An Integrated Field Report

On

Old Geological Sciences Building, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh

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ABSTRACT

This study deals with the geophysical and geo-engineering characteristics of some soil samples of Old Geological Sciences building area at Jahangirnagar University, Savar, Dhaka-1342. The results of all the tests are presented, compared and evaluated to delineate the sub surface ground condition. The soil samples of the studied area are sand-dominated (13 to 70.8%).

The studied soil might be defined as silty sand based on grain size analysis. The sand percentages are increased with increasing depth whereas silt percentages values are decreased with increasing depth. The specific gravity values range from 2.27 to 2.58 which are nearer to the typical values for kaolinite. The study soil is broadly divided into cohesive and non-cohesive soils and the SPT values increases with increasing depth. The top layer consists of soft to medium plastic silty clay and have very soft and medium consistency. The subsequent deep layers of non-plastic sand-silt mix, silty fine sand and fine sand shows medium dense to dense consistency. The SPT value suggests that the deep foundation preferably pile may be provided at the study area.

From overall observations, the grain size analysis suggests a gradual increase in sand percentages with depth as the electrical resistivity increased with increasing particle size. The resistivity of soil decreases with increasing the co-efficient of uniformity. Electrical resistivity decreased with increasing moisture content in soils. The relation between electrical resistivity and specific gravity showed that higher the resistivity value lowers the specific gravity.

ACKNOWLEDGEMENT

First and foremost, I wish to express all of my devotion to the almighty God, the most gracious and merciful beneficent creator who has enabled me to perform this research work and to submit this search work of the same.

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Chapter 1: Introduction

1.1 General

Dhaka, the capital city of Bangladesh, is quickly developing towards the Savar region. Rapid urbanization in this area has sparked renewed interest in geo-engineering features of underlying earth conditions. Geo-engineering information is critical for proper urbanization in a city. Every project involving earth constructions that require a soil or rock foundation or are developed below the ground surface requires knowledge of geotechnical qualities of soil.

This subsurface research included the drilling of one borehole up to 17 meters deep, the performance of the needed field, and laboratory testing of many geotechnical parameters. In total, 11 samples are tested in the laboratory.

This geophysical technique is particularly potent due to the recent development of a viable electrical tomography field system as well as good processing and inversion software (Loke and Barker 1995, 1996). It can be used to investigate complex geology and a variety of other shallow subsurface inquiries (Griffiths and Barker 1993).

This article describes and examines the basics of 2-D electrical imaging, as well as its application in geology investigations based on resistivity data, basic geotechnical properties, and evaluates the shallow subsurface geology of the study area.

1.2 Location and Extent

The selected study area includes the front premise of Faculty of Business Administration which is located at Jahangirnagar University, Savar Upazilla, Dhaka-1342. Geographically, this area is located 23°53'12.1848" N latitude and 90°15'58.104" E longitude.

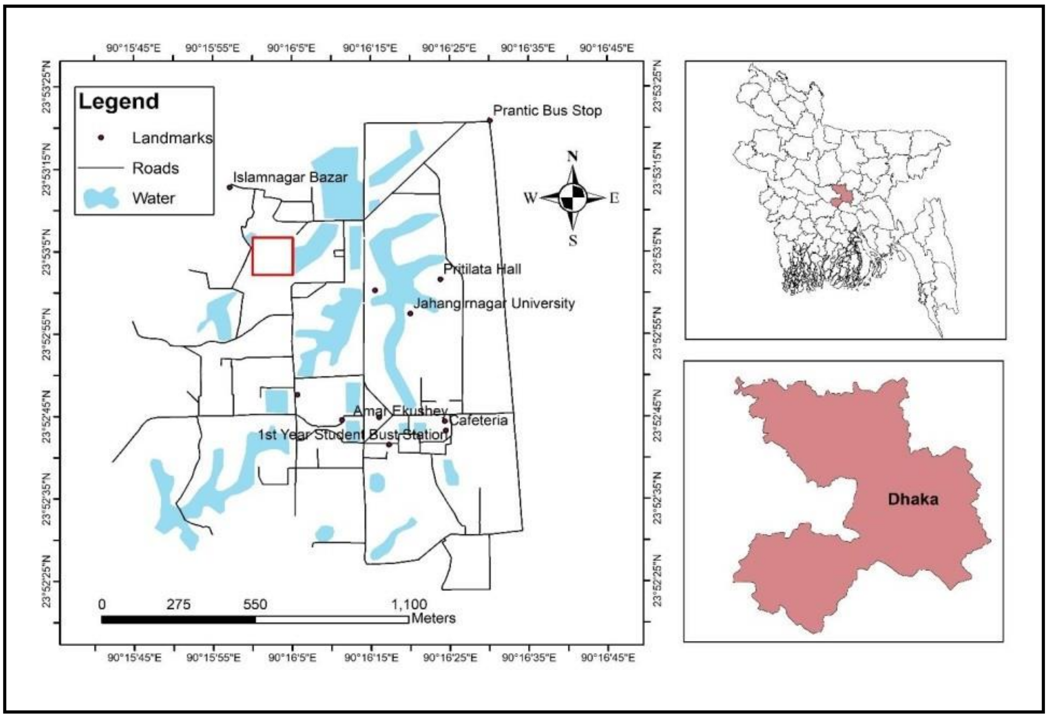

FIGURE 1–1 LOCATION MAP OF THE STUDY AREA

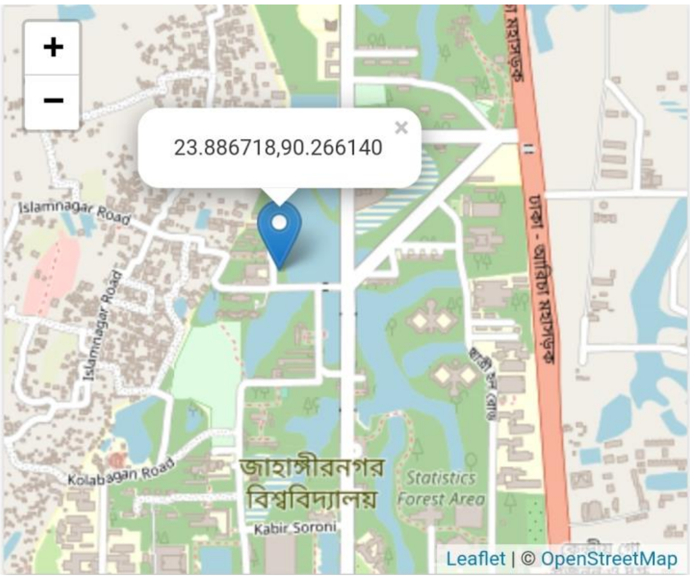

FIGURE 1–2 LATITUDE AND LONGITUDE OF THE STUDY LOCATION

1.3 Aims and Objectives

The primary goal of the field work is to depict the researched area's shallow subsurface geological condition. The major goals are:

- To assess the soils engineering qualities (moisture content, plastic limit, and liquid limit)
- To evaluate the geology of the research region and compare geotechnical properties with resistivity data.
- Finally, produce a report on the planned area's inquiry.

1.4 Previous Investigations

- The Madhupur Tract attracted the attention of many geologists for the Pleistocene deposits. Many authors made valuable contributions on various geological aspects of the investigated and surrounding area.

- Haque (1994) has investigated geotechnical characteristics of some Pleistocene Madhupur clay soils of Dhaka.
- Hossain (2000) examined hydrology of the Jahangirnagar area using the 2-D Electrical imaging survey.
- Kabir (2006) has prepared a geophysical report on 2-d electrical imaging of Jahangirnagar University campus, Savar, Dhaka, Bangladesh. Besides, field work has been conducted by the students of MS session 2002-03 of Department of Geological Sciences, Jahangirnagar University, Savar, Dhaka-1342.

Chapter 2: Geology of the Area

2.1 General

The research region encompasses a large portion of the Dhaka Terrace (Alam, 1988), which is located in central Bangladesh and is part of the Madhupur Tract. The tract is a structural high that appears as a terrace and is exposed as a monoclonal limb. The terrain is sloping to the south and southeast. The terrace has become a center of urban and industrial growth due to its higher elevation than the surrounding alluvial plains. Understanding the geomorphology, geotechnical behavior, stratigraphy, and tectonic or structural setting of the terrace is crucial for its continued expansion and sustainable development.

2.2 Geological Setting of the Study Area

Madhupur Ghar in the north, Bhawal Ghar in the middle, and Dhaka Terrace in the south are the three primary tablelands that make up the Madhupur tract. The research area is located on the Madhupur Tract's Dhaka terrace (Alam, 1988). The area's height varies between 1.5 and 7 meters and slopes south and southeast. The high ground in the Savar area is still above the current flood level, with an average elevation of more than 7 meters above mean sea level. It covers almost 40% of the land area in the examined region and extends northward in a long line where the Madhupur clay deposit is exposed. The drainage pattern of the area is dendritic to trellis and has intensively been dissected by tributaries of the Turag, the Buriganga, the Balur and the Bansi rivers and formed numerous rounded and elongated hillocks (Alam, 1988).

According to some Authors, the Madhupur and the Barind Tracts represent a tectonically uplifted surface. The reason for the uplift was explained by Fergusson (1963), Morgan and McIntire (1959) and others. Fergusson (1963) believed that the Madhupur region has been uplifted in very recent time and he referred to the earthquake of 1762. He suggested that the Madhupur Jungle occurs along the axis of the belt of "Volcano Action" which extends in a north-western direction through Chittagong and Dhaka. Fergusson (1963) considered numerous low lakes in the Sylhet basin to be caused by the subsidence of compensatory to the elevation of the Madhupur Tract. The terrace is formed of number of blocks separated by plastic deformation due to compression forces during last phases of Himalayan upliftment. A series of dendritic to trellis drainage pattern has been developed on the terrace following the fractures or shear zones that has produced a unique geomorphic outlook.

2.3 Stratigraphy of the Area

The sediments that make up the Pleistocene of Bengal differ from the surrounding floodplain sediments, demonstrating local diversity based on the degree of oxidation and the amount of organic material they contain (Morgan and McIntire, 1959).

