2-D Electrical Imaging In Delineating Shallow Subsurface Geology

Md. Mizanur Rahman Sarker, Rashed Abdullah, Mazeda Islam, Abu Sadat Md. Sayem, Hossain Md. Sayem

Abstract: An electrical image has been delineated at a site located in Jahangirnagar University, Savar, Dhaka, Bangladesh to deduce a shallow subsurface heterogeneity in terms of geophysical and geotechnical properties. The depth of investigation covers up to 12m includes the Madhupur Clay Formation of Pleistocene age and upper part of Dupi Tila Formation of Pliocene age. The Madhupur Clay Formation extends up to 7.5m with a wide range in resistivity values (5-45 Ωm) whereas the sand rich Dupi Tila Formation shows relatively higher resistivity (>190 Ωm). The resistivity values are significantly controlled by moisture content and grain size distribution.

Key Words: Electrical Imaging, Dupi Tila Formation, Madhupur Clay and Bangladesh.

1 Introduction

Two popular traditional DC electric techniques use to image the shallow subsurface are the vertical electric sounding (VES) and the electric profiling (EP) [9]. In practice, both methods commonly employ a 4-electrode configuration. The VES method is used for investigating the change in resistivity with depth, whereas EP in the horizontal direction. The limitation of the VES is the assumption of a 1-D Earth that does not occur in many practical situations. The limitation of the EP is that only one-depth level information can be obtained [9]. Also, as both methods can only acquire a limited number of data points, the model obtained from an inversion of the data has a rather low resolution for soils with a small resistivity contrast between them, the traditional DC electric techniques proved to be not very effective, especially for geotechnical projects.

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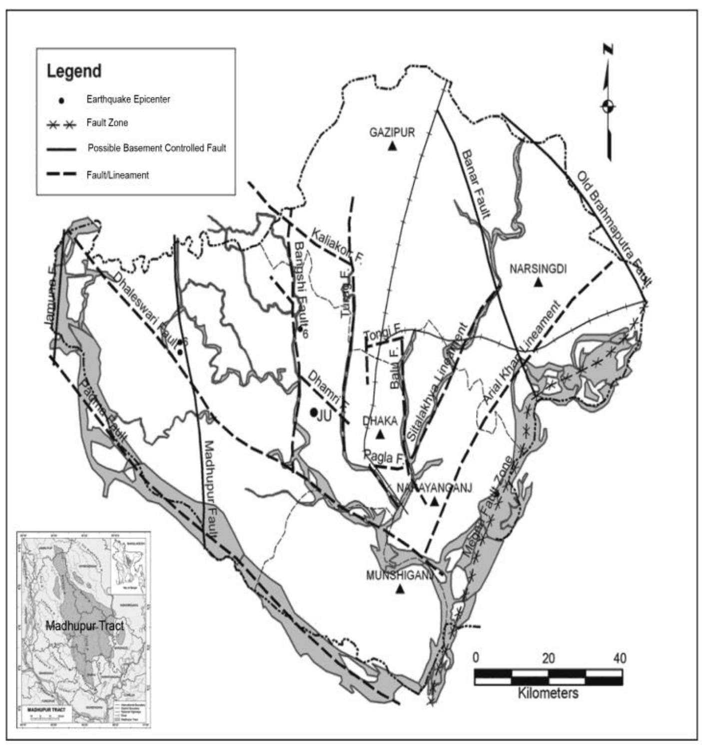
The development of practical electrical tomography field systems [13] and effective processing and inversion software [17], [18] makes electrical resistivity surveys especially powerful. The main advantages of electrical imaging may include investigating variations of resistivity both laterally and vertically (i.e., mapping "true" resistivity), increased resolution of the subsurface due to large amount of data, possibility of combining 2-D pseudosections 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 [5], [9], [11], [12], [15], [16] and [23]. The present work deals with a multi electrode electrical survey at a site located on the Jahangirnagar University campus, Savar, Dhaka, Bangladesh. It also involved analysis of some basic geotechnical properties (such as moisture content, specific gravity, grain size, etc) of samples collected from different depths of the bore holes located along the study line and a comparison between resistivity and other geotechnical properties.



