Laboratory Assessment of Chemical Characteristics using Electrical Resistivity (ER) Technique in Highway Construction

S. A. Qasim¹,a, H. H. Karim¹,b,*, and A. A. Shubber¹,c
¹Civil Engineering Department, University of Technology, Baghdad, Iraq.
bₐ₄ₕₐ₃ₖ₈₄₄₇@gmail.com, b₄ₐ₍₀₆₂@uotechnology.edu.iq, c₄ₐ₆₁₆₂@uotechnology.edu.iq.
*Corresponding author

Abstract. Electrical Resistivity (ER) technique was applied for simulation model constructed at University of Technology / Civil Engineering Department Laboratories, Baghdad-Iraq. The study aims to determine the relationship between changing the chemical properties of the soil and the resistivity of soil layers using 1-D VES. ER has been chosen as a nondestructive geophysical survey method to identify some soil characteristics without destructing the soil by making surface measurements using Wenner configuration. The obtained data results showed that there is a relationship between ER and some soil characteristics. The ER values change with the change of soil properties. Two models were created. In the first model, the ER was measured without changing any of the soil characteristics, and it was with optimum water content. In the second model, 5% of the sodium chloride salt was added to the soil after dissolving with water then the ER was measured. It was found that after adding the salt, the ER is decreased significantly, and thus the ER was affected by the addition of the salt.

Keywords: ER, Pseudo cross-sections, resistivity cross-sections.

1. Introduction
Surface-geophysical methods provide quick, inexpensive, and nondestructive tools to help describe subsurface geophysical formations. They offer information about subsurface properties, such as soil thickness, degree of saturation, and depth to bedrock, position of conductive fluid, position of bedrock fractures, and faults. Subsurface geophysical investigations monitor the variation in the subsurface distribution of soil properties (such as electrical conductivity or resistivity, density, magnetic susceptibility, and relative permittivity). These prospecting are performed at or near the earth's surface. Many factors are affecting the physical properties such as porosity, water content, degree of saturation, permeability. The contrast of these soil/rock physical parameters is the main base of all geophysical methods [1].

Many works have been done to establish a relationship between soil engineering test and Electrical Resistivity Imaging (ERI) data to produce continuous information of the subsurface and to probe into several meters below the surface [2]. Several studies have been the topic of survey design and layout strategies that produce optimum information using different ERI configurations and set up in different geological settings [3-5]. The electrical resistivity of soil depends on various factors such as mineralogy, porosity, pore fluid chemistry, degree of saturation, pore geometry, particle size distribution, salinity, and temperature. The quantity and quality of water in soil have a significant effect on electrical resistivity. Electrical resistivity decreases with increasing moisture content in soils. Clay minerals also
have a strong effect on the electrical resistivity of soil as they are electrically conductive particles having the ability to absorb and release ions and water molecules on their surface through an ion exchange process [6,7].

This study presents the implementations of electrical resistivity (ER) to monitor the change in the soil characteristics without destructing the soil by the measure of its resistance to the passage of current through it. Thus, this study aims to explore how electrical resistivity (ER) as nondestructive testing can be used accurately and reliably to measure the change in soil properties. This work will be achieved by using ABEM Terra meter SAS 4000 and its accessories.

2. Inversion process
The electrical resistivity of the soil is determined by measuring the resistance between two points in the soil, and this is done by transmitting a controlled DC or AC current to another pair of electrodes (A and B) and by measuring the voltage across one pair of electrodes (M and N) [8]. In homogeneous ground conditions, the penetration depth is proportional to the separation between the electrodes and provides information about sub-surface stratification. The measured quantity is called apparent resistivity [9]. Apparent resistivity can be defined as the volumetric average of a heterogeneous half-space based on the complex weighing function that depends on different electrode arrays [10]. The typical setup for the measurement of electrical resistivity using the 4-electrode method is shown in Figure 1.

It should be noted that for homogeneous and isotropic medium, the apparent resistivity is equivalent to the true resistivity value. Naturally occurring soil is a highly heterogeneous medium. Therefore, the true electrical resistivity values can be calculated using inversion algorithms [11,12]. Nowadays various forward modeling software (e.g., Res1D, Res2DINV, Res3DINV, 2DIP, Resix, RINVERT etc.) are available to process a large amount of resistivity data and to minimize the difference between true and apparent resistivity for subsurface earth material by dividing the subsurface into small rectangular cells using finite element and finite difference codes [9,12,13].

