

# Determining Soil Properties using Vertical Electrical Sounding: The Case Study of the Power Electrical Station Project in Al-Debony, Iraq

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## ABSTRACT

A one dimensional electrical survey was carried out in Al-Debony District, about 30 km from the west of Wassit Governorate center. The survey includes three profiles of 30 m long. Each of these profiles consists of three Vertical Electrical Sounding (VES) stations with a separation distance equal to 10 m. The Schlumberger array is used in this paper according to the aim of the study. All obtained data were processed using IPI2WIN software to get the best match between the field curve (after their smoothing) and the theoretical one. The given types of VES curves, for all stations, are shown as HK, KQQ, KHK, HKQ, and HKH. The soil and the presence of different types of water caused a change in electrical resistivity, which is why these curves differed in type. The findings revealed that each sounding station has four to five zones, which illustrate how the resistivity values change with depth. In addition to the salty water and the depth relationship, the low readings indicate the existence of clay layers. Some VES have high resistivity values, suggesting the presence of sand and silt sediments with reduced water salinity as depth increases. Some VES have high resistivity values, which indicate the presence of sand and silt sediments with reduced water salinity as depth increases. There was a good agreement between the data obtained and the information provided from the soil test and borehole sampling. On the other hand, because of the layer's deposition, the salt of the water, and the impact of the lower water table, the topsoil and center portion of the site have high resistivity values.

**Keywords-**soil properties; vertical electrical sounding; power electrical station; Al-Debony district; Iraq

## I. INTRODUCTION

The Al-Debony Power Electrical Station Project is situated in the Al-Debony District, Wasit Governorate, between latitudes 32° 46' 15.92" N and 32° 28' 17.15" N and longitudes 45° 05' 3.74" E and 45° 05' 5.07" E, as shown in Figure 1. Given that the study area contains recent alluvial sediments from the two rivers, Tigris and Euphrates, the Wassit Governorate (Al-Debony District) forms a part of the Mesopotamian Floodplain. In addition, depression-fill deposits have accumulated as a result of several floods.

The main soft layers of silt, clay, silty clay, and fine sand are found in several areas of the Wassit Governorate, including the site under investigation. VES is one of the important electro-geophysical methods widely used in field surveys. It depends on the variation of resistivity values in vertical and horizontal trends with depth. Also, it is widely used for most engineering purposes due to the accuracy of its results in interpreting most problems at different depths [1]. In such an area, the electrical resistivity technique investigation can be deployed to delineate fault and fracture systems to facilitate the

design of engineering structure [2]. Detecting the existence of a geological structure, such as a fracture system, and its spatial continuity in the subsurface is, however, a major drawback for geotechnical investigation.

The electrical resistivity technique deals with the assessment of the engineering performance of sub-soil and rock related to the foundations of roads, railway lines, buildings, tunnels, and power plants. Foundation investigation methods, such as boring, drilling, pitting, and trenching are often costly, invasive, and time-consuming. In contrast, the engineering electrical resistivity technique offers a less laborious, cost-effective alternative that provides accurate results without disturbing the earth materials [3]. The current study uses the VES method to determine the soil properties and cross-section for a site of the Al-Debony station under construction. This method is important for studying the site and reducing the cost of soil investigations by minimizing the number of boreholes required to determine the soil profile and engineering properties.

## II. GEOLOGICAL SETTING

The geological map of the study area consists of approximately 90% Quaternary deposits. Pre-quaternary rocks belong to the Miocene and Pliocene ages (fatha, Anjana, and Muqdadiyah formations). Structurally, the map area lies within both the east-central part of the Mesopotamian Zone and the southwestern part of the Foothill Zone (Makhoul Sub-zone). These two zones represent the outer and central units of the Unstable Shelf of the Nubian-Arabian Platform [6].

