Mehran University Research Journal of Engineering and Technology

https://doi.org/10.22581/muet1982.2302.10

2023, 42(2) 88-92

Behavior of electrical resistivity against different soil properties

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Received: 15 September 2022, Accepted: 24 March 2023, Published: 01 April 2023

K E Y W O R D S

Electrical Resistivity

Moisture Content

Friction Angle

Geophysics

Correlation

A B S T R A C T

Any construction must be designed and built after the subsurface soil has been determined. The subsurface qualities of the soil are rendered by expensive, time-consuming, and risky operations, which on the other hand, raise the project's capital expenditure while also getting the engineering properties of distinct soil materials. Standard sampling techniques for boreholes are used for the assessment of the engineering properties of soil. But it is pretty costly, intrusive, and takes too much time. Therefore, a different method of determining the subsurface soil parameters is required. An alternate strategy for borehole sampling is to use geo-electrical techniques, such as electrical resistivity (ER). This research aims to ascertain the relationship between the electrical resistivity of various soils and their engineering characteristics. Without using the borehole sample method, appropriate correlations will aid in determining the subsurface soil parameters. Good correlations are obtained for the relationship of electrical resistivity against friction angle, cohesion and moisture content with an R2 value of 0.79, 0.41 and 0.66, respectively. The correlation of resistivity with unit weight showed a weak relationship due to typical soil behavior.

1. Introduction

Due to its application in the construction of man-made structures such as tunnels, highways, dams, and slopes, the stability of natural soil structures is essential in geotechnical engineering. The property of soil is one of the essential factors to be considered for the proper design of any structure to make it more sustainable [1]. The soil properties have been determined through conventional techniques using the borehole sampling technique; however, this technique is feasible for a small number of samples but is expensive and time-consuming for large samples [2, 3]. Geophysical investigations, such as seismic refraction, electrical resistivity, and penetrating radar, have long been linked to soil sciences [4, 5]. The applications of such methods are increasing nowadays for construction work as they are cost-effective and non-destructive. Along with these techniques, electrical resistivity is a desirable method for evaluating the subsurface soil parameters [6].

Red laterite soil is one of the soil types that may be found in tropical regions. High temperatures and copious rains are responsible for forming this type of soil. Water acts as a weathering agent, removing soluble materials while leaving behind insoluble ones. Its color is red due to the excess amount of iron oxides in it [7]. Additionally, the engineering properties of soil have more significant uncertainty due to the heterogeneous nature of soil materials [8].

In order to study the complicated behavior of soil, conventional approaches of relationships (models) would not be applicable to analyze its characteristics. Even over shorter distances, the geotechnical characteristics of soil vary in tropical nations due to many variables [9]. In civil engineering projects, soil engineering properties must be identified before utilization. The foundation of various construction projects is typically made of laterite soil.

According to the literature, this soil type can also be used as filler in tropical regions' construction projects [10]. The presence of water is one of the significant factors that affect resistivity [1, 11-13]. The various properties that affect the electrical resistivity of soils are water content, porosity, grain size distribution, degree of saturation, salinity, temperature, and pore fluid chemistry. Numerous scientific studies have examined the relationship between electrical resistivity and other soil characteristics like water content, thermal resistivity, salinity, CEC, hydraulic conductivity, and groundwater distribution; however, the validity of these correlations has not yet been fully established [3, 14-18]. Thus, this work is conducted to evaluate the moisture content (MC) in a landfill using electrical resistivity and to assess the correlation of resistivity with soil properties.

2. Material and Methods

The research study consists of both field investigations and laboratory activities. The research was carried out in Malaysia. Vertical electrical resistivity survey (VES) and soil sampling were done on-site using boring equipment. Simple tools such as a multimeter, a D.C. power supply, measuring tapes, insulated wires, and steel electrodes were employed for the resistivity survey, as shown in Fig. 1. A vertical electrical sounding or 1D survey was performed at the boreholes BH-01 and BH-02.

