Using 2D Electrical Resistivity Imaging to Evaluate Soil Investigations in Palm Towers Site of Al-Muthana Airport, Baghdad, Iraq

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Abstract

For engineering site investigations at Al-Muthana Airport land in Baghdad, Iraq, the two-dimensional electrical resistivity imaging method was used. The site investigation is important for figuring out the subsoil profile, weak spots, and groundwater level of possible production sites in the area. Wenner-Schlumberger array was used to survey six electrical resistivity spreads with a total length of 600m, a length of 100m acquired for each survey line, with a distance of 1m between electrodes. The depth of the investigation was 23.5 for each surveyed line. Robust inversion and model techniques showed that the values of resistivities were not all the same in the six inverted models. Based on the inverted models, the depth of the groundwater was found to be between 3 – 4 meters at the first site and about 4.5 meters at the second site, which is 1 m deeper than what was found in the geotechnical investigation report. Further, the top 1-1.5 m of sediments have different components, hardness, and moisture levels. So, the current study stated that this layer should be picked up and compacted before the foundation is built. Far down 1.5m, the layer seems to be wet, so a layer with low permeability must be added around the foundation.

Keywords: Geophysical engineering; Geotechnical investigation; 2D-Electrical resistivity imaging; Groundwater level

1. Introduction

Geophysical techniques may be applied to identify the range of physical properties at depths beneath the earth's surface representing the substances' local subsurface features (soil, rock, or water). As a quick and inexpensive way to gather information regarding subsurface stratification, these technologies are appropriate for use throughout the reconnaissance stage of a site study program. The data from boreholes and outcrops may be supplemented by geophysical research techniques, which can also be utilized to interpolate between different boreholes (Sivakugan et al., 2013).

Electrical resistivity surveys are one of the best techniques to evaluate soil resistance and underground resistivity dispersion. These measurements show the variation of ground resistance. Non-destructive and sensitive, the approach may describe subsurface characteristic. Electrical resistivity methods are used to investigate vertical and lateral variations in materials. The method may also be used to locate buried structures like cavities, pipelines, clay-filled sinkholes, and buried channels; estimate the depth to the groundwater level; describe the sites of sand and gravel deposits; evaluate the quality

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of rock/soil masses for engineering purposes (Clayton et al., 1993; Samouëlian et al., 2005). For several years, geological, geotechnical, environmental, hydrogeological, and archeological studies have relied on electrical resistivity imaging (ERI), which is regarded as a more appropriate method. Numerous efforts have been made to relate soil engineering testing results to ERI information (Israil and Pachauri, 2003; Cosenza et al., 2006; Gay et al., 2006).

2D Electrical resistivity surveys were carried out for the landfill in the engineering site (Karim et al., 2015). As a geophysical technique, a region east of Baghdad has been studied using 2D ERI to determine the soil's geotechnical characteristics. The study attempts to relate and compare 2D resistivity imaging results with that acquired by traditional site investigation (Karim et al., 2012). Karim (2015) used Wenner, Wenner-Schlumberger, and dipole-dipole 2D (ERI) configurations to investigate near-surface resistivity variations. According to these studies, pseudo sections are good for presenting apparent resistivity, but inversion models show true subsurface resistance. The apparent resistivities were inverted to actual values using the two-dimensional technique. The object of present study is to investigate the soil lithology using 2D ERI technique. They are also used to determine the groundwater levels in the region that could influence the foundation of the infrastructures which will be built in the near future, as well as to identify underground buried facilities to prevent issues while future construction.

2. Location and Geology of the Study Area

The study area is located within Al-Muthana Airport land, representing the Palm Towers residential complex, Baghdad, about 1500 m from the Tigris River's western bank with latitude 33°19'45.80"N and longitude 44°21'44.47"E (Fig.1). According to the tectonic division of Iraq, the area is located on the Mesopotamian plain zone within a region of the unstable shelf. This zone lies in the Geosynclines basin and is marked by a flat area covered by alluvial sediment. Also, the sediments are recent, not exceeding the Quaternary ages. Generally, the soil of the Baghdad area has been derived from around areas, especially the Mesopotamian plains and the desert (Buringh, 1960).

