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The effect of different degree of compaction towards electrical resistivity value for cohesive soil

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Abstract. Electrical resistivity is a non-destructive method used to measure the resistivity of ground properties, which is related to soil properties such as porosity and degree of saturation, as described in Archie's law. In road construction, soil compaction is a crucial process that requires quick quality assessment. Traditional methods, such as sand replacement tests, are time-consuming, limited in coverage, and labour-intensive. Therefore, incorporating electrical resistivity techniques on the current quality control practices may significantly improve efficiency. To achieve this, it is essential to establish the relationship between soil density, moisture content, and electrical resistivity. This study focuses on industrial and natural soil samples compacted using standard proctor moulds using 2.5 kg and 4.5 kg hammers. Resistivity measurements were conducted using the Miller 400A device using Wenner array and 1 cm electrode spacing. The impact of different compaction degrees on electrical resistivity values were compared for the two soil samples. The findings showed that soil dry density increased with the increment of water content until it reached maximum dry density. However, as water content continued to increase, the dry density decreased. Based on the results, electrical resistivity was higher at low water content but reduced with the increments of water contents. The resistivity value for industrial soil decreased from 164 to 12 Ohm.m and 200 to 13 Ohm.m. For natural soil the resistivity value decreased from 45 to 9 Ohm.m and 126 to 11 Ohm.m. The comparison of electrical resistivity values between the two different compaction methods indicated the moisture content limited the capability of the electrical resistivity method to identify the compaction effect in the proctor soil testing. This study demonstrates the potential applicability of electrical resistivity techniques in assessing soil compaction.

1. Introduction

For building to function effectively it is essential that foundation stiffness and allowable movements are controlled. To manage such movements one option is to improve the ground properties. One of the methods for soil improvements is through soil compaction. To achieve proper soil compaction, the quality control process needs to be thoroughly conducted. Current quality control practices for soil compaction includes a laboratory proctor soil compaction testing and also field monitoring typically using sand replacement methods. However, these quality control methods require much effort and time and would oftentimes stall the process of construction project [1].

In recent years, geophysical methods have become popular as they provide a non-destructive approach to profile the subsurface without conducting additional soil tests. Geophysical methods such as electrical resistivity, seismic and GPR have been proven to be able to identify the changes in soil properties such as undrained shear strength, density, moisture content and void ratio [2,3,4]. These methods are able to be utilize in the process of soil quality control as a means of covering more spaces and saving time. The use of these methods alongside the proven current practice of soil compaction quality control would give a more robust and efficient system where the effectiveness of soil quality control in construction may be improved in term of data acquisition and covering of spaces [5,6,7]

Electrical resistivity is one of the geophysical methods that has an established relationship between porosity and degree of saturation according to Archie’s law. This method involves injecting electricity into the subsurface and measuring the soil's electrical resistivity. One of the main strengths of the methods is the ability of the method to measure various depth and can cover a lot of space and saves time [8,9], which the current practice of quality assurance in term of soil compaction often lacks. Several studies have shown the ability of electrical resistivity methods to identify the changes in soil geotechnical parameters such as density and moisture content which relate with porosity and degree of saturation [10]. It is not expected the electrical resistivity to be directly use as a mean of predicting the soil density [11], however, the ability of these methods to identify the changes in geotechnical parameters may be utilize for soil quality control purposes in tandem with the current practice of soil compaction quality control.

The addition of geophysical methods may be of use for ground improvement processes. Technique via soil compaction testing in laboratory and soil density testing in the field using sand replacements methods are commonly used for quality control system, however this may take a lot of time, cover limited spaces and require a lot of manpower, especially in the case of road construction where soil compaction activity is a large part of the constructions process. Assessment of the possibility of electrical resistivity methods as the aid to the current practices of quality control is therefore essential to determine whether it is applicable to improve the current practice of quality control. Therefore, the relationship between soil density, moisture content and electrical resistivity need to be established. This paper aims to highlight the potential applicability of electrical resistivity techniques to be used to achieve such assessments showing how electrical resistivity changes with respect to the soil compaction parameters.

