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Ground condition evaluation based on electrical resistivity survey and basic geotechnical properties of Jahangirnagar University Model Town area, Savar, Dhaka, Bangladesh

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Abstract

The electrical resistivity methods are widely used for identifying the complex subsurface lithology and delineating the characteristics of the aquifer. A field data acquisition system has been performed to enable an electrical image to be produced for a site located at Jahangirnagar Model town adjacent to Islamnagar Bazar area, Savar, Dhaka, Bangladesh. A 100 m electrical sounding image line have been constructed following the Wenner array with 4 m electrode spacing revealed the shallow subsurface lithological variations. A borehole location was selected along the image line and subsoil samples were collected every 1.52 m (5 ft) intervals using a light cable percussion drilling technique. Some geotechnical parameters such as moisture content, specific gravity, grain size distribution, liquid limit, plastic limit, plasticity index were measured in the laboratory. The obtained basic engineering properties are compared with the electrical resistivity of the soil in order to evaluate the shallow subsurface geology of the study area. It is found that the electrical resistivity significantly influenced by the variation of basic soil properties. The geotechnical results also confirmed the significance of the recorded image constructed by the measured electrical resistivity values.

Keywords: Electrical resistivity, Wenner array, electrical image, geotechnical parameters, Madhupur Clay

Introduction

Electrical resistivity 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 hydrogeologic and mineral resource boundaries (RECCELLI-SNYDER 2002).

Among different ground surface measurement techniques, electrical resistivity survey is one of the potential methods for determining the subsurface resistivity distribution. Various geological parameters such as the mineral and fluid content,

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porosity and degree of water saturation in the rock are associated with the ground resistivity. Electrical resistivity surveys have been applied in case of hydrogeological, mining and geotechnical investigations for many decades. More recently, it has been used for environmental surveys also (GRIFFITHS & BARKER 1993, 1994; LOKE 2000). Geoelectrical resistivity survey has long been used for groundwater survey and the method is found to be very successful (SERRES 1969; BUGG & LLOYED 1976; KELLER & FRISCHNECHT 1966; GRIFFITHS *et al.* 1990; ANDREWS *et al.* 1995; WOOBAIDULLAH *et al.* 1996; KABIR *et al.* 2011; IMAM *et al.* 2013; DUANI *et al.* 2018; LECH *et al.* 2020; ISLAM *et al.* 2020; GONÇALVES *et al.* 2021).

The study area is densely populated and very rapidly urbanized. Thousands of people are using ground water for drinking and other purposes. Meanwhile, rapid urbanization requires the construction of roads and buildings. So, the information of subsurface ground condition is urgently needed.

Previous hydrogeological investigations through exploratory drillings and electric loggings provide scattered information about the subsurface in the study area. As the exploratory drillings are very costly, an alternative cheap surface geoelectric resistivity method is applied to know the subsurface information. The interpretation is ambiguous by using the resistivity measurements alone. On the other hand, geotechnical investigation is a challenging task due to natural heterogeneity and the limited data (HASAN *et al.* 2021). Therefore, the borehole data were compared with the resistivity interpretation.

However, the delineation of the aquifer condition and basic geotechnical parameters will help to locate the suitable fresh water source i.e. the aquifers and their geometry and to evaluate the water quality within or nearby areas for ground water development for water supply system and to know the soil quality for the construction purposes that will be beneficial for the local people of the study area.

Therefore, the present study deals with a 2-D electrical imaging technique. Some basic engineering and geotechnical properties including moisture content, specific gravity, grain size distribution and Atterberg limits of collected samples from different depths of the bore holes were measured and compared with the resistivity values in order to evaluate the shallow subsurface geology of the study area.

