	-	-
33	Kachikata	1	U2(HR)	1'11"	2.67	33.3	42	16	-	-
34	Kachikata	2	U1(HR)	11'2"	2.67	34.0	43	18	-	-
35	Kachikata	2	D5(HR)	11'2"	2.67	38.8	40	13	-	-
36	Kachikata	3	U1(HR)	1'10"	2.67	32.3	32	5	-	-
37	Kachikata	3	D5(HR)	[illegible]	2.67	43.0	42	16	-	-

1	2	3	4	5	6	7	8	9	10	11
38	Fulbaria	1	D8(HR) *	2'7"	2.67	40.1	34	10	-	-
39	Amanatganj	1	D1(HR)	4'6"	2.69	31.9	36	11	-	-
40	Amanatganj	2	U4(HR)	4'2"	2.69	42.7	37	10	-	-
41	Amanatganj	2	D3(HR)	4'2"	2.69	36.5	35	10	-	-
42	Amanatganj	3	D3(HR)	4'0"	2.69	37.0	35	9	-	-
43	Banaribara	1	D0(FC) *	0'0"	2.65	60.6	47	18	5	3.60
44	Banaripara	1	D1(FC)	0'0"	2.65	54.2	47	21	9	2.33
45	Banaripara	3	D1(FC)	4'0"	2.62	54.4	61	26	6	4.33

* PC, HR, and SS: in the parenthesis indicate the sool samples collected by Foundation Consultant , Dacca, River Research: Institute, BWDB, Dacca and Sub-soil Engineers, Dacca respectively.

B. TEST ZONE: BHOLA

1	2	3	4	5	6	7	8	9	10	11
1	Charfesson(W)	1	D1(FC)	4'0"	2.67	32.4	36	11	4	2.75
2	Charfesson(NE)	1	D1(FC)	2'9"	2.67	25.8	39	11	4	2.75
3	Mafizabad	1	D1(FC)	2'3"	2.68	29.1	37	12	17	0.71
4	Mafizabad	1	D2(FC)	2'3"	2.68	32.2	31	10	10	1.00
5	Mafizabad Char	2	D1(FC)	2'4"	2.68	39.0	37	8	2	4.00
6	Mafizabad School	3	D1(FC)	2'6"	2.68	28.4	41	22	6	3.67
7	Kuchiamara	1	D1(FC)	2'0"	2.67	31.5	34	6	0	6.00
8	Ershadia	1	D1(FC)	10'0"	2.68	33.5	36	10	4	2.50
9	Aslampur	1	D1(FC)	3'6"	2.68	31.6	41	16	3	5.33
10	Katabania	1	D1(FC)	7'6"	2.67	24.5	39	13	6	2.17
11	Jalil Beparir Hat	1	D1(FC)	9'6"	2.67	28.6	34	7	2	3.50
12	Nilkamal	1	D1(FC)	5'0"	2.67	28.8	36	9	2	4.50
13	Char Jamuna	1	D1(FC)	2'0"	2.68	28.6	34	9	2	4.5
14	Char Kukri Mukri	1	D1(FC)	1'6"	2.68	33.2	40	15	11	1.36
15	Madras (N)	2	D1(FC)	9'6"	2.66	30.3	47	22	17	1.29
16	Madras(N)	1	D2(FC)	7'0"	2.67	38.7	38	13	2	6.50
17	Madras(N)	2	D3(FC)	9'6"	2.66	33.3	39	13	3	4.33
18	Hajarigonj	1	D1(FC)	2'0"	2.68	39.5	33	7	6	1.77
19	South Madras	1	D1(FC)	2'3"	2.68	28.7	39	15	8	1.88
20	Hajir Hat	1	D1(FC)	3'6"	2.67	31.2	33	5	8	0.63
21	Babur Hat	1	D1(FC)	1'0"	2.67	30.6	42	19	19	1.00
22	Hindu Pally	1	D1(FC)	2'0"	2.67	24.8	36	12	4	3.0

1	2	3	4	5	6	7	8	9	10	11
23	Char Manika(S)	1	D1(FC)	1'11"	2.67	27.4	38	13	11	1.18
24	Majher Char	1	D1(FC)	2'0"	2.68	26.4	40	14	6	2.23
25	Anand Prashad(N)	1	D1(FC)	5'0"	2.68	32.7	33	8	10	0.80
26	Anand Prashad(N)	1	D2(FC)	5'0"	2.68	37.3	33	7	8	0.88
27	Kachua Khali	3	D1(FC)	0'0"	2.66	35.0	43	20	4	5.00
28	Dhaligour Nagar	1	D1(FC)	0'0"	2.68	29.6	35	9	10	0.90
29	Nayabangania	1	D1(FC)	1'0"	2.68	42.2	44	18	6	3.00
30	Lakshmipur	1	D1(FC)	4'0"	2.68	34.0	45	19	8	2.38
31	Dasherhat	1	D1(FC)	2'0"	2.67	28.2	40	18	4	4.50
32	Krishna Chandra	1	D1(FC)	5'0"	2.68	35.0	45	19	12	1.58
33	Chandpur	1	D1(FC)	5'0"	2.68	32.0	41	16	3	5.33
34	Chandpur(N)	1	D1(FC)	2'0"	2.67	29.7	42	17	4	4.25
35	Kulagazir Taluk	1	D1(FC)	8'10"	2.67	31.0	41	15	4	3.75
36	Kulagazir Taluk	1	D2(FC)	8'10"	2.68	37.0	47	22	6	1.37
37	Kulagazir Taluk	2	D3(FC)	8'6"	2.68	40.0	46	21	14	1.50
38	Char Shakuchia	1	D1(FC)	12'0"	2.67	26.0	49	24	9	2.66
39	Char Shakuchia	1	D4(FC)	12'0"	2.67	29.8	32	6	5	1.20
40	Char Shakuchia	2	D4(FC)	11'3"	2.67	32.0	38	11	5	2.20
41	Char Shakuchia	2	D1(FC)	11'3"	2.67	29.0	39	13	9	1.44
42	Sakuchia (N)	1	D1(FC)	2'6"	2.67	37.5	37	10	12	0.83
43	Char Faijuddin	1	D1(FC)	G.S.L.	2.66	30.9	39	14	6	2.33

1	2	3	4	5	6	7	8	9	10	11
44	Hazirhat	1	D1(FC)	G.G.L	2.67	41.2	39	14	23	0.61
45	Andir hat	1	D1(FC)	2'0"	2.68	39.4	44	16	4	4.00
46	Andir hat	1	D2(FC)	2'0"	2.68	42.1	45	20	20	1.0
47	Char Mahazan	1	D1(FC)	2'6"	2.67	29.5	38	12	11	1.09
48	West Madua	1	D1(FC)	1'6"	2.68	29.8	46	20	7	6.67
49	Char Gomani	1	D1(FC)	10'2"	2.67	36.0	31	12	9	1.33
50	Char Didarullah	1	D1(FC)	2'0"	2.68	30.8	36	11	15	0.73
51	Bhawanipur	1	D1(FC)	12'0"	2.67	41.0	44	19	8	2.38
52	Char Lamchipata	1	D1(FC)	1'6"	2.66	32.0	36	8	8	1.00
53	Sayedpur	1	D1(FC)	4'0"	2.67	34.0	36	6	6	1.00
54	Sayedpur	1	D2(FC)	4'0"	2.67	36.0	36	7	12	0.58
55	Hazipur	1	D1(FC)	5'0"	2.67	33.4	38	11	4	2.75
56	Sukdev	1	D1(FC)	13'9"	2.68	33.0	47	21	6	3.50
57	Sukdev	1	D2(FC)	13'9"	2.68	31.6	45	18	9	2.00
58	Char Subi	1	D1(FC)	2'6"	2.67	32.6	36	10	4	2.50
59	Char Subi	1	D2(FC)	2'6"	2.67	38.5	46	19	7	2.71
60	Fearpur	1	D1(FC)	G.L.	2.68	27.6	43	18	16	1.13
61	Fearpur	1	D2(FC)	[illegible]	2.68	41.5	39	12	18	0.67
62	Gholam Rahman School	1	D1(FC)	1'6"	2.67	35.5	34	6	3	2.00
63	North Hazad	1	D2(FC)	1'6"	2.67	33.0	37	10	3	3.33

1	2	3	4	5	6	7	8	9	10	11
64	North Murad	1	D4(FC)	1'6"	2.67	40.20	33	10	6	1.67
65	Bhola Madrasha	1	D1(FC)	3'6"	2.67	37.0	36	11	8	1.38
66	Khurki	1	D1(FC)	2'0"	2.67	30.0	32	5	9	0.56
67	Char Chandra	1	D1(FC)	4'0"	2.67	32.0	N.P.	-	1	-
68	South Chanchra	1	D1(FC)	7'0"	2.68	32.0	45	19	17	1.12
69	Durlavpur	1	D1(FC)	2'4"	2.67	25.0	41	13	8	1.63
70	Durlavpur	1	D2(FC)	2'4"	2.67	28.0	37	7	2	3.50
71	Jhin Nagar	1	D1(FC)	2'4"	2.67	24.0	N.P.	-	3	-
72	Bhola Town	1	U1(SS)	0'0"	2.67	30.3	37	10	4	2.50
73	Bhola Town	2	U1(SS)	6"Av.G.L	2.67	33.14	36	10	4	2.50
74	Bhola Town	3	U1(SS)	1'0"	2.68	34.96	41	14	4	3.50
75	Bhola Town	4	U1(SS)	1'1"	2.67	37.23	42	16	5	3.20
76	Bhola Town	5	U1(SS)	1'0"	2.68	29.60	37	10	5	2.00
77	Bhola Town	5	U2(SS)	1'0"	2.67	39.28	43	5	4	1.25
78	East Charpata	1	D2(FC)	13'0"	2.67	27.0	39	10	5	2.00
79	Char Kachapia	2	D2(FC)	5'6"	2.67	36.0	39	11	5	2.20
81	Katabania	1	D2(FC)	7'6"	2.67	40.10	36	14	6	2.33
82	South Char Chiba	1	D2(FC)	4'0"	2.67	26.7	33	6	8	0.75

6. TEST ZONE: PATUAKHALI

1	2	3	4	5	6	7	8	9	10	11
1	Kalagachia	1	D1(FC)	3'0"	2.67	35.0	49	25	-	-
2	Ichadi Board	1	D1(FC)	7'0"	2.67	48.0	47	22	12	1.83
3	Golachipa	1	D1(FC)	4'0"	2.67	28.1	-	-	8	-
4	Golachipa	1	D2(FC)	4'0"	2.67	40.1	36	5	10	0.50
5	Sutabaria Circle	1	D1(FC)	0'0"	2.67	29.5	43	18	14	1.29
6	Sutabaria School	2	D1(FC)	5'0"	2.69	28.0	47	17	10	1.70
7	Kharizzama School	1	D1(FC)	3'6"	2.68	29.6	35	10	23	0.43
8	Kharizzama School	2	D1(FC)	5'0"	2.68	29.8	40	15	11	1.36
9	Kharizzama	3	D1(FC)	6'2"	-	29.0	45	12	12	1.00
10	North Amkhola	1	D1(FC)	3'6"	2.68	38.6	43	17	15	1.13
11	Awliapur Hat	1	D1(FC)	2'6"	2.68	30.5	36	10	21	0.48
12	Awliapur Hat	1	D2(FC)	2'6"	2.68	30.5	36	10	13	0.76
13	Amkhul Hat	1	D1(FC)	3'0"	2.68	28.4	42	16	13	1.23
14	Naluabagi Board	1	D1(FC)	4'6"	2.67	28.7	43	18	4	4.50
15	Naluabagi Board	1	D2(FC)	4'6"	2.67	38.5	37	12	13	0.92
16	Naluabagi School	2	D1(FC)	6'9"	2.67	30.0	35	18	6	3.00
17	Amkhul Hat	3	D2(FC)	8'10"	2.68	35.0	46	13	10	1.30
18	Naluabagi School	3	D2(FC)	7'2"	2.67	34.0	33	3	4	0.75
19	Char Bholaisingh	1	D1(FC)	2'6"	2.67	30.0	46	21	11	1.90
20	Bashbarial (N-W)	1	D1(FC)	6'0"	2.67	24.5	39	13	18	0.72
21	Chandpura	1	D1(FC)	2'3"	2.67	37.0	51	21	25	0.84