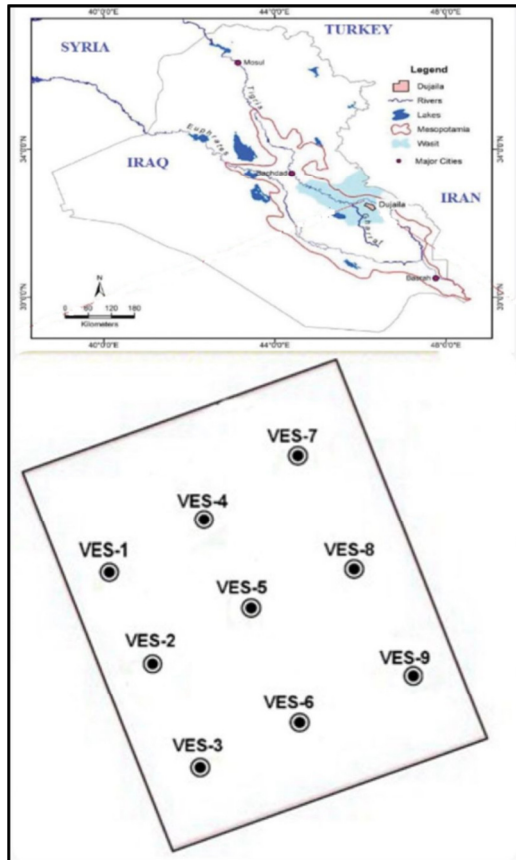


Fig. 1. Location map of Al-Debony power electrical station project in Wassit Governorate.

The study areas have been affected by late regional tectonic movements, which caused the uplifting of the Hemrin Structure in the Foothill Zone and the development of an asymmetrical syncline in the Mesopotamian Zone [4].

### A. Floodplain deposits (Holocene)

Lithologically, they are essentially composed of well bedded fine to medium-grain sand with thin silt and clay and then gradually transition into clay and silt.

### B. Valley Fill Deposits (Holocene)

These deposits are poorly sorted, primarily due to alternating intense floods and abrupt drops in flow, which caused wide variation in grain size and composition. Lithologically, they consist of gravels, sands, and silt, with grain size decreasing downstream. The total thickness of the

valley fill deposits is unknown, but it does not exceed a few m [5]. Figure 3 depicts the layer succession profile at the site, used in this study.

## III. MATERIALS AND METHODOLOGY

VES is a widely employed technique in electrical resistivity surveying, where current and potential electrodes are placed along a straight line with increasing separation to determine variations in resistivity with depth for near-horizontal layers of formation beneath the ground surface. Nine VES stations are distributed along three traverses, located within the electrical power station site.

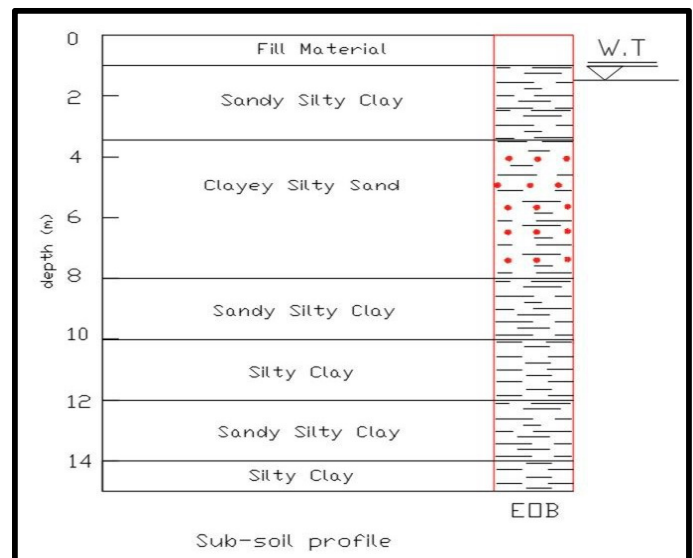


Fig. 2. Layer succession profile at the investigation site.

The VES measurements are carried out by injecting electrical current into the subsurface through two current electrodes and measuring the potential difference across two potential electrodes. The maximum spacing of current electrodes (A and B) is 100 m. The field investigation was conducted on November 1, 2021, using the ABEM electrical instrument type LS2. The instrument belongs to Al-Mawal company for soil investigation. As a part of the project, the relevant authorities selected a site for drilling a key borehole with a maximum depth of 15 m. The customer selected a boring depth that would reach below the zone where significant foundation pressure was exerted on relatively incompressible materials. Therefore, the drilling depth was ten m below the ground surface [8, 9].

A mechanical method using flight augers was employed for the drilling and sampling at the site. Drilling was performed based on the American Society for Testing Materials (ASTM D-1452–D5783) standards, which are utilized to collect the samples [7, 12]. Three different kinds of samples were collected, as per ASTM D-1586. The first type was a disrupted sample, denoted by the sign DS [10], whenever necessary to classify the soil layers at intervals of 0.5 to 1.5 m. Every disrupted sample was forwarded to the lab for additional analysis and testing.

