Soil Site Investigations Using 2D Resistivity Imaging Technique

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ABSTRACT

The use of 2D Electrical Resistivity Imaging (ERI) technique in combination with geotechnical and geological data allow the determination of the lithological composition and detailed internal architecture of the subsurface and understanding the characterisation and description of the geology of the site. This study is aimed to evaluate the use of 2D ERI for the detection and characterisation of heterogeneities in subsurface soil. The survey was conducted using a Wenner-Schlumberger and Wenner configurations along thirteen ERI parallel profiles which have been investigated in the project of Al-Obaidi Electrical Transformation Station site to find the resistivity and depth of soil horizons with their lithological description. Analysis of imaging sections shows that Wenner-Schlumberger sections are with higher resolving power than Wenner sections in both horizontal and vertical variations in resistivity reflecting more pronounced soil horizons with depth, where Wenner sections are limited to the upper soil layers. Resisitvity values in the imaging sections indicate that the stratigraphy of the study area is mostly of clayey soil. 4 to 7 distinct geoelectric layers generally identify the subsurface down to depth of about 20 m. High resistivity values in the top soil, medium-high resistivity values representing the upper soil layers, while lower reitivity values are indicated for the lowerest layers. The resistivity values are inversely proportional to many soil properties such as fine content (clay and silt), salt content (sulphate and gypsum content) for saturated conditions, water content, plasticity index (P.I) and void ratio particularly for saturated condition. The resistivity values are directly proportional to sand content, void ratio, salt contents for dry condition. The integrated use of ERI technique and conventional site investigation has led to a far better understanding of the site than could have been achieved using site investigation methods alone.

Keywords: Site Investigation; 2D; Electrical Resistivity Imaging (ERI); Geotechnical tests

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تحريات التربة الموقعية باستخدام تقنية المقاومة النوعية التصويرية ثنائية الأبعاد

الخلاصة

ان استخدام تقنية المقاومة الكهربائية التصويرية ثنائية الأبعاد (٢DERI) في الربط بين البيانات الجيوتكنيكية والجيولوجية يسمح بايجاد التركيب الطبقي والهيكلية الداخلية المفصلة لسطح التربة وفهم خصائصية ووصف جيولوجية الموقع. تهدف هذه الدراسة الى تقييم استخدام ٢DERI للكشف وتوصيف التغاير في التربة تحت السطحية. تم المسح باستخدام ترتيبي فنر- شلمبرجر وفنر على طول 13 مقطع والتي تم التحري عنها في مشروع موقع محطة العبيدي الكهربائية التحويلية لايجاد المقاومة النوعية مع العمق لطبقات التربة مع وصف تتابعها الطبقي. أظهر تحليل المقاطع التصويرية ان مقاطع فنر– شلمبرجر ذات قوة تحليلية اكبر من مقاطع فنر في كلا التغيرات العمودية والافقية للمقاومة النوعية وكذلك وصف طبقات التربة مع العمق حيث كانت طريقة فنر محدودة لطبقات التربة العليا. أشارت المقاطع التصويرية الكهربائية الى ان التتابع الطبقي لمعظم منطقة الدراسة هو ذو تربة طينية. عموما عرفت ٤–٧ طبقات جيوكهربائية تمثل طبقات ما تحت سطح التربة الى حد عمق ٢٠ م. كانت قيم المقاومة النوعية العالية في التربة القريبة من السطح, وتمثلت القيم المتوسطة غالبا بطبقات التربة العليا, بينما أشارت القيم الواطئة الى طبقات التربة السفلى. ان قيم المقاومة النوعية ذات علاقة عكسية مع العديد من خواص التربة مثل المحتوى الناعم (الطين والغرين), محتوى الملح (الكبريتات والجبس) في الظروف المشبعة، والمحتوى المائي، مؤشر اللدونة (PI) ونسبة الفراغات في الحالة المشبعة. بينما تتناسب قيم المقاومة النوعية طرديا مع محتوى الرمل، نسبة الفراغات، محتوى الملح في الحالة الجافة. وقد أدى الاستخدام المتكامل لتقنية ERI والتحري الموقعي التقليدي الى فهم أفضل للموقع مما كان يتحقق باستخدام أساليب التحري وحدها.

INTRODUCTION

Geophysical methods have become increasingly popular in geotechnical site characterizations especially where subsurface conditions are difficult to evaluate with conventional techniques such as borehole drilling. Geophysical interpretations should be correlated with real "ground-truth" data such as drill borehole logs [1].

Electrical surveys are of the best methods to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. Because the method is non-destructive and very sensitive, it offers a very attractive tool for describing the subsurface properties without digging. Therefore, the electrical resistivity methods are commonly used to map lateral and vertical changes in geological (or man-made) materials. The method may also be used to determine the depth to the water table (normally in arid or semi-arid areas); locate buried features such as cavities, pipelines, clay-filled sinkholes and buried channels; map the saline/fresh water interface in coastal regions; locate economic deposits of sand and gravel; and assess the quality of rock/soil masses in engineering terms [2, 3].

Electrical resistivity imaging (ERI) provides a relatively low cost, noninvasive and rapid means of generating spatial models of physical properties of the subsurface. Resistivity images have been used in studies that include soil and bedrock property characterization, mapping the soil bedrock interface and the water table, detection of cavern, void and fractures detection, sand and gravel mapping, sanitary landfill delineation, assessing contaminated soils and landfills among other types of investigations [1]. Most published studies have detailed the applications of 2D-ERI to landfill investigation such as Naudet et al. (2004) [4] and Chambers et al. (2005 and 2006) [5, 6]. In many cases, resistivity imaging surveys can be planned, executed, and the data interpreted in the matter of hours while causing minimal or no impact to the environment. Proper use of resistivity imaging surveys can provide significant cost saving over other exploratory methods. Resistivity imaging assimilates hundreds of individual resistivity measurements collected over the line of section into two dimensional images of the subsurface. Resistivity imaging can provide large amount of cross-sectional data critical to accurately bidding, planning, and implementing geotechnical investigations [1].

The study is aimed to evaluate the use of 2D ERI for the detection and characterisation of heterogeneities in subsurface soil. In this study, 2D ERI technique was applied to investigate the subsurface soil for Al-Obaidi Electric Transformation Station site project and correlating the obtained data with that of drilling boreholes to show the compatibility between the soil site investigation and resistivity data of this study by field work.

VARIATION OF ELECTRICAL RESISTIVITY AS A FUNCTION OF SOIL PROPERTIES

The purpose of electrical resistivity surveys is to determine the resistivity distribution of the surrounding soil volume. Artificially generated electric currents are supplied to the soil and the resulting potential differences are measured. Potential difference patterns provide information on the form of subsurface heterogeneities and of their electrical properties. The greater the electrical contrast between the soil matrix and heterogeneity, the easier is the detection [7].

The resistivity measurements are normally made by injecting current into the ground through two current electrodes A and B (or C1 and C2) at the external positions , and measuring the resulting voltage difference at two potential electrodes M and N (or P1 and P2) in between.

$$\rho_a = k\left(\frac{V}{I}\right) \qquad \dots (1)$$

$$\rho_a = kR \qquad \dots (2)$$

The apparent resistivity ρ_a is the bulk average resistivity of all soils and rocks influencing the flow of current, I is the current, V is the voltage and k is the geometric factor which depends on the arrangement of the four electrodes [8, 9].

There are many arrays used for resistivity imaging where each array has advantages and disadvantages depending on the nature of the study area. The most common arrays in Resistivity Imaging are Wenner, dipole-dipole and Wenner-Schlumberger [3, 10, 11]. Choosing the right array for the resistivity surveys is important for two reasons, the first one is in each array there are advantages and disadvantages compared with the other arrays, and the second reason is the geological image created by means of (RI) for the same structure will be different for each array. Choosing the right array depends on the target survey, sensitivity of the resistivity meter, electric background noise and the subsurface structure. Moreover, choosing the array requires some considerations such as the depth of the image, vertical and horizontal change in the subsurface, the length of the image and the signal strength [11, 12].