2 GENERAL GEOLOGY OF THE STUDY AREA

The study site is located in the Madhupur Tract in Savar region, Dhaka, Bangladesh which is a north-easterly tilted fault-block bounded on the west by a series of NW-SE trending en-echelon faults including the Dhamrai, Maijail and Kaliakair (Fig. 1). The north and north eastern boundary is delineated by the NW-SE trending Banar Fault downthrown to the north-east [24]. On the south-east, the tract is marked by a NE-SW basement controlled fault zone [6] passing through the Meghna river at the north west, which is thought to be the north-easterly extension, through the Swatch of No Ground (SNG) of the continental margin flexures of the east coast of India during the initial splitting of the Gondwanaland. The Madhupur and the Barind Tracts represent a tectonically uplifted surface. The reason for the uplift of the red bed islands in the Bengal Basin was explained by Fergusson (1963) [8], Morgan and McIntire (1959) [22] and others. Fergusson (1963) [8] believes that the Madhupur region has been uplifted in very recent time and refers to the earthquake of 1762. He suggests 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) [8] considers numerous low lakes in the Sylhet Basin to be caused by the subsidence of compensatory to the elevation of the Madhupur Jungle. 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 and overlain by the Dupi Tila Formation and Alluvium Formation respectively. The so-called Madhupur Clay Formation has recently been named as the Madhupur Clay Residuum by Alam et al. (1990) [2] and as the Madhupur Clay and Sand Formation by Monsur (1990) [19]. The Alluvium Formation was named as the Basabo Silty-Clay Formation by Monsur (1990) [19]. However, an attempt has been made to establish a generalized stratigraphic succession according to Alam (1988) [1], Alam et al. (1990) [2], and Monsur (1990) [19]. The lithology as well as the origin and age of the Madhupur Clay units are described in Table 1.

3 OUTLINES OF FIELD OPERATIONS

The resistivity imaging data were collected at a site located in front of the Geological Sciences building in the Jahangirnagar University Campus, Savar, Dhaka, Bangladesh during the month of April, 2008 (Fig. 2). The principles of electrical tomography have been described by many researchers, e.g., by Barker (1996) [5] and Loke (2000) [16]. For the multi electrode surveys described here, an IGIS DDR3 DC Resistivity Meter has been used. The voltage used in this study ranges from 50 to 200 mv. The 2-D profiles were acquired using Wenner arrangement with an array of 25 electrodes spaced 4m apart indicating a maximum depth of investigation of 12m. Measurements made using this arrangement are less affected by near-surface resistivity variations compared with dipole-dipole arrangement, which distorts the signal. Since the subsurface structure is not too complex, the unprocessed images acquired using this array are relatively simple in form and closely related spatially to the bodies giving rise to them. This array also has better vertical resolution in comparison to other arrays. Figure 3 illustrates the field procedure of the manual electrical imaging of the line measured in this study. The roll-on mode has been employed to build up the data for the electrical image. All the electrodes were addressable as either C_1, C_2, P_1, or P_2. This mode takes measurements for all levels (n=1-8) for electrode 1 before continuing in the same ways for electrode 2 and so on and is useful in manual electrical imaging. Whereas, the other mode, traverse mode, allows the completion of all measurements with level n=1 before commencing with the level n=2 measurements and so on.