1	2	3	4	5	6	7	8	9	10	11
22	Chandpura(S)	2	D2(FC)	5'8"	2.67	31.4	N.P.	-	-	-
23	South Chandpura	2	D1(FC)	6'0"	2.67	28.4	41	9	16	0.56
24	Golkhali	1	D1(FC)	5'0"	2.68	31.5	43	19	19	1.05
25	Goalkhali School	1	D1(FC)	3'8"	2.68	30.0	50	15	12	1.25
26	North Badura	1	D1(FC)	6'0"	2.68	32.7	45	20	20	1.00
27	Patar Char	1	D1(FC)	5'0"	2.67	28.0	35	6	5	1.20
28	Jautha (E)	1	D1(FC)	1'0"	2.68	33.0	47	19	29	0.65
29	South Kalyankalash	1	D1(FC)	1'8"	2.68	39.8	44	16	15	1.06
30	Central Betagi	1	D1(FC)	2'0"	2.68	32.5	38	11	10	1.10
31	Char Chandrail	1	D1(FC)	2'9"	2.68	34.8	42	17	21	0.80
32	Nazmulchatra Sch.	1	D1(FC)	5'0"	2.67	30.6	44	18	10	1.80
33	East Pardakua	1	D1(FC)	8'0"	2.67	32.8	46	20	6	3.30
34	Ulania(S-E)	1	D1(FC)	9'0"	2.67	28.5	39	13	12	1.08
35	Ulania (S-E)	1	D4(FC)	9'0"	2.67	33.3	43	17	8	2.12
36	Gozalia Hat	1	D1(FC)	2'3"	2.68	29.0	45	20	14	1.42
37	Gozalia Hat	1	D2(FC)	2'3"	2.68	36.6	42	17	12	1.41
38	Kalashkhali (C)	1	D1(FC)	7'4"	2.67	38.0	46	20	6	3.33
39	Panpatty (N-W)	1	D1(FC)	5'6"	2.67	35.5	44	18	14	1.26
40	Char Momtaz	1	D1(FC)	1'6"	2.67	38.2	36	9	16	0.56
41	Panpatty Board	1	D1(FC)	2'8"	2.68	34.8	42	16	11	1.45
42	Panpatty Board	1	D2(FC)	2'8"	2.68	31.3	34	8	3	2.66

1	2	3	4	5	6	7	8	9	10	11
43	Al-Ameen	1	D1(FC)	2'4"	2.67	37.8	49	24	13	1.84
44	Ahmedpur	1	D1(FC)	10'0"	2.67	28.0	35	8	6	1.33
45	Gohin Khali	1	D1(FC)	4'0"	2.68	35.4	39	13	12	1.08
46	Gohin Khali	1	D2(FC)	4'0"	2.68	35.4	45	19	12	1.58
47	Haldia Khali	1	D1(FC)	2'6"	2.67	35.0	46	21	10	2.10
48	Haldia Khali	1	D2(FC)	2'6"	2.67	35.0	50	25	19	1.31
49	Chinabunia	1	D1(FC)	2'6"	2.67	31.6	39	13	12	1.08
50	Chinabunia	1	D2(FC)	2'6"	2.87	37.4	40	15	10	1.50
51	Kachua Hat	1	D1(FC)	0'4"	2.67	26.0	40	14	7	2.00
52	Katakhali	1	D1(FC)	5'0"	2.67	31.5	47	22	10	2.20
53	Katakhali	1	D2(FC)	3'0"	2.67	33.6	45	19	23	0.82
54	Alipur Union	1	D1(FC)	2'0"	2.67	26.9	51	25	4	6.25
55	Golachipa College	1	D1(FC)	2'6"	2.68	35.4	40	15	15	1.00
56	Golachipa College	1	D2(FC)	2'6"	2.70	34.5	48	23	11	2.09
57	Fulbunia	1	D1(FC)	5'2"	2.67	34.2	32	10	12	0.83
58	Fulbunia	3	D1(FC)	5'0"	2.67	34.0	35	10	13	0.76
59	Khaprabanga (N)	1	D1(FC)	6'0"	2.67	30.4	33	6	12	0.50
60	Lalu Rahimuddin(N)	1	D1(FC)	6'0"	2.67	40.5	45	21	8	2.62
61	Lalua Rahimuddin	1	D3(FC)	6'0"	2.67	40.5	43	20	8	2.50
62	Nizampur	3	D1(FC)	5'0"	2.67	38.8	47	20	28	0.71
63	Umedpur	1	D1(FC)	6'6"	2.67	36.0	45	20	16	1.25
64	Umedpur	1	D2(FC)	6'6"	2.67	37.6	46	21	17	1.23

1	2	3	4	5	6	7	8	9	10	11
65	Serajpur	3	D1(FC)	7'5"	2.67	34.0	43	9	12	0.75
66	Serajpur	2	D2(FC)	7'0"	2.67	44.0	48	13	8	1.62
67	M.B.College	1	D1(FC)	6'0"	2.67	32.4	46	21	15	1.40
68	Teakhali (S)	1	D1(FC)	6'0"	2.67	31.5	46	20	12	1.66
69	Tangibaria	1	D1(FC)	4'0"	2.68	32.0	45	19	20	0.95
70	Mushaliabad	1	D1(FC)	1'0"	2.67	26.5	38	13	13	1.00
71	Gazipur	1	D1(FC)	2'0"	2.69	30.5	40	14	11	1.27
72	Gazipur	1	D3(FC)	2'0"	2.67	36.1	38	11	7	1.57
73	Sonakhali	1	D1(FC)	2'0"	2.67	40.0	39	14	4	3.50
74	Londa Hafizuddin	1	D1(FC)	0'0"	2.68	35.4	42	17	20	0.85
75	Patua Al-Ameen	1	D1(FC)	1'0"	2.67	24.8	58	28	26	1.07
76	Patua Al-Ameen	1	D2(FC)	1'0"	2.67	37.0	38	11	6	1.83
77	Rupda Bandar	1	D1(FC)	3'0"	2.68	36.0	41	16	8	2.00
78	Taltali	1	D1(FC)	4'0"	2.68	36.4	46	20	19	1.05
79	Taltali	1	D2(FC)	4'10"	2.68	39.0	48	23	17	1.35
80	Barguna	1	D1(FC)	2'6"	2.68	26.6	46	20	13	1.53
81	Barguna	1	D2(FC)	2'6"	2.68	38.5	39	9	12	0.75
82	Subidkhali	1	D1(FC)	5'0"	2.68	31.0	45	20	12	1.66
83	Bauphal	1	D1(FC)	0'6"	2.68	27.2	39	15	12	1.25
84	Dhandi	1	D2(FC)	2'4"	2.68	38.4	43	18	11	1.63
85	Bhawla School	1	D1(FC)	2'6"	2.68	27.4	46	21	6	3.50
86	Bhawla School	1	D2(FC)	2'6"	2.68	38.0	47	21	10	2.10

1	2	3	4	5	6	7	8	9	10	11
87	Gosani School	1	D1(FC)	5'0"	2.68	29.0	45	19	10	1.90
88	North Devpur	1	D1(FC)	0'0"	2.67	26.6	40	15	14	1.07
89	Patuakhali Town	1	D1(FC)	21'4"	2.68	28.8	42	17	5	3.40
90	Bara Baliatali	1	D1(FC)	2'0"	2.68	34.4	47	22	24	0.91
91	Shari Khali	1	D1(FC)	3'0"	2.68	31.6	47	21	22	1275
92	Patharghata	1	U1(SS)	4'6"	2.69	38.1	45	17	25	0.68
93	Pathargata	2	U1(SS)	3'0"	2.68	35.6	57	30	15	2.00
94	Patharghata	3	U1(SS)	5'0"	2.67	51.7	50	33	16	2.06
95	Betagi	1	U1(SS)	1'6"	2.67	45.80	61	26	-	-
96	Betagi	1	U2(SS)	1'6"	2.67	31.52	39	6	-	-
* 97	Betagi	2	D2(SS)	2'0"	2.68	41.10	44	19	-	-
* 98	Betagi	2	D4(SS)	1'9"	2.67"	34.6	41	13	-	-

D. FOOT ZONE: KHULNA

1	2	3	4	5	6	7	8	9	10	11
1	Sankra	1	D3(HR)	4'6"	2.70	37.9	43	19	-	-
2	Sankra	2	U2(HR)	5'0"	2.69	35.0	38	9	-	-
3	Sankra	2	U4 (HR)	5'0"	2.69	35.4	41	11	-	-
4	Sankra	3	U2(HR)	5'1"	2.71	33.8	40	13	-	-
5	Sankra	3	U4(HR)	5'1"	2.71	30.8	34	8	-	-
6	Sankra	4	U2(HR)	4'8"	2.72	30.8	34	9	-	-
7	Sakra	4	U4(HR)	4'8"	2.72	34.5	35	8	-	-
8	Sankra	5	D1(HR)	5'9"	2.70	35.9	41	15	-	-
9	Sankra	5	U2(HR)	5'9"	2.70	36.80	41	11	-	-
10	Sankra	5	U4(HR)	5'9"	2.70	46.70	51	21	-	-
11	Mangla	1	D2(FC)	5'0"	2.69	42.40	33	8	8	1.0
12	Mangla	2	D7(FC)	6'0"	2.70	42.60	42	15	5	3.0
13	Bashalbari	1	D1(FC)	4'0"	2.70	33.0	47	25	10	2.5
14	Bashabari	2	D1(FC)	7'0"	2.66	41.0	52	27	22	1.22

1	2	3	4	5	6	7	8	9	10	11
15	Ferry ghat	1	D3(FC)	2'6"	2.67	34.5	38	18	8	2.25
16	Ferry ghat	2	D3(FC)	3'0"	2.65	33.6	61	28	16	1.75
17	Goalpara	1	D3(FC)	2'11"	2.67	37.5	86	7	7	1.00
18	Goalpara	2	D3(FC)	2'6"	2.67	44.6	52	27	25	1.08
19	Goalpara	3	D2(FC)	3'0"	2.68	27.65	34	8	10	0.80
20	Paikgacha	1	D2(FC)	5'0"	2.68	36.00	33	6	7	0.85
21	Paikgacha	2	D3(FC)	4'6"	2.66	37.0	33	6	2	3.00
22	Paikgacha	3	D2(FC)	5'0"	2.66	33.0	32	6	9	0.66
23	Khalishpur	1	D0(FC)	16'0"	2.67	26.15	36	8	3	2.66
24	Khalishpur	2	D0(FC)	15'0"	2.66	27.42	33	9	2	4.50
25	Khalishpur	3	D1(FC)	6'0"	2.67	32.12	39	11	2	5.50
26	Sheikpara	1	D1(FC)	0'0"	2.66	36.0	52	29	5	5.80
27	Sheikpara	1	D4(FC)	0'0"	2.66	38.0	38	10	7	1.43

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APPENDIX-B

GRAIN SIZE CLASSIFICATIONS

A. TEST ZONE: BARISAL

Sl. No.	Location	Bore Hole No	Sample depth in ft.	Type of sample	Specific gravity	Dry unit weight	D_{60} cm	D_{10} cm	D_{60}/D_{10}
1	River Ghat	1	U1(SS)	Silty clay	2.675	83.33	0.026	0.0035	7.42
2	River Ghat	2	U2(SS)	Silty with fine sand, trace clay	2.67	79.10	0.04	0.006	6.66
3	Hularhat	2	D1(SS)	"	2.71	78.3	0.036	0.007	5.14
4	Hularhat	1	D2(SS)	"	2.70	80.0	0.047	0.007	5.71
5	Keyabunia	1	U1(HR)	Silty clay trace fine sand	2.66	85.0	0.015	0.001	10.00
6	Keyabunia	1	D2(HR)	"	2.66	86.5	0.025	0.0035	7.14
7	I.W.T.A.	1	D2(HR)	Silt trace fine sand	2.67	79.1	0.04	0.006	6.66

1	2	3	4	5	6	7	8	9	10
8.	I.W.T.A.	2	D2(HR)	Silt fine sand	2.67	79.1	0.076	0.025	3.04
9	Banaripara	1	U1(FC)	Sandy silt trace clay	2.65	-	0.0325	0.003	10.83
10	Banaripara	1	U2(FC)	Sandy silt little clay	2.65	-	0.0175	0.0029	6.03
11	Banaripara	1	D4(FC)	Silt with sand, trace clay	2.65	-	0.0435	0.01	4.35