Age	Formation	Member	Bed	Lithologic description	Thickness (m)
HOLOCENE	Basabo Silty-clay	Matuail Clay	Silty Clay	Pale Olive, very sticky silty clay with modern soil on top	5
				Unconformity	
			Clayey Silt	Light yellowish brown very sticky clayey silt, containing plant roots and iron concretions	
				Unconformity	
		Gulshan Sand	Silty Clay	Yellowish red silty clay	It varies
				Unconformity	
			Clayey Silt	Pale yellow clayey silt	
				Unconformity	
			Sand	Light bluish gray, sand-silt-clay to sand, contains plant roots and wood fragments.	2
				Unconformity	
PLEISTOCENE	Madhupur Clay Formation	Dhaka Clay	Kalsi Beds 1	Pale yellowish brown with light brown spotted sandy clay, clayey silt	4
				Unconformity	
			Kalsi Beds 2	Yellowish Brown Silty Clay, containing Fe concretions, very sticky, plant roots.	
				Unconformity	
				Plastic, sticky reddish spots. It contains Fe-concretions, pipe-stems, calcareous nodules, plants roots, micas and manganese spots	5
				Unconformity	
		Mirpur Silty-clay		Light Brown sandy clay to clayey sand. It contains Fe-concretions, pipe-stems, calcareous nodules, plants roots, micas and manganese spots	4
				Unconformity	
		Bhaluka Sand		Pale Yellowish brown silty-sand to sand. It is highly micaceous and contains clayey beds. This sand is cross bedded.	4
				Unconformity	
PLIOCENE	Dupi Tila			Quartz-chalcedony Gravel Bed	
				Oxidized sands with intraformational clay beds. It contain large silicified woods	

FIGURE 2–1 GENERALIZED STRARTIGRAPHIC SUCCESSION OF THE MADHUPUR AREA (AFTER MONSUR, 1995)

The highland of the Madhupur Tract in the Dhaka city and Savar area represents the Madhupur Clay Formation, the oldest exposed rock of the area. It is unconformably underlain by the DupiTila Formation and overlain by Recent Alluvium Formation. The so called Madhupur Clay Formation has recently been named by Alam et al. (1990) as the Madhupur Clay Residuum and by Monsur (1990) as the Madhupur Clay and Sand Formation. The Alluvium Formation was proposed as the Basabo Silty-Clay Formation by Monsur (1990).

The development of actual stratigraphic succession of this area is not possible because no deep drill hole has so far been drilled in this area. So overall stratigraphic succession of Bengal Foredeep can be considered for the study area is given in Fig 2.

Chapter 3: 2D Electrical Imaging

3.1 Methodology

The methodology of the geophysical investigation is described in the following sections.

3.1.1 Principles

The resistivity measurements are normally made by injecting current into the ground through two current electrodes (CI and C2 in Figure 3) and measuring the resulting voltage difference at two potential electrodes (P1 and P2). From the current (I) and voltage (V) values, an apparent resistivity value is calculated.

$$\rho_a = k\ (V/I)$$

Where, k is the geometric factor which depends on the arrangement of the four electrodes.

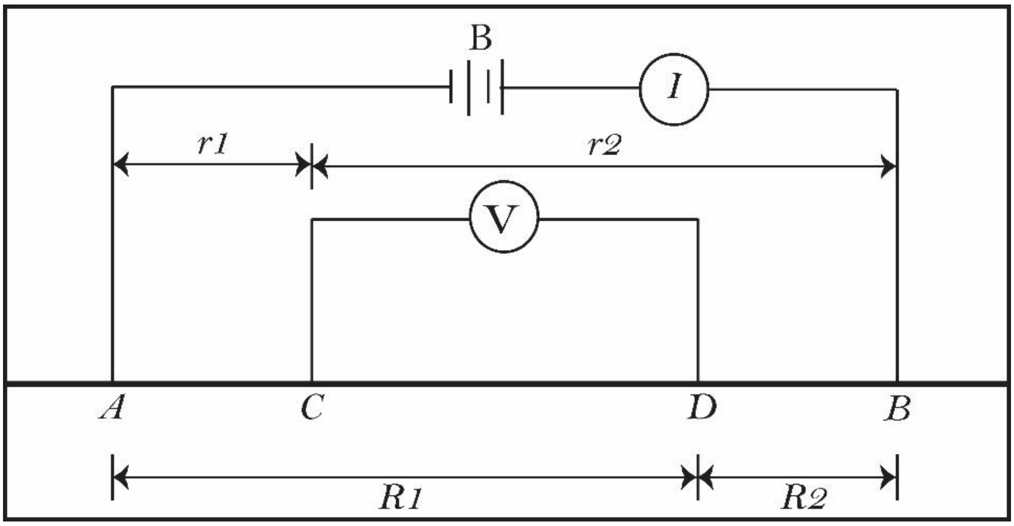

FIGURE 3–1 ARRANGEMENT OF CURRENT ELECTRODES (A & B) AND POTENTIAL ELECTRODES (C & D)

Resistivity methods normally give a resistance value, R= V/1, so in practice the apparent resistivity value is calculated by

$$\rho_a = kR$$

The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out (Loke, 2000).

3.1.2 Electrode Arrangement

In field, several different electrode configurations can be applied. Normally, current and potential electrode sets are laid out along a line. The current electrodes are generally placed on the outside of the potential electrodes. The most widely used linear array types are

- Wenner array
- Schulumberger array
- Dipole- Dipole array

For the present field survey Wenner array was used.

Wenner array:

The simplest and commonly used electrode array for determining resistivity is the Wenner array. This is a symmetrical configuration consists of four electrodes, which are equally spaces along a straight line. Here, the outer two electrodes are current electrodes and the inner two electrodes are potential electrodes. The distance between two adjacent electrodes is called array spacing (a). For the depth exploration using Wenner array, the electrodes are expanded about a fixed center (i.e., the spacing 'a' is increasing). But for the lateral exploration of mapping, the spacing remains constant and all the four electrodes are moved along the line and then again and again.

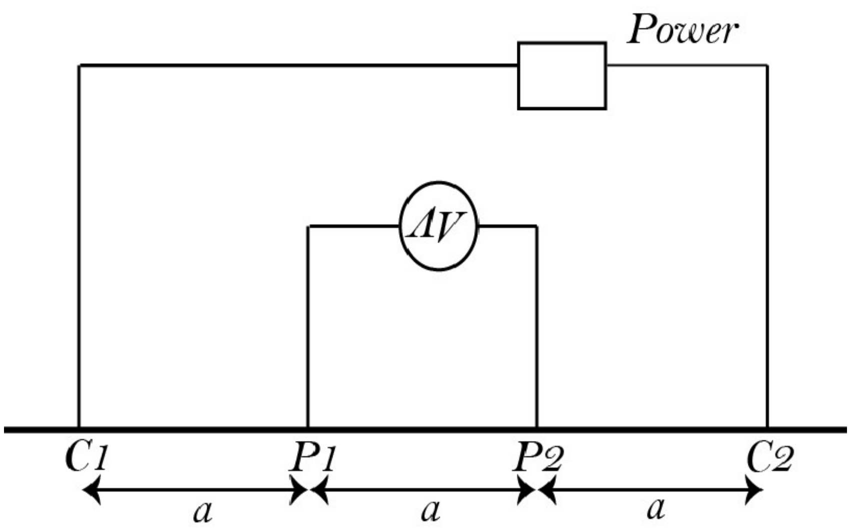

FIGURE 3–2 SCHEMATIC DIAGRAM OF WENNER ARRAY

The apparent resistivity with Wenner array is given by

$$\boldsymbol{\rho_a = 2\pi a\ (V/I)}$$

Where,

V = Potential difference in volts between Pl and P2

I = Current in ampere.

a = Array spacing

ρ_a = Apparent resistivity.

The geometric factor of Wenner array is **2πa**; the resistivity of the subsurface rock depends on the factor.

3.1.3 Relationship between Geology and Resistivity

Resistivity surveys give a picture of the subsurface resistivity distribution. To convert the resistivity picture into a geological picture, some knowledge of typical resistivity values for different types of subsurface materials and the geology of the area surveyed is important. Before dealing with the 2-D and 3-D resistivity surveys, we should briefly look at the resistivity values of some common rocks and soils. Table-2 gives the resistivity values of common rocks and soil (Keller & Frischknecht, 1966).

Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is greatly dependent on the degree of fracturing, and the percentage of the fractures filled with ground water. Sedimentary rocks, which usually are more porous and have higher water content, normally have lower resistivity values. Wet soils and fresh ground water have even lower resistivity values. Clayey soil normally has a lower resistivity value than sandy soil.

However, we note the overlap in the resistivity values of the different classes of rocks and soils. This is because the resistivity of a particular rock or soil sample depends on a number of factors such as the porosity, the degree of water saturation and the concentration of dissolved salts.

Resistivity mainly depends on:

Porosity of rocks, quality of fluids, Chemical content of water, filling pore space, The salinity of pore water, Degree of saturations and clay contents.

Resistivity values have a much larger range compared to other physical quantities mapped by other geophysical methods (Loke, 2000). The resistivity of ground water varies from 10 to 100 Ωm depending on the concentration of dissolved salts. The low resistivity (about 0.2 Ωm) of sea water is due to the relatively high salt content. This makes the resistivity method an ideal technique for mapping the saline and fresh water interface in coastal areas.