Table 1

STRATIGRAPHIC SUCCESSION OF THE MADHUPUR TRACT IN DHAKA REGION

Age	Formation	Lithology	Thickness (m)
Holocene	Alluvium	**Low Land Alluvium** River Bed Deposits Grey sand and silty sand, medium to fine grained and unconsolidated	variable
		Local Unconformity	
		Natural Levee and Interstream Deposits Fine sand, sandy silt, silt and clayey silt, grey, massive and friable.	0-25
		Back Swamp and Depression Deposits Clay and silty clay, grey, bluish grey to dark grey to black, peaty and sticky.	
		High Land Alluvium Mainly silt and clay, occasionally sand, occurs mainly as infilling of incised channels on the high land of the Madhupur Tract above the present flood level.	
		Local Unconformity	
Pleistocene	Madhupur Clay	**Red Clay** Highly weathered, brownish red to brick red, massive, sticky, interbedded with fine sand and silt and contains ferruginous concretions and ferruginous and calcareous nodules, plant roots and manganese spots.	6-25
		Mottled Clay Earthy grey with mottlings of red, brown, yellow, and orange colours; massive, contains micas and calcareous nodules. It is oolitic and sticky, and shows the increasing amount of sand to the base.	
		Regional Unconformity	
Pliocene	Dupi Tila	Yellow to yellowish grey, massive, cross bedded, moderately consolidated, fine to medium grained as well as coarse grained sands with intraformational clay beds and contains large silicified wood fragments and occasional gravels at depth.	120
		Base not seen	

To make a measurement of ground resistivity, current, I, is injected into the ground through two electrodes, C_1 and C_2, and voltage, V, is measured across a second pair of electrodes, P_1 and P_2. From a knowledge of the resistance, R (=V/I), and the inter-electrode distances, apparent ground resistivity can be calculated [5]. Profiles of resistance measurements were made by increasing the electrode spacing from a to multiples n of a. As the spacing is increased, the measurements sample increased greater depths as well as 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, usually at a depth of a/2 [4], [7]. This "median depth of investigation" as it is called is found from experiment [4], [7] to be the optimum plotting depth in the case of homogeneous ground. This plotting depth scales the vertical variations in measured apparent resistivity to approximate the actual resistivity changes with depth. The data can then be contoured to produce an apparent resistivity depth section or pseudosection considered as a smooth image from which useful information can be obtained by visual inspection.

4 DATA FORMAT

The inversion routine is based on the smoothness constrained least-squares method. A new implementation of the least-squares method based on a quasi-Newton optimization technique can be used [16]. The technique has proved to be markedly affective in eliminating electrode geometry effects so that the final processed image provides a good representation of the subsurface geology. The inversion approaches are explained in detail in the RES2DINV manual and the papers [17], [18]. The location of the electrodes and apparent resistivity values must be entered into a text file which can be read by the RES2DINV program. As an example, part of an example data file IMAGING.DAT, is shown below with some comments:

Data in file Comments

IMAGING ; Name of survey line (Imaging)

4.0 ; 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 midpoint).

0 ; Flag for I.P. data (enter 0 for resistivity data only)
3.00 2.0 9.0; x-location, electrode spacing, ap. resistivity value
5.00 2.0 8.2 ; The same information for other data points

7.00 2.0 10.0

9.00 2.0 9.0

11.0 2.0 11.4

13.0 2.0 6.2

15.0 2.0 6.4

17.0 2.0 6.3
....
....
0
0

As an exercise, read in the IMAGING.DAT file using the “File” option on the main menu bar of the RES2DINV program. Next, we select the “Inversion” option, and then the “Least squares inversion” suboption. The program will then automatically try to determine the resistivity values of the blocks in the subsurface model [16]. The results of electric imaging at the study site are presented in Figure 4. The image line is 96 m long and oriented from N to S.

5 RESULTS AND DISCUSSION

The pseudosection of measured apparent resistivity (Fig. 4a) reveals that the resistivity changes both horizontally and vertically in a complicated way, although a general increase in resistivity with depth is apparent. A very irregular topography between the top heterogeneous ground and the underlying higher resistivity material is evident on this pseudosection. The processed image (Fig. 4c) provides a model of true bulk resistivity with a true depth scale from which the computed pseudosection of Figure 4b is obtained.

