CHARACTERIZATION OF KHULNA SUBSOIL AND SETTLEMENT RESPONSE OF THIS SOIL IMPROVED BY GRANULAR FILLS

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Characterization of Khulan Subsoil and Settlement Response of This Soil Improved by Granular Fills

by

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Declaration

This is to certify that this project work entitled ***"Characterization of Khulan Subsoil and Settlement Response of This Soil Improved by Granular Fills"*** has been carried out by Md. Shamsul Alam in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh. The above research work or any part of this work has not been submitted for the award of any degree or diploma.

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Md. Shamsul Alam
December 2012

Dedication
To
My Respected Parents &
Teachers

ABSTRACT

The study area, Khulna City Corporation (KCC) is one of the important urban areas in the South –West part of Bangladesh. In the present study the whole KCC area was subdivided into three zones: North, Middle and South. In the North Zone (Afilgate, Shiromoni, Fulbarigate, Mohesshorpasha, etc) it is found that the soil layers between 0 – 12 m from EGL are mostly clayey silt. In this stratum there exists an organic clay layer with the variation of 3 m to 6 m depth in most of the locations. The soil layers between the depth of 12 m to 18 m at the northeast part of the North zone, which is near Bhairab river, contain predominantly sand, while in the areas namely Fulbarigate, KUET campus the soil at this depth contains predominantly silt.

In the middle zone (Khalishpur, Daulatpur, Boyra, Mujgunni, etc.) it is found that the sub-soil in the western side contains an organic layer of 3m to 4.5 m thickness starting from about 1.5m to 3m depth to downward. Below this depth the soil consists of predominantly silt up to about 18 m depth. In the eastern side of this zone the soil contains predominantly silt up to about 6m to 7.5m depth. Below this depth the soil contains mainly fine sand.

In the South zone (Sonadanga, Nirala, Gollamari, Sheikhpara, West side of Rupsha, Khulna University, etc) the sub-soil contains organic clay up to about 3m to 4.5m depth from EGL. Below this level the soil mainly consists of silt with small portion of clay and organic matters up to about 18 m depth from EGL.

From the model test it was found that the load carrying capacity of soft soil can be increased significantly by adopting ground improvement technique with filling sand under foundations. The rate of settlement of the test footing on untreated ground increased substantially after the settlement of the ground exceeds 20mm. It is also evident that the load bearing capacity of treated grounds do not depend on the depth of filling only but also on the width of granular fills. From the experiment, it was seen that the load bearing capacity was increased by replacement of soft soil with granular materials (sand) at the bottom of the foundation up to 1.95 times than that of untreated soil. The load bearing capacity of treated soil was significantly increased with the increase of depth of sand filling under foundation.

The bearing capacity was increased by 30%, 72% and 85% with the increase of filling depth by 1.0, 1.5 and 2 times the width of foundation respectively when area of foundation is equal to area of sand filling. For the granular fills of depth 150 mm(D_s=1B_f), the degrees of improvement were found as 30%, 56% and 59% higher than that of untreated condition when width of filling were 1B_f, 2B_f and 3B_f respectively. So, it was exhibited that for constant depth ((D_s=1B_f) of compacted sand, bearing capacity was increased significantly up to the width of sand filling equal to twice the width of foundation.

In case of sand fills of depth 225 mm (D_s=1.5B_f),, the degrees of improvement were found as 72%, 79% and 81% higher than that of untreated condition when width of filling were 1B_f, 2.5B_f and 4B_f respectively. From this it is observed that for constant depth (D_s=1.5B_f) of compacted sand, bearing capacity was increased significantly up to the width of sand filling equal to 2.5 times the width of foundation.

When the depth of granular fills was increased up to 300 mm (D_s=2B_f), the degrees of improvement were observed as 85%, 92% and 95% higher than that of untreated condition when width of filling were 1B_f, 3B_f and 5B_f respectively. it is observed from this result that for constant depth ((D_s=2B_f) of compacted sand, bearing capacity was increased significantly up to the width of sand filling equal to 3 times the width of foundation.

Contents

CHAPTER III Sub Soil Characterization

CHAPTER IV Laboratory Investigations and Improvement Technique

CHAPTER V Results and Discussions

CHAPTER VI Conclusions and Recommendations

LIST OF TABLES

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

Nomenclatures

ω_n	Natural water content
W_l	Liquid limit
W_p	Plastic limit
PI	Plasticity Index
q_u	Unconfined compression strength
N	Standard Penetration Test Number
f	Correlation factor
e_o	Initial void ratio
Cc	Compression Index
Cv	Coefficient of consolidation
w	Natural Moisture content
σ'	Maximum pre-consolidation pressure
σ'_o	Effective pressure
Gs	Specific gravity
S	Degree of saturation

Nomenclatures

OC	Organic matter content
c	Cohesion
Ø	Angle of internal friction
c_α	Coefficient of secondary compression
cu	Undrained cohesion
εf	Percent of strain at failure
γd	Dry density
Dr	Relative density
Kgp	Geopier stiffness modulus
kp	Stiffness of pile group
kc	Stiffness of raft
αcp	Average interaction coefficient between pile and raft
kf	Stiffness of pile raft
p_r	Load carried by raft
p_p	Load carried by pile group
λ	Pile stiffness ratio
υ	Poisson's stiffness ratio
ξ	Ratio of end bearing
ρ	Soil modulus
ζ	Radius of influence of file

CHAPTER I

Introduction

1.1 General

The Khulna City Corporation (KCC) area standing on the bank of Bhairab and Rupsha river occupies most of the northern part of the world's largest mangrove Sundarban forest. It is believed that once upon a time Sundarban forest was extended up to the KCC area. In course of time, sedimentation and decomposition of wood and plant had contributed to build up organic soft clay deposit in the KCC area, (Morgan and Mclntire ,1959).

Presently, 43.0 sqkm KCC area comprises the central part of Khulna Divisional City. Due to excellent communication, its current population of 1.22 million is increasing by leaps and bounds (Bangladesh Bureau of Statistics, 2001). To meet the demand of these peoples, more industrial, commercial buildings, hospitals, universities, colleges, schools and housing facilities are being built up rapidly. Moreover, in order to maximize the benefit from important city area, tall buildings with or without basement for commercial purposes and residential buildings are gaining popularity.

Soft ground creates problems for the construction of foundation of any structure such as building, roads and highways, railways, airfields, embankments, dams, storage tanks(Silos/Bunkers), car parks etc due to its very low shear strength and high compressibility. The valuable structures are sometimes collapsed due to excessive total and differential settlement of the structures while constructed on the soft ground without adopting any soil improvement method. The unconfined compression strength q_u and SPT- N value are the indication of softness of ground under study area. The main foundation problems for infrastructure construction are the presence of thick deposits of soft clay which will consolidate and cause large settlements when loaded. The load may be in the form of engineering structures causing compression in the clay or in the form of piezometric drawdown due to the withdrawal of ground water for water supply. In this study area, the rare one is not sever.

Erratic soft subsoil deposits and presence of organic layer in Khulna city area pose potential challenge to the design and construction of foundation for building structures within the area. Therefore, it is essential to develop a general understanding of the characteristic of the subsoil formation of this study area. So an attempt was taken to produce general information about the subsoil of the study area depending on data received from the field and laboratory tests. Options of improving the soft ground are important aspects of this study. A very few and limited research on generalization of geotechnical properties of Khulna area subsoil have been conducted so far. So a generalized information about the subsoil of this study area is formulated under this study for better information of the aforesaid subsoil which may be helpful for designers and other beneficiaries concerned. The technique of improving soft ground particularly for low to medium rise building is also an important goal of this study. In this study, laboratory works have been conducted on a soft ground prepared with the soil in a cubic steel box for various improvement conditions.

1.2 Geology of the Study Area

The study area is crossed by parallel south- southwest distributor channels. The ground water lies either at the surface or at about 1.00 m below the existing ground level during rainy season and dry season, respectively. Historically stable delta front and presence of artifacts found below water table (Morgan and Mclntire, 1959) suggest that large areas of the middle and lower delta area are subsiding. According to the study of Morgan and Mclntire (1959), Bangladesh was filled with sediments of Tertiary to Quaternary age and recent flood plain and piedmont alluvium, which occupies roughly seventy percent of the total land area of Bangladesh. Moreover, the sediments of Bangladesh are divided into two major tectonic units, the Precambrian platform in the northeast and the Bengal Fore deep in the southeast separated by Kolkata-Mymensingh Hinge Line. The thickness of the sedimentary cover on the basement is increasing towards southeast and the area affects by the settlement due to consolidation of the sediments (Siddique et al., 2002). Soft soil in this area is mainly available in alluvial flood plain deposits, depression deposits and tidal plain deposits. The soft soil is comprised of unconsolidated to normally consolidated clays and silt containing organic materials. The alluvial flood plain deposit consists of silts or clay silts. Fine sand with mica abounds at greater depth. The depression deposits contain organic clay overlying inorganic clay at depth and estuarine and tidal flood plain deposits are silt and silty clay; organic soils close to the surface in some places (Siddique et al., 2002). The average elevation is +2.75 m with respect to the mean sea level (Khulna Master Plan, 2001) and the land gradient is approximately 1.0 meter per 20 kilometers (Alam et al., 1990).

1.3 Background of the Present Research

Khulna area especially KCC and its adjacent areas are being developed keeping pace to the urbanization. Generally it is known that the soil of Khulna region is very soft up to a greater depth. There is not enough available data or information on soil properties of Khulna city area in a formulated way from which one can get a preliminary idea about the soil of study area. The generalization geotechnical properties, i.e. soil profile of the study areas is important requirements for the designers, information seekers and the all concerns who want to have a clear idea about the subsoil of this region, when need for analysis for shallow as well as deep foundations. Though the KCC area is one of the oldest developed areas of Khulna district, only a few geotechnical field and laboratory test data of this area are currently available. These are not adequate for generalized geotechnical properties of the subsoil within the study area. Moreover, lack of proper understanding of the foundation system may lead to foundation failure of several buildings in the area. Therefore, it is essential to determine a systematic geotechnical study and the appropriate foundation system for the KCC and its surrounding area.

Many researchers have been conducted to develop a reliable and cost effective solution for the construction of structures on soft ground conditions. Considering the inherent limitations of conventional foundation systems, ground improvement methods have been practiced for a long time. Many researchers have taken initiative to develop a cost effective measure for the improvement of soft ground by earth reinforcement through sand compaction piles. In the case of very low to medium rise building other cost effective and owner user friendly measures are the major demands for the people in this region. So an experiment on the prepared soft ground improved by compacted sand bed has been carried out in laboratory. Load - settlement response for improved ground under different conditions has been observed and a set of better recommendations are given for the construction of structures on the soft ground pertaining the suitable improvement technique.

1.4 Objectives

The main objectives of this research work can be outlined as follows:

I. To analyze the available field and laboratory data of the selected area.

II. To develop a comprehensive soil profile of the study area.

III. To find out a generalized geotechnical properties of subsoil in the study area.

IV. To perform the improvement of soft stratum by replacing soft soil with granular compacted fills expanding laterally and vertically downward under foundation in the model soft soil bed.

V. To find out the best suited soil improvement technique and effective foundation system for the building within the study area.

1.5 Organization of the Thesis

The research work conducted for achieving the stated objectives is presented in several chapters of this thesis. The thesis consists of six chapters. A brief discussion of each chapter is as follows.

Chapter 1 includes location, geology, background of the study area and objectives of this study.

Chapter 2 includes the geotechnical properties and foundation systems for building structures within the study area. Geotechnical properties include index properties, shear strength properties and compressibility properties. The foundation systems include buoyancy raft foundation, piled raft foundation and pile foundation. Ground improvement techniques are rammed aggregate pier, preloading without vertical drain, preloading with vertical drain, cut and replacement method and foundation accommodating large settlement.

Chapter 3 includes the identification of subsoil formation of the study area. A soil profile is presented along north south section of the study area.

Chapter 4 includes the laboratory investigations of the soil used for preparation of soft soil bed in a fabricated cubic steel box. The load-settlement responses are measured for the soft soil bed improved by granular fills.

Chapter 5 includes the results and discussions on the results obtained on load-settlement responses in the laboratory investigations

Chapter 6 includes the conclusions and recommendations on the basis of this study for the study area.

CHAPTER II

Literature Review

2.1 General

This chapter contains a summary of the available geotechnical data of the KCC area and a detail presentation of case studies of different types of foundation systems and ground improvement techniques employed in this area or alike.

2.2 Available Geotechnical Data

The available geotechnical data of the study area i.e., the index properties, shear strength properties and compressibility properties obtained from different sources are presented in the following subsections.

2.2.1 Index Properties

2.1.1.1 Organic Matter Content

Razzaque and Alamgir (1999) reported that the organic matter content at different depths of boreholes at Gollahmari (near Khulna University) varies from 3.27% to 49.81% tabulated in Table 2.1.

Table 2.1: Percent of organic matter content in different depths and borehole locations at Khulna University area (after Razzaque and Alamgir, 1999)

Borehole No	Depth (m)	Per cent ratio of organic soil (dry weight)
1	1.37-1.83	3.27
1	2.89-3.35	42.79
1	5.97-6.40	2.49
3	2.44-2.89	49.81
3	5.79-5.94	5.87

Munshi (2003) showed that organic matter content remains in the range of 5% to 30% up to the depth of 12 m at Mollahat-Noapara Road Section in Bagerhat district which is adjacent to KCC area.

2.2.1.2 Specific Gravity

Bowles (1997) described that specific gravity of the inorganic clay (CL,CH,CH/CL And CL-ML) and inorganic silt (CL,CH,CH/CL) may vary from 2.68 to 2.75 and from 2.60 to 2.68 respectively. Bowles (1978) also reported that specific gravity of organic clay is variable but may be below 2.0. Shafiullah and Ali (BRTC, 2003) described that the specific gravity of organic clay and clayey silt layers remain in the range of 2.14 to 2.49 and 2.74 to 2.78, respectively at Chota Boyra (Khulan Medical College) located within the KCC area.

2.2.1.3 Natural Moisture Content

Razzaque and Alamgir (1999) reported that natural moisture content at Gollamari (near Khulan University) area remains in the range of 40% to 50% for inorganic fine-grained soil and may be as high as 134% for organic clay soil. Siddique et al. (2002) also reported the moisture content within the upper 6 m in Khulna University area to be as high as 400%. That moisture content of organic layer at Chota Boyra (Khulna Medical College) area was found to be in the range of 118% to 222% while the moisture content of the clayey silt layer was found to be in the range of 35% to 40 %, (BRTC,2003).

2.2.1.4 Degree of Saturation

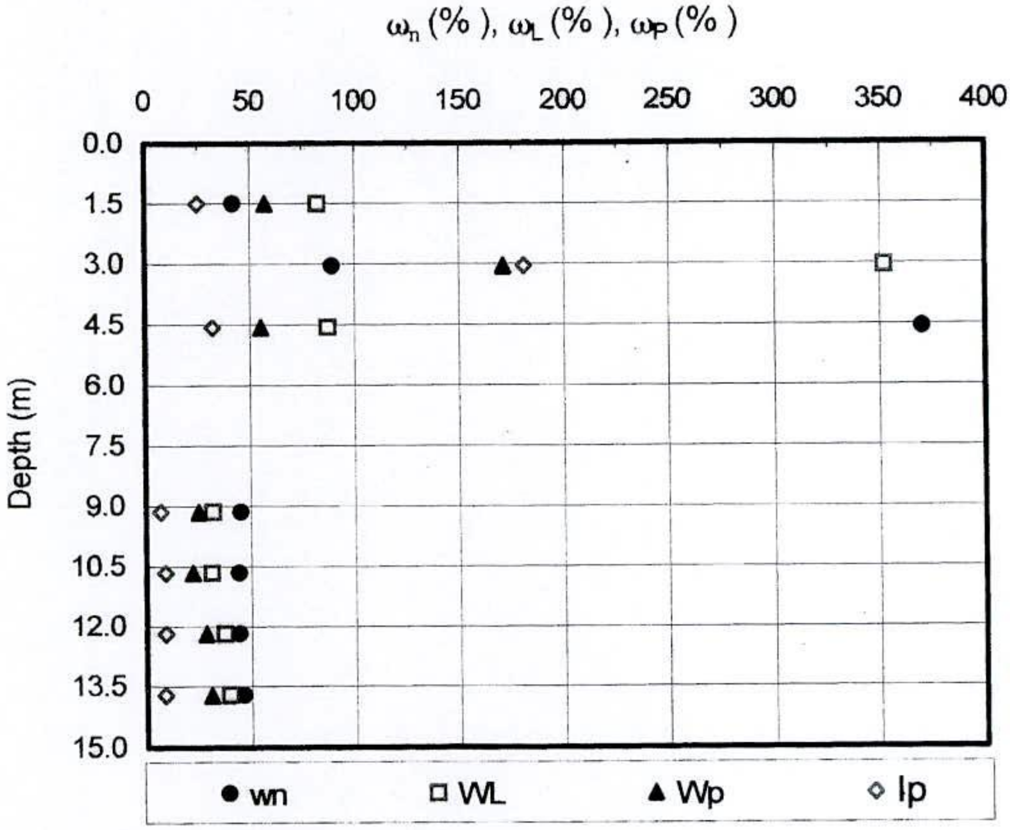
Shafiullah and Ali (BRTC, 2003) reported that the degree of saturation of organic clay, soft inorganic clay and silty soil at Chota Boyra (Khulna Medical College) area are in the range of 82% to 100%, 81% to 96 % and 94% to 97% respectively.

2.2.1.5 Atterberg Limits

Consultancy Research and Testing Services of Department of Civil Engineering of Khulna University of Engineering and Technology (KUET) explored the subsoil condition of Sonadanga Thana Residential project and at Goalkhali Sheikh Abu Naser Hospital Project. According to these, the moisture content of organic layer remains in the range of 89% to 370% while liquid limit and plasticity index vary in the range of 80% to 352% and 24% to 181%, respectively. Moreover, in case of very soft clay layer the moisture content, liquid limit and plasticity index remains in the range of 41% to 53%, 53% to 82% and 16% to 27 % respectively . Beside these, in case of silty clay soil the moisture content, liquid limit and plasticity index are reported to be in the range of 44% to 68 % , 31% to 57 % and 7 % to 18% respectively. A graphical presentation of relationship between natural moisture content, liquid limit and plasticity index with depth is shown in Table 2.2 .

Table 2.2 Atterberg limits with respect to depth at Sonadanga and Goalkhali area (after Hossain and Rahman, 2005)

Location	Soil type	Depth (m)	W_n (%)	W_L (%)	W_p (%)	I_p (%)
Sonadanga	Soft clay	1.50	42.00	82.30	57.20	25.10
	Organic Soil	3.05	89.00	352.00	171.00	181.00
		4.57	370.00	87.20	55.10	32.10
	Silty clay	9.14	45.00	32.00	25.00	7.00
		10.67	44.00	31.10	22.00	9.10
		12.19	44.00	37.40	28.30	9.10
		13.72	46.00	39.70	30.80	8.90
Goalkhali	Soft clay	1.52	14.16	52.80	25.92	26.88
		9.15	53.38	56.00	40.00	16.00
	Organic Soil	3.05	107.12	80.00	55.56	24.44
	Silty clay	16.77	67.92	56.70	38.75	17.95



e 2.1 Natural moisture content and Atterberg limits with respect to depth at
ga area (after Hossain and Rahman, 2005).

Figure 2.1 Natural moisture contend and Atterberg limits with respect to depth at Sonadanga Area (after Hossain and Rahman,2005

2.2.2 Shear Strength Properties

2.2.2.1 Shear Strength Properties and SPT-N Relationship

The approximate correlation among SPT-N value and unconfined compressive strength, q_u for cohesive soils as suggested by Terzaghi and Peck (1948 &1967) is

$q_u = f. N$ (kPa)

where, f = 12.50 for very soft to soft clay

= 13.33 for the medium stiff to hard clay.

On the basis of this, the consistency of clayey silts may be described as shown in Table 2.3

Table 2.3 Correlations between consistency, N-value and q_u of cohesive inorganic fine-grained soils (after Terzaghi and Peck, 1967)

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

*Terzaghi and Peck (1967) used the unit in ton/sft which is converted here to kPa, assuming 1 ton/sft = 100 kPa.

The correlation between N and qu as obtained by Sowers (1953 and 1962) for cohesive soils is presented in Table 2.4 and the average values of f range from 6.7 to 24.

Table 2.4 correlations between N-Value and unconfined compressive strength for different soil types (after Sowers, 1953 and 1962)

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

Sanglerat (1972) proposes the following relationships between N and q_u for different soil types with the values of *f* Ranging from 13.33 to 25.0.

For Clay, $q_u = 25$ N kPa

For silty clay, $q_u = 20$ N kPa

For silty sandy soil, $q_u = 13.33$ N kPa

Murthy (1993) investigated the relationship between N and q_u for the preconsolidated silty clay encountered at Farakka in West Bengal, India. The moisture content of the soils was close to the plastic limit, which for the soils varied from 30 to 40 percent, and the liquid limit from 50 to 100 percent with the preconsolidation ratio in the order of 5. It has been mentioned that there was a considerable scatter of test results and the relationship between q_u and N shows $q_u = 10$ to 20 N (kPa).

From a study (Serajuddin and Chowdhury, 1996) q_u against N-values of the inorganic clay or silty clay layers measured by locally manufactured standard penetration test equipment and local procedure of pulling and releasing the drop weight by a crew of labours has indicated that q_u of saturated cohesive clay and silt layers can be estimated by using the plasticity characteristics of the cohesive clay and silt deposits occurring in different areas of Bangladesh.

The correlation factors are as follows:

(a) $f = 16$ for clays and silts of high plasticity with $w_L \geq 51$ %

(b) $f = 15$ for clays and silts of medium plasticity with $w_L = 36\text{-}50$ %

(c) $f = 13$ for clays and silts of low plasticity with $w_L \leq 51$ %

Consultancy Research and Testing Services of KUET explored and reported the subsoil condition of Sonadanga Thana residential project and at Goalkhali Sheikh Abu Naser Hospital Projects. Table 2.5 and Figure 2.2 are the presentation of particular borehole data at Goalkhali area. Moreover, the relationship between SPT-N value and unconfined compressive strength, q_u (kPa) for different types of soil layers is shown in figure 2.3.

Table 2.5 Typical borehole data of SPT-N value and q_u (kPa) at Goalkhali area (after Hossain and Rahman, 2005)

Location	BH No.	Depth (m)	Soil type	N- value (field)	q_u (kPa)
Goalkhali	2	1.52	Soft clay	2	66.33
		3.05	Organic clay	4	11.53
		4.57	Clay with trace silt	6	20.30
		6.10		4	9.73
		7.62		4	32.93
		10.67		2	18.93
		12.19	Silty clay	4	53.78
		18.29	Clay with trace silt	5	12.96

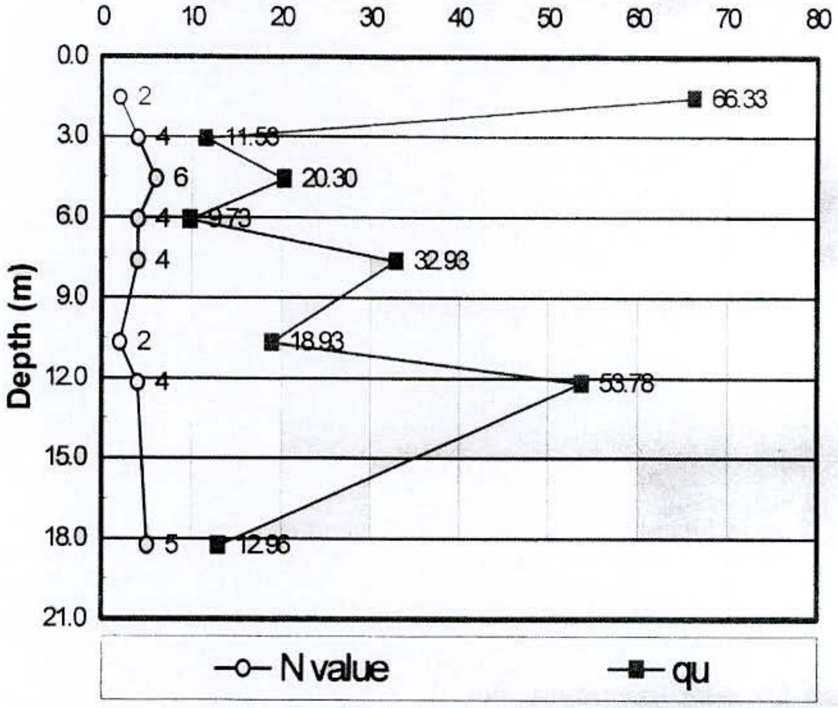


Figure 2.2 SPT-N value and q_u (kPa) with respect to depth at Goalkhali (after Hossain and Rahman, 2005)

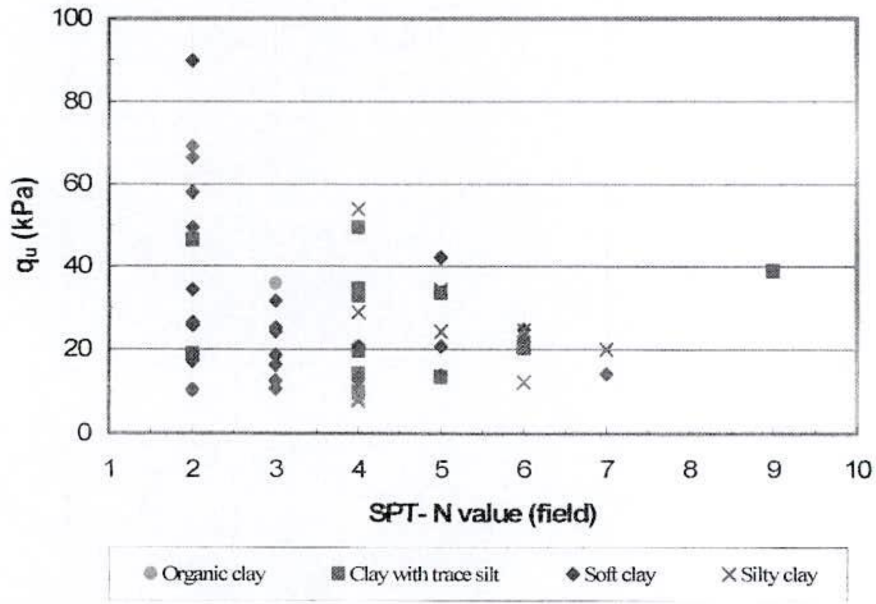


Figure 2.3 SPT-N value and q_u (kPa) of different soil layers at Goalkhali and Sonadanga area.

It can be concluded that the relationship between qu and N is not straightforward. Rather, the relationship is very scattered in nature and it cannot be expressed by a single correlation factor like uniform soil layer.

2.2.3 Consolidation Properties

2.2.3.1 Compression Index and Coefficient of Consolidation

Compressibility characteristics can be termed as low, moderate and high. Table 2.6 can be used to describe the compressibility with respect to compression index and liquid limit.

Compressibility tests data of fine-grained soils of southwest zone of Bangladesh for estimation of primary consolidation settlement are summarized in Table 2.7 (Serajuddin, 1998).

Table 2.6 Compressibility Characteristics with respect to compression index and liquid limit

Compressibility term	Compression index	liquid limit (%)
Low	0-0.19	0-30
Moderate	0.20-0.39	31-50
High	>0.40	>50

Table 2.7 Primary Consolidation parameters of fine-grained soils (Serajuddin, 1998)

Zone	Depth (m)	USCS	w_n (%)	e_o	C_c	C_v
South-West	3.5-9.5	Cl,Ml,CH	24-47	0.706-1.32	0.080-0.520	1.73-100.91

The consolidation parameters of the soil samples at Khulna medical college (KMC) area are summarized in Table 2.8.

Table 2.8 Summary of consolidation parameters at Khulna Medical College (after BRTC, 2003)

BH No	**Depth (m)**	**W (%)**	**e_o**	**C_c**	**$R=C_c/(1+e_o)$**	**Cv (m^2/yr)**
1	6.75	36.4	1.116	0.231	0.11	41-65
1	8	34.6	0.98	0.176	0.09	
2	4.8	58.9	1.703	0.529	0.20	
2	8	39.9	1.23	0.293	0.13	
3	4.8	221.8	5.79	2.97	0.44	3-139
3	8	38.1	1.289	0.301	0.13	18-252
4	4.8	117.9	2.92	1.201	0.31	2.6-8.6
4	8	39.4	1.16	0.245	0.11	50-370

From Table 2.8, it can be found that the moisture content, w_n, initial void ratio, $e_{o,}$ compression index, $C_{c,}$ compression ratio, R and coefficient of volume compressibility, C_v remains in the range of 34.6% to 221.80%, 0.98% to 5.79,0.18 to 2.97, 0.09 to 0.44 and 2.6-8 to 50-370 m^2/yr, respectively. Comparing the obtained compression index, C_c with that of shown in Table 2.6, it can be found that the upper 8.0 m depth layer at Khulna medical College area shows moderate to high compressibility.

2.2.3.2 Empirical Relations for Compression Index

The compression index (Cc) of compressible clays and silts has some empirical relations with liquid limit (w_L), initial void ratio (e_o) and natural moisture content (w_n). Serajuddin and Ahmed (1967) correlated Cc with w_L and e_o of a large number of undisturbed plastic silts and clay soil samples of different areas of Bangladesh and obtained the following empirical equation:

$$C_c = 0.0078\ (w_L\text{-}14\%)$$

$$C_c = 0.44\ (e_o\text{-}0.30)$$

Another correlation study (Serajuddin and Ahmed, 1982) with additional test data from fine-grained soils occurring within about 7m from the ground surface of different areas of the country suggested the relationship:

Cc=0.47 (eo-0.46) with a correlation coefficient of 0.77

Virgin compression index, Cc can be calculated through different soil parameters such as liquid limit, natural moisture content, initial void ratio and plasticity index. The Relationships given by different researchers are shown in the Table 2.9.

Table 2.9 Equations used to calculate Cc for inorganic cohesive soil samples (after Bowles, 1997)

Compression Index, Cc	Comments	Source/ Reference
Cc=0.009 (wl-10)	Clay	Terzhaghi and peck (1967)
Cc=1.15 (eo-0.35) Cc=0.009 w_N + 0.005 w_L	All Clays All Clays	Nishida (1956) Koppula (1986)
Cc=0.046 +0.0104 I_p	Best for Ip <50%	Nakase et al. (1998)
Cc=0.37 (e_o+0.003 w_L+0.004 w_n-0.34)	678 data points	Azaouz et al. (1976)
Cc=0.156+ 0.411 eo+0.00058 w_L	62 data points	Al-khafaji and Andersland (1992)

2.2.3.3 Pre-consolidation Pressure

Analysis of consolation parameters including effective overburden ($p`_o$) and estimated past maximum pre-consolidation pressure (p_c)indicate that the clay and silt soil strata are predominantly normally consolidated in Khulna area. But slightly moderated over consolidated clay and silt layer seem to exist in the southwest zone of Bangladesh, Table 2.10.

Table 2.10 approximate range of preconsolidation values of clays and silts of Khulna (after Serajuddin, 1998)

Location	W_n	w_L	I_p	P'_c (kN/m2)		P'_o	OCR	
				CM	SM	(kN/m^2)	CM	SM
Khulna around	32-53	35-60	11-29	98-175	98-120	36-100	1.75-4.38	1.78-2.18

Where CM and SM are the Casagrande method and square Root method, respectively.

2.2.3.3 Coefficient of Secondary Compression Index (C_a)

Secondary compression and creep are time-dependent deformations that appear to occur at essentially constant effective stress with negligible change in pore water pressure. Secondary compression and creep may be a dispersion process in the soil structure causing particle movement and they may be associated with electrochemical reactions and flocculation. In some field situation secondary compression is more important than primary compression. When soft soil deposits is preloaded or surcharged, the subsequent primary settlements are essentially eliminated, and significant settlement occurs over the economic life of the structure due to secondary compression of the soil (Lee et al., 1983).C_a can be estimated directly form 1D-consolidation test or it can be estimated form indirect relations. The value of C_a for a variety of different types of soil is shown in Table 2.11. C_a will in general with time if the effective overburden pressure, p_o is less that a preconsolidation pressure p'_c. For p'_o greater, than p'_c C_a will decrease with time (Settlement analysis 1994). A first approximation of C_a is 0.0001 w_n for $10<w_n<3000$ where w_n is natural water content in percent NAVFAC(1982).

Ladd (1967) suggested that for N.C. soils,

$C_a (\%) \approx (4\text{-}6) \times C_R$

Where virgin compression ratio $C_R = Cc/(1+e_o)$

Table 2.11 A guide to values of the coefficient of secondary consolidation, C_a (after Lee et al, 1983)

Soil type	C_a	Reference
N.C. clays	0.005-0.02	Ladd, 1967
N.C. alluvial clays* 1% organic content	0.003	Matsuo and kamon, 1975
5% organic content	0.001	
N.C. clay		Yamanouchi et al., 1978
0% organic content	0.004	
9% organic content	0.008	
17% organic content	0.02	
O.C. Clays (O.C.R>2)	<0.001	Labb, 1967
Peat	0.02-0.10	Yasuhara and Takenaka, 1977

❖ For a consolidation stress of 800 kPa and 1600 kPa.

2.3 Ground Water Table

The weekly-recorded ground water table data were obtained from BWDB for the study area. On the basis of these data it is found that at Chota Boyra. North part of the study area. The ground water table varies from 2.75 to 3.75 m. Therefore, the average annual ground water table in the north part remains 3.25 m below EGL. On the other hand, at Shipyard road, Rupsha- south part of the project area, the ground water table varies from 1.0 to 2.25 m. So, the average annual ground water table in the south part lies at 1.63 m below EGL. The weekly ground water table data are shown in Figure 2.4 Therefore, it can be concluded that the ground water table in the south part is very close to the ground surface in comparison with north part.

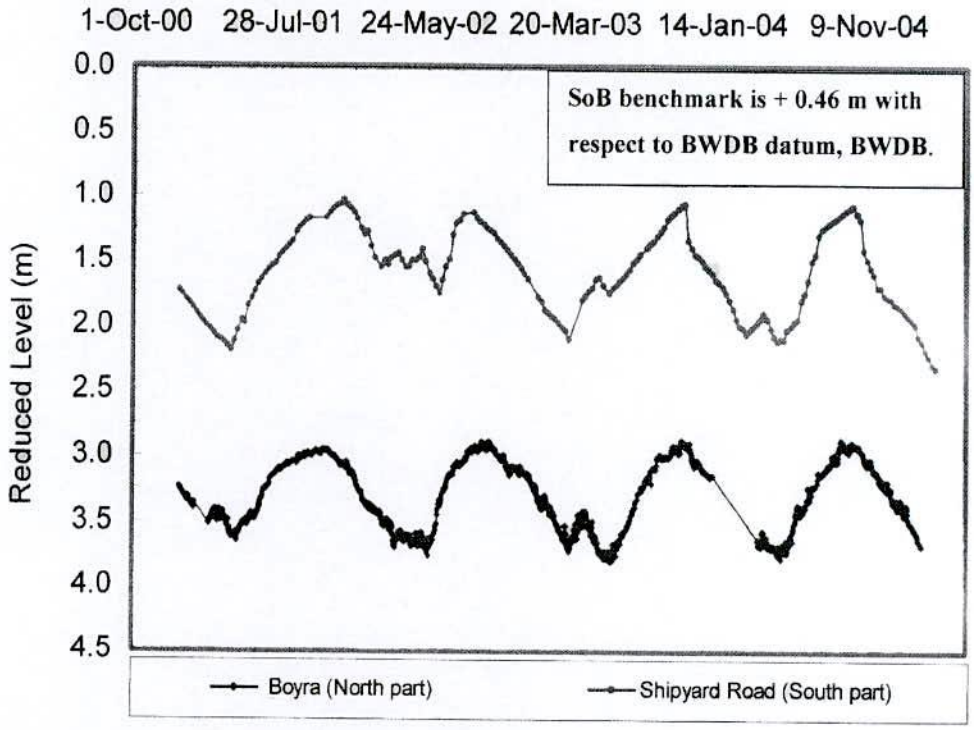


Figure 2.4 Weekly ground water table with respect to BWDB benchmark, (BWDB, 2000-2005).

2.4 Foundation System for the Study Area

In this section, the foundation systems which may generally be suggested in the study area are presented. These are:

i. Buoyancy raft foundation
ii. Piled-raft foundation
iii. Deep pile foundation

2.4.1 Theoretical Background of Buoyancy Raft Foundation

he buoyancy raft works on a similar principle to that of a floating structure where the supporting pressure for the raft is obtained by displacing the weight of earth or overburden by the volume of a large voided foundation. Buoyancy raft is achieved by making voids as a basement structure, Figure 2.5. It is designed so that sufficient overburden is removed to allow the superstructure load to be applied to the ground with little or no increase in the original stress, which existed on the sub- strata prior to excavation and construction.

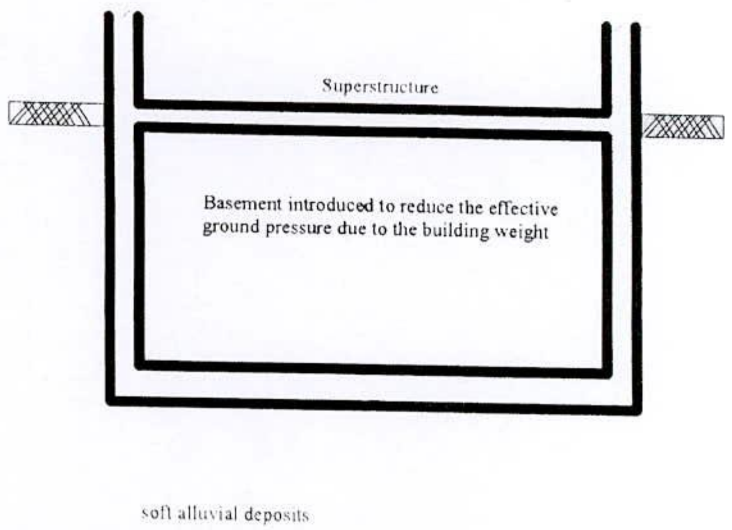


Figure 2.5 Buoyancy raft foundation (after Curtin et al., 1994)

Since buoyancy foundations are expensive compared to the traditional forms, they are used where suitable bearing strata is at a greater depth. For this reason, this foundation system tends to be restricted to site on very deep alluvial deposits where loads on the foundations can be kept concentric. The bottom slab may be the basement of the proposed building and combined with the ground slab and retaining walls. Raft design considers eccentricity of loads and aims to keep differential and tilting within the acceptable limits.

Where the soil is predominantly cohesive, the reduction in ground stress will result in heave i.e settlement in reverse. As with settlement, heave will have short-term(elastic) component and long-term(consolidation) component. The short-term heave normally occurs during the excavation period. Where its magnitude is considered significant, the formation is then trimmed down to its required level. The long term heave is dealt within the same way as long as settlement. The anticipated amount of differential heave is calculated, and the structure is designed to accommodate this movement. The heave of the foundation is shown in Figure 2.6.

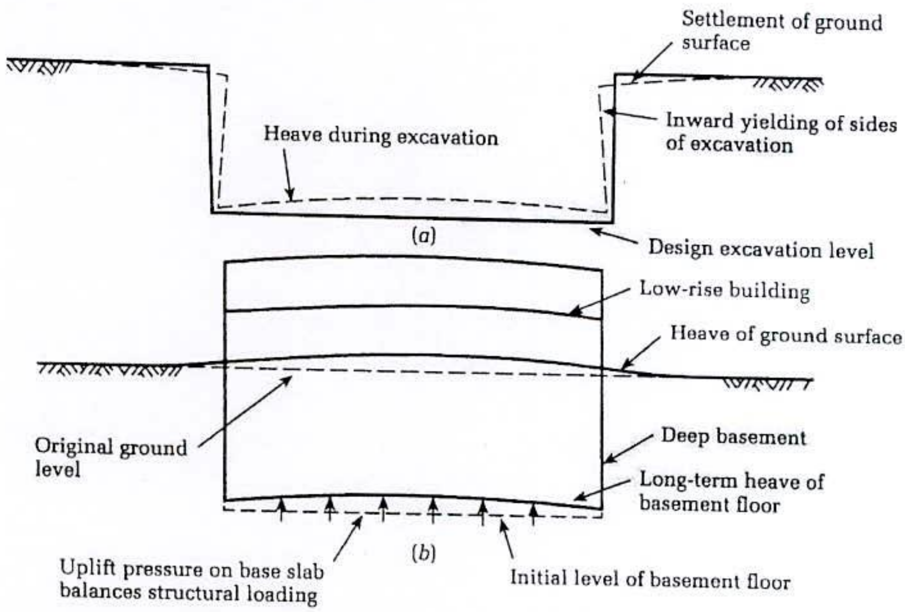


Figure 2.6 Movements around a deep basement supporting a low-rise structure (a) On completion of excavation (b) Final movements of completed structure (after Tomlinson, 2001).

The net average applied pressure on the soil $q = \frac{Q}{A} - \gamma Df$

Where, Df= the depth of embedment

The factor of safety against bearing capacity failure for partially compensated foundations may be given as

$$FS = \frac{q_{u(net)}}{q} = \frac{q_{u(net)}}{\frac{Q}{A} - \gamma D_f} \quad \text{(after Das, 1990)}$$

2.4.2 Case Study on Buoyancy Raft Foundation at Goalkahali Area

2.4.2.1 Geotechnical Data

The upper 1.52m depth layer is very soft clay. The layer between 1.52m and 3.05m is soft clay with decomposed wood. The underlying layer between 3.05 and 12.19 m depth is silty clay. The layer between 12.19 and 18.29 m is clay with trace silt. A typical soil profile of Goalkahli area is shown in Figure 2.7. The SPT-N value varies form 2 to 5 upto the depth of 18.29. The unconfined compression strength, qu varies from 11.53 to 66.33 kPa. The apparent ground water table is 300 mm below the EGL. The initial void ratio and compression index at the depth of 3.05m to 4.5m below EGL remained in the range of 0.89 to 1.00 and 0.32 to 0.48, respectively.

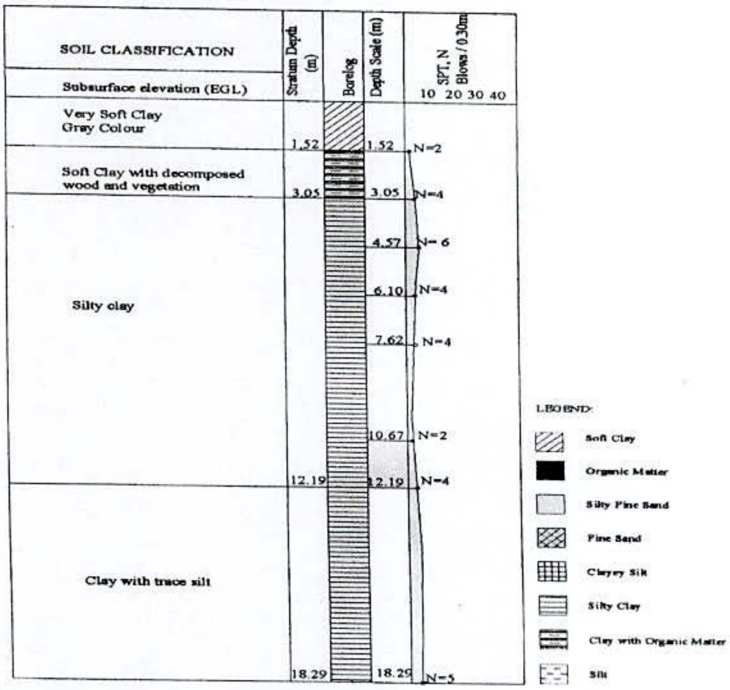


Figure 2.7 Typical sub-soil properties in at Goalkhali, Khulna (after PWD, 2000).