APPENDIX-B

GRAIN SIZE CLASSIFICATIONS

B. TEST ZONE: BHOLA

Sl. No.	Location	Bore hole No	Sample depth in ft.	Type of sample	Specific gravity	Dry unit weight	D_{60} cm	D_{10} cm	D_{60}/D_{10}
1	2	3	4	5	6	7	8	9	10
1	Bhabanipur	1	U2(HR)	silty clay, trace of fine sand	2.67	-	0.03	0.006	5
2	Bhabanipur	2	U2(HR)	-do-	2.66	-	0.02	0.006	4.5
3	Bhabanipur	2	U4(HR)	silt with fine sand trace clay	2.68	-	0.03	0.007	4.57
4	Bhola Town	1	U1(SS)	silt trace fine sand	2.66	-	0.04	0.012	3.52
5	Bhola Town	2	U3(SS)	silt trace fine sand	2.66	-	0.03	0.009	3.88
6	Mofizabad	2	U1(FC)	silt, little clay sand	2.68	95	0.05	0.011	4.54
7	Dhaliagour Nagar	1	U1(FC)	silt clay fine sand	2.68	93.4	0.008	0.001	5.33
8	Chandpur	1	U1(FC)	silt with fine sand trace clay	2.67	91.0	0.035	0.0068	5.14

C. TE T ZONE:PATUAKHALI

1	2	3	4	5	6	7	8	9	10
1	Patuakhali Town	1	D1(SS)	Clayey silt trace fine sand	2.69	84.2	0.075	0.016	4.68
2	Patuakhali Town	1	D5(SS)	Sandy silt trace clay	2.68	84.0	0.070	0.012	5.83
3	Ichadi	1	D1(FC)	Clayey silt little fine sand	2.67	89.0	0.012	0.0029	4.13
4	Kharizzama	1	D1(FC)	Clayey silt little fine sand	2.68	89.0	0.022	0.005	3.86
5	Naluabagi	1	D1(FC)	Clayey silt little fine sand	2.67	94.0	0.014	0.004	3.50
6	Panpatty Board	1	D1(FC)	Silty clay fine sand	2.67	86.7	0.014	0.0035	4.00
7	Panpatty Board	1	D2(FC)	Silt, fine sand trace clay	2.67	91.0	0.065	0.011	5.90
8	Gohinkhali	1	D2(FC)	Clayey silt trace fine sand	2.68	86.0	0.011	0.0025	4.40

1	2	3	4	5	6	7	8	9	10
9	Katakhali	1	D1(FC)	Silty clay trace fine sand	2.69	85.5	0.014	0.003	4.66
10	Golachipa	1	D1(FC)	Silty clay trace fine sand	2.67	90.0	0.011	0.0027	4.07
11	Tongibaria	1	D1(FC)	Silty clay trace fine sand	2.67	90.0	0.011	0.0027	4.07

D. TEST ZONE: KHULNA

1	2	3	4	5	6	7	8	9	10
1	Sankra	1	D1(FC)	Silt, trace of fine sand	2.70	92.3	0.035	0.0035	10.0
2	Sankra	2	D2(FC)	"	2.69	93.3	0.027	0.002	13.5
3	Sankra	5	D3(FC)	"	2.70	92.0	0.074	0.007	10.5
4	Clay Road		U3(FC)	Clayey Sandy silt	2.70	100.0	0.0088	0.0013	6.15
5	Clay	1	U3(FC)	Cley silt little fine sand	2.70	92.0	0.0141	0.001	14.1
6	Clay Road	2	U3(FC)	Sandy clayey silt	2.69	79.0	0.0085	0.0014	6.07
7	Goal Para	3	U1(FC)	Silt, trace little sand	2.68	94.0	0.0161	0.0015	10.7
8	Goalpara	2	U3(FC)	Clayey silt with little sand(organic)	2.69	78.0	0.0097	0.001	9.70
9	Khalishpur	1	U1(FC)	Sandy silt, trace, clay	2.67	-	0.025	0.006	4.16

1	2	3	4	5	6	7	8	9	10
10	Khalishpur	2	U1(FC)	Silt with sand, trace clay	2.67	-	0.029	0.006	4.83
11	Khalishpur	3	D2(FC)	Sand trace silty clay	2.67	-	0.08	0.01	8.0
12	Shiromoni	1	U1(SS)	Silt, little fine sand	2.67	78.10	0.05	0.01	5.0
13	Shiromoni	2	U1(SS)	Silty clay, trace fine sand	2.68	84.50	0.03	0.0015	20.0
14	Gallamara	1	B3(SS)	Silt with clay trace fine sand	2.665	96.33	0.025	0.0045	5.55
15	Gallamara	2	B3(SS)	Silty clay with peat, trace fine sand	2.675	71.76	0.035	0.0045	7.77

E. TEST ZONE: NOAKHALI

1	2	3	4	5	6	7	8	9	10
1	Bashkhali Khal	1	D2(HR)	Silt, trace of fine sand	2.67	88.0	0.03	0.006	5.0
2	Kashabia	1	D2(HR)	Silt, trace of fine sand	2.665	86.4	0.058	0.016	3.6
3	Kashabia	1	D1(HR)	Silt, trace of fine sand	2.665	86.04	0.024	0.0072	3.33
4	Bhatardona	1	D2(HR)	Fine silty sand	2.67	88.8	0.085	0.02	4.25
5	Mahipal	1	UD(SS)	Silt, trace fine sand	2.685	96.48	0.034	0.004	8.50
6	Mahipal	2	UD(SS)	Silt, trace fine sand	2.688	87.82	0.035	0.0065	5.38
7	Ramgati	1	D1(SS)	Silt, little fine sand	2.65	97.50	0.055	0.015	3.66
8	Ramgati	2	D1(SS)	do trace fine sand	2.665	99.60	0.06	0.017	3.53
9	Maijdee Court	4	D5(FC)	Silt and sand	2.67	-	0.042	0.008	5.25

1	2	3	4	5	6	7	8	9	10
10	Maijdee Court	5	D1(FC)	Silt with sand little clay	2.67	-	0.041	0.004	10.25
11	Maijdee Court	6	D3(FC)	Silt with sand, trace clay	2.675	-	0.024	0.0072	3.33
12	Maijdee Court	8	D2(FC)	Silt with sand	2.66	-	0.025	0.0075	3.33

APPENDIX-C

VALUES OF NATURAL VOID RATIO AND COMPRESSION INDEX

A. TEST ZONE: BARISAL

Sl. No.	Location	Bore hole no	Sample Number	Specific Gravity	Dry density pcf	Moisture content %	Liquid limit %	Natural void ratio	Compression index Cc
1	2	3	4	5	6	7	8	9	10
1	River Bank(IWTA)	1	U1(SS)	2.67	83.33	35.20	41	1.023	0.27
2	River Bank(IWTA)	2	U1(SS)	2.67	88.40	34.10	42	0.824	0.17
3	River Bank (IWTA)	3	U1(SS)	2.68	77.00	42.10	44	1.171	0.37
4	Hularhat	1	U1(SS)	2.70	80.0	43.5	38	1.095	0.30
5	Jhalakati River Bank	2	U2(HR)	2.68	89.80	32.0	41	0.875	0.22
6	Barisal River Bank	3	U2(HR)	2.719	82.80	38.6	45	1.072	0.275
7	Barisal River Bank	2	U2(HR)	2.72	90.10	32.0	39	0.905	0.157
8	Barisal River Bank	5	U1(HR)	2.66	72.70	49.4	51	1.344	0.450
9	Jhalakati River Bank	-	U2(HR)	2.72	86.3	32.2	45	0.888	0.205
10	Keyabunia	1	U3(HR)	2.665	85.0	41.9	44	1.13	0.236
11	Keyabunia	2	U2(HR)	2.667	80.3	35.6	50	0.984	0.231
12	Keyabunia	3	U4(HR)	2.663	86.5	32.7	47	0.86	0.178
13	Monoharpur	2	U1(HR)	2.71	79.9	34.6	47	0.944	0.228

1	2	3	4	5	6	7	8	9	10
14	Monoharpur	3	U1(HR)	2.73	79.0	42.17	47	1.151	0.313
15	Fulbaria	1	U2(HR)	2.67	-	34.20	34	0.9109	0.196
16	Fulbaria	2	U2(HR)	2.67	-	32.50	-	0.856	0.182
17	Fulbaria	3	U2(HR)	2.67	-	32.93	-	0.880	0.195
18	Amanatganj	1	U2(HR)	2.69	86.30	36.05	40	0.970	0.261
19	Amanatganj	2	U2(HR)	2.71	79.0	43.57	41	1.202	0.305
20	Amanatganj	3	U3(HR)	2.67	79.0	42.85	41	1.185	0.290
21	Amanatganj	4	U5(HR)	2.69	80.5	44.25	39	1.180	0.260
22	Amanatganj	3	U5(HR)	2.67	79.7	43.28	40	1.145	0.328
23	Pirojpur PDB Tower 63	1	U1(SS)	2.70	93.0	31.20	49	0.810	0.223
24	Pirojpur PDB Tower 96	1	U1(SS)	2.71	82.5	38.20	56	1.040	0.270
25	Pirojpur PDB Tower 103	1	U1(SS)	2.70	94.0	29.0	50	0.800	0.150
26	Banaripara	1	U1(FC)	2.65	-	54.20	47	1.687	0.550
27	Banaripara	3	D2(FC)	2.62	-	77.00	61	1.270	0.350
28	Banaripara	4	U1(FC)	2.67	-	31.00	37	0.720	0.240
29	Banaripara	9	U3(FC)	2.66	-	40.40	36	1.064	0.260

B. TEST ZONE: BHOLA

1	2	3	4	5	6	7	8	9	10
1	Charfession	1	U2(FC)	2.67	99.0	25.80	39	0.94	0.350
2	Char Shiba	1	U4(FC)	2.67	104.0	26.7	33	0.85	0.150
3	Mafizabad	1	U3(FC)	2.68	88.5	32.2	31	0.85	0.270
4	Mafizabad	1	U1(FC)	2.68	95.0	28.4	41	0.89	0.185
5	Katabania	1	U1(FC)	2.67	95.0	24.5	39	0.91	0.240
6	Awazpur (W)	1	U3(FC)	2.67	90.0	33.3	N.P.	0.94	0.300
7	Omrabag	1	U1(FC)	2.67	102.0	24.0	N.P.	0.90	1.150
8	Dhaligour	1	U1(FC)	2.68	93.4	29.6	35	1.26	0.225
9	Chandipur (N)	1	U1(FC)	2.68	87.5	34.0	40	0.77	0.220
10	Chanchra (N)	2	U1(FC)	2.68	95.0	28.4	49	0.84	0.205
11	Chanchra (W)	1	U1(FC)	2.68	86.0	35.2	N.P.	0.95	0.200
12	Sakuchia (N)	1	U1(FC)	2.67	104.0	22.6	37	1.34	0.140
13	Bhawanipur	1	U2(FC)	2.67	80.0	41.0	44	0.835	0.168
14	Sayedpur	1	U3(FC)	2.67	88.0	36.0	36	0.967	0.275
15	Pearpur	1	U3(FC)	2.68	76.5	41.5	39	0.90	0.215
16	Bangerchar	1	U1(FC)	2.69	92.30	35.5	38	0.94	0.190
17	Char Chandra	1	U1(FC)	2.67	90.0	32.0	N.P.	0.76	0.135
18	Bhola Town	1	U1(SS)	2.64	90.0	30.39	37	0.87	0.126
19	Bhda Town	2	U3(SS)	2.66	89.18	29.70	N.P.	0.84	0.118
20	Bhola Town	3	U3(SS)	2.67	88.39	32.85	N.P.	0.885	0.194
21	Bhola Town	4	U2(SS)	2.67	86.71	38.39	44	0.93	0.145
22	Bhola Town	5	U2(SS)	2.66	83.00	37.23	42	0.97	0.247
23	Bhola Town	2	U4(SS)	2.66	93.67	27.05	N.P.	0.80	0.162