TABLE 3.1 RESISTIVITY OF SOME COMMON ROCKS AND MINERALS (KELLER AND FRISCHKNECHT, 1996)

Material		**Resistivity (Ωm)**	**Conductivity (Siemen/m)**
Igneous and Metamorphic Rocks	Granite	5×103 - 106	10-6 - 2×10-4
	Basalt	103 - 106	10-6 - 10-3
	Slate	6×102 - 4×107	2.5×10-8 - 1.7×10-3
	Marble	102 - 2.5×108	4×10-9 - 10-2
	Quartzite	102 - 2×108	5×10-9 - 10-2
Sedimentary Rocks	Sandstone	8 - 4×103	2.5×10-4 - 0.125
	Shale	20 - 2×103	5×10-4 - 0.05
	Limestone	50 - 4×102	2.5×10-3 - 0.02
Soil and Water	Clay	1 – 100	0.01 - 1
	Alluvium	10 – 800	1.25×10-3 - 0.1
	Groundwater (fresh)	10 – 100	0.01 - 0.1
	Sea water	0.2	5

3.2 Sequence of Geophysical Field Investigation

Field/Resistivity line
Resistivity data collection from field
Data input and data conversion by using
Build up apparent resistivity pseudosection
Collection samples from boreholes at different depth
Analysis samples for evaluating basic geotechnical properties
Resistivity data comparing with geotechnical properties
Resistivity data comparing with geotechnical parameters
Finally compare with the geology of the study area

3.3 Operation and Field procedures of Resistivity method

The Field measurements for DC Resistivity investigations basically involves sending a known current into the ground through the current electrodes and observing the resulting voltage across the potential electrodes to get the resistance values. The DDR3 equipment has the facility to provide the operator the direct readout of these resistance values on liquid crystal display. The operation of the DDR3 equipment involves broadly, cancellation of S.P and sending a known amount of current into the ground at appropriate voltages by adjusting the controls(3) and (4) and observing the readouts of the resistance value on the display.

Two distinctive procedures of resistivity methods are:

Electrical profiling/ later profiling or mapping and vertical electrical sounding (VES)/ electrical drilling.

Electrical profiling

If the layers or boundaries are vertical (rather than horizontal); then the electrical profiling is applied. The objective of the profiling is to detect lateral variations in the subsurface resistivity. In this field procedure the current and potential electrodes are maintained in a fixed separation and progressively moved along a line or profile.

This method is applied in mineral exploration to locate fault or shear zones. To detect localized bodies of anomalous conductivity. In determining the step discontinuity.

Vertical electrical sounding (VES)/ electrical drilling

VES is required when the ground consists of a number of more or less horizontal layers. The objectives of VES are to determine the resistivity variation with depth below a given point on the ground surface. This procedure is usually done by increasing the separation current electrode. The Schlumberger configuration is suitable for VES. In VES survey, the center of the electrodes is remained in a fixed position, but the electrode spacing is progressively increased.

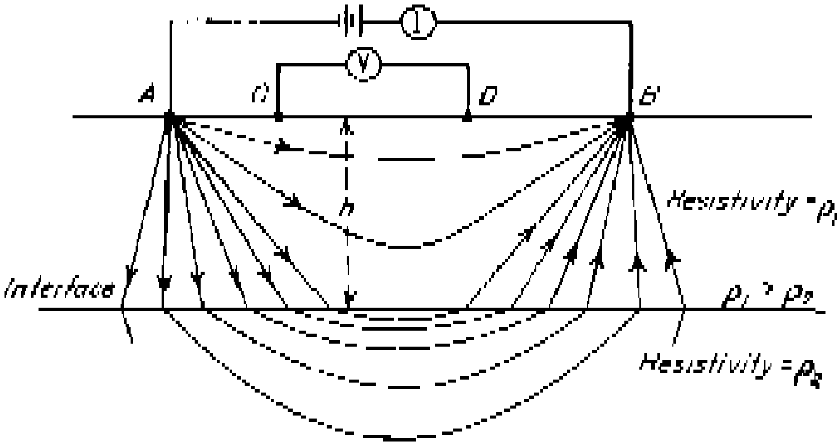

FIGURE 3–3 SCHEMATIC DIAGRAM OF VERTICAL ELECTRICAL SOUNDING

3.3.1 Operation steps for measurements of direct R

i. In this case the instrument works in constant current mode:
ii. Connect the terminal C1 and C2 on the current unit to the current electrodes.
iii. Connect the terminal P1 and P2 on the potential unit to the potential electrodes
iv. Keep the DIRECT/REVERSE in direct position.
v. Switch on the digital display switch on p unit.
vi. Switch on the S.P. switch on p unit.
vii. Switch on the digital display switch on c unit.
viii. Set the P display to read 000 by suitably adjusting the S.P coarse and fine controls. This cancels the back ground self-potential across the potential electrodes.
ix. Keep R and V in position.
x. Set the current control knob of current unit in I position (red). In this position C unit send 100 mA of current.
xi. Press the current switch of C unit and observed the digital readout on C unit. If the readout is 100 then the voltage set on is appropriate.

3.3.2 Operation steps for V and I measurements

i. In this case the V and I measurements are independently made and the ratio V/I is calculated for getting resistance. For these measurements following stages **i to vii** of **3.3.1**.
ii. Keeping the R and V switch of P unit in V position and the current control knob in V/I position.
iii. Press the press for current switch of C unit and note the digital display on which gives current in mA.
iv. Observed the display on P unit. Multiply it with 1 and 0.1 depending on the position 1-0.1 switch. This gives the potential.
v. Compute V/I ratio to get the R values

3.4 Limitations of these Methods

The most severe limitation of the resistivity sounding method is that horizontal (or lateral) changes in the subsurface resistivity. Lateral changes in the subsurface resistivity will cause changes in the apparent resistivity values. As a result, it might be misinterpreted as the subsurface resistivity changes with depth.

Despite its obvious limitations, there are two main reasons why 1-D Resistivity sounding surveys are common. The first reason was the lack of proper field equipment to carry out the more data intensive 2-D and 3-D surveys. The second reason was the lack of practical computer interpretation tools to handle the more complex 2-D and 3-D models.

However, 2-D and even 3-D electrical surveys are now practical commercial techniques with the relatively recent development of multi - electrode resistivity surveying instruments (Griffiths et al, 1990) and fast computer inversion software (Loke, 1994). In the present study, 2-D electrical Imaging is used to study the geotechnical behavior of the near subsurface

3.5 Electrical Imaging

Electrical resistivity surveys involve injecting current into the ground between two electrodes, and measuring the voltage difference between two other electrodes - usually all at the ground surface. For nearly a century, these surveys have been used to perform one-dimensional profiling (detection of lateral changes in underground electrical properties by moving a fixed electrode array along a survey transect) or sounding (detection of vertical changes by expanding an electrode array about a fixed location). Within the last decade, development of multi- conductor electrode cables and computer-driven, automated switching, as well as innovative processing of large resistivity data sets, have allowed simultaneous performance of profiling and sounding to produce two-dimensional “electrical images” depicting detailed variations in subsurface electrical properties.

Electrical tomography (also referred to as Electrical imaging) is a survey technique that aims to construct a picture of the electrical properties of the subsurface by passin an electrical current along many different paths and measerin the associated voltages.

Electrical resistivity tomography (ERT) or electrical resistivity imaging (ERI) is a geophysical technique for imaging sub-surface structures from electrical measurements made at the surface, or by electrodes in one or more boreholes. It is closely related to the medical imaging technique electrical impedance tomography (EIT), and mathematically is the same inverse problem. A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. In this case, it is assumed that resistivity does not change in the direction that is perpendicular to the survey line (Loke, 2000).

Electrical Imaging surveys are typically conducted to determine the resistivity of the subsurface. Resistivity data can be used to determine the location of variations in geologic and soil strata, soil/bedrock interface topography, bedrock fractures, faults, and voids. The method has been used effectively to delineate old waste sites and landfill boundaries and to map hydro-geologic and mineral resource boundaries.

Simply, 2-D electrical imaging that kind of survey technique which is especially suitable for shallow site investigations where understanding complex subsurface structure in detail is important.

3.5.1 2-D Imaging and Data Collection

In recent years, the use of 2-D electrical imaging/tomography surveys is developed to map areas with moderately complex geology (Griffiths & Barker, 1993). A series of earth connections is made by inserting metal stakes (electrodes) into the ground at equal intervals along a line. In most field surveys 50 electrodes are clipped to metal "take outs" equally spaced along lightweight multi-core cables. Depending on the depth range of imaging desired, the unit electrode spacing ranges from 1 to 10 m for hydrogeological and engineering site investigations.

Each single core connects a cylindrical shaped stainless steel takeout to a central switching unit and then to a computer and earth resistance meter.

The switching unit allows any combination of four electrodes to be connected to the resistance meter at any time. The equipment is designed to operate with IBM compatible laptop computer. The latter controls the switching unit and the resistance meter, and stores the measurements in memory and on disc for later processing (Hossain, 2000).

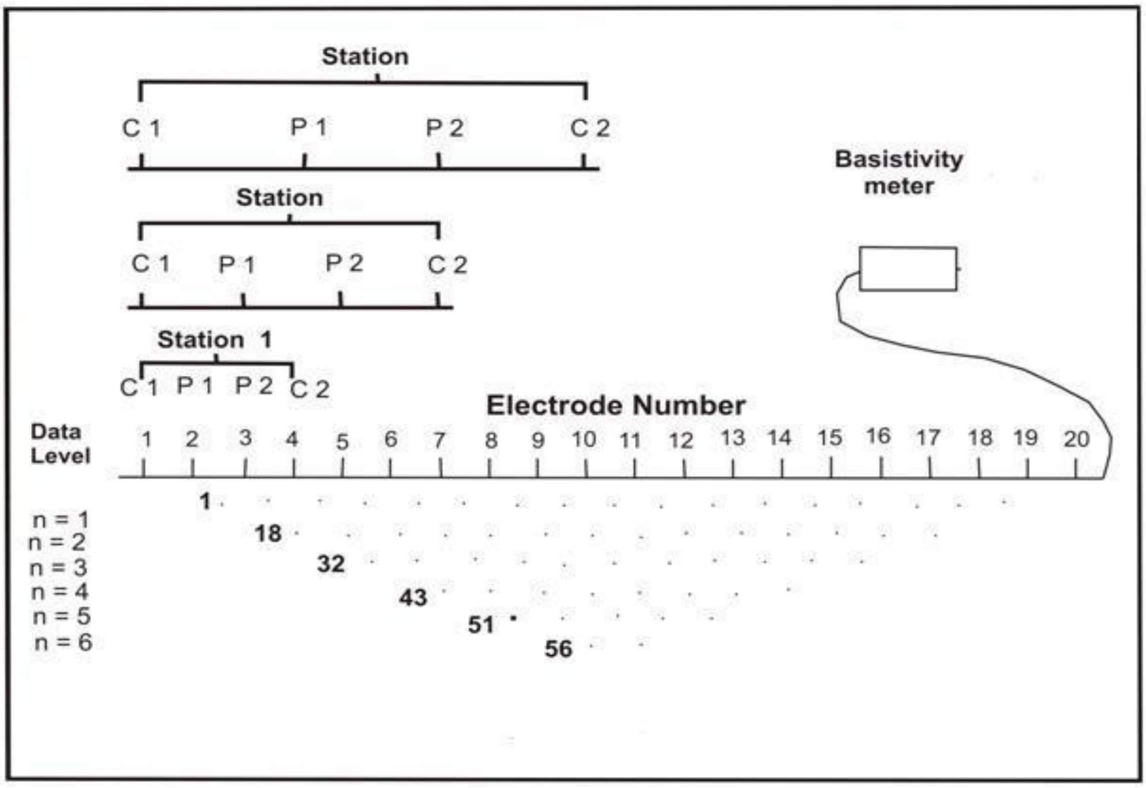

FIGURE 3–4 THE ARRANGEMENT OF ELECTRODES FOR A 2-D ELECTRICAL SURVEY AND THE SEQUENCE OF MEASUREMENTS USED TO BUILD UP A PSEUDOSECTION (LOKE, 2000)