2.4.2.2 Foundation System

Buoyancy raft foundation system for a five-story hospital building was analyzed and designed by the Design Division-3, Public Works Department (PWD). The foundation system is shown in Figure 2.8. The foundation base was placed below the organic layer. As the subsoil strata below the organic layer is very soft clay with high void ration and high ground water table, there was possibility of heaving of soil after excavation. To minimize heaving, compacted sand with crushed aggregate was used below the mat. The detail analysis and calculation of heaving at the bottom of excavation was not available. No settlement plates were inserted to measure the settlement at periodical intervals.

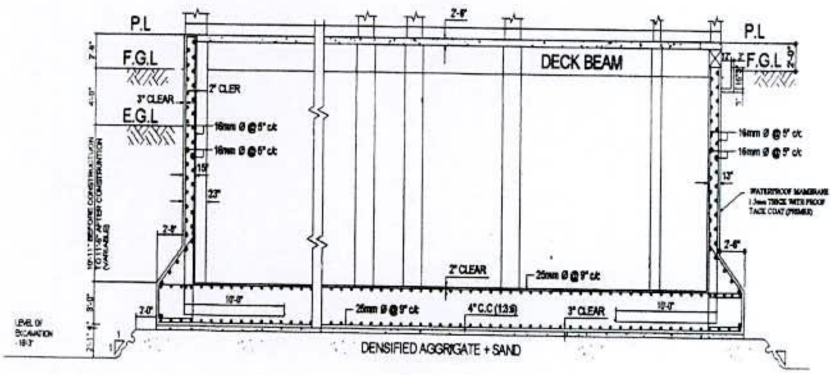


Figure 2.8 Buoyancy raft foundation system at Goalkhali for five-storey hospital building (after PWD, 2000).

2.4.2.3 Performance

Another buoyancy raft foundation was analyzed and designed by Shadedulla and Associates Limited, Dhaka at Goallahmari (Khulna University area) for 4 story Academic Building-II. Razzaque and Alamgir (1999) reported that the recorded settlement was negligible as 20 mm only.

2.4.3 Theoretical Background of Piled Raft Foundation

A piled raft foundation comprises both piles and a pile cap that itself transmit load directly to the ground. The aim of such a foundation is to reduce the number of piles compared with a more conventional piled foundation. The piled raft is two types:

(a) Piled raft for settlement reduction

(b) Piled raft for load transfer

(a) **Piled raft for settlement reduction:** When the raft is safe from bearing capacity considerations but it suffers from excessive settlement, a few numbers of piles under the raft are used to relieve the raft of a part of the total load. As the piles do not have to take all the loads, the number of piles require will be much smaller than the traditional piled foundation. Because of some relief of the load, the raft settlement will also fall within allowable limits (Varghese, 2005).

(b) **Piled raft for load transfer :** Piles are mainly designed to take up the foundation loads and the raft only carries a small proportion (Poulos, 2001)

Simplified analysis method

Poulos- Davis-Randolph (PDR) Method

The ultimate capacity of the piled raft foundation can be taken as the lesser of the two values:

(i) The sum of the ultimate capacities of the raft plus all the piles

(ii) The ultimate capacity of a block containing the piles and the raft, plus that of the portion of the raft outside the periphery of the piles (Impe, 2001)

An approach to combining the separate stiffness of the raft and the pile group has been suggested by Randolph (1983). This approach is based on the use of average interaction factor, a_{cp}, between the pile and pile cap. The pile cap stiffness, k_c and the pile group stiffness, k_p, the overall foundation stiffness,

$$K_f = \frac{k_p + K_c\,(1-2a_{cp})}{1 - \dfrac{\alpha^2_{cp} k_c}{k_p}}$$

While the proportion of load carried by the pile cap (P_c) and the pile group (P_p) is given by

$$\frac{P_c}{(P_c + P_p)} = \frac{Kc\,(1-\alpha_{cp})}{k_p + k_c\,(1-2\alpha_{cp})}$$, (Fleming et al., 1992).

The stiffness, k_p, of the pile group (load divided by settlement) may be expressed as a fraction η_w of the sum of the individual pile stiffness, k. Thus for a group of n piles, $k_p = \eta_w nk$ while the group efficiency can be expressed as $\eta_w = n^{-e}$. the exponent e lies between 0.40 and 0.60 for most pile groups.

The actual e will depend on:

Pile slenderness ratio, l /d

Pile stiffness ratio, $\lambda = \dfrac{E_p}{G_l}$

Pile spacing ratio, s/d,

Homogeneity of soil characterized by ρ

Poisson's ratio, ν

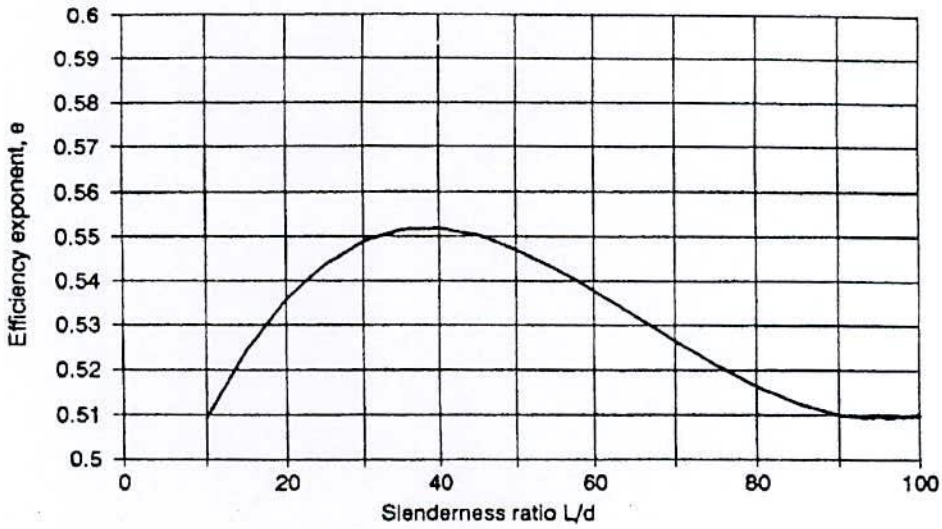


Figure 2.9 Chart for calculation of efficiency exponent, e (after Fleming et al., 1992

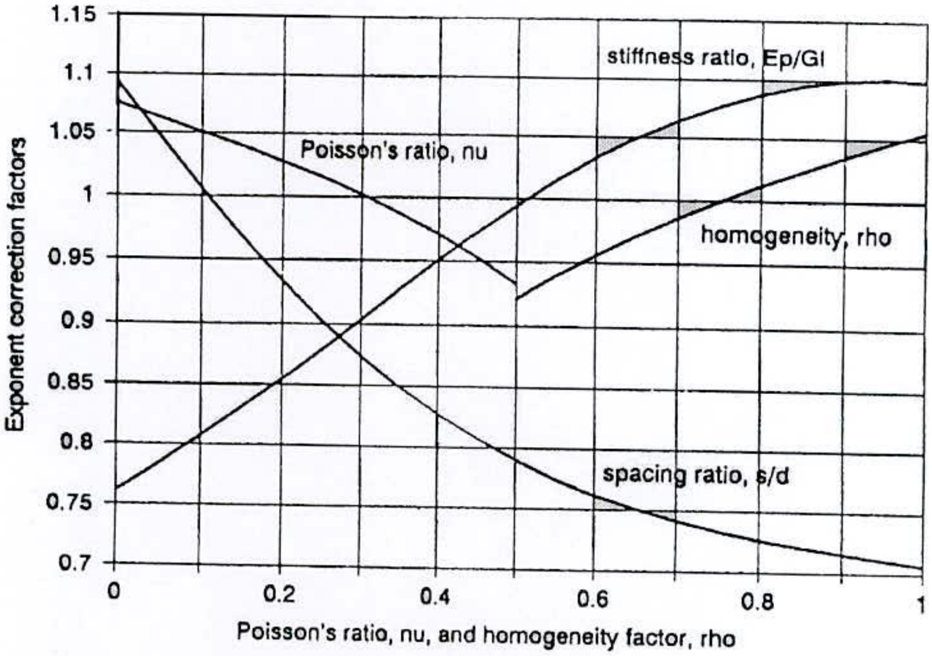


Figure 2.10 Exponent correction factors (after Fleming et al., 1992)

The stiffness of the single pile, $k = \frac{P_t}{w_t}$

And the equation of stiffness, $$\frac{P_t}{w_t} = \frac{\frac{4\eta}{(1-\nu)\xi} + \frac{2\pi\rho}{\xi}\frac{\tanh(\mu l)}{\mu l}\frac{l}{l_0}}{1 + \frac{4\eta}{\pi\lambda(1-\nu)\xi}\frac{tamh(\mu l)}{(\mu l)}\frac{l}{l_0}}$$

L = Length of the raft

Optimization, analysis and design of piled-raft foundation can be done through PLAXIS- 3D or GARP6 computer programmers. Behavior of piled raft foundation depends on the number, length, diameter, disposition of piles, raft thickness and geo-technical properties of the site (Cunha et al., 2001).

2.4.4 Case Study of Piled Raft Foundation at Klang, Malaysia

2.4.4.1 Geotechnical Data

The alluvial deposits at the site consisted of very soft to firm silty clay up to a depth of 25 m to 30 m with presence of intermediate sandy layers. The silty clay stratum were underlain by silty sand. Klang Clay could be divided into two distinct layers at depth of 15m. Some of the compressibility parameters of Klang clay are presented in Figure 2.11.

2.4.4.2 Foundation System

Both temporary surcharging and preloading technique was adopted to control long-term settlement of the subsoil. Then the building was placed on top of it. The net fill height at the site was about 0.5 m to 1.0 m. The temporary surcharging heights remained in the range of 2 m to 5m. After the subsoil achieving the required percentage of settlement and verified using Asaoka's method (Asaoka, 1978), the temporary earth fills were removed and the construction of the foundation begins.

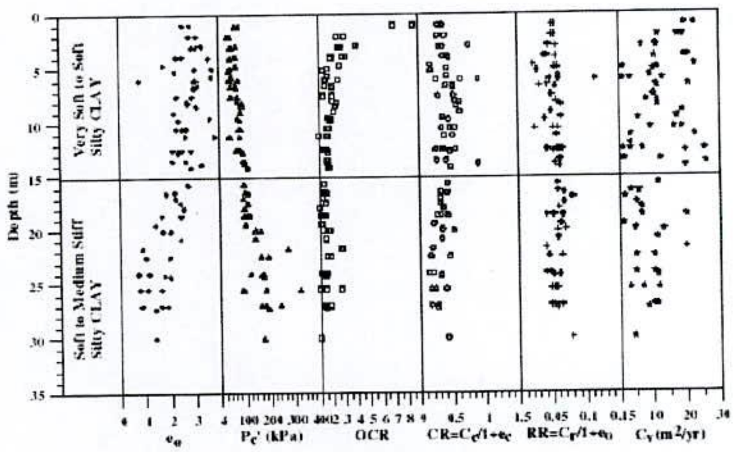


Figure 2.11 Compressibility parameters of Klang Clay (after Tan et al., 2004)

The loading of 5-storied apartments ware highest at the columns and ranges from 100kN to 750 kN. The line load from the brick wall was 9 kN/m (5'' brick wall) and the uniform live load acting on the ground floor raft was 2.7 kN/m^2 (1.5 kN/m^2 live load + 1.2 kN/m^2 floor finishing) as per recommended values given by British Standard 6399 (1996). The main design criterion was to limit the relative rotation (angular distortion) to 1/350 (Skempton and MacDonald, 1956) to prevent cracking in walls and partitions.

The objective of the design was to provide an optimum piled raft foundation system that takes into consideration the bearing capacity contribution of the raft and the piles introduced mainly to limit differential settlement. The approach was to increase the stiffness of areas where the settlement is expected to be the largest by introducing settlement-reducing piles. Horikoshi and Randolph (1998) suggested that for uniformly loaded raft, piles distributed over the central 16-25% of the raft area is sufficient to produce an optimum design and for piled raft subjected to non-uniform vertical loads, the use of piles with varying length would give the most optimum design (Reul and Randolph, 2004). The foundation system adopted for low cost apartments consists of 200mm x 200mm reinforced concrete square piles with pile length varying from 18m to 24m interconnected with 350mm x 700mm strips and 300mm thick raft. Figure 2.12 shows typical section of the strip-raft foundation system and Figure 2.13 shows schematic view of the foundation system superimposed onto the completed low cost apartments.

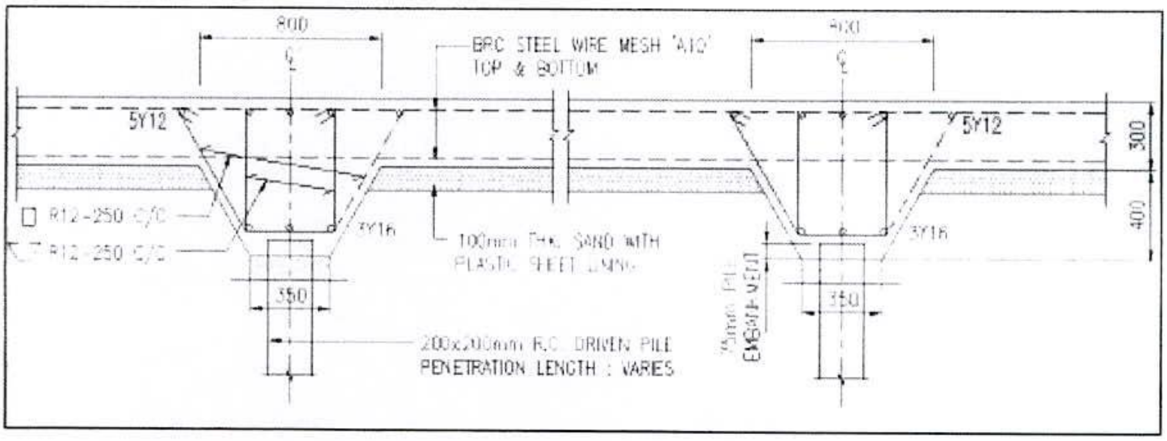


Figure 2.12 Typical section of the strip-raft foundation system (after Tan et al., 2004).

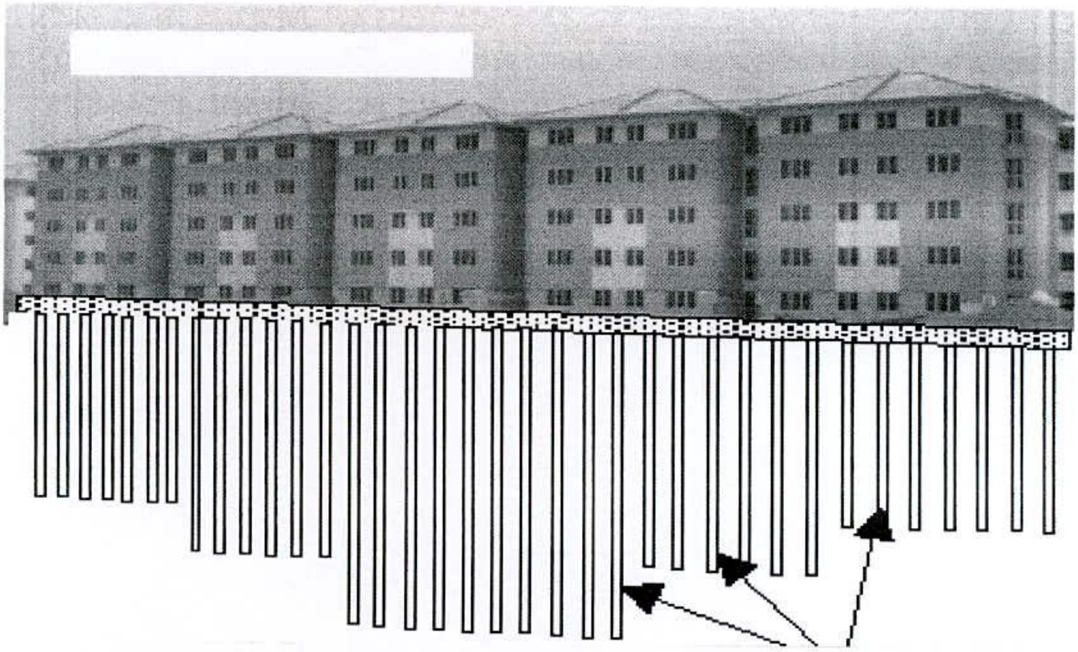


Figure 2.13 Schematic view of the foundation system (after Tan et al., 2004).

The locations of the strips were adjusted during detailed design to ensure the pass beneath all the columns (i.e. concentrated loads) for optimum structural design. Two cases were considered in the detailed analysis of the foundation system, i.e.:

(a) Case 1: Overall settlement behavior

(b) Case 2: Pile-soil-structure interaction

Case 1 considered the overall settlement behavior of the piled raft foundation system in order to predict the settlement profile of the structural design. The settlement analysis was carried out based on Terzaghi's 1-D consolidation theory. Approximate adjustments were made to the pressure imposed on the subsoil due to distribution o the super structure load by the piles using concept of equivalent raft. The settlement profiles were then used to determine the spring stiffness or Winkler's modulus to generate the overall stress on the foundation raft due to the settlement profile.

Case 2 considered the interaction in between the pile-soil-structure (foundation raft) of the foundation system in order to determine the load distribution and local settlement of the piles. The pile-soil-structure interaction can be carried out iteratively using elastic pile interaction software (e.g. PIGLET/PIGEON) together with finite element structural analysis software (e.g. SAFE) until convergence of results was achieved (typically $\pm$ 10%). The iterative approach was proposed due to limitations of available software in modeling pile-soil-structure interaction. The analysis could be carried out using 3-dimensional finite element method (FEM) software (e.g. PLAXIS 3-D Foundation) that could model 3-dimensional pile-soil-structure interaction. The solution for pile interaction proposed by Randolph and Worth (1979) was based on the solution or single pile and extended for pile groups based on the principle of superposition. For cases with different pile lengths, the interaction of pile bases at different levels was very complicated and its effects to shear stress along the pile shaft were unknown. However, for the current application in soft ground, the pile capacity was derived primarily from shaft/skin friction with very little end bearing contribution.

2.4.4.3 Performance

Settlement monitoring works was carried out when the building has been completed for more than six months. The monitoring results showed that the maximum differential settlement recorded was 27.02 mm. The relative maximum local angular distortion recorded is 1/1215. The monitoring results also showed the building experiences marginal tilt of approximately 1/1000. However, the value was well within the limits of 1/250 to 1/500 (Charles and Skinner, 2004) for it to be noticeable.

2.4.5 Theoretical Background of Deep Pile Foundation

Pile foundation may be used to transmit the super structure load to the firm strata. The total capacity of a pile is due to both end and shaft resistance. Where the soil layer at greater depth consists of dense layer, the cast in situ pile may be expected to have better load resistance than driven piles.

Piles in Cohesive Soil

End-bearing pressure

The long term, drained, end-bearing capacity of a pile in clay will be considerably larger than the undrained capacity. However, the settlements required to mobilize the drained capacity would be far too large to be tolerated by most structures. For this reason, the base capacity of the piles in clay is determined in terms of the undrained shear strength of the clay, c_u, and a bearing capacity factor, N_c (Fleming et al., 1992). thus the end bearing pressure is

$$q_b = N_c c_u$$

The appropriate value of Nc is 9 (Skempton, 1951), although due allowance should be made where the pile tip penetrates a stiff layer by only a small amount. A linear interpolation should be made between a value of N_c= 6 for the case of the pile tip just reaching the bearing stratum, up to N_c=9 where the pile tip penetrates the bearing stratum by 3 diameters or more.

Skin Friction

Driven piles

Point resistance of a pile embedded in soft clay is insignificant, it is seldom exceeds 10% of the total capacity (Terzaghi et al., 1996). The skin friction around a pile shaft has been estimated in terms of the undrained shear strength of the soil, by means of an empirical factor, α, (Tomlinson, 1957) giving

$$\tau = \alpha c_u$$

The value of α appears to reduce from unity or more for piles in clay for low strength, down to 0.5 or below for clay of strength above about 100 kN/m2. Cernica (2005) found that the skin friction for driven piles was

$$\tau = 1.5c_u \tan \phi$$

Where, cu = average cohesion, untrained condition

ϕ = angle of internal friction of the clay

The angle of internal friction of the normally consolidated clays can be computed in the long-term shear strength case. Some commonly used long term S case shear strengths of alluvial soils are as shown in Table 2.12

Table 2.12 Long term S Case shear strength of alluvial soil (after Design of pile Foundations, 1994)

Soil type	USCS symbol	Consistency	Angle of internal friction ø(degree)
Fat clay	CH	Very soft	13° to 17°
Fat clay	CH	Soft	17° to 20°
Fat clay	CH	Medium	20° to 21°
Fat clay	CH	Stiff	21° to 23°
Silt	ML	-	25° to 28°

Fleming et al. (1992) showed the values of skin friction of driven piles in Figure 2.14

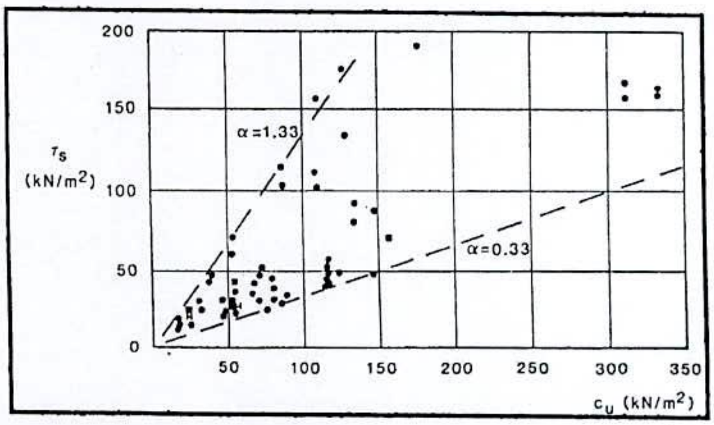


Figure 2.14 Relationship between skin friction and shear strength (after Fleming et al., 1992)

Bored piles

Weltman and Healy (1978). have analyzed a number of pile tests in boulder clays and other glacial tills and suggest values of α varying with the undrained shear strength of the soil as show in Figure 2.15.

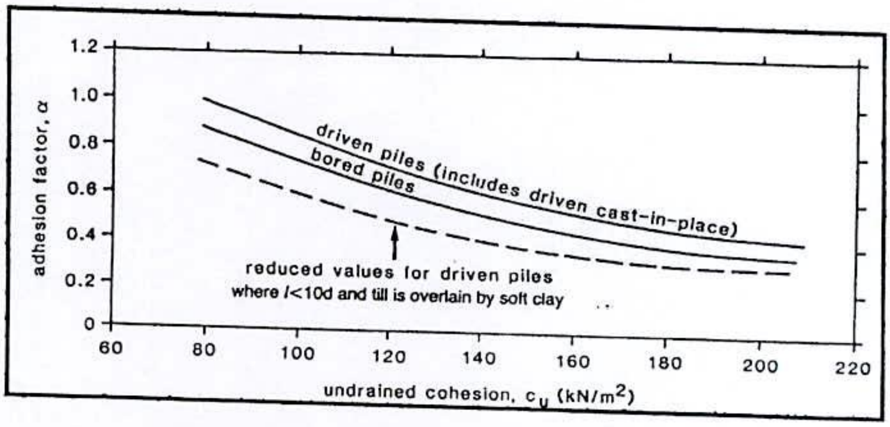


Figure 2.15 Variation of α with shear strength of glacial till (after Weltman and Healy, 1978).

Cernica (2005) shown that the skin friction for bored piles was

$$\tau = 1.5c_u \tan \phi$$

Where, c_u = average cohesion, undrained condition

ϕ = angle of internal friction of the clay, according to Table 2.12

Piles in Silt

End bearing

The pile tip bearing capacity increases linearly to a critical depth (Dc) and remains constant below that depth. The critical depths are given as follows.

D_c= 10 B for loose silts

D_c= 15 B for medium silts

D_c= 20 B for medium silts

The unit end bearing capacity may be computed as follows:

$$q = \sigma_v N_q$$

$\sigma_v = \gamma' D$ for $D < D_c$

$\sigma_v = \gamma' D$ for $D \geq D_c$

$Q_t = A_t q$

Where, N_q = Terzaghi bearing capacity factor, Figure 2.16

σ_v = Vertical earth pressure at the tip with limits

A_t = area of the pile tip

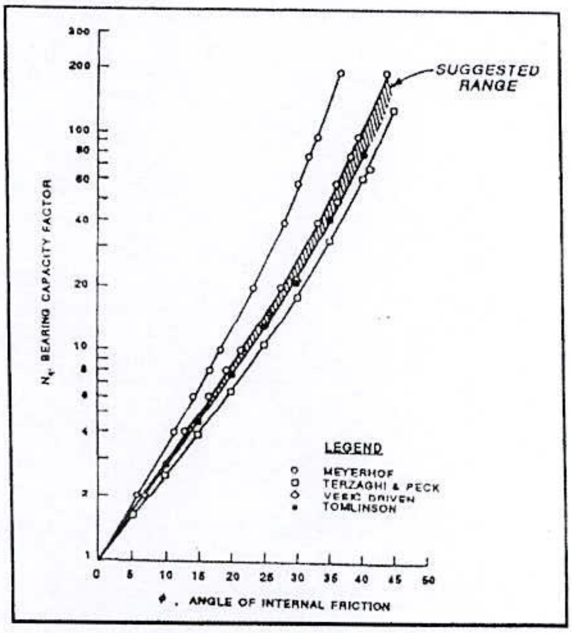


Figure 2.16 Bearing capacity factor (after Design of Pile Foundations, 1994)

Skin friction

The skin friction on a pile in silt is a two-component resistance to pile movement contributed by the angle of internal friction (Ø) and the cohesion (c) acting along the pile shaft. That portion of the resistance contributed by the angle of internal friction (Ø) is limited to a critical depth of (Dc) below which the frictional portion remains constant.

The shaft resistance of piles in silt may be computed as follows:

$f_s = k\gamma' \tan\delta + \alpha c$

Where $D \leq D_c$

$Q_s = A_s f_s$

Q_s = capacity due to skin resistance

f_s = average unit skin friction

A_s = surface area of pile shaft in contact with soil

k = can be determined from Table 2.13

D = depth below ground up to limit depth Dc

α = adhesion factor, Figure 2.17

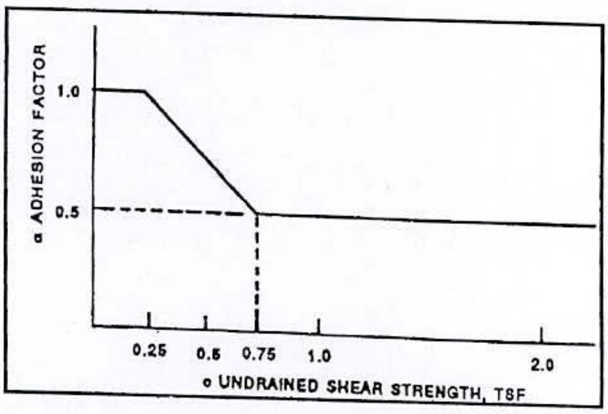
δ = limit value for shaft friction angle from Table 2.14

Table 2.13 common values for lateral earth pressure coefficient, k (after Design of pile Foundations, 1994)

Soil type	Displacement piles		Replacement Piles	
	Compression	Tension	Compression	Tension
Sand	2.0	0.67	1.50	0.50
Silt	1.25	0.50	1.0	0.35
Clay	1.25	0.90	1.0	0.70

Table 2.14 Values of shaft friction angle, δ (after Design of pile Foundations, 1994)

Pile material	δ
Steel	0.67 Φ to 0.83 Φ
Concrete	0.90 Φ to 1.0 Φ
Timber	0.80 Φ to 1.0 Φ



2.4.5

2.4.6

2.4.7

Figure 2.17 Values of α versus undrained shear strength (after Design of Pile Foundations, 1994)

2.4.6 Case Study of Deep Pile Foundation

2.4.6.1 Geotechnical Data

The upper layer between 4.5 and 6.0 m depth is soft organic clay. The layer between 6.0 and 13.75 m depth is silty clay. The layer between 13.75 and 21.50 m depth is fine sand. The SPT-N value of orange clay, silty clay and fine sand layers was found in the range of 2 to 3, 4 to 6 and 22 to 48, respectively. Typical bore log is shown in Figure 2.18. The unconfined compressive strength of organic clay and silty clay was found in the range of 2 to 3, 4 to 6 and 22 to 48, respectively. Typical bore log is shown in Figure 2.18. The unconfined compressive strength of organic clay and silty clay was found in the range of 18 to 90 kPa and 12 to 29 kPa, respectively. Cohesion, c and angle of internal friction, Φ of fine sand layer vary from 5.75 to 7.5 to 7.5 kPa and 29.10 to 32.60°, respectively.

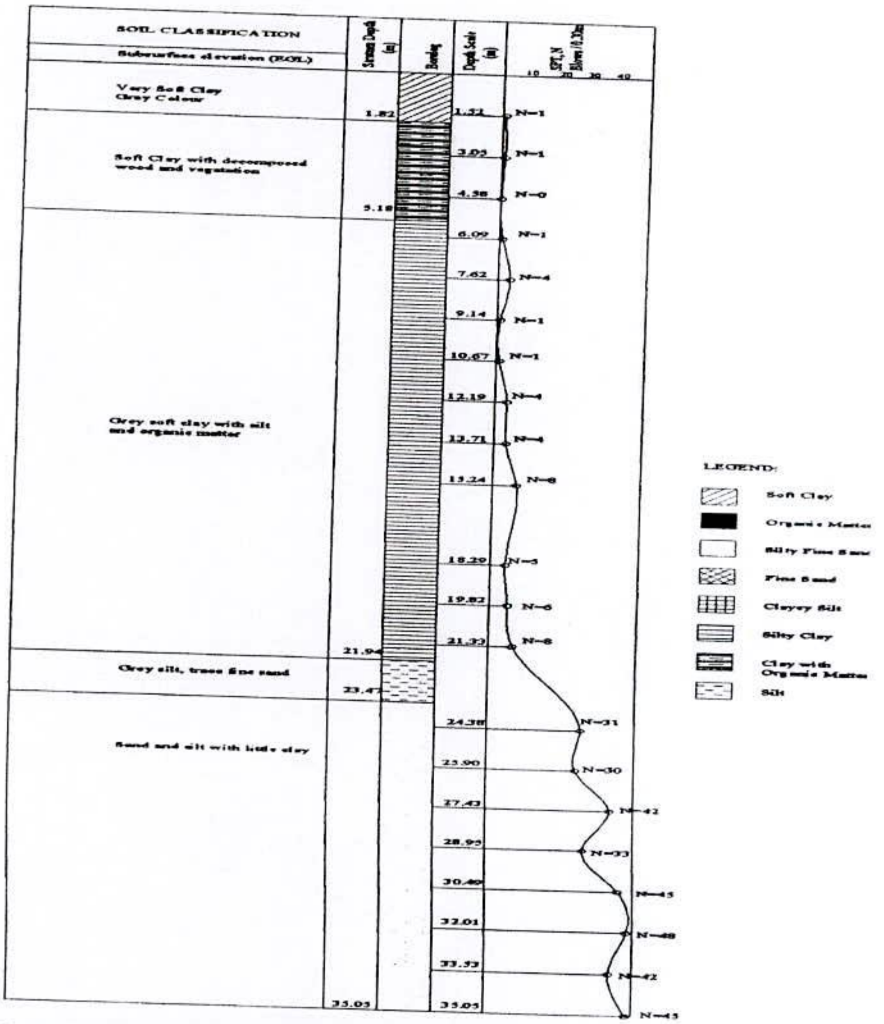


Figure 2.18 Typical borelog at Khulna University campus (after Razzaque and Alamgir, 1999

2.4.6.2 Foundation System

Four-storey residential building was analyzed and designed by Public Works Department (PWD). The foundation system was precast reinforced concrete pile, the effective length of pile was 45'-0" and the dimension of this pile was 12"x 12" , Figure 2.19. The allowable bearing capacity of was 50 kip and the pile is end bearing.

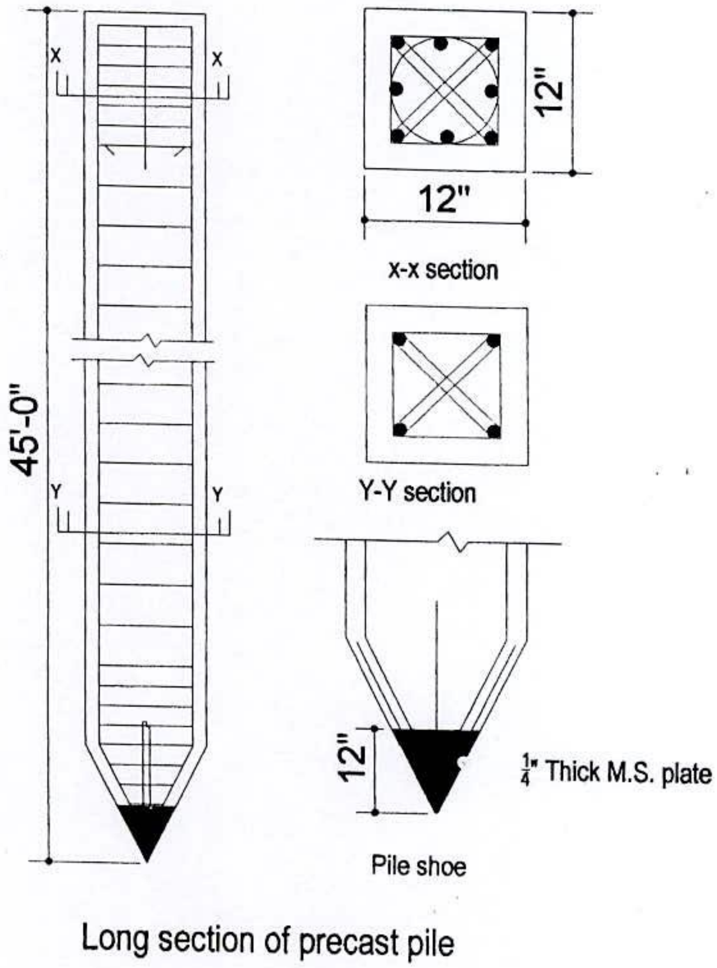


Figure 2.19 Longitudinal section of precast concrete pile (after PWD, 2006)

2.5 Ground Improvement Techniques for the Study Area

In this section, the foundation systems which may be executed in the study area are presented. These are:

(i) Rammed Aggregate Pier (RAP)
(ii) Preloading without vertical drain
(iii) Preloading with vertical drain
(iv) Cut and replacement method
(v) Mattress foundation
(vi) Foundation accommodating large settlement

2.5.1 Theoretical Background of Rammed Aggregate Pier (RAP)

Rammed Aggregate Pier (RAP) is used to improve peat and organic layer. In this method, very stiff short aggregate piers are installed in cavities. The cavity is filled with crushed stone in a number of layers and densified every small layer with high-energy impact rammer. During the densification process, stone chips is pushed laterally into the sidewall of the cavities and the soil surrounded the piers are stressed laterally. These combined actions causes an increase of the confining pressure of the matrix soils, thus providing additional load carrying capacity of the **RAP.**

The pier are designed and constructed to underlie approximately 35% or more of the footing area of the overlying footing. The load carrying capacity of the RAP depends on the friction angle of the material used in the cavities and the amount of confining pressure affording by the surrounding media. Again, the friction angle will depend on the interlocking properties and the relative density of the aggregate. The friction angle of densified crushed stone was measured as high as 50 degrees or more from full-scale field test (Fox and Cowell, 1998).

As the stone chips are pushed laterally into the sidewall of the cavities and the sidewall of the cavities is stressed laterally, strain of the soft soil to some extent can be achieved during the construction of the **RAP.** Because of prestrain, lateral bulging deflection can be minimized under the compression loading of the structure (Handy, 2000). Thus, depending on density and strength of the unimproved soil, the ultimate vertical bearing capacity of a **RAP** element may remain in the range of 100 kips to 300 kips. Typical **RAP** is shown in Figure 2.20.

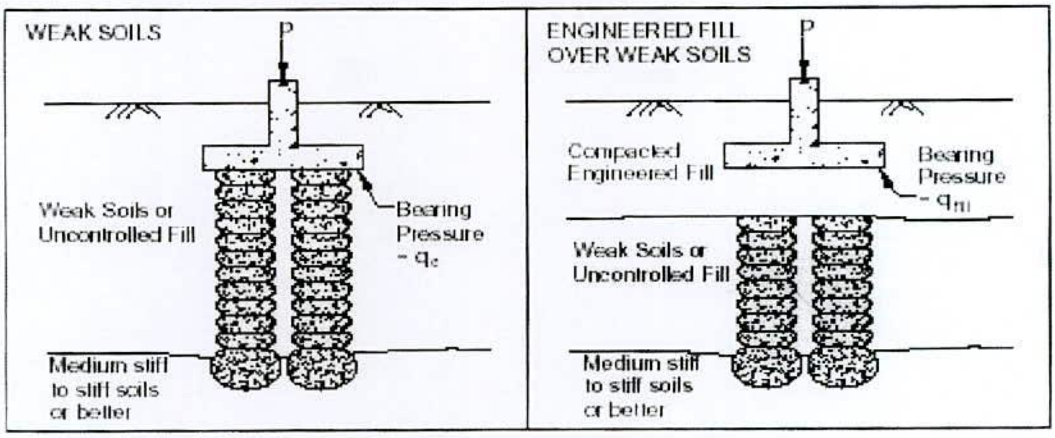


Figure 2.20 Design of RAP foundation (Farrell et al., 2004)

Settlement of the **RAP** supported footing is estimated by assuming that stiff **RAP** elements and soft soil settle uniformly. For equal displacement, stress concentrates on the top of the **RAP** element in proportion to the stiffness ratio of **RAP** to the unimproved soil. In practice, stiffness ratio of **RAP** to native soil ranges from 10 to 50. The long-term settlement can be calculated by using two-zone method, the upper zone (the aggregate pier-matrix soil Zone) and the underlying lower zone, Figure 2.21.

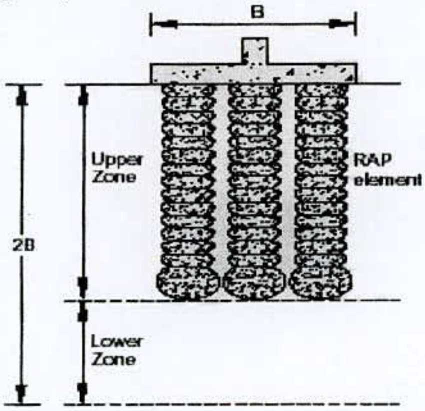


Figure 2.21 Upper zone and lower zone concept (Farrell et al., 2004)

The settlement of the upper zone is:

$$s = \frac{\frac{qR_s}{(R_aR_s + 1 - R_a)}}{k_{gp}}$$

Where, s = Settlement of the Upper-Zone.

q = Footing bearing pressure.

R_s = Stiffness ratio of Geopier element to surrounding soil.

R_a = Ratio of Geopier area to footing area.

K_{gp} = Geopier stiffness modulus.

The settlement component of the lower zone is computed by using conventional geotechnical settlement analysis on the assumption that the vertical stress intensity within the lower zone is the same as that of a bare footing without the stiffened upper zone. The combination of the settlements of these two-zone presents the total long-term settlement.

The RAP foundation system may be appropriate for low to medium rise building structure for the KCC area. In this foundation system, confining pressure along the pier is strengthened by the ramming action and intrusion of aggregate into the surrounding soil. Since the sidewall of the cavities is non-uniform, the bond between RAP and the soil matrix will be more effective. Additionally, below the footing area 35% or more area is covered by RAP i.e. a great portion of the organic clay is replaced by the crushed stone and the remaining portion of it is strengthen by RAP Construction. Therefore, organic layer or interbeded organic layer may not reduce the capacity of the RAP.

The advantage of this technique is that it is very economical. This method can be used in the city urban area without using shore pile and causing other problems. It is very faster method of construction.

The disadvantage is that casings are sometimes required for caving soil conditions. Normally consolidated soft clays that extend more than 30 feet below the ground surface can not be improved due to equipment restrictions.

2.5.2 Case study of Rammed Aggregate Pier (RAP) at Beaverton, USA

2.5.2.1 Geotechnical Data

The top 1.5 m depth layer was uncontrolled fill. The layer between 1.5 and 2.5 m depth was peat. The underlying layer between 2.5 and 4.5 m depth was silt with organic matter. The following layer was firm to stiff silt. The soil profile of the site is shown in Figure 2.22. The Standard Penetration Test (SPT) resistances varied from 3 to 6 blows per foot

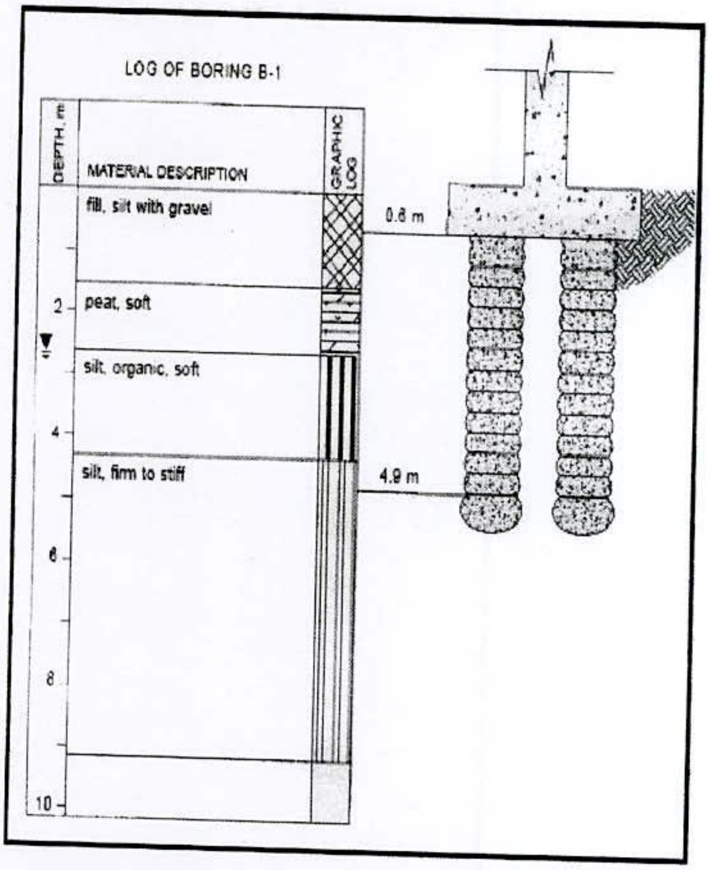


Figure 2.22 Soil profile at site Beaverton, Oregon, USA (after Fox, 2000)

2.5.2.2 Foundation System

The aggregate piers were made by drilling 760 mm (30 inch) diameter holes to the depth of 5.0 from EGL. A small volume of 50 mm down sized crushed stone chips without fines was placed at the bottom of each drilled cavity. This aggregate was the densified with high-energy impact rammer to form the bottom bulb, Figure 2.23. An undulated- sided pier shaft was formed in 300mm (12 inch) thick lift by using well-graded stone chips. The stone chips were further densified by the ramming action. During the process of densification, the stone chips are pushed laterally into the sidewalls of the cavities. This action causes an increase in the lateral stress of the matrix soil. The aggregate pier soil reinforcement method substantially increases the bearing capacity of the reinforced matrix zone and significantly reduces foundation settlement.