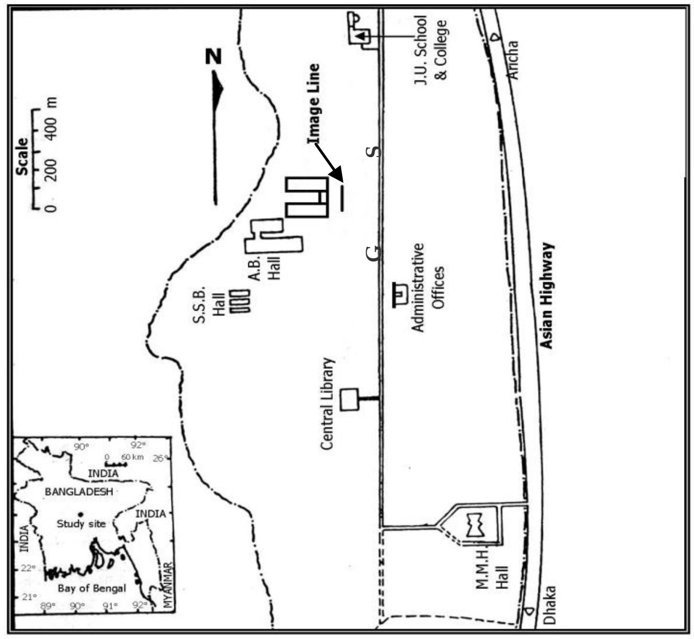


Fig. 2. Location of the electrical image line at the Jahangirnagar University

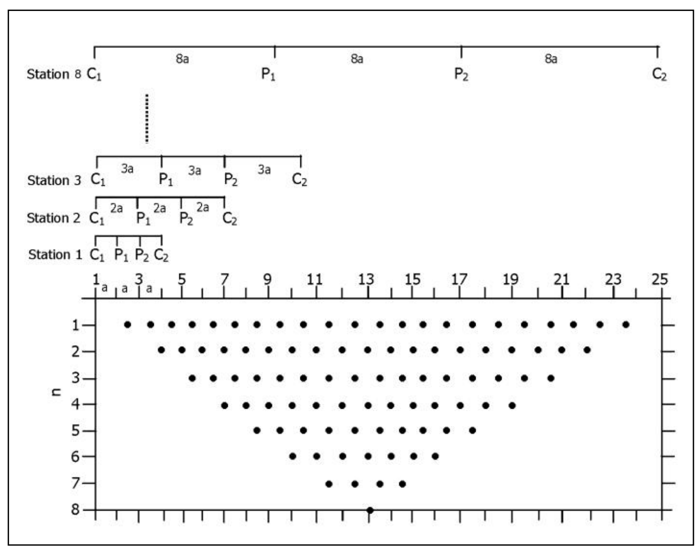


Fig. 3. The measurement sequence used for preparing a pseudosection. Unit electrode spacing a=4m. C and P is current and potential electrode respectively.

As seen on the observed pseudosection, significant heterogeneity is also evident on the true image (Fig. 4c). This may be related with variation in lithology and in moisture content. In order to investigate the subsurface model, the image line was calibrated by borehole data of BH-01. The borehole is about 15m depth and samples are collected at 1m intervals.