The second type, designated "SS," was taken from a split spoon of a standard penetration test that was conducted on-site and was also used as an undisturbed sample. The third type, designated "US," was also undisturbed and obtained according to ASTM D-1587 at 1 to 2 m intervals or whenever the strata shifted to cover every stratum [10]. Following extraction, the damaged sample was cut off, sealed at both ends with paraffin wax or plastic bags, and sent to the lab for additional testing and analysis. The profile of the soil is brownish, sandy to silty clay soil, of medium consistency and grayish, clayey and silty sand soil, of medium density [11].

#### IV. DATA PROCESSING AND INTERPRETATION

After conducting the electrical survey, processing was carried out to enhance the field curves using a smoothing method. The distortions in the field curves can be produced by a variety of factors, including equipment failure, measurement mistakes, and lateral ground in-homogeneities [13, 19]. Log-log paper of cycle 6.25 cm was used for drawing and curve interpretation. To obtain a clear image of the subsurface zones, the distortions in the field curves must be eliminated. Numerous steps must be followed to automatically interpret the field data using the IPI2win application once it has been processed. It should be noted that these stations exhibit nine field curves. Each curve consists of several electrical layers, which represent the resistivity values with depths. These layers are compared with the drilling and with different sampling tests [14], to transform these curves into geo-electrical curves. Two methods of interpretation have been utilized:

##### A. Automatic Interpretation

Field data were obtained for the subsurface zones, reflecting changes in resistivity values with depth, influenced by various properties of the soil layers as well as the quality of the groundwater present in these zones [15, 16]. The field curves were treated with a smoothing process to remove the noise resulted when measurements were taken at the stations. Most of the errors affecting these curves are caused by various factors, such as objects near the surface, high-voltage electrical lines, device-related issues like cable faults, and soil heterogeneity near the surface, all of which can produce distortions in the curves, including cusps, sharp points, and displacements [17, 18].

##### 1) Interpretation of Vertical Electrical Sounding Stations 1 and 2

Figure 3 shows the field and theoretical curves that have been matched automatically by using a program [7, 12], with an error rate of approximately 1.12-2.3 %. From the VES of station 1, it can be noticed that the resistivity characteristic is revealed as ( $\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$ ), and the field curve type is classified as HKH, indicating five electrical layers (zones) with different resistivities. The thickness of the first zone is 1.879 m, with a resistivity value of 14.4  $\Omega\cdot\text{m}$ . This first zone represents the topsoil. The resistivity value of the second zone is 11.96  $\Omega\cdot\text{m}$  at a depth of 1.88 m (i. e thickness of 2.02 m). The sample and its tests of the drilled well indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil. At a depth of 3.9 m, the resistivity value in the third zone is 13.67  $\Omega\cdot\text{m}$ . This zone has a thickness of 13.6 m and is

composed of medium-density, stiff-consistency (CL) clay soil, interlayered with silty clay, and a mixture of clayey sand, silty sand, and clay. At a depth of (17.5) m with a thickness of 20.1 m, the resistivity value of the fourth zone is 8.07  $\Omega\cdot\text{m}$ , while the depth to the fifth zone is 37.6 m and resistivity 10.7  $\Omega\cdot\text{m}$ . This zone consists mostly of sandy clay with interbedded silt.

At VES Station 2, the resistivity pattern is observed as ( $\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$ ) and the field curve type is classified as HKH, consistent with VES Station 1. After having this curve, five zones were obtained according to their resistivity values. The thickness of the first zone is given as 1.36 m with a resistivity value of 14.8  $\Omega\cdot\text{m}$ . It is considered a topsoil zone. The resistivity value of the second zone is 6.09  $\Omega\cdot\text{m}$  at a depth of 1.36 m, with a thickness of 2.35 m.

The sample and its tests indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil. At a depth of 3.7 m, the resistivity value in the third zone is 17.3  $\Omega\cdot\text{m}$ . This zone is 14.6 m in thickness and is composed of medium-density, stiff-consistency (CL) clay soil with silty clay layers and a mixture of clayey sand, silty sand, and clay sediments. At a depth of 18.3 m, the resistivity value of the fourth zone is 4.12  $\Omega\cdot\text{m}$  with a thickness of 22.1 m. It is made up of silt, clay, and sandy materials. However, the depth to the fifth zone was 40.4 m with a resistivity value of 14  $\Omega\cdot\text{m}$ , which is mainly composed of sandy clay.

