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Subsurface Investigation Using Electrical Resistivity Imaging for Proposed Industrial Site near Erbil-Kirkuk Borders, Northern Iraq

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Abstract

The friendly-environment geophysical methods are commonly used in various engineering and near-surface environmental investigations. Electrical Resistivity Imaging technique was used to investigate the subsurface rocks and sediments properties of a proposed industrial site to characterize the lateral and vertical lithological changes via the electrical resistivity, to give an overview about the karst, weak and robust subsoil zones. Nineteen 2D ERI profiles using Wenner array with 2 m electrode spacing have been applied to investigate the specific industry area. One of these profiles has been conducted with one-meter electrode spacing. The surveyed profiles are divided into a number of blocks, each block consists of several parallel profiles in a specific direction. The positions of Electrical Resistivity Imaging profiles in the project area have been determined according to a preliminary subject plan from the civil engineers for factory foundation constructions and proposed locations of heavy machines. The inversion results of profiles showed that areas of blocks A, B, C, and D consist mainly of clastic rocks and sediments, e.g., claystone, siltstone and sandstone. The Electrical Resistivity Imaging inversion sections of blocks A, B, C, and D do not show any indication of cavitation or weak zones of sizes more than 2.0 meters, and no signs of gypsum bodies are found in these areas in general. Gypsum bodies are probably detected at block E, the southern part of the study area. The researchers recommended to keep these rocks in block E away from the continuous running water to avoid cavitation. Furthermore, the construction of heavy machines should keep away from this part of the study area to avoid to some extent, subsoil failure and subsidence in the future. Middle and Northern parts are more consistent to the constructions and factory foundations.

Keywords: Electrical resistivity imaging; Weak-zones; Industrial site; Gypsum layers

1. Introduction

In the last few decades, electrical resistivity imaging (ERI) or tomography (ERT) has been widely used as a pre-excavation reconnaissance geophysical technique in various near surface environmental and engineering explorations (Reynolds, 2011). This non-destructive geophysical method (ERI) is helpful in saving time, efforts and costs, for example, the geophysical methods can cover a large area in a reasonable time and with acceptable results (Al-Saadi et al., 2018). Measurement of the subsurface resistivity has been often applied in environmental prospection and numerous survey methods exist. The vast developments of various field techniques have increased the use of these geophysical methods and became indispensable in near-surface prospecting over the time. The fixed 4-electrode-array can be used to simply map the contrast of resistance, but often a 2D ERI is conducted. Previous studies have shown

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that ERI has the capability to guide engineers effectively to allocate and dig the constructions in the right target position. Some researches in Iraq used electrical resistivity techniques to investigate the shallow-depth fracture and cavity structures.

Abed et al. (2021), conducted 3D to study the cavity area inside gypsum rocks near Hit city, Western Iraq. They constructed the 3D models using four parallel 2D ERI profiles with Dipole-dipole array. Their ERI inversion results show the dimensions of the cavity, which is distinguished as a high-resistivity body comparing to the surrounding rocks and sediments. Salman et al. (2020), carried out 2D electrical resistivity technique using Dipole-dipole and Pole-dipole arrays with a 2 m electrode-spacing, in order to investigate weak zones (fractures, voids and cavities) in the subsurface Gypsum layer and gypseferous soil in the University of Al-Anbar, western Iraq. They identified these layers and determined the ranges of zones which were between 9.5 -11.5 m thickness. They also concluded that dipole-dipole array provides better subsurface image than pole-dipole array due to the best data coverage. Abed and Thabit (2016), investigated K-3 cavities using 2D Resistivity Imaging Technique in Haditha area, Western Iraq. The resistivity data collected along two inter-crossing profiles above the cavity with 105 m length of each profile. In their survey, they used a dipole-dipole array with 5 m electrode-spacing and identified the resistivity contrast between the anomalous part of cavity and resistivity background of rocks, which was about 800:100 Ω .m. In addition, the depth of K-3 cavity was identified which was about 11 m and they compare it with the actual depth of this cavity which was approximately equals to 11.5 m. In fact, the current study area and its surroundings are susceptible to risks derived from the dissolution processes of the gypsum and carbonate subsurface materials present, hence, it would be useful to conduct reconnaissance geophysical surveys and produce subsurface images corresponding to the susceptibility and danger of stability. However, there is no record of electrical resistivity surveys performed within and surrounding the current study area related to the subsurface rock rigidity and karstic risks.