C. TEST ZONE: PATUAKHALI

1	2	3	4	5	6	7	8	9	10
1	Kaylan Kalash	1	U1(FC)	2.68	88.0	33.6	41	0.94	0.13
2	Ichadi Board	1	U1(FC)	2.67	83.0	38.0	47	0.89	0.21
3	Ichadi School	1	U1(FC)	2.67	90.5	31.6	43	0.84	0.31
4	Sutabaria	1	U1(FC)	2.69	95.5	28.0	47	1.24	0.31
5	Kharizzama	1	U1(FC)	2.68	89.0	33.0	40	0.89	0.25
6	Naluabagi	1	U2(FC)	2.67	83.0	30.0	35	0.81	0.27
7	Naluabagi	1	U1(FC)	2.67	94.5	28.5	43	0.85	0.22
8	Char Bholashing	1	U1(FC)	2.67	92.7	30.0	46	0.87	0.20
9	Chandpur (S)	1	U1(FC)	2.67	98.5	28.0	51	0.65	0.33
10	Goolkhali	1	U1(FC)	2.68	88.0	33.6	50	1.02	0.25
11	Jautha (E)	1	U1(FC)	2.68	88.8	33.0	47	0.90	0.20
12	Nazmul Chatra	1	U1(FC)	2.67	92.0	30.6	44	1.02	0.33
13	Panpatty Board	1	U1(FC)	2.67	86.7	34.8	42	0.65	0.23
14	Panpatty (E)	1	U1(FC)	2.67	87.3	35.1	37	0.70	0.20
15	Gohin Khali	1	U1(FC)	2.68	86.0	35.4	39	1.04	0.21
16	Haldiakhali	1	U1(FC)	2.67	86.4	35.0	46	0.87	0.24
17	Chinabunia	1	U1(FC)	2.67	90.6	31.6	39	0.87	0.17
18	Golachipa	1	U1(FC)	2.68	91.5	30.8	40	1.08	0.20
19	Golachipa	1	U2(FC)	2.70	85.6	35.4	48	0.94	0.23
20	Fulbania	1	U1(FC)	2.67	88.6	33.8	35	1.12	0.21
21	Serajpur	1	U1(FC)	2.67	85.8	35.7	56	1.02	0.31
22	Gazipur	1	U1(FC)	2.69	92.0	30.5	40	0.86	0.09
23	Patua Al-Amin	1	U2(FC)	2.67	89.0	37.0	45	1.04	0.26

1	2	3	4	5	6	7	8	9	10
24	Rupdha Bandar	1	U1(FC)	2.68	95.0	36.0	39	1.19	0.21
25	Amtali College	1	U2(FC)	2.68	85.6	35.6	44	0.87	0.23
26	Bauphal	1	U1(FC)	2.68	96.5	27.2	39	1.20	0.23
27	Dhankhali (W)	1	U1(FC)	2.67	87.0	34.6	38	0.98	0.24
28	Digree	1	U2(FC)	2.67	83.0	38.6	34	1.20	0.27
29	Kalakhali	1	U1(FC)	2.66	88.0	34.0	41	1.08	0.34
30	Bolaibunia	1	U1(FC)	2.67	88.0	33.4	32	1.11	0.27
31	Charpara Pikerpara	1	U1(FC)	2.67	87.0	33.7	31	1.10	0.16
32	Pashurbunia	1	U1(FC)	2.68	86.0	36.0	29	0.97	0.21
33	Charkazal (C)	1	U1(FC)	2.68	91.0	31.2	28	0.67	0.16
34	Kazi Kanda	1	U1(FC)	2.67	90.0	32.0	36	0.91	0.21
35	Char Mamtej	1	U1(FC)	2.67	97.0	27.0	35	1.02	0.12
36	Char Subi	1	U1(FC)	2.67	88.5	50.0	40	0.93	0.25
37	Bagerawla	1	U1(FC)	2.67	89.0	32.6	29	0.93	0.30
38	Dhumky	1	U2(FC)	2.67	87.0	34.0	36	0.92	0.27
39	Bankerhat	1	U1(FC)	2.66	90.0	31.8	N.P.	0.95	0.14
40	Char Faizuddin(S)	1	U1(FC)	2.67	94.0	29.0	37	1.08	0.27
41	Patuakhali	1	U1(SS)	2.69	84.2	38.1	35	1.03	0.27
42	Patuakhali	2	U2(SS)	2.68	84.0	39.7	57	1.03	0.38
43	Patuakhali	3	U1(SS)	2.67	70.1	51.7	50	1.46	0.42
44	Patuakhali	3	U3(SS)	2.67	91.2	33.0	N.P.	0.86	0.18

D. TEST ZONE: KHULNA

1	2	3	4	5	6	7	8	9	10
1	Sankra	2	U2(HR)	2.70	86.0	32.2	38	0.870	0.13
2	Sankra	5	U2(HR)	2.70	91.0	37.6	51	1.020	0.29
3	Sankra	2	U4(HR)	2.69	88.4	36.2	41	0.906	0.23
4	Sankra	3	U4(HR)	2.71	84.0	29.6	34	0.805	0.90
5	Sankra	4	U2(HR)	2.72	84.0	34.4	34	0.150	0.20
6	Hard Metal	1	U1(FC)	2.68	100.0	25.0	N.P	0.676	0.10
7	Hard Metal	1	U5(FC)	2.68	83.0	38.0	35	1.116	0.32
8	Sheikpara	1	U5(FC)	2.66	83.0	38.0	38	1.236	0.32
9	Sheikpara	1	U6(FC)	2.67	83.0	38.0	43	1.121	0.28
10	Khalishpur	1	U1(FC)	2.67	-	36.39	41	0.89	0.24
11	Khalishpur	1	U7(FC)	2.68	-	40.13	39	1.092	0.29
12	Paikgacha	1	U2(FC)	2.68	84.5	36.0	33	0.904	0.20
13	Paikgacha	1	U3(FC)	2.66	83.5	37.0	33	0.984	0.21
14	Paikgacha	2	U2(FC)	2.66	88.5	33.0	32	0.647	0.13
15	Goalpara	1	U3(FC)	2.61	104.0	48.0	48	1.102	0.45
16	Khulna Town	1	U3(FC)	2.66	86.0	35.0	40	1.199	0.32
17	Khulna Town	1	U2(FC)	2.60	83.0	58.0	67	1.684	0.61
18	Ferry ghat	1	U5(FC)	2.65	89.0	33.6	61	1.20	0.28
19	Ferry ghat	2	U5(FC)	2.66	85.0	36.6	44	1.266	0.27

1	2	3	4	5	6	7	8	9	10
20	Bashabari	1	U3(FC)	2.66	80.0	40.5	52	1.22	0.53
21	Mangla	1	U_{12}(FC)	2.68	80.0	41.7	39	1.163	0.30
22	Mangla	2	U_7(FC)	2.67	78.0	42.8	42	1.278	0.34
23	Jessore Road	1	U5(FC)	2.66	85.0	36.6	44	1.266	0.27
24	Jessore Road	2	U2(FC)	2.65	89.0	33.6	61	1.200	0.28
25	Balitha	1	U2(FC)	2.65	62.2	81.2	84	2.156	0.67
26	Balitha	2	U2(FC)	2.66	64.0	86.3	82	2.294	0.64
27	Balitha	2	U4(FC)	2.66	68.5	48.8	87	1.297	0.36
28	Balitha	2	U4(FC)	2.66	51.6	46.5	75	1.230	0.31
29	Shiromoni	1	U1(SS)	2.67	78.1	35.2	N.P.	1.054	0.22
30	Shiromoni	2	U1(SS)	2.68	84.5	31.5	45	0.943	0.176
31	Gallamari	1	U1(SS)	2.66	96.3	73.7	58	2.008	0.84
32	Gallamari	2	U2(SS)	2.68	82.1	40.4	56	0.991	0.23

E. TEST ZONE: NOAKHALI

1	2	3	4	5	6	7	8	9	10
1	Ramgati	1	U1(SS)	2.67	97.50	21.30	33.0	0.697	0.143
2	Ramgati	2	U2(SS)	2.67	98.20	20.30	33.0	0.675	0.114
3	Mahipal	1	U0(SS)	2.68	96.48	25.14	36.0	0.742	0.106
4	Mahipal	2	U0(SS)	2.68	87.82	25.40	34.0	0.916	0.149
5	Raipur	1	U5(SS)	2.70	80.50	40.0	38.0	1.100	0.300
6	Raipur	2	U1(SS)	2.69	89.30	31.70	42.0	0.864	0.149
7	Raipur	3	U3(SS)	2.68	81.00	38.80	44.0	1.060	0.280
8	Raipur	4	U3(SS)	2.66	87.00	34.10	40.0	0.904	0.214

APPENDIX-D

SHEAR STRENGTH OF COHESIVE SOILS
(FROM UNCONFINED COMPRESSION TEST)

A. TEST ZONE: BARISAL

Sl. No.	Location	Bore hole No.	Sample Number	Moisture content %	Dry Density pcf	Applied stress psf	Strain at failure %	Shear Strength psf
1	2	3	4	5	6	7	8	9
1	Kawkhali	1	D1(FC)	25.4	96.0	1525	11.0	763
2	Kawkhali	2	D1(FC)	21.1	108.0	5040	20.0	2820
3	Babugonj	1	D2(FC)	61.7	770.5	201	10.0	101
4	Babugonj	2	D2(FC)	39.0	81.7	5520	19.0	260
5	River Bank(I.W.T.A)	1	U1(SS)	35.2	83.3	1120	12.0	560
6	River Bank (I.W.T.A)	2	U0(SS)	34.1	88.4	860	9.0	430
7	River Bank (I.W.T.A)	2	U1(SS)	38.8	79.1	660	9.0	330
8	River Bank (I.W.T.A)	3	U1(SS)	42.1	77.0	440	10.0	220
9	Hularhat	1	U1(SS)	50.3	78.3	340	12.0	170
10	Hularhat	1	U2(SS)	45.0	79.5	540	9.0	270
11	Hularhat	2	U1(SS)	43.5	80.0	280	12.0	140
12	Amanatganj	1	U2(HR)	35.3	86.3	708	19.0	354
13	Amanatganj	1	U4(HR)	39.8	79.7	419	14.0	209
14	Amanatganj	2	U2(HR)	38.5	83.7	900	12.0	450
15	Amanatganj	2	U3(HR)	37.9	80.5	454	16.0	227
16	Amanatganj	2	U4(HR)	37.5	79.0	157	20.0	78
17	Moncharpur	3	U2(HR)	39.3	79.0	365	20.0	182

1	2	3	4	5	6	7	8	9
18	Keyabunia	1	U1(HR)	25.5	85.0	3160	6.5	1580
19	Keyabunia	2	U3(HR)	40.1	80.3	2448	9.5	1224
20	Keyabunia	2	U5(HR)	35.1	86.5	1504	9.0	752
21	Jhalakati	1	U2(HR)	36.3	82.5	1368	11.0	684
22	Jhalakati	1	U5(HR)	31.5	86.3	1349	11.0	675
23	Barisal D.C. Ghat	2	U2(HR)	31.3	90.1	1806	9.5	903
24	Barisal IWTA	3	U3(HR)	43.7	72.7	940	14.0	470
25	Pirojpur PDB Tower 63	1	U1(SS)	31.2	93.0	340	16.0	170
26	Pirojpur PDB Tower 96	1	U1(SS)	38.2	82.5	360	17.0	180
27	Pirojpur PDB Tower 103	1	U1(SS)	39.2	81.0	560	14.0	280
28	Pirojpur PDB Tower 128	1	U1(SS)	44.0	76.5	460	18.0	230
29	Banaripura	1	U0(FC)	60.6	–	362	14.0	181
30	Banaripura	1	U1(FC)	54.2	–	314	16.0	157

B. TEST ZONE:BHOLA

1	2	3	4	5	6	7	8	9
1	Charfession(N)	1	D1(FC)	32.40	90.0	1426	10.0	713
2	Charfession(N-E)	1	D1(FC)	25.80	99.0	1685	10.5	842
3	Char Chiba (S)	1	D4(FC)	26.70	107.0	4200	6.0	2100
4	Mafizabad	1	D1(FC)	29.1	94.0	2563	19.5	1281
5	Mofizabad	1	D3(FC)	32.2	88.5	590	14.5	295
6	Char Mafizabad	2	D1(FC)	39.0	82.0	1944	8.0	972
7	Char Mafizabad	2	D4(FC)	33.0	88.0	734	13.0	367
8	Mafizabad School	3	D1(FC)	28.4	95.0	2649	9.0	1324
9	Kuchimara	1	D1(FC)	31.5	90.7	1407	9.0	703
10	Ershadia	1	D1(FC)	33.5	88.0	2000	11.0	1000
11	Ershadia	1	D4(FC)	31.5	90.7	1407	8.5	703
12	Aslampur	1	D1(FC)	31.6	90.5	3816	8.0	1908
13	Katabania	1	D1(FC)	24.5	95.0	3125	11.0	1562
14	Katabania	1	D4(FC)	40.1	83.8	1205	17.0	602
15	Jalil Beparirhat	1	D1(FC)	28.6	95.0	1825	9.0	912
16	Char Jamuna	1	D1(FC)	28.6	94.6	1022	17.0	511
17	Char Kukri Mukri	1	D1(FC)	33.2	88.5	1577	17.5	788
18	North Madras	1	D1(FC)	28.2	98.0	1925	6.0	705
19	North Madras	2	D3(FC)	33.3	93.0	3240	9.0	1620
20	Hazariganj (C)	1	D1(FC)	39.5	81.2	876	13.5	439
21	Sourth Madras	1	D1(FC)	28.7	94.5	2260	12.0	1130
22	Hazirnat	1	D1(FC)	31.2	91.0	1858	11.5	929