##### 2) Interpretation of Vertical Electrical Sounding Stations 3 and 4

Figure 4 displays the field and theoretical curves that have been matched automatically by using the IPI2WIN program with an error rate of approximately 1.11-1.35 %. In VES Station 3, it can be observed that the resistivity characteristic appears as ( $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$ ) and the field curve is of type KHK, in which five electrical layers (zones) of different resistivities are shown. The first zone has a resistivity value of 5.8  $\Omega\cdot\text{m}$  with a thickness of 1.35 m. It represents the topsoil zone. The second zone has a resistivity value of 11.96  $\Omega\cdot\text{m}$  at a depth of 1.35 m with a thickness equal to 1.16 m. According to the sample and the test performed on it, this zone consists of sandy silt clay soil, and medium consistency (CL) layers.

At a depth of 2.41 m, the resistivity value of the third zone is 5.9  $\Omega\cdot\text{m}$ , with 6.72 m thickness. This zone consists of clayey and sandy silty sand and clay sediments, with medium density and stiff consistency (CL), in addition to the silty clay layers. At a depth of 9.13 m, the resistivity is 7.05  $\Omega\cdot\text{m}$ , with a zone thickness equal to 15.87 m. This zone consists of sand, clay, and silt overlapping. Finally, the depth to the fifth zone is 25.0 m, having a resistivity 4.17  $\Omega\cdot\text{m}$ . It mainly consists of sand, clay, and silt overlapping. VES Station 4 also shows consistency with VES Station 3, where the resistivity pattern is illustrated as ( $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$ ) and the field curve is KHK. The first zone has a resistivity value of 6.25  $\Omega\cdot\text{m}$ , with a thickness of 0.90 m.

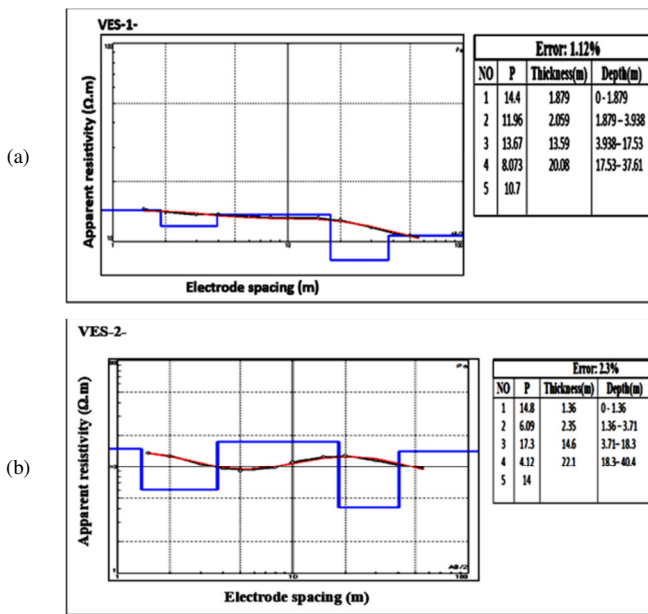


Fig. 3. Automatic interpretation of the field curves for VES stations (a) 1 and (b) 2.

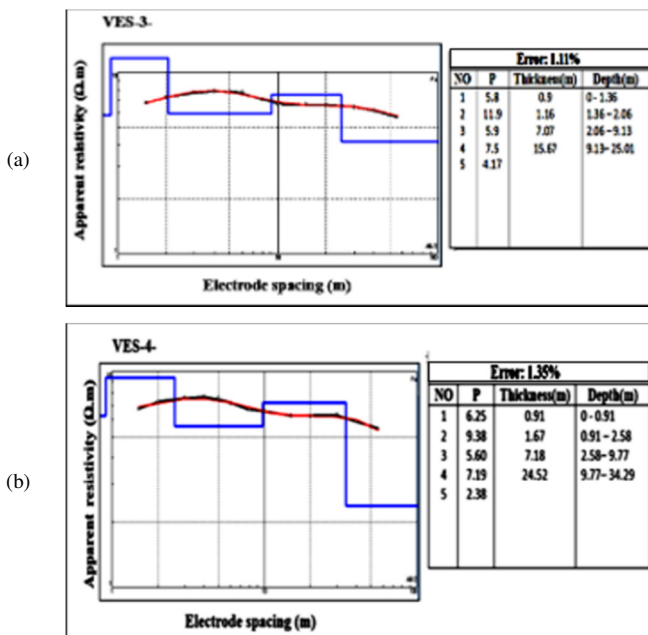


Fig. 4. Automatic interpretation of the field curves for VES stations (a) 3 and (b) 4.

