Electrical Resistivity Changes in Wet and Dry Side of Optimum Moisture Content for Soils with Low to High Fines Content

Hamid Rostami and Abdolreza Osouli

Abstract Compacted soil is an essential element in the construction of geo-structures as not any soil site on its own is ideal for the intended construction. This research is an experimental study that investigates the interactional effect of moisture and fines contents on electrical resistivity (ER) of compacted soils. The soil type used in this study is sand with 0%, 30%, and 60% fines content. A non-conductive standard proctor mold is built and modified for measuring the electrical resistivity of soil samples with different dry densities and moisture contents. The electrical resistivity measurements are conducted using four electrodes; two electrodes for injecting the current and two electrodes for measuring the electrical potential difference. The soil specimens are tested under the same electrical setup in both dry and wet sides of the soil compaction curve. The results show that there is an inverse relationship between the electrical resistivity amount and both soil density and moisture content. The plot of electrical resistivity versus moisture content indicates that even though the electrical resistivity decreases with increasing the moisture content, the rate of electrical resistivity changes is different in wet and dry sides of optimum moisture content (OMC). In the dry side of OMC, the electrical resistivity decreases with a steep slope because of an increase in both soil density and moisture content. However, on the wet side of optimum moisture content, the soil density starts to decrease and electrical resistivity moves with a milder slope just because of an increase in moisture content.

Keywords Soil compaction · Electrical resistivity · Optimum moisture content · Fines content

1 Introduction

Electrical resistivity (ER) is an intrinsic characteristic of each material and is measured as the capability of contradicting the flow of electrical current. The basic

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principle of the ER method is that when a constant current is injected in to the soil through the electrodes, the current that flows between the electrodes has an inverse relationship with the resistance of the soil [1]. ER is a geophysical testing method and is commonly used in geotechnical engineering, geology, and environmental studies [2–4]. The most important factors that influence the ER of soils are moisture content, porosity, particle sizes, bulk density, and plasticity [5]. Electrical current in soil is strongly dependent on the moisture content and degree of saturation. Therefore, they are the primary factors that affect the electrical resistivity of soils [6, 7].

ER can potentially be used to detect any difference in soil density because the electrical resistivity of soil materials increases with decreasing the soil density. The measurement of ER can be used as an alternative to traditional methods for quality control and estimation of soil density.

Conventionally, the soil compaction is usually estimated using the measurements of dry density and moisture contents of the soil [8]. However, there are often difficulties with traditional laboratory approaches when high accuracy is needed. The ER method is a non-destructive, fast, and cost-effective manner for investigating the subsurface materials without the need of sampling and laboratory tests. There have been several studies that investigate the measurement of soil compaction using the ER for practical engineering purposes. Kowalczyk et al. [9] investigated the relationship between ER and moisture content and the degree of compaction for non-cohesive soil. The results showed that the ER is a function of both moisture content and degree of compaction. Abidin et al. [10] explored the relationship between the ER, moisture content, and bulk density. They showed that the ER decreased with increasing the moisture content in a curvilinear form. Other research [11] proved that ER can be used as an indirect indicator of soil moisture content.

The correlation between ER, moisture content, and soil density is likely to depend on particular combinations of the ranges of moisture content and soil fines that may be encountered. It will then be necessary to study the effects of those combinations in order to develop reliable correlations to ER measurements. In this paper, there is an attempt to determine the moisture content range for various types soils in which ER measurement can be used as a reliable representation of soil density. In this research, the soil specimens are tested under the same electrical setup in both dry and wet sides of OMC for three different types of soils from coarse-grained to fine-grained soils with various amounts of fines content.