The objective of this work is to investigate the shallow-depth subsurface geologic features in detail using ERI survey technique, i.e., delineate the lateral and vertical lithological changes by characterizing the distribution of the resistivity, to give an overview about the karst, weak and robust subsoil zones in general. This study will provide a preliminary geotechnical assessment to the subsurface soil and structures, which will assist the civil engineers, to a large extent, in selecting the suitable area to construct the foundations and allocate the machine and heavy structures of the factory properly, for the next work plan. Therefore, to avoid to a some extend, any geotechnical construction settling and failure in the future. This work is integrated in parallel with any available geologic information within and around the study area, such as outcrops and digging trenches if possible.

2. Tectonic Setting of the Study Area

In general, the study area tectonically is located within the low folded zone, which represents part of the Western Zagros Fold-Thrust Belt (WZFTB) of the outer platform of Arabian platform for Iraqi Territory (Aqrabi et al., 2010; Jassim & Goff, 2006). In particular, the study area lies within the Kirkuk subzone, the southeast integral part of the low-folded zone (Foot-hill Zone) (Fig. 1a) (Aqrabi et al., 2010; Fouad, 2014). The low-folded zone represents the start of the morphologic and the topographical front features of the WZFTB. This zone comprises of series of largely spaced, low magnitude gentle folds. Structurally, the WZFTB zone consists of many relatively narrow long anticlines, which are Makhmur and Qarachogh structures and represent parts of these anticlines, which are separated by wide synclines, mostly in the NW–SE direction (Aqrabi et al., 2010; Fouad, 2014; Jassim and Goff, 2006; Sissakian et

al., 2015). Most of these topographic features e.g., Synclines, are covered by Middle the Miocene-Pleistocene sediments (Aqrabi et al., 2010; Sissakian et al., 2015).

Fig. 1. a) Location of the study area within the Tectonic Map of Iraq; b) Location of the study area

within the Iraqi Geologic Map, after Aqrabi et al., (2010)

3. Stratigraphy of the Study Area

The stratigraphy studies for the current study area showed the dominating of several stratigraphic formations mainly related to the Middle Miocene - Pleistocene geological ages, as mentioned before in previous studies section (e.g., Sissakian and Al-Jibouri, 2012). Fatha, Injana and Mukdadya formations are the main stratigraphic succession exposed or even extended widely in the subsurface within and around the study area (Fig. 1b), (Aqrabi et al., 2010). These beside various types of Quaternary sediments (clastic sediments), which are deposited in some parts around the study area (Sissakian et al., 2015). The Fatha Formation (Middle Miocene) is outcropped fairly within and around the study area and extended widely in the subsurface as well. The ideal lithologic units of the Fatha Formation consist of cycles of red claystone, reddish brown or green marl, gypsum and interbedded with limestone (Sissakian and Abdul-Jabbar, 2005; Sissakian and Al-Jibouri, 2012; Sissakian et al., 2015). Further, in the study area, Injana Formation (Late Miocene) is outcropped widely. The lithologic units of this formation in ideal cycle are consisting of brown claystones, reddish-brown siltstones interbedded with brown and grey sandstones. Furthermore, Mukdadya Formation (Late Miocene - Pliocene) emerged in some parts within and around the studied area. The Formation consists of a succession of brownish-grey claystones with pebbly sandstones, mostly grey, and grey to brown siltstones layers as well (Sissakian and Al-Jibouri, 2012; Sissakian et al., 2015). We highlighted the geologic formations within the study area and environs in details, this is because of the importance of the mentioned lithologic units as raw materials, which can be exploited and used in different materials building industry factories.

4. Principles of Electrical Resistivity Method

Electrical Resistivity surveying technique is one of the oldest geophysical methods which is used to characterize the conductivity of the subsurface soil and structures (Reynold, 2011). The quantity of electrical conductivity σ (or its reciprocal, the resistivity ρ) of earth components is specified by the number of conductive materials, such as, metallic conductors and interconnection of aqueous fluids (Everett, 2013; Loke, 2021). In electrical resistivity surveys, an electrical current is inserted into the ground with two conductive electrodes (commonly denoted as C1 and C2 or A and B), and the potential difference resulting from the current flow is measured with two other separate electrodes, denoted as P1 and P2 or M and N (Loke, 2021). A single reading yields Ohms Resistance (Eq. 1):

$$R = \frac{U}{I} \quad (1)$$

Therefore, R is depending on the distribution of the subsurface resistivity and on the geometry (i.e., configuration) of the electrode arrays. The relation between resistance and resistivity is represented by a geometry factor K (Eq. 2):