The Wenner electrode configuration is an array in which the four electrodes are arranged in line with equal electrode spacing. If the survey is in a noisy area and a good vertical resolution is required with a limited survey the Werner array will be the best option [13]. While the other commonly used array is Wenner-Schlumberger array which is hybrid between Wenner and Schlumberger arrays [14] arising out of a relatively recent work with electrical imagine surveys. If there is uncertainty whether both reasonably good horizontal and vertical resolution are required, the Wenner-Schlumberger array with overlapping data levels is the best option. This array is moderately sensitive to both horizontal and vertical structures [13, 15].

The electrical resistivity is a function of a number of soil properties, including the nature of the solid constituents (particle size distribution, mineralogy), arrangement of voids (porosity, pore size distribution and connectivity), degree of water saturation (water content), electrical resistivity of the fluid (solute concentration) and temperature. The porosity is the major control of resistivity of rocks, and that resistivity generally increases as porosity decreases. Porosity and cementation, on the other hand, are related. It then means that electrical resistivity could be used to determine the degree of cementation to better characterize the subsurface soil for engineering structures [16].

The air medium is an insulator (i.e. infinitively resistive), the water solution resistivity is a function of the ionic concentration, and the resistivity of the solid grains is related to the electrical charges density at the surface of the constituents. These parameters affect the electrical resistivity, but in different ways and to different extents. Electrical resistivity experiments have been performed to establish relationships between the electrical resistivity and each of these soil characteristics [3].

The most common minerals forming soils and rocks have very high resistivity in a dry condition, and the resistivity of soils and rocks is therefore normally a function of the amount and quality of water in pore spaces and fractures. The degree of connection between the cavities is also important. Consequently, the resistivity of a type of soil or rock may vary widely. The resistivity of the pore water is determined by the concentration of ions in solution, the type of ions and the temperature.

METHODOLOGY

Field work Survey Design

The field work was conducted during 4-months (from February to June 2012) which was carried out in two main stages; the 2D resistivity imaging survey and geotechnical investigation included drilling, sampling and testing. The Geoelectrical investigation is comprised of 2D Electrical resistivity imaging along selected traverse lines within the land plot allocated for the project Al-Obaidi Electrical Transformation Station site in north east Baghdad (between Baghdad and Diyala Governorate territories). The 2D electrical resistivity mapping of the subsurface, on the other hand, gives more detail information that help to construct the subsurface layer stratification, and to determine the depth extent and relief of the foundation rock [17].

2D resistivity imaging surveys, using the instrument SAS 4000 Terrameter resistivity imaging system, along thirteen resistivity imaging spreads were carried out in the site. The length of each spread was 120 m. Nine of these spreads are outside the camp with 3 m spacing and four are inside the camp with different spacing (4-5 m) due to many obstructions (machines, vehicles, construction materials, etc.) in the site Figure (1).

For the 2D surveys, in order to obtain the best results, comparisons were made among the three common conventional arrays, and the most suitable arrays will be chosen for the study area. Accordingly, the Wenner and Wenner-Schlumberger configurations were employed along these profiles. These electrode arrays were chosen for its superiority in delineating lateral resistivity heterogeneities as compared to other electrode configurations. In order to study the lateral resistivity variations in sufficient detail, the survey were carried in an arrangement that involves forty one electrodes placed three meter apart and attached to multi-electrode consoles. The profile lines run in E–W direction, each profile line covers the area deemed to be interesting for the survey. The actual position of the traverse line is entirely in the premises of construction site. Several steps were followed to generate a model from the pseudosection. These steps are:

1. Collecting the subsurface apparent resistivity for the thirteen lines through the two implemented arrays.
2. All datasets were inverted using RES2DINV software to calculate the true resistivity.
3. Creating an image for each section of resistivity measurement to estimate subsurface soil properties.
4. Correlating the resistivity range values with data collected from boreholes.

The main aim of implementing electrical resistivity measurements, along with geotechnical investigation, is to cover the gap areas between boreholes achieved by conventional methods (drilling), in addition to save both cost and time. Resistivity imaging technique was used to find out geoelectrical parameters from which some geotechnical data can be estimated. Besides, the true electrical resistivity extracted from electrical images (sections) will be correlated with some experimentally tested geotechnical properties. Thus, the geotechnical site investigations were conducted after geophysical investigation. Accordingly, geotechnical investigation tests were used to specify additional engineering characteristics of the subsurface strata and determining their physical/mechanical and chemical properties that are relevant to the project.

Drilling of borehole is normally carried out for a number of reasons, such as, establish the general nature of the strata below a site, establish lateral and vertical variability of soil conditions, verify the interpretation of geophysical surveys, obtain samples for laboratory testing, allow in situ tests to be carried out.

The geotechnical data were used from 7 boreholes (6 are already existed and drilled by NCCLR while the seventh one was drilled in the middle of spread no. 8 for the present study) in the site. For the later borehole, 14 soil samples have been collected for laboratory testing in addition to in-situ testing for measuring the geotechnical properties (particle size distribution analysis, chemical, physical and mechanical properties). The soil properties were conducted in the Soil Mechanic Labs of the University of Technology.

The samples were subsequently identified and classified under classification scheme. These data permitted differentiating between the main lithological types occurring in the area and establishing a relationship between ERI data and lithological classes.

The engineering geotechnical investigation was carried out on the basis of the results of the geophysical investigation in order to optimize the information about the site in an economically viable way. The geotechnical investigation, along with the geophysical analysis, focuses on the following key factors to assess the suitability of the site for the proposed constructions, determine the thickness and the engineering characteristics of each dominant subsurface layer as this will have significant effect for design, identify the level of ground water during the investigation time (almost based on geophysical information), if encountered, and finally prepare geotechnical profile with all necessary information.

Data Analysis

Electrical Resistivity Imaging (ERI) data were collected using SAS Terrameter 4000 system with 41 electrodes using the Wenner and Wenner-Schlumberger arrays. These arrays gather resistivity measurements for each profile to create a pseudosection.

Processing and interpretations of the 2D resistivity imaging data was done using RES2DINV software. RES2DINV is a computer program that automatically determines the true resistivity model for the subsurface from the measured data. All datasets were inverted using RES2DINV software [18]. The software generates a calculated model of the pseudosection from the inverted model, the Root Mean Square (RMS) error between the calculated and the measured pseudosection is computed. A least-squares algorithm is used to reduce the RMS error between the measured and the calculated apparent resistivity in an iterative mode. Two inversion methods are available in the software package, the Gauss–Newton smoothness constrained least-squares [19] and Gauss–Newton robust model constrained [20], both routines were tested for data inversion, as a general rule, features depicted for both methods can be considered real [13]. Interpretation of the models was based on the resistivity range of some geological materials presented by several researchers (such as Palacky, 1987 [21]; Reynolds, 1997 [22] and Guerin et al., 2002 [23]) and the data obtained from geological mapping and geotechnical investigation carried out in the site [24].

INTERPRETATION AND DISCUSSION

Correlation between Imaging Resistivity and Boreholes

Soil stratification data from the drilled borehole (B.H.7) provide accurate details for the subsurface structure Figure (2). There are some limitations by using boreholes data as they provide information for a limited area, require a longer time, destruct the study area. However, boreholes data are needed to confirm and tie the results of geological and geophysical interpretations.

To emphasize the integration between the data results obtained from resistivity images and that obtained from soil site investigation, a correlation may be made between them. At the beginning, the implementation of Erigraph program for resistivity section no. 2 with borehole no. 6 Figure (3) to give an indication and overview for the correlation between resistivity and borehole data.