Materials and Methods

Study area

The study area is located in Jahangirnagar Model Town beside Jahangirnagar University Campus, Savar, Dhaka, Bangladesh (Fig. 1). The entire irregular western margin of the Madhupur tract is formed by a series of six en echelon faults. Most of the previous authors presumed that the Madhupur and the Barind Tracts represent tectonically uplifted surfaces. The reason for the uplift of the red bed islands in the Bengal Basin was explained by MORGAN & MCINTIRE (1959) and FERGUSSON (1963). Stratigraphy of the study area is revealed from the rocks exposed as well as the rocks encountered in the wells bored. The Madhupur Clay Formation is the oldest exposed rock of the Madhupur tract area is underlain by Dupi Tila Formation and overlain by Alluvium. However, a generalized stratigraphic succession has been made by ALAM (1988), ALAM *et al.* (1990) and MONSUR (1990).

Fig. 1. Map showing the location of the study area including electrical imaging line.

2-D electrical imaging procedures

In the present study, 2-D electrical imaging is used to obtain a good 2-D picture of the subsurface. For this an IGIS DDR3 DC Resistivity Meter (manufactured by Integrated Geo Instruments & Services [P] Ltd., India) has been used. The voltage ranges from 50 to 200 mv. The system employed consists of 25 electrodes being deployed at a time with the unit electrode spacing being 4 m. 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, P1, or P2. The data were collected during March 2015.

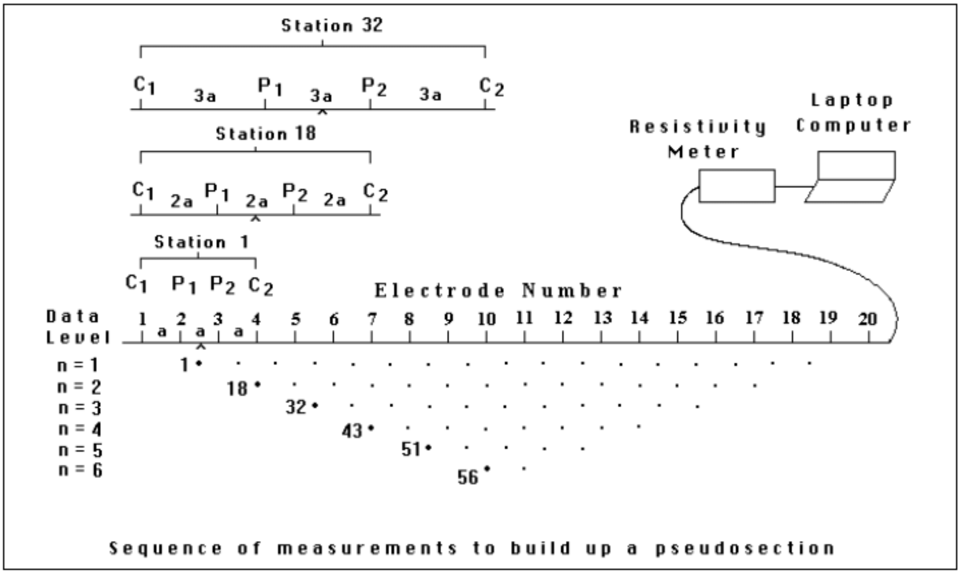

Fig. 2. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection (LOKE 2000).

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 (BARKER 1996; HOSSAIN 2000).

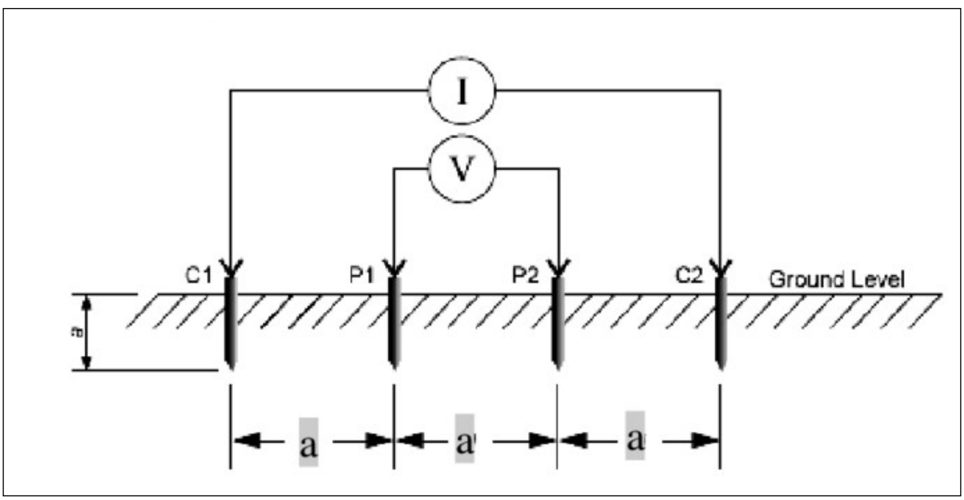

Fig. 3. Wenner Configuration (ZUHAIRI 2016).

