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3D Resistivity Imaging Investigation for Engineering Construction Project Studies at Al-Muthana Airport in Baghdad, Iraq

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Abstract

Engineering project assessment at Al-Muthana Airport in Baghdad, Iraq, has been studied using a 3D electrical resistivity imaging survey. The site investigation is crucial for assessing the future of the region's infrastructures since it reveals the location of buried facilities or weak zones below the surface and measures localized groundwater levels. Wenner-Schlumberger array was used to conduct four parallel 2D electrical resistivity spreads_(MU1 to MU4). Each spread line was 100 m in length with 1 m electrode spacing and an average spacing of 9 meters between any two adjacent lines. The depth of the investigation was around 23.8 m. Survey lines were drawn going from northwest to southeast. These spreads were combined to provide a 3D image of a 2700 m2 space.The robust inversion method and the inverse model generated using the standard least-squares method showed horizontal slices identified three zones with resistivity distribution ranging from 2 to 45.5 ohm.m. The first zone, from surface to 3.37 m, had relatively high resistivity of sandy silty clay soil with relatively low moisture content; the second zone, approximately from 3.37 to 12.2 m, had very low resistivity representing groundwater table; and the third zone, from 12.2 to 23.8 m representing high stiffness and density and relatively high resistivity due to gravel presence in the deposits. The second zone highlights potential risk zones for construction projects; as a result, it is advised that the zone surrounding the foundation be filled with a low permeability layer and that the towers be built on deep foundations.

Keywords: Geophysical engineering; geotechnical investigation; 3D Electrical resistivity imaging; Groundwater level.

تحقيق التصوير بالمقاومة ثلاثية الأبعاد لدراسات مشروع البناء الهندسي في مطار المثنى في بغداد ، العراق

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الخلاصة

استخدمت دراسات المشروع الهندسي في مطار المثنى ببغداد، العراق، تحريا بالمقاومة النوعية التصويرية ثلاثية الأبعاد. يعد التحري الموقعي أمرًا بالغ الأهمية لتقييم مستقبل البنى التحتية في المنطقة لأنه يكشف عن موقع المنشآت المدفونة أو المناطق الضعيفة تحت السطح ويقيس مستويات المياه الجوفية المحلية. تم استخدام ترتيب فنر – شلمبرجير Wenner–Schlumberger لمسح أربع مسارات مقاومة نوعية كهربائية متوازية ثنائية الأبعاد (MU1 إلى MU4). كان طول كل خط انتشار 100 متر مع مسافة 1 متر بين الأقطاب ومتوسط تباعد 9 أمتار بين أي خطين متجاورين. كان عمق التحري حوالي 23.8 م. تم أخذ خطوط المسح من اتجاه NW إلى SE. تم جمع بيانات هذه المسارات لإنشاء صورة ثلاثية الأبعاد لمساحة 2700 م^2. أظهرت طريقة الانعكاس القوية والنموذج العكسي الذي تم إنشاؤه باستخدام طريقة المربعات الصغرى القياسية أن الشرائح الأفقية حددت ثلاث مناطق بتوزيع مقاومة يتراوح من 2 إلى 45.5 أوم.م. المنطقة الأولى، من السطح إلى 3.37 م ، كانت ذات مقاومة نوعية عالية نسبيًا مؤلفة من تربة طينية غرينية رملية ذات محتوى رطوبة قليل نسبيا؛ المنطقة الثانية، من حوالي 3.37 إلى 12.2 متر ، ذات مقاومة منخفضة جدًا تمثل منسوب المياه الجوفية ؛ والمنطقة الثالثة من 12.2 إلى 23.8 متر تمثل صلابة عالية وكثافة ومقاومة عالية نسبيًا بسبب وجود الحصى في الرواسب. المنطقة الثانية تشير إلى مناطق الخطر المحتملة لمشاريع البناء؛ لذلك يوصى بملء المنطقة حول الأساس بطبقة منخفضة النفاذية، ويوصى باستخدام الأساسات العميقة لبناء الأبراج.