![Figure 1. a: Arrangement of four electrodes to measure field electrical resistivity (Wenner configuration); after modification [14]. b: Soil resistivity measurements in near-surface profile [3].](image)

3. Identification of electrical resistivity ER technique
The DC resistivity method is one of the simplest geophysical techniques used to measure earth conductivity, but it is still employed extensively because of its easy use and relatively easy interpretation [15]. The objective of electrical resistivity (ER) investigations is to evaluate the subsurface resistivity distribution by performed profiles on the ground surface. From such profiles, the true resistivity of the subsurface can be detected. The ground resistivity is a function of different geological parameters such as the mineral and fluid content, porosity, and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining, and geotechnical investigations. More recently, it has been used for environmental surveys. The resistivity profiles are generally performed by injecting current into the ground through two current electrodes (C1 and C2), and
measuring the resulting voltage difference at two potential electrodes (P1 and P2), as shown in Figure 2.

![Figure 2. A conventional four-electrode array to measure the subsurface resistivity [16].](image)

From the current (I) and voltage (V) values, an apparent resistivity ($\rho_a$) value is calculated:

$$\rho_a = \frac{kV}{I}$$

where $k$ is the geometric factor that depends on the arrangement of the four electrodes. Resistivity meters normally give a resistance value:

$$R = \frac{V}{I}$$

So, in practice, the apparent resistivity value is calculated by:

$$\rho_a = kR$$

The calculated resistivity value is not the true resistivity of the subsurface, but an “apparent” value which is the resistivity of a homogeneous ground that will give the same resistance value for the same electrode arrangement. The relationship between the “apparent” resistivity and the “true” resistivity is complex. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out [16] as shown in Figure 2.

The main implementation for electrical resistivity (ER) is groundwater investigation. Moreover, it is used in environmental and engineering studies [15]. The ER technique was known in the 1920s by the experiments of the Schlumberger brothers, for about the later 60 years, for quantitative interpretation, conventional sounding surveys [17] were usually applied. In this method, the center point of the electrode array remains fixed, but the spacing between the electrodes is increased to obtain more information about the deeper sections of the subsurface [16].

4. Modeling and methodology
The study site for field investigation was selected at the University of Technology/Civil Engineering Department Laboratories. The work lasted 4 months, started on 15 September 2020 and ended on 10 January 2021. The classification test was conducted on the used soil, and the test result were as shown in Table 1.

| Dia. mm | %Passing |
|---------|----------|
| 10      | 100.00   |
| 4.75    | 100.00   |
| 2.36    | 100.00   |
| 1.18    | 82.80    |
| 0.6     | 79.80    |
| 0.3     | 62.30    |
| 0.15    | 31.50    |
| 0.075   | 25.400   |
According to SCRB specifications (2003) / R6, this soil is considered sandy soil, knowing that during the test, it was found that it was not possible to check liquid limit and plastic limit. Also, the optimum water content and Bulk density were examined as in Table 2.

**Table 2. Properties of the used soil.**

| No. | Index Property          | Index value | Standards   |
|-----|-------------------------|-------------|-------------|
| 1   | Liquid Limit%           | NP          | ASTM D 4318 |
| 2   | Plastic Limit%          | NP          | ASTM D 4318 |
| 3   | Plasticity Index%       | NP          | ASTM D 4318 |
| 4   | Optimum water content%  | 10.7        | ASTM D 1557 |
| 5   | Bulk density for first model | 1.13      | ASTM D 4914 |
| 6   | Bulk density for second model | 1.2       | ASTM D 4914 |

The simulation model was a wooden box created from MDF wood, and its dimensions were 2.5m × 1m × 1m, as shown in Figure 3. Firstly, a polyethylene sheet was placed into the model to protect the water content of the soil as show in Figure 4. The model was filled to 50 cm with soil. Then the ER was measured at two times. In the first model, the ER was measured without changing any of the soil characteristics, and it was with optimum water content. In the second model, 5% of the sodium chloride salt was added to the soil after dissolving with water. Each model was divided into three profiles lengthwise and three profiles crosswise. After that, the electrical resistivity (ER) was measured for each profile.