Mainly, Wenner electrode configuration (Fig. 3) is executed where the electrodes are expanded about a fixed center, increasing the spacing 'a' in steps. The first step is to make all the possible measurements with the Wenner array with electrode spacing of "1a". After completing the sequence of measurements with "1a" spacing, the next sequence of measurements with "2a" electrode spacing is made. The process is repeated, increasing the electrode spacing each time in multiples N of a. As the spacing is increased, the measurements record 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 (EDWARDS 1977; BARKER 1989).

Fig. 2 shows the arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection. For this, 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 inversion approaches are explained in detail in the Res2Dinv manual and in the papers (LOKE & BARKER 1995, 1996). 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 method quickly produces an image that geometrically and quantitatively approaches a true resistivity cross-section of the subsurface (HOSSAIN 2000) and provides valuable subsurface information.

Methods for Geotechnical Properties Analyses

Based on electrical resistivity image, a borehole location is selected (Fig. 4) for collecting soil samples in order to know the subsurface geo-engineering properties as well as to compare with the resistivity data. A light cable percussion drilling technique was used to collect both disturbed and undisturbed samples at every 5 ft (1.52 m) interval. The basic geotechnical properties including moisture content (w%), liquid limit (L_L), plastic limit (P_L), plasticity index (I_P), specific gravity (Gs) and grain size distribution of the collected samples were measured in the Engineering Geology Laboratory, Department of Geological Sciences, Jahangirnagar University using Standard methods, e.g. American Society for Testing Materials and British Standards (ASTM 1974, BS 1377 & 1975).

Results And Discussion

The core objective of this work is to portray the shallow subsurface geological condition of the investigated area based on the correlation between electrical resistivity data and the basic geotechnical properties. For this, the basic geotechnical properties of the collected samples at different depths along the resistivity line were measured in the laboratory. Finally, the geotechnical properties were compared with resistivity data and evaluated the geology of the study area.

Electrical resistivity interpretation

Resistivity data were collected for one electrical image line which was 100 m long and oriented south-north. The resistivity data were analyzed using the program RES2DINV. The results of electric imaging at study site are presented in Fig. 4.

From the results of electrical image (Fig. 4a), it is evident that the pseudo-section of measured apparent resistivity changes both laterally and vertically in a complicated way and a general increase in resistivity with depth. It is evident that there is a wide range of irregular topography between the upper heterogeneous subsurface layers and the underlying higher resistivity materials. The pseudo-section (Fig. 4b) of calculated apparent resistivity also shows stratification and the layers are clearer than measured apparent resistivity section.