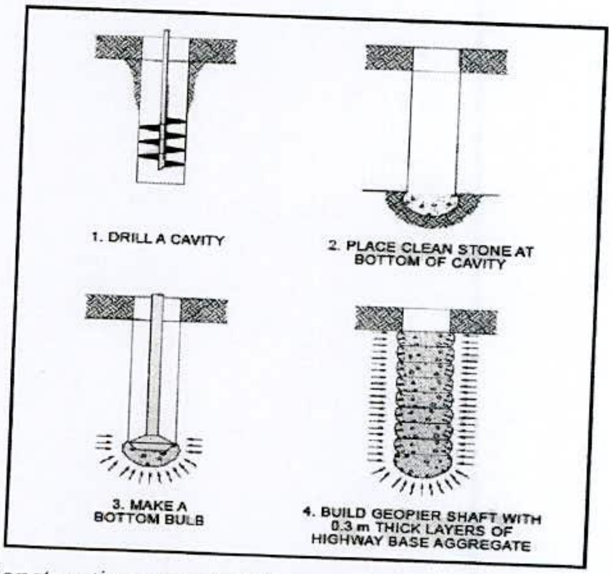


Figure 2.23 Construction process of rammed aggregate pier (after Fox, 2000)

Column loads were moderately heavy for this four-storey office building and ranged from 50 to 400 tons. Modulus load tests confirmed capacities of 40 tons per pier for the relatively long piers up to 7m in length. The piers extended into medium stiff sandy silts through the fills and soft highly organic silt and peat soils. Allowable composite footing bearing pressure was confirmed at the relatively high value of 336 kPa (3.36 tsf)

Soft ground at the campus of Khulna University of Engineering and Technology was improved by using RAP. The ground at the site consists of soft fine-grained soil up to great depth with a layer of organic soils at 4.5 to 9.0 m depth from the EGL. The RAP was cylindrical shape having 0.75 m diameter and 3.40 m length. It was installed manually as single, double and group. Field measurement showed that the ultimate bearing capacity of footing resting of single, double and group RAP treated ground increased by 1.5, 1.8 and 1.96 times, respectively (Hossain, 2007)

2.5.2.3 Performance

The building experienced excellent settlement performance with observed total settlements of less than 20 mm (0.80 in). The modulus load test data indicated that the pier did not bulge appreciably during increased load intensity. The pier provided significant side friction to resist essentially full load up to a stress intensity of about 960 kPa (9.60 tsf).

2.5.3 Theoretical Background of Preloading without Vertical Drain

The simple preloading means that a surcharge equal to a future site load is applied. When consolidation of the foundation soil is practically completed (90% of total settlement), the surcharge is removed and the new building is erected. This ground improvement technique is suitable for normally consolidated soft clay, silt and organic deposit. The functions of preloading are to gain bearing strength and to reduce its compressibility within the time available for the preloading operation.

The initial settlement under the surcharge is,

$$S_{sf} = \frac{C_c}{1+e_o} \text{ H.log} \frac{P_0 + P_1}{P_0}$$

Where, S_{sf} = final settlement due to surcharge

H = thickness of consolidating layer

e_0 = initial void ratio of representative element of soil

C_c = compression index

P_o = initial vertical pressure

P_1 = stress increase due to surcharge

The rate of settlement (vertical condition),

The settlement s_t at time t can be expressed as

$S_t = U_v sf$

Where, U_v is the average consolidation ratio (vertical consolidation)

$$U_v = 1 - \sum_{m=0}^{m=\alpha} \frac{2}{M^2} e^{-M^2 T_v}$$, with m= 0,1,2,3……..

Where $M = (2m+1)\,\pi/2$

$Tv = C_v t / L^2$

t = time, s

C_v = coefficient of vertical consolidation m^2/s

L= Longest drainage path in clay layer, equal to half of H with top and bottom drainage and equal to H with top drainage only.

Terzaghi suggested the following equations for U_v

For U_v = 0 to 53%: $T_v = \frac{\pi}{4}\left(\frac{U\,\%}{100}\right)^2$

For $U_{v=}$ to 100 % : $T_v = 1.781 - 0.933\,[\log(100\text{-}U\,\%)]$ (after Das,1985)

2.5.4 Case study of Preloading without Vertical Drain

2.5.4.1 Geotechnical Data

The site was 150 km northwest of Athens, Greece, on a coastal plain of moderate seismic activity. The building location was covered by marshland, the referenced to low sea level was + 0.30m. Previous industrial installation adjacent to this site had been founded on 12-16 m piles. The area plan of the building was 144m long, 33 m wide and 16 m high, Figure 2.24. It was used to store ore, in heaps up to 14 m high, weighing 21.6 kN/m^3, and having an angle of repose of 40°.

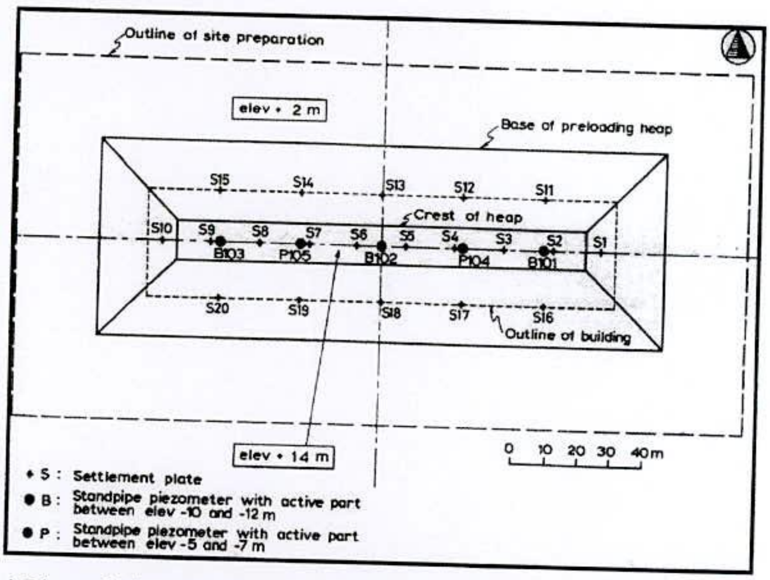


Figure 2.24 Plan of site preparation (after Stamatopoulos and Kotzias, 1985).

Five boreholes showed recent random deposits of soft and compressible soils, as far down as elevation- 10.9m, Figure. 2.25, with some increase in strength below-9.5m.

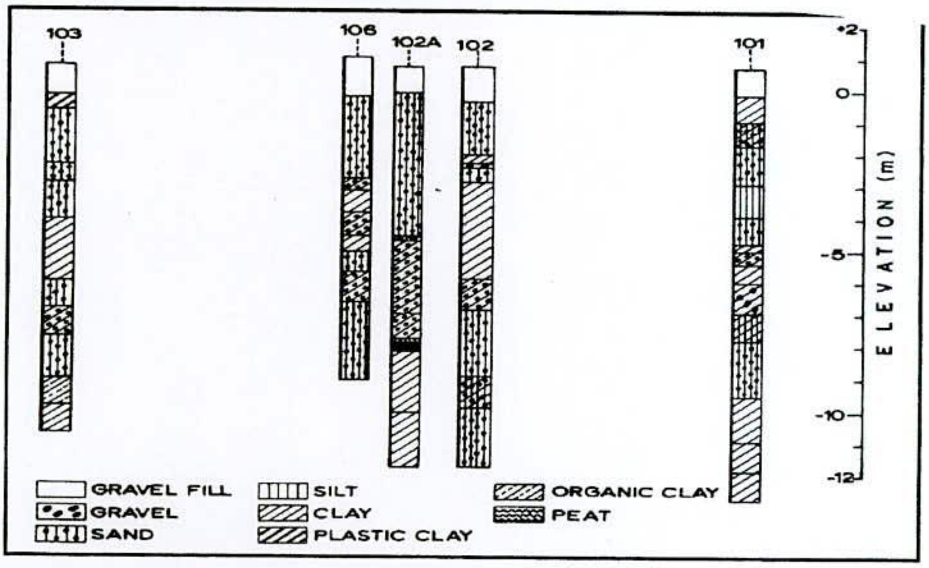


Figure 2.25 Boringlogs at coastal plain (after Stamatopoulos and Kotzias, 1985).

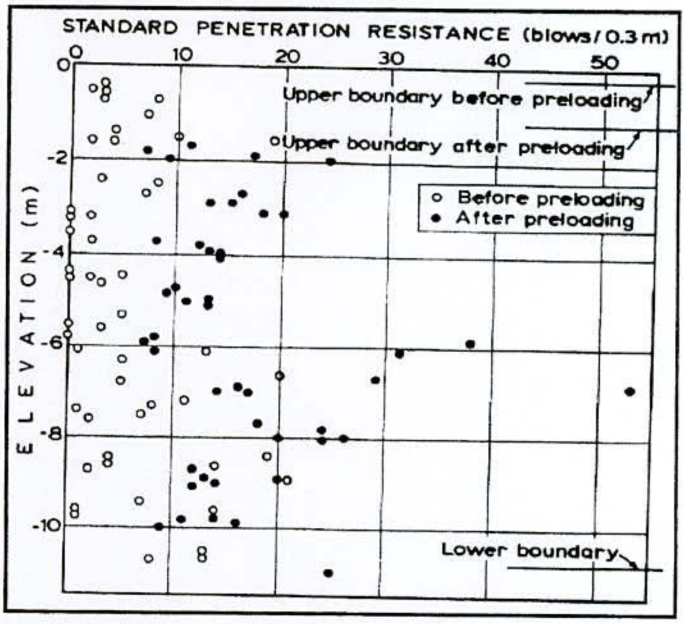


Figure 2.26 Standard penetration resistance versus elevation (after Stamatopoulos and Kotzias, 1985).

Starting at-10.9 m, there was layer of very stiff clay (**CL**) of different provenance and older geologic age. The soil types, the results of standard penetration test was shown in Figure 2.26

2.5.4.2 Foundation System

The decision was taken to preload the site by creating 12 m height embankment of total earthwork volume 65000 m^3. The preload was 1.8 times of the permanent structure. The resulting settlement under the preload were expected to be 0.76 m along the centerline and 0.48 m along the footings.

2.5.4.3 Performance

The improvements of the soil were as follows:

1. The water table showed a rise, from elevation +0.4m before preloading to +0.80m after preloading. The upper boundary of soft soils moved from about elevation- 0.30 m to about elevation -1.2 m. The lower boundary did not show much movement and remained at about elevation -10.90m.

2. The N value increased from an average 0, 6 blows/0.3m before preloading to 16 blows/0.30 m after preloading, that it is increased by 168% . The zero and other very low values (16 results of 0,1 and 2 blows/0.30 m) that were observed before preloading were completely eliminated, the lowest value observed after preloading being 7 blows/0.30m.

3. The increase is about the same for cohesive and cohesion less soils.

4. The in-situ permeability was decreased nine fold from mean value o 2.9 x 10^{-5} m/sec.

5. The mean value of the water content dropped from 31.5 to 26.90 %, which corresponds to a change of the dry density approximately from 1460 to 1560 kg/ m^3 . This result implies a reduction in volume by about 7% .

6. The shear strength of clay determined from triaxial UU test increased three fold. In case of CU tests, the mean value changed from 54 to 85 kN/m^2.

2.5.5 Theoretical Background of Preloading with Vertical Drains

In a case where the rate of primary consolidation is too slow, the natural drainage layers are supplemented by the installation of vertical drains. The vertical drain consists of sand drains or prefabricated wick drains. The pattern of vertical drain and vacuum technique are shown in Figure 2.27 and Figure 2.28, respectively.

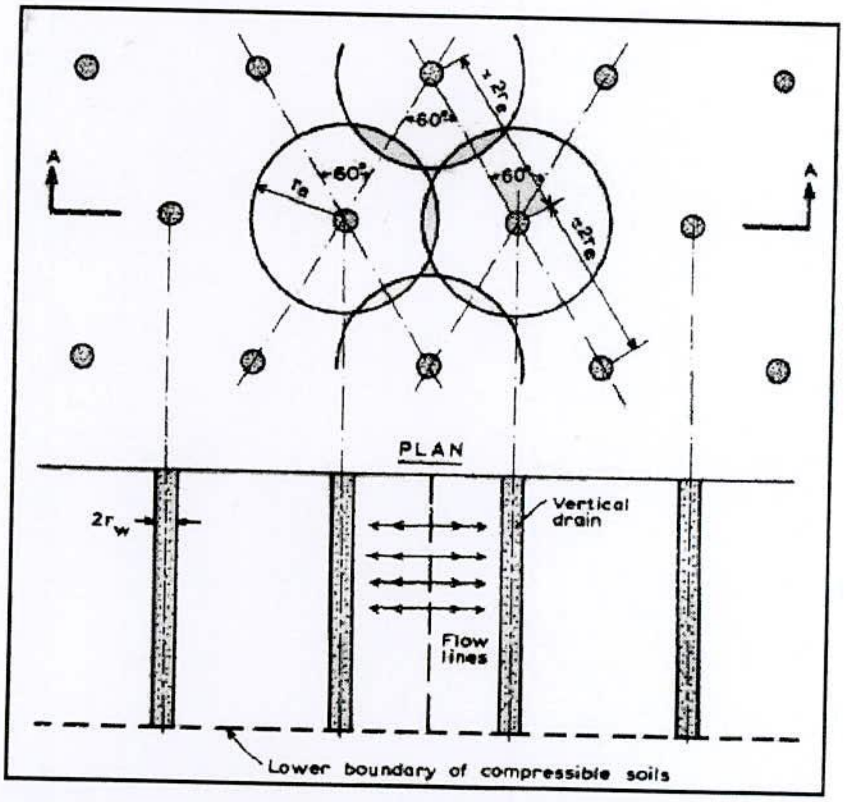


Figure 2.27 Pattern of equidistant drains (after Stamatopoulos and Kotzias, 1985).

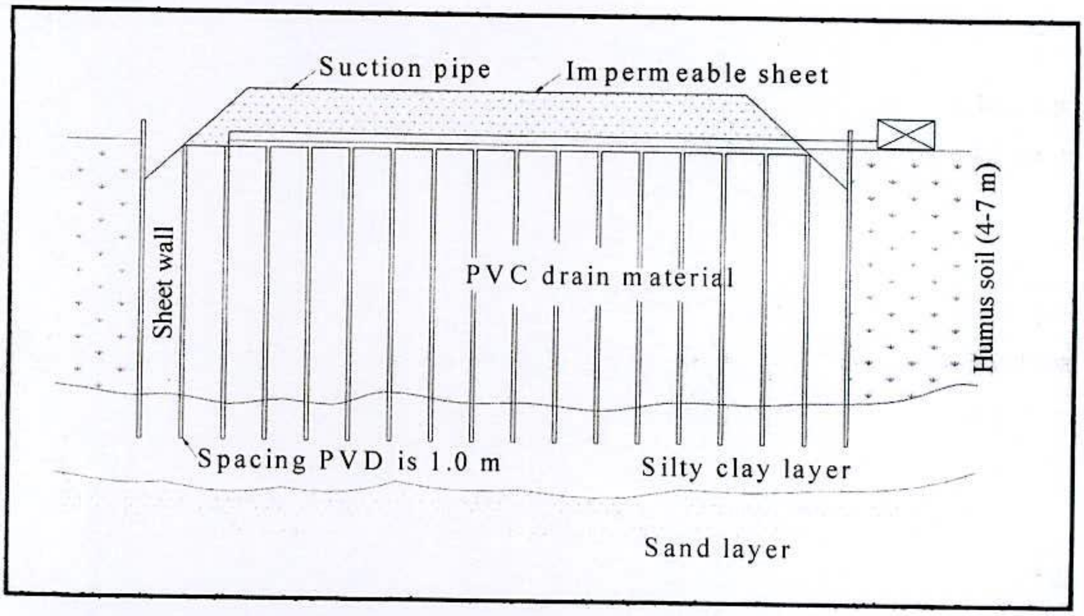


Figure 2.28 Vacuum technique used at Hazawa station, Japanese national railway (after Lee et al., 1993).

$$\frac{\delta u_e}{\delta t} = c_R\left(\frac{\delta^2 u_e}{\delta r^2} + \frac{1}{r}.\frac{\delta u_e}{\delta r}\right)$$

where, $c_R = \frac{m_v k_h}{\gamma_w}$

c_R = the coefficient of consolidation for radial drainage

k_H = the coefficient of permeability in horizontal direction

The solution for equal vertical strains is given by

$$U = 1 - e^{-2T_R / F(n)}$$

Where, U is the average consolidation ratio

$$T_R = \frac{C_R}{r_e^2}.t$$

$$F(n)\frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2} \text{ and } n = \frac{r_e}{r_w}$$

2.5.6 Case study of Preloading with Vertical Drains

The effectiveness of sand piles in improving a typical soft ground at south western region of Bangladesh to construct a water control structure (6-vent regulator) in a river was examined. At the site, a soft alluvium fine-grained soil deposit exists up to 12m depth from the ground surface. The site was improved by total 765 numbers of sand piles, 0.20 m in diameter and 8.80 to 9.40 m long, installed in square grid at 0.75 m spacing by vibro-displacement method. Typical sand of Bangladesh, Sylhet sand, is used in the sand pile. Prior to the commencement of concreting for floor construction of regulator, subsoil explorations were performed to examine the improvement. The investigation reversals that the sand piles substantially improved the bearing capacity of the natural ground. Therefore, the soft ground improvement using sand pile technique is revealed as fast, economical and an efficient method to improve weak soil compare with other conventional ground improvement technique. The use of smaller diameter with close spacing was found suitable in such soft soil deposits for the vibro-displacement type of sand pile construction while comparing the construction problem arises for the installation of large diameter due to the development of side friction (Hossain, 2007)

2.5.7 Cut Replacement Method for foundation in Khulna University Building.

2.5.7.1 Geotechnical Data

The subsoil formation of the Khulna University area shows the top 1.8 m thick layer consists of very soft clay. The underlain layer between 1.8 m and 5.20 m from EGL is soft clay with decomposed wood and vegetation. The layer between 5.20 m and 22.0 m From EGL is soft clay with silt and organic matter and the following layer between 22.0 m and 35.05 m from EGL is the combination of fine sand with silt and clay, Figure 2.29.

The unconfined compressive strength, natural moisture content, liquid limit and SPT-N value of the upper 14m thick soft clay layer varied from 20 to 28 kN/m2, 41 to 134 %, 50 to 75 % and 0 to 4, respectively, The presence of organic matter for the layer between 3 to 4.0 m depths from EGL varied from 42.79 to 49.81%.

2.5.7.2 Foundation System

The mat foundation for the four-storey Khulna University Building was constructed over compacted sand fill after removal of 4 m soft ground. The filling sand was a mixture of two different sand of fineness modulus 2.2 and 1.2 at a ratio 1:1 and compacted properly by sheep foot roller. During compaction, the optimum water content and the lift of sand layer were 14 to 15% and 230 mm, respectively. The RCC mat of 305mm to 457 mm thickness was cast over this mixed compacted sand- filling layer. Detail of the foundation system is shown in Figure 2.30

2.5.7.3 Performance

Razzaque and Alamgir (1999) studied the long-term settlement of this building during the time period between February 1994 and March 1999, Table 2.15. The variation of settlement (mm) with time (days) is shown in Figure 2.31. The Table 2.15 and Figure 2.41 show that the building settled by 508 mm during one and a half year construction period. After this construction period, the building further settled by 252 mm within the next four and a half year and almost no settlement appeared after this time period. The pattern of relative settlement was uniform and maximum angular distortion remained 1/1299, which was far below the allowable limits. The above findings demonstrate that cut and replacement method may successfully reduce differential settlement of low-rise buildings, which was built over soft clay. Here, the sand filling layers acted as stiffening medium to distribute the building loads uniformly.

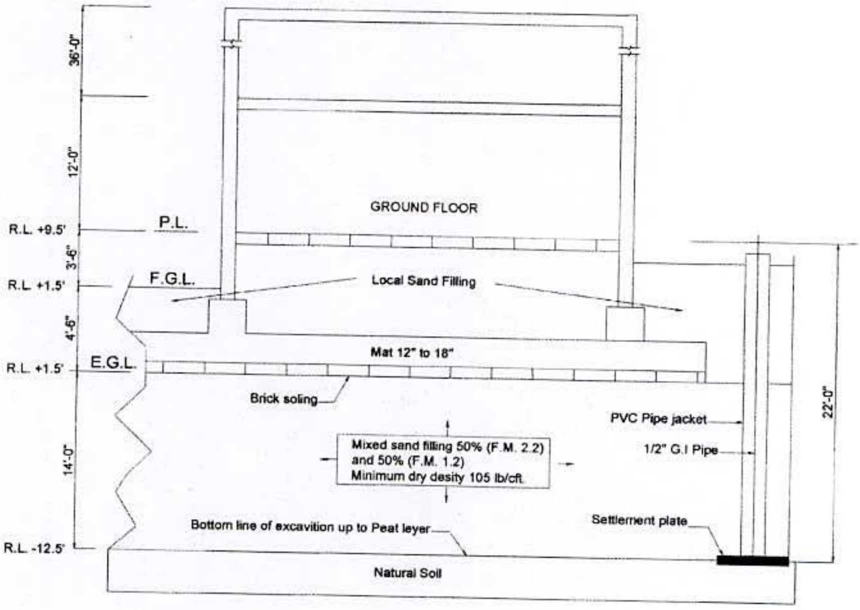


Fig. 2.29 Mat foundation on engineered fill for academic building-I at Khulna University area (after Razzaque and Alamgir, 1999).

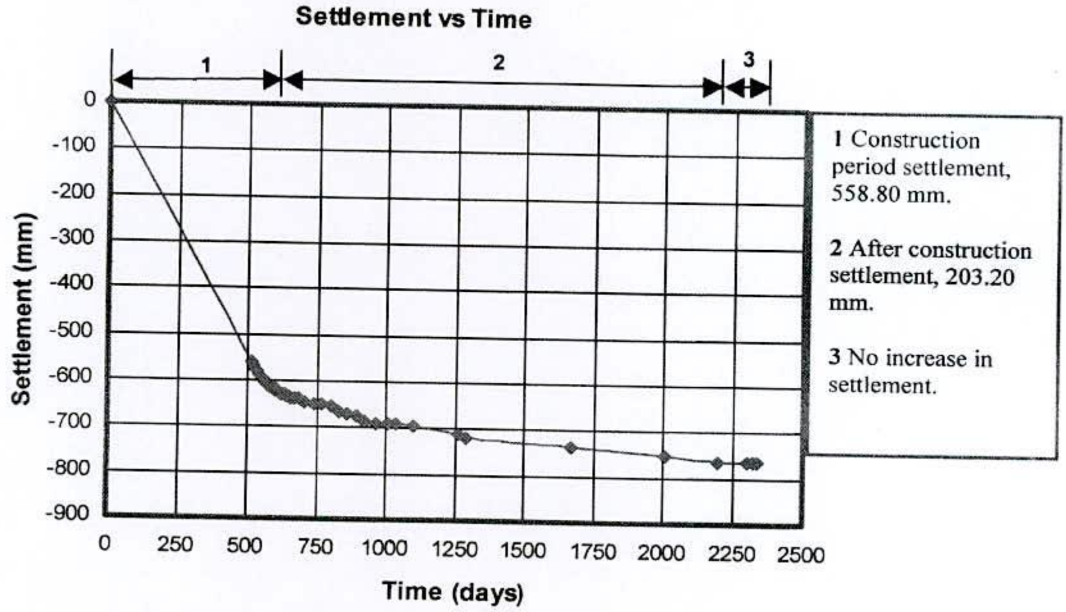


Fig. 2.30 Observed settlements with respect to time of Academic Building–I at Khulna University (after Razzaque and Alamgir, 1999).

Table 2.15 Records o foundation settlement for Academic Building-I (after Razzaque and Alamgir, 1999).

Date	Elapsed time	Settlement,	Date	Elapsed time	Settlement
	days	mm		Days	mm
01-Nov-1992	0	0	Continuation of records		
27-Apr-1994	515	-557.78	29-Sep-1994	672	-635.51
05-May-1994	524	-556.93	12-Oct-1994	685	-637.03
12-May-1994	531	-576.07	03-Nov-1994	706	-644.65
16-May-1994	535	-580.64	04-Dec-1994	737	-647.70
25-May-1994	544	-586.74	03-Jan-1995	767	-649.22
02-Jun-1994	552	-592.84	07-Feb-1995	802	-653.80
09-Jun-1994	559	-595.88	09-Mar-1995	832	-664.46
16-Jun-1994	566	-603.50	03-Apr-1995	857	-669.04
23-Jun-1994	573	-608.08	09-May-1995	893	-675.13
29-Jun-1994	580	-611.12	11-Jun-1995	926	-687.32
08-Jul-1994	589	612.65	22-Jun-1995	967	-690.37
15-Jul-1994	596	-615.70	31-Jul-1995	1006	-691.90
21-Jul-1994	602	-618.74	31-Aug-1995	1037	-691.90
28-Jul-1994	609	-620.27	02-Nov-1995	1100	-696.47
04-Aug-1994	616	-624.84	11-Apr-1996	1260	-711.71
11-Aug-1994	623	-627.89	11-May-1996	1290	-719.33
18-Aug-1994	630	-629.41	26-May-1997	1670	-737.62
24-Aug-1994	636	-629.41	01-May-1998	2010	-752.86
01-Sep-1994	644	-630.94	04-Nov-1998	2195	-765.05
08-Sep-1994	651	-633.98	11-Feb-1999	2305	-765.05
15-Sep-1994	658	-635.51	28- Feb-1999	2322	-765.05
25-Sep-1994	668	-635.51	16-Mar-1999	2338	-765.05

2.5.8 Mattress Foundation for Boy's Hostel Building in Khulna Medical College Area.

2.5.8.1 Geotechnical Data

A generalized soil profile of the project site is presented in Figure 2.32. The DPL (Dynamic Probing Light) test were conducted to ascertain the depth of soft top layer more precisely.

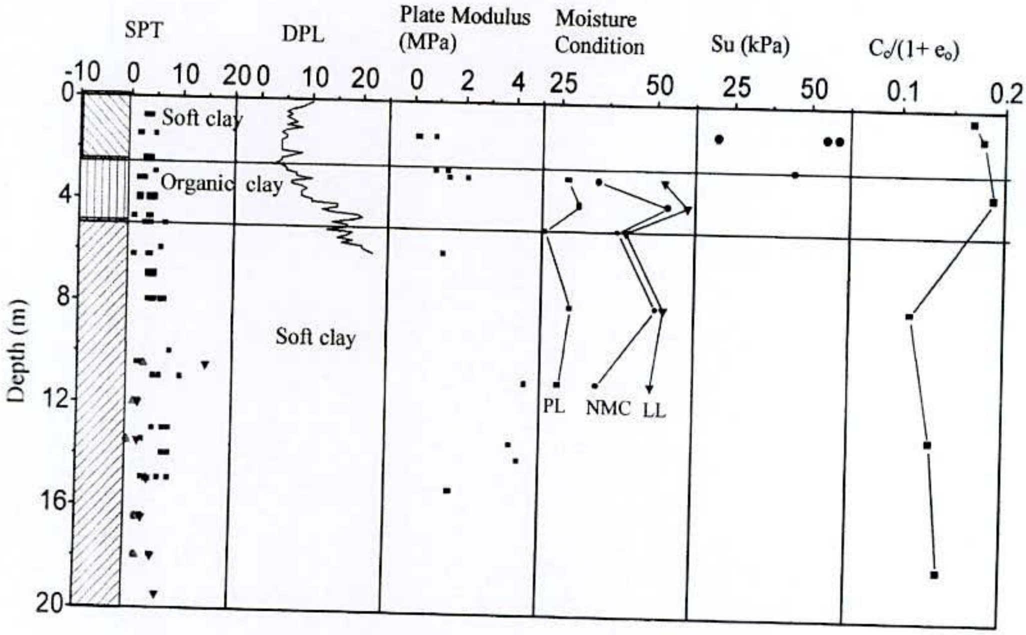


Fig. 2.31 Typical borelog at Khulna Medical College (after Kabir et al., 1997)

2.5.8.2 Foundation System

Granular mattress used in column and wall footing were designed and constructed for KMC building, Figure 2.33 and Figure 2.34. The function of granular mattress can be described as the following. (a) Increase in bearing capacity by allowing very fast dissipation of pore pressure, especially from the region immediately underneath the geotextile layer. (b) Distribution of stress over a large area. (c) Minimize total and differential settlement.

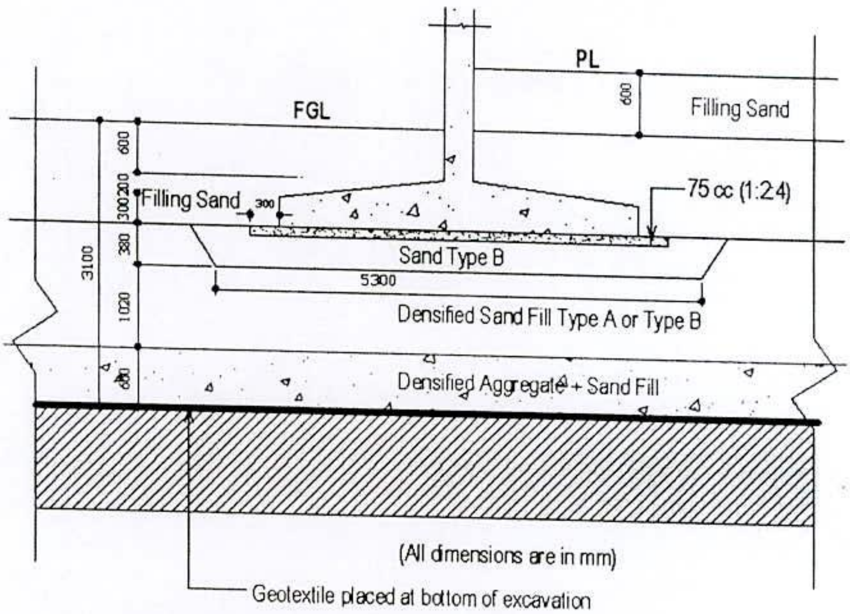


Fig. 2.32 Detail of column footing on mattress (after Kabir et al., 1997).

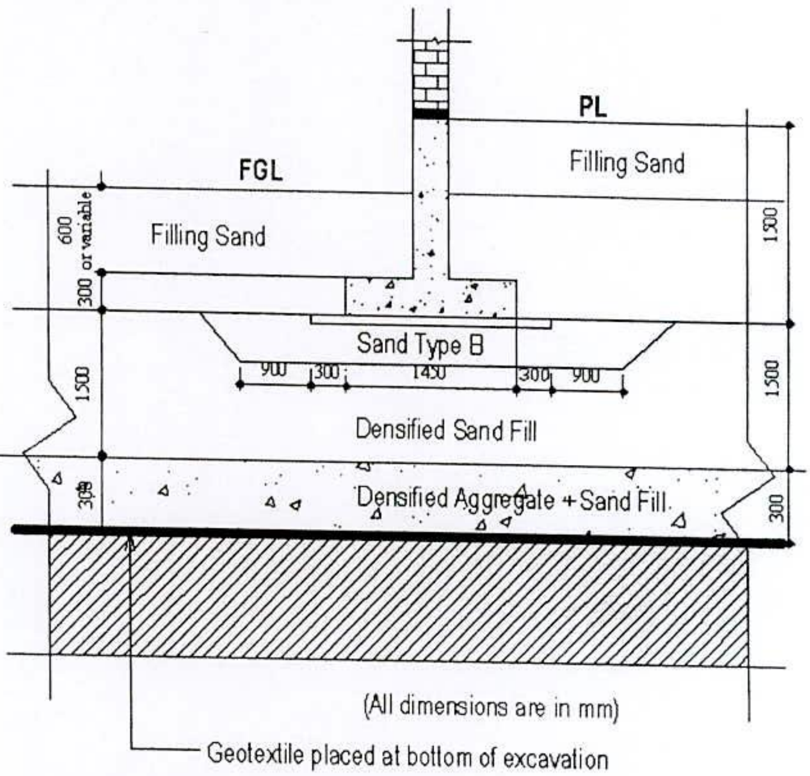


Fig. 2.33 Details of wall footing on mattress (after Kabir et al., 1997).

The aggregate layer consisted of two parts crushed brick aggregates and one part course sand. The crushed brick aggregate consisted of 25mm down graded aggregate conforming to the ASTM grading for concrete aggregates. The coarse sand consisted of river sand called Sylhet sand, having fineness modulus ≥ 2.5.

The fill layer consisted local sand having Fineness Modulus (FM) greater than 1.0. Fines passing number 200 sieve was limited to 5 % for FM up to 1.5 and 10% for FM greater than 1.5. The sand and aggregate were densefied in layers by using twin steel drum vibratory rollers. The densities of the materials were monitored by TRL dynamic penetrometer.

A geotextile separator and filter layer was placed at the bottom of the excavation of the soft clay layer. A non woven needle punched geotextile was used. The weight, grab tensile strength and permeability were greater than or equal to 200 gsm, 750 Newton and 1×10^{-3} m/s, respectively.

The modulii values of the aggregate layers were established from TRL phynetrometer tests and its indirect correlation with modulii. The modulii values for the clay layers were calculated from the undrained shear strength, consolidation and screw plate load testes. For the clays both undrained and drained modulii were calculated. Typical values for sands, aggregates and clay layers are presented in Table 2.16. The modulus of sub grade reaction of wall and column footing are presented in Table 2.17.

Table 2.16 Elastic modulii for the aggregates and clay layers (after Kabir et al., 1997)

Aggregates/clay		Modulii (MPa)
Sand		50
Coarse aggregates		80
Clay	Undrained	3.0
	Drained	1.0

Table 2.17 Modulus of sub grade reaction for wall and column footings (after Kabir et al., 1997)

Modulus of subgrade reaction	Value in kN/m^3
K_u	4240
K_d	1920
K_{um}	13180
K_{dm}	8970
K_u	1310
K_d	600
K_{um}	2170
K_{dm}	1250

2.5.8.3 Predicted Performance

Continuous inverted Tee beam type footings were used for load bearing walls and continuous tapered footings were used for column foundations of framed structures. A beam on elastic foundation program based on finite element analysis developed by Hulse and Mosley (1986) was used to analyze both the types of footings. Settlement and distortion under working load dictated the proportioning and design of the footings. The deflection of the footings for the foundation cases for wall and column footings are presented in Figures 2.35 and Figure 2.36, respectively.

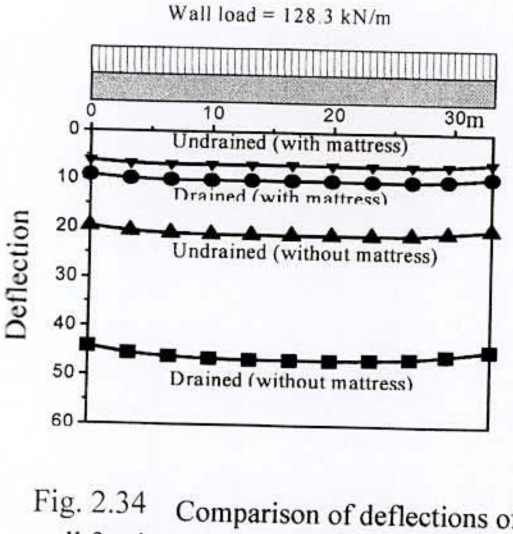


Fig. 2.34 Comparison of deflections of wall footing (after Kabir et al., 1997)

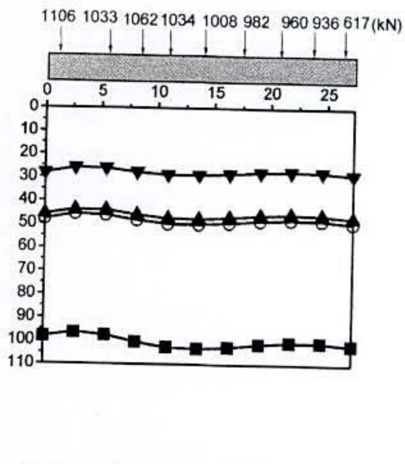


Fig. 2.35 Comparison of deflections of column footing (after Kabir et al., 1997).

Four cases of foundations were considered to provide a comparative representation of cases with and without mattress foundation as well as those under undrained and drained conditions. The results in Figure 2.35 were for an inverted Tee beam wall footing, 1.45 m wide, 33.2m long having 250 mm wide web and 300 mm thick flange. The findings showed that provision of the mattress reduced the settlement to less than 1/3, Figure 2.36 showed the results of a typical strip footing for carrying column loads. The footing was 5.3 m wide, 410 mm deep and 27.3 m long. The concluding findings were that provision of mattress foundation reduced the total and differential settlement into half than the foundation system without mattress.

2.5.9 Shallow Foundation Accommodating Large Settlement

Navy engineers of U.S.A designed a shallow foundation system that allowed 3 ft of settlement. The design minimizes the risk of foundation failure without a pile system, while saving about $ 2.20 million. The project was three separated one-story buildings with ceiling heights of 23 ft. Maximum wall load was 5 kips per linear ft and the maximum bearing wall span is about 140 ft. The building finished grade was at about 6 ft above the original ground surface.

2.5.9.1 Geotechnical Data

The sub soils consisted of 4 ft of recent medium dense silty in sand, 55 to 60 ft of soft silty clay with slight organic content and the dense silty sand extending to 120 t deep, Figure 2.37. The results of soil testing showed that silty clay material to have been normally consolidated and to have high compressibility characteristics.

2.5.9.2 Foundation System

Settlement analysis indicated that the ultimate settlement resulting from the fill load alone was approximately equal to 33 % of the height of the fill placed. To use sand drains along with preloading by surcharge to accelerate settlement would require longer period for a substantial settlement to take place. To use pile foundations to avoid large settlement of the building would have cost 400,000 US dollar for pile alone. Furthermore, support of these buildings on piles, while allowing the surrounding ground to subside would create untoward operation and maintenance problems.

A foundation system consisting of strictly controlled engineered fill placed on a firm stone base and inverted " T'' shaped footings were considered for the support of the buildings. Compacted structural fill, which would act as a relatively rigid mat, could be placed over the thick clay soil to support the proposed buildings. To promote uniform settlement of the structural fill, a 2ft thick layer of crushed stone, ranging from 2 to 6 inch in size was placed on the existing ground to increase the overall rigidity of the fill.

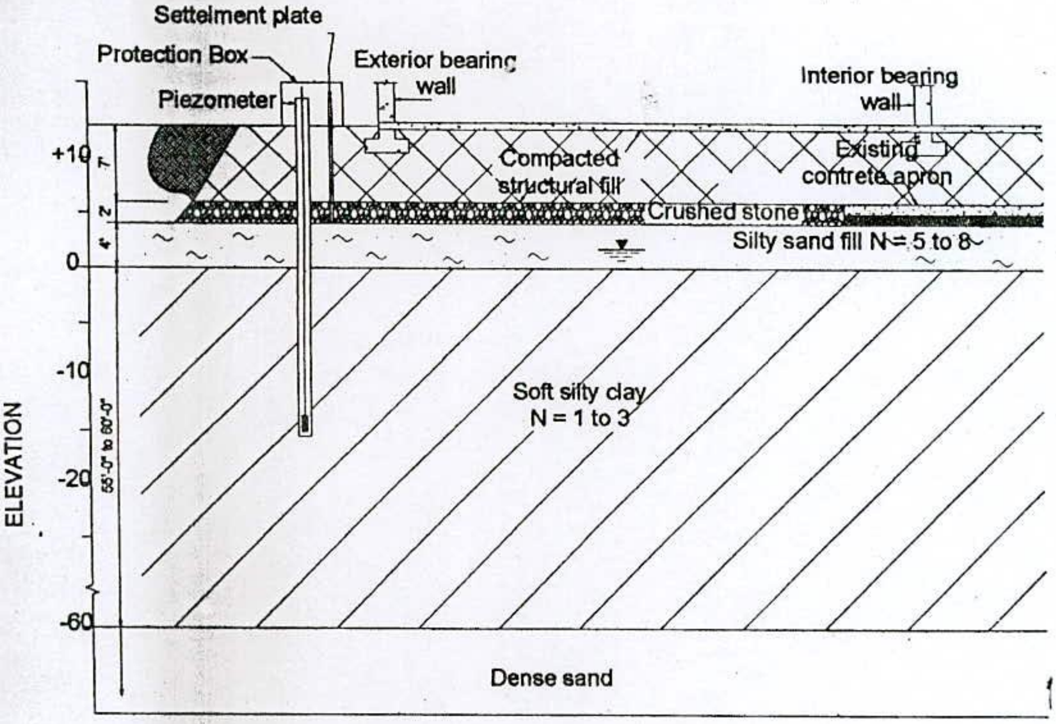


Figure 2.37 Compacted was placed on a 2-ft thick layer of crushed stone (after Wu and Scheessele, 1982).

The footings were designed as inverted " T'' shaped grade beams. These inverted "T'' shaped footings were sized and reinforced to provide the strength required to carry the superstructure , Figure 2.38.

The structural system for the super structure is load bearing masonry walls (composite brick and concrete masonry unit) and open web joists for the partial second floor and the floor. The masonry walls are not flexible in terms of accommodating differential settlements. The wall footings were designed to be rigid enough to bridge over or otherwise resist differential settlements in the event that the footing lose support or a span of 20 ft or a cantilever span of 10 ft such as at a building corner. Considering these potential footing sub grade problems, the inverted " T " beam footing sizes and reinforcing were selected so as to provide the strength and effective moments of inertia required to resist footing deflections.

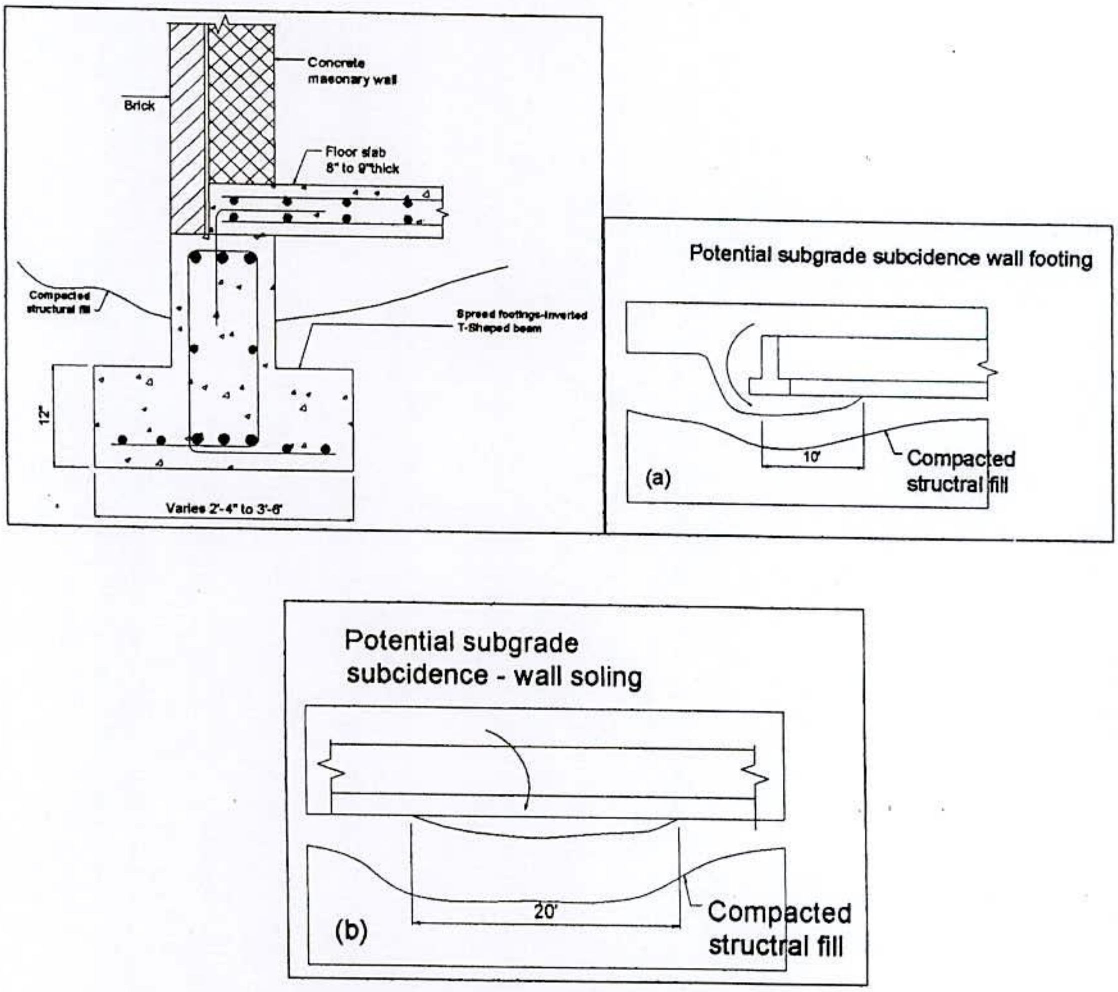


Fig. 2.37 "T" shaped grade beams footings (after Wu & Scheessele, 1982).