2. Compaction and electrical resistivity method

In this study, the electrical resistivity methods were used to identify the changes in soil density from the standard proctor compaction test. This study was conducted by using industrial soil and natural soil and compacted using standard proctor mould and compacted with 2.5 kg and 4.5 kg hammers dropped from heights of 30.5 cm and 45.7 cm respectively. Three identical layers were compacted with 27 blow repetitions per layer. The test was conducted on two different types of soil using two different compaction effort (2.5 and 4.5 kg proctor hammer) on a standard proctor mould with a volume of 1000 cm^3. The purpose of using two different compaction effort was to create different variable in soil density. The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) from the standard proctor test were assessed on both natural and industrial soil. The resistivity of the compacted soil was measured after each compaction were conducted. This study intends to identify the effect of density and also the effect of different energy from the proctor test towards the electrical resistivity value.

2.1. Soil identification

Two different type of soil was used in this study. The soil sample used for this testing were industrial soil (kaolin) and natural soil sample. Both samples were dominated with silt and clay in size. Several tests were conducted to identify the properties of the soil sample used in this study. The testing conducted on the soil involves, specific gravity, particle size distribution, plastic limit and liquid limit, and pH value. The obtained data of the soil properties are presented in **Table 1**. The particle size distribution for both soil sample are relatively the same with both soil categorised as clayey SILT. The industrial soil sample has a plastic limit and liquid limit of 29% and 59%, respectively and a specific gravity of 2.39 and pH value of 4.13. As for the natural soil, the soil has a plastic limit and liquid limit of 23% and 45% respectively and a specific gravity of 2.63 with a Ph value of 2.64.

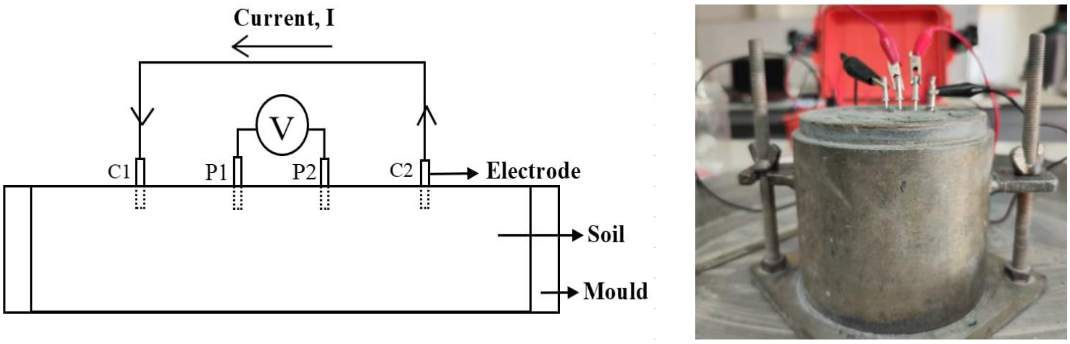
Table 1. Physical properties of tested soil

Soil properties	Industrial Soil	Natural Soil
Particle size distribution:		
Sand, %	0	7
Silt, %	83	80
Clay, %	17	13
Atterberg limit:		
Liquid limit, %	59	45
Plastic limit, %	29	23
Specific gravity, Gs	2.39	2.63
pH	4.13	2.64

2.2. Compaction and electrical resistivity testing

The compaction test for this study was carried out using the Proctor test. The oven dried sample were mixed with water at various proportion. Standard proctor mould with diameter of 10.15 cm and height of 11.53 cm was used. The soil samples were compacted in three layers in accordance to BS standard. The compaction load was performed using a hammer that weigh 2.5 kg and 4.5 kg which was drop from the height of 30.5 cm and 45.7 cm respectively for 27 times per layer as shown in **Figure 1**. The resulting compaction test were then weighted to determine the moisture content and density of the compacted soil. After the compacted soil was weighted, the resistivity of the soil was measured. The electrical resistivity measurement was taken by using Miller resistance meter. The resistivity measurement was taken on top of the open proctor mould as shown in **Figure 2(b)** after the compacted soil was weighted. The resistance measurement was measured for 3 times for the purpose of data accuracy. The electrode used to operate the testing was labelled as **C1** and **C2**, **P1** and **P2**. **C1** and **C2** electrodes were used as the current electrodes whilst **P1** and **P2** was used as the potential electrode as illustrated in **Figure 2(a)** The currents were injected through **C1** to **C2** and the differences of voltages was measured in between the **P1** and **P2.**