Al-Mabrook Construction Contracting Co. LTD, (2020) investigated the site's subsoil strata using 24 wells at depths of 30 and 35 m; it is consisted of the following layers of different nature and various thicknesses described below:

- Medium strengthens stiff with depth, having brownish visions in colors, (sandy)-lean to fat silty clay with shiny crystals of soluble salts and black spots of organic matter/plants roots close to surface together with rusty (yellowish) traces of iron oxide compounds, overlying.

- Loose to medium dense strengthens with depth to dense and very dense, having grayish, greenish, and brownish appearances in colors, fine to medium-grained (clayey) silty sand with rusty (yellowish) traces of iron oxide compounds and shiny crystals of silica minerals together with some fine-grained Gravel, intervened by a layer of very stiff (sandy) fat silty clay having brownish visions in colors.

As shown in Fig.2, some nearby boreholes to 2D survey lines will be used later in interpreting 2D electrical sections geotechnical soil boring logs in the study area as shown in Fig.3.

Free groundwater was encountered in all the boreholes during drilling at measured depths and levels. The groundwater level was recorded at levels of about 2.7-3.2 m below the natural ground surface (Al-Mabrook Construction Contracting Co. LTD, 2020).
Fig. 1. Location of the study area within the map of Iraq, red rectangle showing the borders of the surveyed site.

Fig. 2. Aero-photo shows survey lines setup and borehole’s locations at Al-Muthana Airport site.
3. Materials and Methods

The field investigation was conducted from 9 to 12 February 2022 in central Baghdad at two sites within the Al-Muthana Airport. The first site is near the wall on the eastern and northeastern sides, while the second is on the western and south-western sides (Fig. 2). The Wenner-Schlumberger 2D ERI array was performed along six parallel spread lines. Each line is 100 meters long with a 1-meter electrode spacing. The MU1 to MU4 lines run from SE to NW, while lines MU5 and MU6 trend from SW to NE direction. The spacing between lines MU1 to MU4 is 27 meters, with an average of 9 meters between any two adjacent lines. The spacing between parallel lines MU5 and MU6 was 24.4m apart. SYSCAL pro Switch device was placed in the center of the survey line to measure electrical resistivity. The site’s deepest investigation is 20 meters. The 2D resistivity measurements were processed and inverted using the RES2DINVx64 program, version 4.8.12 (Geotomo Software, 2018).

4. Results and Discussion

4.1. Spread Line MU1

The resistivity values in this spread are ranging between 1.01 to 31.32 ohm.m with RMS of 0.69% after 7 iterations (Fig.5). Two main zones appeared in the inverted model of this spread:

The unsaturated zone above water level up to 3m with resistivity value of > 30ohm.m. This zone includes two subzones:

- Subzone of relatively high-resistivity (between 10– >30 ohm.m) with thickness not exceeding 1-1.5m appears under electrode 1 to approximately electrode 80. This zone, according to nearby BH3, consists of sandy clay with little fine-grained gravel, and that is the cause of relatively high-resistivity, then it disappears and replaces by a zone with lower resistivity (<2 ohm.m) between
electrodes 80 and 100. Fig.4 shows that subsurface water seepage from nearby pipes or pumps forms the lower resistivity zone.

- Subzone of 10 ohm.m resistivity appeared under electrodes 47 to 50 in a lens-shaped silty clay, and between electrodes 63 to the end of the spread line with resistivity (between 10- > 30 ohms.m) confined between depths 1 to 4m. This subzone is accompanied with buried features (such as construction remains) or dense compacted silty clay with fine-grained sand, causing increased resistivity.

Saturated zone from water level to the bottom of the spread. This zone has two subzones:

- Subzone with resistivity value of 3-6 ohm.m at depth 4-12m. According to borehole 3, this subzone is silty sand with clay and gravel, causing a lateral variation in resistivity.
- Subzone from depth 12m to the bottom of the spread with resistivity 6-12 ohm.m. This subzone's relative increase in resistivity was due to increased stiffness and density of layers and the presence of gravel with silty sand deposits.