1. Introduction

The electrical resistivity technique is used in subsurface investigations by measuring electrical resistivity based on the response of the earth to the flow of electrical current. Materials are naturally electrical, and each material has a different sensitivity to conduct electricity. Assessment and evaluation procedures are necessary to identify the characteristics of the elemental particles that make up materials. Electricity is produced when electrical charges pass through a conductor, such as a medium or electrodes. Electrical Resistivity Imaging (ERI) method is one of the most promising techniques which is well-suited for applications in the fields of geohydrology, environmental science and engineering [1] [2].

There are three survey procedures to take resistivity measurements 1D, 2D, and 3D; both 2 and 3- D are preferable for subsurface imaging. However, 2-D and even 3-D electrical surveys are now practical commercial techniques with the relatively recent development of multi-electrode resistivity surveying instruments [3] and fast computer inversion software [4].
In most cases, a 3D data collection is constructed by combining information from several parallel two-dimensional spread lines in preparation for a 3D data cube and inversion. The best 3D imaging data is obtained by placing many electrodes in a rectangular grid and detecting the apparent resistivity in all possible and available orientations. The most usual and alternative methods measure the apparent resistivity in two orthogonal orientations (X, Y) or a single path (X or Y). Effective field methods were outlined by [5] [6] [7] [8] [9].

Measurements are conducted across a series of constant separation traverses, with the electrode separation gradually increasing with each succeeding one, to obtain detailed data and deep electrical imaging. Using a three-dimensional inversion approach, get a certain resistivity distribution of the subsurface from the measured apparent resistivities, which invert to true resistivity [10].

For several years, geological, geotechnical, environmental, hydrogeological, and archaeological 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 [11] [12] [13].

A few investigations have applied the resistivity approach for identifying underlying soil in Iraq, such as [14] using a Wenner- Schlumberger arrangement to use it at the University of Technology in Baghdad. A resistivity map was created, showing some low and high electrical sections representing the heterogeneity in the sediments.

Seven 2D imaging spread Dipole-dipole arrangements were applied to create a 3D image and used it to locate cavities in complex lithology. The 3D models' horizontal slices provide an accurate representation of the subsoil. They expose a series of caverns just below the ground's surface. These caverns appear like points with wildly varying resistivity ratings. Compared to the traditional Least-square method, the robust constraint technique provides an inverse model with sharper and straighter borders [15].

The purpose of this research is to evaluate soil lithology using a 3D electrical resistivity imaging (ERI) method. Besides, it may also be used to locate subsurface buried facilities or weak zones and to measure local groundwater levels, which are essential in determining the future of the region's infrastructure.

2. Materials and Methods:

2.1. Location and geology of the study area:

The study area is located within Al-Muthana Airport land, representing the Palm Towers residential complex, Baghdad Governorate. It is about 1500 m from the Tigris River's western bank with latitude 33°19'45.80"N and longitude 44°21'44.47"E, Figure 1. Baghdad is located in the Mesopotamia basin, an area distinguished by a thick sedimentary layer. Fluvial sediments compose the majority of these deposits. There is a wide range of horizontal and vertical soil variations. Clay and silicate minerals, along with disposal materials including gravel, concrete blocks, and other building detritus, comprise the top section, known as the fill layer deposits. This layer's thickness varies from 1 to 15 meters [16].