1	2	3	4	5	6	7	8	9
23	Baburhat	1	D1(FC)	30.6	92.0	2880	20.0	1440
24	Faridabad (E)	1	D2(FC)	32.0	90.0	1565	13.0	782
25	Faridabad	1	D7(FC)	36.4	84.5	3279	14.5	1639
26	West Awazpur	1	D1(FC)	25.4	94.0	2333	6.9	1166
27	West Awazpur	2	D1(FC)	30.6	95.0	2300	6.0	1150
28	West Awazpur	2	D4(FC)	29.2	98.5	1986	8.0	992
29	Hindu Pally	1	D1(FC)	24.8	100.5	1828	11.5	914
30	Char Manika (S)	1	D1(FC)	27.4	96.5	1396	17.5	698
31	Majher Char	1	D1(FC)	26.4	98.0	2146	12.0	1073
32	Roychand	1	D1(FC)	24.4	101.3	2520	12.0	1260
33	Roychand	1	D2(FC)	28.0	95.6	2174	10.5	1087
34	Ananda Prasad(N)	1	D1(FC)	32.7	92.0	3670	20.0	1833
35	Ananda Prasad(N)	1	D3(FC)	37.3	85.0	1710	85.0	855
36	Char Umed (W)	1	D1(FC)	33.6	88.0	1526	12.0	763
37	Char Rapachia	1	D3(FC)	36.0	85.0	1195	9.0	597
38	Kachuakhali	1	D1(FC)	34.0	86.5	1260	10.0	630
39	Kachuakhali	2	D1(FC)	29.0	95.0	2160	9.5	1080
40	Kachuakhali	3	D2(FC)	38.0	82.7	1166	11.0	583
41	Char Sokina(N)	1	D1(FC)	29.0	96.0	2300	6.0	1150
42	Dhaligaur Nagar	1	D1(FC)	29.6	93.4	1555	12.5	777
43	Nayabangania	1	D1(FC)	42.2	78.0	2174	20.0	1037

1'	2	3	4	5	6	7	8	9
44	Bisharanpur (W)	1	D3(FC)	34.0	93.0	1265	18.0	632
45	Lakshmipur	1	D1(FC)	34.0	92.0	1660	12.0	830
48	Dasherhat	1	D1(FC)	28.2	95.2	2376	9.0	1188
47	Krishna Chandra	1	D1(FC)	35.0	90.0	2590	17.0	1295
48	Chandpur	1	D1(FC)	32.0	91.0	2330	14.0	1165
49	Gurinda	1	D1(FC)	28.7	95.0	3369	11.0	1684
50	Chandipur (N)	1	D1(FC)	28.4	95.0	1267	19.5	633
51	Chandipur (N)	2	D2(FC)	34.0	87.5	1339	11.0	669
52	Chandhra (N)	1	D1(FC)	28.4	95.0	1267	19.5	633
53	Chanchra (W)	1	D1(FC)	35.2	86.0	1612	8.5	806
54	Kulagazir Taluk	1	D1(FC)	31.0	90.0	3455	11.0	1727
55	Kulagazir Taluk	1	D4(FC)	37.0	85.0	1265	85.0	632
56	Kulagazir Taluk	2	D1(FC)	30.0	97.0	2015	16.0	1007
57	Kulagazir Taluk	2	D5(FC)	40.0	82.0	710	16.0	355
58	Char Sakuchia (S)	1	D1(FC)	26.0	100.0	4030	7.0	2015
59	Char Sakuchia (S)	1	D4(FC)	41.0	86.0	1555	11.0	777
60	Char Sakuchia (S)	2	D1(FC)	29.0	95.0	3885	12.0	1942
61	Char Sakuchia	2	D3(FC)	24.0	104.0	5010	14.0	2505
62	Sakuchia (w)	1	D1(FC)	37.5	83.3	780	20.0	390
63	Hazirhat	1	D1(FC)	41.2	79.0	1359	20.0	679
64	Andirhat	1	D4(FC)	42.1	78.0	562	15.0	281
65	west Madua	1	D1(FC)	29.8	93.0	1670	8.5	835

1	2	3	4	5	6	7	8	9
66	Char Gomani	1	D2(FC)	36.0	91.0	1625	9.0	812
67	Char Gomani	1	D1(FC)	36.0	92.0	1465	9.0	732
68	Char Didarullah	1	D1(FC)	30.8	92.0	1382	10.7	691
69	Char Didarullah	1	D5(FC)	38.0	82.7	2664	5.0	1332
70	Bhawanipur	1	D2(FC)	41.0	80.0	2390	11.0	1195
71	Char Lamchipata(E)	1	D1(FC)	32.0	90.0	1670	16.0	835
72	Sayedpur	1	D1(FC)	34.0	88.0	2040	7.0	1020
73	Sayedpur	1	D3(FC)	36.0	88.0	1425	15.0	712
74	Charpata (E)	1	D3(FC)	27.0	96.0	1403	6.0	702
75	Hazipur	1	D1(FC)	33.4	88.0	1584	11.0	792
76	Char Khalifa	1	D8(FC)	35.0	90.0	1610	15.0	805
77	Sukdev	1	D3(FC)	33.0	90.0	2810	9.0	1405
78	Char Subia	1	D1(FC)	32.6	89.4	3456	9.4	1728
79	Char Subi	1	D3(FC)	35.5	85.7	3672	10.1	1836
80	Char Subi	1	D5(FC)	39.2	81.2	1684	10.1	842
81	Pearpur	1	D1(FC)	27.6	96.0	1195	20.0	597
82	Pearpur	1	D3(FC)	41.5	76.5	633	20.0	366
83	Golam Rahman	1	D1(FC)	35.5	85.6	1514	15.5	757
84	North Murad	1	D2(FC)	33.0	89.0	2160	9.0	1080
85	North Murad	1	D4(FC)	40.2	65.5	878	14.5	439

1	2	3	4	5	6	7	8	9
86	Islamia Madrasha	1	D1(FC)	37.0	85.0	1452	20.0	.726
87	Khurki	1	D1(FC)	30.0	92.7	3207	13.0	1603
88	Char Chandra	1	D1(FC)	32.0	90.0	2793	8.0	1396
89	South Chandra	1	D1(FC)	32.0	90.0	2170	15.0	1085
90	South Jhin Nagar	1	D1(FC)	24.0	100.0	1814	11.0	907
91	Durlavpur	1	D1(FC)	25.0	99.0	3412	13.0	1706
92	Durlavpur	1	D2(FC)	28.0	95.0	2779	8.5	1389
93	Bhola Town	1	U1(SS)	30.3	90.0	1008	6.0	504
94	Bhola Town	1	U2(SS)	32.4	88.0	922	12.0	461
95	Bhola Town	2	U1(SS)	33.1	93.7	1094	8.0	547
96	Bhola Town	2	U3(SS)	29.7	89.1	1037	5.0	518
97	Bhola Town	3	U1(SS)	36.2	87.9	800	16.0	400
98	Bhola Town	3	U3(SS)	32.3	88.3	946	7.0	473
99	Bhola Town	4	U1(SS)	34.9	88.6	700	10.0	350
100	Bhola Town	4	U2(SS)	38.3	86.7	948	20.0	474
101	Bhola Town	4	U3(SS)	40.1	79.6	540	16.0	270

C.TEST ZONE: PATUAKHALI

1	2	3	4	5	6	7	8	9
1	Kalagochia	1	D1(FC)	35.0	86.0	1080	19.0	540
2	Ichadi Board	1	D1(FC)	38.0	83.0	1285	20.0	647
3	Ichadi School	3	D1(FC)	33.0	89.0	1987	12.0	993
4	Ichadi School	3	D2(FC)	33.6	88.0	1744	11.0	877
5	Golachipa	1	D2(FC)	40.1	81.0	892	14.0	446
6	Sutabaria Circle	1	D1(FC)	29.5	93.5	2620	19.0	1310
7	Sutabaria School	1	D1(FC)	28.0	95.5	1468	19.0	734
8	Sutabaria School	1	D2(FC)	26.0	98.6	2448	7.5	1324
9	Sutabaria School	3	D2(FC)	40.0	81.0	1252	7.0	626
10	Kharizzama	1	D2(FC)	37.5	80.5	576	18.0	288
11	Kharizzama	1	D1(FC)	29.6	93.5	3279	20.0	1639
12	Kharizzama	2	D2(FC)	33.0	89.0	2166	13.0	1083
13	Kharizzama	3	D1(FC)	29.0	94.0	1152	20.0	576
14	Kharizzama	3	D2(FC)	29.8	93.0	1728	12.0	864
15	Awliapur	1	D1(FC)	30.5	92.0	2188	15.5	1094
16	Awliapur	1	D2(FC)	30.5	92.0	2188	15.5	1094
17	Amkhul Hat	1	D1(FC)	28.4	95.0	1483	16.5	741
18	Amkhul Hat	1	D2(FC)	28.4	95.0	1209	17.5	604
19	Amkhul Hat	3	D1(FC)	33.5	88.0	3744	4.5	1872
20	Amkhul Hat	3	D2(FC)	35.0	86.5	2044	20.0	1022

1	2	3	4	5	6	7	8	9
21	Naluabagi Board	1	D1(FC)	28.7	94.5	2995	12.0	1497
22	Naluabagi Board	1	D2(FC)	38.5	82.3	1310	18.0	655
23	Naluabagi School	2	D1(FC)	30.0	83.0	1972	14.0	986
24	Naluabagi School	3	D1(FC)	34.0	87.8	576	18.0	288
25	Char Bholaishing	1	D1(FC)	30.0	92.7	3052	18.0	1526
26	Bashbaria (N-W)	1	D1(FC)	24.5	101.0	2520	20.0	1260
27	Chandpura (S)	1	D1(FC)	37.0	84.0	1670	20.0	885
28	Chandpura (S)	2	D2(FC)	31.4	91.0	1152	9.0	576
29	Chandpura (S)	3	D1(FC)	28.4	95.0	2505	20.0	1252
30	Chandpura (S)	3	D2(FC)	33.0	84.0	2016	9.0	1008
31	Gokkhali	1	D1(FC)	31.5	98.0	1800	20.0	900
32	Golkhali	2	D1(FC)	30.0	93.0	3528	20.0	1764
33	Golkhali	3	D1(FC)	28.0	95.5	2937	20.0	1468
34	North Badura	1	D3(FC)	30.0	91.0	1080	7.0	540
35	Patarchar	1	D1(FC)	28.0	96.0	3740	7.0	1870
36	Central Betagi	1	D2(FC)	37.5	83.5	576	18.0	288
37	East Jautha	1	D1(FC)	32.7	89.0	2448	14.0	1224
38	Kaylan Kalash(S)	1	D1(FC)	39.8	81.0	1224	20.0	612
39	Char Chandrail	1	D1(FC)	34.8	66.5	2016	10.0	1008
40	Nazmul Chatra	1	D1(FC)	30.6	92.0	1400	17.0	700