2.5.9.3 Performance

The construction of this project began in August 1976. The average rate of settlement measured after completion of the buildings was about 3 in. per year, which is about 16 % higher than prediction by analytical results. From the beginning of the project on March 1981, the average and maximum settlements were about 1.3 and 1.58 ft. respectively. No wall cracks or structural distress of the buildings has occurred.

CHAPTER III

Sub-Soil Characterization

3.1 General

Field and laboratory tests data obtained form 123 boreholes at 53 locations in and around the KCC area are analyzed to develop a soil profile along the north south section of the study area. For characterization of geotechnical properties of the study area, the field and laboratory data were collected from Consultancy, Research, and Testing Services (CRTS) of Khulna University of Engineering and Technology (KUET). All sites are shown in the Table 3.1.

Table 3.1 List of Sites for Soil Investigation

Site No.	Zone	CRTS, KUET Ref. No.	Total Boreholes	Address/Location
1	North	B-289	3	Afilgate
2	North	B-187	3	Cable Shilpa Ltd. Shiromoni
3	North	B-237	3	Police Training Centre, Shiromoni
4	North	B-086	2	Police Barqak, Shiromoni
5	North	B-000	2	KUET, Fulbarigate
6	North	B-083	3	KUET, Fulbarigate
7	North	B-247	3	KUET Road, Fulbarigate
8	North	B-164	2	Mr Abul Khaer, Fulbarigate
9	North	B-117	3	Mirerdanga, Fulbarigate
10	North	B-241	3	Mirerdanga, Fulbarigate
11	North	B-059	2	Baby Home, Moheshorpasha
12	Middle	B-036	3	Nasir Hospital , Goalkhali
13	Middle	B-040	2	Setara Begum, Muzjunni
14	Middle	B-160	3	Palpara Road , Khalishpur

Table 3.1 List of Sites for Soil Investigation

Site No.	Zone	CRTS, KUET Ref. No.	Total Boreholes	Address/Location
15	Middle	B-261	3	Fire Service Station, Khalishpur
16	Middle	E-002	3	Hardboard mill , Khalishpur
17	Middle	E-005	3	North Zone Housing State, Khalishpur
18	Middle	E-004	2	Co-ooperative training centre, Boyra
19	Middle	B-125	3	Imam Training Centre, Boyra
20	Middle	B-266	3	Md Nazrul Islam, Muzjunni
21	Middle	B-221	3	Navy Colony, Boyra
22	Middle	B-283	3	DIG Office, Khulna
23	Middle	B-107	3	Regional PATC, Boyra
24	Middle	B-114	3	Environmental Research Centre
25	Middle	B-063	2	Medical College, Boyra
26	Middle	B-161	2	Srudent Hostel, Medical College, Boyra
27	Middle	T-199	2	MTTC, Khulna
28	Middle	B-062	2	Residence of OC , Sonadanga
29	Middle	B-082	3	Mdormitory of Female Police, Zoragate
30	Middle	B-169	3	Shishu Sadan , Khulna
31	Middle	B-197	3	ICMA, Sonadanga
32	Middle	B-222	2	Sonadanga Thana
33	Middle	B-225	3	Khulna Thana Quarter
34	Middle	B-233	3	Female TTC Khulna
35	Middle	B-254	2	Modina Trading, Ghat No-4
36	Middle	B-252	3	Diabetic Hospital, Khulna
37	Middle	B-274	3	KDA Plot No-32, Sonadanga
38	Middle	E-001	3	KDA Community Centre
39	Middle	B-285	3	Sonadanga, Khulna
40	Middle	B-255	3	Adv. Abdur Rahman, HMM Road, Helatola

Table 3.1 List of Sites for Soil Investigation

Site No.	Zone	CRTS, KUET Ref. No.	Total Boreholes	Address/Location
41	Middle	B-128	3	Blind Hospital, Helatola
42	Middle	B-111	3	Tibbet Market, Helatola
43	Middle	B-028	3	Iqbal Road, Khulna
44	Middle	B-184	1	H-43, Khanjahan Ali Road, Tarerpukur
45	Middle	B-236	2	HMM Road, Khulna
46	Middle	B-260	3	Opsonin Office Building, Sheikhpara
47	South	B-179	2	Khulna University Prof. Quarter
48	South	B-203	3	Khulna University Building
49	South	B-126	2	Chandmari, Khulna
50	South	B-253	2	Rokeya Khatoon , Farazipara
51	South	B-001	1	Chandmari, Khulna
52	South	B-037	3	Labanchara, Khulna
53	South	E-003	3	Baniakhamar, Khulna

3.2 Identification of Sub-Soil Formation

Based on the geotechnical data obtained, the study area is divided into three zones namely North Zone, Middle Zone and South Zone. The North Zone covers from Afil Jute Mill area to Mohesherpasha area, the Middle Zone covers from Daulatpur area to Sonadanga area and the South Zone covers Gollamari, Chandmari, Rupsha areas. Unified Soil Classification System, USCS- ASTM D 2488, ASTM D-2487 and Visual - Manual Procedure were used to identify and classify the soil of the study area. Soil profiles with USCS symbols and SPT values along the North- South section are presented in the Appendix-A. The map of the Khulna City Area is shown in the Fig. 3.1.

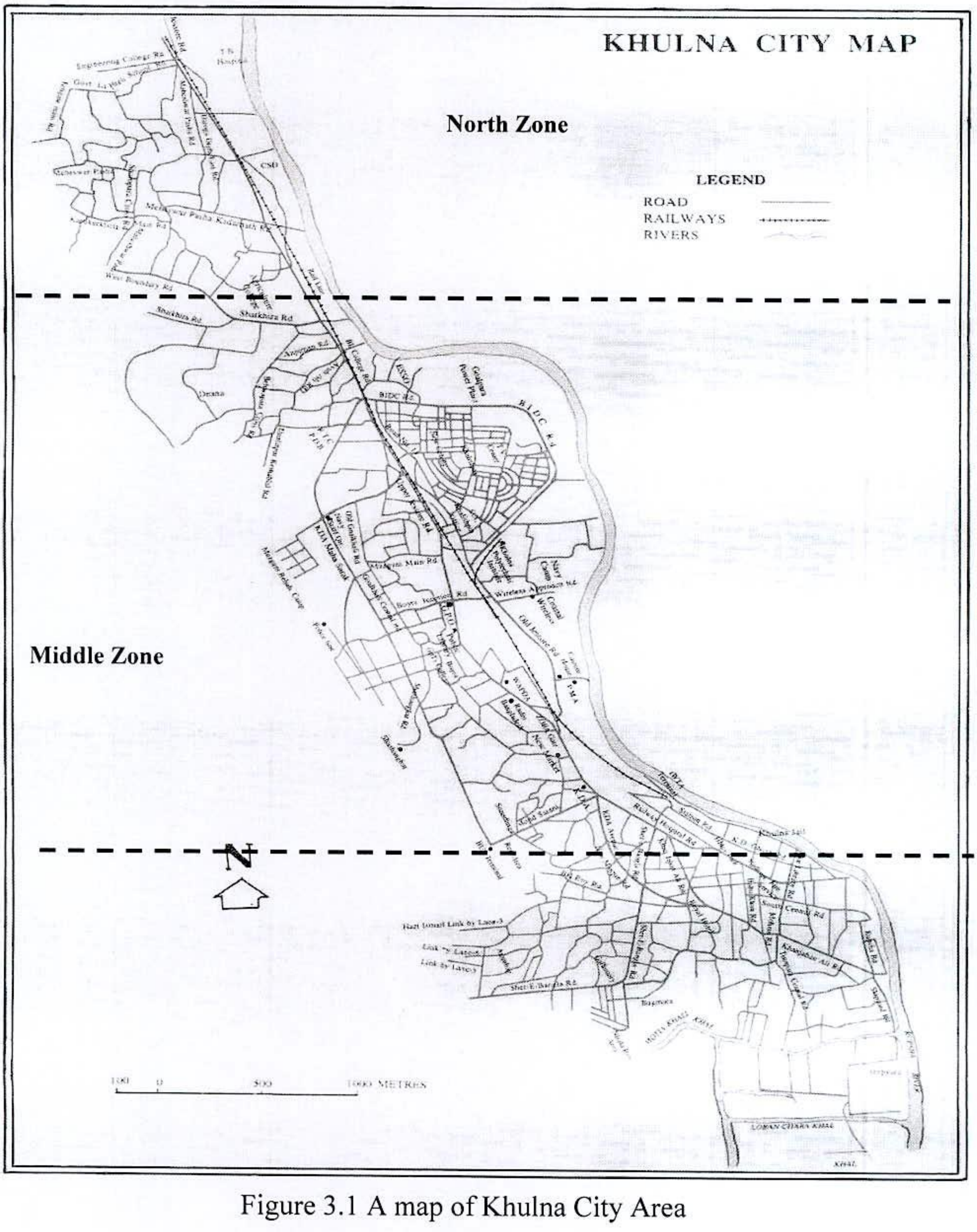


Figure 3.1 A map of Khulna City Area

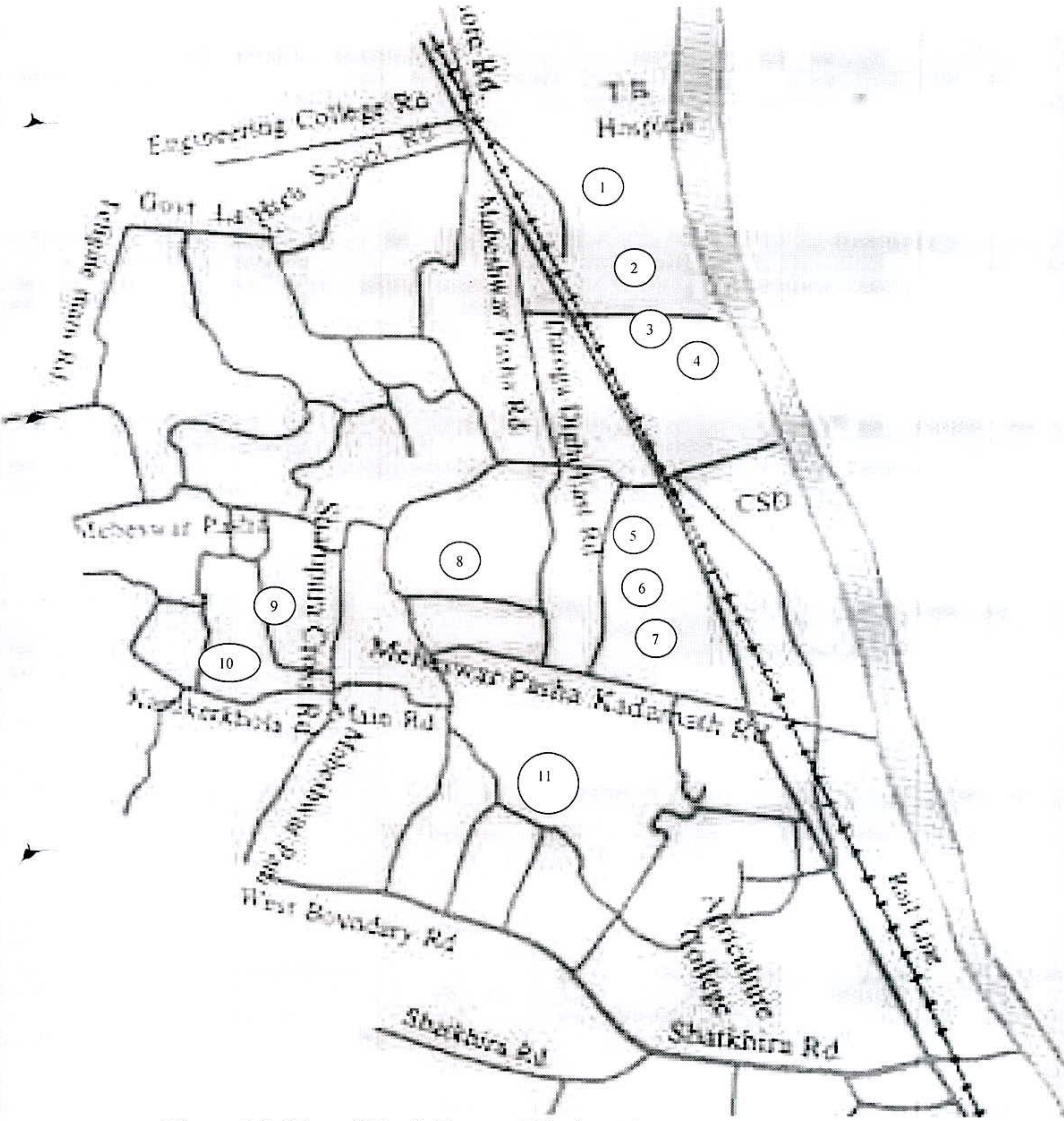


Figure 3.2 Map of North Zone of Khulna City Corporation

Figure 3.3 Map of Middle Zone of Khulna City Corporation

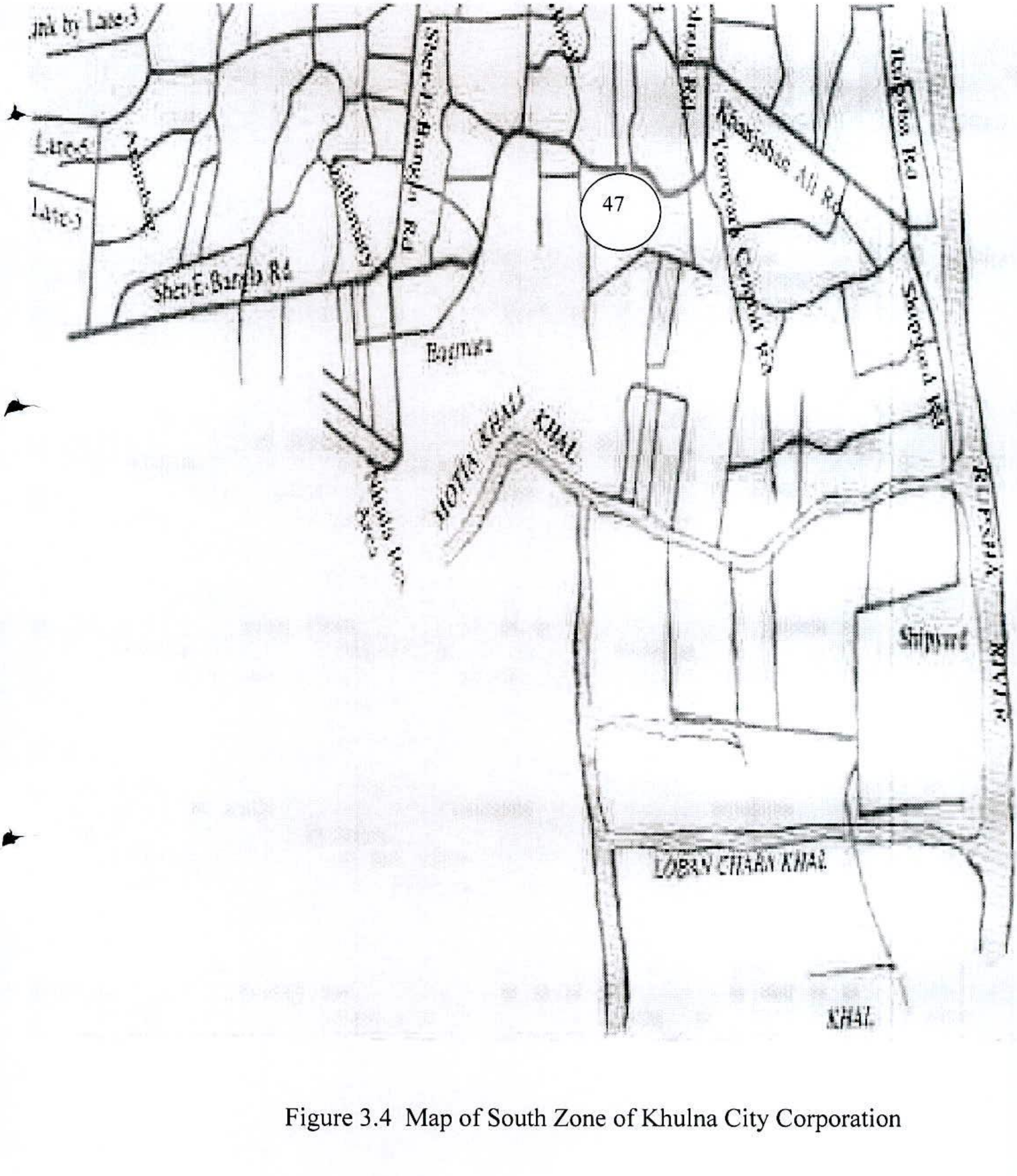


Figure 3.4 Map of South Zone of Khulna City Corporation

3.2.1 Identification of Sub-Soil in North Zone

In the North Zone (Afilgate, Shiromoni, Fulbarigate, Mohesshorpasha, etc), there are 26 boreholes at 11 locations from which soil characterization is prepared. In this zone, it is found that the soil layers between 0-12 m from EGL are mostly clayey silt. In this stratum there exists an organic clay layer having variation from 3- 6 m depth in most of the locations. The soil layers between the depth of 12 to 15 m at the northeast part of this zone contain predominantly sand, while in the areas namely Fulbarigate, KUET campus the soil at this depth contains predominantly silt. The map of North Zone is shown in the Fig. 3.2.

3.2.2 Identification of Sub-Soil in Middle Zone

In the middle zone (Khalishpur, Daulatpur, Boyra, Mujgunni, etc.), there are 83 boreholes at 37 locations from which soil characterization is prepared. In the zone, it is found that the western side of this zone the sub-soil contains an organic layer of 3 to 5m thickness starting from about 1.5 m to 3 m depth to downward. Below this depth the soil consists of predominantly silt up to about 20m depth. In the eastern side of this zone the soil contains predominantly silt up to about 6 m to 7.5 m depth. Below this depth the soil contains mainly fine sand. The map of Middle Zone is shown in the Fig. 3.3.

3.2.3 Identification of Sub-Soil in the South Zone

In the South Zone (Sonadanga, Nirala, Gollamari, Sheikhpara, West side of Rupsha, Khulna University, etc), there are 14 boreholes at 7 locations from which a soil characterization is prepared. In the this zone, the sub-soil contains organic clay up to about 3m to 5m depth from existing ground level(EGL). Below this level the soil mainly consists of silt with small portion of clay and organic matters up to about 20m depth from EGL. The map of Middle Zone is shown in the Fig. 3.4.

3.3 Grain Size Distribution of Soil in the Study Area

Combined sieve and hydrometer analyses were performed on soil samples collected from the several locations. The test was carried out as per ASTM D 422-63 in order to determine the grain size distribution of the collected soil samples at different depths and locations. The distribution of percent of sand, silt and clay particles of some selected sites were taken into consideration. It is evident from the observation that percent of fine sand, silt and clay particles ranges from 1 to 65, 10 to 70, 7 to 46 and 10 to 73 respectively in the inorganic subsoil layers of study area.

3.4 Organic Matter Content

Organic matter content was determined form disturbed organic soil samples at different depth. It is found in the secondary source that the organic content exists in the soil of the study area up to 49.81 %. Razzaque and Alamgir(1999) reported that the organic content at different depths of bore holes at Gollamari (Khulna University) area varies from 3.27 % to 49.81 %.

3.5 Specific Gravity

Specific Gravity was determined form disturbed soil samples at different depths at different locations. It may be noted that specific gravity of soil of the area ranges form 1.61 at Female TTC , Khulna to 2.80 at Nasir Hospital site, Goalkhali. The usual range of specific gravity for inorganic clay varies between 2.68 and 2.75 (Bowles, 1997). The reason of lower than usual value may be attributed due to the presence of some organic matter and the difference of upper range of value may be due to the presence of significant amount of colloidal particles. The values of specific gravity for organic clay vary from 2.14 to 2.17 (BRTC, 2003) or may be even less than 2.0 (Bowles, 1978)

3.6 Atterberg Limits and Natural Water Content

ASTM D-4318-86 described method of Atterberg Limits Tests were performed on samples collected at different depths of different borehole locations to determine liquid limit, plastic limit and plasticity index as well as natural moisture content. A summary of the natural moisture content (w_n), Liquid limit (w_L), Plastic limit (w_P) and Plasticity index (I_p) are shown in Table 3.2, Table 3.3 and Table 3.4.

3.6.1 Atterberg Limits and Natural Water Content in the North Zone

It was observed that the liquid limit of the inorganic and organic soil in the North Zone ranges from 27% to 260%. The plastic limit varies from 23% to 75% and the natural moisture content was found from 27% to 139%. It indicates that the high percent of water pertaining to the soil are soft and compressible. From the observed data, it can be said that the soil of the study area is highly plastic. The liquid limit, plastic limit, and natural moisture content of soil of the North Zone are presented in the Table 3.2.

Table 3.2 Summary of Atterberg Limits and natural water content in the North Zone

Site No.	BH No	Location	Depth (m)	*Soil Type	N-value	W_n (%)	W_L (%)	W_P (%)	I_p
1	BH-1	Afilgate	1.50	CH	4	34	55	29	26
			3.00	CH	3	36	51	28	23
			4.50	OH	2	111	53	38	15
			7.50	OL	2	38	34	30	4
	BH-2		3.00	CH	3	49	52	28	24
			4.50	OH	2	58	58	42	16
			6.00	OH	6	130	65	43	22
			7.50	ML	2	67	42	31	11
2	BH-1	Cable facroty Ltd.,Shiromoni	5.00	ML	6	32	33	30	3
	BH-2		10.00	ML	2	35	34	24	10
	BH-3		18.00	ML	5	37	30	28	2
3	BH-1	Police training Centre, Shiromoni	3.00	ML	7	27	32	26	6
			4.50	ML	3	36	37	31	6
			6.00	ML	4	36	30	26	4
	BH-2		1.50	CL	6	31	42	25	17
			4.50	ML	8	40	34	25	9

*Soil type means USCS Symbol

Table 3.2 Summary of Atterberg Limits and natural water content in the North Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
4	BH-1	Police Barak,Shiromoni	4.50	ML	4	42	33	28	6
			7.50	ML	5	37	32	27	5
			9.00	ML	7	36	27	25	2
	BH-2	Police Barak,Shiromoni	1.50	CL	8	30	33	26	8
			3.00	CL	6	33	38	32	6
			4.50	ML	5	38	31	25	6
			6.00	ML	6	43	31	28	2
			9.00	ML	3	33	33	29	4
5	BH-2	KUET, Fulbarigate	6.00	MH	6	154	125	72	53
			7.50	CL	5	97	45	30	15
			10.50	CL	4	39	38	25	13
6	BH-2	KUET, Fulbarigate	1.50	MH	3	66	60	29	31
			3.00	MH	2	62	120	70	50
			4.50	CL	5	136	40	31	9
			6.00	MH	3	72	52	34	18
7	BH-1	QUET Road, Fulbarigate	1.50	CL	5	38	42	30	12
			4.50	MH	3	50	96	50	46
			10.50	MH	3	48	55	42	13
			12.00	CL	4	45	41	31	10
	BH-2		6.00	MH	5	49	116	68	46
	BH-3		1.50	CL	3	37	44	32	12
			6.00	MH	3	66	71	49	22
			12.00	CL	4	57	43	32	11

*Soil type means USCS Symbol

Table 3.2 Summary of Atterberg Limits and natural water content in the North Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	W_n (%)	W_L (%)	W_P (%)	I_p
8	BH-1	Abul Khaer, Fulbarigate	1.50	ML	5	36	43	30	13
			4.50	ML	5	36	48	32	16
			6.00	MH	3	58	70	41	29
			9.00	MH	7	80	69	43	26
			13.50	MH	4	49	63	46	17
	BH-2		3.00	ML	4	40	46	28	18
			6.00	MH	4	56	69	35	34
			9.00	MH	4	84	62	34	28
			10.50	ML	6	48	47	36	11
			12.00	MH	4	47	58	36	22
			15.00	ML	6	50	43	32	11
9	BH-1	Mirerdanga, Fulbarigate	1.50	ML	7	32	31	23	7
			3.00	ML	4	28	34	28	7
			4.50	ML	11	42	33	27	6
	BH-2		1.50	ML	6	34	36	27	9
			3.00	ML	5	32	33	28	5
	BH-3		3.00	ML	4	34	35	27	8
11	BH-1	Baby Home, Moheshorpasa	4.50	MH	4	44	60	36	24
			6.00	MH	4	93	139	75	64
			9.00	ML	9	35	42	32	10
			15.00	ML	5	47	40	28	12
	BH-2		1.50	ML	4	34	33	29	4
			4.50	ML	3	47	48	29	19
			7.50	MH	5	260	76	39	37
			10.50	ML	6	54	50	32	18
			13.50	ML	6	68	48	32	16

*Soil type means USCS Symbol

3.6.2 Atterberg Limits and Natural Water Content in the Middle Zone

It was observed that the liquid limit of the organic and inorganic soil in the Middle Zone ranges from 29% to 313%. The plastic limit varies from 11% to 268% and the natural moisture content was found from 15% to 348%. It indicates that the high percent of water pertaining to soil are soft and compressible. From the observed data, it can be said that the soil of the study area is highly plastic. The liquid limit, plastic limit, and natural moisture content of soil of the Middle Zone are presented in the Table 3.3.

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
12	BH-1	Nasir Hospital, Goalkhali	3.00	OH	2	79	171	62	109
			7.50	OL	5	53	50	33	17
			9.00	ML	3	68	45	32	13
			13.50	ML	4	49	41	33	8
			15.00	ML	6	49	45	33	12
	BH-2		3.00	OH	6	67	55	31	24
			7.50	ML	4	43	48	33	15
			13.50	ML	6	38	40	34	5
			18.00	MH	5	92	61	42	19
	BH-3		1.50	OH	2	45	58	33	26
			12.00	MH	6	57	76	40	36
13	BH-1	Setara Begum,Muijgunni	3.00	CH	1	50	120	41	79
			4.50	OH	3	83	62	38	24
			6.00	ML	5	56	38	28	10
			7.50	MH	7	35	60	39	21
	BH-2		1.50	CH	6	31	78	30	48
			3.00	CH	1	53	110	42	68
			4.50	ML	3	79	44	37	7
			6.00	ML	5	60	38	28	10
			7.50	ML	6	39	36	27	9
			9.00	ML	4	38	35	26	9
			10.50	ML	5	35	32	27	5

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	W_n (%)	W_L (%)	W_P (%)	I_p
14	BH-1	Palpara road, Khalishpur	1.50	ML	6	34	33	25	8
			3.00	ML	3	33	31	28	3
17	BH-1	North zone of Housing state, Khalishpur	3.00	ML	4	32	38	26	12
			6.00	ML	3	45	38	26	12
			7.50	ML	4	37	37	26	11
			10.50	ML	6	35	44	34	10
			12.00	ML	5	50	50	38	12
			13.50	ML	4	44	49	37	12
			15.00	MH	6	44	57	39	18
			16.50	MH	5	56	54	35	19
18	BH-1	Co-operative training centre, Boyra	3.00	MH	2	66	56	46	10
			4.50	ML	3	48	40	36	4
			7.50	ML	6	17	40	35	5
			10.50	ML	6	43	41	36	5
	BH-2		3.00	ML	2	67	47	39	8
			6.00	ML	5	36	38	31	7
			7.50	ML	6	30	37	35	2
			10.50	ML	7	36	37	35	2

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
19	BH-1	Imam Training Centre,Boyra	4.50	OH	5	348	101	51	50
			6.00	ML	6	68	45	34	10
			9.00	ML	4	40	44	33	11
			10.50	ML	5	54	41	32	9
	BH-2		3.00	MH	2	106	101	50	51
			4.50	MH	5	56	107	67	40
			6.00	ML	4	56	45	31	14
			10.50	ML	3	52	42	31	11
20	BH-1	Md Nazrul Islam Mujgunni Highway road	1.50	ML	7	30	32	26	6
			1.50	OH	7	90	313	190	123
	BH-3		7.50	ML	3	55	40	31	9
21	BH-1	Navy colony, Boyra	1.50	CH	3	43	60	28	32
			4.50	OH	3	337	223	142	81
			7.50	ML	3	57	43	33	10
			10.50	ML	3	46	50	36	14
			13.50	ML	4	38	39	32	7
	BH-2		3.00	OH	2	50	70	41	29
			6.00	MH	2	60	52	31	21
			9.00	ML	3	47	37	28	9
			12.00	ML	4	51	38	30	8
	BH-3		12.00	MH	4	60	52	32	20

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	W_n (%)	W_L (%)	W_P (%)	I_p
22	BH-1	DIG office, Khulna	3.00	ML	4	33	43	33	10
	BH-2		3.00	MH	5	38	84	39	45
	BH-3		6.00	MH	4	72	78	45	33
			9.00	ML	3	41	36	31	5
23	BH-1	Regional PATC, Boyra	7.50	OH	5	94	91	60	30
			10.50	ML	5	44	34	31	3
	BH-2		9.00	ML	5	38	34	29	4
			10.50	ML	4	46	36	28	8
			12.00	ML	5	44	33	28	5
	BH-3		7.50	OH	7	66	115	77	38
24	BH-1	Environment Reserch Centre, Khulna	1.50	ML	7	34	34	28	6
			4.50	OL	7	338	37	33	4
			6.00	OH	4	46	122	90	32
			7.50	ML	5	36	42	31	12
			9.00	ML	5	34	34	31	3
	BH-2		1.50	ML	3	34	35	30	4
			4.50	OH	5	278	166	160	6
			6.00	OH	3	59	102	55	47
			7.50	ML	7	38	40	33	7
	BH-3		6.00	OH	6	64	195	140	55
			7.50	ML	7	42	37	34	3
			13.50	ML	10	27	34	34	0

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
25	BH-1	Medical college, Boyra	1.50	ML	4	35	33	28	5
			3.00	MH	2	47	58	32	26
			4.50	OH	3	70	74	40	34
			6.00	OH	2	97	86	50	36
			7.50	MH	5	59	52	32	20
			9.00	ML	4	45	49	33	16
	BH-2		1.50	CL	6	34	49	22	27
			4.50	OH	5	56	288	166	122
			6.00	OH	3	126	81	45	36
			7.50	MH	5	52	95	41	54
			9.00	ML	2	43	48	34	14
			10.50	ML	5	33	36	30	6
26	BH-1	Student Hostel No -2, Medical college, Boyra	1.50	MH	4	41	58	33	25
			3.00	ML	3	48	39	35	4
	BH-2		3.00	ML	2	46	45	33	12
			4.50	OH	2	61	59	40	19
			6.00	OH	1	31	109	76	33
			9.00	ML	5	99	40	31	9
27	BH-1	MTTC, Khulna	3.00	MH	2	37	78	42	36
			7.50	MH	4	53	56	42	14
			9.00	ML	4	59	48	38	10
			10.50	ML	4	67	45	34	11
			12.00	MH	4	64	51	42	9

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	W_n (%)	W_L (%)	W_P (%)	I_p
28	BH-1	OC Residence, Sonadanga Thana	1.50	MH	2	49	67	36	31
			3.00	MH	2	48	73	36	37
			4.50	MH	2	48	52	33	19
			6.00	ML	5	49	45	30	15
			7.50	ML	4	43	41	33	8
			12.00	ML	5	42	33	27	7
			15.00	ML	6	15	36	30	6
	BH-2		3.00	MH	2	48	71	38	33
			4.50	ML	4	68	45	30	15
			6.00	ML	3	62	42	29	13
			10.50	ML	4	47	35	25	10
			15.00	ML	4	42	34	32	2
29	BH-1	Dormitory of Female Police, Zoragate	6.00	OH	7	83	126	89	37
			9.00	ML	4	38	44	30	14
	BH-2		4.50	ML	6	34	39	28	11
			7.50	MH	5	58	65	41	24
			9.00	MH	4	70	58	33	25
	BH-3		1.50	ML	10	29	32	25	7
			3.00	ML	3	32	38	30	8
			4.50	ML	3	28	46	33	13
			9.00	ML	6	77	39	35	4

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
30	BH-1	Shishu Sadan, Khulna	1.50	ML	8	34	40	30	10
			4.50	OH	3	68	112	49	63
			7.50	ML	5	46	42	31	11
	BH-2		3.00	ML	7	41	42	33	9
			7.50	ML	5	50	42	32	10
	BH-3		3.00	ML	4	38	42	32	10
			9.00	ML	4	46	41	33	8
31	BH-1	ICMA,Sonadanga	1.50	ML	4	37	41	30	11
			3.00	ML	3	49	48	30	18
			4.50	OH	3	297	143	82	62
			6.00	MH	2	49	52	38	13
			9.00	ML	2	55	44	34	10
			10.50	ML	5	57	39	33	6
	BH-3		1.50	ML	3	34	40	31	9
			3.00	ML	3	49	49	31	18
			4.50	OH	2	102	143	88	55
			6.00	MH	2	143	52	38	15
			7.50	ML	2	63	47	40	7
			9.00	ML	3	51	44	36	8

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
33	BH-1	Khulna Thana Quarter	1.50	ML	6	40	41	30	11
			3.00	ML	5	40	46	34	12
			4.50	ML	6	42	38	24	14
	BH-2		1.50	ML	5	35	38	26	12
			7.50	ML	4	50	49	39	10
34	BH-1	Female TTC, Khulna	3.00	ML	4	38	40	29	11
35	BH-1	Modina Trading Corp., Ghat No-4, Khulna	4.50	MH	7	35	98	73	25
			6.00	MH	7	77	91	56	35
			7.50	ML	6	60	41	28	13
			9.00	ML	6	74	37	30	7
			10.50	ML	3	95	31	27	4
36	BH-1	Diabetic Hospital, Khulna	3.00	ML	4	40	47	28	19
			7.50	ML	4	39	45	30	15
37	BH-1	KDA Plot No- 32, Sonadanga	1.50	ML	2	40	47	39	8
			4.50	OH	3	291	60	37	23
			7.50	ML	4	37	39	32	7
	BH-2		4.50	OH	3	234	74	43	31

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
38	BH-1	Community Centre of KDA	7.50	MH	2	68	77	68	9
			9.00	ML	5	54	38	35	3
			10.50	ML	5	34	38	37	1
	BH-2		7.50	MH	3	65	51	45	6
			9.00	ML	5	53	39	36	3
39	BH-1	Sonadanga, Khulna	1.50	ML	4	41	43	31	12
			3.00	OH	3	111	90	55	35
			4.50	MH	5	100	62	33	29
			7.50	ML	4	52	41	32	9
	BH-3		3.00	MH	2	56	70	46	24
			4.00	MH	6	44	56	35	21
			7.50	ML	2	44	44	32	12
			9.00	ML	2	54	34	24	10
40	BH-1	Adv. Abdur Rahman, HMM road ,Helatola	4.50	MH	4	52	185	126	59
			10.50	ML	2	53	36	33	3
	BH-2		3.00	ML	5	39	38	25	13
			6.50	ML	4	35	69	40	29
			9.00	ML	4	50	40	34	6

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth, m	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
41	BH-1	Blind Hospital, Helatola	1.50	ML	5	25	44	37	6
			4.50	OH	4	276	297	268	29
			7.50	ML	3	43	40	37	3
	BH-2		6.00	ML	2	50	44	37	7
			7.50	ML	3	46	41	40	1
	BH-3		4.50	OH	5	228	145	97	48
			6.00	ML	2	51	51	41	10
			7.50	ML	3	57	48	48	1
			9.00	ML	4	60	49	41	8
42	BH-1	Tibbet Market, Helatola	3.00	ML	3	33	37	28	9
			6.00	OH	3	79	106	70	37
			7.50	ML	6	66	54	24	30
			10.50	ML	3	51	50	11	39
	BH-2		3.00	ML	3	41	47	31	17
			6.00	ML	4	51	38	29	9
			7.50	ML	4	41	58	36	22
			9.00	ML	3	53	38	34	4
	BH-3		3.00	ML	3	38	34	28	6
			4.50	ML	2	51	49	29	20
			7.50	ML	3	46	52	37	15

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth, m	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
			9.00	MH	3	51	46	31	15
			10.50	OH	3	52	42	37	5
43	BH-1	Iqbal road, Khulna	1.50	ML	5	31	50	29	21
			6.00	OH	5	41	85	56	29
			7.50	MH	5	123	85	57	28
			9.00	ML	4	37	58	38	20
			10.50	MH	5	55	35	30	5
	BH-2		1.50	ML	7	31	42	19	23
			4.50	ML	4	32	41	28	12
			6.00	ML	8	46	139	93	47
			7.50	ML	5	233	127	78	49
			9.00	ML	4	39	46	29	17
			10.50	ML	7	45	37	30	7
44	BH-1	H-43, Khanjan Ali road, Tarerpukur	1.50	ML	4	31	37	31	6
			4.50	MH	4	51	54	31	23
			7.50	ML	3	36	36	30	6
			9.00	MH	5	37	33	32	1

*Soil type means USCS Symbol

Table 3.3 Summary of Atterberg Limits and natural water content in the Middle Zone

Site No.	BH No.	Location	Depth (m)	Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
45	BH-1	HMM Road, Khulna	6.00	ML	4	130	91	55	36
			7.50	ML	4	161	62	43	19
	BH-2		6.00	ML	4	47	52	35	17
			7.50	OH	5	277	95	69	26
46	BH-1	Opsonin office Building, Sheikhpara	1.50	OH	7	32	29	21	8
			4.50	OH	5	45	250	140	110
			9.00	ML	5	46	39	32	7
	BH-2		6.00	ML	6	336	47	36	11
			7.50	ML	6	51	38	33	5
	BH-3		6.00	ML	5	160	48	32	16
			9.00	ML	7	56	32	28	4

*Soil type means USCS Symbol

3.6.3 Atterberg Limits and Natural Water Content in the South Zone

It was observed that the liquid limit of inorganic and organic soil in the South Zone ranges from 32% to 146%. The plastic limit varies from 25% to 88% and the natural moisture content was found from 28% to 134%. It indicates that the high percent of water pertaining to soil layer are soft and compressible. From the observed data, it can be said that the soil of the study area is highly plastic. The liquid limit, plastic limit, and natural moisture content of soil of the North Zone are presented in the Table 3.4.

Table 3.4 Summary of Atterberg Limits and natural water content in the South Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
47	BH-1	Professor's Quarter, Khulna University	3.0	OL	1	74	85	58	27
			6.0	OL	2	116	53	37	17
			9.0	OL	1	45	39	35	3
			12.0	OH	4	49	74	52	21
			15.0	OL	4	50	53	43	10
			24.0	OL	4	53	50	38	12
49	BH-1	Chanmari, Khulna	4.5	CH	3	78	52	31	21
			7.5	OH	2	46	45	36	9
	BH-2		4.5	OH	2	45	47	32	15
			6.0	OH	3	40	45	33	12
			7.5	CL	2	51	37	30	7
50	BH-1	Rokeya Khatoon, Farazipara	3.0	ML	5	35	47	33	14
			9.0	ML	3	35	40	29	11
	BH-2		1.5	ML	4	28	34	29	5
			4.5	OH	5	55	68	47	21
			7.5	ML	4	33	37	25	12
51	BH-1	Chanmari, Khulna	1.5	CH	2	34	71	46	25
			4.5	CH	4	42	42	37	5
			7.5	CL	3	51	39	33	6
52	BH-1	Labanchara, Khulna	1.5	CL	4	41	42	31	11
			10	OH	2	52	146	68	78
			4.5	OH	3	134	70	47	23
			6.0	OH	2	101	104	47	57

*Soil type means USCS Symbol

Table 3.4 Summary of Atterberg Limits and natural water content in the South Zone

Site No.	BH No.	Location	Depth (m)	*Soil Type	N-value	w_n (%)	w_L (%)	w_P (%)	I_p
			7.5	MH	2	58	60	39	21
			9.0	ML	2	66	46	39	8
			10.5	ML	3	36	36	33	3
			13.5	ML	4	30	32	27	5
			15.0	ML	4	35	33	29	4
			16.5	ML	8	39	35	29	6
	BH-2		1.5	ML	4	53	50	35	15
			3.0	ML	2	45	41	31	10
			7.5	MH	3	38	53	29	23
	BH-3		3.0	MH	2	60	54	34	20
			4.5	MH	2	77	52	33	19
			6.0	ML	2	37	38	26	13
53	BH-1	Baniakahamar	1.5	ML	5	38	37	34	3
			3.0	ML	4	45	36	32	4
			6.0	ML	4	32	50	40	10
			7.5	ML	4	35	42	35	7

*Soil type means USCS Symbol

3.7 Shear Strength Characteristics in Cohesive Soil

ASTM D2166-86 described method was used to determine unconfined compressive strength for undisturbed cohesive soil samples collected from different depth at different locations of the study area. The values of different parameters obtained from these tests are summarized in the Table 3.5,3.6 & 3.7. It is found that q_u values varies from 9.30 to 153.45 kPa in the North Zone, 4.39 to 276.00 in the Middle Zone and 12.67 to 200 kPa in the South Zone, so their averages do not give any common idea about the study area. The samples were collected at a depth 1.5 m to 20m from EGL.