To show the characterization and correlation of resistivity imaging sections with boreholes, the spread no.1 with borehole no. 6 (at distance 3 m) is taken, as an example, for such correlation. The section is represented by 4 geoelectric layers as follows as in Figure (4):

Generally, the resistivity within this section is ranging between (<1 to 30) ohm.m for Wenner-Schlumberger array while the range (2-5) ohm.m is predominant in the whole section. The overburden soils exhibit a pronounced thickness variation along the section. Four geoelectrical layers have been recognized and correlated with the stratigraphy of B.H.6 as follows: the first and second layer with relatively high resistivity (2.5–15 ohm.m) are explained as clayey soil with conductive response which is correlated to stiff brown lean clay in borehole; the third layer with very low resistivity (<1–2 ohm.m) may be explained as conductive expansive soil near the water table; while low resistivity (about 2 ohm.m) is recognized for layers 4 to 6 of B. H. 6 which are correlated to stiff or very stiff clay to silty – sandy clay with higher moisture content. Besides some anomalous areas are indicated with relatively high resistivity (27 ohm.m) which could indicate the presence of sand lens (or pockets) and low resistivity (<2 ohm.m) which may represent conductive soil probably water logged horizon. Thus, 4 geoelectrical layers are identified in this section compared to 6 layers in borehole where the last 3 layers appear as one geoelectrical layer (2 ohm.m) as shown in Figure (4). As a result of this correlation, it can be stated that the resistivity is inversely proportional to clay content and directly proportional to sand content and soil stiffness. Where the dark color of soil texture (as brown or grey) could be due to the increase of clay. That means the first two layers (2 to 15 ohm.m) are clayey silt soils with sand but the last four layers ($\leq$2 ohm.m) are clayey soils. The correlation for the rest resistivity sections with boreholes are shown from Figure (5) to Figure (16).

Variation of Soil Electrical Resistivity with Depth

To show the variations of electrical resistivity with depth Figures (17 to19), the stratigraphy of drilling boreholes have been correlated with electrical imaging sections using Wenner and Wenner-Schlumberger arrays Figures (4 to 16). Comparing imaging sections achieved by Wenner-Schlumberger and Wenner arrays, it can be seen that Wenner sections are with lower details in resistivity changes or variations with less pronounced horizons (less recognized geoelectrical zones) and limited to the upper part of these sections compared to Wenner-Schlumberger sections. Thus, the last sections give clearer pictures than Wenner sections as they reflect more anomalous areas. Also, in Wenner sections, the resistivity changes are limited to the upper soil layers. Besides, it can be seen that the resisivity are with relatively higher values, particularly for the upper soil layers, for Wenner-Schlumberger sections than in Wenner sections.

It is noticed that the relation between results of resistivity imaging sections and borehole stratigraphy is in a good agreement. Four to seven distinct geoelectric layers generally represent the subsurface in the study area. The resistivity values indicate that the stratigraphy of the study area is mostly of clayey soil. Where, high resistivity values in the uppermost soil, medium – high resistivity values represent the upper soil layers (approximatly above water table) and lower resistivity values are indicated below water table and the lowest resistivity values are indicated at the lowest layer. The resistivity range is highly indicative of waterlogged conductive soil. A possible ground water indication, based on geotechnical and geophysical investigation studies, may be expected at the expansive clay which is around 2 m below the natural ground level Figure (2). It is obvious that the resistivity for both arrays also decreases with increasing stiffness of soil texture with depth and increasing soil moisture content particularly at depth 10 to 20 m.

After results analysis and interpretation the resistivity imaging sections of Figures (4 to 16) it can be stated that the soil sratigraphy of the area of study is mostly of clayey soil with resistivity of about 1–15 ohm.m in general. It can be also seen that the resistivity values decrease with depth due to increase in water content. For all spreads, the resistivity values are ranging from about 5–50 ohm.m. Higher values (15–55 ohm.m) are assigned to the first upper layers above water table. Lower values (1–7 ohm.m) are assigned to the lower layers (from 3^{rd} to 7^{th} geoelectric layers).

Determination of Some Soil Geotechnical Properties and their Relationships with Electrical Resistivity

Some geotechnical properties can be determined or estimated from soil resistivity such as porosity, grain size, water content (moisture content), consistency limits (liquid limit, plastic limit and liquidity and plasticity indices), unconfined compression strength q_u, gypsum content and some hydraulic parameters of groundwater strata (such as porosity, hydraulic conductivity, transmissivity, specific yield, specific retention, storage coefficient and specific capacity) [25, 26]. Besides, the analysis of the relationships between soil geotechnical properties with electrical resistivity really provides advantages for the geotechnical engineers to solve site investigation problems and any problems related to geology, more rationally, and also efficiently and economically.

The variation in resistivity values is attributed to the variation in sediments type, moisture content, absence of salts (such as gypsum). Low resistivity values may be attributed to ground water (ranging around 2-3 m below NGL) or increase in moisture content or clay content. The relation between grain size composition and resistivity reflects that the decrease in resistivity with increasing fine content (clay and silt), while the increase in resistivity with increasing coarse grains (sand and gravel). Resistivity decreases with increasing L.L and P.L. as the increase in these parameters gives an indication about the increase in soil cohesion and plasticity so resistivity decreases. Resistivity decreases with increasing unconfined compression strength q_u, as this parameter increases the soil hardness increases and consequently resistivity decreases. Resistivity increases with increasing gypsum content (if water content is low), or but resistivity decreases with higher water content due to leaching process and increasing conductivity.

Relations between true electrical resistivity (ρ_t) extracted from electrical imaging sections and some soil geotechnical properties obtained experimentally have been carried out Figures (20 and 21). These relations stated that the resistivity values are directly proportional to sand content and void ratio, salt content % (sulphate SO_3 and gypsum $CaSO_4.H_2O$) for dry condition. While, resistivity with the most soil properties is inversely proportional such as fine content% (clay and silt), salt content % for saturated conditions, water content (moisture content), plastic and liquid limits and void ratio particularly for saturated and fully saturated. From above discussion, it can be stated that electrical resistivity analysis proved that a combination of this integrated study provided a reasonable compromise between them. Thus, the integrated use of ERI and conventional site investigation has led to a far better understanding of the site than could have been achieved using traditional site investigation methods alone.

CONCLUSIONS

The main conclusions drawn from this study are:

1. The area of study is characterized by its subsurface complexity due to sediments heterogeneity which is represented by the presence of some pockets of silts and sand inter-bedded with clays.
2. The use of Electrical Resistivity Imaging (ERI) technique in combination with geotechnical and geological data allowed the determination of the lithological composition and gives better understanding the characterisation and description of the geology of the site.
3. In general, electrical resistivity in the site decreases with depth as the study area mostly consists of clayey soil and due to ground water effect.
4. Electrical imaging sections reflect that the stratigraphy of the study area is mostly of clayey soil. 4-7 distinct geoelectric layers generally represent the subsurface in the study area. High resistivity values in the topsoil, medium-high resistivity values representing the upper soil layers, while lower resistivity values are indicated in the lowest layers.
5. Wenner-Schlumberger sections are with higher resolving power than Wenner sections in both horizontal and vertical variations in resistivity reflecting more pronounced soil horizons with depth.
6. The resistivity values are inversely proportional fine content (clay and silt), salt content (sulphate and gypsum) for saturated conditions, water content, plasticity index (P.I), and void ratio particularly for saturated condition. While, these values are directly proportional to sand content, void ratio, and salt contents for dry condition.
7. Good correlations have been obtained between the results of resistivity imaging and borehole stratigraphy for this site.

8. The integrated use of ERI and conventional site investigation has led to a far better understanding of the site than could have been achieved using traditional site investigation methods alone.

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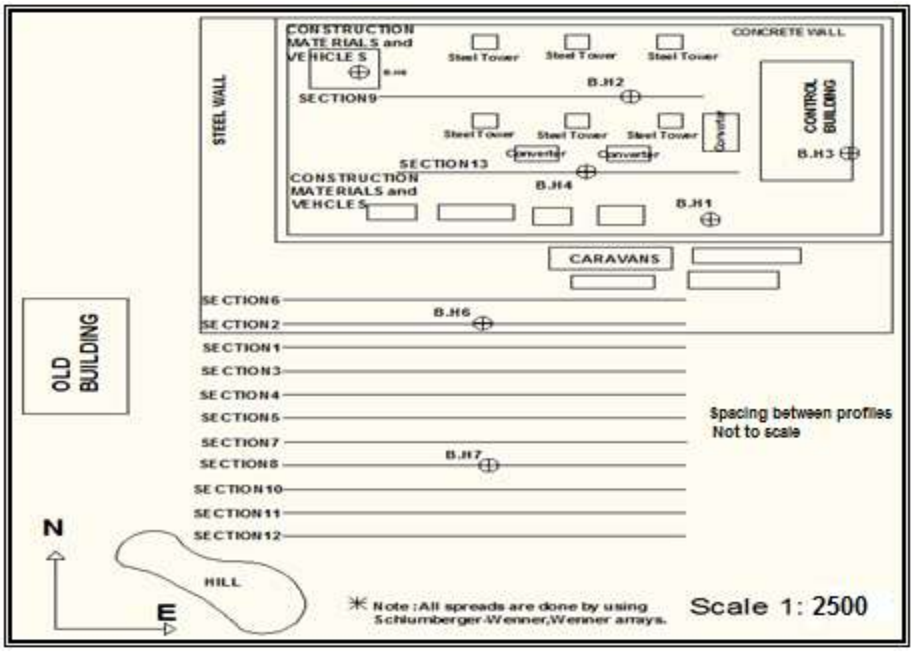


Figure (1) Site planning with resistivity imaging spreads.