1	2	3	4	5	6	7	8	9
41	Pardakua (E)	1	D1(FC)	32.8	90.0	1580	5.0	790
42	Ulania (S-E)	1	D1(FC)	28.5	89.5	2850	6.0	1425
43	Ulania (S-E)	1	D3(FC)	27.0	100.0	3410	13.0	1705
44	Ulania (S-E)	1	D5(FC)	33.3	90.0	2995	14.0	1497
45	Gozalia Hat	1	D1(FC)	29.0	94.0	1952	19.0	976
46	Gozalia Hat	1	D2(FC)	36.6	84.4	979	16.0	489
47	Khalishakhali (C)	1	D1(FC)	38.0	83.0	1625	16.0	812
48	Khalishakhali(C)	1	D3(FC)	40.4	82.0	1700	11.0	850
49	Panpatty(N-W)	1	D1(FC)	35.5	88.0	1725	19.0	862
50	Char Kapalbara	1	D1(FC)	42.10	80.0	2980	12.0	1490
51	Char Montaz	1	D1(FC)	38.2	82.5	2188	18.0	1094
52	Rangabali	1	D1(FC)	28.2	95.2	1958	11.0	979
53	Panpatty Board	1	D1(FC)	34.8	86.7	400	20.0	200
54	Pantpatty Board	1	D2(FC)	31.20	91.0	748	11.0	374
55	Gohinkhali	1	D2(FC)	35.4	86.0	2552	15.0	1276
56	Haldia Khali	1	D2(FC)	35.0	86.4	1872	20.0	936
57	Chinabunia	1	D1(FC)	31.6	90.6	1972	16.0	986
58	Chinabunia	1	D2(FC)	37.4	83.5	993	15.0	496
59	Moudhubi	1	D3(FC)	35.9	82.0	705	20.0	352
60	Moudhubi	2	D3(FC)	34.2	88.0	805	17.0	402

1	2	3	4	5	6	7	8	9
61	Kachua Hat	1	D1(FC)	26.0	98.5	2304	11.8	1152
62	Katakhali	1	D1(FC)	31.5	90.5	2450	18.0	1225
63	Katakhali	1	D2(FC)	33.6	88.0	2592	12.0	1296
64	Alipur	1	D1(FC)	26.9	97.5	2278	19.0	1139
65	Golachipa	2	D1(FC)	35.4	85.5	950	19.0	475
66	Golachipa	2	D2(FC)	34.5	87.0	763	19.0	381
67	Golachipa	1	D1(FC)	30.8	91.5	1929	19.0	964
68	Mongalsuk	2	D1(FC)	37.2	83.4	864	20.0	432
69	Mongalsuk	2	D2(FC)	46.7	72.0	2260	18.0	1130
70	Fulbania	2	D1(FC)	34.2	88.0	2563	12.0	1281
71	Khaparbanga (N)	1	D1(FC)	30.4	92.3	705	12.0	352
72	Lalua Rahimuddin	1	D3(FC)	40.5	82.0	1035	13.0	517
73	Umedpur	1	D2(FC)	37.0	84.0	1840	18.0	920
74	Serajpur	1	D1(FC)	34.5	87.0	582	18.0	291
75	Serajpur	2	D2(FC)	44.0	72.0	864	16.0	432
76	Serajpur	3	D1(FC)	34.0	87.5	1296	19.0	648
77	Serajpur	3	D2(FC)	40.0	80.0	570	19.0	285
78	Teakhali(S)	1	D1(FC)	31.5	92.0	1440	20.0	720
79	Tongibaria	1	D1(FC)	32.0	90.0	1612	20.0	806
80	Musallibad	1	D1(FC)	26.5	98.0	763	18.5	381

1	2	3	4	5	6	7	8	9
81	Gazipur	1	D1(FC)	30.5	92.0	2563	19.0	1281
82	Sonakhali	1	D1(FC)	40.0	81.0	683	14.0	341
83	Londa Hafizuddin	1	D1(FC)	35.4	86.0	892	13.0	446
84	Patua Al-Amin	1	D2(FC)	37.0	89.0	979	15.0	489
85	Patua Al-Amin	1	D1(FC)	24.8	101.5	1843	14.0	921
86	Rupdhabandar	1	D2(FC)	36.4	85.0	1267	20.0	633
87	Taltali	1	D1(FC)	36.4	84.5	1627	15.0	813
88	Taltali	1	D3(FC)	39.0	81.7	1022	20.0	511
89	Amtali	1	D2(FC)	35.6	85.6	1238	18.0	619
90	Amtali	1	D4(FC)	36.4	84.6	734	15.0	367
91	Borguna	1	D1(FC)	26.6	97.7	1440	18.0	720
92	Borguna	1	D2(FC)	38.5	82.8	1540	15.0	770
93	Subidkhali	2	D2(FC)	33.0	92.0	2445	11.0	1222
94	Subid Khali	1	D1(FC)	31.0	93.0	2820	20.0	1410
95	Bauphal	1	D1(FC)	27.2	96.5	1997	19.0	998
96	Showla	1	D1(FC)	27.4	96.0	4075	15.0	2032
97	Showla	1	D2(FC)	38.0	93.0	1180	20.0	590
98	Devpur (N)	1	D1(FC)	36.2	95.0	1627	17.0	813
99	Shaheed Streeti	1	D1(FC)	26.8	94.5	2043	20.0	1021
100	Shaheed Sreeti	1	D2(FC)	30.0	92.7	1280	17.0	640

1	2	3	4	5	6	7	8	9
101	Devpur (N)	1	D2(FC)	38.6	82.0	1224	18.0	612
102	Bara Baliatali	1	D1(FC)	34.4	87.0	1641	20.0	820
103	Bara Baliatali	1	D2(FC)	36.4	84.6	1584	19.0	792
104	Shankhali	1	D1(FC)	31.6	90.5	2534	20.0	1267
105	Shankhali	1	D2(FC)	35.2	86.0	1433	18.0	716
106	Dhankhali (W)	1	D1(FC)	34.6	87.0	1440	20.0	720
107	Kalaya	1	D2(FC)	32.0	90.0	1840	17.0	920
108	Digree	1	D1(FC)	31.5	90.0	2504	20.0	1252
109	Digree	1	D3(FC)	33.0	89.0	871	19.0	436
110	Kalakhali	1	D1(FC)	34.0	88.0	2188	18.0	1094
111	Bolaibunia	1	D1(FC)	33.4	88.0	767	18.0	383
112	Bolaibunia	1	D2(FC)	34.0	87.0	1116	20.0	558
113	Charpara Pikepara	1	D1(FC)	33.7	87.0	1870	20.0	935
114	Charpara Pikepara	1	D2(FC)	28.5	95.0	691	7.5	345
115	Pashurbunia	1	D1(FC)	36.0	85.0	1296	9.5	648
116	Pashurbunia	1	D2(FC)	38.0	83.0	1431	10.0	716
117	Char Kazal (C)	1	D1(FC)	31.2	91.0	1004	12.0	802
118	Char Kazal	1	D3(FC)	37.8	83.0	894	13.0	447
119	Kazikanda	1	D1(FC)	32.0	90.0	2173	17.0	1086
120	Char Momtaz	1	D1(FC)	27.0	97.0	2335	7.5	1157

1	2	3	4	5	6	7	8	9
121	Ahmedpur	1	D1(FC)	28.0	95.0	2407	5.5	1203
122	Ahmedpur	1	D2(FC)	27.3	95.0	1777	5.0	888
123	Char Subi	1	D1(FC)	50.0	88.5	2304	9.5	1152
124	Bagerhawla	1	D1(FC)	32.6	89.0	1728	12.0	864
125	Dasherhat	1	D1(FC)	34.4	88.0	1744	15.0	872
126	Dhumky	1	D2(FC)	34.0	87.0	2205	11.0	1102
127	Guptagong	1	D1(FC)	32.6	89.0	1956	11.0	978
128	Shahbazpur	1	D1(FC)	20.0	108.0	2797	12.0	1398
129	Bankerhat	1	D1(FC)	31.8	90.0	1627	13.0	813
130	Hazirhat	1	D1(FC)	30.0	93.0	1518	9.5	759
131	Kukrimukri	1	D1(FC)	32.6	89.0	2087	9.0	1043
132	Pathargata	1	U1(SS)	38.1	84.2	840	16.0	420
133	Pathargata	1	U2(SS)	34.0	84.5	620	16.0	310
134	Pathargata	1	U3(SS)	39.4	82.5	740	18.0	370
135	Pathargata	2	U1(SS)	35.6	87.5	620	14.0	310
136	Pathargata	2	U2(SS)	39.7	84.0	640	20.0	320
137	Pathargata	2	U8(SS)	37.1	86.3	980	20.0	490
138	Pathargata	3	U1(SS)	51.7	70.1	520	20.0	260
139	Pathergata	3	U2(SS)	37.2	84.1	884	7.0	442
140	Betagi	1	U1(SS)	47.60	68.6	1336	20.0	666
141	Betagi	1	U2(SS)	33.7	90.6	3746	13.0	1873

D. TEST ZONE: KHULNA

1	2	3	4	5	6	7	8	9
1	Hard Metal Gallery (Town)	1	D2(FC)	25.0	100.0	1643	5.0	821
2	Hard Metal Gallery (Town)	1	D7(FC)	27.0	97.0	2754	8.0	1377
3	Hard Metal Gallery (Town)	1	D9(FC)	31.0	92.0	2131	14.0	1065
4	Sheikpara	1	U1(FC)	38.7	91.0	1766	26.6	883
5	Sheikpara	1	U1(FC)	36.3	85.0	1271	20.0	635
6	Sheikpara	2	U1(FC)	37.0	83.0	1810	14.0	905
7	Sheikpara	3	U0(FC)	38.8	83.0	2283	8.0	1141
8	Sheikpara	3	U1(FC)	34.5	87.0	1022	19.0	511
9	Sheikpara	4	U1(FC)	38.6	82.0	673	20.0	336
10	Sheikpara	4	U4(FC)	38.0	83.0	1047	20.0	523
11	Khan Jahan Ali Road, KDA Plot	1	D3(FC)	58.6	80.0	1206	11.0	603
12	Khan Jahan Ali Road, KDA Plot	1	D5(FC)	43.3	78.0	930	17.0	465
13	Khan Jahan Ali Road, KDA Plot	2	D1(FC)	31.9	90.0	2305	15.0	1152
14	Khan Jahan Ali Road, KDA Plot	2	D5(FC)	37.3	84.0	1084	20.0	542
15	Khan Jahan Ali Road, (KDA Plot)	1	D2(FC)	36.8	84.0	1276	9.0	638

1	2	3	4	5	6	7	8	9
16	Khan Jahan Ali Road (KDA Plot)	1	D5(FC)	40.0	81.0	673	20.0	336
17	Khan Jahan Ali Road (KDA Plot)	2	D2(FC)	35.6	87.0	1795	20.0	897
18	Khan Jahan Ali Road (KDA Plot)	3	D2(FC)	35.5	86.5	1794	20.0	897
19	Khan Jahan Ali Road (KDA Plot)	3	D5(FC)	41.0	82.0	1452	19.0	726
20	Khalishpur	1	U1(FC)	36.3	-	1373	11.0	686
21	Khalishpur	1	U2(FC)	26.7	-	1545	13.0	772
22	Khalishpur	2	U0(FC)	26.1	-	4067	7.5	2033
23	Khalishpur	3	U0(FC)	27.4	-	1999	7.0	999
24	Khalishpur	3	U1(FC)	32.1	-	1962	20.0	981
25	Khalishpur	4	U1(FC)	29.5	-	2815	14.0	1407
26	Paikgacha	3	U2(FC)	35.5	84.5	698	17.0	349
27	Paikgacha	4	U3(FC)	37.43	83.5	1391	15.0	695
28	Paikgacha	6	U2(FC)	32.6	86.5	1232	15.0	616
29	Khulna Town (PWB's Building)	1	U1(FC)	36.0	85.0	1495	17.0	747
30	Khulna Town (PWB's Building)	1	U2(FC)	33.7	89.0	1122	20.0	561
31	Khulna Town	1	U4(FC)	30.0	93.0	2730	20.0	1365
32	Khulna Town	1	U0(FC)	24.0	162.0	3384	19.0	1692
33	Khulna Town	1	U2(FC)	30.0	90.0	2880	20.0	1440