$$\rho = KR \quad (2)$$

where K represents the geometry of the electrode array. For a homogeneous half-space medium, Eq. (2) yields the true resistivity of the ground medium. In fact, in the presence of heterogeneities in resistivities, Eq. (2) represents the apparent resistivity, $\rho = \rho_a$. The measured apparent resistivities of several readings obtained from overlapping electrode arrays can be inverted to subsurface resistivity sections or images by solving an inverse tomographic problem. In field surveys, a large number of individual resistivity measurements with multiple electrode arrays are conducted to obtain proper estimation of the subsurface resistivity distribution by means of non-linear regularized inversion techniques. The main objective of inversion is to define a resistivity model that explains the field measured data (Al-Saadi et al., 2018).

5. Instrumentation and Fieldwork

A multi-channel Terameter LS 140 with four channels measurements has been used as a resistivity meter in the field survey, which is manufactured from ABEM-Sweden company. Four wheel-cables with the 21 takeout for each cable have been used with 84 steel conductive electrodes utilized in total. The geophysical fieldwork surveying was conducted in winter (2015), and it took about seven working days in general (Fig. 2a). The geographic coordinates of the corners of the study area have been shown in Fig. 2b. Nineteen 2D ERI profiles have been surveyed during that time. The positions of ERI survey lines in the study area have been determined according to a preliminary subjected plan from the civil engineers for factory foundation constructions. So, profiles locations were selected to be as close as possible to the heavy structures' positions from the proposed engineer's plan. We displayed the 19 surveyed profiles in the study area as number of blocks, each block may consist of one (e.g., block E) or more parallel profiles depending on the accessibility and required information, e.g., block A (3); block B (4); block C (5) and block D (5) ERI surveyed profiles. Two survey orientations were selected for the ERI profiles; one in the northeast direction, i.e., along the rock's layers dip direction, and the second was in the northwest direction, i.e., along the strike of rock's layers (Fig. 2b). For the setups of eighteen ERI profiles, two meters electrode-spacing have been employed, which covered about 160 m length in total for each individual surveyed profile, and we investigate about 25 m depth of penetration. In general, the distance between one to another surveyed profile was around 20.0 meters.

Fig. 2. a) Photograph of the ERI field work in the study area in 2015, b) Aeromap showing the distribution of Nineteen surveyed profiles which displayed as Blocks from A - E, each block consist of one or more parallel profiles, the black arrows show the survey direction of profiles

One of these profiles (block E) has been conducted with one-meter electrode-spacing, this in order to get more detailed subsurface image in a part of the studied area. However, due to the excavation work on this site, i.e., leveling and civil structures foundations; many offsets for the profile's locations were carried out. The Wenner configuration has been employed in profile surveying, this is because the lateral subsoil variation and weak zones detection are the main targets of this survey, as mentioned before. The Wenner array is good in depicting vertical changes as well, i.e., resolving horizontal structures, and has better Signal/Noise among the other electrical resistivity arrays (Dahlin and Zhou, 2004; Loke, 2021). The acquired data are analyzed and checked directly in the field, whereas the Terrameter Ls equipment can show a preliminary 2D image, i.e., pseudo-section of the distribution of resistivity data on its screen after the measurement directly.

5.1. Data Processing and Inversion

For preliminary processing of the measurements, the resistivity data acquired from the survey were prepared with proprietary software from the instrument manufacturer (Prosys II, from Iris Instrument). The main steps include: checking the distribution of the resistivity in pseudo-sections and masking of data outliers. The 2D model interpretation was performed using the new version of software package "RES2DINVx64" version 4.08 from Geotomo Software. It performs smoothness-constrained inversion using finite difference forward modeling method and Quasi-Newton techniques. The same inversion process was carried out for the 19 profiles. Typically, a convergence of the data fit was reached after 4-5 iterations. The data fit is expressed in root mean squared (RMS) error, which represents the relative difference between the calculated apparent resistivity response and the measured model data (Al-Saadi et al., 2018; Chirindja et al., 2016). The sections with the lowest RMS error are displayed.

Unified color scale was used for all inversion displays, in order to show the low and high resistivity locations in all inverted ERI sections. The dark blue-blue colors are for resistivity values equal or less than 50.0 ohm.m, while the red and dark red colors are for resistivity values more than 300.0 ohm.m (Figs. 3 & 4). The main features of the ERI models were identical in all inversion runs. All inversion models display a wide range of resistivity values ranging from 4 to 500 ohm.m, and depict the subsurface down to a depth of around 25 m, except the high-resolution ERI profile of one-meter electrode spacing, which depict the subsurface down to a depth of 13 m in total.