The former is regarded as the topsoil zone. The resistivity value of the second zone is calculated as 9.38 Ω·m at a depth of 0.90 m with a thickness of 1.68 m. The sample and its test indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil. At a depth of 2.58 m, the resistivity value of the third zone is 5.6 Ω·m, with 7.18 m thickness and is composed of medium-density, stiff consistency (CL) clay soil with silty clay layers and a mixture of clayey in addition to the sand, silty sand, and clay soil. At a depth of 9.77

m, the resistivity value calculated for the fourth zone is 7.19 Ω·m, with a thickness of 24.52 m. This zone consists of silt, clay grey, red, and sand. Finally, the depth to the fifth zone is 34.29 m with a resistivity value 2.38 Ω·m. This zone is made up of silt, clay, and sand.

**B. Interpretation of Vertical Electrical Sounding Stations 5 and 6**

Figure 5 shows the field and theoretical curves that have been matched automatically by using the IPI2WIN program (17) with an error rate of approximately 2.28 %. In VES-5, the resistivity characteristic is shown as ( $\rho_1 > \rho_2 < \rho_3 > \rho_4$ ) and the field curve is of HK type in which four electrical layers (zones) of different resistivities are shown. The resistivity value of the first zone is calculated as 17.66 Ω·m, with a thickness of 2.1 m. It is regarded as a topsoil zone. The resistivity value of the second zone is 5.51 Ω·m at a depth of 2.1 m, having a thickness of 2.6 m.

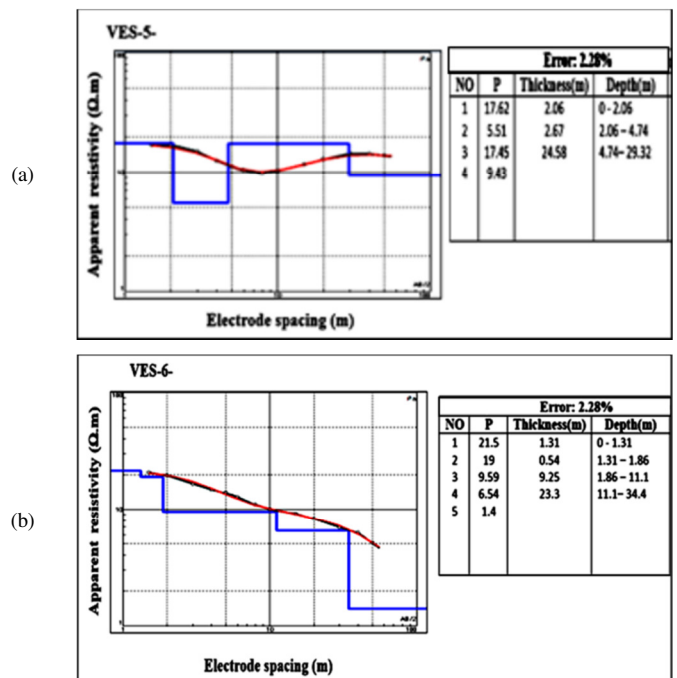


Fig. 5. Automatic interpretation of the field curves for VES stations (a) 5 and (b) 6.

The sample and its tests indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil. At a depth of 4.7 m, the resistivity value of the third zone is 17.45 Ω·m, with a thickness of 24.6 m. This zone is composed of a mixture of clayey sand, silty sand, and clay soil, having medium density and stiff consistency (CL). The depth of the fourth zone is 29.30 m with a resistivity value of 4.43 Ω·m. This zone consists of silt, clay, and sandy materials. Unlike the previously observed curve types, VES Station 6 is completely different, showing a QQQ-type field curve, where the resistivity pattern is revealed as ( $\rho_1 > \rho_2 > \rho_3 > \rho_4 > \rho_5$ ),

demonstrating five electrical layers (zones) with different resistivities.

The resistivity value of the first zone is calculated as 21.5 Ω·m, with a thickness of 1.3 m. It is regarded as a topsoil zone. The resistivity value of the second zone is 19 Ω·m at a depth of 1.3 m, having a thickness of 0.50 m. The sample and the tests conducted on it indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil.

At a depth of 1.8 m, the resistivity value in the third zone is 9.59 Ω·m, with medium density and stiff consistency (CL) and silty-clay layers. However, its thickness is 9.25 m and is composed of a mixture of clayey and sand, silty sand, and clay soil. At a depth of 11.1 m, the resistivity value of the fourth zone is 6.54 Ω·m, having a thickness of 23.3 m. It is made up of silt, clay, and sandy materials. The depth of the fifth zone is 34.3 m, with a resistivity of 1.4 Ω·m.