There are two survey modes which can be employed to build up the data for an electrical image (i.e., a cross-section of the distribution of subsurface resistivity) using a 4-electrode Wenner array; the traverse mode and the roll-on mode.

3.5.2 Instruments and Field Procedure

The coverage of the measurements must be 2-D as well to obtain a good 2-D picture of the subsurface. In this field study, three parallel lines were chosen with the same electrode spacing.

IGIS DDR3 DC Resistivity Meter has been used for this field investigation. The system employed consists of 25 electrodes being employed at a time; the unit electrode spacing being 2 m indicating a maximum depth of investigation of 8 m (approximately). Electrode 1 and electrode 25 are located at the east and west end of the image line, respectively. The roll-on mode has been employed to build up the data for the electrical image. All the electrodes were addressable as either C1, C2 (for current electrode) and P1, or P2 (for potential electrode).

Instruments:

The DDR-3 resistivity meter consists of current unit (c unit) and potential unit (P unit). For investigating “Near surface investigation of the Madhupur Clay formation using electrode imaging” the equipment used consists of:

C-unit P-unit

- Connecting cable (Red and Black) Hammer - 2
- Winch - 4 (Yellow and Red) 2 - current electrodes
- 2 - Potential electrodes Measurement Tape
- Battery - 9 volt and 1.5 volt Tester
- Screw driver

Measurement procedures:

To make a measurement of ground resistivity, current, I, is injected into the ground through two electrodes, C1 and C2 and a voltage, V, is measured across a second pair of electrodes, P1 and P2. From a knowledge of the resistance, R (=V/I) and the inter-electrode distance, an apparent ground resistivity can be calculated (Hossain, 2000).

For the field survey a possible sequence of measurements for the Wenner electrode array for a system with 25 electrodes. The spacing between adjacent electrodes is “a”. The first step is to make all the possible measurements with the Wenner array with an electrode spacing of “1a”. For the first measurement, electrodes number 1, 2, 3 and 4 are used. The electrode 1 is used as the first current electrode C1, electrode 2 as the first potential electrode P1, electrode 3 as the second potential electrode P2 and electrode 4 as the second current electrode C2. For the second measurement, electrodes number 2, 3, 4 and 5 are used for C1, P1, P2 and C2 respectively. This is repeated down the line of electrodes until electrodes 22, 23, 24 and 25 are used for the last measurement with “1a” spacing. For a system with 25 electrodes, there are 22 (25 -3) possible measurements with “1a” spacing for the Wenner array. After completing the sequence of measurements with “1a” spacing, the next sequence of measurements with “2a” electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. The electrodes are chosen so that the spacing between adjacent electrodes is “2a”. For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until electrodes 14, 16, 18 and 20 are used for the last measurement with spacing “2a”. For a system with 20 electrodes, note that there are 19 (25 -2x3) possible measurements with “2a” spacing.

Fig. 9, the arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection. The same process is repeated for measurements with “3a”, “4a”, “5a”, “6a”, "7a" and "8a" spacings. As the electrode spacing increases, the number of measurements decreases. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements. As the spacing is increased, the measurements sample increasingly greater depths and increasingly greater volumes of ground. Since increasing the electrode separation weights the observed apparent resistivity towards greater depth, the measurement is plotted beneath the centre of the four electrodes used, at a depth proportional to the electrode separation, a, usually at a depth of a/2. All measured data are given in the Appendix.

3.5.3 Pseudosection: Data Plotting Method

The pseudo section contouring method is normally used to plot the data from a 2-D imaging survey. The horizontal location of the point is placed at the mid-point of the set of electrodes used to make that measurement. The vertical location of the plotting point is placed at a distance which is proportional to the separation between the electrodes. The pseudosection plot obtained by contouring the apparent resistivity values is a convenient means to display the data. This Pseudo-section gives a very approximate useful picture that is illustrated by an example apparent resistivity section. The pseudo section is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation (Figure 3.5).

One common mistake made is to try to use the pseudo section as a final picture of the true subsurface resistivity (Loke, 2000).

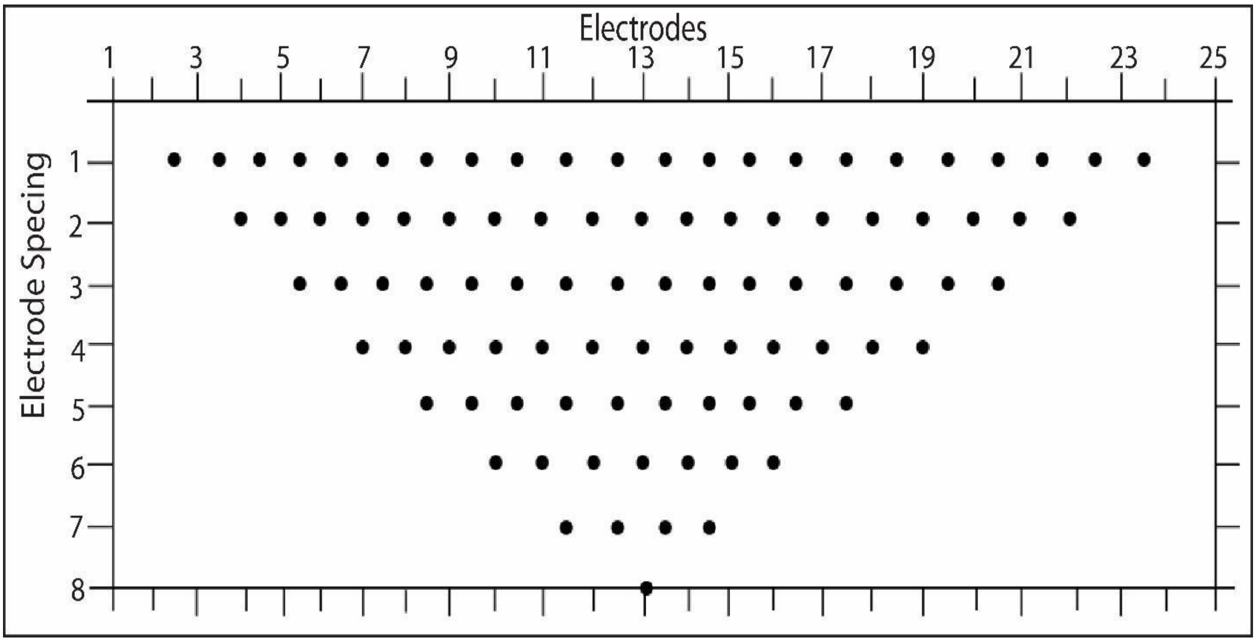

FIGURE 3–5 THE MEASUREMENT SEQUENCE USED FOR BUILDING UP A PSEUDOSECTION.

3.6 Data analysis and interpretation

The resistance measurements are reduced to apparent resistivity values after the field survey. The steps involved in converting the apparent resistivity values into a resistivity model section that can be used for geological interpretation is described (Loke, 2000).

3.6.1 Data input format

To interpret the data from a 2-D imaging survey, a 2-D model for the subsurface which consists of a large number of rectangular blocks is usually used. A computer program is used to determine the resistivity of the blocks so that the calculated apparent resistivity values agree with the measured values from the field survey.

The location of the electrodes and apparent resistivity values must be entered into a text file which can be read by the RES2DINV program. The program manual gives a detailed description of the data format used. As an example, part of an example data file LANDFILL.DAT, is shown with some comments:

Data in file Comments

IMAGING : Name of survey line (Imaging)

4 : Smallest electrode spacing

1 : Array type (Wenner = 1, Dipole-dipole = 3)

92 : Total number of measurements

1 : Type of x-location for datum points (1 for mid-point).

0 : Flag for I.P. data (enter 0 for resistivity data only)

THE X-LOCATION	ELECTRODE SPACING	APPARENT RESISTIVITY VALUE
6	4	16.34
10	4	3.9
14	4	10.56
18	4	11.18
22	4	11.94
26	4	6.79
30	4	11.81
34	4	11.31
38	4	5.53
42	4	9.55
46	4	10.56
50	4	8.8
54	4	12.06
58	4	9.05
62	4	9.05
66	4	8.8

As an exercise, read in the LANDFILL.DAT file using the "File" option on the main menu bar of the RES2DINV program. Next select the "Inversion" option, and then the "Leastsquares inversion" suboption. The program will then automatically try to determine the resistivity values of the blocks in the subsurface model (Loke, 2000).

3.6.2 Automatic Imaging

The unprocessed image comprises two components of information. The section reflects the subsurface geology; but strong effects of the electrode geometry can also distort the section. As a result, wrong geological interpretation may happen.

