Effect of Moisture content on the Electrical Resistivity of Sand

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Abstract: In this study a few tests were performed on Ottawa sand. The focus was to characterize the relevant electrical properties and then investigate the relationship between resistivity (material property) and resistance (used to monitor). A non-linear relationship trend is observed between moisture content and electrical resistivity values.

1. Introduction:

Conventional borehole sampling and its subsequent geotechnical testing is the most precise and direct method for characterizing soil, but conversely it is also time-consuming and expensive (Danish K., 2016). In contrast, electrical resistivity surveys are non-destructive and less expensive which can be a viable method to determine soil properties, if reliable correlations could be established through extensive testing. The main objective of this paper is to establish the relationship between resistivity and moisture content of sandy soil.

2. Objective:

The objective was to investigate how moisture content may affect the critical electrical property for moist sand. Also investigate the relationship between resistivity and resistance.

3. Methodology:

For this study a cylindrical mold of height 4 inches and diameter 2 inches was used. Three insertions were made on the curved surface of the mold, two of them on one side and the other on the diametrically opposite side, for wire probes to be inserted. Figure 1 shows the pictorial representation of the probe configuration for electrical measurements. Four specimens with varying moisture contents (5%, 10%, 15% and 20%) were prepared. For each increment in the moisture content of the specimen the weight was recorded followed by a measurement of the resistance and reactance values using a commercial LCR device over a frequency sweep ranging from 20 Hz to 100 kHz. For the purpose of this experiment, readings were noted at the following frequencies: 20 Hz, 40 Hz, 60 Hz, 80 Hz, 100 Hz, 500 Hz, 1 kHz, 5kHz, 10 kHz, 50 kHz and 100 kHz. A soil conductivity meter was used to measure the conductivity of the specimen. In order to get the resistivity value, the reciprocal of the conductivity value was taken.

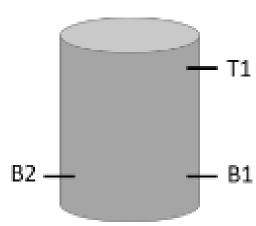

Figure 1 Probe configuration for electrical resistance measurements

4. Results:

Figure 2 depicts the impedance versus frequency plot for the vertical probe configuration with varying moisture contents. From Figure 2 two observations can be made. First, that as the water content is increased from 5% to 20% there is a decrease in the impedance value. Second, the impedance value decreases with increasing frequency until up to a certain frequency where it levels off. In this case at 50 kHz the impedance value begins to level off. This corresponds to case 2: Special bulk material – resistance only (Vipulanandan et al, 2013). This indicates that the impedance of the sand is mostly influenced by the resistance of the material.