1	2	3	4	5	6	7	8	9
34	Khulna Town	1	U6(FC)	38.0	83.0	897	20.0	448
35	Khulna Town (PWB's Building)	2	U0(FC)	27.0	97.0	2576	19.0	1288
36	"	3	U1(FC)	36.0	85.0	1495	17.0	747
37	"	3	U3(FC)	33.7	89.0	1122	20.0	561
38	"	3	U4(FC)	30.0	93.0	2730	20.0	1365
39	Khulna Town (PWB's Building)	4	U5(FC)	38.4	83.0	996	17.0	498
40	Khulna Town	5	U1(FC)	33.0	89.0	2453	14.0	1226
41	Khulna Town	5	U3(FC)	35.0	85.0	2039	11.0	1019
42	Goalpara (PDB Hostel)	1	U3(FC)	37.5	83.0	935	13.0	467
43	Goalpara	1	U6(FC)	27.0	97.0	4487	9.5	2243
44	Goalpara	2	U6(FC)	41.0	80.0	804	14.0	402
45	Goalpara	3	U0(FC)	26.0	98.5	3216	20.0	1608
46	Goalpara	3	U2(FC)	27.5	96.0	3861	14.0	1930
47	Ferryghat	1	U0(FC)	29.6	94.0	844	14.0	422
48	Ferryghat	1	U3(FC)	34.5	86.5	2031	18.0	1015
49	Ferryghat	2	U3(FC)	33.6	89.0	1623	11.0	811
50	Ferryghat	3	U3(FC	31.0	92.0	2671	16.0	1335
51	Ferryghat	3	U5(FC)	36.6	85.0	1271	20.0	635

1	2	3	4	5	6	7	8	9
52	Bashabari	1	U1(FC)	33.0	89.0	1872	11.0	936
53	Bashabari	3	U2(FC)	40.5	60.0	864	20.0	432
54	Mangla	2	U2(FC)	42.3	79.0	622	18.0	311
55	Mangla	2	U4(FC)	40.2	81.0	774	8.0	387
56	Mangla	2	U7(FC)	42.8	78.0	1139	17.0	569
57	Jessore Road	1	U0(FC)	29.6	94.0	844	14.0	422
58	Jessore Road	1	U3(FC)	34.5	86.5	2031	18.0	1015
59	Jessore Road	2	U3(FC)	33.6	89.0	1623	11.0	811
60	Jessore Road	2	U5(FC)	47.0	90.0	1138	13.0	569
61	Jessore Road	3	U3(FC)	31.0	92.0	2671	16.0	1335
62	Jessore Road	3	U5(FC)	36.6	85.0	1271	20.0	635
63	Power Station Goalpara	1	U1(FC)	29.5	94.0	2084	19.0	1042
64	"	1	U3(FC)	26.0	99.0	5418	5.0	2709
65	Goalpara	2	U1(FC)	38.3	84.0	1136	10.0	568
66	Goalpara	2	U3(FC)	44.0	78.0	1272	15.0	636
67	Bagerhat (PDB Tower 1)	1	U1(FC)	37.0	84.0	2188	17.0	1094
68	Bagerhat (PDB Tower 8)	1	U1(FC)	43.2	73.0	921	13.0	460
69	Bagerhat (PDB Tower 9)	1	U1(FC)	36.4	84.6	1396	18.0	698
70	Bagerhat (PDB Tower 13)	1	U1(FC)	40.5	60.2	792	18.0	396

1	2	3	4	5	6	7	8	9
71	Bagerhat (PDB Tower 14)	1	U1(FC)	32.4	89.6	1425	20.0	712
72	Mangla (PDB Tower 25)	1	U1(FC)	33.0	89.0	1785	15.0	892
73	Mangla (PDB Tower 32)	1	U1(FC)	34.0	88.5	597	20.0	298
74	Mangla (PDB Tower 35)	1	U1(FC)	29.2	93.5	1454	11.0	727
75	PDB Tower 54	1	U1(FC)	31.2	91.0	1684	20.0	842
76	PDB Tower 61	1	U1(FC)	44.0	76.0	951	12.0	475
77	PDB Tower 67	1	U1(FC)	28.6	94.7	2763	16.0	1381
78	PDB Tower 71	1	U1(FC)	36.0	85.0	2304	14.0	1152
79	PDB Tower 74	1	U1(FC)	41.5	78.0	2840	10.0	1420
80	PDB Tower 79	1	U2(FC)	40.0	81.0	905	13.0	452
81	Shiromoni	1	U1(SS)	35.2	78.1	680	13.0	340
82	Shiromoni	2	U1(SS)	37.0	77.1	560	20.0	280

APPENDIX-E

TRIAXIAL COMPRESSION TEST RESULTS

A. TEST ZONE: BARISAL

Sl. No.	Location	Bore hole No.	Sample No.	Initial moisture content	Initial dry density	Lateral stress psf	Strain at failure %	Applied stress psf	Cohesion psf	Angle of internal friction Ø
1	2	3	4	5	6	7	8	9	10	11
1	Monohorpur	2	U2(HR)	42.4	79.9	720	18	1466	446	0°
				42.1	78.2	1440	19	2107		
				41.3	80.2	2880	20	4041		
2	Kachikata	1	U2(HR)	31.3	91.0	720	6	2913	461	23°
				30.5	92.0	1440	13	5898		
				30.5	92.0	2880	20	7920		
3	Kachikata	2	U4(HR)	30.93	91.3	1152	6	4608	288	30°
				30.55	92.2	1656	8	6112		
				31.06	90.8	3312	11	11163		
4	Amanatganj	1	U2(HR)	36.99	81.3	720	16	2830	432	21.9°
				36.95	81.0	1440	20	6019		
				38.30	81.3	2680	16	7535		
5	Amanatganj	6	U5(HR)	33.13	85.7	1440	18	6255	720	29°
				33.4	85.7	2880	14	11059		
				32.8	85.7	5760	7	18754		

1	2	3	4	5	6	7	8	9	10	11
6	Banaripara	2	U2(FC)	49.7	70.0	1440	19	2088	288	4^{o}
				50.0	70.0	2880	20	3772		
				49.7	70.0	4320	20	5472		
7	Banaripara	4	U1(FC)	39.8	81.0	1440	19	2333	360	4^{o}
				40.3	81.0	2880	19	4046		
				40.7	80.0	4320	19	5775		
8	Banaripara	5	U1(FC)	30.6	92.0	1440	19	2909	576	5^{o}
				30.6	92.0	2880	19	4868		
				30.4	92.0	4320	19	6595		

b. TEST ZONE: BHOLA

1	2	3	4	5	6	7	8	9	10	11
1	Madras (N)	2	U0(FC)	30.0	95.5	720	16	2475	1135	3^{o}
				30.9	93.0	1440	19	2385		
				30.0	93.5	2880	20			
2	Awazpur (W)	1	U3(FC)	32.8	89.0	1440	10	4060	890	33.8^{o}
				32.0	90.1	2160	12	8640		
				30.8	91.5	2880	11	10800		
3	Omrabag	1	U1(FC)	25.9	102.0	1440	18	2160	432	16^{o}
				25.7	101.8	2880	16	3312		
				25.4	102.0	4320	19	4363		
4	Aslampur	1	U0(FC)	28.5	97.0	1440	8	5823	576	36^{o}
				28.6	96.0	2592	6	9504		
				29.0	98.0	4310	8	14400		
5	Char Umed(E)	1	U0(FC)	29.4	97.0	1440	17	2980	864	12^{o}
				29.1	98.0	2880	15	3794		
				29.1	97.0	4320	14	4766		
6	Chandipur (N)	2	U0(FC)	32.6	93.0	1440	17	2347	720	10^{o}
				30.9	93.0	2880	18	2908		
				31.7	93.5	4320	15	3888		
7	Char Faijuddin	1	UI(FC)	31.9	92.0	1440	17	2649	1008	5^{o}
				32.2	92.0	2880	18	3017		
				32.6	91.5	4320	16	3305		

1	2	3	4	5	6	7	8	9	10	11
8	Andirhat	1	U1(FC)	32.2 32.5 32.5	92.0 92.5 92.8	1440 2880 4320	18 17 17	2527 3264 3987	864	9.5°
9	Andirhat	1	U3(FC)	31.3 32.4 33.0	94.5 93.2 98.5	1440 2880 4320	16 17 18	1955 2165 2320	864	3°
10	Char Mohazon Kandi	1	U1(FC)	29.7 29.9 30.8	95.5 95.0 93.5	1440 2880 4320	18 16 19	2880 3542 4068	892	10°
11	West Madua	1	U1(FC)	26.0 27.0 25.8	100.5 100.0 101.2	1440 2880 4320	17 20 16	3730 4852 5860	1152	13°
12	Char Pata (E)	2	U1(FC)	32.8 32.1 31.5	91.6 90.0 92.6	720 1440 2880	19 18 19	2545 3245 4003	790	15°

C. TEST ZONE: PATUAKHALI

1	2	3	4	5	6	7	8	9	10	11
1	Kaylan Kalash(N)	2	U1(FC)	34.0	88.2	1440	20	2160	520	12.5°
				34.0	87.5	2880	18	3240		
				33.3	88.5	4320	20	3744		
2	Golachipa	1	U1(FC)	29.4	95.2	1440	10	2880	1296	2°
				29.3	96.6	2880	18	3017		
				30.1	95.0	5760	16	3229		
3	Kharizzama	1	U2(FC)	31.3	93.0	1440	16	2592	548	14.5°
				30.3	93.5	2880	14	4017		
				30.9	93.3	4320	15	4752		
4	Amkhola (N)	1	U1(FC)	38.6	82.0	720	16	673	260	4°
				37.8	81.5	1440	20	778		
				37.6	82.7	2880	20	950		
5	East Jautha	1	U0(FC)	29.9	94.2	1440	18	2826	1267	2°
				30.7	94.2	2880	17	3031		
				30.8	94.0	5760	15	3332		
6	Pardakua (E)	1	U3(FC)	36.5	85.0	1440	14	2880	490	20°
				34.6	85.5	2880	17	4565		
				32.3	88.7	4320	16	5915		
7	Goaalia Hat	1	U1(FC)	31.7	92.0	1440	16	2592	1038	4°
				31.0	92.5	2880	18	2973		
				32.2	91.6	4320	17	3243		
8	Fulbunia	1	U1(FC)	37.8	88.0	2044	17	3369	172	26°
				32.0	85.0	2880	16	3758		
				34.0	89.0	4320	18	7156		

1	2	3	4	5	6	7	8	9	10	11
9	Lalua Rahimuddin	1	U1(FC)	39.2	80.5	720	16	630	220	8°
				38.7	81.0	1440	19	880		
				30.7	90.5	2880	20	1320		
10	Umedpur	1	U1(FC)	37.3	88.5	720	14	680	935	17°
				30.8	91.5	1440	16	3730		
				31.3	89.5	2880	18	5080		
11	Nizampur	1	U1(FC)	36.0	84.0	1440	20	2376	432	20°
				32.2	84.2	2880	20	4176		
				29.2	82.2	4320	12	4320		
12	Anipara	1	U1(FC)	32.6	91.2	1440	16	2376	922	5°
				32.6	91.9	2880	18	2743		
				32.3	91.8	4320	17	3038		
13	Akkelpur	1	U1(FC)	34.1	85.5	1440	14	3384	432	23°
				29.6	87.0	2880	20	5328		
				29.2	87.5	4320	20	7300		
14	Gazipur	1	U2(FC)	38.0	80.5	1440	14	3192	1152	21°
				36.8	80.5	2880	14	6575		
				33.4	85.0	4320	16	8286		
15	Patua Al-Amin	1	U0(FC)	34.7	95.5	720	15	2736	1180	4.5°
				29.3	95.5	1440	18	2908		
				30.3	95.5	2880	16	3117		
16	Gauphal	1	U2(FC)	29.1	96.0	1440	19	4052	1512	15°
				29.4	95.5	2880	16	5860		
				29.9	94.5	5760	18	8064		

D. TEST ZONE: KHULNA

1	2	3	4	5	6	7	8	9	10	11
1	Balitha	1	U2(HR)	67.0	60.5	144	11	547	72	26°
				64.0	62.2	288	12	965		
				68.7	58.7	504	15	1469		
2	Balitha	1	U4(HR)	33.8	87.7	1008	7	3840	-	37°
				34.5	87.5	756	6	3286		
				35.8	86.0	1188	7	6192		
3	Balitha	2	U4(HR)	36.6	84.6	1440	18	2884	76	5.5°
				35.9	85.5	2880	20	4738		
				37.1	84.7	5760	21	8107		
4	Sankra	2	U2(HR)	32.0	89.8	994	-	652	144	26°
				32.1	89.0	1988	-	1058		
				31.0	92.0	3976	-	2030		
5	Sankra	3	U2(HR)	29.4	92.3	994	-	608	320	22.5°
				28.6	93.3	1988	-	943		
				31.7	88.5	3976	-	1886		
6	Khalishpur	1	U2(FC)	26.7	-	720	11	2304	864	13°
				25.5	-	1440	11	2808		
				26.7	-	2880	11	2088		