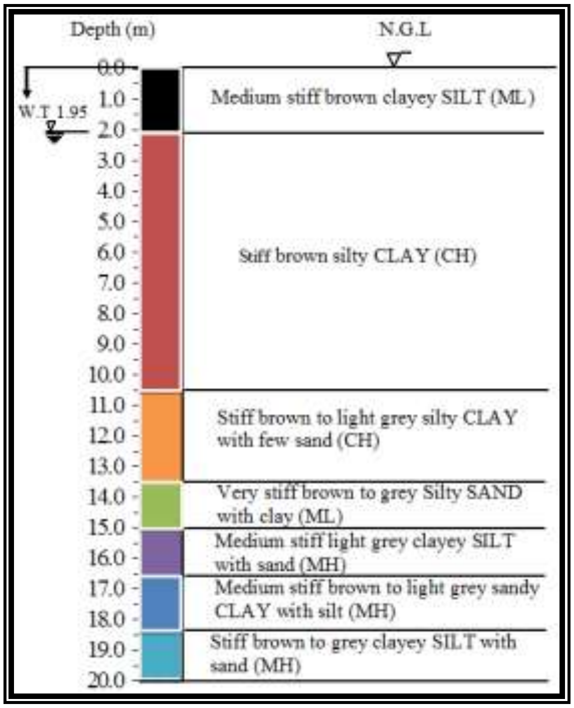


Figure (2)Soil stratification of B.H.7.

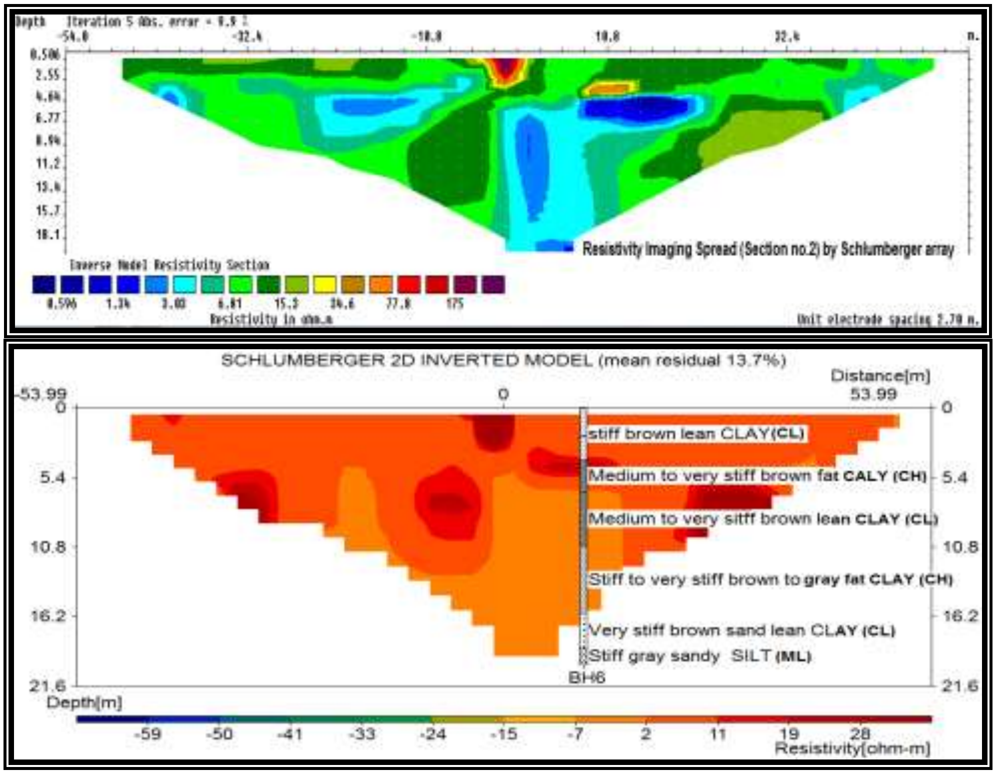
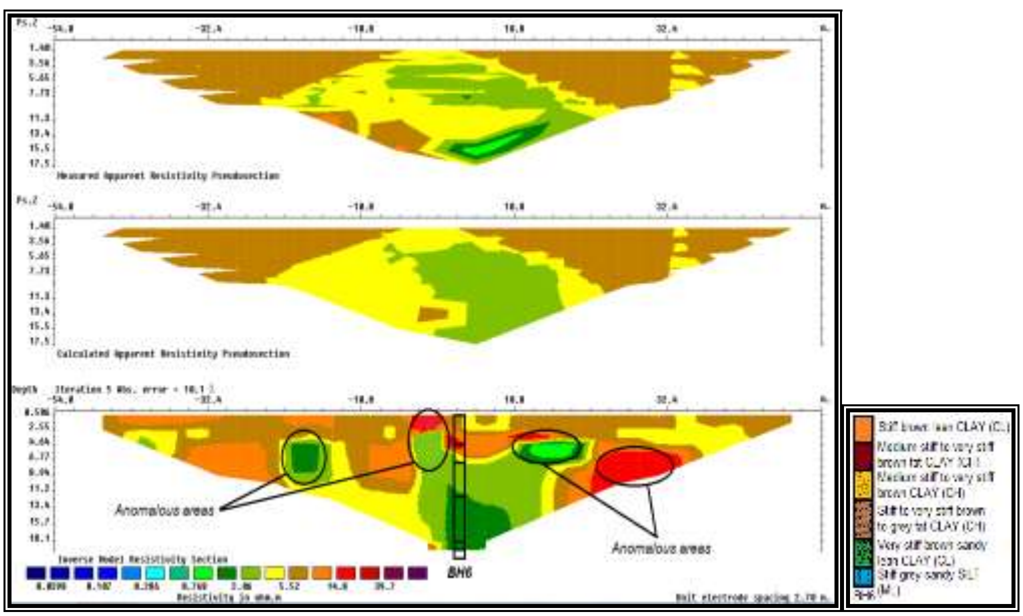


Figure (3) Borehole 6 on resistivity image section 2.



Figure(4) Correlation of Wenner-Schlumberger section 1 with B.H.6.

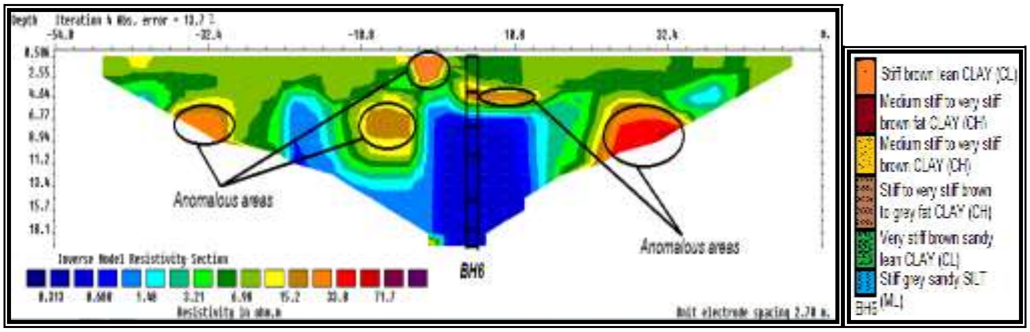


Figure (5). Correlation of Wenner-Schlumberger section 2 with B.H.6.