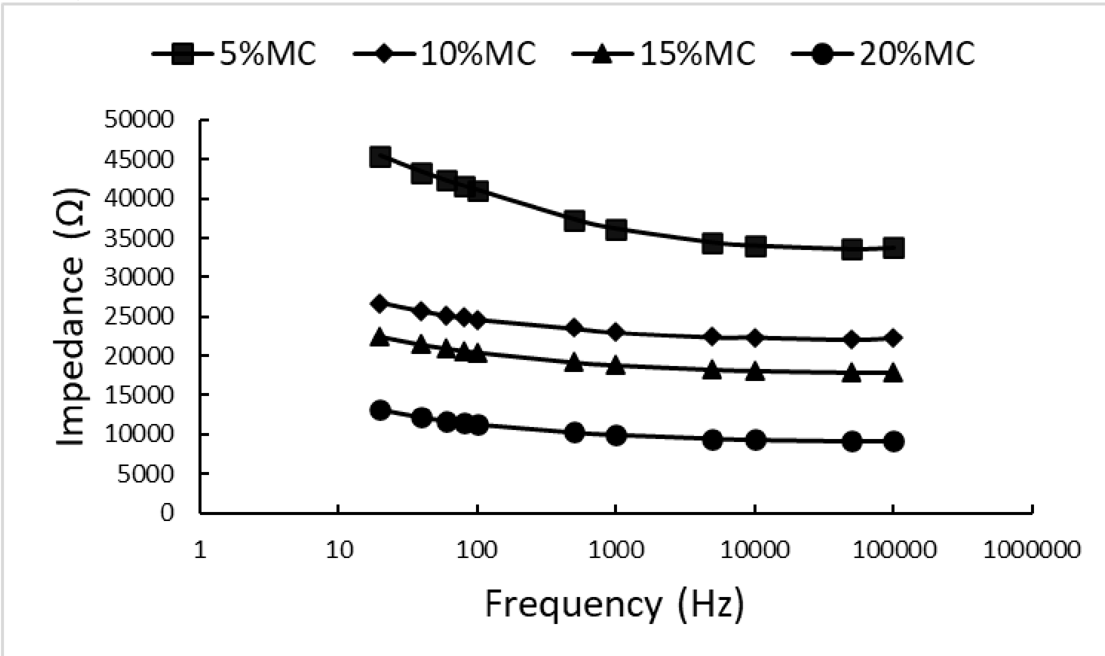

Figure 2 Impedance vs frequency plot for probe combination T1-B1 with varying moisture content

Figure 3 depicts the experimental resistivity values and model resistivity values as a function of the moisture content. The experimental results indicate that electrical resistivity is significantly influenced by water content, however this influence is minor when the water content is above 15%. For the specimen under study the electrical resistivities with different moisture contents of 10%, 15% and 20% decrease by 60%, 84.6% and 94.7%, respectively, when compared with the specimen with moisture content of 5%. This phenomenon corresponds to the onset of saturation conditions in the sand for which the resistivity value remains nearly constant.

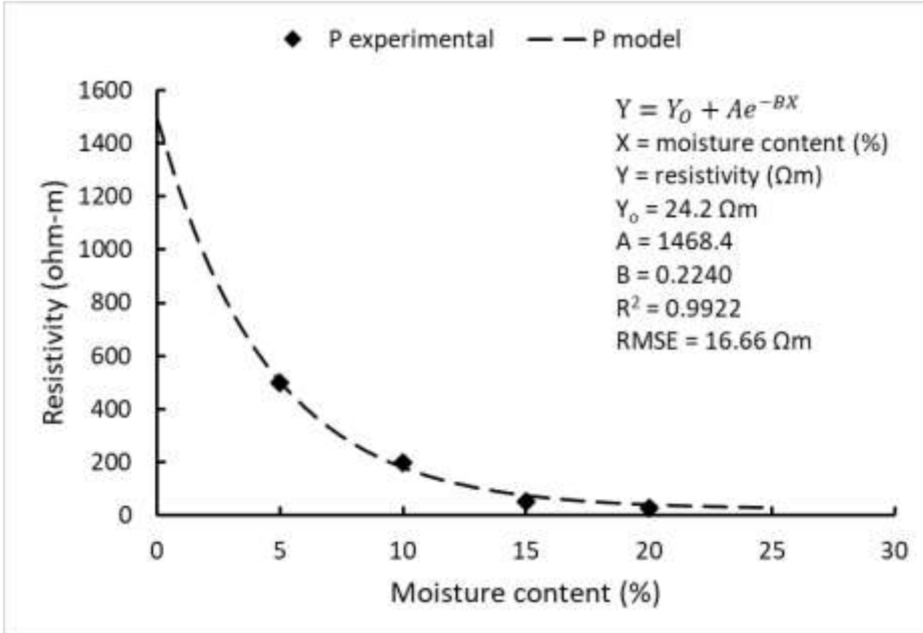

Figure 3 Experimental resistivity values and model resistivity values as a function of moisture content

This observation can be explained by the fact that dry sand has a very high value of electrical resistivity (Fukue et al, 1999). The resistivity of sandy soil primarily depends on the amount of permeating fluid, the porosity and the pore continuity of the sandy soil (Mi et al, 2015). Hence, for a slight increase in the water content we can see a significant amount of decrease in the resistivity value.