Table 3.5 Summary of q_u of cohesive soils at different depth and locations in the North Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
1.	BH-1	Afilgate, Khulna	1.50	4	59.50	9.30 - 104.10
			4.50	2	47.50	
			6.00	8	29.20	
			9.00	8	24.80	
			10.50	11	46.20	
	BH-2		1.50	6	104.10	
			3.00	3	20.00	
			4.50	2	9.30	
			6.00	6	36.10	
2	BH-1	Cable Shilpa Ltd. Shiromoni	1.50	6	76.00	26.30 - 153.45
	BH-2		1.50	6	51.87	
			7.50	3	26.30	
			9.00	5	31.88	
	BH-3		1.50	5	30.09	
			3.00	9	153.45	
			7.50	5	26.70	
3	BH-1	Police Training Centre, Shiromoni	3.00	7	77.00	45.00 – 118.48
			6.00	4	45.00	
	BH-2		1.50	6	79.50	
			3.00	6	92.87	
			4.50	8	96.52	
			6.00	9	108.55	
	BH-3		1.50	11	118.48	

Table 3.5 Summary of q_u of cohesive soils at different depth and locations in the North Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
4	BH-1	Police Barqak, Shiromoni	1.50	6	84.00	23.00 – 92.80
			3.00	9	92.80	
			4.50	4	48.00	
			6.00	4	27.00	
			7.50	5	23.00	
			9.00	7	37.00	
	BH-2	Police Barqak, Shiromoni	1.50	8	65.00	
			3.00	6	49.00	
			4.50	5	23.00	
			6.00	6	25.80	
			7.50	4	32.60	
			9.00	3	63.00	
5	BH-1	KUET, Fulbarigate	4.50	3	36.00	28.76 – 62.60
			6.00	2	28.76	
			9.00	3	49.00	
			10.50	4	56.00	
			13.50	5	41.00	
	BH-2		1.50	3	53.50	
			3.00	4	52.00	
			4.50	5	62.60	
			6.00	6	59.85	
			7.50	5	58.70	
			9.00	5	55.00	
			10.50	4	56.00	
6	BH-2	KUET, Fulbarigate	1.50	3	29.50	12.57 – 41.96
			3.00	2	31.82	
			4.50	5	12.57	
			6.00	3	41.06	
			7.50	2	12.75	
			9.00	3	28.13	

Table 3.5 Summary of q_u of cohesive soils at different depth and locations in the North Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
7	BH-1	KUET Road, Fulbarigate	1.50	5	54.50	32.00 – 89.00
			4.5o	3	32.70	
			9.00	4	53.70	
			10.50	3	34.00	
			13.50	4	41.00	
	BH-2		1.50	5	55.00	
			4.50	3	30.00	
			6.00	5	48.00	
			7.50	6	75.00	
			13.50	7	89.00	
	BH-3		1.50	3	34.00	
			4.50	3	32.00	
			6.00	3	34.00	
			7.50	4	49.00	
			12.00	4	46.00	
8	BH-1	Mr Abul Khaer, Fulbarigate	1.50	5	48.00	9.60 – 59.00
			4.50	5	50.70	
			6.00	3	32.00	
			9.00	7	9.60	
			10.50	5	50.7	
			13.50	4	28.8	
			16.00	7	63.4	
	BH-2		1.50	5	59.00	
			3.00	4	37.00	
			4.50	4	38.00	
			6.00	4	27.00	
			7.50	4	27.00	
			9.00	4	32.00	
			10.50	6	57.00	
			12.00	4	36.60	
			15.00	6	55.70	

Table 3.5 Summary of q_u of cohesive soils at different depth and locations in the North Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
9	BH-1	Mirerdanga, Fulbarigate	1.50	7	73.77	12.97 – 86.48
			3.00	4	71.31	
			4.50	11	12.97	
	BH-2		1.50	6	86.48	
			3.00	5	81.49	
	BH-3		1.50	5	80.52	
			3.00	4	49.35	
			4.50	13	25.04	
11	BH-1	Baby Home, Moheshorpasha	1.50	8	107.80	13.07 – 100.68
			3.00	3	58.84	
			6.00	4	42.67	
			9.00	9	86.96	
			10.50	4	68.90	
			12.00	4	21.70	
			15.00	5	41.07	
	BH-2		1.50	4	100.68	
			4.50	3	13.07	
			6.00	5	31.67	
			7.50	5	58.13	
			9.00	8	50.63	
			10.50	6	16.63	
			13.50	6	58.13	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
12	BH-1	Nasir Hospital , Goalkhali	3.00	2	10.40	8.42 – 69.22
			4.50	2	46.31	
			6.00	4	49.42	
			7.50	5	13.47	
			9.00	3	11.07	
			10.50	4	14.22	
			13.50	4	8.42	
			15.00	6	12.16	
	BH-2		1.50	2	66.33	
			3.00	4	11.53	
			4.50	6	20.30	
			6.00	4	9.73	
			7.50	4	32.93	
			10.50	2	18.93	
			12.00	6	53.78	
			15.00	5	12.96	
	BH-3		1.50	2	69.22	
			3.00	4	13.00	
			9.00	5	13.90	
			12.00	5	34.40	
			13.50	5	42.22	
			15.00	6	24.78	
13	BH-1	Setara Begum, Muzjunni	1.50	1	20.00	10.20 – 96.00
			3.00	1	24.00	
			4.50	3	10.20	
			6.00	5	16.00	
			7.50	7	96.00	
			9.00	6	87.00	
			10.50	4	64.00	
	BH-2		10.50	5	29.50	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
14	BH-1	Palpara Road , Khalishpur	3.00	3	59.00	30.00 – 59.00
			4.50	15	30.00	
	BH-2		1.50	6	38.00	
15	**BH-1**	Fire Service Station, Khalishpur	3.00	6	53.50	20.92 - 86.24
			4.50	5	20.92	
	BH-2		4.50	6	26.16	
	BH-3		1.50	5	86.24	
			3.00	4	34.80	
			4.50	4	42.60	
17	BH-1	North Zone Housing State, Khalishpur	3.00	4	30.00	30.00 – 111.00
			4.50	2	100.00	
			6.00	3	82.00	
			7.50	4	50.00	
			10.50	6	111.00	
			13.50	4	38.00	
			15.00	6	32.00	
			16.50	5	66.00	
18	BH-1	Co-operative training centre, Boyra	6.00	6	100.00	36.00 – 126.00
			9.00	6	56.00	
			10.50	6	66.00	
			12.00	4	89.00	
			13.50	6	92.00	
			15.50	7	84.00	
	BH-2		1.50	4	75.00	
			3.00	3	36.00	
			4.50	2	45.00	
			6.00	5	95.00	
			7.50	6	60.00	
			10.50	7	100.00	
			12.00	7	126.00	
			13.50	9	83.00	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
19	BH-1	Imam Training Centre, Boyra	4.50	5	20.89	15.54 – 60.93
			6.00	6	26.75	
			7.50	5	58.87	
			9.00	4	15.54	
	BH-2		3.00	2	17.89	
			4.50	5	37.65	
			6.00	4	17.95	
			7.50	3	60.93	
20	BH-1	Md Nazrul Islam, Muzjunni	1.50	7	84.00	33.00 – 92.00
			3.00	5	69.00	
			4.50	7	52.00	
	BH-2		1.50	2	33.00	
			4.50	3	50.00	
			7.50	4	49.00	
	BH-3		1.50	7	92.00	
			3.00	6	56.00	
			4.50	8	57.00	
21	BH-1	Navy Colony, Boyra	1.50	3	84.25	14.10 – 95.10
			6.00	4	46.30	
			7.50	3	21.40	
			9.00	5	82.83	
			10.50	3	25.60	
			13.50	4	49.58	
	BH-2		1.50	4	36.36	
			3.00	2	18.02	
			6.00	2	29.48	
			9.00	3	45.17	
			12.00	4	36.56	
	BH-3		1.50	5	95.10	
			7.50	4	42.97	
			10.50	5	40.76	
			12.00	4	14.10	
			13.50	5	24.24	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
22	BH-1	DIG Office, Khulna	3.00	4	52.30	7.90 – 108.90
			4.50	3	38.00	
			7.50	4	7.90	
	BH-2		3.00	5	24.70	
			6.00	3	108.90	
			9.00	2	36.40	
			10.50	11	31.10	
	BH-3		4.50	2	62.00	
			6.00	4	61.20	
			7.50	5	70.10	
23	BH-1	Regional PATC, Boyra	1.50	6	31.80	11.00 – 77.10
			7.50	5	33.20	
			10.50	5	11.00	
			15.00	7	38.70	
	BH-2		1.50	8	49.90	
			6.00	7	56.00	
			9.00	5	33.50	
			10.50	4	21.60	
	BH-3		1.50	9	55.30	
			6.00	7	50.25	
			7.50	7	77.10	
			10.50	5	39.50	
			13.50	9	18.00	
			15.01	8	70.50	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
24	BH-1	Environmental Research Centre	1.50	7	99.00	27.00 – 130.00
			4.50	7	130.00	
			6.00	4	52.00	
			7.50	5	81.00	
			9.00	5	31.00	
	BH-2	Environmental Research Centre	1.50	3	68.00	
			4.50	5	40.00	
			6.00	3	53.00	
			7.50	7	69.00	
			9.00	8	32.00	
	BH-3		1.50	4	23.00	
			3.00	2	27.00	
			4.50	4	43.00	
			6.00	6	35.00	
			7.50	9	63.00	
			9.00	7	34.00	
25	BH-1	Medical College, Boyra	1.50	4	86.93	11.16 – 86.93
			3.00	2	27.20	
			6.00	2	24.34	
			7.50	5	52.88	
			9.00	4	37.06	
			12.00	12	24.61	
	BH-2		1.50	6	41.00	
			3.00	2	17.33	
			4.50	5	17.05	
			6.00	3	22.00	
			7.50	5	22.50	
			9.00	2	36.61	
			10.50	5	11.16	
			12.00	10	28.93	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
26	BH-1	Student Hostel, Medical College, Boyra	1.50	4	75.10	11.70 – 94.00
			3.00	3	55.50	
			4.50	2	46.36	
			6.00	3	23.00	
			9.00	5	78.40	
			10.50	3	11.70	
	BH-2		1.50	5	94.00	
			3.00	2	54.00	
			4.50	2	16.00	
			6.00	1	29.00	
			9.00	5	41.30	
			10.50	3	41.70	
			12.00	9	33.80	
			13.50	4	55.70	
			16.50	6	11.70	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
27	BH-1	MTTC, Khulna	1.50	5	59.00	8.76 – 113.70
			3.00	2	12.10	
			7.50	4	35.25	
			9.00	4	33.55	
			10.50	4	8.76	
			12.00	4	14.64	
			13.50	4	24.15	
			15.00	7	19.75	
			16.50	7	19.75	
	BH-2		1.50	7	113.70	
			3.00	4	69.40	
			4.50	2	24.50	
			7.50	5	44.10	
			10.50	4	16.50	
			13.50	6	50.00	
			12.00	5	45.05	
			16.50	5	45.05	
			60.00	4	19.50	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
28	BH-1	Residence of OC , Sonadanga	1.50	2	25.30	15.15 – 56.30
			3.00	2	52.50	
			4.50	2	29.15	
			6.00	5	20.60	
			7.50	4	61.20	
			9.00	6	45.70	
			12.00	5	45.40	
			15.00	6	15.15	
	BH-2		1.50	2	56.30	
			4.50	4	17.40	
			7.50	3	16.35	
			9.0O	4	15.40	
			10.5O	4	23.06	
			12.00	4	30.13	
			15.00	4	28.10	
29	BH-1	Dormitory of Female Police, Zoragate	1.50	10	78.32	41.70 – 276.00
			6.00	7	78.30	
			7.50	5	53.50	
			9.00	4	48.50	
	BH-2		1.50	14	111.60	
			6.00	10	276.00	
			7.50	5	57.24	
	BH-3		3.00	3	83.40	
			6.00	7	41.70	
			7.50	4	51.40	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
30	BH-1	Shishu Sadan , Khulna	1.50	8	81.00	27.00 – 81.00
			3.00	2	38.00	
			4.50	3	46.00	
			6.00	5	49.00	
			7.50	5	59.00	
			9.00	3	30.00	
	BH-2		1.50	7	58.00	
			3.00	7	27.00	
			4.50	4	37.00	
			6.00	6	66.00	
			7.50	5	38.00	
			10.50	3	34.00	
			15.00	9	51.00	
	BH-3		1.50	8	78.00	
			3.00	4	38.00	
			6.00	7	76.00	
			9.00	4	35.00	
31	BH-1	ICMA, Sonadanga	1.50	4	51.60	5.00 – 92.00
			3.00	3	40.00	
			4.50	3	26.60	
			6.00	2	26.60	
			9.00	2	29.00	
			10.50	5	54.90	
	BH-2		1.50	4	62.50	
			3.00	4	92.00	
			4.50	2	20.20	
			6.00	2	31.70	
			7.50	1	5.20	
			9.00	4	5.00	
	BH-3		1.50	3	58.60	
			3.00	3	37.60	
			4.50	2	6.75	
			6.00	2	15.70	
			7.50	2	6.30	
			9.00	3	42.87	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
33	BH-1	Khulna Thana Quarter	1.50	6	60.00	41.00 – 65.00
			3.00	5	55.00	
			4.50	6	50.00	
	BH-2		1.50	5	62.00	
			3.00	5	58.00	
			4.50	7	65.00	
			7.50	4	41.00	
34	BH-1	Female TTC Khulna	7.50	3	12.50	12.50 – 90.50
			10.50	5	62.80	
			13.50	5	39.00	
	BH-2		4.50	3	42.00	
			6.00	7	86.00	
			9.00	7	70.00	
			12.00	11	90.50	
			15.00	9	22.20	
	BH-3		3.00	3	47.00	
			4.50	4	36.00	
			9.00	3	21.00	
			10.50	5	23.00	
35	BH-1	Modina Trading, Ghat No-4	4.50	7	76.00	64.00 – 98.00
			6.00	7	64.00	
			7.50	6	65.00	
			9.00	6	98.00	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
36	BH-1	Diabetic Hospital, Khulna	1.50	6	30.00	22.00 – 93.00
			3.00	4	86.00	
			6.00	11	33.00	
			7.50	4	93.00	
			9.00	7	85.00	
			12.00	16	36.00	
	BH-2		3.00	4	86.00	
			9.00	7	54.00	
			10.50	12	22.00	
	BH-3		1.50	4	72.00	
			6.00	10	40.00	
37	BH-1	KDA Plot No-32, Sonadanga	1.50	2	58.20	21.20 – 77.60
			3.00	2	53.30	
			4.50	3	21.20	
			7.50	4	61.40	
	BH-2		1.50	5	77.60	
			4.50	3	32.00	
			7.50	6	49.30	
			9.00	5	23.70	
38	BH-1		9.00	5	80.00	33.00 – 80.00
			10.50	5	53.00	
			12.00	5	33.00	
			13.50	5	75.00	
	BH-2		3.00	9	65.00	
			6.00	3	39.00	
			10.50	4	45.00	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
39	BH-1	Sonadanga, Khulna	1.50	4	66.30	19.30 – 89.20
			3.00	3	27.50	
			4.50	5	41.30	
			7.50	4	39.70	
	BH-2		1.50	4	56.50	
			3.00	2	19.30	
			4.50	3	29.70	
			6.00	7	89.20	
			7.50	3	25.40	
	BH-3		1.50	5	56.30	
			3.00	2	36.10	
			4.50	6	66.30	
			7.50	2	35.20	
			9.00	2	29.40	
40	BH-1	Adv. Abdur Rahman, HMM Road, Helatola	3.00	4	27.00	16.00 – 63.00
			4.50	4	66.00	
			6.00	4	38.00	
	BH-2		1.50	3	44.00	
			3.00	5	63.00	
			7.50	5	16.00	
41	BH-1	Blind Hospital, Helatola	1.50	5	21.83	11.29 – 55.16
			4.50	4	41.28	
			6.00	2	16.33	
			7.50	3	24.79	
			9.00	2	21.37	
	BH-2		1.50	5	52.30	
			4.50	3	29.44	
			6.00	2	45.93	
			7.50	3	23.57	
	BH-3		1.50	3	55.16	
			4.50	5	49.54	
			6.00	2	46.33	
			7.50	3	11.64	
			9.00	4	11.29	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
42	BH-1	Tibbet Market, Helatola	1.50	6	45.31	4.39 – 62.40
			3.00	3	54.32	
			4.50	5	31.55	
			6.00	3	57.62	
			7.50	6	60.43	
			9.00	3	36.82	
			10.50	3	17.83	
	BH-2		1.50	6	54.32	
			3.00	3	19.63	
			4.50	5	38.91	
			6.00	4	62.40	
			7.50	4	58.32	
			9.00	3	15.56	
			10.50	4	6.62	
	BH-3		1.50	7	29.87	
			3.00	3	31.65	
			4.50	2	4.39	
			6.00	8	58.75	
			7.50	3	32.19	
			9.00	3	27.98	
43	BH-1	Iqbal Road, Khulna	1.50	5	80.00	16.00 – 95.00
			3.00	7	41.50	
			6.00	5	19.00	
			7.50	5	78.00	
			9.00	4	70.00	
			10.50	5	23.00	
	BH-2		1.50	7	95.00	
			3.00	4	93.00	
			4.50	4	52.50	
			9.00	4	64.00	
			10.50	7	16.00	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
44	BH-1	H-43, Khanjahan Ali Road, Tarerpukur	1.50	4	95.88	36.90 – 95.88
			3.00	7	53.40	
			4.50	4	50.10	
			6.00	4	70.25	
			7.50	3	54.70	
			9.00	5	81.92	
			10.50	6	62.50	
			12.00	4	36.90	
45	BH-1	HMM Road, Khulna	1.50	1	40.90	9.33 – 82.16
			3.00	4	40.62	
			4.50	4	53.24	
			6.00	4	58.17	
			7.50	4	20.47	
	BH-2		4.50	3	31.43	
			6.00	4	34.84	
			7.50	5	82.16	
			9.00	3	9.33	
			10.50	4	28.57	
			12.00	4	24.86	

Table 3.6 Summary of q_u of cohesive soils at different depth and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	q_u kPa	q_u (Range)
46	BH-1	Opsonin Office Building, Sheikhpara	1.50	7	146.00	12.00 – 146.00
			3.00	2	93.00	
			4.50	5	37.00	
			7.50	5	53.00	
			9.00	5	26.00	
	BH-2		5.00	10	114.00	
			3.00	4	31.00	
			4.50	8	24.00	
			6.00	6	58.00	
			7.50	6	57.00	
			9.00	5	91.00	
	BH-3		1.50	7	76.00	
			3.00	4	92.00	
			4.50	7	29.00	
			6.00	5	61.00	
			7.50	6	74.00	
			9.00	7	12.00	

Table 3.7 Summary of q_u of cohesive soils at different depth and locations in the South Zone

Site No	BH No	Location	Depth, m	N-value	q_u kPa	q_u (Range)
47	BH-1	Khulna University Prof. Quarter	3.00	1	11.60	11.37 – 96.24
			7.50	1	13.91	
			12.00	4	12.67	
			18.00	4	18.27	
	BH-2		1.50	1	11.37	
			4.50	1	19.93	
			9.00	4	96.24	
			13.50	4	82.00	
48	BH-1	Khulna University Building	3.00	2	25.87	25.47 – 31.48
			6.00	4	31.10	
			9.00	4	25.47	
			10.50	3	31.10	
			12.00	3	31.10	
			13.50	2	25.87	
	BH-2		1.50	2	31.13	
			3.00	2	31.10	
			4.50	3	26.00	
			7.50	3	31.13	
			10.50	3	30.12	
			13.50	4	25.47	
	BH-3		3.00	2	31.13	
			6.00	2	30.12	
			9.00	2	25.47	
			12.00	3	31.48	
			13.50	2	30.50	

3.8 Shear Strength Characteristics in Non- cohesive (Sandy) Soil

ASTM D3089-98 describes the direct shear test used to determine shear strength parameters, c and Φ of disturbed samples collected form different depths and tested in the Geotechnical Laboratory of KUET. The shear strength parameters, so obtained, have been compared with the usual range of such parameters suggested by Terzagi and Peck, 1967, which is shown in the Table 2.3. It is evident that the deeper layer of KCC soil is c - Φ type in which silt is dominating part. The obtained relative density revels that the compactness of the soil ranges from very loose to dense. Moreover, the obtained angle of internal friction is lower than that of values suggested by Bowles and Peck at al with relation to the relative density. The reasons may be attributed to the presence of mica content and organic matter with silt. However a useful relationship is drawn between Φ and N for the range of soil samples collected from 1.5m to 20m depth from EGL, shown in the Figure 3.8, 3.9 and 3.10. A summary of N-value, C and Φ for different depths and locations are tabulated in the Table 3.10,3.11 & 3.12. From the Figures a general equations cannot be established due the erratic nature of existing soil of the study area.

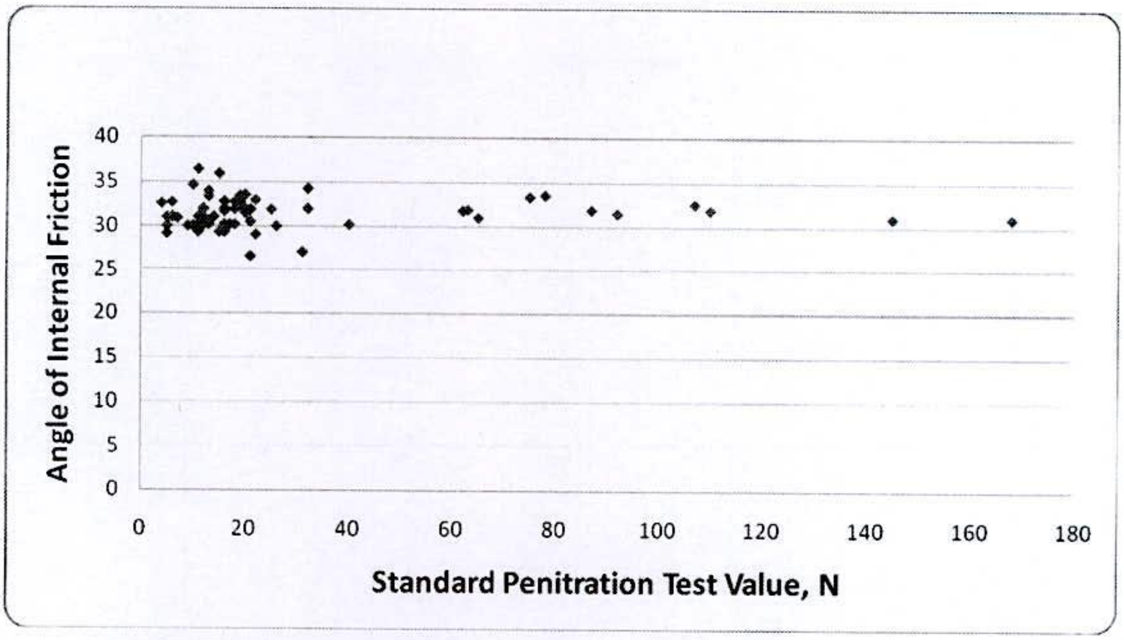


Figure 3.5 Relationship between angle of internal friction and SPT-values in the North Zone

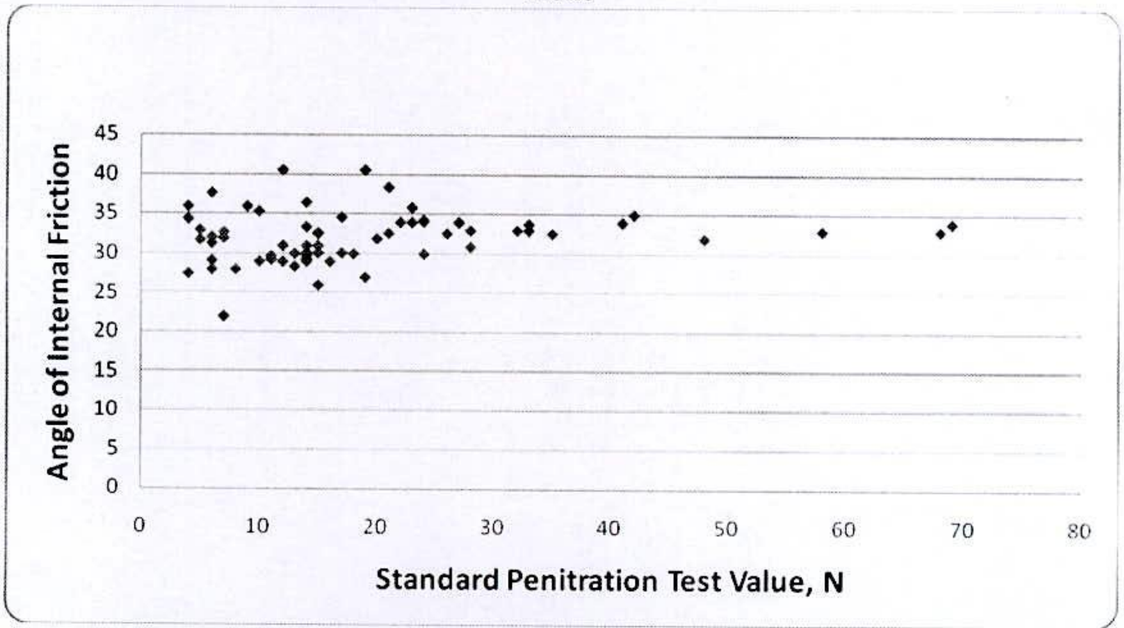


Figure 3.6 Relationship between angle of internal friction and SPT-values in the Middle Zone

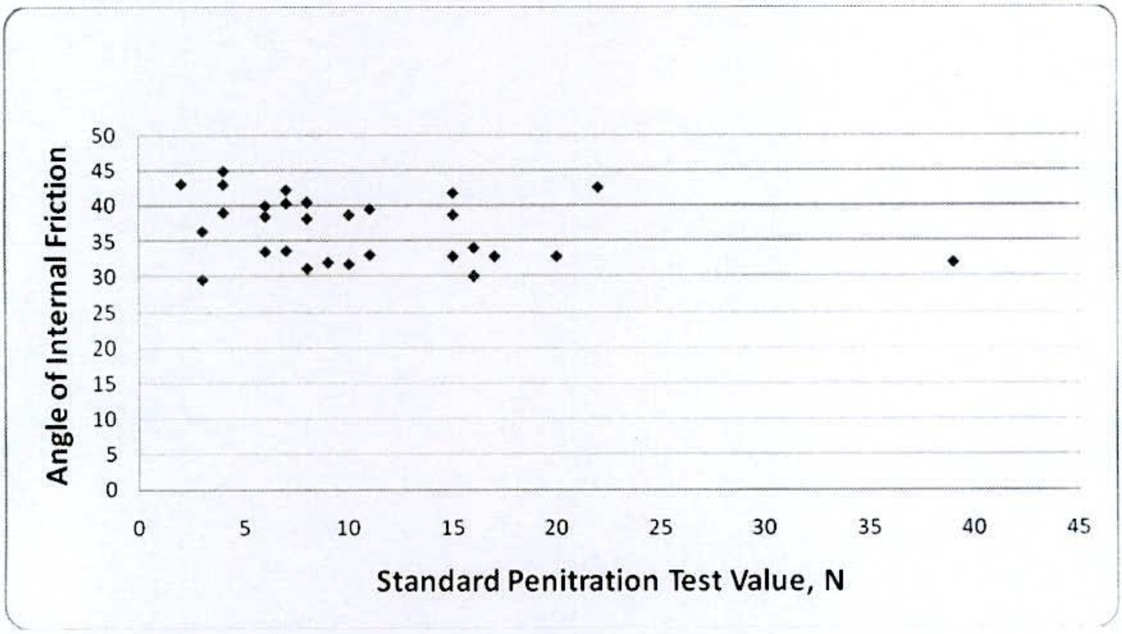


Figure 3.7 Relationship between angle of internal friction and SPT-values in the South Zone

Table 3.8 Summary of c and Φ value of soils at different depths and locations in the North zone

Site No.	BH No.	Location	Depth, m	N-value	C(kPa)	Φ(°)	Φ(°) Range
1	BH-1	Afilgate, Khulna	15.00	22	2.90	33.00	32.00 – 33.00
	BH-2		12.00	15	1.40	36.00	
			13.50	32	6.20	32.00	
			15.00	16	2.90	32.00	
2	BH-1	Cable Shilpa Ltd. Shiromoni	7.50	5	2.40	31.00	27.00 – 33.60
			10.50	11	3.36	29.30	
			13.50	65	2.88	31.00	
			16.50	87	1.92	31.90	
			18.00	145	2.40	31.00	
	BH-2		10.50	12	5.77	31.00	
			12.00	21	5.77	31.90	
			13.50	31	3.36	27.00	
			15.00	40	8.65	30.20	
			18.00	168	2.88	31.00	
	BH-3		12.00	16	6.25	32.80	
			15.00	21	6.25	31.90	
			16.50	78	5.77	33.60	
			18.00	110	0.90	31.90	

Table 3.8 Summary of c and Φ value of soils at different depths and locations in the North zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
3	BH-1	Police Training Centre, Shiromoni	7.50	26	0.95	30.00	30.00 – 33.40
			9.00	13	1.91	33.40	
			13.5	92	5.73	31.50	
	BH-2		6.00	9	4.77	30.00	
			15.00	62	0.47	31.80	
	BH-3		4.50	10	0.47	30.00	
			13.50	75	10.03	33.40	
4	BH-1	Police Barak, Shiromoni	10.50	12	9.00	32.00	29.00 – 32.00
			13.50	21	5.00	30.50	
			15.00	22	10.50	29.00	
	BH-2		16.50	25	10.00	31.90	
6	BH-2	KUET	10.50	11	0	36.50	32.74-36.50
			12.00	13	0	34.00	
			13.50	10	0	34.70	
			16.50	6	0	32.74	
			18.00	19	0	33.50	
9	BH-1	Mirerdanga, Fulbarigate	7.50	6	2.88	31.07	29.29-32.78
			9.00	16	5.28	31.70	
			10.50	15	3.84	29.29	
			12.00	16	0	32.78	
			13.50	19	0	32.78	
			15.00	18	3.84	30.18	

Table 3.8 Summary of c and Φ value of soils at different depths and locations in the North zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
9	BH-2	Mirerdanga, Fulbarigate	6.00	11	2.40	31.07	29.29-33.61
			7.50	11	4.8	30.18	
			9.00	14	2.88	31.07	
			10.50	16	6.72	30.18	
			12.00	12	6.72	30.18	
			13.50	18	5.28	31.93	
			15.00	20	7.69	33.61	
	BH-3		6.00	16	8.65	29.29	
			7.50	18	0	32.78	
			9.00	13	0.96	30.18	
			10.50	12	0.96	31.93	
			12.00	17	1.92	30.18	
			13.50	63	3.32	31.93	
			15.00	21	9.19	26.50	
			16.50	20	4.80	31.93	
			18.00	20	4.80	31.50	
10	BH-1	Mirerdanga, Fulbarigate	4.50	5	1.43	29.10	29.10-32.60
			6.00	5	2.39	30.00	
			9.00	32	4.77	34.30	
			12.00	107	1.91	32.60	
	BH-2		3.00	4	2.39	32.60	
			6.00	7	3.78	30.90	
			10.50	20	5.73	31.8	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
14	BH-1	Palpara Road , Khalishpur	4.50	15	6.68	26.00	30.00-35.00
			7.50	69	7.64	34.00	
			10.50	68	4.30	33.00	
			13.50	22	7.64	34.00	
	BH-2		4.50	24	8.11	30.00	
			6.00	42	5.73	35.00	
			9.00	33	2.86	33.00	
			12.00	28	8.12	33.00	
15	BH-1	Fire Service Station, Khalishpur	6.00	5	0	31.76	29.13-34.26
			9.00	15	0.95	32.61	
			12.00	17	11.45	30.10	
			13.50	24	7.16	34.26	
	BH-2		6.00	6	0.44	29.13	
			10.50	6	0	32.13	
			12.00	21	9.07	32.61	
			15.00	35	8.60	32.61	
	BH-3		7.50	7	0	32.73	
			10.50	13	7.16	30.02	
			13.50	14	8.12	30.02	
			18.00	26	10.02	32.61	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
19	BH-1	Imam Training Centre, Boyra	1.50	4	3.84	27.47	27.47-32.62
			12.00	14	5.77	29.25	
			13.50	15	1.92	32.62	
			15.00	20	4.32	31.92	
			16.50	12	0.48	31.05	
	BH-2		13.50	11	0.48	29.25	
			15.00	14	0.48	29.25	
			16.50	13	0.96	28.37	
20	BH-1	Md Nazrul Islam, Muzjunni	12.00	12	1.43	29.00	29.00-31.00
	BH-2		10.50	6	2.38	28.00	
	BH-3		13.50	12	0.95	31.00	
22	BH-1	DIG Office, Khulna	10.50	7	9.50	22.00	22.00-34.10
			18.00	41	4.30	34.00	
	BH-2		12.00	5	0.95	33.00	
	BH-3		16.50	27	10.00	34.00	
			18.00	27	10.00	34.00	
			10.50	14	2.20	29.72	
			12.00	15	10.00	31.00	
			12.00	24	1.40	34.10	
			16.50	14	2.00	29.00	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
24	BH-1	Environmental Research Centre	10.50	14	2.20	29.72	29.00-34.10
	BH-2		12.00	15	10.00	31.00	
	BH-3		12.00	24	1.40	34.10	
			16.50	14	2.00	29.00	
26	BH-1	Student Hostel, Medical College	13.50	4	2.88	36.00	34.00-36.00
	BH-2		12.00	9	1.44	36.00	
	BH-2		13.50	4	5.77	34.40	
29	BH-1	Dormitory of Female Police, Zoragate	3.00	10	3.51	29.00	27.00-34.00
			10.50	18	2.86	30.00	
			13.50	58	4.06	33.00	
	BH-2		1.50	14	1.91	31.00	
			3.00	8	0.95	28.00	
			10.50	19	3.82	27.00	
			12.00	48	0.96	32.00	
			13.50	32	4.77	33.00	
			16.50	7	0.48	32.00	
	BH-3		10.50	16	1.43	29.00	
			12.00	23	7.16	34.00	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
30	BH-1	Shishu Sadan , Khulna	13.50	14	4.80	28.00	28.00-36.00
			15.00	25	8.20	34.00	
			18.00	8	2.88	31.00	
	BH-2		13.50	14	1.92	34.00	
			15.00	9	8.20	34.00	
	BH-3		13.50	14	4.80	32.00	
			15.00	23	5.30	36.00	
31	BH-1	ICMA, Sonadanga	15.00	15	0.96	34.43	31.93-34.43
	BH-2		13.50	15	6.72	33.61	
	BH-3		13.50	17	7.70	31.93	
			16.50	46	0.96	33.61	
			18.00	46	0.96	33.61	
32	BH-2	Sonadanga Thana	15.00	22	6.21	32.6	32.60
33	BH-1	Khulna Thana Quarter	10.50	14	1.91	31.00	28.00-33.00
			12.00	24	0.48	28.00	
	BH-2		12.00	18	4.77	33.00	
			15.00	16	0.95	33.00	
35	BH-1	Modina Trading, Ghat No-4	12.00	14	0.48	30.00	27.00-30.00
			13.50	16	6.68	27.00	
			15.00	17	2.68	29.00	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
36	BH-1	Diabetic Hospital, Khulna	13.50	21	4.70	36.00	30.00-36.00
			16.50	24	5.70	30.00	
			18.00	15	8.10	35.00	
	BH-2		4.50	11	4.80	33.00	
			12.00	19	7.20	33.00	
			15.00	24	6.20	33.00	
			18.00	15	8.10	34.00	
	BH-3		4.50	8	3.80	30.00	
			13.50	29	7.20	33.00	
			18.00	13	4.00	36.00	
37	BH-1	KDA Plot No-32, Sonadanga	9.00	7	0.95	35.00	30.00-35.00
			12.00	21	2.39	32.00	
			15.00	25	0.47	31.00	
	BH-2		9.00	5	1.91	31.00	
			12.00	16	0.47	31.00	
			13.50	12	0.95	30.00	
			15.00	36	2.39	33.00	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
38	BH-1	KDA Community Centre	4.50	1	10.00	38.26	24.28-41.98
			16.50	14	23.00	24.28	
			18.00	15	22.00	33.69	
	BH-2		4.50	2	21.00	35.54	
			12.00	8	19.00	41.98	
			16.50	13	25.00	32.74	
39	BH-1	Sonadanga, Khulna	12.00	32	3.82	33.00	32.00-36.00
			13.50	17	5.25	32.00	
			15.00	10	3.82	36.00	
	BH-2		12.00	40	6.68	33.00	
			13.50	28	2.39	34.00	
			15.00	29	7.64	33.00	
			18.00	17	8.50	31.00	
	BH-3		15.00	26	8.11	33.00	
			16.50	24	9.07	33.00	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
41	BH-1	Blind Hospital, Helatola	15.00	7	7.21	26.50	26.50-32.80
			16.50	7	8.17	27.50	
			18.00	7	8.17	27.50	
	BH-2		9.00	3	0.48	31.50	
			10.50	4	3.36	31.00	
	BH-3		10.50	9	3.36	30.20	
			12.00	15	1.92	31.90	
			13.50	17	4.80	31.00	
			15.00	156	2.40	32.80	
42	BH-1	Tibbet Market, Helatola	12.00	9	7.21	31.07	25.54-32.07
			13.50	19	16.34	25.54	
	BH-2		13.50	9	6.73	28.38	
			15.00	12	5.29	31.07	
	BH-3		12.00	9	6.37	32.78	
			13.50	14	4.81	31.93	
43	BH-1	Iqbal Road, Khulna	4.50	4	14.41	38.31	35.28-43.10
			10.50	5	8.75	37.6	
			13.50	11	14.91	39.04	
			16.50	33	11.06	37.58	
	BH-2		3.00	4	11.54	43.10	
			13.50	11	19.71	39.04	
			15.00	18	22.54	31.09	
			16.50	28	17.25	35.28	
			18.00	22	11.54	36.82	

Table 3.9 Summary of c and Φ value of soils at different depths and locations in the Middle Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
44	BH-1	H-43, Khanjahan Ali Road, Tarerpukur	15.00	10	6.24	31.00	31.00
45	BH-1	HMM Road, Khulna	13.50	15	7.64	29.10	29.00-30.90
			15.00	28	11.64	30.90	
	BH-2		15.00	51	11.94	30.90	
46	BH-1	Opsonin Office Building, Sheikhpara	12.00	26	9.10	30.00	26.00-33.00
			15.00	24	3.80	30.00	
	BH-2		10.50	27	8.60	32.00	
			13.50	56	7.16	33.00	
			15.00	86	7.16	33.00	
			16.50	70	7.16	31.00	
	BH-3		12.00	23	5.70	36.00	
			18.00	64	9.10	26.00	

Table 3.10 Summary of c and ϕ value of soils at different depths and locations in the South Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	ϕ(°)	ϕ(°) Range
49	BH-1	Chandmari, Khulna	9.00	10	5.28	31.70	31.70-33.61
			12.00	9	0.96	31.93	
			13.50	39	1.44	31.93	
			15.00	20	0.96	32.78	
	BH-2		10.50	7	0.48	33.61	
			12.00	8	1.92	31.07	
			13.50	15	1.44	32.78	
			15.00	17	1.44	32.78	
50	BH-2	Rokeya Khatoon , Farazipara	16.50	11	2.40	33.00	30.00-33.00
			18.00	16	0.96	30.00	
51	BH-1	Chandmari, Khulna	9.00	3	19.00	36.37	36.37-43.03
			10.50	4	4.00	43.03	
			13.50	7	10.00	42.27	
			15.00	7	10	40.36	

Table 3.10 Summary of c and Φ value of soils at different depths and locations in the South Zone

Site No.	BH No.	Location	Depth, m	N-value	c(kPa)	Φ(°)	Φ(°) Range
52	BH-1	Labanchara, Khulna	12.00	2	8.66	43.10	29.50-44.95
			15.00	4	7.70	39.04	
			18.00	4	0.49	44.95	
	BH-2		6.00	3	15.00	29.50	
			10.50	6	10.00	38.50	
			12.00	8	5.00	38.20	
			13.50	15	3.30	41.80	
			18.00	8	11.25	40.50	
	BH-3		9.00	6	12.00	33.50	
			13.50	11	8.50	39.50	
			16.50	22	5.60	42.60	
53	BH-1	Baniakhamar, Khulna	9.00	10	26.00	38.70	30.00-40.00
			10.50	6	19.00	40.00	
			12.00	15	23.00	38.70	
			13.50	16	31.00	34.00	
			15.00	16	27.00	30.00	

3.9 Compressibility Characteristics

Following ASTM D2435-96 one-dimensional consolidation test method was used to determine compressibility properties of the soil tested in the Geotechnical Laboratory of KUET. The results obtained from these tests are discussed below.

3.9.1 Compression Index

The compressive index, Cc of soil at different layers at different locations are summarized and shown in the Table 3.12, 3.13 and 3.14. It is found that the Cc values observed in the laboratory are 0.167 to 1.96 in the north zone, 0.20 to 3.90 in the middle zone and 0.24 to 1.26 in the south zone. The values of compression index vary with wide ranges, so their averages do not give any common idea about the study area. The obtained compression indexes have also been compared with the different equations of the same types of soil proposed by different researchers shown in the Table 3.5. The theoretically calculated Cc values obtained from these equations and observed Cc values obtained from the laboratory tests are shown in Table 3.6. It may be noted that the Cc values obtained from Nakase (1998), Terzaghi and Peck (1967), Azzouz and Andersland, Al-Khafaji and Andersland (1992) equations are comparable with the observed values.