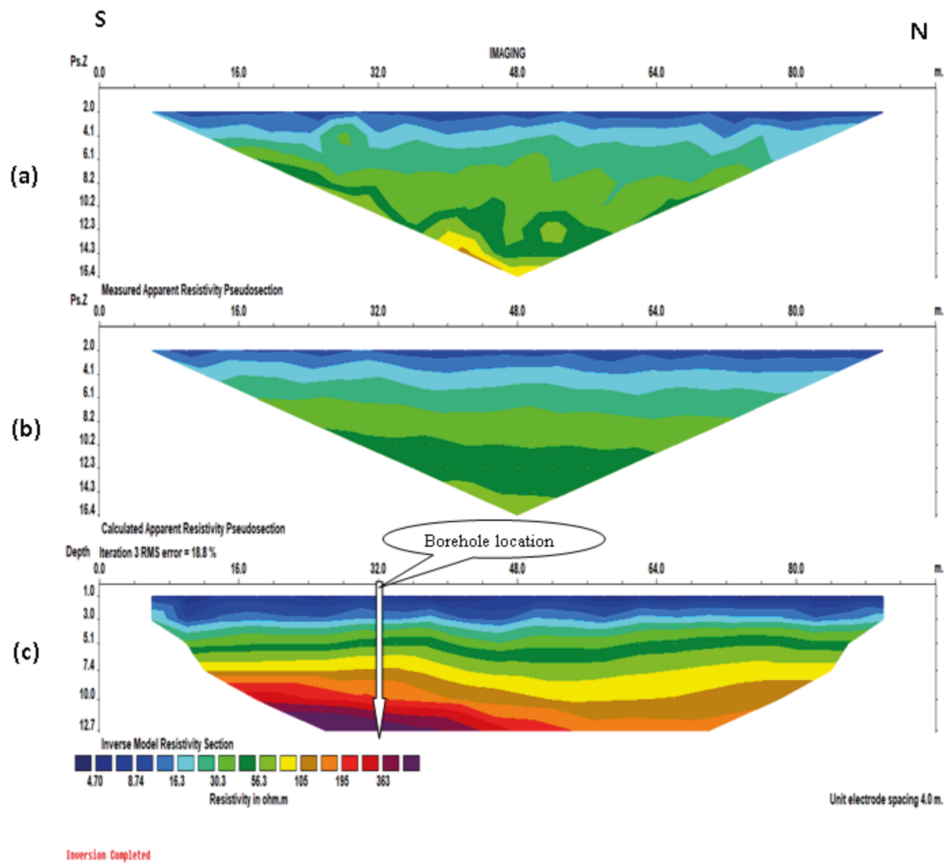

Fig. 4. The results of electrical imaging at the study site (a) Pseudosection of measured apparent resistivity, (b) Pseudosection of calculated apparent resistivity, (c) Inverted model.

From the pseudo-section of inverted model (Fig. 4c), it is clear that the apparent resistivity variation is more or less from 2 Ωm to more than 445 Ωm. The lower resistivity of top and middle layers than bottom layer indicates silty and clayey layers where as higher resistivity of bottom layer indicates sandy layer. Resistivity variation is prominent in southern zones between 12 m and 54 m electrode spacing and at a depth below 12 m where sand size particles are increasing indicating aquifer with fresh water pocket.

Interpretation of geotechnical properties

Standard Penetration Test (SPT)

The Standard Penetration Test (SPT) readily determine the consistency/relative density of an investigated site. The SPT value is represented by N and the SPT values with respective interval of depth for the borehole are shown in Fig. 5. It can be found that the SPT value increases with increasing depth up to 13.5 m (44 ft) and below this depth it decreases.

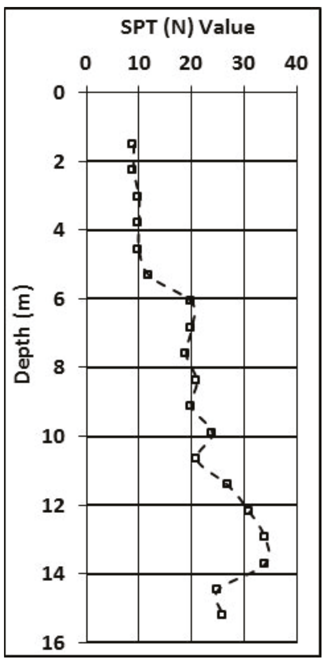

Fig. 5. Variation of SPT values with respect to depth.

Based on the nature and visual composition, the study soil is broadly divided into cohesive and non-cohesive soils. The density of the soil is initially very loose but sticky in nature (up to 1.5 m) which might be fill materials. The cohesive soil extending from 1.5-8.0 m whereas the subsequent layers below 8.0 m are non-cohesive.

The SPT values (N=10-20) suggest that the soils of this layer has stiff to very stiff consistency according to TERZAGHI & PECK (1967). The SPT value (N=20-34) indicates that this soil might be of medium dense to dense in nature according to BS 5930 (1981). Therefore, the overall SPT values suggest that the analyzed soil might have very good strength for light to moderate load bearing structures and 12 m depth would be the suitable foundation depth. For heavy load bearing structures, a further detailed study is required.