The electrode spacing varied between 0.5 and 6 meters when employing the Wenner array method. A 1D model of the subsurface soil was made using an inversion technique based on variations in resistivity and thickness. A percussion drilling technique was employed to collect soil samples from the subsurface. The soil samples were tested in the lab using the collected samples. The soil samples underwent tests for moisture content, unit weight, and direct shear following British standards. To assess the resistivity in the laboratory, the electrical resistivity of various soil samples from various depths was computed. The power source and multimeter were connected to two disc electrodes, which were fastened to the side of the cylindrical soil samples. 30V, 60V, and 90V of voltage were provided, and the resulting difference in current was observed. Shear strength parameters, such as angle of internal friction and cohesion, were determined by direct shear test in observance with BS 1377: Part 7: 1990, clause 6. ELE direct shear testing equipment with digital figures logger and DS 7 data recording software was used, as shown in Fig. 2.

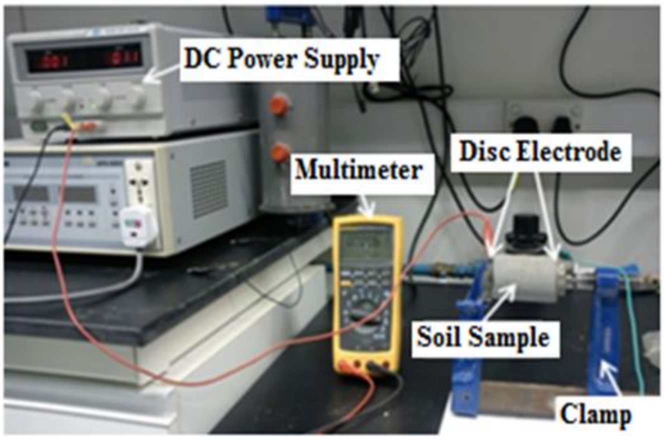

Fig. 1. Experimental arrangement for ER measurement

Fig. 2. Experimental arrangement for ER measurement

3. Results and Discussion

The results of this study were discussed in four subsections. In the first sub-section, soil investigation is covered, electrical resistivity is covered in the second, geotechnical properties and resistivity data correlations are highlighted in the third, and electrical resistivity and moisture content correlations are covered in the fourth.

3.1 Soil Investigation

Twelve soil samples from boreholes 1 and 2 were brought to the geotechnical testing lab on direct shear, resistivity, unit weight, and moisture content. Samples ranged in moisture content from 18 to 52 percent. Results for the soil's strength qualities revealed more or fewer shear strength factors. Table 1 presents the resistivity and geotechnical investigation data of the examined samples. According to the resistivity inversions, the thickness and resistivity values of the subsurface soil vary. 1892.42 -m to 17.40 -m was the range of electrical resistivity values.

3.2 Electrical Resistivity (ER)

For the resistivity tests, soil samples were taken at different depths. The resistivity test was conducted on the soil samples taken from boreholes 1 and 2. The same depth as that used for the field resistivity test was used to collect the samples. According to a field survey, the resistivity value at 0.57 meters of depth was 1892.44 -m. As a result, this depth was used to collect the soil samples. It was observed that the resistivity value in the lab was higher than the resistivity in the field. The difference in temperature and the alteration in saturation could be the cause. The maximum variations in resistivity values were found as 2.3% for the laboratory and 95% for the field.

Table 1

Geotechnical data of soil sample

Borehole No. 1				
Sample ID	Moisture Content %	Unit Weight (KN/m^3)	Cohesion (KPa)	Friction Angle (Deg)
1	23.67	19.99	22.03	29.11
2	23.44	19.17	24.67	16.48
3	34.36	18.18	25.60	6.84
4	42.01	18.12	27.80	9.48
5	32.65	18.90	21.73	8.08
6	34.95	21.87	25.60	10.48
Borehole No. 2				
1	18.79	20.13	39.20	23.22
2	37.76	18.39	15.92	31.51
3	40.06	17.38	29.59	23.21
4	52.42	16.52	18.67	5.36
5	45.55	16.45	21.91	13.01
6	51.79	17.33	11.40	10.02
7	45.50	16.38	5.16	9.10

Note: ER values ranged between 1892.42 Ω-m to 17.40 Ω-m.

3.3 Relationship Between ER Data and Geotechnical Properties

The field and the laboratory's electrical resistivity results were analyzed to establish a relationship between electrical resistivity and soil characteristics like moisture content, shear strength, and unit weight. Due to the large fluctuation in the trend, certain data were excluded from the final curve fitting. The graphs' problematic areas are shown with red circles. Outliers of the data (circled in red) were removed in the analysis to determine the relationships between electrical resistivity and soil properties, as shown in Fig. 3 to 6.

$$MC = -0.045Ln \times ER + 0.64 \quad (1)$$

Where MC is moisture content (%), and ER is the electrical resistivity (ohm.m).