Table 3.11 List of equations used to calculated Cc for inorganic cohesive soil samples (after Bowles, 1997)

Compression Index, Cc	Equation No	Comments	Source/ Reference
Cc=.009(WL-10)	Eq-1	Clays of moderate St and(±30% error	Terzaghi and Peck (1967)
Cc=1.15(eo-0.35)	Eq-2	All clays	Nishida (1956)
Cc= .009Wn+.005WL	Eq-3	All clays	Koppula(1986)
Cc= .046+.0104Ip	Eq-4	Best for Ip<50%	Nakase et al.(1998)
Cc=0.37(eo+.003WL+.0004Wn-0.34)	Eq-5	678 data points	Azzouz et al.(1976)
Cc=-0.156+.411eo+.00058WL	Eq-6	62 data points	Al-Khafaji and Andersland (1992)

Table 3.12 Summary of Actual and Calculated Cc values of soils of different locations and depths in the North Zone

Site No	BH No	Location	Depth, m	Cc (observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
1	BH-2	Afilgate, Khulna	3.00	0.58	1.53	49	52	28	24	0.38	1.36	0.70	0.29	0.52	0.81
2	BH-3	Cable Shilpa Ltd. Shiromoni	7.50	0.27	0.94	37	30	28	2	0.18	0.68	0.48	0.07	0.28	0.56
3	BH-1	Police Training Centre, Shiromoni	3.00	0.24	0.96	26	32	27	5	0.20	0.70	0.39	0.10	0.28	0.57
			6.00	0.16	0.89	36	30	26	4	0.18	0.62	0.47	0.09	0.26	0.54
	BH-2		4.50	0.357	1.08	40	34	25	9	0.22	0.84	0.53	0.14	0.33	0.62
4	BH-1	Police Barqak, Shiromoni	4.50	0.27	1.00	42	33	28	6	0.21	0.75	0.54	0.10	0.30	0.59
			7.50	0.27	0.90	37	32	27	5	0.20	0.63	0.49	0.10	0.26	0.54
	BH-2		4.50	0.24	0.93	38	31	25	6	0.19	0.67	0.50	0.11	0.27	0.56
			6.00	0.47	0.97	43	31	28	2	0.18	0.71	0.54	0.07	0.29	0.57

Table 3.12 Summary of Actual and Calculated Cc values of soils of different locations and depths in the North Zone

Site No.	BH No.	Location	Depth, m	Cc (observed)	e_o	w_n (%)	w_L (%)	w_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
6	BH-2	KUET, Campus	4.50	0.80	2.81	136	40	31	9	0.27	2.83	1.42	0.14	0.99	1.33
			6.00	0.59	1.84	72	52	34	18	0.37	1.71	0.90	0.22	0.64	0.94
7	BH-1	KUET Road, Fulbarigate	4.50	0.53	1.20	50	96	50	46	0.77	0.98	0.93	0.51	0.45	0.70
			10.50	0.47	1.17	48	55	42	13	0.41	0.94	0.71	0.18	0.39	0.67
8	BH-1	Mr Abul Khaer, Fulbarigate	4.50	0.57	1.03	36	48	32	16	0.34	0.78	0.56	0.21	0.33	0.61
			6.50	0.31	1.26	58	70	41	29	0.54	1.05	0.87	0.34	0.44	0.71
	BH-2		3.00	0.37	0.94	40	46	28	18	0.32	0.68	0.59	0.23	0.29	0.57
			6.00	0.36	1.14	56	69	35	34	0.53	0.91	0.85	0.39	0.40	0.66

Table 3.12 Summary of Actual and Calculated Cc values of soils of different locations and depths in the North Zone

Site No	BH No	Location	Depth, m	Cc (observed)	e_o	w_n (%)	w_L (%)	w_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
9	BH-1	Mirerdanga, Fulbarigate	3.00	0.32	0.86	28	34	28	7	0.22	0.59	0.42	0.11	0.25	0.53
			4.50	0.33	1.11	42	33	27	6	0.21	0.87	0.54	0.11	0.34	0.63
	BH-2		3.00	0.36	0.99	32	33	28	5	0.21	0.74	0.45	0.09	0.30	0.58
	BH-3		3.00	0.34	0.95	34	35	27	8	0.23	0.69	0.48	0.13	0.28	0.57
11	BH-1	Baby Home, Moheshorpasha	4.50	0.29	1.04	44	60	36	24	0.45	0.79	0.70	0.29	0.35	0.62
	BH-2		7.50	1.96	1.04	260	76	39	37	0.59	0.79	2.72	0.41	0.40	0.63

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No.	BH No.	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
12	BH-1	Nasir Hospital , Goalkhali	9.00	0.52	0.89	68	45	32	13	0.31	0.62	0.84	0.17	0.28	0.55
	BH-2		7.50	0.44	1.08	43	48	33	15	0.34	0.84	0.63	0.20	0.35	0.63
	BH-3		15.00	0.46	1.48	57	76	40	36	0.59	1.30	0.89	0.41	0.53	0.81
13	BH-1	Setara Begum, Muzjunni	3.00	0.53	1.41	50	120	41	79	0.99	1.22	1.05	0.84	0.55	0.81
			6.00	0.53	1.49	56	38	28	10	0.25	1.31	0.69	0.15	0.49	0.79
	BH-2		3.00	0.60	1.50	53	110	42	68	0.90	1.32	1.02	0.73	0.57	0.84
			4.50	0.66	1.47	79	44	37	7	0.31	1.29	0.93	0.12	0.49	0.79
14	BH-1	Palpara Road , Khalishpur	3.0	0.24	0.87	33	31	28	3	0.19	0.60	0.45	0.08	0.25	0.53

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No.	BH No.	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
19	BH-1	Imam Training Centre, Boyra	4.50	3.90	6.19	348	101	51	50	0.82	6.72	3.64	0.54	2.34	2.76
			6.00	0.59	1.81	68	45	34	10	0.31	1.68	0.83	0.15	0.62	0.93
			9.00	0.39	1.18	40	44	33	11	0.31	0.95	0.58	0.16	0.38	0.67
	BH-2		3.00	0.22	1.14	106	101	50	51	0.81	0.91	1.46	0.55	0.44	0.68
			4.50	0.41	1.48	56	107	67	40	0.87	1.30	1.04	0.45	0.56	0.83
20	BH-1	Md Nazrul Islam, Muzjunni	4.50	0.80	1.46	90	313	190	123	2.73	1.28	2.38	1.28	0.79	0.94
22	BH-2	DIG Office, Khulna	3.00	0.34	1.19	38	84	39	45	0.67	0.97	0.76	0.50	0.43	0.69
	BH-3		6.00	1.15	1.92	72	78	45	33	0.61	1.81	1.04	0.38	0.70	0.99

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No.	BH No.	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
23	BH-1	Regional PATC, Boyra	10.50	0.43	1.02	44	34	31	3	0.22	0.77	0.57	0.08	0.31	0.59
	BH-2		9.00	0.37	1.12	38	34	29	4	0.21	0.89	0.51	0.09	0.35	0.64
			10.50	0.30	1.01	46	36	28	8	0.23	0.76	0.60	0.13	0.31	0.59
			12.00	0.33	1.09	44	33	28	5	0.20	0.85	0.56	0.09	0.34	0.62
24	BH-1	Environmental Research Centre	4.50	1.42	3.92	338	37	33	4	0.24	4.11	3.23	0.09	1.43	1.79
	BH-2		6.00	0.73	1.78	59	102	55	47	0.83	1.64	1.04	0.52	0.67	0.95
			7.50	0.26	0.88	38	40	33	7	0.27	0.61	0.54	0.11	0.26	0.54
	BH-3		6.00	0.49	1.74	64	195	140	55	1.67	1.60	1.55	0.60	0.76	0.98
			9.00	0.32	1.07	42	37	34	3	0.24	0.83	0.56	0.08	0.33	0.62

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No.	BH No.	Location	Depth, m	Cc(observed)	e_o	w_n (%)	w_L (%)	w_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
25	BH-1	Medical College, Boyra	1.5	0.3	0.94	35	33	28	5	0.21	0.68	0.48	0.09	0.28	0.56
25	BH-1	Medical College, Boyra	4.5	0.58	1.34	70	74	40	34	0.58	1.14	1.00	0.38	0.48	0.75
25	BH-2	Medical College, Boyra	7.5	1.29	1.19	52	95	41	54	0.77	0.97	0.94	0.59	0.44	0.70
26	BH-2	Srudent Hostel, Medical College, Boyra	3.0	0.8	1.1	46	45	33	12	0.32	0.86	0.64	0.17	0.35	0.63
26	BH-2	Srudent Hostel, Medical College, Boyra	6.0	0.39	1.86	31	109	76	33	0.89	1.74	0.82	0.38	0.70	0.98
27	BH-1	MTTC, Khulna	3.0	0.28	0.88	37	78	42	36	0.61	0.61	0.72	0.41	0.31	0.56
27	BH-1	MTTC, Khulna	7.5	0.54	1.44	53	56	42	14	0.41	1.25	0.76	0.19	0.49	0.78

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No.	BH No.	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
28	BH-1	Residence of OC , Sonadanga	3.00	0.49	1.06	48	73	36	37	0.57	0.82	0.80	0.42	0.37	0.63
			6.00	0.43	1.21	49	45	30	15	0.31	0.99	0.67	0.20	0.39	0.68
	BH-2		3.00	0.43	1.21	48	71	38	33	0.55	0.99	0.78	0.37	0.42	0.69
			6.00	0.38	1.11	62	42	29	13	0.29	0.87	0.77	0.17	0.36	0.64
29	BH-3	Dormitory of Female Police, Zoragate	3.00	0.2	0.86	32	38	30	8	0.25	0.59	0.48	0.13	0.25	0.53
30	BH-1	Shishu Sadan , Khulna	4.50	0.67	1.13	68	112	49	63	0.92	0.90	1.17	0.68	0.44	0.69
			7.50	0.27	1.05	46	42	31	11	0.29	0.81	0.62	0.16	0.33	0.61
	BH-3		3.00	0.25	1.04	38	42	32	10	0.29	0.79	0.55	0.15	0.33	0.61

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No	BH No	Location	Depth m	Cc (observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
31	BH-1	ICMA, Sonadanga	3.00	0.42	1.10	49	48	30	18	0.34	0.86	0.68	0.23	0.36	0.64
			4.50	2.65	9.65	297	143	82	62	1.20	10.70	3.38	0.66	3.66	4.21
			6.00	0.42	1.31	49	52	38	13	0.37	1.10	0.70	0.18	0.44	0.72
			9.00	0.48	1.46	55	44	34	10	0.31	1.28	0.71	0.15	0.49	0.78
33	BH-1	Khulna Thana Quarter	3.00	0.36	0.97	40	46	34	12	0.32	0.72	0.59	0.17	0.31	0.58
			4.50	0.34	0.97	42	38	24	14	0.25	0.72	0.57	0.19	0.30	0.58
35	BH-1	Modina Trading, Ghat No-4	6.00	0.59	2.70	77	91	56	35	0.73	2.70	1.15	0.40	1.00	1.32
			7.50	0.52	1.20	60	41	28	13	0.28	0.98	0.75	0.18	0.39	0.67
36		Diabetic Hospital, Khulna	3.00	0.37	1.10	40	47	28	19	0.33	0.86	0.60	0.24	0.35	0.64

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No	BH No	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
37	BH-2	KDA Plot No-32, Sonadanga	4.50	2.68	6.27	234	74	43	31	0.58	6.81	2.48	0.36	2.33	2.78
39	BH-1	Sonadanga, Khulna	4.50	0.87	2.45	100	62	33	29	0.47	2.42	1.21	0.34	0.88	1.20
			7.50	0.37	1.17	52	41	32	9	0.28	0.94	0.67	0.14	0.38	0.66
	BH-3		7.50	0.29	1.05	44	44	32	12	0.31	0.81	0.62	0.17	0.33	0.61
			9.00	0.35	1.51	54	34	24	10	0.22	1.33	0.66	0.15	0.49	0.80
41	BH-1	Blind Hospital, Helatola	7.50	0.36	1.13	43	40	37	3	0.27	0.90	0.58	0.07	0.36	0.64
	BH-2	Blind Hospital, Helatola	6.00	0.47	1.37	50	44	37	7	0.31	1.17	0.67	0.12	0.45	0.74

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No.	BH No.	Location	Depth, m	Cc(observed)	e_o	w_n (%)	w_L (%)	w_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
42	BH-1	Tibbet Market, Helatola	7.50	0.42	1.61	66	54	24	30	0.40	1.45	0.86	0.35	0.55	0.85
	BH-2		3.00	0.31	1.06	41	47	31	17	0.33	0.82	0.61	0.21	0.34	0.62
			6.00	0.48	1.41	51	38	29	9	0.25	1.22	0.65	0.14	0.46	0.76
	BH-3		7.50	0.35	1.20	46	52	37	15	0.38	0.98	0.67	0.20	0.40	0.68
			9.00	0.34	1.30	51	46	31	15	0.32	1.09	0.69	0.20	0.43	0.72
43	BH-2	Iqbal Road, Khulna	4.50	0.37	1.02	32	41	28	12	0.28	0.77	0.49	0.17	0.32	0.60
	BH-2		9.00	0.4	1.01	39	46	29	17	0.32	0.76	0.58	0.22	0.32	0.60
44	BH-1	H-43, Khanjahan Ali Road, Tarerpukur	4.50	0.67	1.68	51	54	31	23	0.40	1.53	0.73	0.28	0.58	0.88
45	BH-2	HMM Road, Khulna	6.00	0.519	1.40	47	52	35	17	0.38	1.21	0.68	0.22	0.47	0.76

Table 3.13 Summary of Actual and Calculated Cc values of soils of different locations and depths in the Middle Zone

Sl. No.	BH No.	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
46	BH-1	Opsonin Office Building, Sheikhpara	4.50	0.46	1.40	45	250	140	110	2.16	1.21	1.66	1.15	0.69	0.88
			9.00	0.23	1.14	46	39	32	7	0.26	0.91	0.61	0.12	0.36	0.65
	BH-2		6.00	2.92	5.50	336	47	36	11	0.33	5.92	3.26	0.16	2.03	2.44
	BH-2		7.50	0.47	0.99	51	38	33	5	0.25	0.74	0.65	0.10	0.31	0.58

Table 3.14 Summary of Actual and Calculated Cc values of soils of different locations and depths in the South Zone

Sl. No	BH No	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
47	BH-1	Khulna University Prof. Quarter	3.00	0.96	2.03	74	85	58	27	0.68	1.94	1.09	0.32	0.75	1.04
	BH-1		6.00	1.26	3.42	116	53	37	17	0.39	3.53	1.31	0.21	1.23	1.59
49	BH-1	Chandmari, Khulna	4.50	0.6	1.92	78	52	31	21	0.38	1.81	0.97	0.25	0.67	0.98
	BH-2		4.50	0.55	1.32	45	47	32	15	0.33	1.12	0.64	0.20	0.44	0.73
50	BH-1	Rokeya Khatoon , Farazipara	3.00	0.24	0.93	35	47	33	14	0.33	0.67	0.55	0.19	0.29	0.57
	BH-2		4.50	0.27	0.97	55	68	47	21	0.52	0.71	0.84	0.26	0.33	0.59
	BH-2		7.50	0.3	1.03	33	37	25	12	0.24	0.78	0.48	0.17	0.32	0.60

Table 3.14 Summary of Actual and Calculated Cc values of soils of different locations and depths in the South Zone

Sl. No	BH No	Location	Depth, m	Cc(observed)	e_o	W_n (%)	W_L (%)	W_P (%)	I_p	Theoretical Cc					
										Eq-1	Eq-2	Eq-3	Eq-4	Eq-5	Eq-6
52	BH-1	Labanchara, Khulna	4.50	0.53	2.19	134	70	47	23	0.54	2.12	1.56	0.28	0.80	1.10
			7.50	0.35	1.22	58	60	39	21	0.45	1.00	0.82	0.26	0.42	0.69
			9.00	0.62	1.38	66	46	39	8	0.33	1.18	0.83	0.12	0.46	0.75
	BH-2		3.00	0.29	1.40	45	41	31	10	0.28	1.21	0.61	0.14	0.46	0.76
			7.50	0.32	2.10	38	53	29	23	0.38	2.01	0.61	0.28	0.73	1.05
	BH-3		3.00	0.37	1.90	60	54	34	20	0.39	1.78	0.81	0.25	0.66	0.97
			4.50	0.39	2.05	77	52	33	19	0.38	1.96	0.95	0.24	0.72	1.03

3.9.2 Secondary Compression Index

The values of secondary compression index of the inorganic soil samples are not observe and summarized in this research works. But Table 3.16 shows the equations used to calculate secondary compression index (Bowles, 1997) for fat clay, CH to elastic silt, MH while Table 3.17, 3.18 and 3.19 show the calculated values of secondary compression index ca. It may be concluded that NAVFAC (1982) and Nakase et al equations describe KCC soil of the study area better than the Mesri et al. (1990) equation.

Table 3.15 List of equation of secondary compression index and references (after Bowles, 1997)

Secondary compression index, $C\alpha$	Comments	Source/ Reference	Equation
I $C\alpha$ =0.0001Wl	-	NAVFAC (1982)	Eq-1
$C\alpha$ =0.00168+0.00033Ip	-	Nakase et al. (1988)	Eq-2
$C\alpha$ =0.0015 to 0.03 Cc	Sandy clay	Mesri et al. (1990)	Eq-3

Table 3.16 Summary of secondary compression index calculated for the North zone

Site No.	BH No.	Location	Depth (m)	Cc (observed)	w_n (%)	I_p	Theoretical, Ca		
							Eq-1	Eq-2	Eq-3
1	BH-2	Afilgate, Khulna	3.00	0.58	49	24	0.0049	0.0096	0.0087
2	BH-3	Cable Shilpa Ltd. Shiromoni	7.50	0.27	37	2	0.0037	0.0023	0.0041
3	BH-1	Police Training Centre, Shiromoni	3.00	0.24	26	5	0.0026	0.0033	0.0036
			6.00	0.167	36	4	0.0036	0.0030	0.0025
	BH-2		4.50	0.357	40	9	0.0040	0.0047	0.0054
4	BH-1	Police Barqak, Shiromoni	4.50	0.27	42	6	0.0042	0.0035	0.0041
			7.50	0.27	37	5	0.0037	0.0033	0.0041
	BH-2		4.50	0.24	38	6	0.0038	0.0037	0.0036
			6.00	0.47	43	2	0.0043	0.0024	0.0071
6	BH-2	KUET, Fulbarigate	4.50	0.8	136	9	0.0136	0.0047	0.0120
			6.00	0.59	72	18	0.0072	0.0075	0.0089
7	BH-1		4.50	0.53	50	46	0.0050	0.0169	0.0080
	BH-1		10.50	0.47	48	13	0.0048	0.0060	0.0071
8	BH-1	Mr Abul Khaer, Fulbarigate	4.50	0.57	36	16	0.0036	0.0070	0.0086
			6.00	0.31	58	29	0.0058	0.0113	0.0047
	BH-2		3.00	0.37	40	18	0.0040	0.0076	0.0056
			6.00	0.36	56	34	0.0056	0.0129	0.0054
9	BH-1	Mirerdanga, Fulbarigate	3.00	0.32	28	7	0.0028	0.0038	0.0048
			4.50	0.33	42	6	0.0042	0.0038	0.0050
	BH-2		3.00	0.36	32	5	0.0032	0.0033	0.0054
	BH-3		3.00	0.34	34	8	0.0034	0.0045	0.0051
11	BH-1	Baby Home, Moheshorpa sha	4.50	0.29	44	24	0.0044	0.0097	0.0044
	BH-2		7.50	1.96	260	37	0.0260	0.0138	0.0294

Table 3.17 Summary of secondary compression index calculated for the Middle zone

Sl. No.	BH No.	Location	Depth, (m)	Cc (observed)	w_n (%)	I_p	Theoretical, Ca		
							Eq-1	Eq-2	Eq-3
12	BH-1	Nasir Hospital, Goalkhali	9.00	0.52	68	13	0.0068	0.0059	0.0078
	BH-2		7.50	0.44	43	15	0.0043	0.0067	0.0066
	BH-3		15.00	0.46	57	36	0.0057	0.0136	0.0069
13	BH-1	Setara Begum, Muzjunni	3.00	0.53	50	79	0.0050	0.0278	0.0080
			6.00	0.53	56	10	0.0056	0.0050	0.0080
	BH-2		3.00	0.6	53	68	0.0053	0.0241	0.0090
			4.50	0.66	79	7	0.0079	0.0040	0.0099
14	BH-1	Palpara Road, Khalishpur	3.00	0.24	33	3	0.0033	0.0027	0.0036
19	BH-1	Imam Training Centre, Boyra	4.5	3.9	348	50	0.0348	0.0180	0.0585
			6.0	0.59	68	10	0.0068	0.0051	0.0089
			9.0	0.395	40	11	0.0040	0.0053	0.0059
	BH-2		3.0	0.22	106	51	0.0106	0.0185	0.0033
	BH-2		4.5	0.41	56	40	0.0056	0.0150	0.0062
20	BH-1	Md Nazrul Islam, Muzjunni	4.5	0.8	90	123	0.0090	0.0423	0.0120
22	BH-2	DIG Office, Khulna	3.0	0.34	38	45	0.0038	0.0165	0.0051
	BH-3		6.0	1.15	72	33	0.0072	0.0126	0.0173
23	BH-1	Regional PATC, Boyra	10.5	0.43	44	3	0.0044	0.0028	0.0065
	BH-2		9.0	0.37	38	4	0.0038	0.0030	0.0056
			10.5	0.3	46	8	0.0046	0.0043	0.0045
			12.0	0.33	44	5	0.0044	0.0033	0.0050
24	BH-1	Environmental Research Centre	4.5	1.42	338	4	0.0338	0.0031	0.0213
	BH-2		6.0	0.73	59	47	0.0059	0.0172	0.0110
			7.5	0.26	38	7	0.0038	0.0039	0.0039
	BH-3		6.0	0.49	64	55	0.0064	0.0198	0.0074
			9.0	0.32	42	3	0.0042	0.0028	0.0048
25	BH-1	Medical College, Boyra	1.5	0.3	35	5	0.0035	0.0033	0.0045
			4.5	0.58	70	34	0.0070	0.0128	0.0087
	BH-2		7.5	1.29	52	54	0.0052	0.0197	0.0194

Table 3.17 Summary of secondary compression index calculated for the Middle zone

Sl. No	BH No	Location	Depth, m	Cc (observed)	W_n (%)	I_p	Theoretical, Ca		
							Eq-1	Eq-2	Eq-3
26	BH-1	Srudent Hostel, Medical College, Boyra	3.00	0.80	46	12	0.0046	0.0056	0.0120
	BH-2		6.00	0.39	31	33	0.0031	0.0126	0.0059
27	BH-1	MTTC, Khulna	3.00	0.28	37	36	0.0037	0.0136	0.0042
			7.50	0.54	53	14	0.0053	0.0063	0.0081
28	BH-1	Residence of OC, Sonadanga	3.00	0.49	48	37	0.0048	0.0140	0.0074
			6.00	0.43	49	15	0.0049	0.0066	0.0065
	BH-2		3.00	0.43	48	33	0.0048	0.0125	0.0065
			6.00	0.38	62	13	0.0062	0.0059	0.0057
29	BH-3	Mdormitory of Female Police, Zoragate	3.00	0.2	32	8	0.0032	0.0043	0.0030
30	BH-1	Shishu Sadan, Khulna	4.50	0.67	68	63	0.0068	0.0225	0.0101
			7.50	0.27	46	11	0.0046	0.0053	0.0041
	BH-3		3.00	0.25	38	10	0.0038	0.0050	0.0038
31	BH-1	ICMA, Sonadanga	3.00	0.42	49	18	0.0049	0.0077	0.0063
			4.50	2.65	297	62	0.0297	0.0220	0.0398
			6.00	0.42	49	13	0.0049	0.0061	0.0063
			9.00	0.48	55	10	0.0055	0.0050	0.0072
33	BH-1	Khulna Thana Quarter	3.00	0.36	40	12	0.0040	0.0056	0.0054
			4.50	0.34	42	14	0.0042	0.0063	0.0051
35	BH-1	Modina Trading, Ghat No-4	6.00	0.59	77	35	0.0077	0.0132	0.0089
			7.50	0.52	60	13	0.0060	0.0060	0.0078
36	BH-1	Diabetic Hospital, Khulna	3.00	0.37	40	19	0.0040	0.0080	0.0056
37	BH-2	KDA Plot No-32, Sonadanga	4.50	2.68	234	31	0.0234	0.0119	0.0402

Table 3.17 Summary of secondary compression index calculated for the Middle Zone

Sl. No	BH No	Location	Depth, m	Cc (observed)	W_n (%)	I_p	Theoretical, Ca		
							Eq-1	Eq-2	Eq-3
39	BH-1	Sonadanga, Khulna	4.50	0.87	100	29	0.0100	0.0113	0.0131
			7.50	0.37	52	9	0.0052	0.0047	0.0056
	BH-3		7.50	0.29	44	12	0.0044	0.0056	0.0044
			9.00	0.35	54	10	0.0054	0.0050	0.0053
41	BH-1	Blind Hospital, Helatola	7.50	0.36	43	3	0.0043	0.0025	0.0054
	BH-2		6.00	0.47	50	7	0.0050	0.0040	0.0071
42	BH-1	Tibbet Market, Helatola	7.50	0.42	66	30	0.0066	0.0116	0.0063
	BH-2		3.00	0.31	41	17	0.0041	0.0071	0.0047
			6.00	0.48	51	9	0.0051	0.0047	0.0072
	BH-3		7.50	0.35	46	15	0.0046	0.0066	0.0053
			9.00	0.34	51	15	0.0051	0.0066	0.0051
43	BH-2	Iqbal Road, Khulna	4.50	0.375	32	12	0.0032	0.0057	0.0056
			9.00	0.4	39	17	0.0039	0.0074	0.0060
44	BH-1	H-43, Khanjahan Ali Road, Tarerpukur	4.50	0.67	51	23	0.0051	0.0093	0.0101
45	BH-2	HMM Road, Khulna	6.00	0.51	47	17	0.0047	0.0073	0.0078
46	BH-1	Opsonin Office Building, Sheikhpara	4.50	0.46	45	110	0.0045	0.0380	0.0069
			9.00	0.23	46	7	0.0046	0.0040	0.0035
	BH-2		6.00	2.92	336	11	0.0336	0.0053	0.0438
			7.50	0.47	51	5	0.0051	0.0033	0.0071

Table 3.18 Summary of secondary compression index calculated for the South Zone

Sl. No.	BH No.	Location	Depth, m	Cc (observed)	w_n (%)	I_p	Theoretical, Ca		
							Eq-1	Eq-2	Eq-3
47	BH-1	Khulna University Prof. Quarter	3.0	0.96	74	27	0.0074	0.0106	0.0144
			6.0	1.26	116	17	0.0116	0.0071	0.0189
49	BH-1	Chandmari, Khulna	4.5	0.6	78	21	0.0078	0.0085	0.0090
	BH-2		4.5	0.55	45	15	0.0045	0.0066	0.0083
50	BH-1	Rokeya Khatoon , Farazipara	3.0	0.24	35	14	0.0035	0.0063	0.0036
	BH-2		4.5	0.27	55	21	0.0055	0.0086	0.0041
			7.5	0.3	33	12	0.0033	0.0056	0.0045
52	BH-1	Labanchara, Khulna	4.5	0.53	134	23	0.0134	0.0094	0.0080
			7.5	0.35	58	21	0.0058	0.0087	0.0053
			9.0	0.62	66	8	0.0066	0.0042	0.0093
	BH-2		3.0	0.29	45	10	0.0045	0.0049	0.0044
			7.5	0.32	38	23	0.0038	0.0093	0.0048
	BH-3		3.0	0.37	60	20	0.0060	0.0083	0.0056
			4.5	0.39	77	19	0.0077	0.0081	0.0059

CHAPTER IV

Laboratory Investigations and Improvement Technique

4.1 General

Experimental soft soil bed was prepared in a cubic steel box in geotechnical engineering laboratory of Civil Engineering Department, KUET in which model foundation was situated at the middle of the box after cutting soft soil up to the required depth in case of untreated soil. In case of treated soil i.e., improved soil, the foundation was situated at the middle of the box after preparing the compacted sand bed in the excavated area in soft soil bed. The laboratory investigations were conducted on the model foundations prepared in soft soil bed.

4.2 Statement of the Problem

The sub-soil of the Khulna region, the south-west part of Bangladesh, contains fine-grained soils with significant amount of organic content, which often creates problems to the geotechnical engineers to select an economic foundation for the construction of massive structures due to low shear strength and high compressibility (Alamgir et al., 2001). Recently the performance have also been studied in this region at field level and acceptable results were reported (Haque, 2000; Zaher, 2000; Alamgir and Zaher, 2001; Haque at al., 2001; Sobhan, 2001 and Hossain, 2007). As the performance of the soil bed improvement techniques greatly depend on the properties of soil particles and the technique used. As a part of clear understanding for suggestive technique to improve the soft soil, laboratory investigations were conducted adopting only one technique, cut and fill, with different sizes and depths of granular fills.

4.3 Work Plan

The methodology of this research was accomplished by the work plan described below:

(i) To fabricate a cubic box of size 900mm x 900mm x 900mm by steel to prepare the artificial soft soil bed.

(ii) To collection disturbed samples for the preparation of artificial soft soil bed in the fabricated steel box from a selected site in the KCC (Khulna City Corporation)

(iii) To determine index and engineering properties of the collected soil by adopting standard laboratory test procedures.

(iv) To add water to the collected soil equal to 0.85 times the liquid limit of the soil to prepare homogeneous slurry.

(v) To pour the slurry into the cubic steel box and left it undisturbed with a steel plate of thickness 10mm for two days to obtain the artificial soft bed.

(vi) To prepare compacted sand bed and place of a model foundation on this compacted bed at the middle of soft soil bed. Then load was applied and increased up to failure on the model foundation with the variation of dimensions of the compacted sand bed as shown in Figure 4.2.

(vii) Measurement of bearing capacity along with settlement response of treated and untreated soil beds for each condition of compacted sand bed.

4.4 Collection of Soil for the Preparation of Soft Soil bed

The artificial soil bed was prepared with the disturbed soil collected from the east side of the Department of Civil Engineering of KUET. In this study, disturbed soil was collected from a depth of about 1.5m from the existing soil surface which was transported and stored in the Geotechnical Engineering Laboratory of the Department of Civil Engineering, KUET.

4.5 Physical and Index Properties of the Soil

Physical and index properties of the soil were determined in order to classify the collected soil. The disturbed samples were air-dried and the soil lumps were broken carefully with a wooden hammer so as to avoid breakage of soil particle. The following tests were performed to determine index properties of the soil.

(i) Specific gravity
(ii) Atterberg limits
(iii) Grain size distribution

The specific gravity, liquid limit, plastic limit and plasticity index, and grain size distribution of all the soil samples were determined following the procedures specified in ASTM D854, BS1377, ASTM D424, ASTM D422 respectively. The percentage of sand silt and clay were determined according to MIT Classification System (1931). The soils were also classified according to Unified Soil Classification System (Casagrande, 1948). Table 4.1 shows the index properties and classification of the soil used. The grain size distribution curve is shown in Figure.4.1

Grain Size Test Results

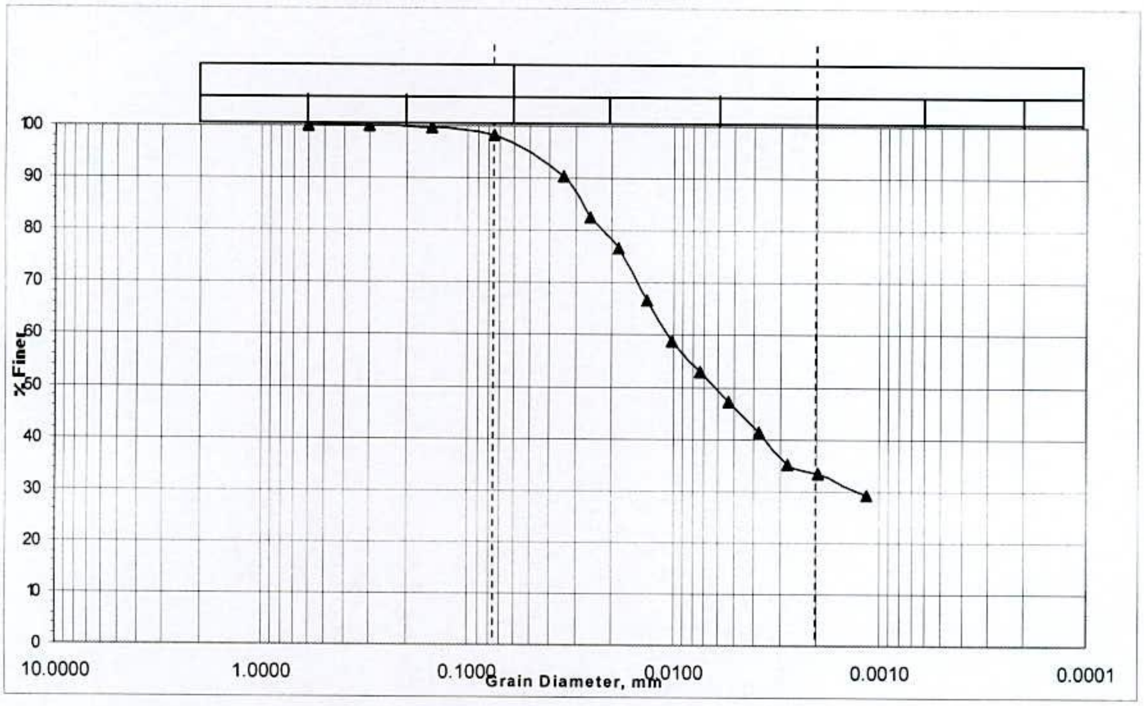


Figure 4.1 Grin Size Distribution Curve of Collected Soil

Table 4.1 Index Properties and Classification of Soil Sample

Index Properties and Classification	Soil used from eastside of Department of Civil Engineering, KUET
Specific Gravity	2.71
Liquid Limit, LL	39
Plastic Limit, PL	24
Plasticity Index, PI	15
Sand (%)	2%
Silt (%)	66%
Clay (%)	32%
Activity	0.47
USCS Symbol	ML

4.6 Preparation of Artificial Soft Beds

The artificial soft soil bed was prepared in the cubic box. The powdered soil was sieved through No. 40 sieve and the sieved samples were mixed with water at 0.85 times the liquid limit to form soil slurry. The soil and water were mixed thoroughly by hand kneading to form slurry to ensure full saturation. The product was then poured into the cubic box and was kept undisturbed with a surcharge pressure for two days. During this time, the testing box was covered by polythene sheet to avoid losing of moisture content from the soil. This soil is known as artificial soil bed which was used for carrying model foundation with or without adopting any improvement technique.

A sand layer of 50 mm thickness was provided at the bottom of artificial soft soil bed in this study to dissipate excess pore pressure during loading. To avoid clogging of sand layer with fine-grained soil, geo-textile was used in the interface of sand and soft soil bed.

Bearing capacity with settlement response of the soft soil bed was determined due to apply of loading through a model foundation without improvement by granular materials (i.e., untreated soil bed) or with improvement by granular materials (i.e., treated soil bed) in the soil bed.

4.7 Techniques for Improvement of Soft Soil Bed

One untreated soil bed and nine treated soil beds improved by granular materials (sand of FM=1.5) were taken under investigations. The soft soil was improved by cutting the soft soil to a required depth and then filling the cutting depth by granular materials as shown in the Figure 4.3. The dimensions of the compacted sand in soft soil bed and just under the model foundation were 150mm x 150mm x 150mm, 375mm x 375mm x 150mm, 600mm x 600mm x 150mm, 150mm x 150mm x 225mm, 375mm x 375mm x 225mm, 600mm x 600mm x 225mm, 150mm x 150mm x 300mm, 450mm x 450mm x 300mm, 750mm x 750mm x 300mm as shown in the Figure 4.3. A 150 mm RCC cube was used as a model foundation on which load was applied. For each model test sand was poured in the excavated area and compacted by 5.50 lb weight with 25 numbers of blows for each 75mm layer. The height of free drop of hammer was maintained to 150 mm. The arrangements and dimensions of the improvement techniques in the soft soil bed with the model foundation are shown in Figure 4.3 and the discussions on these techniques are illustrated in the following sub-articles.

4.7.1 Loading on Model Foundation for Untreated Soft Soil

A typical loading diagram on the untreated soft soil bed is shown in the Figure 4.2 where placements of footings along with applied load are shown. The untreated soft soil is leveled as follows for the convenience of tests records and analysis.

G-1: Soft soil bed not treated by sand filling

4.7.2 Loading on Model Foundation for Treated Soft Soil

The soft soil beds treated by sand filling are shown in the Figure 4.3 where placements of footings along with applied load are shown. The treated soil beds are leveled as follows for convenience of tests records and analysis.

G-2: Soft soil bed treated by sand filling whose $L_s = B_f$ and $D_s = B_f$ (150mm x 150mm x 150mm)

G-3: Soft soil bed treated by sand filling whose $Ls = 2B_f$ and $Ds = B_f$(300mm x 300mm x 150mm)

G-4: Soft soil bed treated by sand filling whose $Ls = 3B_f$ and $Ds = B_f$ (450mm x 450mm x 150mm)

G-5: Soft soil bed treated by sand filling whose $L_s = B_f$ and $D_s = 1.5B_f$ (150mm x 150mm x 225 mm)

G-6: Soft soil bed treated by sand filling whose $L_s = 2.5B_f$ and $D_s = 1.5B_f$ (375mm x 375mm x 225mm)

G-7: Soft soil bed treated by sand filling whose $L_s = 4B_f$ and $D_s = 1.5B_f$ (600mm x 600mm x 225mm

G-8: Soft soil bed treated by sand filling whose $L_s = B_f$ and $D_s = 2B_f$ (150mm x 150mm x 300mm)

G-9: Soft soil bed treated by sand filling whose $L_s = 3B_f$ and $D_s = 2B_f$ (450mm x 450mm x 300mm)

G-10: Soft soil bed treated by sand filling $L_s = 5B_f$ and $D_s = 2B_f$ (750mm x 750mm x 300mm)

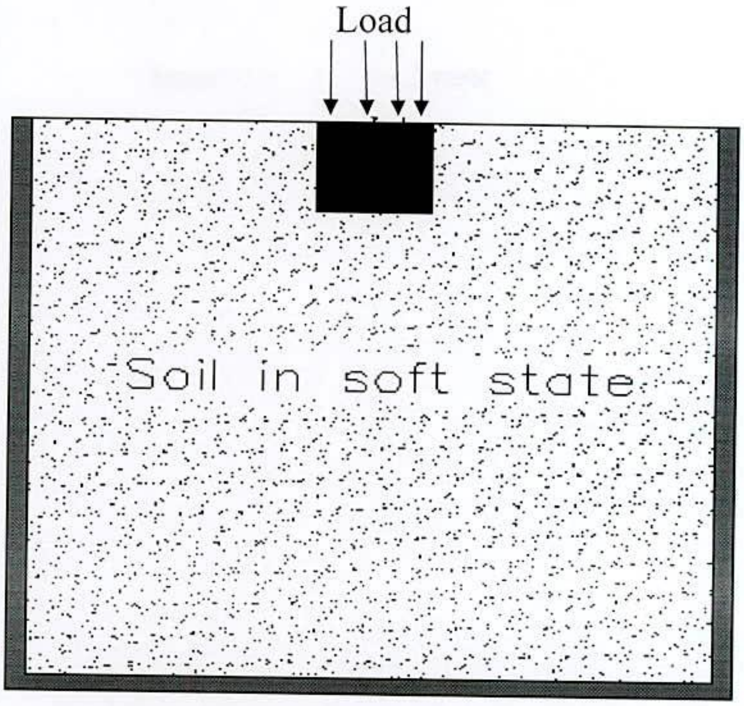


Figure 4.2 Untreated Soft Soil Bed (G-1)

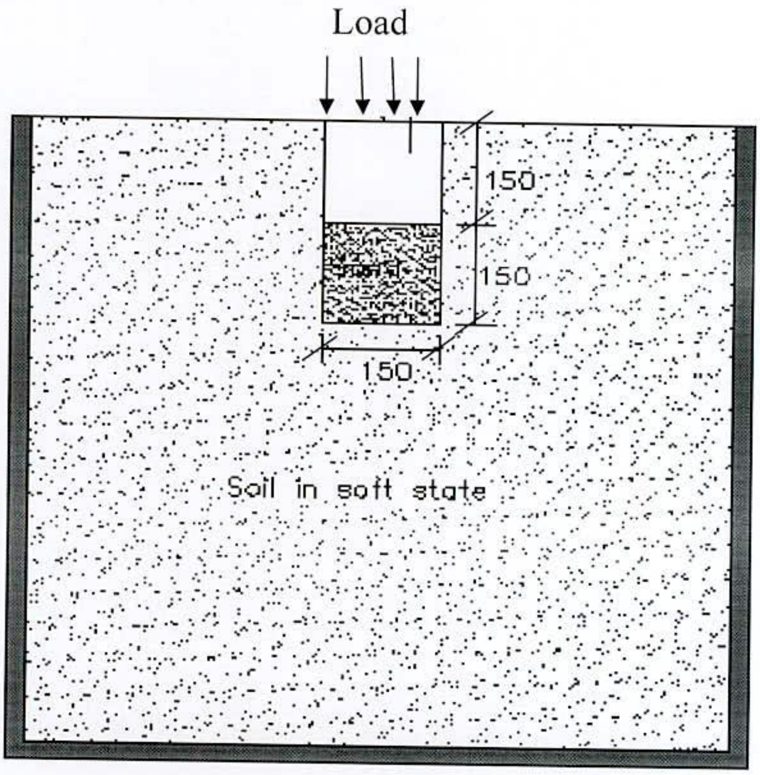


Figure 4.3a Soft Soil Bed Improved by Granular Fills (G-2)

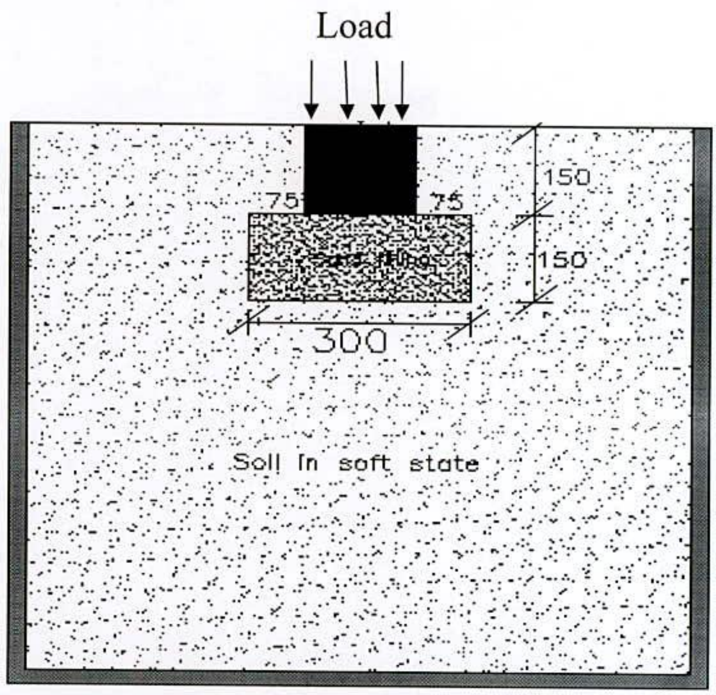


Figure 4.3b Soft Soil Bed Improved by Granular Fills (G-3)

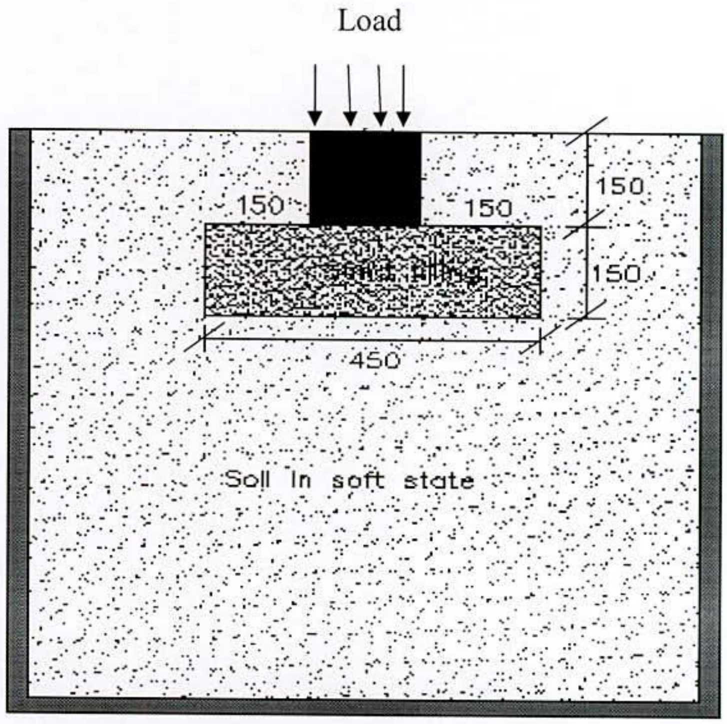


Figure 4.3c Soft Soil Bed Improved by Granular Fills (G-4)

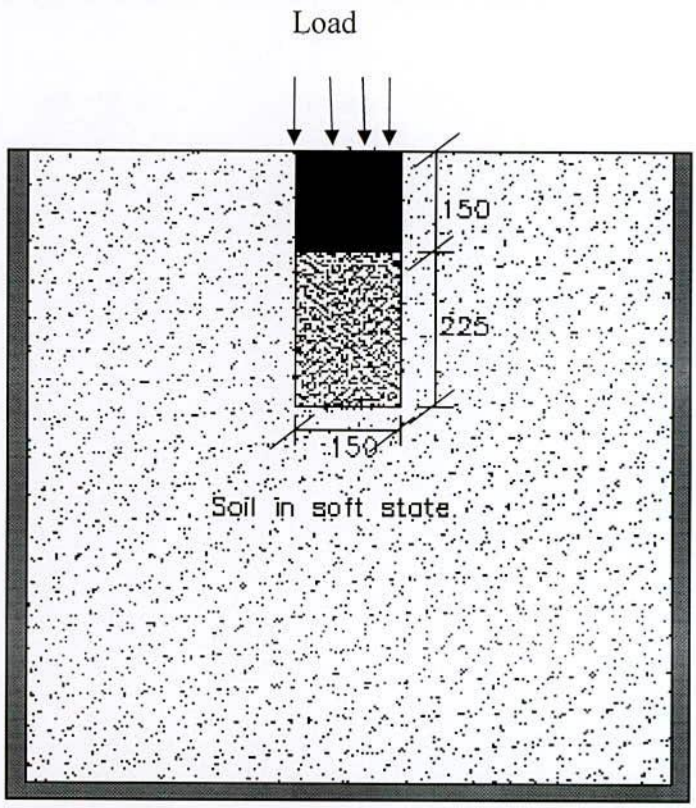


Figure 4.3d Soft Soil Bed Improved by Granular Fills (G-5)