The Wenner array is a very satisfactory configuration for imaging purposes (Griffiths and Barker, 1993). In general, when the provided subsurface structure is not to complex, the unprocessed images measured using Wenner array are relatively simple in form and closely related spatially to the bodies giving rise to them. An inversion of the data is required to improve the resolution of the image. The recent technique developed by Loke and Barker (1996) has proved to be markedly successful in eliminating electrode geometry effects so that the final processed image provides a good representation of the subsurface. This technique is based on the smoothness-constrained least-squares method and it produces a two-dimensional subsurface model directly from the apparent resistivity pseudosection. The inversion technique is completely automatic and it does not even require the user to supply a starting model. Though the algorithm considerably sharpens the image and corrects the depth variation in resistivity, sharp boundaries still appear gradational and resistivity contrasts can be less than true. Even so, the method quickly produces an image that geometrically and quantitatively approaches a true resistivity cross-section of the subsurface (Hossain, 2000).

3.6.3 Analysis and Interpretation

The amount of pore water, its resistivity, and the configuration of the pores are the primary determinants of soil and rock properties. Resistivity surveys can be useful in locating bodies of anomalous materials or measuring the depths of bedrock surfaces to the extent that lithological variations are accompanied by variances in resistivity. The groundwater surface in coarse, granular soils is usually defined by an abrupt shift in water saturation, and hence by a change in resistivity. However, in fine-grained soils, there may be no such resistivity shift when a piezometric surface is present. Because pore water conditions are the primary determinant of a soil's or rocks resistivity, there are wide variations in resistivity for any given soil or rock type.

3.6.4 2D Electrical Imaging & Interpretation

Resistivity data were collected for one electrical image lines in front of Old Arts Building, Jahangirnagar University. The image line was 96 m long and oriented from East to West. The measuring points are equally marked at ever 4m. The resistivity data were analyzed using the RES2DINV. The result of electric imaging at study site are presented in Fig. 1.

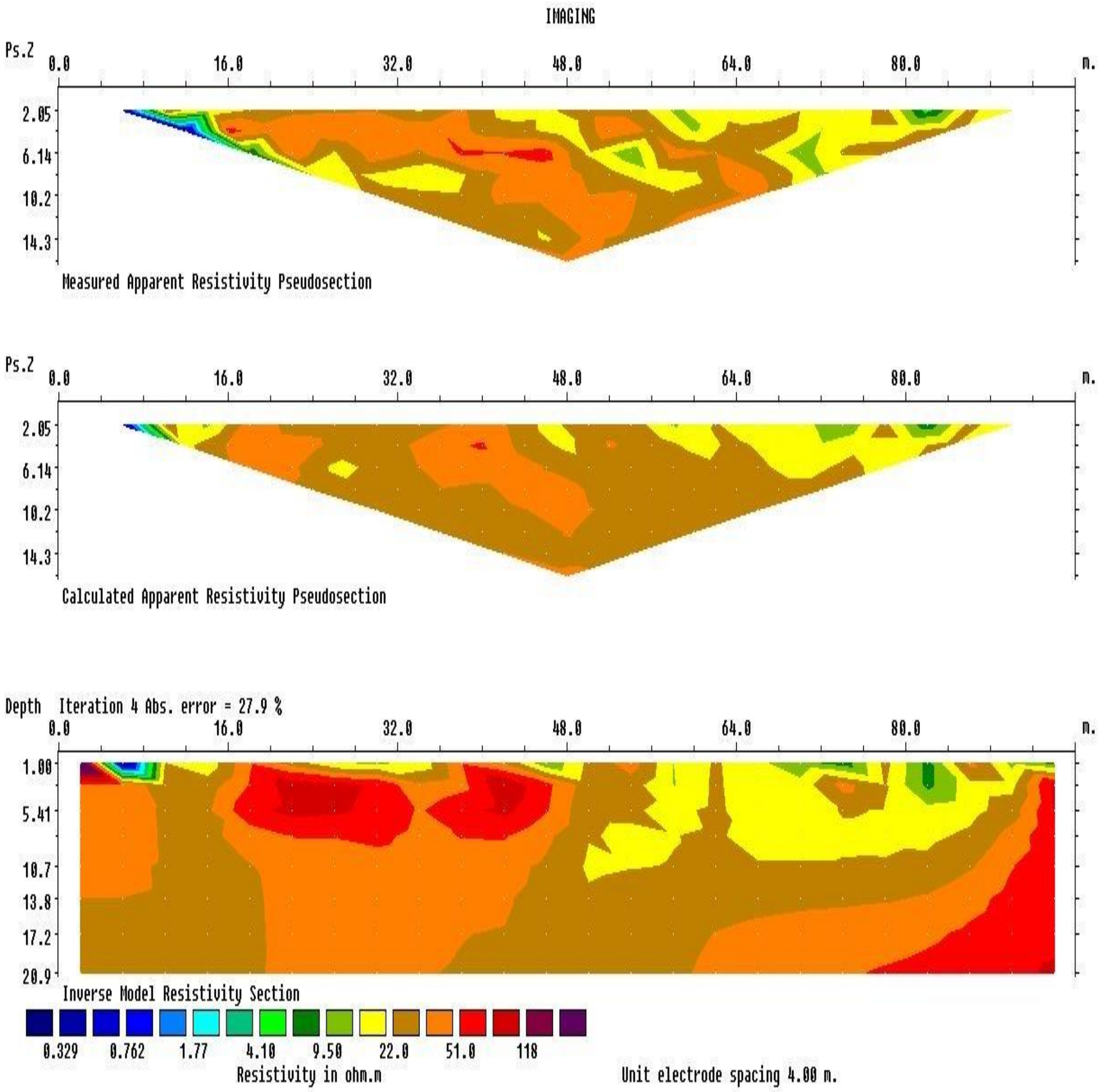

FIGURE 3–6 INVERTED MODEL OF ELECTRICAL IMAGING OF STUDY AREA

Based on the obtained electrical image, the sub-surface resistivity can be described as follows:

Measured Apparent Resistivity Pseudo section:

The subsurface is highly inhomogeneous with measured apparent resistivity approximately from 0 ohm-m to 118 ohm-m. No clearly visible layer can be identified. But top of the in eastern portion apparent resistivity value is lower than the other part of the pseudo section.

Calculated Apparent Resistivity Pseudo Section:

The pseudo section of calculated apparent resistivity shows stratification and the layers are clearer than measured apparent resistivity pseudo section. The top layer consists the resistivity from 0 ohm-m to 15.75 ohm-m, the middle layer from about 15.75 ohm-m to 22 ohm-m, bottom layer from about 36.5 ohm-m to 118 ohm-m.

Inverse Model Resistivity Section:

Inverse model resistivity varies from approximately 0 ohm-m to 236 ohm-m. The electric imaging section showed several variations of resistivity in lateral and vertical directions. Three layers have been identified with irregular thickness of apparent resistivity. In top the pseudo section resistivity value is low, 0 ohm-m to 22 ohm-m layer, in eastern part of the layer has lower resistivity value than the western part. This lower resistivity value indicates loose weathered topsoil.

After then resistivity value is increased depth. But in three prominent zones, astonishingly higher resistivity (51.8 ohm-m to 236 ohm-m) are found. One is in left part the pseudo section (zone 1) with lateral extent from 0 m to 6 m and depth approximately from 0 to 2.5, another two are with lateral extent from 16 m to more than 36m having same depth around 0m to 8m. These high resistivity zones are surrounded by comparatively lower resistivity zone, (resistivity value approximately from 22 ohm-m to 51 ohm-m). Having high resistivity value of these zones probably indicate presence of sand layer, which is surrounded by comparatively lower resistivity clay layer. As the geometric mean resistivity value of Madhupur Clay is 55 ohm-m (Majumder, 1996)

From the pseudo section of measured, calculated and inverted model, it is cleared that the two prominent zones with high resistivity values may indicate sandy layer. The natural water content of these sandy layer higher than the other layers. These three prominent zones may indicate two shallow aquifers with fresh water confined with impermeable clay layers.

Chapter 4: Geo-engineering Investigation

4.1 Field Methodology

The field research is mostly based on data from interviews, empirical field observations, and previous research. After gathering information and conducting a preliminary site inspection, various field approaches for sample collection were used.

4.1.1 Site Investigation

In brief discussion of the site investigation, drilling and collection of disturbed and undisturbed natural samples are discussed in this section. Different stages of site investigation activities are listed as following:

TABLE 4.1 STAGES OF SITE INVESTIGATION (MODIFIED FROM IAEG, 1981 & BS.5930)

SITE INVESTIGATION STAGES	INVESTIGATION STAGES
Desk study	Recognition of need for project Initial project conception Desk study, to obtain basic knowledge of ground conditions Recognition of major problems
Preliminary	Site reconnaissance and preliminary field investigations Design of main ground investigation
Main	Ground investigation Information recovered during investigation Evolution of ground condition using obtain information Results, discussion and future recommendation The obtained basic engineering properties will be helpful for further construction works and foundation designs

4.2 Drilling Techniques and Sample Collection

One borehole was drilled in front of Old Geological Sciences Building, Jahangirnagar University campus, extending 50ft (15.24 m) with the technical assistance of the engineering firm "Creative Soil Investigation" (Fig 4.1).

Light cable percussion drilling method was use for collecting samples and wash boring technique was used as a means of advancing the borehole to enable the tube samples to be taken. This technique used because it helps to take relatively undisturbed soil immediately below the hole. Thin wall opened Shelby tubes (U75 & U100) samplers were used to collect the undisturbed samples. The U75 thin walled Shelby tube (Outer diameter 76mm and inner diameter 75mm) and The U100 thin walled Shelby tube (Outer diameter 100mm and inner diameter 96mm) has been penetrated into the undisturbed soil information at the bottom of the borehole by applying continuous force. When the tube was brought to the surface, some soil was removed from each end and molten wax applied in thin layers to form a seal to kept the soil at natural state. On the other hand, split spoon sampler (Fig. 4.2) was used for collecting disturbed soil samples. Samples both in the undisturbed and disturbed state were collected continuously each 5 it intervals. Total 4 undisturbed and 7 disturbed samples were collected in the Shelby tube from the study area.