Basic engineering properties

A summary of the physical properties such as moisture content, specific gravity, grain size distribution and Atterberg limits of all the samples of the tested soils are given in Table 1. The measured geotechnical properties and its variation with depth of the collected samples are shown in Fig. 6. The natural moisture content values of the soil lie between 20.96% and 25.88% and show a very small variation with depths. The specific gravity falls within a range of 2.48 to 2.55. The specific gravity of soils in their natural state depends on mineral composition, the particle size distribution, texture and void ratio, and their moisture contents. The small variation of specific gravity reveals that the soils have almost similar mineral composition.

Table 1. Basic physical properties of tested soils.

Depth (m)	Moisture Content W (%)	G_S	Atterberg Limit (%)			Grain size distribution		
			L_L	P_L	I_P	Sand %	Silt %	Clay %
1.22	21.26	2.55	47.00	19.29	27.71	10.03	55.15	34.82
2.75	20.96	2.48	53.50	20.80	32.70	9.85	56.81	33.34
4.27	25.88	2.52	56.01	26.61	29.40	11.41	57.44	31.15
5.18	23.67	2.53	61.00	22.50	38.50	13.55	58.23	28.22

From the grain size distribution results as well as visual observations, it can be seen that the percentage of finer particles (silt & clay) is very high up to a depth of 6 m, after that the sand percentages increase gradually. The percentage of clay ranges from 28.22 to 34.82%, silt from 55.15 to 58.23% and sand from 8.85 to 13.55%. It is found that silt & clay constitute more than 85% up to 6 m depth and the soil of cohesive layer can be named as clayey silt. The percentage of silt does not show a large variation with respect to depth. The obtained grain size analysis is very much close to the value determined by ISLAM (1997) and HOSSAIN (2001).

The analyzed soils show higher liquid-plastic limit values; the liquid limit values range from 47.0% to 61.0% and plastic limit values range from 19.29% to 26.61%. The plasticity index values lie between 27.71% and 38.5%. The variations among the physical properties with respect to depth may be explained by the variations of soil composition and degree of weathering. All the basic properties are close to the recommended values of the Madhupur Clay Formation quoted by different authors (ISLAM 1997; NAIRUZZAMAN 2000; HAQUE *et al.* 2013, 2014). The obtained values are also closer to the values recommended by HOUGH (1957), GIDIGASU (1976), GRIM (1962), GILLOT (1987) and BELL (2000) for kaolinite and illite. The obtained limit values suggest that the studied soil is intermediate to high plasticity clay and has low to high potential soil expansion in nature according to SNETHEN (1979) and HEAD (1992), respectively.