In Fig. 4, weak unit weight and electrical resistivity correlations have been found with a regression value of 0.36. It is established that the increment in a unit weight of soil due to resistivity increased. The relationship between unit weight and electrical resistivity was weak; the regression value was 0.37. The reason for the weak relationship is attributed to the fact that the weight component of soil depends on the solid particles available in it. According to the relationship between friction angle and soil resistivity (Fig. 5), the resistivity value rises as the friction angle increases. The regression value of the relationship was 0.79, and equation (2) shows the relationship between electrical resistivity and soil friction angle.

$$FR = 3E - 0.7ER^2 + 0.0013ER + 8.71 \quad (2)$$

Where, FR is the friction angle (degree), and ER is the electrical resistivity (ohm.m).

The relationship between electrical resistivity and cohesion, which has a regression value of 0.41, is shown in Fig. 6. The pattern indicates that when resistivity increases, the cohesion value also rises.

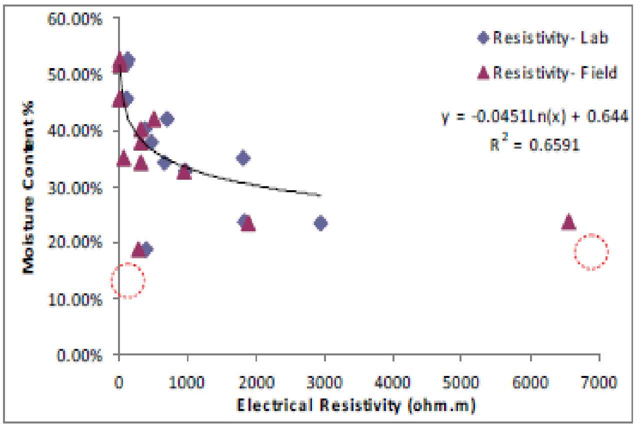

Fig. 3. Relationship between ER and MC

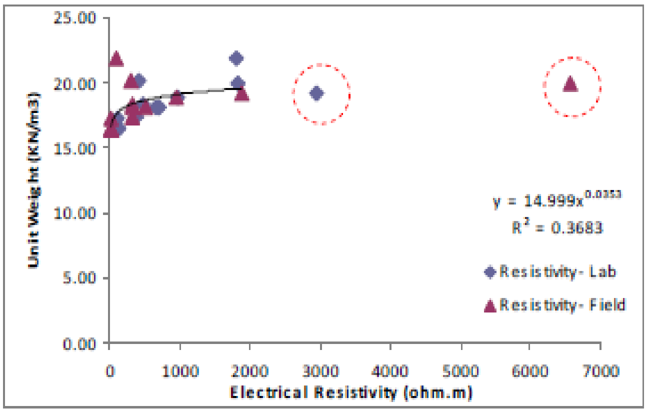

Fig. 4. Relationship between ER and unit weight

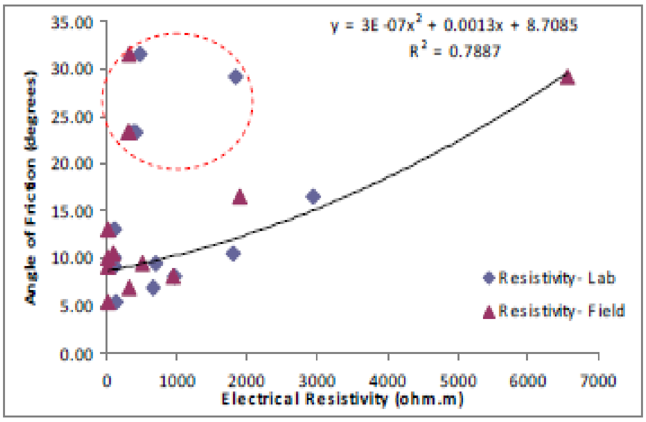

Fig. 5. Relationship between ER and the angle of friction

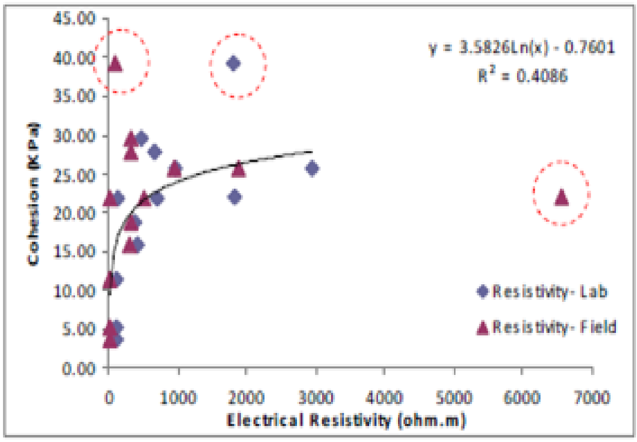

Fig. 6. Relationship between ER and cohesion

3.4 *Relationship between MC and ER*