6. Results and Discussion

The ERI survey of industrial factory project area is divided into five blocks as mentioned before (Fig. 2b). These blocks represent the suggested location of heavy and sensitive factory structures. Accordingly, the resistivity tomography inversion results will be discussed and interpreted for each individual block as following:

6.1. Block A

Four 2D ERI profiles are conducted at block A area. Three profiles are in NW direction and one profile in NE direction. The profile numbers are 21, 22, 23 and 24. Fig. 3 shows the ERI inversion sections for profiles 21, 22, and 23. They show resistivity contrast values ranging from less than 4.0 ohm.m to ≈ 500.0 ohm.m in general. The high resistivity subzones are restricted to the upper 7.0 meters of the sections. These high resistivity features probably correspond to the sandstone and sandy siltstone rock layers of few meters' thicknesses. However, at depth deeper than 7.0 meters all clastic rocks layers show resistivity values less than 150.0 ohm.m. Apparently at these depths the moisture content, i.e., water saturation has great and direct impacts. The clastic rocks features show different resistivity contrast and great heterogeneity near the surface, which is probably due to the different moisture content as well. In other word, the high resistivity spots (dark red – red-brown colors) are corresponded to the dry sandstone or sandy siltstone rocks inclined layers. This situation became more pronounced in profile 24, which is along the dip direction of these rocks. The lateral variation in the resistivity can be noticed clearly in this inversion section (Fig. 4). No clear evidence of cavitation or weak zones at block A area can be detected till down to a depth of 25.0 meters in general.

Fig. 3. The electrical resistivity variations along profile 24 from block A, which is in the SW-NE survey direction

Fig. 4. The electrical resistivity variations along profile 24 from Block A, Which is in the SW-NE survey direction

6.2. Blocks B and C

Nine 2D resistivity profiles were surveyed at these two blocks. However, at block B the area was not entirely suitable for the survey due to the construction work and foundation excavations. Therefore, offset of profile's locations were done to avoid to some extend the work activities. Fig. 5 shows the NE-direction profiles, which are profiles 15, 16 and 17, the lateral variation in resistivities near the surface to down to a depth of 7.0 meters are more pronounced. The horizontal anomalies shapes are almost disappeared for these inversion sections. Sandstone rock-layers are probably encountered along these profiles. They show high resistivity values that reach to about 500.0 ohm.m (Fig. 5).

Fig. 5. The electrical resistivity variations along profile 15, 16 and 17 from Block B, Which is in the SW-NE survey direction

However, Fig. 6 shows the ERI inversion sections of profiles 12, 14, 18 and 19. The other two profiles in this block have almost the same subsurface features. These were in NW survey direction. These sections show that the first 7.0 meters of lateral variation in electrical resistivity values, though it is not those strong variations. They also show horizontal anomalies shapes that correspond to the horizontal or nearly horizontal bedding, since these profiles are along or nearly along the rock's layers strike direction. The resistivity values here are ranging between 4.0 ohm.m to 500 ohms.m. The area is

probably covered by claystone to siltstone rock layers. At depth more than 7.0 meters the resistivity values are almost similar with values less than 90 ohm.m.

Fig. 6. The electrical resistivity variations along profiles 12, 14 and 18 from Block C, which is in the SE-NW survey direction

6.3. Block D

Five 2D resistivity profiles were conducted at the block D area. Fig. 7 shows the inversion sections along profiles 7, 8, and 9, which were in NW-SE survey direction. The resistivity inversion results show near surface lateral variations down to a depth of 7.0 meters. The horizontal layering is also pronounced in these sections, since they are nearly along the strike of the sediment bedding. They are not exactly parallel to the bedding strike, they have around 15° to 20° layer declination. Accordingly, the 2D tomography profile is running over many beds of claystone, siltstone, sandstone with thicknesses of several meters. These results explain the lateral. However, at depth of deeper than 7.0 meters, the moisture content of the clastic rocks is the main control of the resistivity. Therefore, the resistivity values are ranging between 10.0 ohm.m to ≈ 120 ohm.m (Fig. 7). On the other hand, the inversion resistivity sections along profiles 10 and 11 also show the near surface lateral variation and particularly for profile 10. While, profile 11 does not show clear lateral changes in the resistivity (Fig. 8). This profile is lying along small valley, which is covered by eroded soil and rocks debris. In general, there is no clear indication can be noticed for cavities or weak zones down to a depth of 25.0 meters. Variations and heterogeneity in subsurface resistivities.