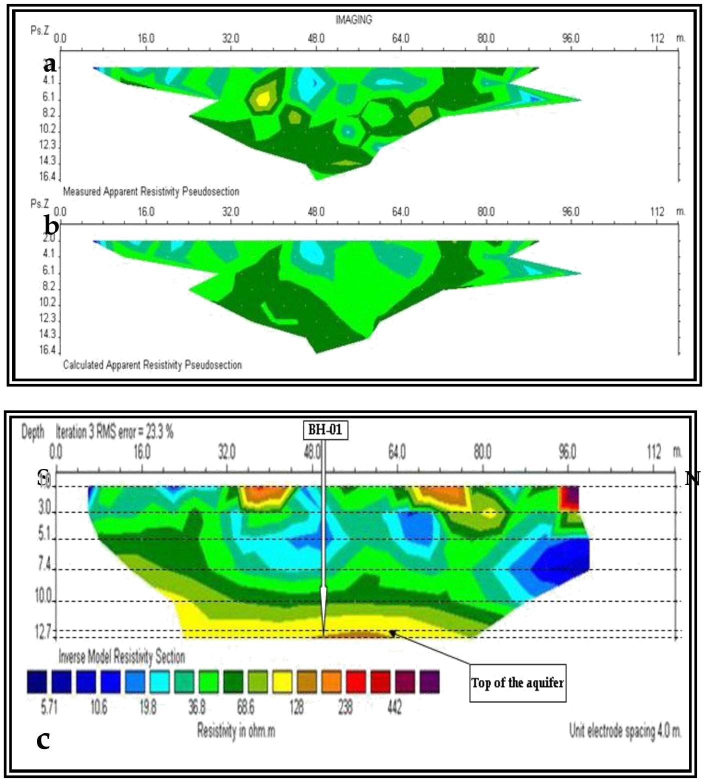


Fig. 4. The result of electrical imaging at the study area (**a**) Psedosection of measured apparent resistivity, (**b**) Psedosection of calculated apparent resistivity and (**c**) the inverted model.

From the pseudosection of measured, calculated and inverted model, it is clear that the apparent resistivity variation is about 5Ωm to 128Ωm. From the Figure 4c, it is evident that up to 8m depth the soil of the study area is not homogeneous and the resistivity values at that depth are irregularly distributed because of recent landfill soil. Relatively higher resistivity values vary from 128Ωm to 300Ωm at two locations (40m and 72m) from the starting point. This indicates that the soil of the two locations is more compacted and has less moisture content than the surrounding area. It can also be mentioned that soil of this two locations are older than the adjacent area. At the end of the imaging line (96m) from the starting point, it is found that there is pocket of higher resistivity values (up to 442Ωm) because of the presence of a dried tree trunk in that place and at the same location in greater depths (5 to 10m), the resistivity values are very low. This is because the area is composed of very loose soil with high moisture content. A north sloping surface with high resistivity value (>200Ωm) has been marked which is probable delineating the boundary between Madhupur Clay and Dupi Tila Aquifer.

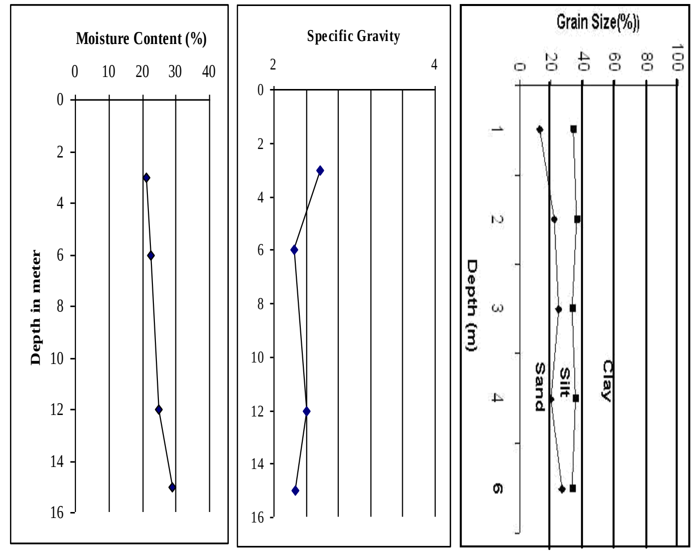


Fig. 5. Basic geotechnical properties of soil sample collected from the BH-01.