C. Interpretation of Vertical Electrical Sounding Stations 7 and 8

Figure 6 portrays the field and theoretical curves automatically matched using the IPI2WIN program, with an approximate error rate of 1.23–2.06%. In VES Station 7, the resistivity characteristic is shown as  $(\rho_1 < \rho_2 > \rho_3 > \rho_4 > \rho_5)$  and accordingly, the type of the field curve is KQQ, exhibiting five electrical layers (zones) with different resistivities. The resistivity value of the first zone is calculated as 26.7 Ω·m, with a thickness of 2.25 m. It is regarded as a topsoil zone. The resistivity value of the second zone is 3.05 Ω·m at a depth of 2.25 m, having a thickness of 2.23 m. The sample and its tests indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil. At a depth of 4.48 m, the resistivity value in the third zone is 19 Ω·m. It is composed of clayey and sandy, silty sand and clay soil, with a density of 1.72 g/cm<sup>3</sup> and stiff consistency (CL), with silty clay layers, and its thickness is 4.0 m.

At a depth of 8.48 m, the resistivity value of the fourth zone is 13.4 Ω·m, having a thickness of 20.2 m. It consists of silt, clay, and sandy materials. The depth of the fifth zone, on the other hand, is 28.68 m, with a resistivity value of 2.00 Ω·m. This zone consists of silt, clay, and sandy materials. According to the resistivity pattern  $(\rho_1 > \rho_2 > \rho_3 < \rho_4 > \rho_5)$ , VES Station 8 shows an HKQ-type field curve, with five electrical layers (zones) of different resistivities. The resistivity value of the first zone is calculated as 18.36 Ω·m, with a thickness of 2.06 m. It is regarded as a topsoil zone. The resistivity value of the second layer is 17.83 Ω·m, which exists at a depth of 2.06 m, and has a thickness of 9.19 m. The sample and its tests indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil. At a depth of 11.25 m, the resistivity value of the third zone is 18.36 Ω·m. It is composed of clayey and sandy, silty sand and clay soil, having a density of 1.72 g/cm<sup>3</sup> and stiff consistency (CL), with silty clay layers. It should be noted that the thickness of the zone is 11.63 m.

At a depth of 22.88 m, the resistivity value of the fourth zone is 8.21 Ω·m, with a thickness of 39.72 m. It consists of sandy, clay, and silt overlapping. Finally, the depth of the fifth zone is 62.6 m, with a resistivity value of 7.72 Ω·m.

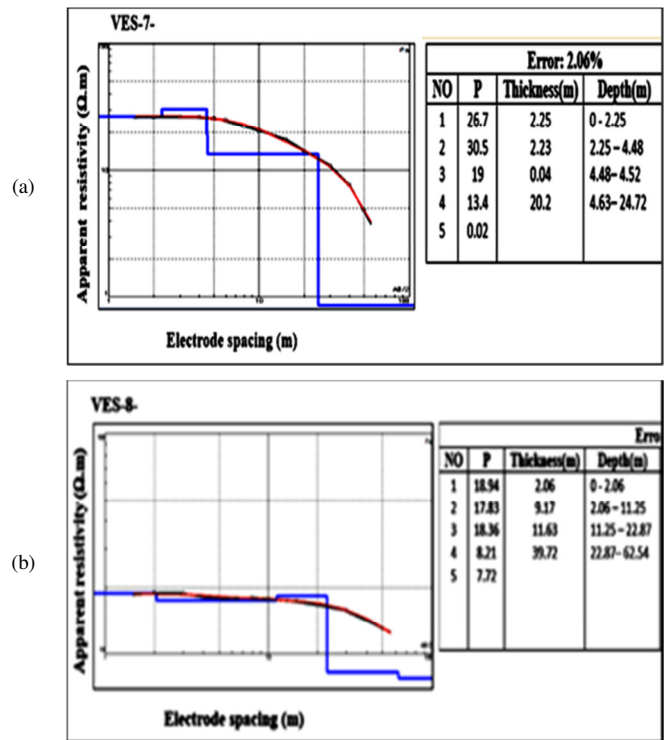


Fig. 6. Automatic interpretation of the field curves for VES stations (a) 7 and (b) 8.

D. Interpretation of Vertical Electrical Sounding Station 9

Figure 7 displays the final measuring station, represented by VES Station 9. According to the resistivity pattern  $(\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5)$ , the type of the field curve is KHK, with five electrical layers (zones) of different resistivities.