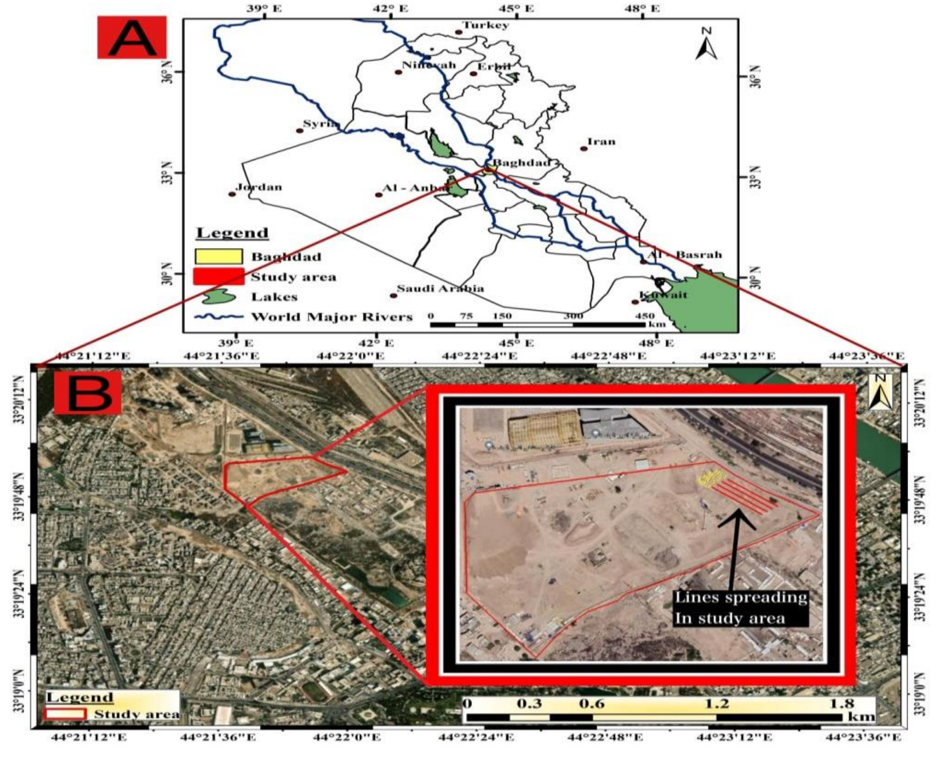


Figure 1: (A) Location of the study area (Google.com/maps). (B) Red rectangle represents the study area and the position of four 2D surveyed lines in right side of the area.

3. Stratification of the soil sections:

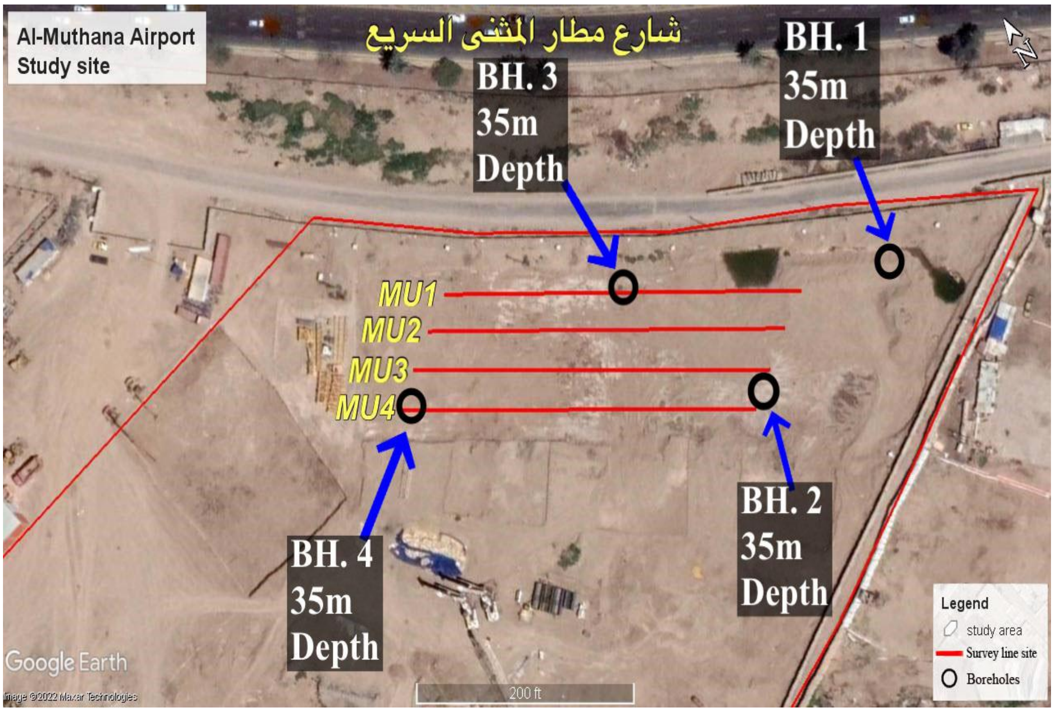
The site's subsoil layers were investigated using 24 wells at depths of 30 and 35 m by Al-Mabrook Construction Contracting Co. LTD, 2020; it consisted of the following layers of different nature and various thicknesses described below:

1) Medium hardens to stiffness with depth, with brownish colored vision (sandy)-lean to soft silty clay, and black areas of organic matter roots near the top, as well as rusty (yellowish) evidence of iron oxide compounds above.