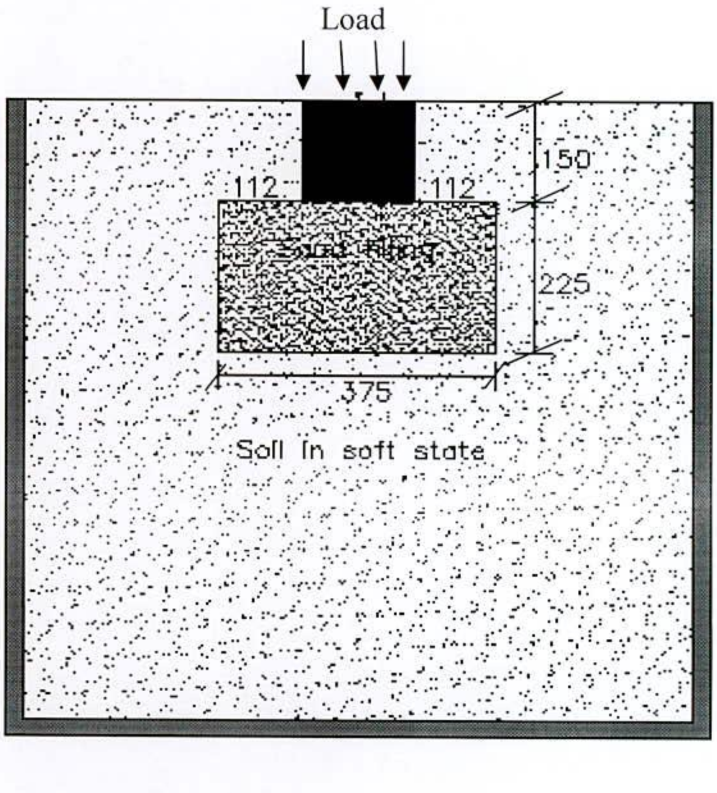


Figure 4.3e Soft Soil Bed Improved by Granular Fills (G-6)

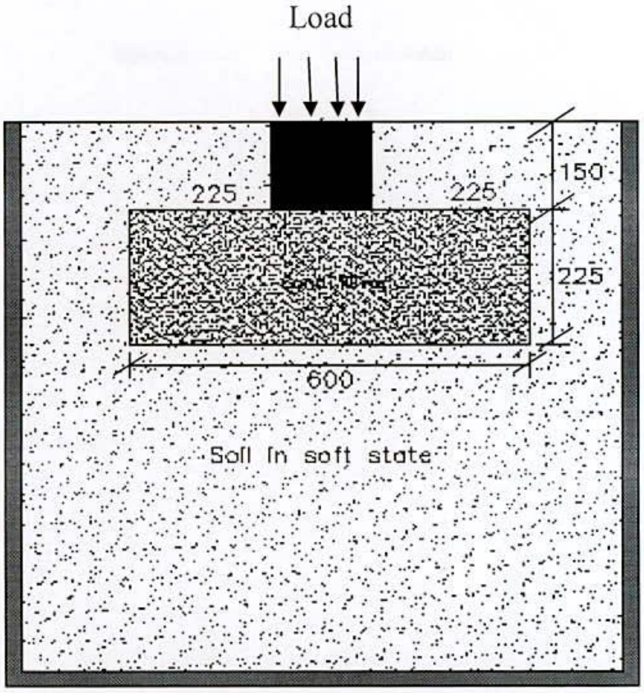


Figure 4.3f Soft Soil Bed Improved by Granular Fills (G-7)

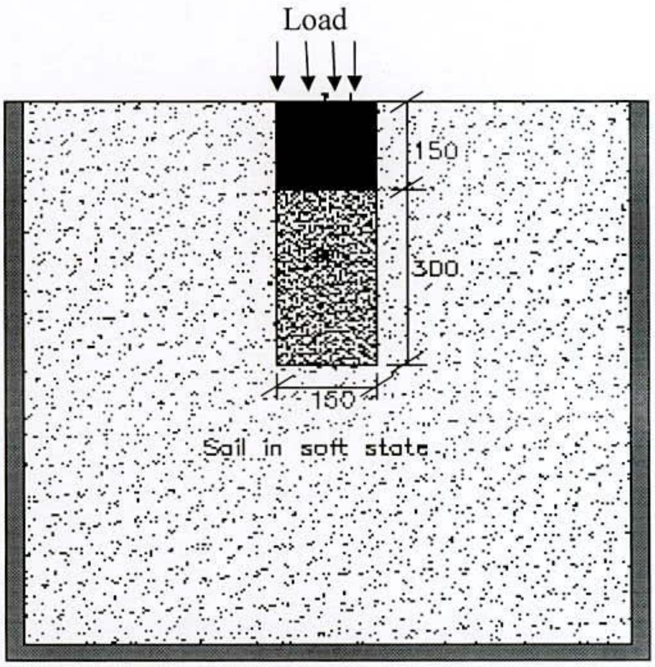


Figure 4.3g Soft Soil Bed Improved by Granular Fills (G-8)

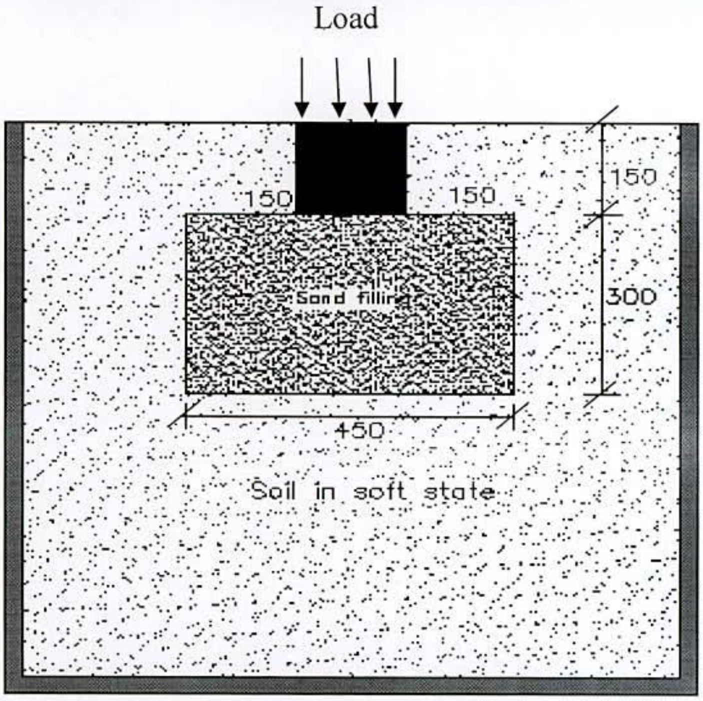


Figure 4.3h Soft Soil Bed Improved by Granular Fills (G-9)

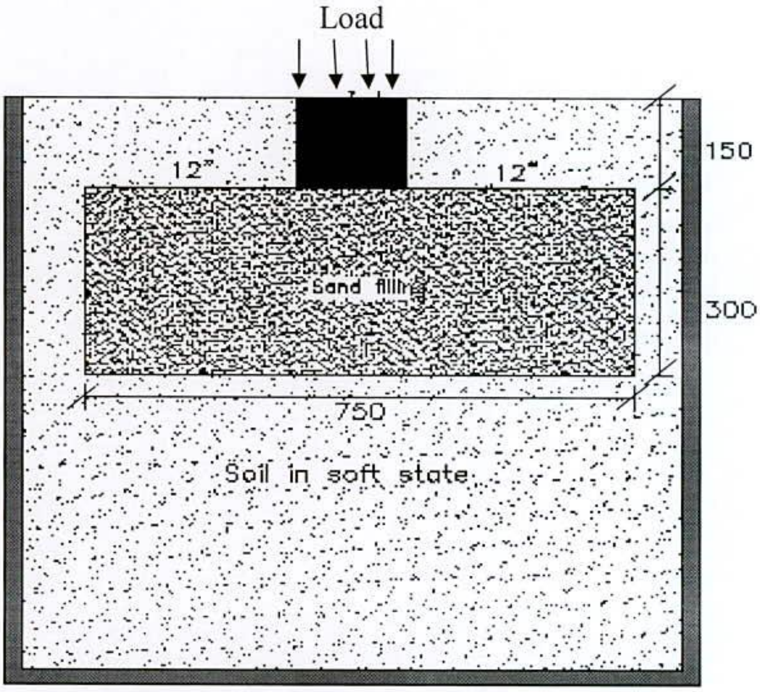


Figure 4.3i Soft Soil Bed Improved by Granular Fills (G-10)

4.8 Load Test on Model Footing

The performances of improved soil beds were determined carrying out the footing load test. The load-settlement behavior of experimental soil beds were evaluated based on the plate load test concept. This test involving static loading to the concrete footing was used to determine bearing pressure for an allowable settlement. The footing load test procedure can be found in ASTM-1194, D-1195 and D-1196.

4.8.1 CC Footing

A cubic CC footing of size 150 mm x 150 mm x 150 mm was used in the experiment to apply load to the prepared soil beds. The footing was cast in the laboratory with Portland cement and the ratio of mixing was 1:1.5:3. After casting, the reinforced concrete footing, as shown in Figure 4.2 & 4.3, was submerged in water for curing of 28 days for proper strengthening. This solid cubic block was used as a model foundation. The weight of footing was measured as 7.84 kg (17.25lb).

4.8.2 Hydraulic Jack

Hydraulic jack was used to apply load in the footing during load test. The capacity of hydraulic jack used for the laboratory investigation was 5 tons. The identity mentioned in the jack is MARUTO Testing Machine Company, Made in Japan, ID: SO5L.12.5. The identity mentioned in the dial is NKS, NAGANO, 440, ID: 2393504.

4.8.3 Dial Gauge

In footing load test, the settlements with respect to load were measured by deformation dial gauge. The dial gauge used for measuring deformation has the capacity of 25 mm. The identity mentioned in the dial gauge is Mitutoyo, No 2050-08, made in Japan. The dial gauge was set on a platform to ease the setting of dial and get accurate measurement of settlement. The accuracy of the dial gauge used in the work was 0.001 mm.

4.8.4 Experimental Set-up

A cubic concrete block mentioned in the article 4.8.1 was used as footing to apply load to the experimental soil beds. In this study, square shape was considered to present the maximum field conditions where both the test footing and soft soil beds were square in shape. The footing was placed at the center of the experimental soil bed. Then a hydraulic jack was placed on the footing to apply load to both treated and untreated soft soil beds. The settlement of footing was measured by the dial gauge with reference to an independent datum.

4.8.5 Load Settlement Tests

The footing load test was conducted on the untreated and treated soil beds by the following steps:

A hydraulic jack and a deformation dial gauge were set up as described earlier. The load was then applied by hydraulic jack and settlement was recorded by the dial gauge.

(i) The load was applied to the soil in cumulative equal increments of not more than 100 kPa or not more than one-fifth of the estimated allowable bearing pressure.

(ii) For an applied load, reading for settlement was taken from deformation dial gauge at the elapsed time of 0.25, 0.50, 1,2,4,8,16,30,60,120,180,300,480,1440 minutes measured from the starting of loading. If the settlement was more than 0.25 mm per hour, then the reading for the settlement was taken at the time of 120 minute.

(iii)The load was increased up to the settlement occurred more than 50 mm.

(iv) With the help of the load and settlement data for 10 conditions, load-settlement curves are drawn and shown in the Figure 5.1

4.8.6 Method of Determining Bearing Capacity from Test Data

A "net load" versus "final settlement" curve was plotted on linear scale. From this curves load bearing capacity of the test soil beds were determined. The ultimate load bearing capacity of the soft soil bed improved by granular fills are determined corresponding to the settlement of 25 mm which are discussed in chapter 5.

CHAPTER V

Results and Discussions

5.1 General

The results obtained from the laboratory investigations are prepared and discussed in this chapter. Footing load tests are the basis of obtaining the results. The tests are carried out for both untreated and treated soft beds where different improvement conditions were adopted.

5.2 Load –Settlement Behavior

The load-settlement behavior of one untreated soft soil bed and nine treated soft soil beds improved by granular fills were determined by the footing load test. The load settlement curves against all tests are shown in the Figure: 5.1 and also discussed in the following articles:

5.2.1 Load - Settlement Behavior of Untreated Soil Bed (G-1)

The load test on individual square footing of size 150 mm x 150 mm was performed on untreated soft soil bed to find out settlement response. Settlements recorded against increment of loads on the model foundation are plotted in the Figure: 5.1a from where the bearing capacity of untreated soft soil bed was determined at 25 mm settlement. In this works the load of 64 kPa found by tangent of the change of curve was considered as the bearing capacity of the untreated soil, which is shown in the Figure 5.1a.

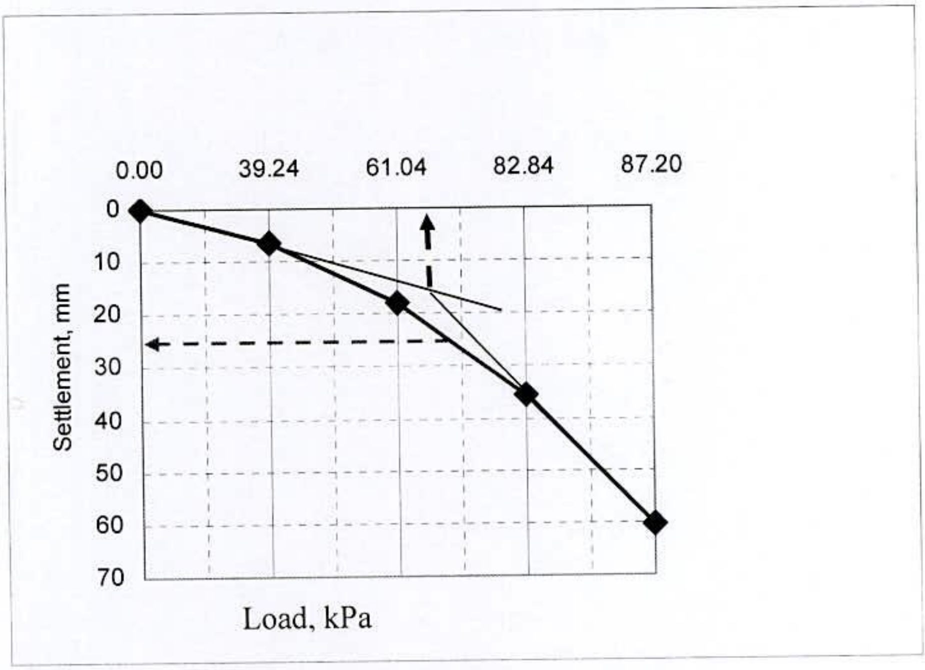


Figure 5.1a Load – Settlement Curve for Untreated Soil Bed G-1

5.2.2 Load - Settlement Behavior of Treated Soil Bed

Soil improvement techniques were applied to improve the inherent character of soft soil by increasing bearing capacity and minimizing settlement. Nine sand beds of different dimensions under the model foundation were formed to examine the load- settlement behavior. The load settlement curves against all tests are shown in the Figure 5.1b to 5.1j. The results obtained from the experiments for different treated conditions are discussed in the following articles.

5.2.2.1 Load - Settlement Behavior of Treated Soil Bed (G-2)

The load test was carried out on the treated soil bed G-2 as shown in the Figure 4.2a. The model CC footing was placed on the soft soil treated by granular fills of depth 150 mm (D_s), equal to the width of model foundation (B_f) and both the length and width of granular fills were also equal to the width of model foundation (B_f). The settlements against increments of load are recorded for two samples and plotted in the Figure 5.1b. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-2 was found as 83 kPa which was 1.30 times more than that of untreated soil bed.

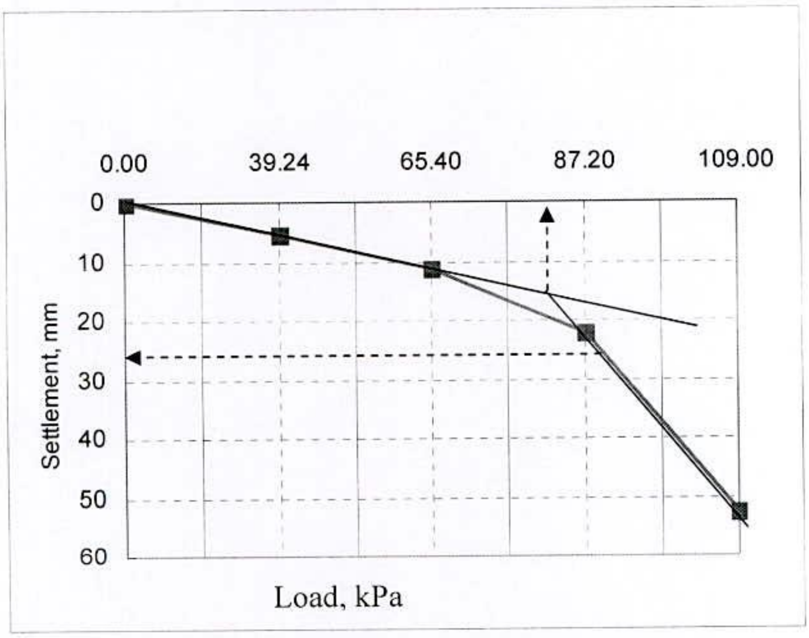


Figure: 5.1b Loads – Settlement Curve for Treated Soil Bed G-2

5.2.2.2 Load - Settlement Behavior of Treated Soil Bed (G-3)

The test was carried out on the treated soil bed G-3 as shown in the Figure 4.2b. The model CC footing was placed on the treated granular fills of depth 150 mm (D_s), equal to the width of model foundation (B_f) and both the length and width of granular fills were equal to two times of width of model foundation ($2B_f$). The settlements against increments of load are recorded for two samples and plotted in the Figure 5.1c. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-3 was found as 100 kPa which was 1.56 times more than that of the untreated soil bed.

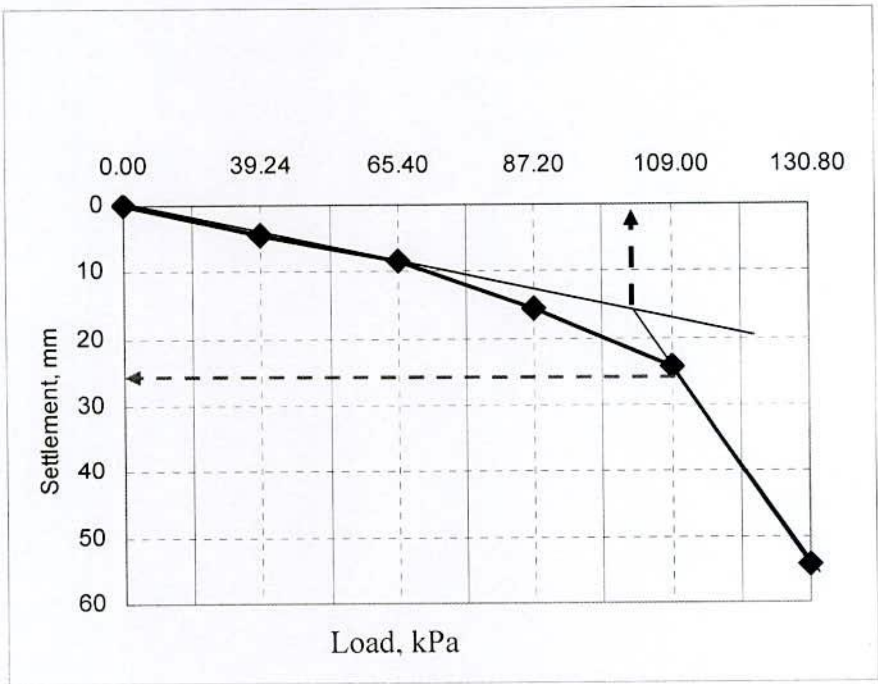


Figure: 5.1c Loads – Settlement Curve for Treated Soil Bed G-3

5.2.2.3 Load - Settlement Behavior of Treated Soil Bed (G-4)

The test was carried out on the treated soil bed G-4 as shown in the Figure 4.2c. The model CC footing was placed on the treated granular fills of depth 150 mm (D_s), equal to the width of model foundation (B_f) and both the length and width of granular fills were equal to three times of width of model foundation ($3B_f$). The settlements against increments of load are recorded for two samples and plotted in the Figure 5.1d. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-4 was found as 102 kPa which was 1.59 times more than that of untreated soil bed.

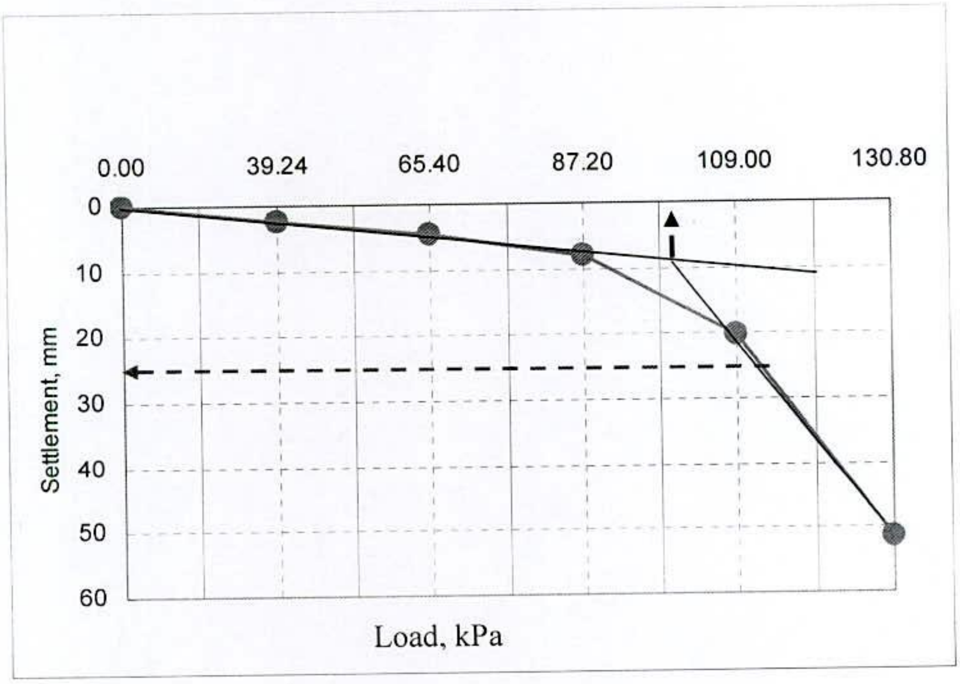


Figure: 5.1d Loads – Settlement Curve for Treated Soil Bed G-4

5.2.2.4 Load - Settlement Behavior of Treated Soil Bed (G-5)

The test was carried out on the treated soil bed G-5 as shown in the Figure 4.2d. The model CC footing was placed on the treated granular fills of depth 225 mm(D_s), equal to 1.5 times of the width of model foundation (1.5B_f) and both the length and width of granular fills were equal to the width of model foundation (B_f). The settlements against increments of loads were recorded and plotted in the Figure: 5.1e. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-5 was found as 110 kPa which was 1.72 times more than that of untreated soil bed.

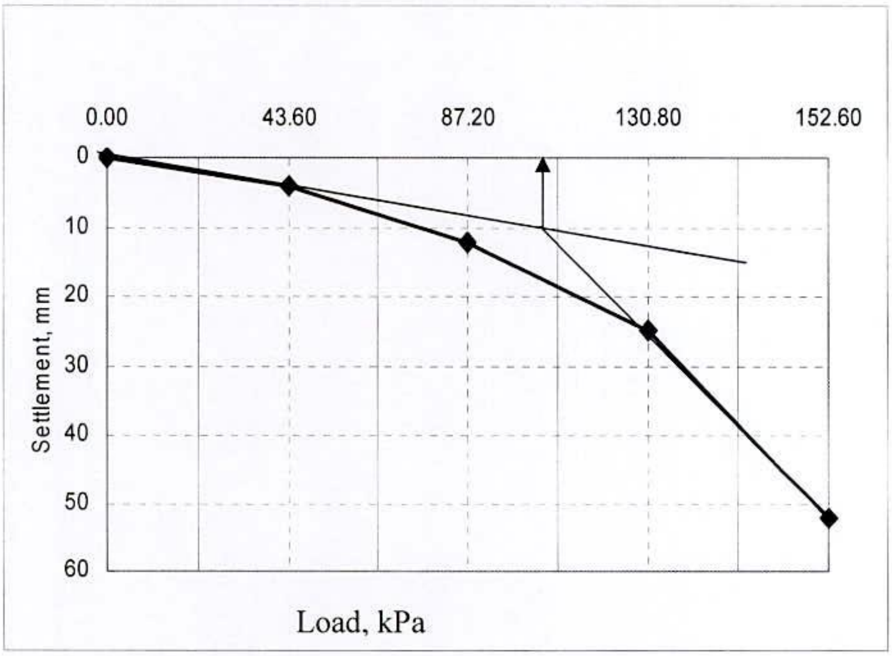


Figure: 5.1e Loads – Settlement Curve for Treated Soil Bed G-5

5.2.2.5 Load - Settlement Behavior of Treated Soil Bed (G-6)

The load test was carried out on the treated soil bed G-6 as shown in the Figure 4.2e. The model CC footing was placed on the treated granular fills of depth 225 mm (D_s), equal to 1.5 time of the width of model foundation ($1.5B_f$) and both the length and width of granular fills was equal to 2.5 times of the width of model foundation ($2.5B_f$). The settlements against increments of loads were recorded and plotted in the Figure 5.1f. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-5 was found as 115 kPa which was 1.79 times more than that of untreated soil bed.

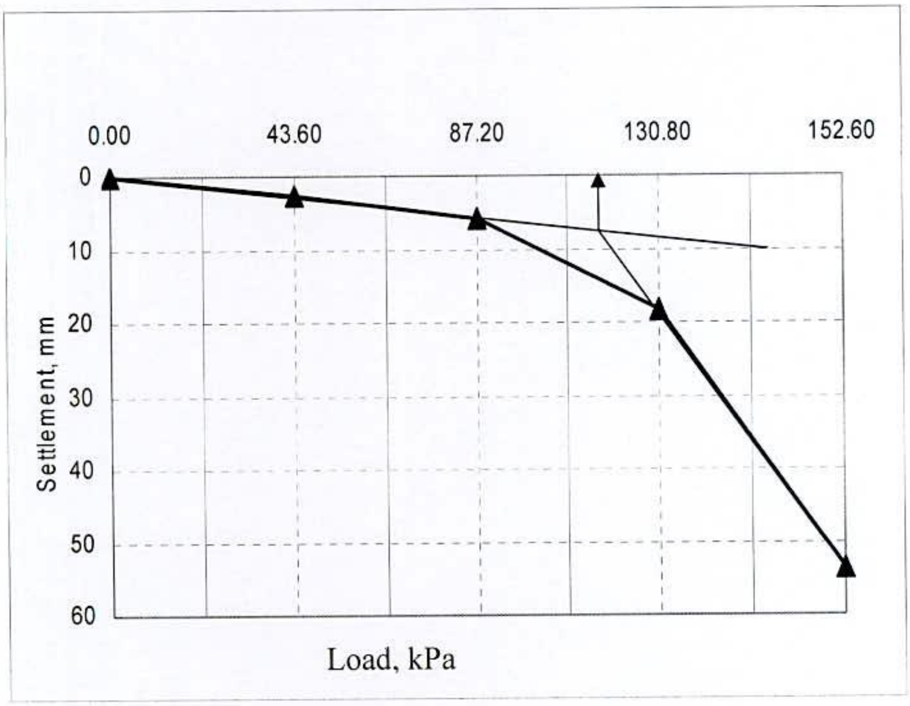


Figure: 5.1f Loads – Settlement Curve for Treated Soil Bed G-6

5.2.2.6 Load - Settlement Behavior of Treated Soil bed (G-7)

The test was carried out on the treated soil bed G-7 as shown in the Figure 4.2f. The model CC footing was placed on the treated granular fills of depth 225mm(D_s), equal to 1.5 time of the width of model foundation (1.5B_f) and both the length and width of granular fills was equal to 4 times of the width of model foundation (4B_f). The settlements against increments of loads were recorded and plotted in the Figure: 5.1g. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-7 was found as 116 kPa which was 1.81 times more than that of untreated soil bed.

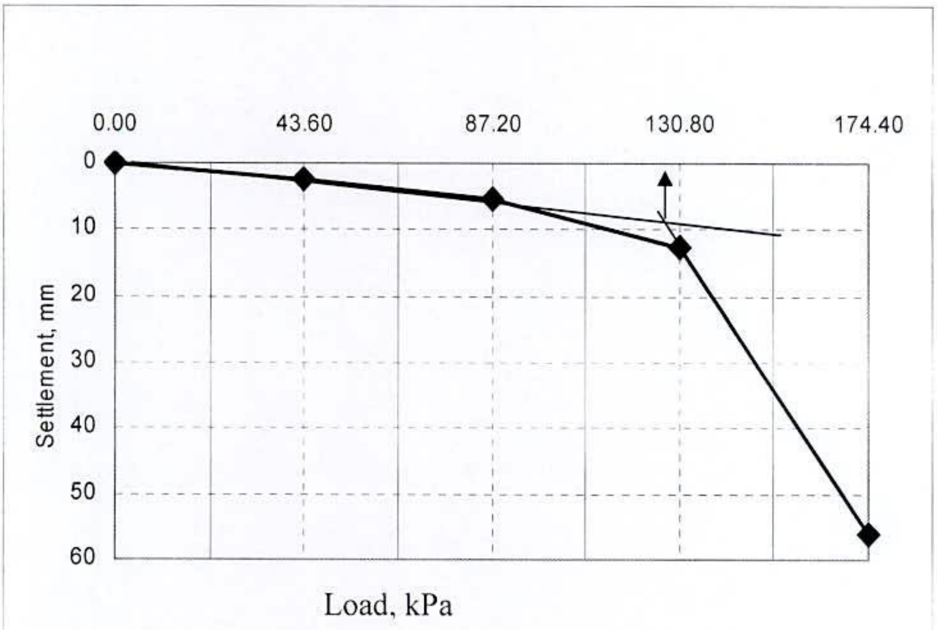


Figure: 5.1g Loads – Settlement Curve for Treated Soil Bed G-7

5.2.2.7 Load - Settlement Behavior of Treated Soil Bed (G-8)

The test was carried out on the treated soil bed G-8 as shown in the Figure 4.2g. The model CC footing was placed on the treated granular fills of depth 300mm (D_s), equal to 2 times of the width of model foundation ($2B_f$) and both the length and width of granular fills were equal to the width of model foundation(B_f). The settlements against increments of loads were recorded and plotted in the Figure 5.1h. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-8 was found as 119 kPa which is 1.85 times more than that of untreated soil bed.

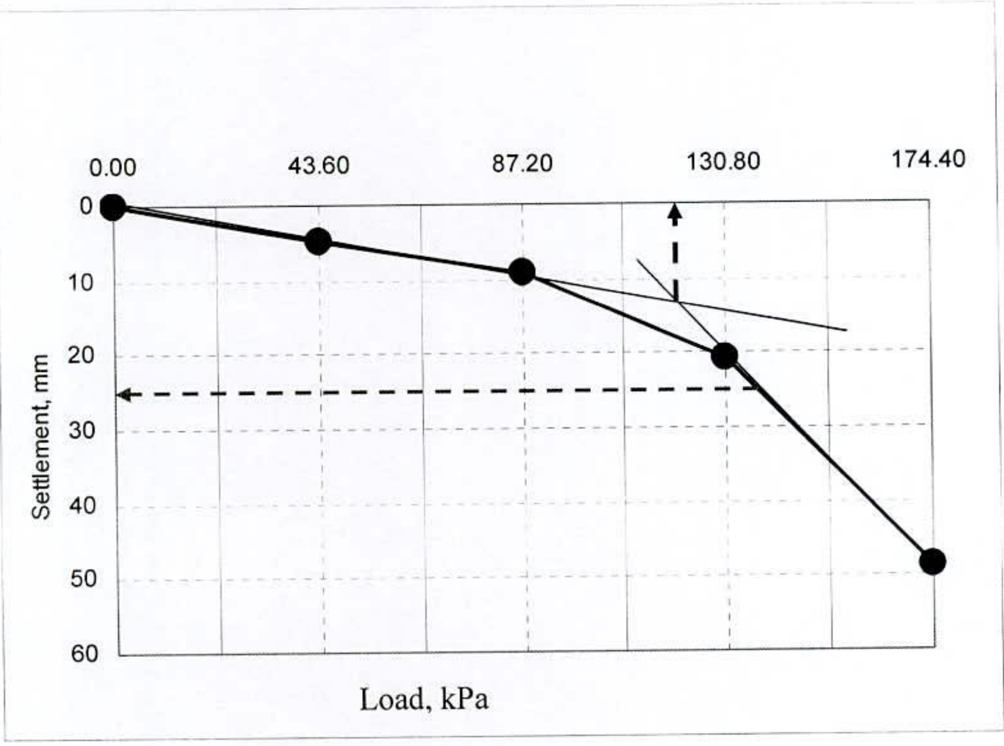


Figure: 5.1h Loads – Settlement Curve for Treated Soil Bed (G-8)

5.2.2.8 Load - Settlement Behavior of Treated Soil Bed (G-9)

The test was carried out on the treated soil bed G-9 as shown in the Figure 4.2h. The model CC footing was placed on the treated granular fills of depth 300 mm(D_s), equal to 2 times of the width of model foundation ($2B_f$) and both the length and width of granular fills were equal to 3 times of the width of model foundation ($3B_f$). The settlements against increments of applied loads were recorded and plotted in the Figure 5.1i. From two tests an average load against 25 mm settlement was determined. In this case load bearing capacity of the treated soil bed G-9 was found as 123 kPa which is 1.92 times more than that of untreated soil bed.

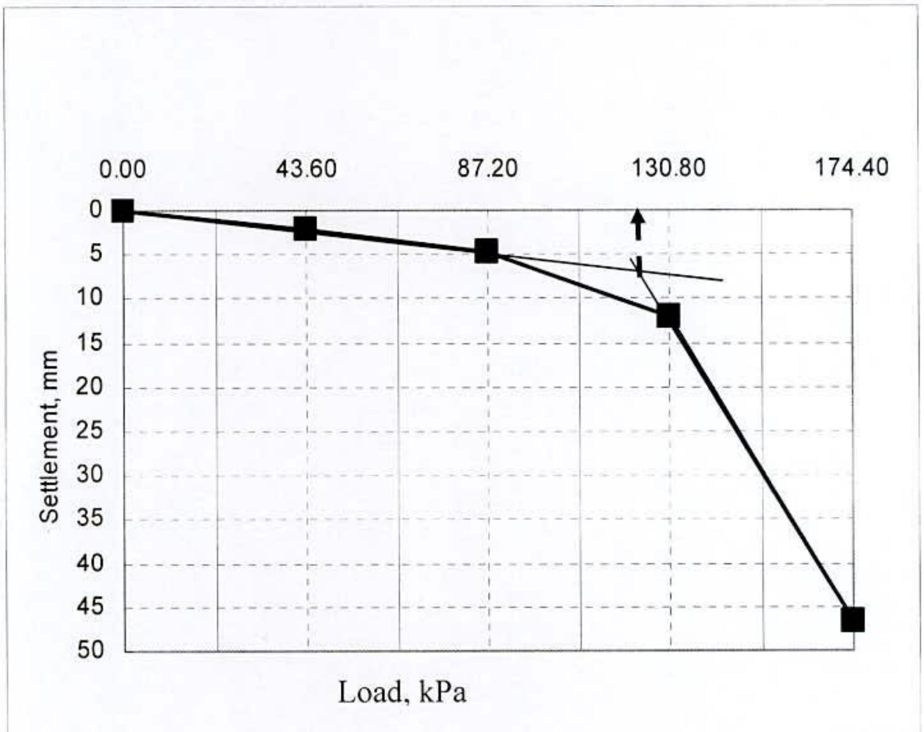


Figure: 5.1i Loads – Settlement Curve for Treated Soil Bed (G-9)

5.2.2.9 Load - Settlement Behavior of Treated Soil Bed (G-10)

The tests are carried out on the treated soil bed G-10 as shown in the Figure 4.2i. The model CC footing was placed on the treated granular fills of depth 300 mm(D_s), equal to 2 times of the width of model foundation ($2B_f$) and both the length and width of granular fills was equal to 5 times of the width of model foundation ($5B_f$). The settlements against increments of loads are recorded and plotted in the Figure: 5.1j. From two tests an average load against 25 mm settlement was determined. In this case the bearing capacity of the treated soil bed G-10 was found as 125 kPa which is 1.95 times more than that of untreated soil bed.

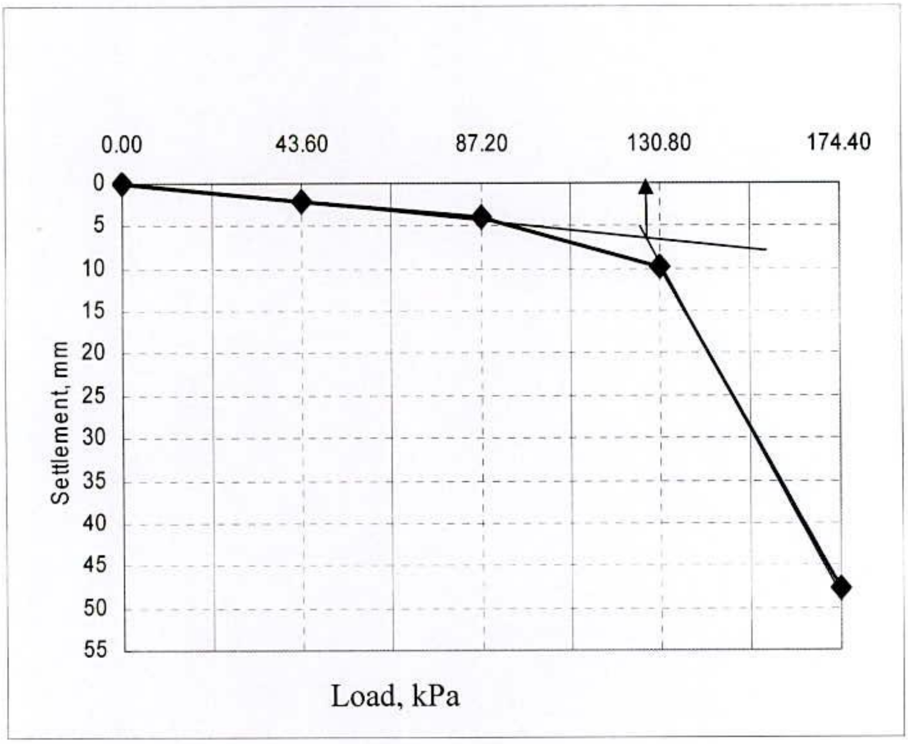


Figure: 5.1j Loads – Settlement Curve for Treated Soil Bed (G-10)

5.3 Degree of Improvement

The bearing capacity of prepared soft soil bed was determined at 25 mm settlement of the model foundation. The bearing capacity of untreated soft bed was found as 68 kPa. The degrees of improvement in 9 different conditions were found 1.30 to 1.95 times of the untreated conditions which are described below and also shown in the Table 5.1.

5.3.1 Effect of loading on Foundation for Constant Ds (Ds = Bf) with the Variation of Lateral Dimension of Sand Filling

At the same depth of filling three tests were conducted by increasing the length and width of filling. The degree of improvement was 1.30 times of the untreated soft bed when both the length and width of filling was same as that of model foundation. When both length and width of filling was two times of B_f, the degree of improvement was found 1.56 times of untreated soft bed which was 30% higher than that of G-1 condition. When both length and width of filling was three times of B_f, the degree of improvement was found 1.59 times of untreated soft bed which was 59% higher than that of G-1 condition. All the values are shown in the Table 5.1.

5.3.2 Effect of loading on Foundation for $D_s = 1.5\ B_f$ with the Variation of Lateral Dimension of Sand Filling

At the same depth of filling three tests were conducted by extending length and width of filling. The degree of improvement was found 1.72 times of the untreated soft bed when both the length and width of filling was same as that of model foundation. When both length and width of filling was two and a half times of B_f, the degree of improvement was found 1.79 times of untreated soft bed which was 79 % higher than that of G-1 condition. When both length and width of filling was four times of B_f the degree of improvement was found 1.81 times of untreated soft bed which was 81% higher than that of G-1 condition. All the values are shown in the Table 5.1.

5.3.3 Effect of loading on Foundation for $D_s = 2B_f$ with the Variation of Lateral Dimension of Sand Filling (B_s)

At the same depth of filling three tests were conducted by extending width and breadth of filling. The degree of improvement was found 1.85 times of the untreated soft bed when both the length and width of filling was same as that of model foundation. When both length and width of filling was three times of B_f, the degree of improvement was found 1.92 times of untreated soft bed which was 92% higher than G-1 condition. When both length and width of filling was five times of B_f the degree of improvement was found 1.98 times than that of untreated soft bed which was 95% higher than G-1 condition. All the values are shown in the Table 5.1.

Table-5.1 Load Bearing Capacity of Treated and Untreated Soft Soil Beds

Experiment No.	Figure No.	Bearing Capacity, q_{ult}		Selected Bearing Capacity, q_{ult} (kPa)	Degree of Improvement	Bearing Capacity Improved (%) w.r.t. untreated sample
		at 25 mm Settlement (kPa)	from Tangent in Graph (kPa)			
G-1	5.1a	68	64	64		
G-2	5.1b	88	83	83	1.30	30 %
G-3	5.1c	110	100	100	1.56	56 %
G-4	5.1d	112	102	102	1.59	59 %
G-5	5.1e	130	110	110	1.72	72 %
G-6	5.1f	133	115	115	1.79	79 %
G-7	5.1g	135	121	116	1.81	81%
G-8	5.1h	138	119	119	1.85	85 %
G-9	5.1i	151	123	123	1.92	92 %
G-10	5.1j	154	127	125	1.95	95 %

5.3.4 Effect of loading on Foundation for $B_s = B_f$ with the Variation in Depth of Filling (D_s)

From the Table 5.2, it is exhibited that the degree of improvements of treated soft soil are 1.30, 1.72 and 1.85 in the case of depth of fillings (D_s) equal to B_f, $1.5B_f$ and $2B_f$ respectively. So it may be mentioned that the degree of improvement of soft soil increases significantly with the increase of depth of compacted sand filling.