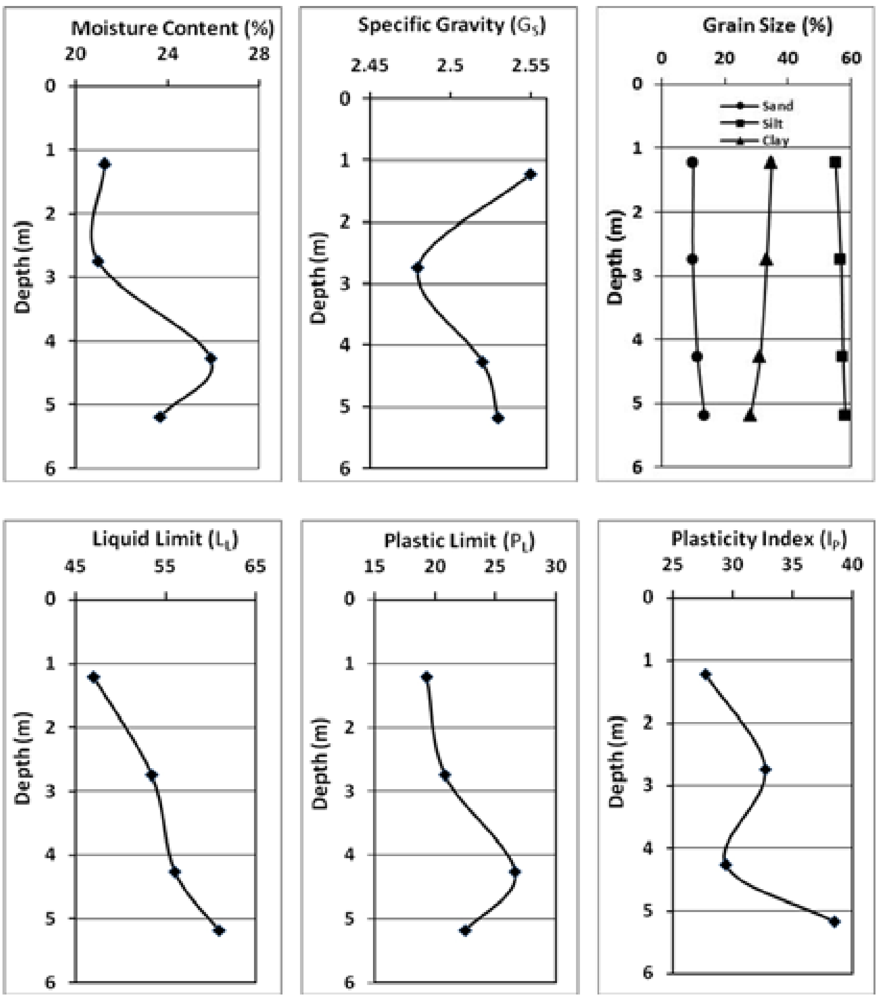

Fig. 6. Basic geotechnical properties of the collected soil samples from the borehole.

Engineering classification of the studied soil samples

A soil classification places a soil in a limited number of groups on the basis of grading and plasticity of a disturbed sample of cohesive layer (BS 5930, 1981). The obtained results of the liquid limit and plasticity index of the studied four samples of the top cohesive layers are plotted in the Standard Plasticity Chart (Fig. 7). All the

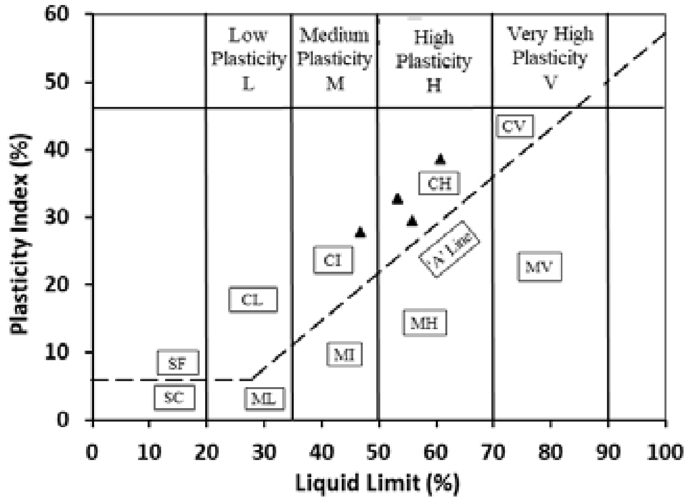

Fig. 7. Plasticity Chart of the studied soil samples [Modified after BS 5930 (1981)].

samples lie above the "A" line and generally occupy the field of clay soils which represents intermediate to high plasticity clay (CI to CH). Therefore, considering the Atterberg consistency limit values as well as their position on the plasticity chart, the top layer of the studied soil (up to 8.0 m) are cohesive and can be classified as intermediate to high plasticity inorganic clay whereas the soils below 8.0 m are non-cohesive in nature and named as fine to medium sand.