2) 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) soft silty clay having brownish visions in colors.

Later, as indicated in Figure 2, certain drilled boreholes close to the surveyed lines will be used for comparison and interpretation of electrical resistivity sections. All of the boreholes had free groundwater when they were drilled to the specified depths and altitudes. The groundwater level was found to be between 2.7 and 3.2 meters below the surface of the ground [17].

Figure 2: Survey lines setup and adjacent boreholes positions at Al-Muthana Airport site



(Google.com/maps).

4. Fieldwork:

4.1. Data acquisition:

The field investigation was conducted from 9 to 12 February 2022 at the site within the Al-Muthana Airport. The site is near the wall on the eastern and northeastern sides (Figure 2). The 3D Survey setup was constructed in a fairly small region. The data collection consists of dense measures along parallel 2D spreads. The parallel 2D lines were combined to create a substantially 3D data set. 2D resistivity measurements were obtained at four parallel lines (MU1 to MU4) by implementing Wenner-Schlumberger arrangement. The survey lines were taken from NW to SE direction. The spacing between lines MU1 to MU4 is 27 meters, with an average of 9 meters between any two adjacent lines, and each line had 100 meters in length using a 1-

meter electrode spacing. 3D resistivity is equipment-limited because it requires a greater number of electrodes than a similar set of 2D lines to cover the same region with the same accuracy and depth of penetration. Besides these limits and additional field duration, a 100m × 27m electrode grid requires 400 electrodes and a significant amount of time. Adding electrodes increases field time geometrically rather than linearly. SYSCAL pro Switch device was placed in the center of the survey line to measure electrical resistivity. The depth of investigation for each survey line was 23.8 meters. The 3D resistivity measurements were processed and inverted using the RES3DINV ver. 2.15 program [18].

5. Data processing:

By applying RES2DINV (the option "collate data into RES3DINV format" from the "file" submenu), the application generated a 3D data file (filename.dat) which was processed using RES3DINV to generate a 3-dimensional data file for the study site.

A three-dimensional technique was invented after the merge the four 2D parallel lines into a single file. Data collected from surveys might be used to create a 3-dimensional arrangement by storing the data in one file.

The constructed 3D data file consisted of 8952 resistivity measurements, i.e., 2238 resistivity measurements for each individual 2D line.
All 2D datasets were gathered and stored as (TXT.) files that included 2D dating profile document numbers, titles, directions, and starting point positions to create a model for 3D resistivity.

6. Results and discussion:

6.1. 3D Resistivity Imaging Results:

As mentioned above, the dimension of the area is 100 m by 27 m. The results of the combination of 3D robust constrain method inversion of the data set from both directions are shown in Figure 3. The resistivity values for inversion sections of the subsurface ranged between 2 and 56.8 ohm.m. The depth of penetration was 23.8 m. The total RMS after six iterations was 1.98 %.

The inverse model is the actual image that is used for interpretation. A lower RMS error represents a better match between the calculated and measured pseudo section; hence a smaller value is desired.
The 15 sequential depth slices made up the 3D inversion model. Their depths are 0.0-0.50 m, 0.50-1.08 m, 1.08-1.74 m, 1.74-2.50 m, 2.50- 3.37 m, 3.37-4.38 m, 4.38-5.53 m, 5.53-6.86 m, 6.86-8.39 m, 8.39- 10.2 m, 10.2-12.2 m, 12.2-14.5 m, 14.5-17.2 m, 17.2-20.3 m and 20.3-23.8 m, respectively.

The model demonstrates variation in resistivity levels and is separated into three zones. According to the results of cross-sectional drilling borehole logs (Figure 5), and the Cross-section of three correlated boreholes (Figure 6). The first four slices represented sandy silty clay soil from 0.00 to 2.50 m depth, and a change in the proportion of sand and clays as well as a difference in the relative humidity could both produce a change in resistivity. The moisture content increased in the fifth slice with a decrease in resistivity with a depth of 2.50 to 3.37m. The sixth to eleventh slices from depth 3.37 to 12.2 m show a reduction in resistivity value due to the presence of water. An alternate layer of clayey, silty sand beds can be found at the location. Although it appeared to be approximately uniform in resistivity, the addition of water completely changed its resistivity value, representing weak points or a depth of danger for civil engineering projects. The last slices from depth 12.2 to 23.8 m showed that the resistivity value increased with depth due to an increase in layer stiffness and density at depths with gravel in the deposits.