FIGURE 4–1 LIGHT CABLE PERCUSSION DRILLING DURING FIELD INVESTIGATION

FIGURE 4–2 SAMPLES COLLECTED FROM THE SITE WITH SPLIT SPOON

4.3 Drilling equipment

A typical mobile, light weight cable tool percussion on drilling system includes a winch of 1–2- ton capacity with a hand operated friction clutch, a small diesel engine and all a frame derrick about 6m in height. Three sets of temporary casing of 10″, 8″, and 6″ diameters are also required a Split Spoon sampler is used with a drilling rig.

4.4 Drilling operations

Drilling is affected by the repeated raising, dropping and rotating of a chisel drilling bit, suspended by a drill cable, with a hole containing water, water is derived from the formation or added from the bore hole top. A slurry of disturbed sediment and water is formed that is removed using a bailer. Sizes of casing and tool were generally for disturbed sample of geological horizons penetrated are obtained at regular intervals using a bailer for lithological analysis. Additional lithological data can be obtained from standard penetration rate and by taking open tube or piston core sediment sample.

4.5 Standard Penetration Test (SPT)

In SPT test, a split spoon sampler of 2 inches (50 mm) outer diameter and 35 mm inner diameter is made to penetrate 18″ (6″ + 6″ + 6″) or 450 mm into the soil by dropping a 65 Kg hammer, falling freely from a height of 30 inches (750 mm). Number of hammer blows required for penetration of each inch’s length of the sampler is recorded. The number of blows for the last

12// penetration of the total 18// is known as the standard penetration values as specified by ASTM and is plotted as the SPT value at the particular depth (Smith, 1990).

FIGURE 4–3 SPLIT SPOON SAMPLER USED DURING FIELD INVESTIGATION

TABLE 4.2 RELATIVE DENSITY SCALE FOR COHESIVE SOIL (E.G., CLAY) (AFTER BS 5930)

Term	SPT
Very Soft	0-2
Soft	2-4
Medium	4-8
Stiff	8-15
Very Stiff	15-30
Hard	>30

Field Report							
Drilling Company Name:		Creative Soil Investigation Ltd.					
Location: Old Geological Sciences Building							
D.= Disturb sample **UD** = Undisturb sample					**DIA** 100 mm		
Depth	**Standard Penetration Test**				**Samples**		
(ft)	6”	6”	6”	Total	Dis	U.D	**Visual Classification**
0-2	Wash Boring						
2-3.5						UD-1	
3.5-5	7	10	11	21	D-1		Brownish grey Silty clay,Very stiff,medium to high plasticity
5-7´	Wash Boring						
7-8.5						UD-2	
8.5-10	4	7	11	18	D-2		Brownish color Silty clay,very stiff,medium to high plasticity.
10-12´	Wash Boring						
12-13.5						UD-3	
13.5-15	8	11	15	26	D-3		Reddish gray color,Silty clay,very stiff,medium to high plasticity.
15-17	Wash Boring						
17-18.5						UD-4	
18.5-20	6	9	11	20	D-4		Grayish brown color, Silty clay Very stiff,medium to high plasticity.
20-22	Wash Boring						
22-23.5							
23.5-25	3	5	6	11	D-5		Reddish brown color,silty clay,Stiff,has low to medium plasticity.
25-27	Wash Boring						
27-28.5							
28.5-30	3	7	7	14	D-6		Yellowish brown color,clayey silt,Stiff,has low plasticity .
30-32	Wash Boring						
32-33.5							
33.5-35	5	8	11	19	D-7		Yellowish brown in color,silty sand,Medium dense.Grain size is very fine to fine.
35-37	Wash Boring						
37-38.5							
38.5-40	7	15	16	31	D-8		Very fine to fine grained yellowish brown ,medium dense sand.
40-42	Wash Boring						
42-43.5							
43.5-45	10	10	18	28	D-9		Light yellowish brown in color,fine to medium grained,medium dense sand.
45-47	Wash Boring						
47-48.5							
48.5-50	9	13	16	29	D-10		Light yellowish brown in color,fine to medium grained,medium dense sand.
50-52	Wash Boring						
52-53.5							
53.5-55	8	13	18	31	D-11		Redish brown,Fine to medium grained ,medium dense sand.
55-57	Wash Boring						
57-58.5							
58.5-60	7	16	16	32	D-12		Yellowish brown in color,fine to medium grained,Medium dense sand.

4.6 Interpretation from Bore Log Data

4.6.1 Standard Penetration Test

In SPT test, a split spoon sampler of 2 inches (50 mm) outer diameter and 35 mm inner diameter is made to penetrate 18″ (6″+6″+6″) or 450 mm into the soil by dropping a 65 Kg hammer, falling freely from a height of 30 inches (750 mm). Number of hammer blows required for penetration of each inch’s length of the sampler is recorded. The number of blows for the last 12″ penetration of the total 18″ is known as the standard penetration values as specified by ASTM and is plotted as the SPT value at the particular depth (Smith, 1990).

The variation of SPT will respect to depth is shown in the Figure. The result suggests that the SPT increases with depth in the Madhupur clay soil.

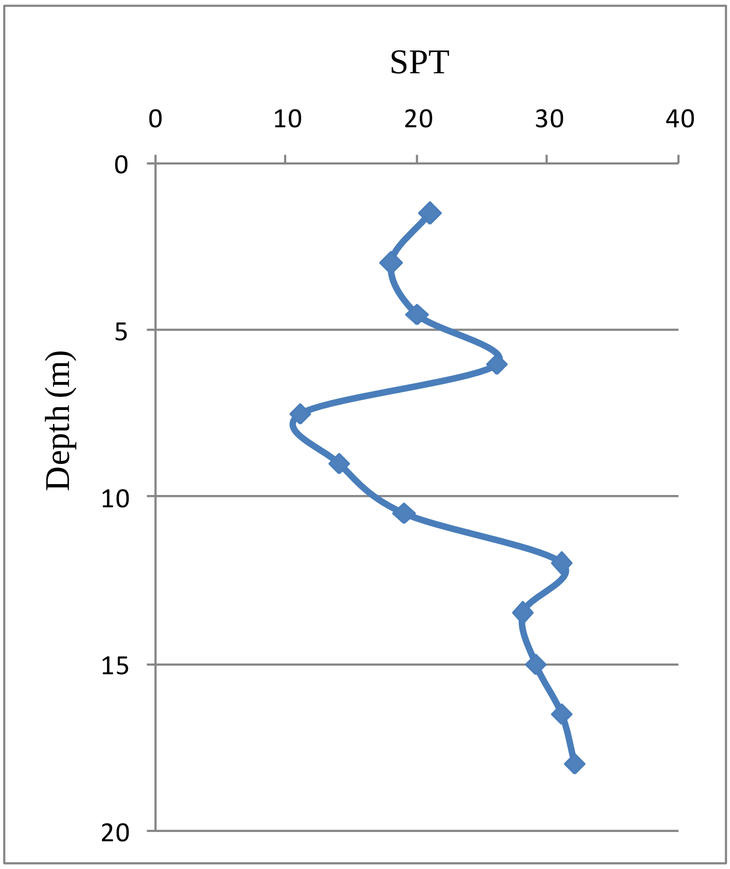

FIGURE 4–4 SPT WITH RESPECT TO DEPTH

4.7 Secondary Data Interpretation

4.7.1 Moisture Content

Moisture content plays an important role in understanding the behavior of fine-grained soils. Soil having the higher moisture content is organic soil (Mitchell, 1976). It is the moisture content which changes the soils from a liquid state to a plastic and solid states. Consolidation and compaction of soils in the field is also controlled by the quality of water present. Natural moisture content has been determined by oven dry method. The detail data for each test is mentioned in the appendix. It can be calculated by the following form

$W_n = (M2 - M3) / (M3 - M1) \times 100$

Where, M1 is the mass of container

M2, is the mass of container and wet soil

M3, is the mass of container and dry soil

TABLE 4.3 VARIATIONS OF THE NATURAL MOISTURE CONTENT VALUES WITH RESPECT TO DEPTH

Sample No	Depth(m)	Moisture Content (%)
3	3	21.09
5	6	22.37
9	12	24.79
11	15	28.9

The moisture content values of the studied soils lie between 21.09% and 28.9 % (given in table). It is found that the moisture content value increases with depth (Figure 4.5).

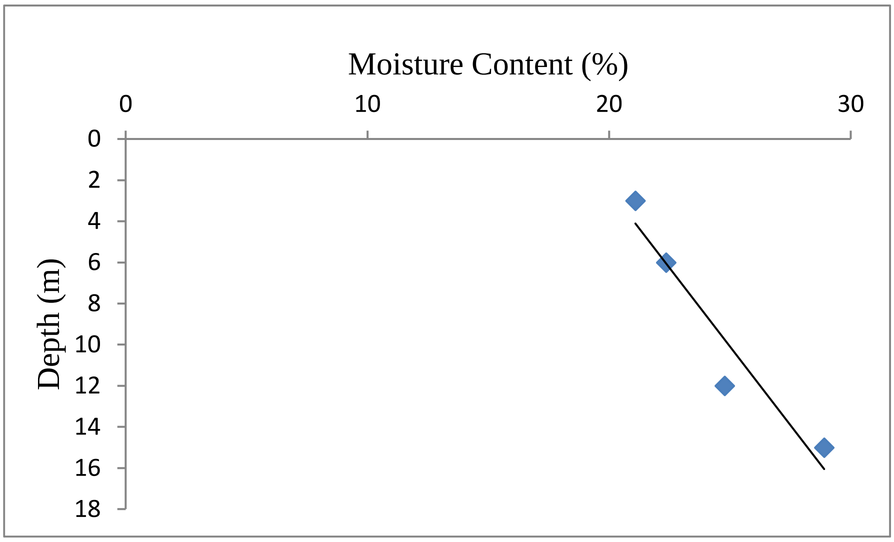

FIGURE 4–5 VARIATION OF MOISTURE CONTENT WITH RESPECT TO DEPTH FOR BH-01

WASA (1991) reported that the moisture content of the Madhupur clay ranges from 25 to 31%. Haque (1994) mentioned that the natural moisture content of the Madhupur clay formation lies between 18 to 28%. Islam (1997) mentioned that the natural moisture contents of the Madhupur clay formation ranges 17 to 29%. Nairuzzaman (2000) pointed out that the natural moisture contents of Madhupur clay ranges from 29.06 to 45.23%. Ahammed, et al. (2006) mentioned that the natural moisture content of the Madhupur clay formation lies between 15 to 36%. Hauqe et al., 2013 also mentioned that moisture content of the Madhupur clay ranges from 17.89 to 30.38%. According to Sayem et al., (2007), the natural moisture content values of the soils of Naraygang area range from 25.35 to 32.23% and the value decreases with increasing depth. The obtained result is very close to the values obtained by Nairuzzaman, (2000), Haque (1994) and Ahammed, et al., (2006).