![Figure 3. Wooden box model created from MDF wood.](image)

![Figure 4. Polyethylene sheet to protect the water content of the soil.](image)

The system used was ABEM Terra meter SAS 4000. It comprised the following parts (ABEM SAS Terra meter 4000, four single cores cable of 2 m length, four steel electrodes, external 12 volts battery, measuring tape, small hammer) as illustrated in Figure 5). IP12W in software was used to analyze data acquired.
5. Electrical Resistivity (ER) Survey

Electrical resistivity (ER) was applied to provide a cover along the soil profiles to get quantitative information about their geo-electric properties. The 1D electrical resistivity survey is also known as vertical electrical sounding (VES). It is the simplest form of resistivity survey. In this method, the center point of the electrode array remains fixed, but the spacing between the electrodes is changed to obtain more information about the deeper sections of the soil. To investigate the variation of soil characteristics in the simulation model, Wenner alpha configuration (array) was utilized. Each model was divided into three profiles lengthwise and three profiles crosswise. In each profile, the spacing intervals between successive vertical electrical sounding points (0.1, 0.2, 0.3, 0.5, and 0.7 m) and the electrodes spacing (0.1, 0.2, 0.3, 0.5, and 0.7 m) were adopted to investigate the whole depth of the simulation model because the current penetrates deeper into the sub-surface with increasing separations of electrodes [13]. Some of the electrical resistivity (ER) measurements are shown in Tables 3 and 4.

| Spacing(a) m | Prof. 1 | Prof. 2 | Prof. 3 | Prof. 4 | Prof. 5 | Prof. 6 |
|-------------|---------|---------|---------|---------|---------|---------|
| 0.1         | 1269    | 1269    | 1269    | 1051    | 903     | 768     |
| 0.1         | 1269    | 1269    | 860     | 1269    | 1179    | 822     |
| 0.1         | 1269    | 1269    | 1024    | 1065    | 1269    | 1102    |
| 0.1         | 888     | 1269    | 710     | 1269    | 1269    | 1269    |
| 0.2         | 2539    | 2539    | 2539    | 2539    | 2539    |         |
| 0.2         | 2539    | 2539    | 2539    | -       | -       | -       |
| 0.2         | 2539    | 2539    | 2272    | -       | -       | -       |
| 0.3         | 3809    | 3809    | 3809    | -       | -       | -       |
| 0.5         | 6348    | 6348    | 6348    | -       | -       | -       |
| 0.7         | 8888    | 8888    | 8888    | -       | -       | -       |

| Spacing(a) m | Prof. 1 | Prof. 2 | Prof. 3 | Prof. 4 | Prof. 5 | Prof. 6 |
|-------------|---------|---------|---------|---------|---------|---------|
| 0.1         | 264     | 346     | 111     | 137     | 402     | 141     |
| 0.1         | 151     | 166     | 133     | 137     | 129     | 136     |
| 0.1         | 904     | 266     | 91      | 134     | 103     | 137     |
| 0.1         | 907     | 250     | 135     | 155     | 113     | 186     |
| 0.1         | 243     | 396     | 124     | 568     | 490     | 187     |
| 0.2         | 868     | 836     | 394     | 316     | 253     | 318     |
| 0.2         | 469     | 834     | 294     | -       | -       | -       |
| 0.2         | 491     | 601     | 284     | -       | -       | -       |
| 0.3         | 969     | 1363    | 902     | -       | -       | -       |
| 0.5         | 1964    | 2673    | 1789    | -       | -       | -       |
| 0.7         | 3822    | 3381    | 3164    | -       | -       | -       |
6. Electrical resistivity (ER) interpretation

6.1 The first model
The analyzed and corrected data acquired from the first model were plotted as resistivity curves in Figure 6.

![Resistivity curves for the first model](image)

---

**Figure 6.** Resistivity curves for the first model.

The created pseudo and resistivity cross-sections for each profile are shown in Figure 7. This figure clearly shows that the resistivity values for the first model are increasing from top to bottom. For the first, second and the third profile, the resistivity values increasing from (1000 to 10000 ohm.m) and for the fourth profile the resistivity values increasing from (700 to 3000 ohm.m) while for the fifth and the sixth profile, the resistivity values increasing from (650 to 2500 ohm.m).
Figure 7. Pseudo and resistivity cross-sections for the first model.
6.2 The second model

The analyzed and corrected data acquired from the second model were plotted as resistivity curves in Figure 8.

![Resistivity curves for the second model.](image)

**Figure 8.** Resistivity curves for the second model.

The created pseudo and resistivity cross-sections for each profile are shown in Figure 9.

- The first profile increases from top (300 ohm.m) to bottom (3000 ohm.m).
- The second profile increases from bottom (278 ohm.m) to top (359 ohm.m).
- The third profile increases from top (200 ohm.m) to bottom (2000 ohm.m).
- The fourth profile increases from top (140 ohm.m) to bottom (300 ohm.m).
- The fifth profile increased from bottom (237 ohm.m) to top (316 ohm.m).
- The sixth profile increases from top (140 ohm.m) to bottom (300 ohm.m).