2 Material and Method

The soil samples were prepared with three different fines contents 0%, 30%, and 60%, which are called hereinafter Sample 1, Sample 2, and Sample 3, respectively. Figure 1 depicts the soil grain size distribution that was determined for these samples using sieve analysis. Table 1 shows the soil classification according to the Unified Soil Classification System (USCS).
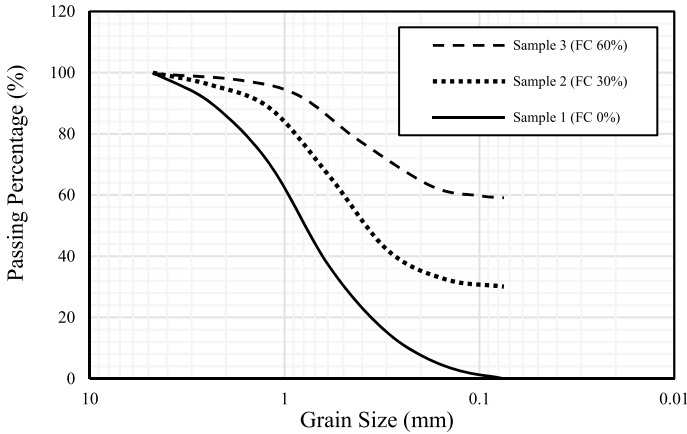
Fig. 1 Grading curves for soil samples

Table 1 Sample information and USCS classification

Sample no	Group symbol (USCS)	FC (%)	LL (%)	PI (%)	Description
1	SW	0	–	–	Clean and well-graded sands
2	SM	30	11.5	3	Silty sand
3	ML	60	21	7	Low-plastic silt

For the soil compaction, the standard proctor test was conducted according to the criteria of ASTM D-698. The only difference was using a mold machine from a 4-inch diameter PVC Schedule 80 pipe instead of regular steel mold for the standard proctor test. Fig. 2 shows the laboratory equipment used for ER measurement of compacted soils.

PVC was chosen because it was a good electrical insulator with resistivity of 1015 Ω-cm. It should be noted that, from geotechnical point of view, the plastic mold had no effect on results of moisture contents or soil density in comparison with regular proctor mold. Moreover, the plastic mold allowed insertion of two lateral electrodes (M and N) in the soil after its compaction. These electrodes were measuring the electrical potential, while the current was applied to the soil specimen through the top and bottom electrodes (A and B) (See Fig. 3).

The electrical resistivity of compacted soils was measured using SuperSting R1 and an Adapter Box. The SuperSting measures the resistance of material in Ohm Ω, which depends upon the shape and the size of specimen. In order to calculate the resistivity of soil material with the unit of Ohm Ω-cm, a correction factor was needed. This factor is derived by dividing the sample cross-sectional area by the distance between the electrodes A and B [12].

Fig. 2 Electrical laboratory test equipment

Fig. 3 A schematic view of PVC mold and four electrodes
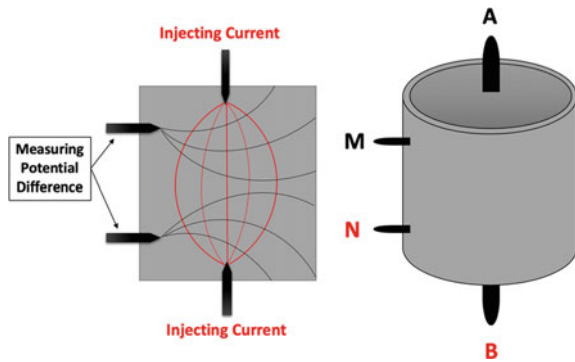
It should be noted that to assure repeatability of the results, 40% of the tests were repeated and the results of dry density, moisture content, and electrical resistivity were within ± 3.5% margin of error. Figure 3 illustrates a schematic view of the PVC mold, electrodes, and electrical current in soil sample.