Correlation between Geophysical and Engineering Investigation

The correlation between the resistivity data and the drilling data (SPT value), it is observed that the subsurface lithologies are corresponded with each other (Table 2). According to Abu-Hassanein *et al.* (1996) and Jia *et al.* (2014), the soil with higher percentages of finer particles has high plasticity value and shows lower resistivity value. If the particle size is larger, the resistivity of the soil is also higher or vice-versa. The present study is also consistent with the above observations. From the results of electrical imaging, it is evident that the resistivity values are increasing with depth as well as the grain size especially in the area of borehole location. The variations of resistivity may be caused for the variation of degree of saturation and grain size. The grain size analysis and visual observation reveals that the finer particles (silt & clay) constitute over 85% up to the depth of 6 m. Below 6 m depth, the percentage of finer particles decreases and the sand percentage increases gradually which satisfied both electrical image and borehole engineering data. The upper low resistive clay layer may be the top of Madhupur Clay and high resistive (>300 Ωm) sand layer may be the top of the Dupi Tila Formation. This sand layer may be the excellent aquifer for fresh water sources.

Table 2. Correlation between SPT variation and electrical imaging.

<table>
<tr><th>Depth (m)</th><th>Drilling data</th><th>Resistivity imaging data</th><th>Lithology</th></tr>
<tr><td rowspan="2">0-5</td><td>Very loose soil</td><td rowspan="2">Low resistivity (<5 Ωm) materials</td><td rowspan="2">Filled materials</td></tr>
<tr><td rowspan="2">Stiff to very stiff soil</td></tr>
<tr><td rowspan="2">5-11</td><td rowspan="2">Moderate resistivity (35-55 Ωm) materials</td><td rowspan="2">Clay (Madhupur Clay)</td></tr>
<tr><td rowspan="2">Medium dense to dense soil</td></tr>
<tr><td>11-15+</td><td>High resistivity (300 Ωm) materials</td><td>Sand (Dupi Tila Sandstone)</td></tr>
</table>

Conclusion

Electrical imaging survey has enabled an improved field scale assessment of relative variations in shallow relatively complex geology. The resistivity image line of the study area shows heterogeneous stratifications. The images of electric resistivity 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 different degrees of saturation and grain size distribution.

From the corrected SPT values graph it is seen that the density of the soil is initially very loose (0 to 1.5 m) and stiff to very stiff (N value 10-20 and up to 8m). After 8 m depth the SPT value increases and it ranges from 20-34 up to 15 m depth. Visual inspection indicates that the samples might be of Dupi Tila sandstone. The N value (20-34) below 8 m depth indicates that the soil might be medium dense to dense in nature. The density value obtained from 12 m depth indicates that this depth is good for moderate load bearing structures and depth further below could be good for high load bearing structures.

The resistivity value is increasing downwards. From geotechnical parameters and image section at borehole, it is clearly showed that the clay proportion is decreasing but the silt proportion is almost constant and the overall grain size analysis suggests a gradual increase in sand percentages with depth. Around 12 m to 54 m electrode spacing and at a depth more than 12 m, there is high resistive sand zone which may indicate the potential aquifer of fresh water source for drinking purpose.

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বৈদ্যুতিক রোধ জরিপ ও মৌলিক ভূ-প্রকৌশল বৈশিষ্ট্যের ভিত্তিতে বাংলাদেশের ঢাকা জেলার সাভার উপজেলার জাহাঙ্গীরনগর বিশ্ববিদ্যালয় মডেল টাউন এলাকার ভূমির অভ্যন্তরীণ অবস্থা মূল্যায়ন

মোঃ হাসান ইমাম, হুসাইন মোঃ সায়েম, মোঃ এমদাদুল হক ও মাহমুদা খাতুন

সারসংক্ষেপ

বৈদ্যুতিক রোধ জরিপ ভূ-পদার্থ বিদ্যার একটি অন্যতম এবং বহুল ব্যবহৃত জরিপ পদ্ধতি। ভূ-অভ্যন্তরের শিলার জটিল অবস্থা এবং ভূ-অভ্যন্তরীণ জলাধারের বৈশিষ্ট্য নির্ণয় করার জন্য বৈদ্যুতিক রোধ পদ্ধতি ব্যাপকভাবে ব্যবহৃত হয়। এ গবেষণা প্রবন্ধে মাঠ পর্যায়ে সংগৃহীত বিভিন্ন উপাত্ত বিশ্লেষণ করে এবং বৈদ্যুতিক রোধের প্রতিচ্ছবি তৈরি করে ঢাকা জেলার সাভার উপজেলার জাহাঙ্গীরনগর মডেল টাউন এলাকার ভূ-অভ্যন্তরীণ অবস্থা ও ভূ-অভ্যন্তরীণ জলাধার সনাক্ত করা হয়েছে।