The basic geotechnical properties of the collected samples are measured using Standard methods e.g. ASTM Standards [3]. The grain size distributions and the other properties like moisture content (W_n) and specific gravity (γ) are measured in the Engineering Geology Laboratory, Department of Geological Sciences, Jahangirnagar University. Natural moisture content can be calculated by the following formula:

$$W_n = \frac{M_1 - M_3}{M_3 - M_1} \times 100$$

Where, M_1 = Mass of container, M_2 = Mass of container and wet soil, and M_3 = Mass of container and dry soil. The specific gravity of all samples was determined by the density bottle (Pycnometer) using following equation:

$$\gamma = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)}$$

Where, M_1 = Mass of density bottle, M_2 = Mass of density bottle and dry soil, M_3 = Mass of density bottle, soil and water, and M_4 = Mass of density bottle when full of water. The geotechnical properties of the collected samples are measured and generalized soil profiles of BH-01 is shown in Figures 5. The moisture content gradually increases up to the depth 15m. The water surface of nearby pond was at some depth below the surface during the period of investigation. So, probably below this depth, the subsurface may corresponds with the high saturated zone. For this reason the resistivity of this area is increasing with depth. From 3m to 8m of BH-1, this zone shows increased resistivity value than the overlying layer. It may be the top of the fresh Madhupur Clay. From the grain size distribution, it is evident that the clay percentages are increasing with depth of 5m. But below 5m sand content increases gradually. The visual inspection of the samples, some iron nodules were found. From geotechnical parameters, bore log and image section at BH-01, it is clearly showed that the overall grain size analysis suggests a gradual increase in clay percentages with depth up to 7.5m. But below this depth (7.5m to 15m), it is evident that the sand percentage is gradually increasing. For this reason the resistivity values are gradually increasing with depth as well as the grain size and moisture content is also increasing. At 15m depth a sand layer has been encountered which shows the resistivity value of 220Ωm. the resistivity value for this horizon from the present study is close to the resistivity value of Dupi Tila (average 190Ωm) [20]. From this observation it can be concluded that the top of the sandstone layer may be the top of the Dupi Tila Formation, which serves as an excellent aquifer for this region. The specific gravity (γ) values of all the samples (BH-01) are in the range of 2.25 - 2.58. The average specific gravity of the study area is 2.55 which are well agreement with that of Haque (1994) [14] and Kabir et al (2011) [15]. This small variations of the specific gravity values at different locations and at different depths may be due to several reasons: the variations in types of clay minerals, presence of other minerals in the specimen, the variation of size range, the technique of pre-test preparation and testing procedure, and due to the degree of desiccation or drying [10]. The moisture content (Wn) values of all the samples have been determined by oven-drying method. The moisture content values lie from 21.09% to 28.90%. WASA (1991) [25] reported that the Madhupur Clay contains natural moisture content from 25% to 31%. Haque (1994) [14] mentioned that the natural moisture content at Jahangirnagar University campus lies from 18% to 28%. The obtained values of the moisture contents are closer to that of WASA (1991) [25] and Haque (1994) [14]. This small variation of moisture contents may cause due to the seasonal variation of groundwater table, difference in geomorphic conditions of the study site and due to climate effect in the area.

CONCLUSIONS

Electrical imaging tool has quite successfully been utilized to provide a cost effective characterization of the near surface variations in geologic and soil strata in the Madhupur Tract, Bangladesh. The technique appears to be helpful in differentiating silty clay and sandy clay soils in the study area. The silty clay soil has a resistivity of 5 to 20Ωm, and the sandy clay soil has a resistivity of 15 to 45Ωm. The depth of investigation using electrical imaging in the Madhupur Clay Formation was about 12m. The images of electric resistivity and measured geotechnical parameters of the study area correspond with Clay Formation up to 7.5m depth. Below this depth sand percentage is gradually increased with depth and at the end of the borehole at 15m depth, medium to fine sand have been found whose resistivity value (220Ωm) is near to the resistivity value of Dupi Tila sandstone (190Ωm). It indicates that the end of the borehole may be the top of the Dupi Tila Formation, which serves as an excellent aquifer of this region. However, more data need to be involved in substantiating such a correlation.

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