An exponential function of the form $Y = Y_O + Ae^{-BX}$ was chosen to model the experimental resistivity data points. Here X is the moisture content, Y is the resistivity value and A and B are model constants. The equation provided a good fit for the experimental data points with a root mean square error (RMSE) of 16.66 Ωm.

The impedance-frequency measurements were performed over a frequency range of 20 Hz to 100 kHz. Based on the measured impedance-frequency plot a suitable equivalent circuit was chosen. The equivalent circuit is shown in Figure 4. In this the bulk material is taken as resistance only while the two contact points are taken as a resistor and capacitor in parallel. Bulk resistance, contact resistance and contact capacitance values for all the probe configurations were computed by optimizing the model impedance data points in EXCEL program.

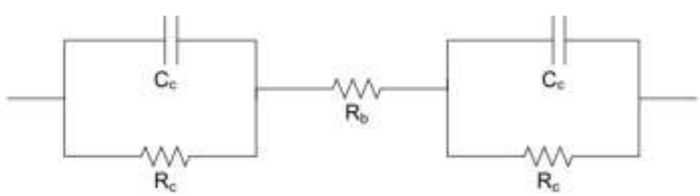

Figure 4 Equivalent circuit for case 2

Figure 5 depicts the experimental impedance points versus the model impedance curve for the vertical probe configuration of the 5% moist sand.

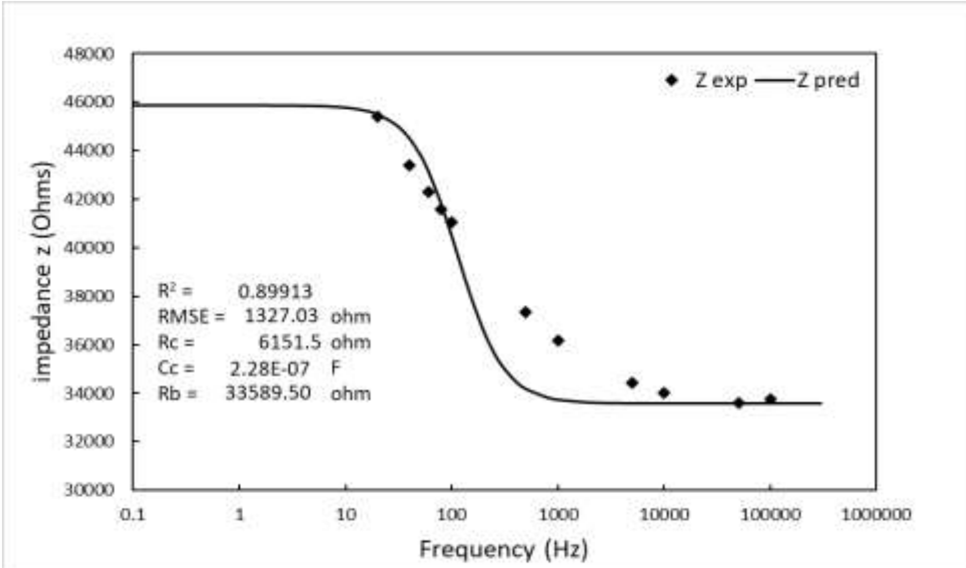

Figure 5 Impedance versus frequency plot of vertical probe configuration for 5% moist sand

Although resistance is not a material property, the percentage change in resistance will be directly related to the percentage change in resistivity. The bulk resistance (*Rb*) for (1) the horizontal combination B1-B2 decreased from 14435.88 Ω to 1860.99 Ω, (2) the vertical combination T1-B1 decreased from 33589.5 Ω to 9175.99 Ω, (3) the diagonal combination T1-B2 decreased from 33635.79 Ω to 9509.52 Ω. The contact resistance (*Rc*) for (1) the horizontal combination B1-B2 decreased from 3047.50 Ω to 674 Ω, (2) the vertical combination T1-B1 decreased from 6151.5 Ω to 2078.5 Ω, (3) the diagonal combination T1-B2 decreased from 5317.5 Ω to 2109 Ω. The contact capacitance (*Cc*) for (1) the horizontal combination B1-B2 increased from 4.28E-07 F to 2.88E-06 F, (2) the vertical combination T1-B1 decreased from 2.28E-07 to 8.62E-07, (3) the diagonal combination T1-B2 decreased from 2.66E-07 F to 7.83E-07 F. An index was defined as the product of the contact resistance and contact capacitance $R\text{c} \times C\text{c}$. The plot of $R\text{c}C\text{c}\ versus\ time$ for the horizontal configuration B1-B2, vertical combination T1-B1 and diagonal combination T1-B2 are shown in Figure 6.