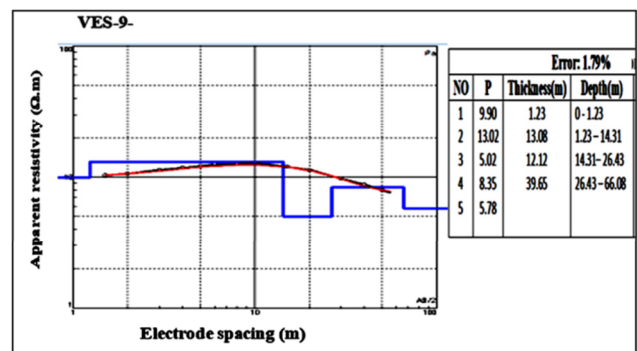


Fig. 7. The automatic interpretation of the field curves for station VES 9.

The resistivity value of the first zone is calculated as 9.9 Ω·m, with a thickness of 1.23 m. It is regarded as a topsoil zone. The resistivity value of the second layer (zone) is 13.02 Ω·m, which exists at a depth of 1.23 m, and has a thickness of 11.85 m. The sample and its tests indicate that this zone is composed of medium consistency (CL) layers of sandy silt clay soil. At a depth of 13.08 m, the resistivity value of the third zone is 5.02 Ω·m, having a thickness of 13.35 m. This zone

consists of clayey and sandy, silty sand, and clay soil, with a density of  $1.72 \text{ g/cm}^3$  and stiff consistency (CL), even with silty clay layers. At a depth of 26.43 m, the resistivity value of the fourth zone is  $8.35 \text{ } \Omega\cdot\text{m}$ , with a thickness of 39.65 m. It is made up of silt, clay, and sandy materials. Finally, the depth to the fifth zone is 66.08 m with a resistivity of  $5.78 \text{ } \Omega\cdot\text{m}$ . It is made up of silt, clay, and sandy materials.

V. PSEUDO-CROSS-SECTION OF THE VES STATIONS

The pseudo-cross-section of the VES stations represents the distribution of resistivity values in both horizontal and vertical directions, which may reflect the physical properties of the sediments in various engineering fields. It also indicates the extent of their impact on engineering projects that require soil improvement techniques and testing methods for the bearing strength of these layers [15, 16]. The IPI2win software was used to clarify the distribution of the variation of resistivity values for all VES stations. Figure 8 shows the resistivity values for the nine VES stations with the depths. Three parallel cross-sections for the VES stations were drawn, labeled as displayed in Figure 8. Generally, each profile represents the

distribution of resistivity values for both depth and horizontal distances, which may reflect many variations that affect these resistivity values [13, 20].

All these cross-sections provide an apparent picture of the area and may represent the floodplain deposits with sequential layers, where the resistivity values decrease, with clay and silty clay being dominant. This is reflected in the decreasing resistivity values, especially in the center of profile A and along the sides of profiles b and c in Figure 8.

A. Pseudo-cross-section of Vertical Electrical Sounding Stations 1, 2, and 3

The pseudo cross-section of this profile comprises three VES stations, namely 1, 2, and 3. It can be noted that the low resistivity values are distributed in the center of the profile due to the resistivity value reflection of VES Station 2, whereas the high resistivity values were distributed on both sides, as seen in Figure 8(a). The variations in these values are due to the lithology of the layers, saline water in the soil, and even the presence of dry sand and silt, especially in the topsoil above the water level.