**Fig.4.** Location of the water pump adjacent to the survey line MU1

**Fig.5.** The 2D inverted model for spread line MU1 with BH3 column showing resistivity variations along the section

### 4.2. Spread Line MU2

The resistivity values in this spread vary between 3.37 to 16.59 ohm.m with RMS of 0.50% after 7 iterations (Fig.6). Three main zones can be clearly noticed in the inverted model of this spread:

- The zone above water level is 4m in depth from the surface. This zone's resistivity varies laterally with lithology and humidity. This layer is sandy, silty clay of less than 1m thick with a resistivity of 8-20 ohm.m. Changes in sands and clays or humidity may cause lateral resistivity changes.
• The second zone extends from 4 to 12m in depth. Despite a vertical variation in lithology in surrounding boreholes, this zone appears approximately homogeneous in resistivity, that means groundwater controls resistivity values in this zone. Besides, there is convergence in the layer deposits forming this zone.

• The third zone extends from 12m to the bottom. The resistivity is increased from 6 to 12 ohm.m. This increase could be due to a change in sediments, such as the amount of sand and gravel and increased stiffness and density.

Fig.6. The 2D inverted model for line MU2, showing resistivity variation and water table

4.3. Spread Line MU3

The resistivity values in this line vary between 2.68 to 18.77 ohm.m with RMS of 0.59% after 7 iterations (Fig.7). The same three zones appear in the inverted model of the MU2 spread as well:

• The zone from surface to 4m in depth where groundwater level was discovered via inverted model. The top layer has a 1m thickness and resistivity of 6 to 20 ohm.m. Changing deposit nature and moisture content affected this layer's resistivity. Also, the clayey silty sand layer, which lies beneath the top layer, affects the spread under electrodes 17 to 20, 50 to 64, and 79 to 93.

• The second zone is below the water level extends from 4 to 12m. According to nearby BH2, this zone to some extent, consist of clayey silty sand beds, but water controlled its resistivity value; thus, it appeared homogeneous in resistivity, where its resistivity ranges between 4 to 5ohm.m.

• The third zone extends from 12m to the bottom of the spread. This zone's resistivity is ranging between 6 to 12ohm.m. According to BH2 drilling records, this zone's relative increase in resistivity was due to the presence of gravel and increased stiffness and density of the soil layers.

Fig.7. The 2D inverted model for line MU3 with BH2 column showing resistivity variations along the ERI section.

4.4. Spread Line MU4

The resistivity values vary between 2.04 to 21.94 ohm.m with RMS of 0.95% after 7 iterations (Fig.8). Also, three main zones were found in the inverted model of this spread:

• According to the inverted model, this zone located above water level was 4m in depth. A clear top layer with a thickness of 1m and resistivity between 6 to 25 ohm.m is found between electrodes 28
to 99, representing gravelly sandy clay in nearby borehole 4. It is not found between electrodes 9 to 28 due to a sudden decrease in resistivity to about 2-4 ohm.m. Changing in resistivity of this layer may be related to changes in the deposit's nature and moisture content. The lens-shaped anomaly under electrodes 14 to 23 and depth 2-4m with relatively high-resistivity (14 to 20 ohm.m). This anomaly may be dry silty clay or buried construction remains.

- The second zone has a semi-homogeneous to homogeneous resistivity layer between 4m and 12m depth. BH4 describes this zone alternates silty clay with clayey, silty sand beds. Water completely controlled its resistivity, approximating semi-homogeneity or convergence in resistivity (3-5 ohm.m).
- As in the inverted model of MU3, the third zone is found from approximately 12m depth to the bottom of the spread. The resistivity of this zone is ranged between 6 to 12 ohm.m. This zone's relative increase in resistivity was because of changing the nature of deposits where there was a presence of gravel and increased stiffness and density of beds at that depth, according to drilling records of BH4.