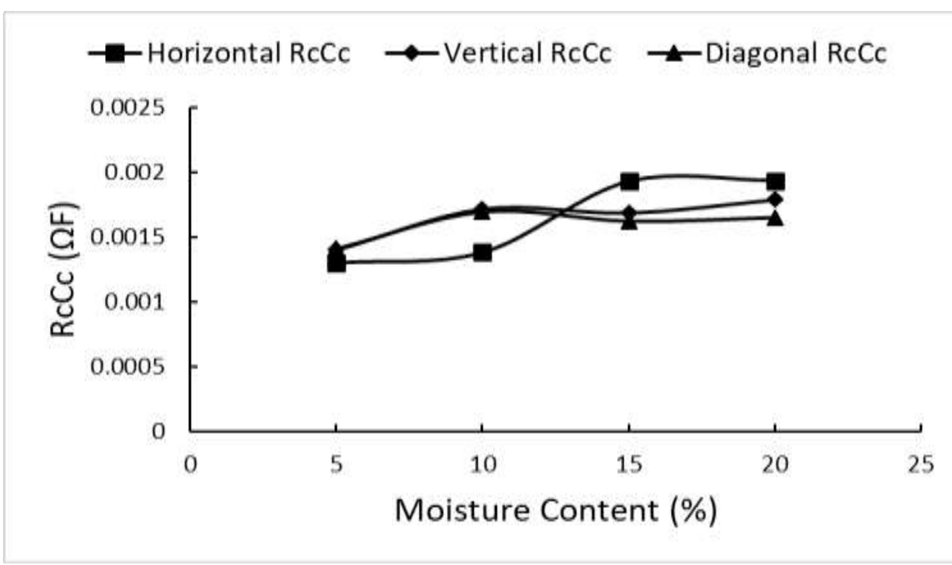

Figure 6 Variation of index RcCc of horizontal probe configuration, vertical probe configuration and diagonal probe configuration over the various moisture contents

$RcCc$ value for horizontal probe configuration B1- B2 increased from 0.001304 ΩF to 0.001939 ΩF, vertical probe configuration T1-B1 increased from 0.001404 ΩF to 0.001791 ΩF and for the diagonal probe configuration T1-B2 increased from 0.001413 ΩF to 0.001651 ΩF respectively from 5% moisture content to 20% moisture content. This corresponds to a change of 48.75%, 27.55% and 16.82% respectively.

5. CONCLUSION:

From this study we were able to draw certain conclusions:

1. The resistivity of Ottawa sand is dependent on the amount of permeating fluid, the porosity and pore continuity of the sand specimen. Thus, the resistivity value drops for higher water content and after saturation the value remains constant.
2. The impedance value of Ottawa sand over the frequency range of 20 Hz to 100 kHz (for a given water content) decreases from 20 Hz to 50 kHz beyond which it becomes nearly constant. This behavior shown by Ottawa sand signifies that the impedance of the sand is mostly influenced by the resistance of the sand. Hence, it follows case 2.
3. Maximum change in resistance and resistivity occurs in the range of 5 to 15 percent water content. After that the change is rather minuscule.
4. An exponential function was successfully used to model the resistivity data for the varying moisture contents.
5. The index *RcCc* increased in value for all probe configurations with subsequent increase in moisture content. This indicates that there is a direct relation between index RcCc and moisture content in sand.

6. Acknowledgments:

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7. References:

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