Figure 1. Compaction test in a standard proctor mould by using 4.5 kg hammer.



(a) (b)

Figure 2. (a) Schematic diagram of soil electrical resistivity measurement for soil testing (b) Resistivity testing conducted after the soil was compacted

2.3. Electrical resistivity measurements

In this study, direct current is used to determine the resistance of the soil sample. Electrical resistance is the ability of materials to resist electrical current flow within a medium. The resistance is denoted as “R (unit Ohm (Ω))” can be referred to **Equation 1**, where “V” is the voltage and “I” is the current. To obtain the resistivity value, the electrical resistivity measurement needs to consider the geomteric factor when conducting the electrical resistivity testing. This geometrical factor can be expressed in term of the type of electrical array used to measure the resistivity value. In this study, wenner array was used to conduct the electrical resistivity testing. The electrical resistivity measurement for wenner array is shown in **Equation 2**.

$$R = \frac{V}{I} \tag{1}$$

Where :

= Resistance
= Voltage
= Current

$$\rho_A = 2\pi a \rho \tag{2}$$

Where :

= Apparent resistivity (Ohm.m)
= Spacing in between the electrodes (meter)
= measured resistance (Ohm)

3. Results and discussion

This study involved the compaction of soil using a standard and modified proctor compaction with two different proctor hammers, one weighing 2.5 kg and the other weighing 4.5 kg. After each compaction, the electrical resistivity of the compacted soil was assessed as showed in **Table 2** and **Table 3**. For the 2.5 kg hammer, the dry density of the compacted natural soil was measured at 1588, 1612, 1613, and 1513 kg/m3, with corresponding electrical resistivity values of 45, 19, 15, and 9 Ohm-m, respectively. The moisture content for the natural soil samples ranged from 8, 15, 20 and 26%. For the 4.5 kg hammer, the dry density of the compacted natural soil was measured at 1667, 1681, 1696, 1695, and 1624.3 kg/m3, with corresponding electrical resistivity values of 126, 60, 42, 14, and 11 Ohm-m, respectively. The corresponding moisture content of the compacted natural soil using 4.5kg hammer was 3, 5, 10, 14 and 25% as showed in **Figure 3**. The same process was conducted on the industrial soil. For the 2.5kg hammer, the dry density of the industrial soil was 1257, 1291, 1343, 1377, 1302 and 1223 kg/m^3, with corresponding electrical resistivity value of 164, 101, 52, 46, 12 and 12 Ohm-m. The moisture content for the industrial soil samples ranges from 13, 18, 24, 28, 37 and 43%, respectively. For the 4.5 kg hammer, the dry density of the compacted industrial soil was measured to be 1228, 1304, 1408, 1481, 1483 and 1289 kg/m^3, with corresponding electrical resistivity value of 200, 125, 71, 53, 37, and 13 Ohm-m, respectively. The moisture content for the industrial soil ranges from 9, 14, 18, 23, 28 and 35 % as showed in **Figure 4**.