The relationship between laboratory electrical resistivity and moisture content for the laterite soil samples shows a curvilinear trend. The regression data reveal a significant relationship between the two variables, with the electrical resistivity of laterite soil increasing as moisture content falls. For more on the correlation between soil moisture content and laterite, see Fig. 7 and 8. The soil pH values are generally in the alkaline range. However, a slightly acidic value of 6.05 was recorded at varying intervals. Acidic soils have the potential to catalyze corrosion.

On the contrary, alkaline soils tend to lower the corrosion rate. Additionally, soils become more acidic when bases are leached from the soil and replaced by hydrogen ions. The humidity is the main cause of leaching, leading to acidity.

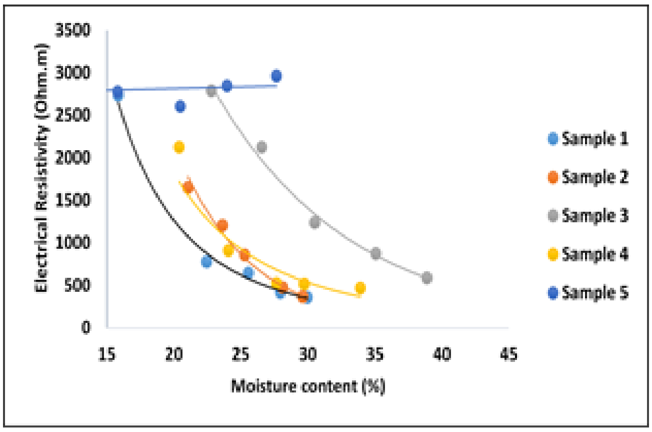

Fig. 7. Relationship between MC and LER for the 1st 5 samples

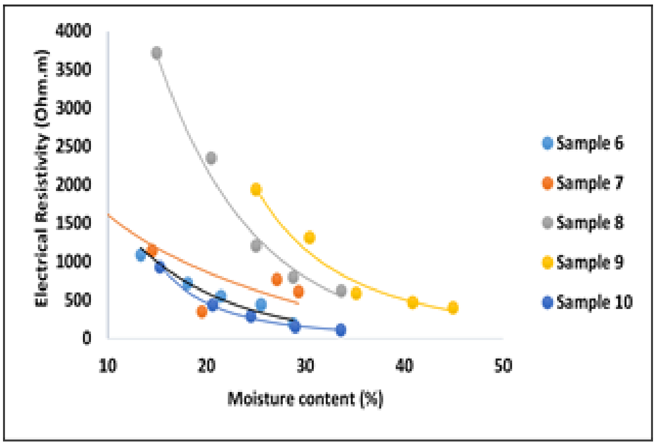

Fig. 8. Relationship between MC and LER for samples from 6-10

4. Conclusion

This study established a connection between resistivity and soil parameters. Moisture content, friction angle, cohesiveness, and unit weight values were all related to resistivity. There was a good relationship between ER and MC with a regression value of 0.66. The relationship was also vital for ER and FR, with a regression value of 0.79. However, there was not a good relationship between ER and unit weight or cohesion due to lower regression values, for instance, 0.36 and 0.41, respectively. The outcomes demonstrated the utility of the electrical resistivity method as a substitute for borehole sampling. However, more study is required to change borehole sampling with the resistivity method. Additional results and tests will help investigate the relationships and let engineers comprehensively apply geo-electrical techniques for the determinations of subsurface soils, which will help save cost, time, and effort.

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