১০০ মিটার প্রতিচ্ছবি রেখা বরাবর প্রতি ৪ মিটার অন্তর ওয়েনার সাউন্ডিং পদ্ধতি প্রয়োগ করা হয়েছে এবং এর সাহায্যে অগভীর ভূ-অভ্যন্তরের কাঠামোগত পার্থক্য সনাক্ত ও মূল্যায়ন করা হয়েছে। প্রতিচ্ছবি রেখা বরাবর একটি খনন কূপের স্থান চিহ্নিত করা হয়েছে এবং ঐ স্থানে লাইট ক্যাবল পারকাশন খনন পদ্ধতিতে কূপ খনন করে প্রতি ১.৫২ মিটার (৫ ফুট) অন্তর মৃত্তিকার নমুনা এস.পি.টি পদ্ধতিতে সংগ্রহ করা হয়েছে। সংগৃহীত নমুনাসমূহ পরীক্ষাগারে বিশ্লেষণের মাধ্যমে ভূ-প্রকৌশল বিদ্যার গুরুত্বপূর্ণ বৈশিষ্ট্য ও নিয়ামক সমূহ যেমন- আর্দ্রতার পরিমাণ, আপেক্ষিক গুরুত্ব, মৃত্তিকা কনার বন্টন, তরল সীমা, প্লাস্টিক সীমা এবং প্লাস্টিসিটি গুনাংক নির্ণয় করা হয়েছে। প্রাপ্ত ভূ-প্রকৌশল বৈশিষ্ট্যসমূহকে মৃত্তিকার বৈদ্যুতিক রোধের সাথে তুলনা করা হয়েছে এবং এর সাহায্যে উক্ত এলাকার অগভীর ভূ-অভ্যন্তরীণ ভূতাত্ত্বিক বৈশিষ্ট্য নির্ণয় করা হয়েছে।

রোধ প্রতিচ্ছবি রেখার সাহায্যে দেখা যায় যে, উক্ত এলাকায় অসমসত্ত্ব স্তরায়ন হয়েছে। বৈদ্যুতিক রোধ প্রতিচ্ছবি ও ভূ-প্রকৌশল বৈশিষ্ট্য সমূহ মধুপুর কর্দমের সাথে সামাঞ্জস্যপূর্ণ। এস.পি.টির মান (৮মিটার গভীরে) থেকে বলা যায় যে উক্ত মৃত্তিকা "মাঝারি মানের ঘন থেকে ঘন" এই শ্রেনীতে অবস্থান করে। ঘনত্ব বৈশিষ্ট্যের আলোকে আরো বলা যায় যে, ১২ মিটার গভীরের মৃত্তিকা মাঝারি মানের ভরসহনীয় কাঠামো নির্মানের জন্য উপযোগী এবং তার নীচের মৃত্তিকা উচ্চ ভর সহনীয় কাঠামো নির্মাণের জন্য সম্পূর্ন উপযোগী। ভূ-প্রকৌশল বৈশিষ্ট্য ও বৈদ্যুতিক রোধ প্রতিচ্ছবি থেকে দ্বিধাহীন ভাবে বলা যায় যে, গভীরতা বৃদ্ধির সাথে সাথে কর্দম কণিকার পরিমাণ কমে যায়, পলল কণিকার পরিমাণ প্রায় সমান থাকে এবং বালুর পরিমান বৃদ্ধি পেতে থাকে। ১২ মিটার বা তার অধিক গভীরতায় উচ্চ রোধ সম্পন্ন বালুর স্তর বিদ্যমান এবং এই স্তরটি সুপেয় পানির জলাধার হিসেবে বিবেচনার দাবি রাখে।