It was found that the two different weights used for the compaction testing gives different optimum moisture content (OMC) and maximum dry density (MDD) for both soils as shown in **Figure 3** and **Figure 4**. For the industrial soil, the OMC was 28% and 26%, with a MDD of 1370 and 1480 kg/m3 for the 2.5kg and 4.5 kg hammer respectively. For the natural soil, the OMC and MDD for both weights were found to be 18% and 12 % with a corresponding MDD of 1620 and 1700 kg/m3 for 2.5 kg and 4.5 kg hammer respectively. The findings suggest that the use of a heavier hammer resulted in greater dry densities of the soil samples with the need of less moisture content. The effect of compaction towards the soil sample has the same outcome by previous compaction tests conducted by several studies [12, 13]. It was expected that the 2.5kg hammer compaction effort would provide higher resistivity value of soil compared to the 4.5kg hammer. The findings show that was the case for the industrial soil, where the resistivity was lower for the 4.5kg hammer, however up to 22% moisture content, the difference of electrical resistivity value was almost diminished between the two different compaction which showed that the effect of moisture content was limiting the capability of the electrical resistivity method to identify the effect of compaction in the proctor soil testing. The resistivity value was shown to have small differences in the resistivity value at the OMC and MDD of the natural soil with both resistivity of the 2.5kg and 4.5kg hammer having 16 Ohm-m and 22 Ohm-m, respectively. It was found that although the 4.5kg soil having a more compacted soil compared to the 2.5kg hammer, but the resistivity value is still higher for the denser soil. This might be due to the higher moisture content in the less compacted soil at 18% compared to the denser soil at 12%. The effect of moisture contents within the soil are agreed upon several studies that stated the high moisture contents lowers the resistivity value of soil [14,15,16]. This shows that although the soil is denser, but the effect of moisture content would also affect the value of the resistivity which may give different interpretation of the resistivity value in term of soil density.

Table 2 - Soil properties condition after compaction for Industrial soil

2.5 kg hammer	***Dry density ρd (kg/m3)***	1257	1291	1343	1377	1302	1223
	Moisture content, Mc (%)	13	18	24	28	37	43
	Resistivity Ωm	164	101	52	46	12	12
	Saturation, Sr (%)	0.35	0.48	0.64	0.74	0.98	1.00
4.5 kg hammer	***Dry density ρd (kg/m3)***	1228	1304	1408	1481	1483	1289
	Moisture content, Mc (%)	9	14	18	23	28	35
	Resistivity Ωm	200	125	71	53	37	13
	Saturation, Sr (%)	0.23	0.37	0.48	0.61	0.74	1.0

` Table 3 - Soil properties condition after compaction for Natural soil

2.5 kg hammer	***Dry density ρd (kg/m^3)***	1588	1612	1613	1513	
	Moisture content, Mc (%)	8	15	20	26	
	Resistivity Ωm	45	19	15	9	
4.5 kg hammer	***Dry density ρd (kg/m^3)***	1667	1681	1696	1695	1624
	Moisture content, Mc (%)	3	5	10	14	25
	Resistivity Ωm	126	61	42	14	11