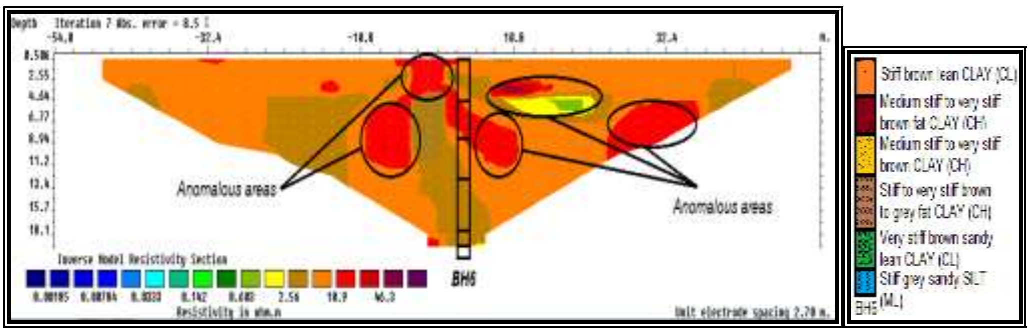


Figure (6) Correlation of Wenner-Schlumberger section 3 with B.H.6.

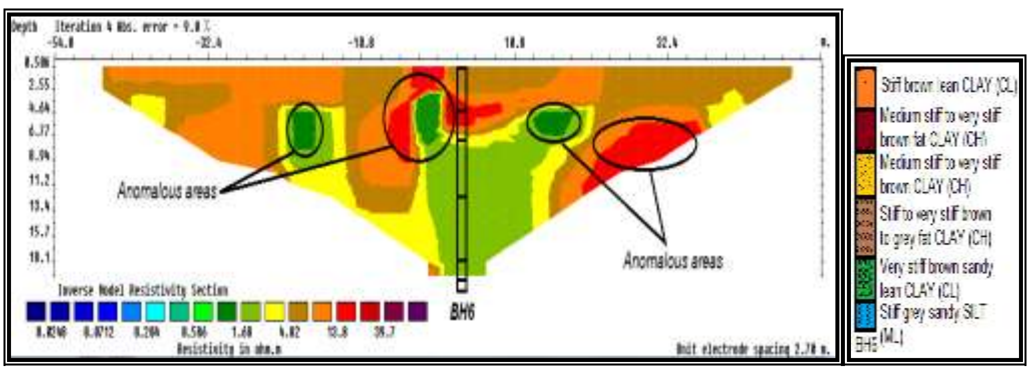


Figure (7). Correlation of Wenner-Schlumberger section 4 with B.H.6.

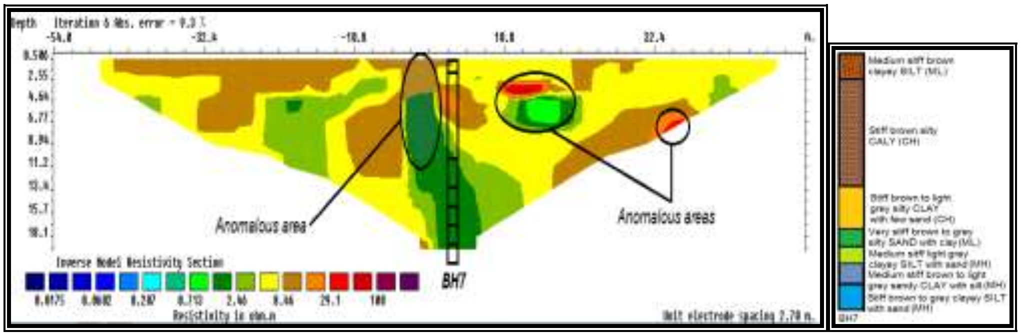


Figure (8) Correlation of Wenner-Schlumberger section 5 with B.H.7.

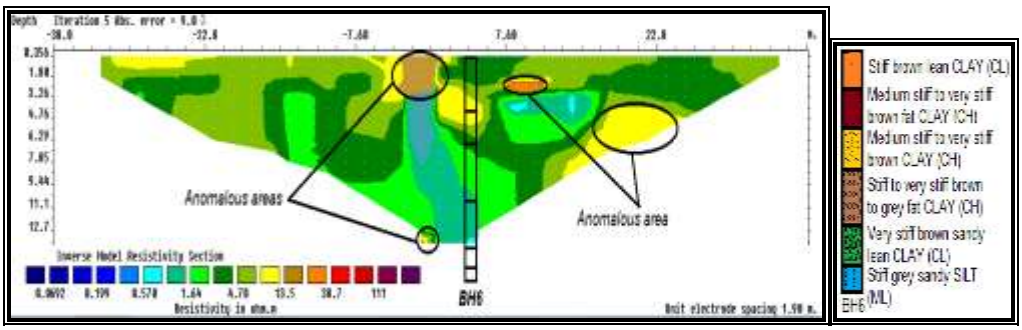


Figure (9) Correlation of Wenner-Schlumberger section 6 with B.H.6.

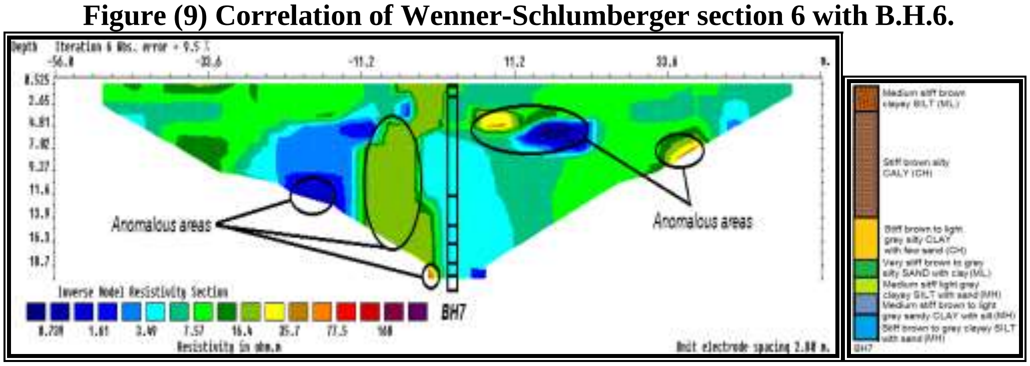


Figure (10) Correlation of Wenner-Schlumberger section 7 with B.H.7.

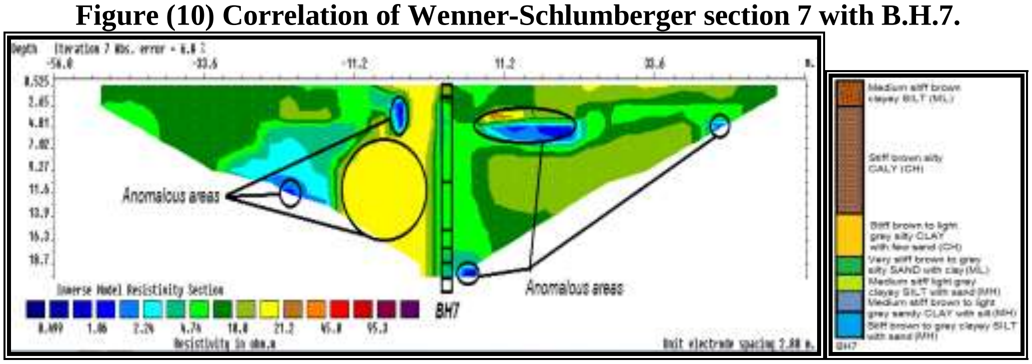


Figure (11) Correlation of Wenner-Schlumberger section 8 with B.H.7.

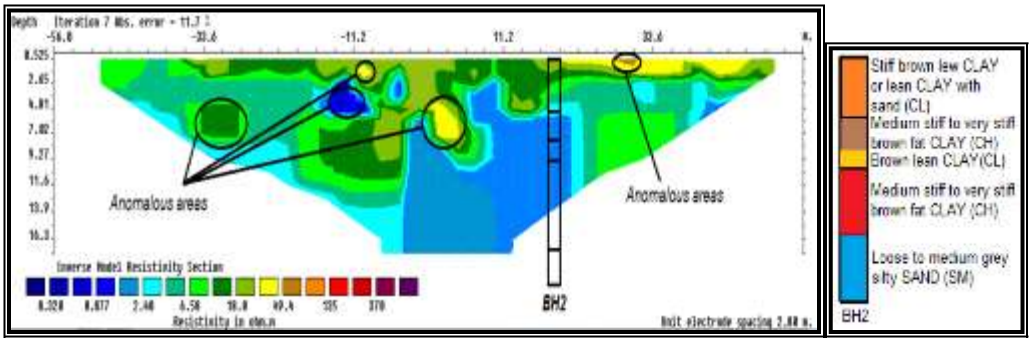


Figure (12) Correlation of Wenner-Schlumberger section 9 with B.H.2.