4.7.2 Specific Gravity

The observed specific gravity values of all samples in the investigated area range from 2.58 to 2.73, as indicated in table. The particular gravity values varied depending on the depth and location.

In the figure a linear trend line showing specific gravity decreases with increasing depth that means specific gravity deceases with increasing particles size.

TABLE 4.4 VARIATION OF THE NATURAL SPECIFIC GRAVITY WITH RESPECT TO DEPTH

Sample No	Depth(m)	Specific Gravity
3	3	2.58
5	6	2.25
9	12	2.4
11	15	2.27

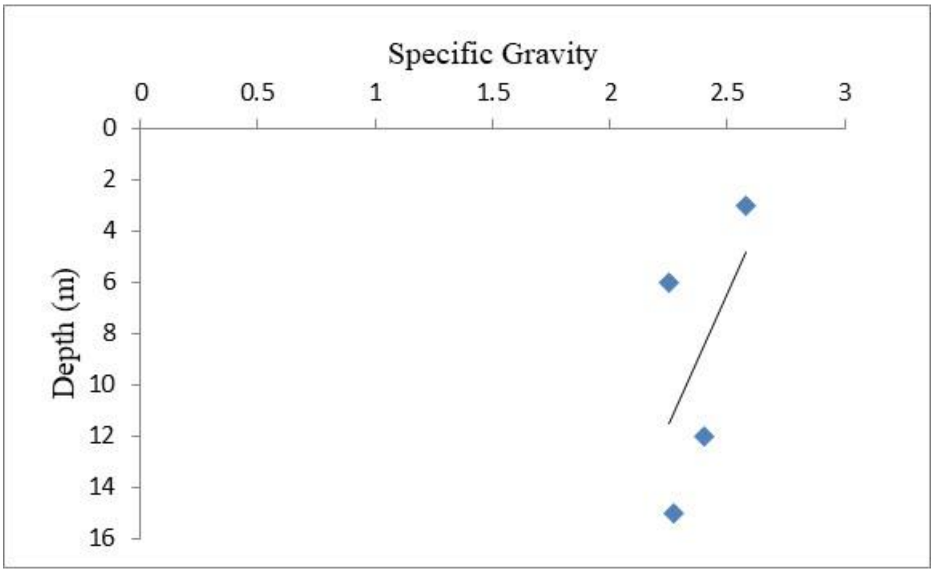

FIGURE 4–6 VARIATION OF SPECIFIC GRAVITY WITH RESPECT TO DEPTH FOR BH-01

Lambe (1956) mentioned that the specific gravity values of most soil lies between 2.65 and 2.85. Bowles (1984) pointed out that the specific gravity of soils generally ranges from 2.55 and 2.80 but most soils being between 2.60 to 2.75. Rao et al. (1988) analyzed some tropical soil and reported that the specific gravity values ranges from 2.50 to 2.79. Hossain & Chowdhury (1994) pointed out that the specific gravity from 2.40 to 2.68 for the Gault Clay of England, Haque (1994) mentioned that the specific gravity of Madhupur Clay soils of Dhaka City ranges from 2.37 to 2.63, Islam (1997) pointed out a specific gravity of 2.51 to 2.70 for Madhupur Clay of Gazipur area. Islam[2] (1997) mentioned that the specific gravity of the Madhupur Clay of North Western Dhaka City lies between 2.64 and 2.69. Nairuzzaman (2000) pointed out that the specific gravity values of Madhupur Clay Formation of greater Dhaka City ranges from 2.44 to 2.71, average is 2.59.

The obtained result is very close to the values obtained by Nairuzzaman (2000).

Chapter 5: Sedimentological Analysis

5.1 Particle Size Analysis

Grain size analysis of a soil sample involves determining the weight percentage of grains within various sizes ranges (Craig, 1987). Grim (1962) noted that the fineness or grain size of particles significantly influences a soil's limit values and permeability values. According to Young & Warkentin (1975), particle size distribution affects the strength and compressibility of soils, both of which are crucial factors in evaluating the bearing capacity and stability for engineering purposes.

The particles size distribution of all the samples of the study area is listed in table 5.1. It is observed that there is a range of variation in the size of particles. Sand percentages range from 13% to 71% and the value are increased with increasing depth whereas silt percentage ranges from 20% to 35% and the values are decreased with increasing depth and the clay percentage ranges from 7.9% to 53%.

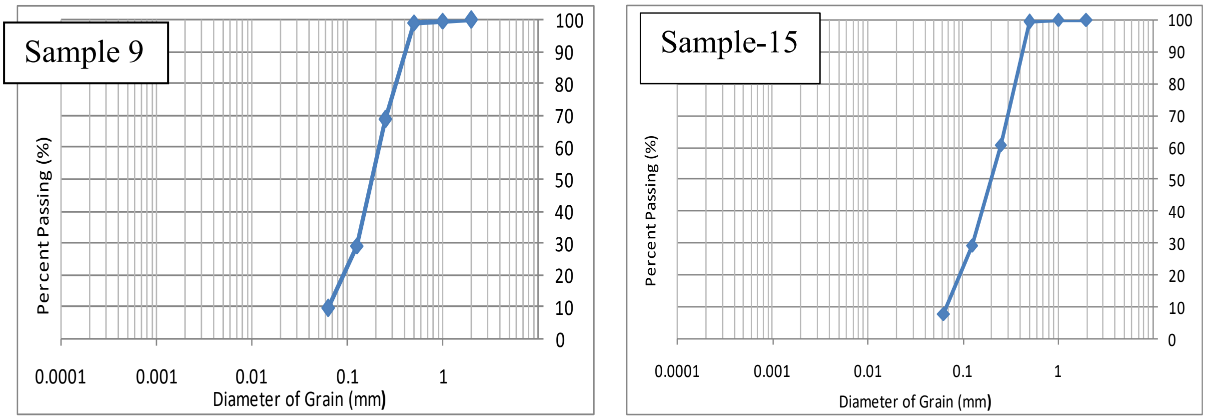

FIGURE 5–1 GRAIN SIZE ANALYSIS FOR SOME SELECTED SAMPLES OF BOREHOLE

TABLE 5.1 GRAIN SIZE DISTRIBUTION OF THE STUDY AREA

Depth(m)	Sand (%)	Silt (%)	Clay (%)
1	13	34	53
2	22	36	42
3	25	33	42
4	20	35	45
6	27	33	40
12	71	20	9
15	70.8	21.3	7.9