The layered boundaries in the inverse model generated by the robust constraint method are sharper and straighter (Figure 3). The inverse model generated using the standard least-squares method has a gradient border (Figure 4).

The comparison between the two methods appeared that the inverse model produced by the standard least-squares method (Figure 4) has a gradational boundary, and the subsurface zones in the robust constraint method appear closer to the actual and more consistent with the record of drilled wells unlike the model produced by the standard least-squares method.

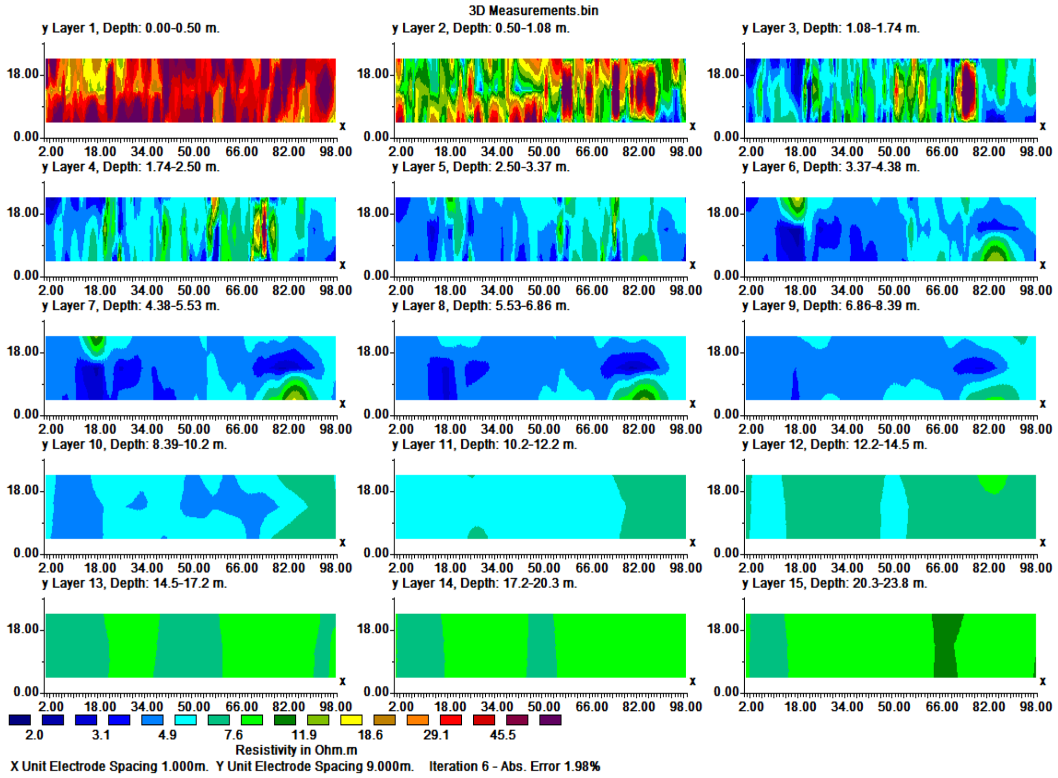


Figure 3: 3D Inversion model of subsurface resistivity distribution with depth using robust constraint method, which shows horizontal slices with sharper and straighter boundaries.