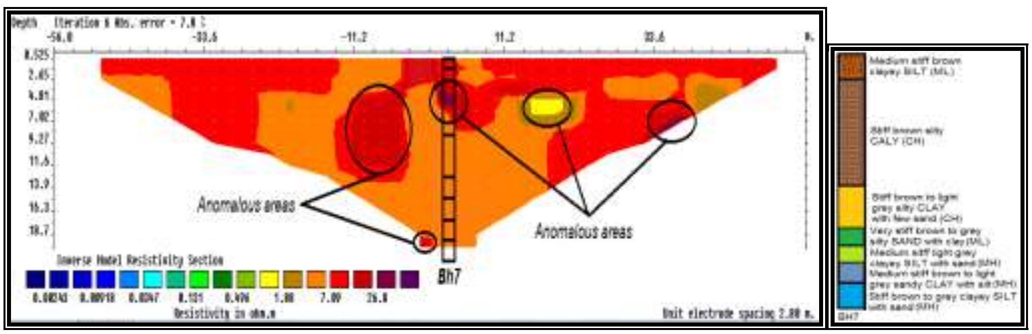


Figure (13) Correlation of Wenner-Schlumberger section 10 with B.H.7.

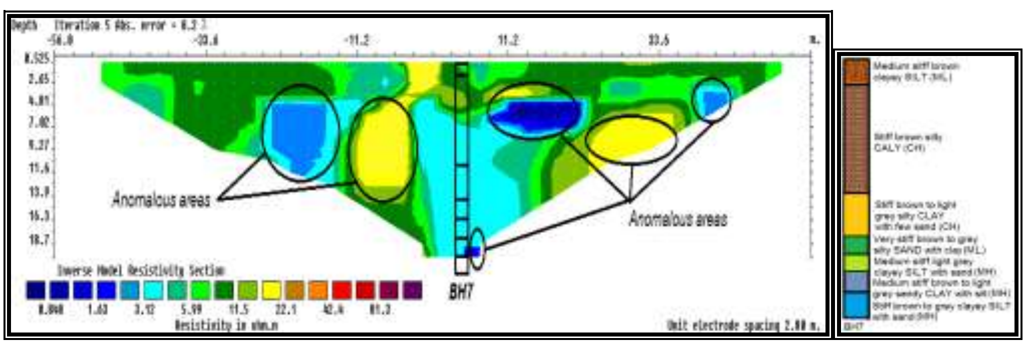


Figure (14) Correlation of Wenner-Schlumberger section 11 with B.H.7.

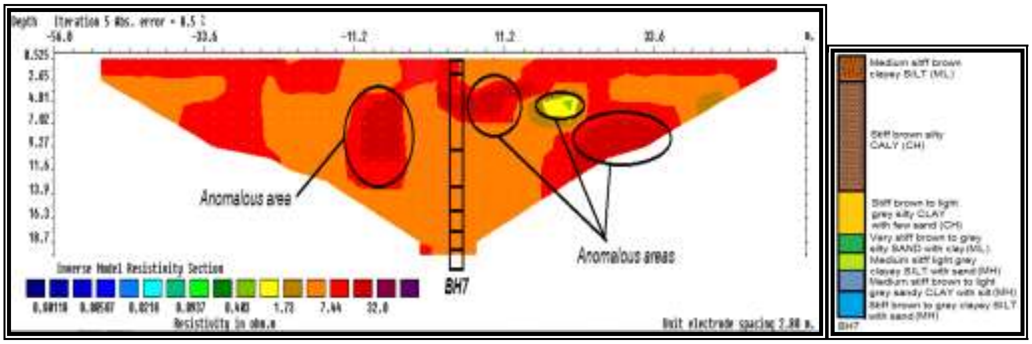


Figure (15) Correlation of Wenner-Schlumberger section 12 with B.H.7.

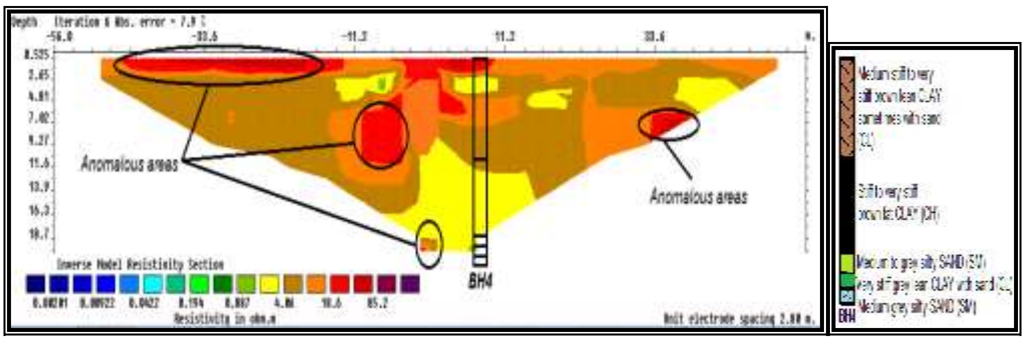


Figure (16) Correlation of Wenner-Schlumberger section 13 with B.H.4.