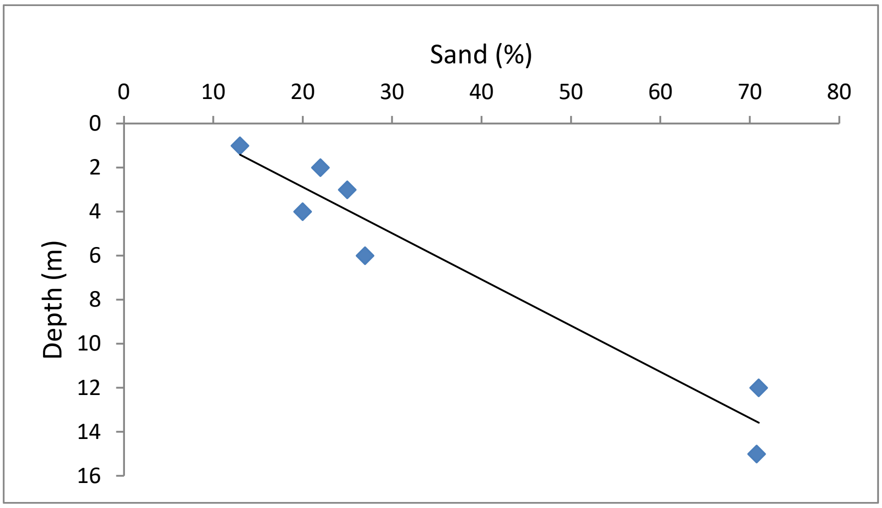

FIGURE 5–2 VARIATION OF SAND (%) WITH RESPECT TO DEPTH OF BOREHOLES

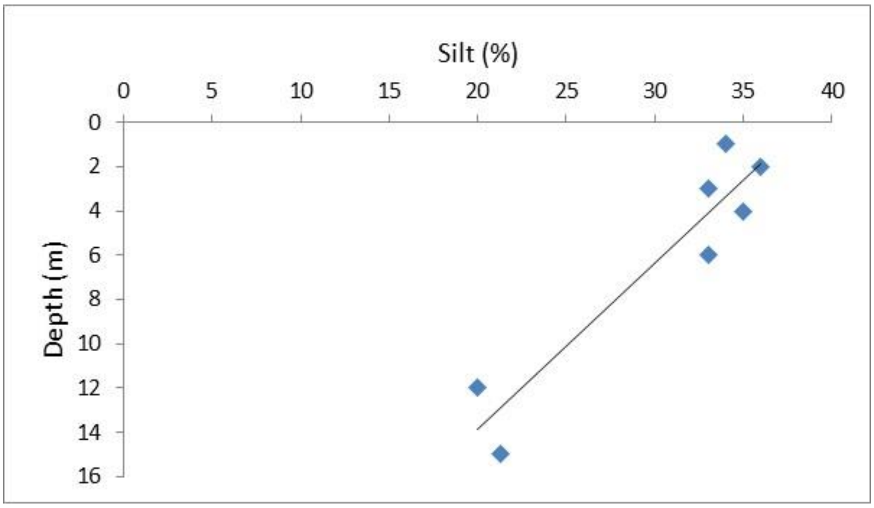

FIGURE 5–3 VARIATION OF SILT (%) WITH RESPECT TO DEPTH OF BOREHOLES

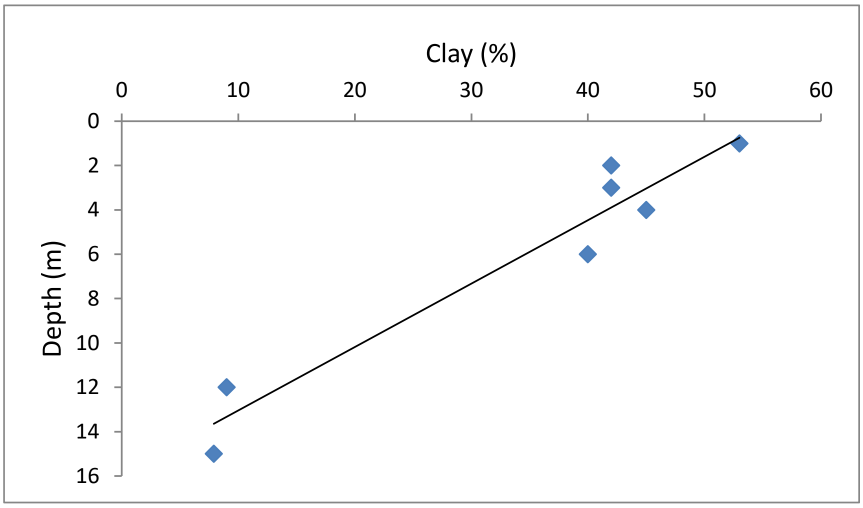

FIGURE 5–4 VARIATION OF CLAY (%) WITH RESPECT TO DEPTH OF BOREHOLES

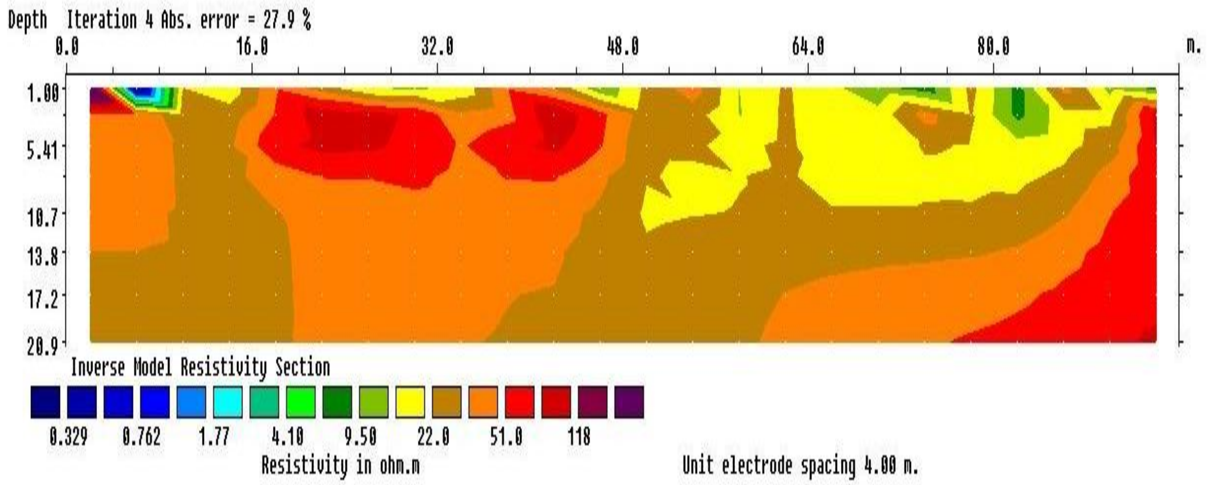

FIGURE 5–5 ELECTRICAL IMAGING OF THE STUDY AREA

From the graph, observed that sand increased with depth, silt and clay decreased with depth.

Rao et al. (1988) examined some tropical red soil and reported that the soil consists of sand, silt and clay percentages 14.0%, 19.5% and 66.5% respectively. Several researchers studied the grain size distribution of Madhupur Clay soils from different place. Haque (1994) studied the grain size pattern of Madhupur Clay of Dhaka and Savar and pointed out that. The Madhupur Clay consists of 17% to 19 % sand, 67% to 72% silt and 11% to 15% clay. Hossain (2001) mentioned that the tropical clay soils of Dhaka are silt dominated clay which consists of 8% to 19% sand, 56% to 63% silt and 22% to 33% clay size particles. According to Ahammed et al. (2006), the grain size of some pleistocene sediments from Savar and Tongi Thana areas of Dhaka and Gazipur districts ranges from 4% to 25% sand, 25% to 48% silt and 30% to 59% clay friction. Chowdhury et al (2009) pointed out that the Madhupur Clay samples of the Mirpur area contain 18% to 42% sand, 15% to 31% silt and 29% to 35% clay whereas the samples of Tangail are shown 7% to 35% sand, 37% to 58% silt and 24% to 35% clay.

Chapter 6: Correlation between Geophysical and Engineering Investigation

It is observed that the resistivity and drilling data correspond with each other. Based on the electrical resistivity values, borehole lithology and the oil SPT, a correlation is made for the studied ground surface which is given in the following table.

DRILLING DATA	RESISTIVITY IMAGING DATA	LITHOLOGY
`VERY STIFF, MEDIUM TO HIGH PLASTICITY (0-7.62M)	Low resistivity material (0-22.8) ohm-m (0-7m)	Silty Clay
LOW TO MEDIUM PLASTICITY (7.62-10.21M)	Moderate resistivity material (22.8-37.3)ohm-m (7-10m)	Clayey Silt
MEDIUM DENSE SOIL (10.21-11.27M)	Moderate to high (37.3-51.8) ohm-m	Silty Sand
MEDIUM DENSE TO DENSE (11.27-18.28M)	High to very high resistivity (51.8-118) ohm-m	Sand

The electrical resistivity of compacted residual soil decreases with increasing dry density and tends to constant at higher dry density. The electrical resistivity of soils decreases with increasing water content the same degree of soil water content, there is a noticeable decrease with increasing water content the same degree of soil resistivity with the increasing dry density or vice versa. But the effect of dry density on electrical resistivity is negligible for higher water contents (Kong et al., 2018). In most earth materials, porosity and chemical content of water filling the pore spaces are more important in governing resistivity than is conductivity of mineral grains of which the material itself is composed. (Dobrin et al., 1988). The resistivity of soils decreased with increase of temperature. Moisture content is identified as one of the major factors that cause change in soil resistivity. Electrical resistivity decreased with increasing moisture content in soils (Sayem and Kong, 2019). Water content and electrical resistivity of soil has been successfully correlated by various researchers (Kong, et al., 2018; Sayem and Kong, 2019; Sudha et al., 2009). The obtained correlation showed nonlinear relationship between soil moisture and resistivity.

The natural water content is high near the sacrificial zone and gradually increases with depth. The images of electric resistivity show that apparent resistivity increases with depth and measured geotechnical parameters of the study area correspond with Madhupur Clay formation.

The difference between resistivities and geotechnical parameters of the samples at borehole may be caused due to the variation of degree of saturation and grain size. It is found that the resistivity of the soil decreases with water content and tends to be constant at higher water content.

Chapter 7: Conclusion

7.1 Correlation between geophysical and engineering investigation

From the corrected SPT values graph it is seen that the density of the soil is initially stiff (N value 8-20 and up to 10m). After 10 m depth the SPT value increases and it ranges from (20-32) up to 18m depth. Based on the nature and visual composition, the study soil is broadly divided into cohesive and non-cohesive soils.

The N value indicates that the soil might be of medium dense to dense in nature. The density value obtained from 12m depth indicates that 12m depth is good for moderate load bearing structures and further depth could be good for high load bearing structures.

The resistivity value for the top most layers is about 5 ohm-m. 35 ohm-m for the middle layer and about 110 ohm-m for the lower high resistive layer. The subsequent deep layers of the non-cohesive soil and the subsequent layers of non-plastic sand- silt mix, silty fine sand and fine sand existing to the depth of the investigation generally have been observed in a medium dense to dense state. This layer extended from 9.14m to below the ground. The SPT value suggests that the deep foundation preferably pile may be provided at the study area.

7.2 Discussion

Electrical imaging survey has enabled an improved field scale assessment of relative variations in shallow relatively complex geology. Electrical Imaging technique has been quite successfully utilized to provide a cost-effective characterization of the near surface variations in geologic and soil strata of this case study (Loke, 2000).

The development of practical electrical tomography field systems (Griffiths et al. 1990) and effective processing and inversion software (Loke and Barker, 1995. 1996) makes electrical resistivity surveys especially powerful. The main advantages of electrical imaging may include investigating variations of resistivity both laterally and vertically (i.e.. mapping "true resistivity), increased resolution of the subsurface due to large amount of data, possibility of combining 2-D pseudo sections into a 3-D model (when electrode spreads are arranged in parallel) and fast computer- controlled data acquisition. The technique is particularly useful in shallow subsurface investigations, including hydrogeological, geotechnical and environmental studies.

The Geotechnical parameters and image sections showed that the upper portions of each the three layers are silty sand but the sand proportion is almost constant. From the images, the apparent resistivity variation is more or less from 2 ohm-m to 140 ohm-m. The resistivity value for the top most layer is about 5-ohm m. 35-ohm m for the middle layer and about 110-ohm m for the lower high resistive layer.

The natural water content is high near the sacrificial zone and gradually decreases at the depth of 1.25 m then gradually increases with depth. The images of electric resistivity and measured geotechnical parameters of the study area correspond with Madhupur Clay formation. The difference between resistivity's and geotechnical parameters of the samples at bore hole may be caused due to the variation of degree of saturation and grain size.

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