Table-5.2 Load Bearing Capacity of Treated Soft Soil Beds for Width of Sand Filling Equal to the Width of Model Foundation

Experiment No.	Figure No.	Dimensions of filling sand (mm)		Bearing Capacity, q_{ult} at 25 mm settlement (kPa)	Degree of Improvement
		$L_s = B_s$	D_s		
G-2	5.1b	150	150	83	1.30
G-5	5.1e	150	225	110	1.72
G-8	5.1h	150	300	119	1.85

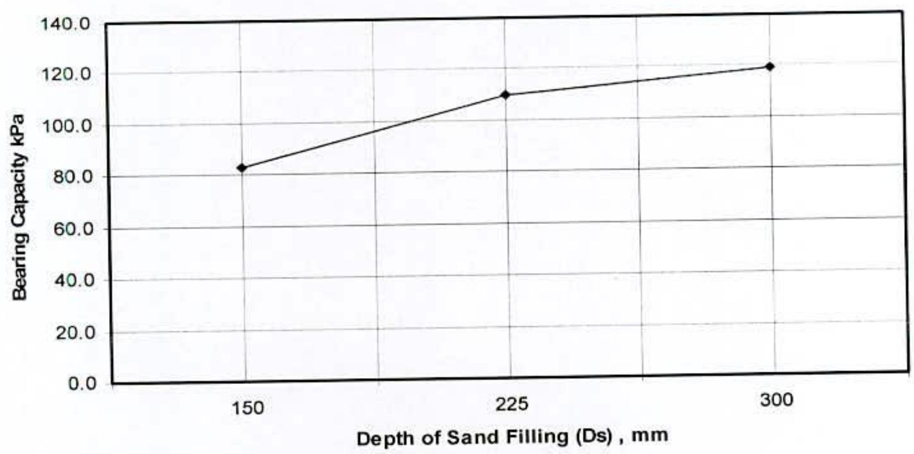


Figure 5.2 Variation of Bearing Capacity with Increasing of Depth (D_s) for Constant B_s (B_s=B_f)

CHAPTER VI

Conclusions and Recommendations

6.1 Conclusions

For the purpose of soil characterization, the data obtained from 123 boreholes at 53 sites within the KCC area were collected and analyzed to prepare a soil profile for the study area. The laboratory experiment to have load-settlement response of soft soil improved by granular fills was carried out. Depending on the results and data obtained, the following observations and conclusions are made.

(i). The whole KCC area was subdivided into three zones: North, Middle and South as shown in Figure 3.1.

(ii). In the North Zone (Afilgate, Shiromoni, Fulbarigate, Mohesshorpasha, etc) it is found that the soil layers between 0 - 40 ft from EGL are mostly clayey silt. In this stratum there exists an organic clay layer having variation from 10 ft to 20 ft depth in most of the locations. The soil layers between the depth of 40 to 60 ft at the northeast part of this zone contain predominantly sand, while in the areas namely Fulbarigate, KUET campus the soil at this depth contains predominantly silt.

(iii). In the middle zone (Khalishpur, Daulatpur, Boyra, Mujgunni, etc.) it is found that In the western side of this zone the sub-soil contains an organic layer of 10 to 15 ft thickness starting from about 5 ft to 10 ft depth to downward. Below this depth the soil consists of predominantly silt up to about 60 ft depth. In the eastern side of this zone the soil contains predominantly silt up to about 20ft to 25 ft depth. Below this depth the soil contains mainly fine sand.

(iv). In the South zone (Sonadanga, Nirala, Gollamari, Sheikhpara, West side of Rupsha, Khulna University, etc) the sub-soil contains organic clay up to about 10 ft to 15 ft depth from EGL. Below this level the soil mainly consists of silt with small portion of clay and organic matters up to about 60 ft depth from EGL.

(v). In the laboratory, the test results show that the load carrying capacity of soft soil can be increased significantly by adopting ground improvement technique with filling sand under foundations.

(vi). The rate of settlement of the test footing on untreated ground increased substantially after the settlement of the ground exceeds 20mm.

(vii). It is evident from the test that the load bearing capacity of treated grounds do not depend on the depth of filling only but also the width of granular fills.

(viii). From the experiment, it was seen that the load bearing capacity was increased by replacement of soft soil with granular materials (sand) at the bottom of the foundation up to 1.98 times than that of untreated soil bed for

(ix). The load bearing capacity of treated soft soil bed was significantly increased with the increase of depth of sand filling under foundation. The bearing capacity was increased by 30%, 72% and 85% with the increase of filling depth by 1.0, 1.5 and 2 times the width of foundation respectively when both the length and width of granular fills were equal to the width of model foundation.

(x). For the granular fills of depth 150 mm($D_s=1B_f$), the degrees of improvement were found as 30%, 56% and 59% higher than that of untreated condition when width of filling were $1B_f$, $2B_f$, and $3B_f$ respectively. From this it was concluded that for constant depth (($D_s=1B_f$) of compacted sand, bearing capacity was increased significantly up to the width of sand filling equal to twice the width of foundation.

(xi). For the granular fills of depth 225mm ($D_s=1.5B_f$),, the degrees of improvement were found as 72%, 79% and 81% higher than that of untreated condition when width of filling were $1B_f$, $2.5B_f$, and $4B_f$ respectively. From this it was concluded that for constant depth ($D_s=1.5B_f$) of compacted sand, bearing capacity was increased significantly up to the width of sand filling equal to 2.5 times the width of foundation.

(xii). When the depth of granular fills was 300 mm ($D_s=2B_f$), the degrees of improvement were observed as 85%, 92% and 95% higher than that of untreated condition when width of filling were $1B_f$, $3B_f$ and $5B_f$ respectively. From this it was concluded that for constant depth (($D_s=2B_f$) of compacted sand, bearing capacity was increased significantly up to the width of sand filling equal to 3 times the width of foundation.

6.2 Recommendations for Further Study

Several aspects of the work presented in this thesis require further study and have been described in the relevant chapters. Some of the important areas for further research may be listed as follows:

(i). A data base information on Khulna Sub-soil will might be prepared with the help of GIS.

(ii). Geo-textiles in single or multi layers along with granular fills as a technique of soil improvement can be carried out and will be compared with this data.

(iii). Soil improvement by different granular material like pea gravels, stone chips, and brick chips with sand in different proportions may be used for improvement of soft soil and a comparative study can be shown among the techniques. .

(iv). Due to time limitations nine cases of different depths and widths of filling sand would be taken under consideration. It can be extended with other cases varying depth and width of filling sand.

(v). For this works different types of sand can be used as filling granular materials.

Appendix-A

(Soil Profiles and SPT-N Value along the North South Section)

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

North Zone

Site No	1				2						3			
Ref. No	B-289				B-187						B-237			
Location	Afil gate, Khulna				Cable Shilpa Ltd, Shiromoni						Police Training Centre, Shiromoni			
Bore Hole	BH-1		BH-2		BH-1		BH-2		BH-3		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	4	Clayey Silt	6	Clayey Silt	6	Clayey Silt	6	Clayey Silt	5	Clayey Silt	9	Clayey Silt	6
3.0	Clayey Silt	3	Clayey Silt	3	Clayey Silt	2	Clayey Silt	2	Clayey Silt	9	Clayey Silt	7	Clayey Silt	6
4.5	Organic Clay	2	Organic Clay	2	Clayey Silt	5	Clayey Silt	2	Clayey Silt	1	Clayey Silt	3	Silty Clay	8
6.0	Organic Clay	8	Organic Clay	6	Clayey Silt	5	Clayey Silt	2	Clayey Silt	3	Clayey Silt	4	Silty Sand	9
7.5	Organic Clay	2	Clayey Silt	2	Clayey Silt	5	Clayey Silt	3	Clayey Silt	5	Silty Sand	26	Clayey Silt	7
9.0	Sandy Clay	8	Clayey Silt	8	Clayey Silt	2	Clayey Silt	5	Clayey Silt	12	Fine Sand	13	Clayey Silt	7
10.5	Sandy Clay	11	Clayey Silt	7	Fine Sand	11	Fine Sand	12	Silty Sand	17	Silty Sand	25	Silty Sand	12
12.0	Silty Sand	17	Silty Sand	15	Fine Sand	30	Silty Sand	21	Fine Sand	16	Silty Sand	17	Fine Sand	62
13.5	Silty Sand	18	Silty Sand	32	Medium Sand	65	Silty Sand	31	Fine Sand	135	Fine Sand	92	Fine Sand	61
15.0	Silty Sand	22	Silty Sand	16	Fine Sand	83	Fine Sand	40	Silty Sand	21	Fine Sand	58	Fine Sand	62
16.5					Fine Sand	87	Silty Sand	-	Fine Sand	78				
18.0					Fine Sand	145	Fine Sand	168	Fine Sand	110				

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

North Zone

Site No	3		4				5				6	
Ref. No	B-237		B-086				B-00				B-083	
Location	Police Training Centre, Shiromoni		Police barrack, Shiromoni				Fulbarigate				KUET	
Bore Hole	BH-3		BH-1		BH-2		BH-1		BH-2		BH-1	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	11	Clayey Silt	6	Clayey Silt	8	Clayey Silt	7	Clayey Silt	3	Clayey Silt	3
3.0	Clayey Silt	8	Clayey Silt	9	Clayey Silt	6	Clayey Silt	4	Clayey Silt	4	Organic Clay	2
4.5	Silty Clay	10	Clayey Silt	4	Clayey Silt	5	Clayey Silt	3	Clayey Silt	5	Clayey Silt	5
6.0	Silty Sand	9	Clayey Silt	4	Clayey Silt	6	Organic Clay	2	Organic Clay	6	Clayey Silt	3
7.5	Clayey Silt	4	Clayey Silt	5	Clayey Silt	4	Organic Clay	3	Clayey Silt	5	Clayey Silt	2
9.0	Clayey Silt	13	Clayey Silt	7	Clayey Silt	3	Organic Clay	3	Clayey Silt	5	Clayey Silt	3
10.5	Silty Sand	8	Fine Sand	12	Sandy Clay	17	Clayey Silt	4	Clayey Silt	4	Fine Sand	11
12.0	Fine Sand	26	Clayey Silt	5	Clayey Silt	7	Clayey Silt	3	Clayey Silt	3	Fine Sand	13
13.5	Fine Sand	75	Fine Sand	21	Clayey Silt	6	Clayey Silt	5	Clayey Silt	8	Fine Sand	10
15.0	Fine Sand	66	Fine Sand	22	Sandy Clay	12	Clayey Silt	4	Clayey Silt	10	Clayey Silt	7
16.5					Fine Sand	25					Clayey Silt	6
18.0											Fine Sand	19

Soil Profiles and SPT Values along the North -South Section in Khulna City Area
North Zone

Site No	7						8				9			
Ref. No	B-247						B-164				B-117			
Location	KUET road, Fulbarigate						Abul Khaer, Fulbarigate				Mirerdanga, Fulbarigate			
Bore Hole	BH-1		BH-2		BH-3		BH-1		BH-2		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	5	Clayey Silt	5	Clayey Silt	3	Clayey Silt	5	Clayey Silt	5	Clayey Silt	7	Clayey Silt	6
3.0	Silty Sand	11	Clayey Silt	4	Clayey Silt	5	Clayey Silt	7	Clayey Silt	4	Clayey Silt	4	Clayey Silt	5
4.5	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3	Clayey Silt	5	Clayey Silt	4	Fine Sand	11	Silty Sand	13
6.0	Clayey Silt	2	Organic Clay	5	Clayey Silt	3	Clayey Silt	3	Clayey Silt	4	Clayey Silt	2	Silty Sand	11
7.5	Organic Clay	5	Clayey Silt	6	Organic Clay	4	Clayey Silt	5	Clayey Silt	4	Clayey Silt	6	Silty Sand	11
9.0	Clayey Silt	4	Clayey Silt	6	Clayey Silt	5	Clayey Silt	7	Clayey Silt	4	Fine Sand	16	Silty Sand	14
10.5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	5	Clayey Silt	5	Clayey Silt	6	Fine Sand	15	Fine Sand	16
12.0	Clayey Silt	2	Clayey Silt	5	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Fine Sand	16	Silty Sand	12
13.5	Clayey Silt	4	Clayey Silt	7	Clayey Silt	5	Clayey Silt	4	Clayey Silt	7	Fine Sand	19	Fine Sand	18
15.0	Clayey Silt	5	Clayey Silt	7	Clayey Silt	6	Silty Clay	7	Clayey Silt	6	Fine Sand	18	Fine Sand	20
16.5			Clayey Silt	6										
18.0			ML	3										

Soil Profiles and SPT Values along the North -South Section in Khulna City Area
North Zone

Site No	9		10						11			
Ref. No	B-117		B-241						B-059			
Location	Mirerdanga		Mirerdanga, Fulbarigate						Baby Home , Mohesshorpasha			
Bore Hole	BH-3		BH-1		BH-2		BH-3		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	5	Clayey Silt	1	Clayey Silt	6	Clayey Silt	5	Clayey Silt	8	Clayey Silt	4
3.0	Clayey Silt	4	Clayey Silt	6	Clayey Silt	4	Clayey Silt	7	Clayey Silt	3	Clayey Silt	3
4.5	Silty Sand	13	Clayey Silt	5	Clayey Silt	5	Silty Sand	11	Clayey Silt	4	Clayey Silt	3
6.0	Fine Sand	16	Clayey Silt	5	Clayey Silt	7	Silty Sand	12	Organic Clay	4	Clayey Silt	5
7.5	Fine Sand	18	Clayey Silt	5	Clayey Silt	8	Silty Sand	14	Organic Clay	7	Clayey Silt	5
9.0	Silty Sand	13	Fine Sand	32	Silty Sand	16	Fine Sand	20	Clayey Silt	9	Clayey Silt	8
10.5	Silty Sand	12	Fine Sand	41	Fine Sand	20	Fine Sand	20	Clayey Silt	4	Clayey Silt	6
12.0	Fine Sand	17	Fine Sand	107	Fine Sand	30	Fine Sand	29	Clayey Silt	4	Clayey Silt	4
13.5	Fine Sand	63			Fine Sand	45	Fine Sand	30	Clayey Silt	5	Clayey Silt	6
15.0	Fine Sand	21			Fine Sand	48	Fine Sand	32	Clayey Silt	5	Clayey Silt	5
16.5	Silty Sand	20										
18.0	Silty Sand	20										

Soil Profiles and SPT Values along the North -South Section in Khulna City Area
Middle Zone

Site No	12						13				14			
Ref. No	B-036						B-040				B-160			
Location	Nasir Hospital, Goalkhali						Setara Begum, Mujgunni				Palpara Road , khalishpur			
Bore Hole	BH-1		BH-2		BH-3		BH-1		BH-2		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Organic Clay	1	Clayey Silt	2	Clayey Silt	2	Clayey Silt	1	Clayey Silt	6	Clayey Silt	6	Clayey Silt	6
3.0	Organic Clay	2	Organic Clay	4	Clayey Silt	4	Organic Clay	1	Organic Clay	1	Clayey Silt	3	Clayey Silt	3
4.5	Organic Clay	2	Clayey Silt	6	Organic Clay	4	Organic Clay	3	Silty Clay	3	Clayey Silt	15	Clayey Silt	24
6.0	Organic Clay	4	Clayey Silt	4	Clayey Silt	2	Clayey Silt	5	Clayey Silt	5	Fine Sand	20	Fine Sand	42
7.5	Clayey Silt	5	Clayey Silt	4	Clayey Silt	3	Clayey Silt	7	Clayey Silt	6	Fine Sand	69	Fine Sand	39
9.0	Clayey Silt	3	Clayey Silt	3	Clayey Silt	5	Clayey Silt	6	Clayey Silt	4	Fine Sand	43	Fine Sand	33
10.5	Clayey Silt	4	Clayey Silt	2	Clayey Silt	3	Clayey Silt	4	Clayey Silt	5	Fine Sand	68	Fine Sand	102
12.0	Clayey Silt	6	Clayey Silt	6	Clayey Silt	5	Clayey Silt	5	Clayey Silt	6	Fine Sand	62	Fine Sand	28
13.5	Clayey Silt	4	Clayey Silt	5	Clayey Silt	5	Clayey Silt	5	Clayey Silt	5	Fine Sand	22	Fine Sand	17
15.0	Clayey Silt	6	Clayey Silt	4	Clayey Silt	6	Clayey Silt	5	Clayey Silt	4	Fine Sand	113	Fine Sand	95
16.5	Clayey Silt	6	Clayey Silt	5	Clayey Silt	3			Clayey Silt	5				
18.0	Clayey Silt	4	Clayey Silt	5	Clayey Silt	5								

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

Middle Zone

Site No	15						16				17	
Ref. No	B-261						E-002				E-005	
Location	Fire service station, Khalishpur						Hardboard Mill				Housing Zone , Khalishpur	
Bore Hole	BH-1		BH-2		BH-3		BH-1		BH-2		BH-1	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	8	Clayey Silt	6	Clayey Silt	5	Clayey Silt	5	Fine Sand	5	Clayey Silt	3
3.0	Clayey Silt	6	Clayey Silt	7	Clayey Silt	4	Fine Sand	5	Fine Sand	7	Clayey Silt	4
4.5	Clayey Silt	5	Clayey Silt	6	Clayey Silt	4	Fine Sand	6	Fine Sand	9	Clayey Silt	2
6.0	Sandy silt	5	Sandy silt	6	Clayey Silt	4	Fine Sand	11	Fine Sand	11	Clayey Silt	3
7.5	Sandy silt	5	Sandy silt	6	Sandy silt	7	Fine Sand	17	Fine Sand	13	Clayey Silt	4
9.0	Sandy silt	15	Sandy silt	7	Sandy silt	13	Fine Sand	18	Fine Sand	18	Organic Clay	9
10.5	Silty Sand	15	Clayey Silt	6	Silty Sand	13	Medium Sand	23	Fine Sand	19	Clayey Silt	6
12.0	Silty Sand	17	Silty Sand	21	Silty Sand	20			Fine Sand	18	Clayey Silt	5
13.5	Silty Sand	24	Silty Sand	30	Silty Sand	14			Fine Sand	22	Clayey Silt	4
15.0	Silty Sand	31	Silty Sand	35	Silty Sand	20					Clayey Silt	6
16.5					Fine Sand	23					Clayey Silt	5
18.0					Fine Sand	26						

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

Middle Zone

Site No	18				19				20					
Ref. No	E-004				B-125				B-266					
Location	Co-operative training centre, Boyra				Imam Training Centre, Boyra				Md. Nazrul Islam, Mujgunni					
Bore Hole	BH-1		BH-2		BH-1		BH-2		BH-1		BH-2		BH-3	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Organic Clay	2	Fine Sand	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	7	Clayey Silt	2	Clayey Silt	7
3.0	Clayey Silt	2	Organic Clay	3	Clayey Silt	2	Clayey Silt	2	Clayey Silt	5	Clayey Silt	5	Clayey Silt	6
4.5	Clayey Silt	3	Clayey Silt	2	Organic Clay	5	Clayey Silt	5	Clayey Silt	7	Clayey Silt	3	Clayey Silt	8
6.0	Clayey Silt	6	Clayey Silt	5	Clayey Silt	6	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	8
7.5	Clayey Silt	6	Clayey Silt	6	Clayey Silt	5	Clayey Silt	3	Clayey Silt	5	Clayey Silt	4	Clayey Silt	3
9.0	Clayey Silt	6	Clayey Silt	7	Clayey Silt	4	Clayey Silt	3	Clayey Silt	5	Clayey Silt	2	Clayey Silt	4
10.5	Clayey Silt	6	Clayey Silt	7	Clayey Silt	5	Clayey Silt	3	Clayey Silt	8	Clayey Silt	6	Clayey Silt	6
12.0	Clayey Silt	4	Clayey Silt	7	Fine Sand	14	Clayey Silt	6	Silty Sand	12	Silty Sand	10	Silty Sand	11
13.5	Clayey Silt	6	Clayey Silt	9	Fine Sand	15	Fine Sand	11	Clayey Silt	5	Clayey Silt	5	Silty Sand	12
15.0	Clayey Silt	7	Clayey Silt	8	Fine Sand	20	Fine Sand	14	Clayey Silt	6	Clayey Silt	7	Clayey Silt	7
16.5	Clayey Silt	7			Fine Sand	12	Fine Sand	13	Clayey Silt	7	Clayey Silt	7	Clayey Silt	7
18.0					Clayey Silt	11	Fine Sand	9	Clayey Silt	12	Clayey Silt	17	Clayey Silt	12

Soil Profiles and SPT Values along the North -South Section in Khulna City Area MIDDLE Z0NE

Site No	21						22					
Ref. No	B-221						B-283					
Location	Navy Colony, Boyra						DIG Office Khulna					
Bore Hole	BH-1		BH-2		BH-3		BH-1		BH-2		BH-3	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	5	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3
3.0	Clayey Silt	3	Organic Clay	2	Clayey Silt	2	Clayey Silt	4	Clayey Silt	5	Clayey Silt	2
4.5	Organic Clay	3	Organic Clay	3	Organic Clay	2	Clayey Silt	3	Clayey Silt	2	Clayey Silt	2
6.0	Organic Clay	4	Clayey Silt	2	Clayey Silt	3	Clayey Silt	6	Clayey Silt	3	Clayey Silt	4
7.5	Clayey Silt	3	Clayey Silt	2	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	5
9.0	Clayey Silt	5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	3	Clayey Silt	2	Clayey Silt	3
10.5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	5	Clayey Silt	7	Clayey Silt	11	Clayey Silt	5
12.0	Clayey Silt	3	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	5	Clayey Silt	4
13.5	Clayey Silt	4	Clayey Silt	3	Clayey Silt	5	Clayey Silt	4	Clayey Silt	4	Clayey Silt	5
15.0	Clayey Silt	3	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	2	Clayey Silt	7
16.5							Clayey Silt	4	Clayey Silt	4	Silty Sand	27
18.0							Silty Sand	41		-	Silty Sand	27

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

MIDDLE ZONE

Site No	23						24					
Ref. No	B-107						B-114					
Location	Regional PATC, Boyra						Environmental Research MI Centre					
Bore Hole	BH-1		BH-2		BH-3		BH-1		BH-2		BH-3	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	6	Clayey Silt	8	Clayey Silt	9	Clayey Silt	7	Clayey Silt	3	Clayey Silt	4
3.0	Fine Sand	17	Fine Sand	14	Clayey Silt	11	Clayey Silt	4	Clayey Silt	4	Clayey Silt	2
4.5	Fine Sand	14	Clayey Silt	4	Fine Sand	15	Organic Clay	7	Organic Clay	5	Organic Clay	4
6.0	Organic Clay	4	Organic Clay	7	Organic Clay	7	Organic Clay	4	Clayey Silt	3	Organic Clay	6
7.5	Organic Clay	5	Organic Clay	5	Organic Clay	7	Clayey Silt	5	Clayey Silt	7	Clayey Silt	9
9.0	Clayey Silt	8	Clayey Silt	5	Clayey Silt	8	Clayey Silt	5	Fine Sand	8	Clayey Silt	7
10.5	Clayey Silt	5	Clayey Silt	4	Clayey Silt	5	Fine Sand	14	Clayey Silt	9	Silty Sand	12
12.0	Clayey Silt	12	Clayey Silt	5	Clayey Silt	10	Fine Sand	10	Fine Sand	15	Fine Sand	24
13.5	Clayey Silt	6	Clayey Silt	14	Clayey Silt	9	Clayey Silt	9	Clayey Silt	6	Clayey Silt	10
15.0	Clayey Silt	7	Clayey Silt	7	Clayey Silt	8	Silty sand	20	Clayey Silt	9	Clayey Silt	8
16.5	Clayey Silt	6	Clayey Silt	7	Clayey Silt	8	Clayey Silt	7	Fine Sand	15	Clayey Silt	14
18.0	Fine Sand	33	Fine Sand	15	Fine Sand	28	Clayey Silt	6	Clayey Silt	8	Clayey Silt	9

Soil Profiles and SPT Values along the North -South Section in Khulna City Area
MIDDLE ZONE

Site No	25				26				27			
Ref. No	B-063				B-261				T-199			
Location	Medical college, Boyra				Medical college (Student Hostel)				MTTC, Khulna			
Bore Hole	BH-1		BH-2		BH-1		BH-2		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	4	Clayey Silt	6	Clayey Silt	4	Clayey Silt	5	Clayey Silt	5	Clayey Silt	7
3.0	Clayey Silt	2	Clayey Silt	2	Clayey Silt	3	Clayey Silt	2	Clayey Silt	2	Clayey Silt	4
4.5	Organic Clay	3	Organic Clay	5	Organic Clay	2	Organic Clay	2	Clayey Silt	3	Clayey Silt	2
6.0	Clayey Silt	2	Organic Clay	3	Organic Clay	3	Organic Clay	1	Clayey Silt	4	Clayey Silt	7
7.5	Clayey Silt	5	Clayey Silt	5	Organic Clay	5	Clayey Silt	8	Clayey Silt	4	Clayey Silt	5
9.0	Clayey Silt	4	Clayey Silt	2	Clayey Silt	5	Clayey Silt	5	Clayey Silt	4	Clayey Silt	2
10.5	Clayey Silt	4	Clayey Silt	5	Clayey Silt	3	Clayey Silt	3	Clayey Silt	4	Clayey Silt	4
12.0	Fine Sand	12	Fine Sand	10	Fine Sand	8	Fine Sand	9	Clayey Silt	4	Clayey Silt	6
13.5	Fine Sand	19	Fine Sand	23	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	6
15.0	Fine Sand	6	Fine Sand	21	Clayey Silt	5	Organic Clay	2	Clayey Silt	7	Clayey Silt	5
16.5					Clayey Silt	5	Clayey Silt	6	Organic Clay	7	Clayey Silt	5
18.0					Clayey Silt	6	Clayey Silt	13	Organic Clay	13	Clayey Silt	4

Soil Profiles and SPT Values along the North -South Section in Khulna City Area
MIDDLE ZONE

Site No	28				29						30			
Ref. No	B-062				B-082						B-169			
Location	Residence of O.C, Sonadanga				Dormitory for Female Police, Joragate						Shishu Sadan, Khulna			
Bore Hole	BH-1		BH-2		BH-1		BH-2		BH-3		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	2	Clayey Silt	2	Sandy silt	10	Sandy silt	14	Sandy silt	10	Clayey Silt	8	Clayey Silt	7
3.0	Clayey Silt	2	Clayey Silt	2	Sandy silt	10	Sandy silt	8	Clayey Silt	3	Clayey Silt	2	Clayey Silt	7
4.5	Clayey Silt	2	Clayey Silt	4	Clayey Silt	5	Clayey Silt	6	Clayey Silt	3	Clayey Silt	3	Clayey Silt	4
6.0	Clayey Silt	5	Clayey Silt	3	Clayey Silt	7	Clayey Silt	10	Clayey Silt	7	Clayey Silt	5	Clayey Silt	6
7.5	Clayey Silt	4	Clayey Silt	3	Clayey Silt	5	Clayey Silt	5	Clayey Silt	4	Clayey Silt	5	Clayey Silt	5
9.0	Clayey Silt	6	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	6	Clayey Silt	3	Clayey Silt	3
10.5	Clayey Silt	5	Clayey Silt	4	Sity sand	18	Silty Sand	19	Silty Sand	16	Clayey Silt	4	Clayey Silt	3
12.0	Clayey Silt	5	Clayey Silt	4	Sity sand	43	Silty Sand	48	Silty Sand	23	Clayey Silt	5	Clayey Silt	4
13.5	Clayey Silt	5	Clayey Silt	5	Sity sand	58	Silty Sand	32	Silty Sand	32	Silty Sand	14	Fine Sand	14
15.0	Clayey Silt	6	Clayey Silt	4	Sity sand	66	Clayey Silt	11	Clayey Silt	10	Fine Sand	25	Fine Sand	9
16.5							Clayey Silt	7	Clayey Silt	8	Fine Sand	8		
18.0							Clayey Silt	7	Clayey Silt	9	Fine Sand	8		

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

MIDDLE ZONE

Site No	30		31						32		33			
Ref. No	B-169		B-197						B-222		B-225			
Location			ICMA, Sonadanga						Sonadanga Thana, KMP		Khulna Thana Quarter			
Bore Hole	BH-1		BH-1		BH-2		BH-3		BH-2		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	8	Clayey Silt	4	Clayey Silt	4	Clayey Silt	3	Clayey Silt	2	Clayey Silt	6	Clayey Silt	5
3.0	Clayey Silt	4	Clayey Silt	3	Clayey Silt	4	Clayey Silt	3	Clayey Silt	3	Clayey Silt	5	Clayey Silt	5
4.5	Clayey Silt	3	Organic Clay	3	Organic Clay	2	Organic Clay	2	Clayey Silt	3	Clayey Silt	6	Clayey Silt	7
6.0	Organic Clay	7	Clayey Silt	2	Clayey Silt	2	Clayey Silt	2	Clayey Silt	3	Organic Clay	4	Organic Clay	6
7.5	Clayey Silt	4	Clayey Silt	1	Clayey Silt	1	Clayey Silt	2	Clayey Silt	2	Organic Clay	5	Organic Clay	4
9.0	Clayey Silt	4	Clayey Silt	2	Clayey Silt	4	Clayey Silt	3	Clayey Silt	2	Silty Sand	10	Silty Sand	14
10.5	Clayey Silt	5	Clayey Silt	5	Clayey Silt	5	Clayey Silt	5	Clayey Silt	3	Silty Sand	14	Silty Sand	15
12.0	Clayey Silt	3	Clayey Silt	12	Clayey Silt	9	Clayey Silt	15	Clayey Silt	7	Silty Sand	24	Silty Sand	18
13.5	Fine Sand	14	Silty Sand	10	Silty Sand	15	Silty Sand	17	Clayey Silt	7	Silty Sand	15	Silty Sand	14
15.0	Fine Sand	23	Silty Sand	15	Silty Sand	14	Silty Sand	14	Fine Sand	22	Fine Sand	33	Silty Sand	16
16.5			Silty Sand	50	Silty Sand	38	Silty Sand	46						
18.0			Silty Sand	50	Silty Sand	38	Silty Sand	46						

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

MIDDLE ZONE

Site No	34						35				36			
Ref. No	B-233						B-254				B-252			
Location	Female TTC, Khulna						Ghat No-4 (Modina Trading)				Diabetic Hospital, Khulna			
Bore Hole	BH-1		BH-2		BH-3		BH-1		BH-2		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	4	Clayey Silt	5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	7	Clayey Silt	6	Clayey Silt	8
3.0	Clayey Silt	4	Organic Clay	3	Organic Clay	3	Clayey Silt	7	Clayey Silt	5	Clayey Silt	4	Clayey Silt	4
4.5	Organic Clay	3	Organic Clay	3	Organic Clay	4	Clayey Silt	7	Clayey Silt	6	Clayey Silt	7	Clayey Silt	11
6.0	Organic Clay	2	Clayey Silt	7	Organic Clay	4	Clayey Silt	7	Clayey Silt	11	Clayey Silt	11	Clayey Silt	3
7.5	Clayey Silt	3	Clayey Silt	6	Clayey Silt	3	Clayey Silt	6	Clayey Silt	5	Clayey Silt	4	Clayey Silt	7
9.0	Clayey Silt	3	Clayey Silt	7	Clayey Silt	3	Clayey Silt	6	Clayey Silt	7	Clayey Silt	7	Clayey Silt	7
10.5	Clayey Silt	5	Clayey Silt	7	Clayey Silt	5	Clayey Silt	3	Clayey Silt	5	Clayey Silt	7	Clayey Silt	12
12.0	Clayey Silt	9	Clayey Silt	11	Clayey Silt	5	Silty Sand	14	Silty Sand	10	Fine Sand	16	Fine Sand	19
13.5	Clayey Silt	5	Clayey Silt	9	Clayey Silt	5	Silty Sand	16	Silty Sand	30	Fine Sand	21	Fine Sand	24
15.0	Clayey Silt	7	Clayey Silt	9	Clayey Silt	7	Silty Sand	17	Silty Sand	14	Fine Sand	42	Fine Sand	24
16.5	Clayey Silt	7	Clayey Silt	7	Clayey Silt	8			Clayey Silt	5	Fine Sand	24	Fine Sand	45
18.0	Clayey Silt	8	Clayey Silt	8	Clayey Silt	9			Clayey Silt	6	Fine Sand	15	Fine Sand	15

Soil Profiles and SPT Values along the North -South Section in Khulna City Area
MIDDLE Z0NE

Site No	36		37				38				39			
Ref. No	B-252		B-274				E-001				B-285			
Location			Sonadanga (KDA Plot No-32)				KDA Community Centre				Sonadanga			
Bore Hole	BH-3		BH-1		BH-2		BH-1		BH-2		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	4	Clayey Silt	2	Clayey Silt	5	Clayey Silt	-	Clayey Silt	-	Clayey Silt	4	Clayey Silt	4
3.0	Clayey Silt	8	Organic Clay	2	Organic Clay	2	Fine Sand	3	Clayey Silt	9	Organic Clay	3	Organic Clay	2
4.5	Clayey Silt	8	Clayey Silt	3	Clayey Silt	3	Clayey Silt	1	Fine Sand	2	Clayey Silt	5	Clayey Silt	3
6.0	Clayey Silt	10	Clayey Silt	7	Clayey Silt	8	Clayey Silt	7	Organic Clay	3	Clayey Silt	5	Clayey Silt	7
7.5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	6	Organic Clay	2	Organic Clay	3	Clayey Silt	4	Clayey Silt	3
9.0	Clayey Silt	7	Clayey Silt	7	Clayey Silt	5	Clayey Silt	5	Clayey Silt	5	Clayey Silt	2	Clayey Silt	3
10.5	Clayey Silt	8	Clayey Silt	3	Clayey Silt	3	Clayey Silt	5	Clayey Silt	4	Clayey Silt	3	Clayey Silt	4
12.0	Fine Sand	16	Silty Sand	21	Sandy silt	16	Clayey Silt	5	Clayey Silt	8	Silty Sand	32	Silty Sand	40
13.5	Fine Sand	29	Sandy silt	9	Sandy silt	12	Clayey Silt	5	Fine Sand	10	Silty Sand	17	Silty Sand	28
15.0	Fine Sand	16	Silty Sand	25	Silty Sand	36	Fine Sand	17	Fine Sand	13	Clayey Silt	10	Silty Sand	29
16.5	Fine Sand	22					Fine Sand	14	Fine Sand	13	Clayey Silt	6	Clayey Silt	8
18.0	Fine Sand	13					Fine Sand	15	Fine Sand	14	Clayey Silt	6	Silty Sand	17

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

MIDDLE ZONE

Site No	39		40				41					
Ref. No	B-285		B-255				B-128					
Location	Sonadanga		HMM road, Helatola (Adv. Abdur Rahman)				Helatola (Blind Hospital)					
Bore Hole	BH-3		BH-1		BH-2		BH-1		BH-2		BH-3	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	5	Clayey Silt	2	Clayey Silt	3	Clayey Silt	5	Clayey Silt	5	Clayey Silt	3
3.0	Organic Clay	2	Clayey Silt	4	Clayey Silt	5	Clayey Silt	2	Clayey Silt	2	Clayey Silt	2
4.5	Clayey Silt	6	Organic Clay	4	Clayey Silt	3	Organic Clay	4	Organic Clay	3	Organic Clay	5
6.0	Clayey Silt	5	Clayey Silt	4	Organic Clay	4	Clayey Silt	2	Clayey Silt	2	Clayey Silt	2
7.5	Clayey Silt	2	Clayey Silt	5	Clayey Silt	5	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3
9.0	Clayey Silt	2	Clayey Silt	2	Clayey Silt	4	Clayey Silt	2	Clayey Silt	3	Clayey Silt	4
10.5	Clayey Silt	8	Clayey Silt	2	Clayey Silt	3	Clayey Silt	4	Clayey Silt	4	Clayey Silt	9
12.0	Silty Sand	42	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4	Clayey Silt	5	Fine Sand	15
13.5	Silty Sand	24	Clayey Silt	4	Clayey Silt	5	Clayey Silt	6	Clayey Silt	5	Fine Sand	17
15.0	Silty Sand	26	Clayey Silt	5	Clayey Silt	7	Clayey Silt	7	Clayey Silt	8	Fine Sand	156
16.5	Silty Sand	24	Silty Sand	14	Clayey Silt	-	Fine Sand	7				
18.0	Clayey Silt	7			Clayey Silt	7	Fine Sand	7				

Soil Profiles and SPT Values along the North -South Section in Khulna City Area MIDDLE ZONE

Site No	42						43				44	
Ref. No	B-111						B-028				B-184	
Location	Helatola (Tibbet Market)						Iqbal road, Khulna				H-43, Tarerpukur Khanjan Ali road	
Bore Hole	BH-1		BH-2		BH-3		BH-1		BH-2		BH-1	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	6	Clayey Silt	6	Clayey Silt	7	Clayey Silt	5	Clayey Silt	7	Clayey Silt	4
3.0	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3	Clayey Silt	7	Clayey Silt	4	Clayey Silt	7
4.5	Clayey Silt	5	Clayey Silt	5	Clayey Silt	2	Clayey Silt	4	Clayey Silt	4	Clayey Silt	4
6.0	Clayey Silt	3	Clayey Silt	4	Clayey Silt	8	Organic Clay	5	Clayey Silt	8	Organic Clay	4
7.5	Clayey Silt	6	Clayey Silt	4	Clayey Silt	3	Organic Clay	5	Organic Clay	5	Clayey Silt	3
9.0	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3	Clayey Silt	4	Clayey Silt	4	Clayey Silt	5
10.5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	3	Clayey Silt	5	Clayey Silt	7	Clayey Silt	6
12.0	Fine Sand	9	Clayey Silt	7	Fine Sand	9	Clayey Silt	7	Clayey Silt	8	Clayey Silt	6
13.5	Fine Sand	19	Fine Sand	9	Fine Sand	14	Fine Sand	11	Clayey Silt	11	Clayey Silt	4
15.0	Clayey Silt	8	Fine Sand	12	Clayey Silt	7	Fine Sand	17	Fine Sand	18	Silty Sand	10
16.5		-					Fine Sand	33	Fine Sand	28	Silty Sand	10
18.0							Fine Sand	33	Fine Sand	22	Silty Sand	12

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

MIDDLE ZONE

Site No	45				46					
Ref. No	B-236				B-260					
Location	HMM road, Khulna				Sheikh para (Opsonin office building)					
Bore Hole	BH-1		BH-2		BH-1		BH-2		BH-3	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	1	Clayey Silt	-	Clayey Silt	7	Clayey Silt	10	Clayey Silt	7
3.0	Clayey Silt	4	Clayey Silt	6	Clayey Silt	2	Clayey Silt	4	Clayey Silt	4
4.5	Organic Clay	4	Clayey Silt	3	Clayey Silt	5	Clayey Silt	8	Clayey Silt	7
6.0	Organic Clay	4	Clayey Silt	4	Clayey Silt	3	Clayey Silt	6	Clayey Silt	5
7.5	Organic Clay	4	Clayey Silt	5	Clayey Silt	5	Clayey Silt	6	Clayey Silt	6
9.0	Organic Clay	3	Clayey Silt	3	Clayey Silt	5	Clayey Silt	5	Clayey Silt	7
10.5	Clayey Silt	3	Clayey Silt	4	Fine Sand	18	Fine Sand	27	Fine Sand	32
12.0	Clayey Silt	3	Clayey Silt	4	Fine Sand	26	Fine Sand	26	Fine Sand	23
13.5	Fine Sand	15	Clayey Silt	6	Fine Sand	26	Fine Sand	56	Fine Sand	29
15.0	Fine Sand	28	Fine Sand	51	Fine Sand	24	Fine Sand	86	Fine Sand	23
16.5					Fine Sand	52	Fine Sand	70	Fine Sand	58
18.0					Fine Sand	52	Fine Sand	70	Fine Sand	64

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

SOUTH ZONE

Site No	47				48						49			
Ref. No	B-179				B-203						B-126			
Location	Khulna University (Prof. Quarter)				Khulna University building, Khulna						Chanmari , Khulna			
Bore Hole	BH-1		BH-2		BH-1		BH-2		BH-3		BH-1		BH-2	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Organic Clay	1	Clayey Silt	1	Organic Clay	1	Organic Clay	2	Organic Clay	1	Clayey Silt	1	Clayey Silt	2
3.0	Organic Clay	1	Organic Clay	1	Organic Clay	2	Organic Clay	2	Organic Clay	2	Clayey Silt	1	Organic Clay	2
4.5	Organic Clay	1	Organic Clay	1	Organic Clay	2	Organic Clay	3	Organic Clay	2	Clayey Silt	3	Clayey Silt	2
6.0	Organic Clay	2	Clayey Silt	2	Clayey Silt	4	Clayey Silt	3	Clayey Silt	2	Clayey Silt	2	Clayey Silt	3
7.5	Clayey Silt	1	Organic Clay	3	Clayey Silt	4	Clayey Silt	3	Clayey Silt	4	Clayey Silt	2	Clayey Silt	2
9.0	Organic Clay	1	Clayey Silt	4	Clayey Silt	4	Clayey Silt	2	Clayey Silt	2	Fine Sand	10	Fine Sand	11
10.5	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3	Clayey Silt	3	Fine Sand	6	Fine Sand	7
12.0	Organic Clay	4	Clayey Silt	4	Clayey Silt	3	Clayey Silt	2	Clayey Silt	3	Fine Sand	9	Fine Sand	8
13.5	Clayey Silt	4	Clayey Silt	4	Clayey Silt	2	Clayey Silt	4	Clayey Silt	2	Fine Sand	39	Fine Sand	15
15.0	Organic Clay	4	Clayey Silt	3	Clayey Silt	2	Clayey Silt	3	Clayey Silt	3	Fine Sand	20	Fine Sand	17
16.5	Clayey Silt	4	Clayey Silt	4										
18.0	Organic Clay	4	Clayey Silt	4										

Soil Profiles and SPT Values along the North -South Section in Khulna City Area

SOUTH ZONE

Site No	50				51		52						53	
Ref. No	B-253				B-001		B-037						E-003	
Location	Farazipara (Rokeya Khatun)				Chanmari		Lobonchora, Khulna						Bania Khamar	
Bore Hole	BH-1		BH-2		BH-1		BH-1		BH-2		BH-3		BH-1	
Depth in m	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value	Soil Type	N-value
1.5	Clayey Silt	5	Clayey Silt	4	Clayey Silt	2	Clayey Silt	4	Clayey Silt	4	Clayey Silt	5	Clayey Silt	5
3.0	Clayey Silt	5	Clayey Silt	4	Organic Clay	2	Organic Clay	2	Clayey Silt	2	Clayey Silt	2	Organic Clay	4
4.5	Clayey Silt	4	Organic Clay	5	Clayey Silt	4	Clayey Silt	3	Clayey Silt	8	Clayey Silt	2	Clayey Silt	7
6.0	Organic Clay	6	Clayey Silt	3	Clayey Silt	1	Organic Clay	2	Clayey Silt	3	Clayey Silt	2	Fine Sand	4
7.5	Clayey Silt	3	Clayey Silt	4	Clayey Silt	3	Clayey Silt	2	Clayey Silt	3	Clayey Silt	3	Fine Sand	4
9.0	Clayey Silt	3	Clayey Silt	3	Fine Sand	3	Clayey Silt	2	Clayey Silt	4	Silty Sand	6	Fine Sand	10
10.5	Clayey Silt	3	Clayey Silt	3	Fine Sand	4	Clayey Silt	3	Clayey Silt	6	Silty Sand	11	Fine Sand	6
12.0	Clayey Silt	4	Clayey Silt	4	Fine Sand	4	Clayey Silt	2	Fine Sand	8	Silty Sand	11	Fine Sand	15
13.5	Clayey Silt	7	Clayey Silt	5	Fine Sand	7	Clayey Silt	4	Fine Sand	15	Fine Sand	11	Fine Sand	16
15.0	Clayey Silt	7	Clayey Silt	6	Fine Sand	7	Clayey Silt	4	Fine Sand	8	Fine Sand	11	Clayey Silt	16
16.5	Fine Sand	22	Clayey Silt	11			Clayey Silt	8	Clayey Silt	4	Fine Sand	22		
18.0	Fine Sand	17	Fine Sand	16			Clayey Silt	4	Clayey Silt	8	Fine Sand	28		