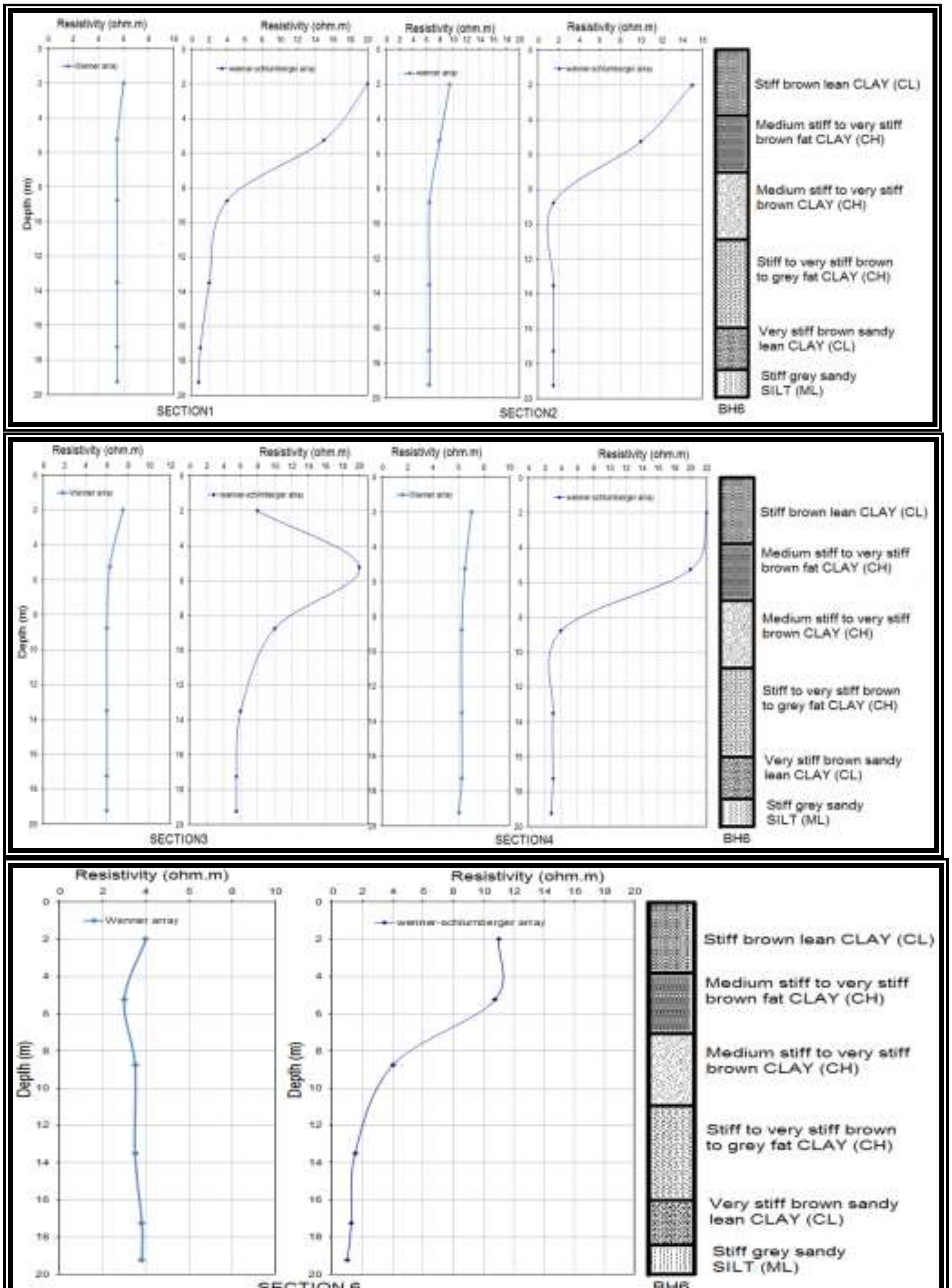


Figure (17) Variation of resistivity for section 1, 2, 3, 4 and 6 with depth of B.H. 6.

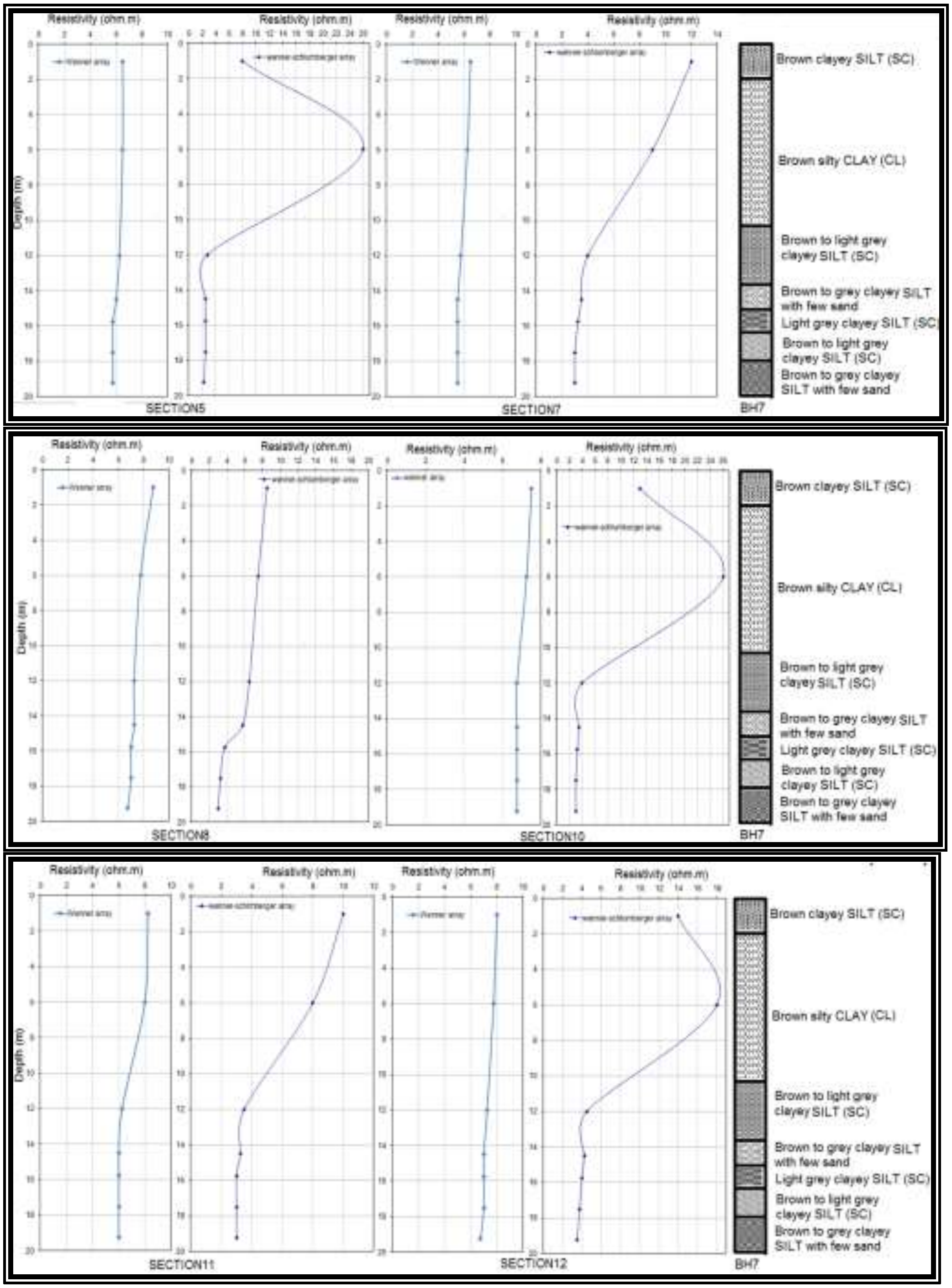


Figure (18) Variation of resistivity for section 5, 7, 8, 10, 11and 12 with depth of B.H. 7.

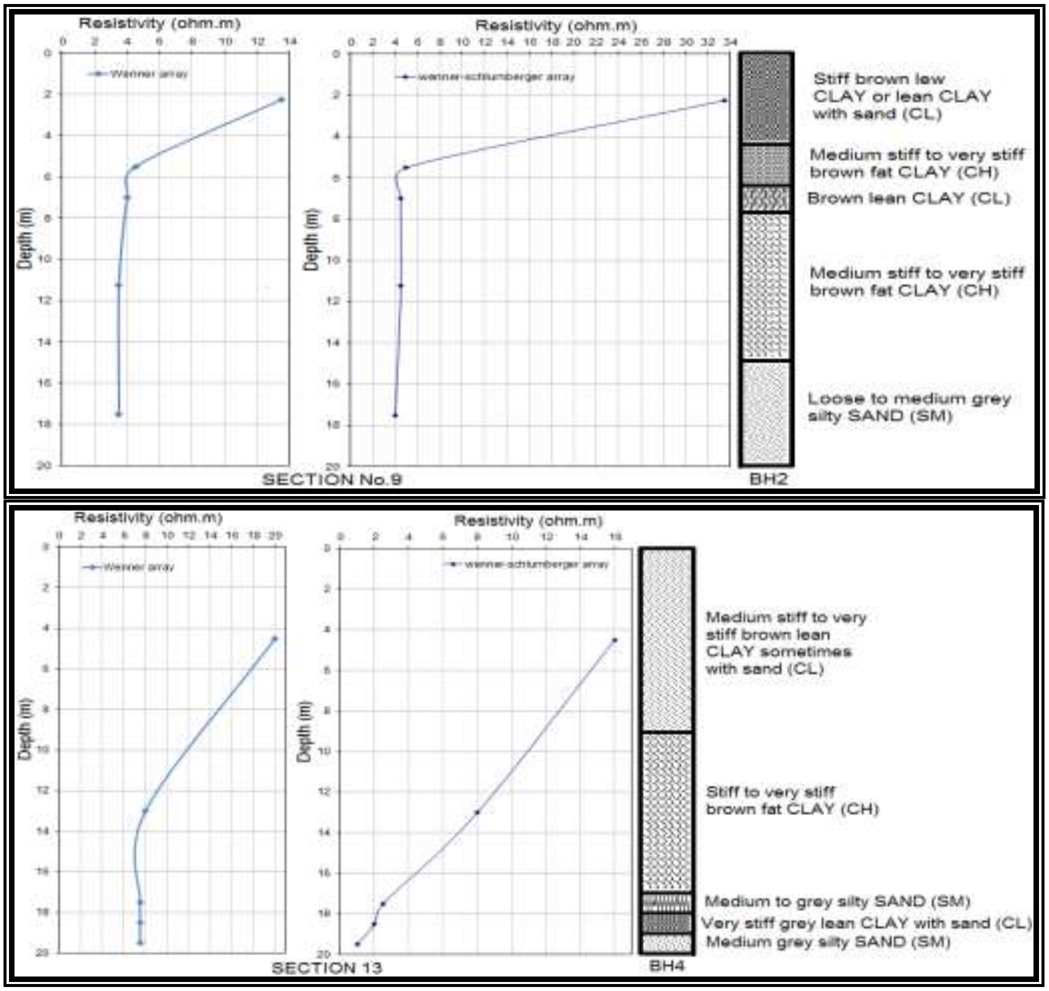


Figure (19) Variation of resistivity for sections 9 and 13 with depth of B.H. 2 and B.H. 4respectively.