3   Results and Discussion

The dry density versus moisture content curves for soil Samples 1 through 3 are presented in Fig. 4. This figure shows that Sample 1 with 0% fines content has the lowest optimum moisture content (OMC), while the Sample 2 with 60% fines
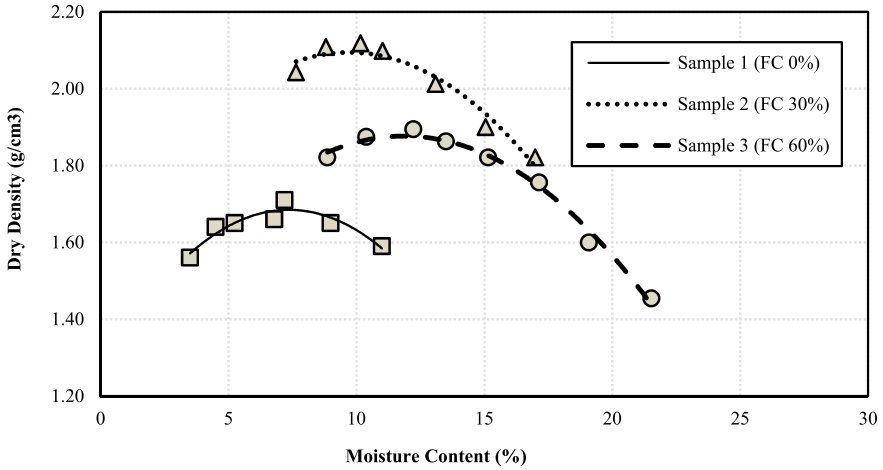
Fig. 4 Compaction curves for different soil samples

content has the highest OMC, which is compatible with typical behavior of well-graded sands [13]. These previous studies indicate that the addition of fines content with low plasticity to sandy soil up to a certain percentage, which varies from about 10% to 30% and depends upon the gradation of sand to be compacted, decreases the OMC and increases the Maximum Dry Density (MDD) of sand. With adding low-plastic fines content, OMC and MDD start to have an inverse trend.

Figure 5 illustrates electrical resistivity values versus moisture content for all soil samples tested. For the three types of samples, electrical resistivity values were found to decrease with increasing of moisture content. Resistivity values decrease with a
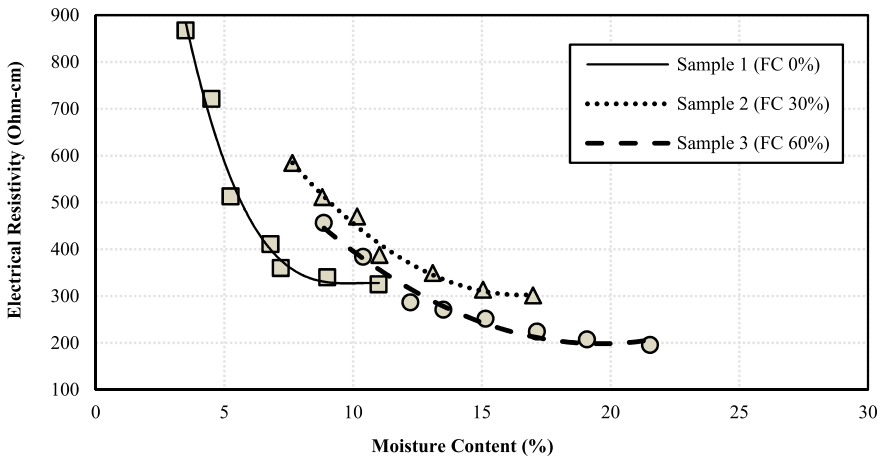

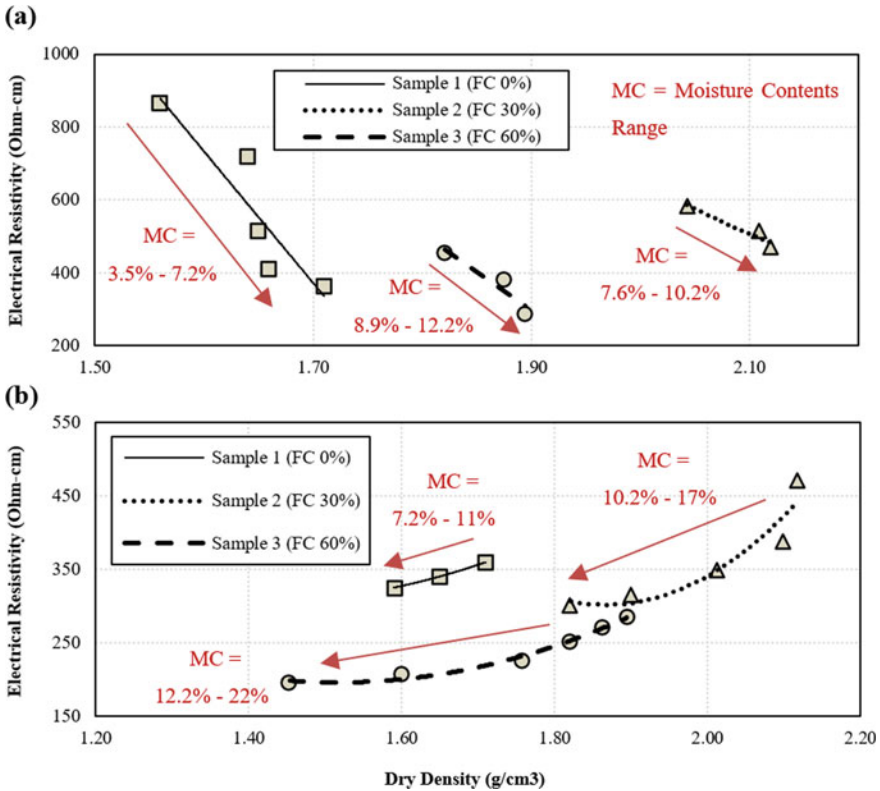**Fig. 5** Electrical resistivity versus moisture content