1	2.	3	4	5	6	7	8	9	10	11
7	Mangla	2	U2(FC)	42.5	79.0	720	14	1826	550	11°
				42.4	79.0	1440	13	2026		
				42.5	79.0	2880	13	2636		
8	Khulna Town	1	U1(FC)	31.3	91.0	1440	19	2227	432	6°
				30.8	90.0	2880	18	2652		
				31.7	90.0	4320	18	2809		
9	Khulna Town	2	U2(FC)	34.4	88.0	1440	20	1152	250	5°
				34.6	89.0	2880	20	1428		
				34.7	88.0	4320	20	1735		
10	Khulna Town	3	U3(FC)	39.6	86.0	1440	19	1063	425	4°
				36.2	86.0	2880	18	2023		
				37.1	86.0	4320	19	2365		

E. TEST ZONE: NOAKHALI

1	2	3	4	5	6	7	8	9	10	11
1	Bashkhali	1	U2(HR)	35.10	88.0	1440	14	7891	1512	10.5°
				35.40	86.4	2880	14	12984		
				33.40	88.0	5760	14	18230		
2	Char Hazari	1	U4(HR)	32.99	87.4	1440	19	3258	144	20°
				37.07	89.8	2880	9	6342		
				37.20	85.2	4320	14	12850		
3	Char Hazari	2	U5(HR)	34.82	86.5	1440	12	3865	158	23°
				29.96	89.3	2880	12	7258		
				30.02	89.0	4320	12	12537		
4	Char Hazari	3	U5(HR)	35.17	85.6	1440	9	4369	288	24.5°
				38.47	88.8	2880	10	7230		
				26.87	92.2	4320	9	11328		

APPENDIX-F

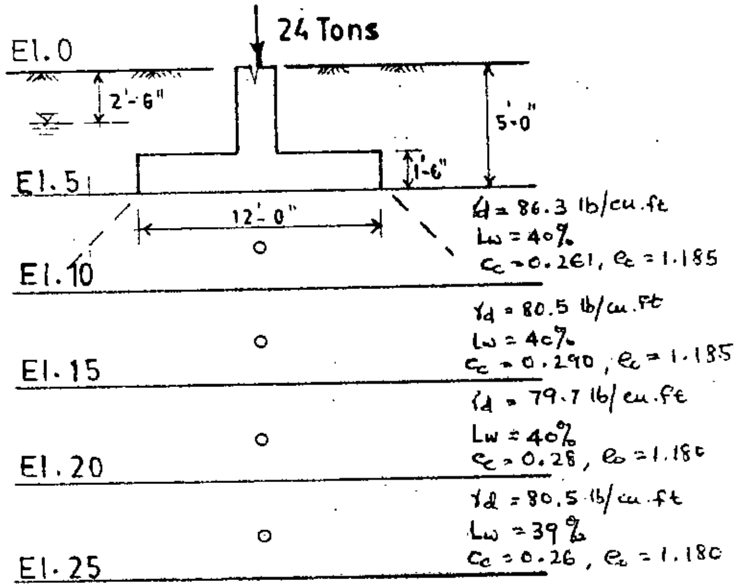
COMPUTATIONS OF SETTLEMENT

A. FOOTING FOUNDATION

Locations: Amanatganj, Barisal Town

Type of structure: A 4 storey Building supported on footings.

q_d = 0.21 T/sq.ft



$$A = \frac{24}{0.21} = 114.28 \text{ sq.ft}$$

Assume 12'x10' rectangular footing

Equivalent load $\frac{24}{120} = 0.20$ Tons/sq.ft

Computations for values of P_o:

(2.5)(86.3 = 215.75 lb/cu.ft.

(7.5)(120-86.3)= 252.75 lb/cu.ft.

= 468.50 lb/cu.ft at El.10

5(120-80.5) = 197.5 lb/cu.ft

= 666.00 lb/cu.ft at El.15

.5(120-79.7) = 201.50 lb/cu.ft

= 867.5 lb/cu.ft at El.20

5(120-80.5) = 197.5 lb/cu.ft

= 1065.0 lb/cu.ft at EL.25

Computations for values of Δ_p: $\tan 30^{o} = 0.58$

At El.7.5, $A = \left[12+2(2.5)\tan 30^{o}\right]\left[10+2(2.5)\tan 30^{o}\right]$

$= (14.9)(12.9)$ sq. ft.

$$\Delta_p \text{ at El.7.5} = \frac{0.20\times120}{(14.9)(12.9)} = 0.124 \text{ Tons/sq. ft.}$$

At El. 12.5, $\Delta_p = \dfrac{0.20\times120}{387.09} = 0.062$ Tons/sq. ft.

At El.17.5, $\Delta_p = \dfrac{0.20\times120}{649.25} = 0.037$ Tons/sq. ft.

At El.22.5, $\Delta_p = \dfrac{0.20\times120}{978.70} = 0.0245$ Tons/sq. ft.

Settlement computations:

El.0 to El.10, $S = \dfrac{0.261}{1+0.97}(10\times12)\log_{10}\dfrac{0.213+0.124}{0.213}$

$= 3.15"$

El.10 to El.15, $S = \dfrac{0.290}{1+1.185}(5\times12)\log_{10}\dfrac{0.3027+0.062}{0.3027}$

$= 0.63"$

El.15 to El.20, $S = 0.286$

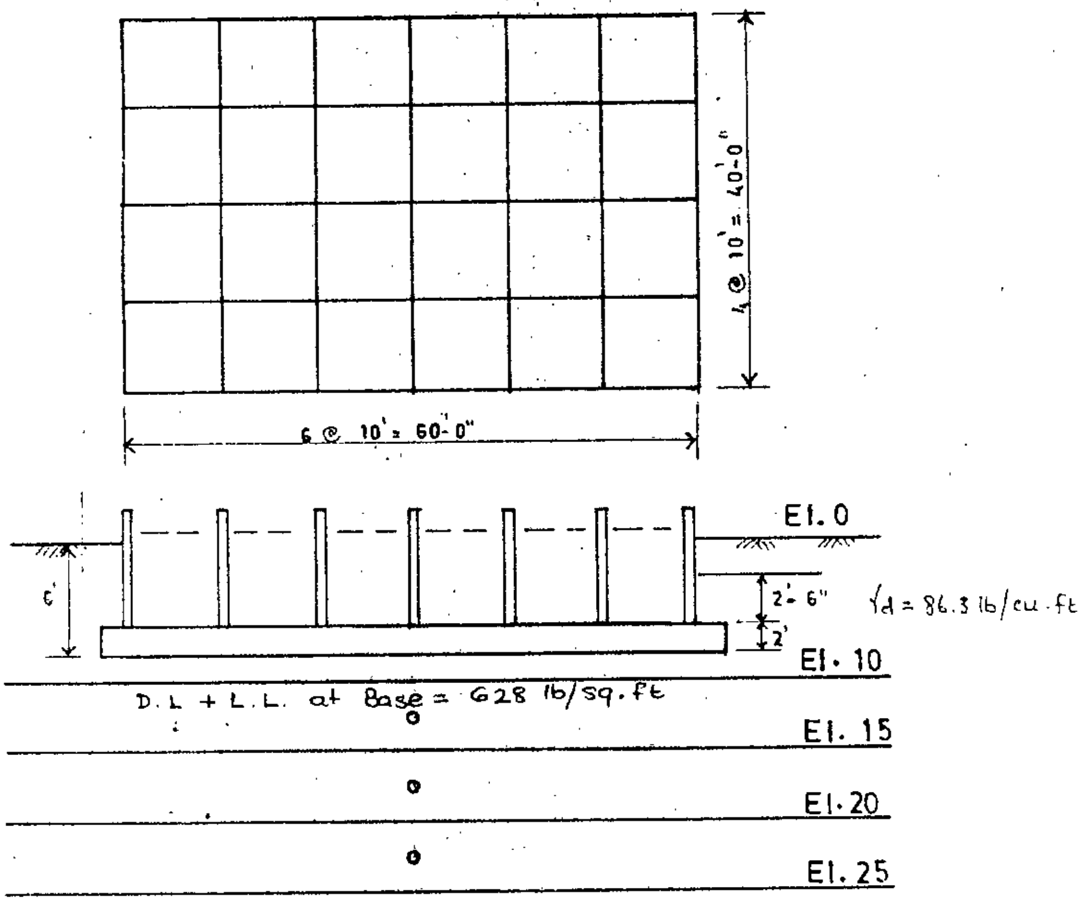
El.20 to El.25 , $S = 0.164"$

Total settlement: 4.23"

Note:

The structure is safe against bearing capacity but unsafe against settlement.

B. RAFT FOUNDATION



Computation for values of P_o at mid-depth of clay:

(2.5)(86.3)	= 215.75	lb/cu.ft
(7.5)(120-86.3)	= 252.75	"
5(120-80.5)	= 197.50	"
5(120-79.7)	= 201.50	"
5(120-80.5)	= 197.50	"
	= 1065.0	lb/cu.ft.

Net load at base of Raft:

D.L + L.L = 628 lb/sq. ft

Soil removed (silty clay) = 6x86.3 = 517 lb/sq.ft

Net pressure: 111 lb/sq.ft

Equivalent load = $\frac{111.0}{22000}$ = 0.050 Tons/sq.ft.

Computations for values of Δ_p:

$$A = \left[60+2(2.5)(0.58)\right]\left[(40+2(2.5)(0.58)\right]$$

At El. 7.5, $\Delta_p \; \frac{0.050\times(60\times40)}{2698} = 0.044$ Tons/sq.ft.

At El. 12.5, $\Delta_p = 0.0358$ Tons/sq.ft.

At El. 17.5, $\Delta_p = 0.0247$ Tons/sq.ft.

Computation of settlement :

El.0 to El.10.0, $S = \frac{0.261}{1+0.97}\,(10 \times 12)\,\log_{10}\frac{0.213+0.044}{0.213}$

$= 1.27''$

El.10 to El.15.0, $S = 0.38''$

El.15 to El.20.0, $S = 0.23''$

El.20 to El.25.0, $S = 0.17''$

Total settlement = 2.05"

Note:

Depth of excavation be increased to minimise the settlement to its tolerable limit.

Computation of Settlement for

FOOTING FOUNDATION

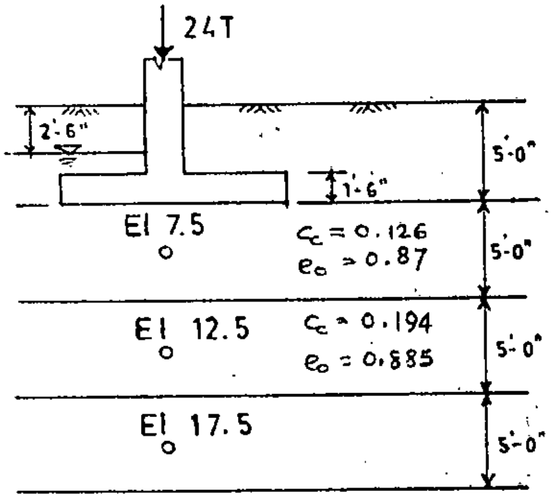
Location: BHOLA TOWN

Type of soil: Medium soft clay soil

Type of structure: 4 storey Building

Column load = 24 Tons

Bearing capacity: 0.95 Tons/sq.ft.



Footing area = $\frac{24}{0.95}$ = 25.26 sq.ft

Try 6'x5' = 30 sq.ft

Equivalent load = $\frac{24}{30}$ = 0.8 Ton/sq.ft

Computation for P_o: See earlier calculation.

Computation for values of Δ_p:

At El.7.5, $A = [6+2(2.5)(0.58)]\,[5+(2.5)(0.58)]$

$= 70.31$ sq.ft

$$\Delta_p = \frac{0.8 \times 30}{70.31} = 0.341 \text{ Tons/sq.ft.}$$

At El.12.5 A = 201.39 sq.ft.

Δ_p = 0.19 Ton/sq.ft.

At El.17.5 A = 399.75 sq.ft

Δ_p = 0.006 Ton/sq.ft.

Computation of Settlement:

$$El.0 \text{ to } El.10, \quad S = \frac{0.126}{1+0.87} \times (10\times12)\ \log_{10} \frac{0.213+0.341}{0.213}$$

$$= 3.34''$$

El.10 to El.15, $S = 0.876''$

El.15 to El.20, $S = 0.043''$

Total settlement $S = 4.26''$