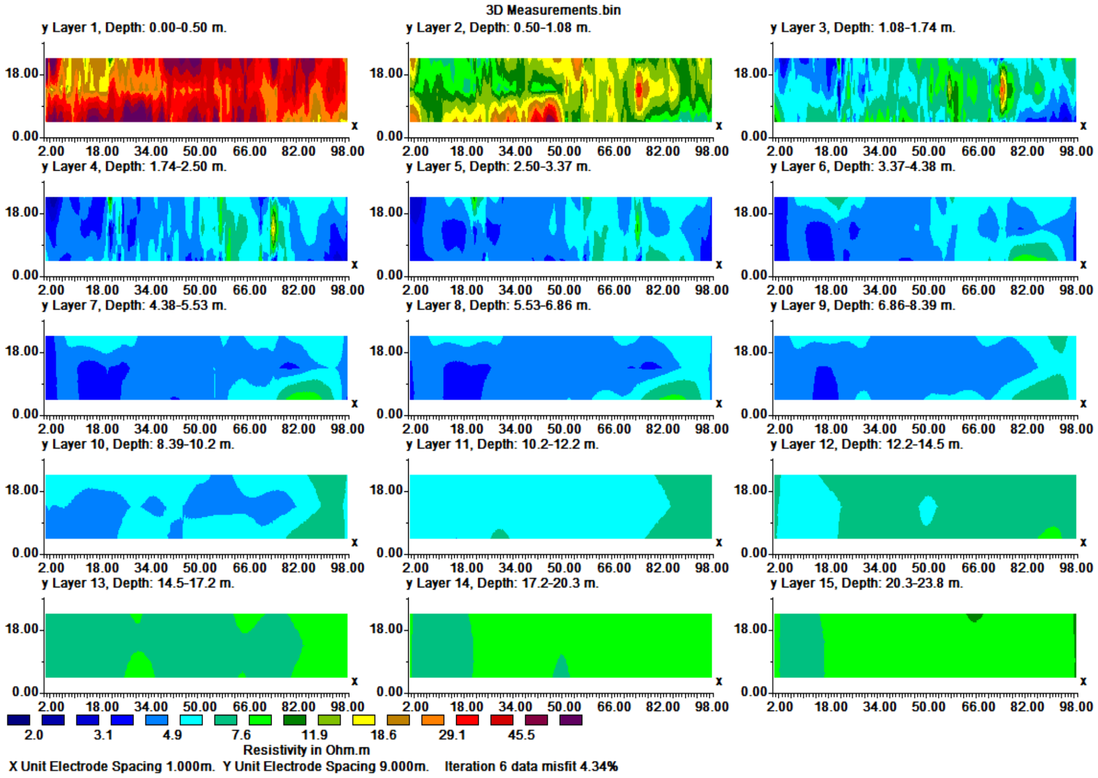


Figure 4: 3D Inversion model of subsurface resistivity distribution with depth using the standard least-squares method, which shows horizontal slices with a gradient border.