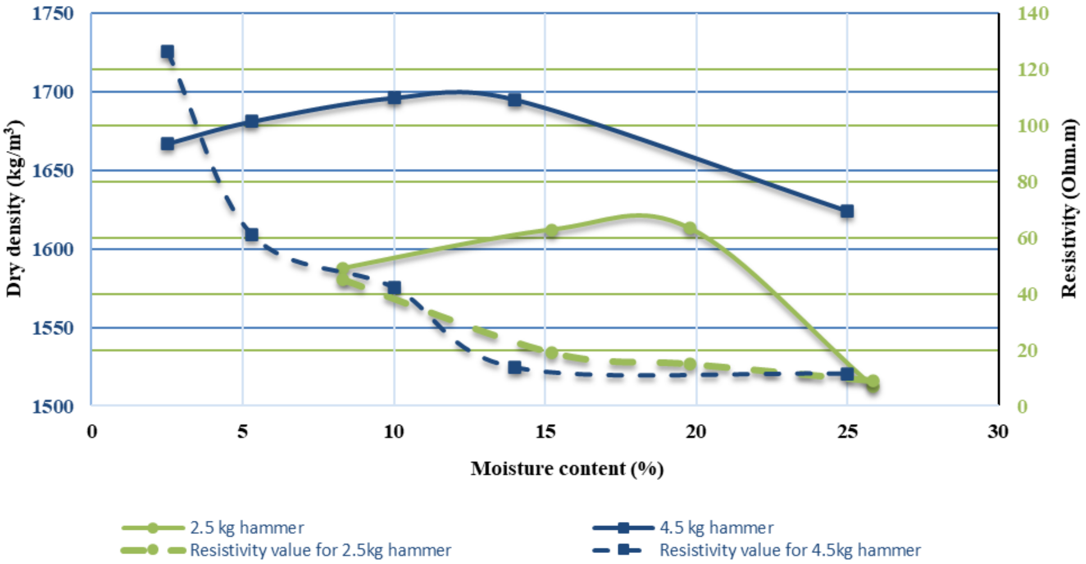


Figure 3. Dry density and resistivity vs moisture content for natural soil

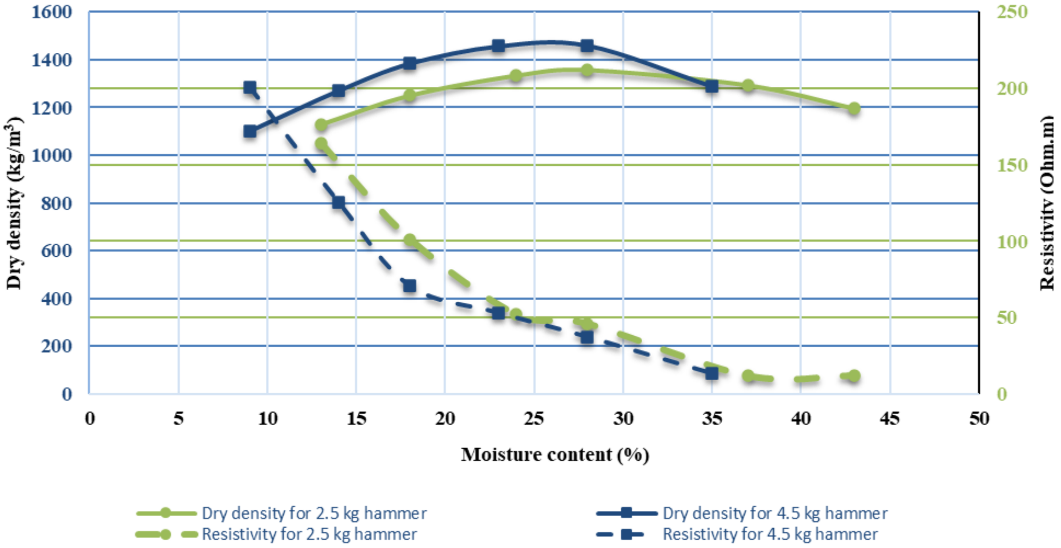


Figure 4. Dry density and resistivity vs moisture content for industrial soil

4. Conclusion

In this study the use of electrical resistivity method was intended to locate the OMC and MDD of the compacted soil by using proctor soil test. However, from the findings it shows the electrical resistivity methods may not be able to directly be use as a measure of soil density by using normal soil proctor test based on the nature of addition of water to make the soil denser. However, based on the experiments carried out in this study several conclusions can be drawn for further improvements and implementations of electrical resistivity methods in soil compactions:

1. The resistivity testing findings suggest that both soil density and moisture content have an impact on the interpretation of resistivity values in terms of soil compaction and density.

2. The difference in resistivity values between the two hammers diminished at higher moisture content, indicating that moisture content limited the capability of the electrical resistivity method to identify the effect of compaction.

3. The effect of soil compaction might be able to be highlighted more if the moisture content is kept similar with the use of different compaction effort to reach specific soil density instead of using water as a medium to help the soil reach its maximum dry density.

4. The possibility of electrical resistivity methods as the aid to the quality control is needed further investigation due to the relationship between soil density, moisture content and electrical resistivity need to be established for all types of soil since this assessment showing how electrical resistivity changes with respect to the soil compaction parameters.

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