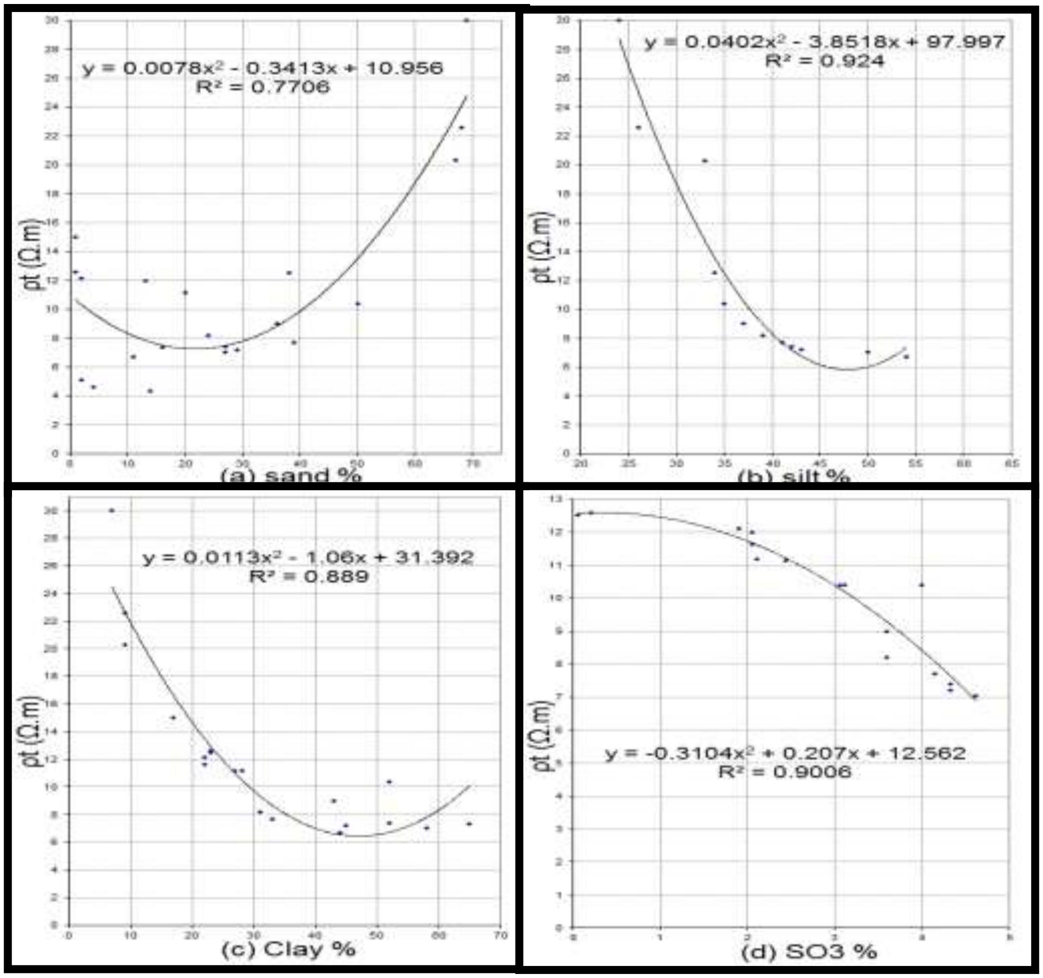


Figure (20) Relationships between true resistivity and some geotechnical properties (sand, silt, clay and SO_3%).

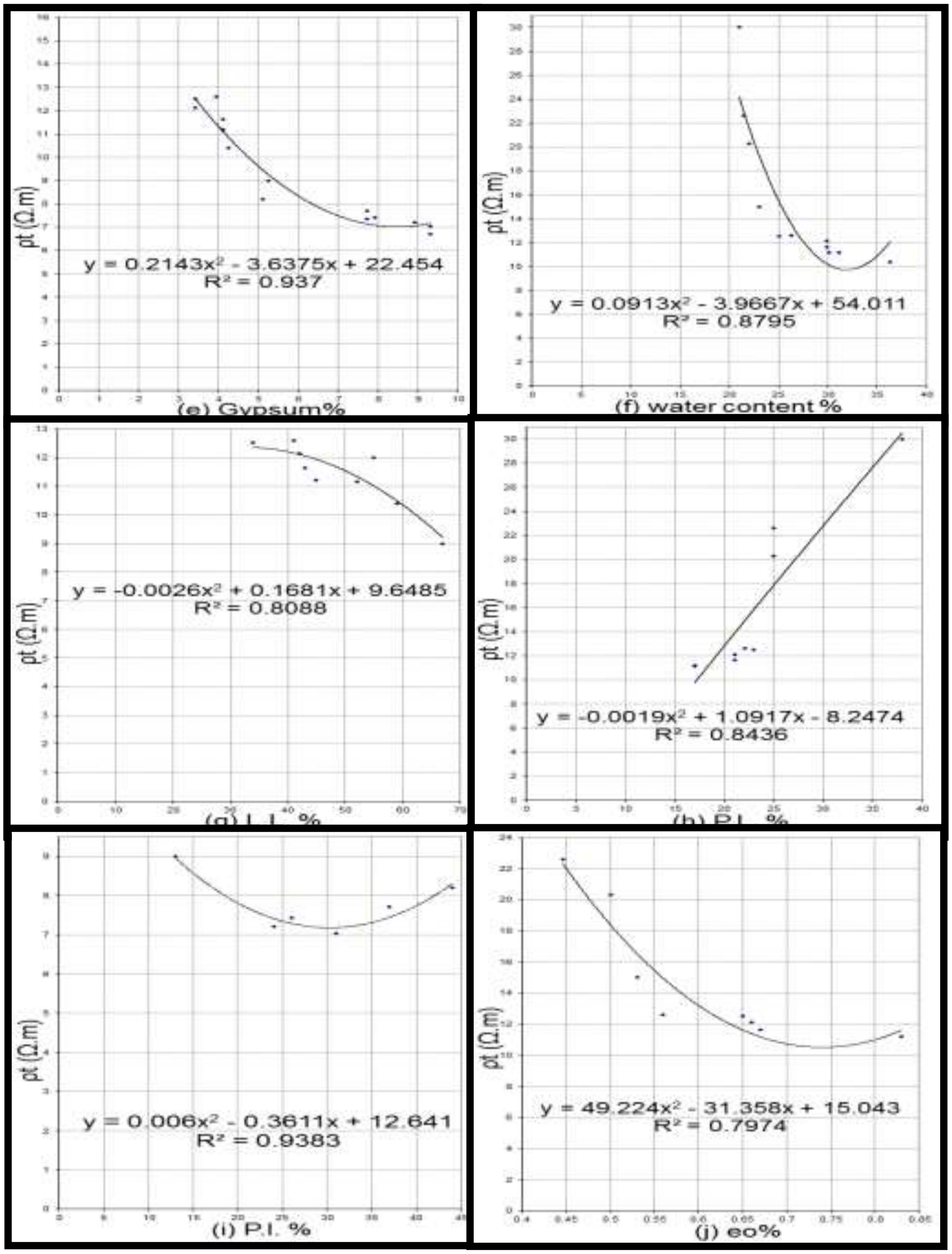


Figure (21) Relationships between true resistivity and some geotechnical properties (gypsum content, water content, L.L, P.L., P.I and e_o%).