![Fig.8. The 2D inverted model for line MU4 with BH4 column showing resistivity variations along the ERI section.](image)

### 4.5. Spread Line MU5

Previous models have clear resistivity zone boundaries. This spread's inverted resistivity values are higher than the previous four lines. The resistivity values vary between 1.28 to 45.98 ohm.m with RMS of 0.66% after 7 iterations (Fig.10). According to nearby borehole 24, the top 1m of silty clay with sand has a resistivity between 8 to 30 ohm.m. This layer's wide range in resistivity is related to the percent change of sand to clay; as sand resistivity rises, humidity and hardness may also change resistance.

Under electrodes 9 to 13, at 1m depth, there is a low-resistivity (<3 ohm.m). This spot has lower resistivity than above and below which could be formed by accumulated rainwater or unknown subsurface seepage. Under electrodes 94 to 96, at 2m depth, there is a low-resistivity spot. Field observations indicate this spot was created by a subsurface seeping from a nearby water-filled bit (Fig.9).

Detecting subsurface water seepage from the pit shows the accuracy of field measurements. Sandy silty clay layer in BH24 can be detected in the inverted model as a zone of resistivity between 11 to 30 ohm.m. This zone is above water level; therefore, instauration and changing sand and silt percent may make spot-shaped anomalies between 2-4m depth under electrodes 10 to15, 19 to 25, and 65 to 73, respectively. At depth of 4-4.5m, a sudden change in resistivity indicates groundwater level. Under that depth, the resistivity is reduced to (5-10 ohm.m) but was still higher than the previous four inverted models. Under electrodes 57 to 66, the resistivity increases from 10 to 18 ohm.m. This increase is consistent with gravel in the sediments, as well as stiffness and density increase as it was found in nearby borehole BH24.
Fig. 9. Location of the pit contains water adjacent to the survey line MU5

Fig. 10. The 2D inverted model for line MU5 with BH24 column showing resistivity variations along the ERI section.

4.6. Spread Line MU6

The resistivity values vary between 2.37 to 53.41 ohm.m with RMS of 0.57% after 7 iterations (Fig. 11). According to nearby borehole BH23, the top layer is 4m thick and consists of silty clay with sand. While the inverted model, reflects 1m layer with relatively high resistivity (>30 ohm.m). That is due to either the well's bed thickness wasn't recorded correctly, or the deposit where it was drilled varies from this line's deposit. Under the top layer, a 1m-thick low-resistivity layer was spotted laterally along the inverted model. This layer may be moist silty clay. A zone of higher resistivity extends from 2-4m in depth under electrode 53 to the end of the spread may represent silty sand above water level. A spot of very low resistivity (<3 ohm.m) located under electrodes 14 to 19 at depth 2-4m. This low resistivity can be related to an unknown subsurface source of water that continuously seeps towards the area, as seen by the decrease in resistivity from electrode 1 to the spot. At depth 4.5m, the resistivity changes suddenly, possibly due to water level or changing deposits from silty clay to silty sand. The underwater
zone level continues to the bottom of the inverted model but with a lateral change in resistivity. Lateral change in resistivity may be due to changing sand, silt, and clay percentages.

![Fig.11. The 2D inverted model for line MU6 with BH23 column showing resistivity variations along the ERI section.](image)

5. Conclusions

The 2D electrical survey method was applied using the Wenner-Schlumberger array. The 2D electrical survey was carried out at Palm Towers within Al-Muthana Airport land. The groundwater depth was found to approximately 4-4.5m in the inverted models with more than 1 m depth which was ranged between 2.7-3.2 m. The presence of a top layer with a thickness of 1-1.5m consists of sediment variables in components, hardness, and moisture. This layer must be excavated before conducting the foundation, and the soil under the foundation must be compacted. The layer after 1.5m seems to be moisturized; therefore, filling the zone around the foundation with a low permeability layer is recommended. The Towers are recommended to be constructed on deep foundations as the stress imposed by the structure on the subsoil is expected to exceed the gross allowable bearing capacity.

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References