decreasing rate when moisture content increased up to 1–1.5 times the optimum moisture content, then electrical resistivity becomes almost constant with further increases in the moisture content. It indicates that when void spaces between grains fill and become connected to each other with fluid, adding more water to the soil has no considerable effect on the electrical conductivity of material. This is very similar to the variation of coefficient of permeability from dry to wet side of optimum moisture content.

Figure 5 also shows that in high moisture content ranges, the resistivity of individual soil samples decreases with increasing the percentage of fines content. In coarse granular soils, electrical resistivity is a function of the soil porosity, soil structure, and arrangement of the grains that provide different paths for the current. In fine-grained soils, however, it is mainly affected by the surface conductivity of the fine particles that considerably pave the way for electrical flow [14]. Furthermore, the increase of fines content results in filling the voids that exist between the particles and consequently minimize the volume of voids and connect the grains.

The relationship between electrical resistivity and soil density is more complicated. Figure 6a depicts the electrical resistivity values versus soil density on the dry side of OMC. According to this figure, the electrical resistivity has a decreasing trend for all three samples when the soil become denser, which is in agreement with conventional relationship between electrical resistivity and soil density. However, as shown by Fig. 6b, in wet side of OMC, the electrical resistivity continues to decrease with decreasing the soil density. It indicates that for Sample 1 (clean sand), soil density can be only detectable using electrical resistivity measurement up to OMC since the soil density has no considerable change versus electrical resistivity in wet side of compaction curve. However, for Samples 2 and 3 with 30% and 60% fines content, respectively, electrical resistivity can be used to detect the soil density change even in the wet side and up to 5% OMC.

4 Conclusion

This experimental study investigates the effect of moisture and fines contents on the relationship between electrical resistivity and soil density. Three different percentages of low-plastic (i.e., PI < 7%) fines content (i.e., 0%, 30%, and 60%) are compacted based on the standard proctor test procedure and using a PVC mold. The results clearly show that there is a relation between soil electrical resistivity and soil density that is affected by moisture content and fines content. The soil sample with zero percent fines content has a considerable high resistivity in low moisture content in comparison with two other samples. Regarding the moisture content, it should be noted that the OMC plays an important role in the soil resistivity-density relation, especially for clean sands. On the dry side of OMC, soil resistivity decreases with a steep gradient as a result of increase in soil density and moisture content. On the wet side of OMC, however, the electrical resistivity decreases with a decreasing rate when soil density starts to decrease. The moisture content gradually plays a

Fig. 6 Electrical resistivity versus soil dry density: **a** moisture content less than OMC (dry side); **b** moisture content greater than OMC (wet side)

more dominant role in this side for clean sands (Sample 1). Although electrical resistivity can be used as an effective method for measurement and quality control of field compaction, this study shows that two important parameters of soils, moisture content and fines content, must be considered if this approach is to be employed. The laboratory results show that in fine grained material and in more than 5% above optimum moisture content may lead to an incorrect soil density evaluation.

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