After adding 5% of the sodium chloride salt in the second model, the electrical resistivity (ER) values changed significantly compared to the first model. The great effect of the salt on the electrical resistivity (ER) values can be seen, as these values decreased significantly after adding the salt because the presence of salt causes an increase in conductivity, which is the inverse of the resistivity as it causes a decrease in the resistivity.
Figure 9. Pseudo and resistivity cross-sections for the second model.
7. Conclusions

- The soil resistivity in the simulation model is affected by the addition of salt. After adding the salt, the soil resistivity decreases.
- It is obvious from pseudo sections that the resistivity values increase from top to bottom for the two models.
- The resistivity of the soil is decreased approximately from (10000 ohm.m) for the first model (before adding salt) to (3000 ohm.m) for the second model (after adding salt).
- Electrical resistivity investigation is adopted as an efficient tool to identify some soil characteristics without destructing the soil.

References

[1] Karim, H. H., Karim, H. I. And Al-Rubye, M. A. H., 2015. Application of Ground Penetrating Radar (GPR) in Subsurface Site Investigation in Kut City. M.Sc. thesis submitted to the Building and Construction Department of University of Technology.
[2] Karim, H.H., AL-Qaissy, M.R. and Aziz, N.A., 2014. 2D and 3D resistivity imaging for soil site investigation. Engineering & Technology Journal, 32(1 Part A), pp.249-272.
[3] Islam, T., Chik, Z., Mustafa, M.M. and Sanusi, H., 2012. Estimation of soil electrical properties in a multilayer earth model with boundary element formulation. Mathematical Problems in Engineering, 2012.
[4] Karim, H.H., Alwan, I.A.K. and Al-Neami, M.A., 2013. Characteristics of 2-D electrical resistivity imaging survey for soil. Engineering & Technology Journal, 31(19 Part A), pp.70-89.
[5] Chik, Z., Murad, O.F. and Rahmad, M., 2016. Dependency of dry density of soil on water content in the measurement of electrical resistivity of soil. Journal of engineering research and technology, 2(2).
[6] Fukue, M., Minato, T., Horibe, H. and Taya, N., 1999. The micro-structures of clay given by resistivity measurements. Engineering geology, 54(1-2), pp.43-53.
[7] Paranis D. S., 1986, Principles of Applied Geophysics, 4th ed.: Chapman & Hall.
[8] Syed Osman, SB and Tuan Harith, ZZ, 2010. Correlation of electrical resistivity with some soil properties in predicting factor of safety in slopes using simple multi meter.
[9] Dahlin, T., 2001. The development of DC resistivity imaging techniques. Computers & Geosciences, 27(9), pp.1019-1029.
[10] Compare, V., Cozzolino, M., Mauriello, P. and Patella, D., 2009. Resistivity probability tomography imaging at the Castle of Zena, Italy. EURASIP Journal on Image and Video processing, pp.1-9.
[11] Loke, M. H. and Barker, R. D., 1996. Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method,” Geophysical Prospecting, 44, pp. 131-152.
[12] Loke, M.H., 2001. Tutorial: 2-D and 3-D electrical imaging surveys. I: Course notes for USGS workshop “2-D and 3-D inversion and modeling of surface and borehole resistivity data”. Storrs, CT, pp.13-16.
[13] DeGroot-Hedlin, C. and Constable, S., 1990. Occam’s inversion to generate smooth, two-dimensional models from magnetotelluric data. Geophysics, 55(12), pp.1613-1624.
[14] Kalinski, R.J. and Kelly, W.E., 1994. Electrical-resistivity measurements for evaluating compacted-soil liners. Journal of Geotechnical Engineering, 120(2), pp.451-457.
[15] Thabit, J.M., Bayraktutan, M.S. and Khalid, S.H., 2011, May. Evaluation of Resistivity Method in Delineation Ground Water Hydrocarbon Contamination Southwest of Karbala City. In 18th International Petroleum and Natural Gas Congress and Exhibition of Turkey (pp. cp-377). European Association of Geoscientists & Engineers.
[16] Loke, M.H., 2000. Electrical imaging surveys for environmental and engineering studies: A practical guide to 2-D and 3-D surveys. Penang, Malaysia.
[17] Koefoed, O., 1979. Geosounding principles, 1. Resistivity sounding measurements.