6.4. Block E

Only one 2D profile was conducted at this block. This is because the leveling and excavation works at this sub-area. However, the result of the 2D resistivity imaging along this profile was interesting. It shows prominent anomalies which may be related to the gypsum layers (Fig. 9). One proposed gypsum layer of 3.0 to 4.0 meters is indicated at the middle of the inversion section (yellowish- brown to red color), which is near the surface.

Fig. 7. The electrical resistivity variations along three profiles within Block D, which is in NW-SE survey direction

While, the second proposed gypsum layer is detected at the end of this section and at a depth around 4.0-5.0 meters. This layer is probably subjected to the differential dissolvment, particularly when water level lies in or close shallow-depths Earth-layers (Abed et al. 2021; Abdulrazzaq et al., 2020). Sandstone layers are probably found here with claystone and siltstone. Apparently, there is a big change in the rock's lithologies toward the fold axis (toward SW-direction). No obvious gypsum layers/bodies are probably encountered at blocks A, B, C, and D. While at block E gypsum and sandstone layers are probably presence. The resistivity results do not reveal any indication of cavitation within these gypsum layers. However, at the trench, which is drilled near block E, there is a gypsum rocks at the facing end wall. It shows the effect of old erosion along old valley, which is covered by rocks debris. Such valleys are usually found at the mountain foot, i.e., at the southwestern parts of the project site area.

Fig. 8. The electrical resistivity variations along two profiles within block D in NE-SW survey

Fig. 9. The electrical resistivity variations along one profile within Block E in the NW-SE survey direction, which is in the southern part of the study area

In general, Fig.10 illustrates the general lateral variations of the surveyed profiles in different blocks and how it happens. The high inclination of the rock's layers, quick lithology variations and the limited thickness (several meters) are probably the main reasons for the lateral changes in the resistivity values, while the water-saturated rocks and sediments in the deeper depths are responsible for the low-resistivity features in the displayed sections.

Fig. 10. The Sketch of lateral Resistivity variation along the rocks and sediments earth-layers, which are generally dominated in the study area

7. Conclusions

The ERI survey results show that areas of blocks A, B, C, and D mainly consist of clastic rocks and sediments, e.g., claystone, siltstone and sandstone with relatively high-resistivity anomalies in the shallow depths. These identified lithologies were consistent with the stratigraphical information and rock outcrops of the study area. There are no Gypsum rocks are detected in these areas and down to a depth of 25.0 meters. The Lateral variation in resistivity values near the surface and down to ≈ 7.0 meters depth corresponds to the lateral variation in the rock's lithology from claystone to sandstone. At depths deeper than 7.0 – 8.0 meters, the contrast in the clastic rock's resistivity values is clearly reduced, due

to the increment of the moisture content. The rock resistivities at those depths are ranging between 5.0 ohm.m to 120.0 ohm.m in general.

The ERI survey inversion sections of blocks A, B, C, and D do not show any indication of cavitation or weak zones of sizes more than 2.0 meters in diameter, and down to a depth of 25.0 meters. Gypsum rocks are probably detected at Block E. These gypsum beds show a high inclination with a thickness of several meters. Sandstone and siltstone layers are more common at block E as well. It seems that the rock lithology is changing toward the fold axis, i.e., towards the S-W direction relative to the project site. High angle dipping gypsum beds can be found at this location (block E), and become more abundant toward the S-W direction. Fig. 9 shows the area that probably have surface and subsurface Gypsum beds. However, the resistivity survey result of block E in general, do not show any indication of subsurface cavitation of sizes more than 1.0 meter in diameter.

8. Recommendations

Most of the project site area is composed of clastic rocks and sediments. These probably should not show any cavitation problems. In turn, the southwestern part of the project site contains of some Gypsum rocks. Although, these rocks do not show any indications of cavitation more than 1.0 meters yet. Nevertheless, precaution should be considered for future solubility of these rocks. So, it is recommended to keep these rocks away from continuous running water, because direct contact of gypsum rocks/beds to the running water may lead to develop cavitation or/and weak-zones within relatively short time, or factory life time. Furthermore, the construction of heavy machines should to keep away from this part of the study area to avoid to some extent, the subsoil failure and subsidence. So, northern parts of the study area are more preferable for constructing the heavy machines and other important factory foundations.

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