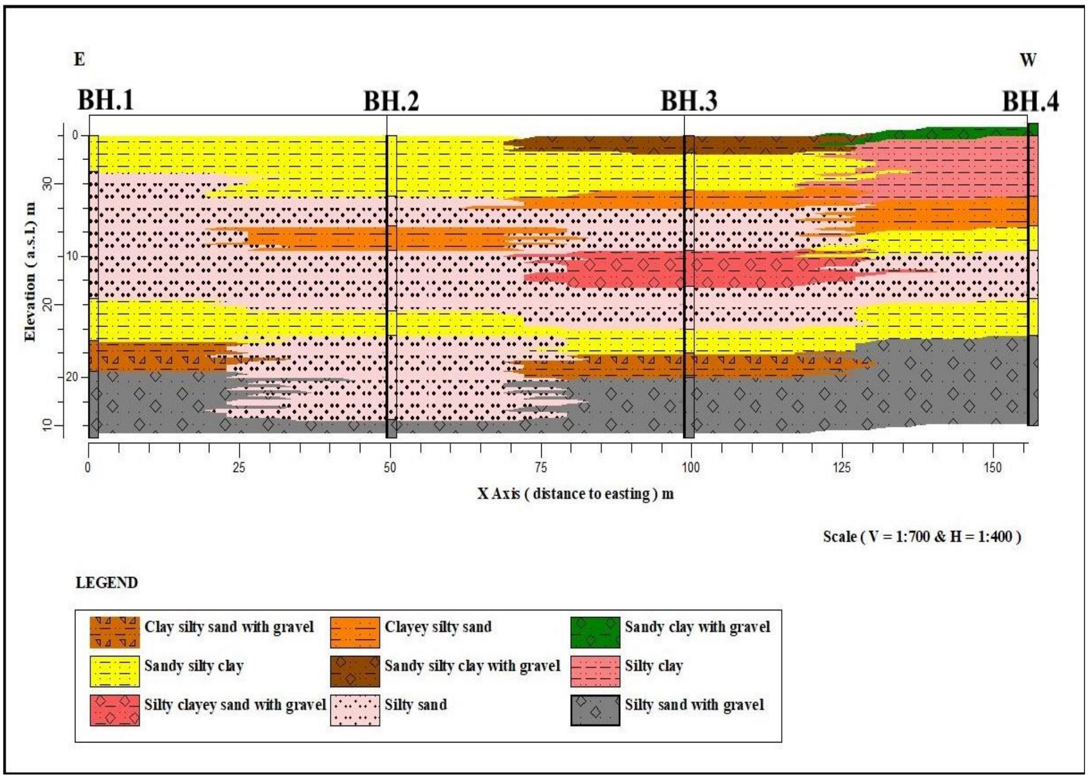


Figure 5: Cross-sectional boreholes of BH.1, BH.2, BH.3, and BH.4.

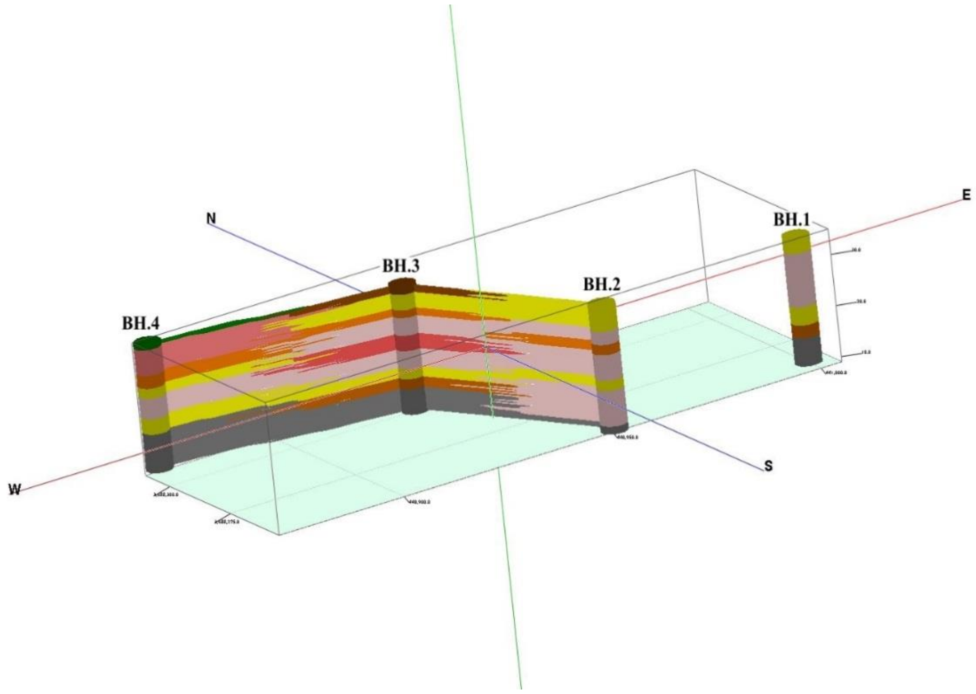


Figure 6 : A cross-section of three correlated boreholes within the study area.

7. Conclusions:

The 3D electrical survey was carried out at Palm Towers within Al-Muthana Airport land. The following conclusions are achieved:

1. The electrical resistivity survey method was conducted using the Wenner-Schlumberger array, and the inversion models of the subsurface identify well the main conditions of the subsurface soil layers.
2. The variation in resistivity values through the depth-slices reflected three zones identified by the model; the first zone represents sandy silty clay soil with lower moisture content; the second zone represents sediments within the water table, which decreases the resistivities; while the third zone represents high stiffness and density and relatively high resistivity due to the gravel presence in the deposits.
3. The second zone indicates potential danger areas for construction projects; therefore, filling the zone around the foundation with a low permeability layer is recommended, and deep foundations are recommended to be used to build the Towers.
4. The robust constraint method-generated inverse model has sharper and straighter layered boundaries. The gradient boundary is present in the inverse model produced by the conventional least-squares method. The strong constraint method is the best because it gives clear boundaries.
5. The groundwater level was found in slice six at depths of about 3.4-4.4 m in the inverted models with approximately more than 1 m depth as recorded in the report of the geotechnical investigation which ranged between 2.7- 3.2 m.

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