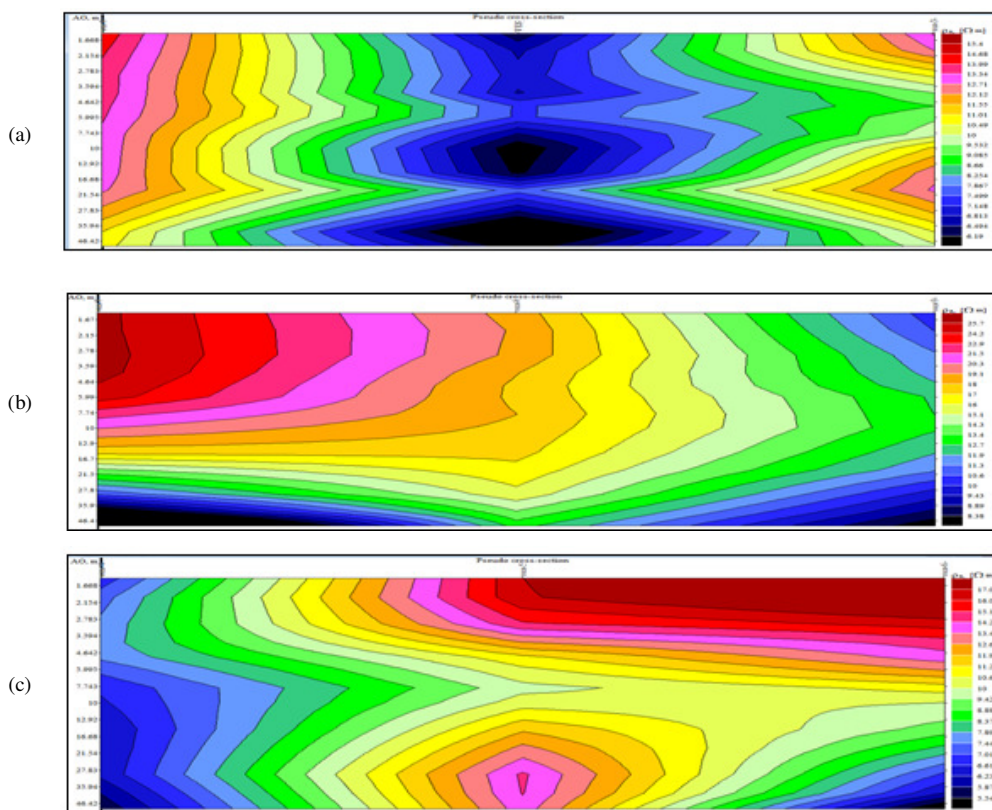


Fig. 8. Pseudo-cross sections of all VES stations.

B. Pseudo-cross-section of Vertical Electrical Sounding Stations 4, 5, and 6

In this profile (Figure 8(b)), the pseudo-cross-section of VES-4, VES-5, and VES-6 shows a low resistivity distribution on the right side and below the section, while the trend to the

left exhibits high resistivity values. The variations in these values are related to the lithology, saline groundwater, the effects of the rivers near these stations, and the presence of dry sand and silt, especially in the topsoil above the water table.

### C. Pseudo-cross-section of Vertical Electrical Sounding Stations 7, 8, and 9

The pseudo-cross-section of this profile is composed of VES Stations 7, 8, and 9. It can be noted the low resistivity values are distributed conversely with that section, where the interpretation of the resistivity cross-sections occurred. It can be observed that there are many low resistivity regions (red color) in the sections where subsurface zones do not continue horizontally, as portrayed in Figure 8(b). In contrast, high resistivity values are distributed in the central part of the cross-section in Figure 8(c), which is the opposite of the section shown in Figure 8(a). The variations of these values are due to the lithology of the layers, water salinity, the presence of dry sand, and silt, especially in the top soil above the water level.

The pseudo-section represents the variation in resistivity values in both horizontal and vertical directions. Each pseudo-section contains three measurement stations, which produce a field curve that is interpreted into five zones, representing the variation in resistivity with depth. This variation reflects lithological properties, as well as factors, such as porosity, grain size, and water content. The interpretation of the subsurface resistivity cross-section considers the high resistivity similar to that of fill materials and sand-bearing clay deposits. This is followed by a clay-rich sand layer saturated with water. Then a third layer of sandy clay with low resistivity with moisture content is followed by a clay layer with low resistivity. This interpretation is consistent with both the change in lithology and the moisture level.

## VI. CONCLUSION

Based on the results derived from processing and interpreting field data, obtained from the nine Vertical Electrical Sounding stations (VES), the following conclusions can be drawn:

The results showed the existence of four to five geo-electrical zones, which were distinguished based on their specific resistivity characteristics from the electric field curves, (HK, KQQ, KHK, HKQ, and HKH). These curves explained the nature of the gradual change in the apparent resistivity values of the sediments with depth, which reflects the change in the thickness of the clay and sand deposits inside the soil layer and the difference in their physical properties. Also, the results of the qualitative interpretation demonstrated that the region is divided into zones according to the type and shape of the electric field curve. This provides an initial picture of the nature of the region and explains that the results indicate the presence of varying areas in terms of electrical resistance, reflecting changes in the thickness of the sedimentary layers and their physical properties.

Regarding the effect of water and clay content on electrical resistance, it is observed that as clay increases electrical conductivity, resistance is reduced. The presence of areas with a high percentage of clay and saltwater causes a decrease in electrical resistance with depth. Soil electrical resistivity depends on various soil properties, such as salt, water, texture, and temperature. In many applications, one or two highly variable properties can be considered the main factors influencing the profile distribution of electrical resistivity.

Generally, the VES method can be used for geotechnical studies by analyzing the distribution of electrical resistivity in the soil profile of the Power Electrical Station Project.

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