A New Approach for the Electrical Resistance of Compacted Soils

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ABSTRACT

The study describes a relationship of compacted soils and electrical resistance by a geometrical model. From an overview made of the previous studies dealing with the compaction measurement by electrical properties, a mathematical approach that is based on numerical integration of the conventional compaction mould is proposed. A right-circular cylinder having 'h' height and 'r' radius is modeled by perpendicular slices to the r-axis. Following the assumption of evenly traveling of electrical current among the path described in r-diameter circulars, the method of slicing has been applied. Results of the study look encouraging as compacted soil characteristics could be measured using an alternative approach.

KEYWORDS: soil, compaction, electrical resistance.

INTRODUCTION

Soil water content and dry density are two key properties for compaction quality control when considering the stability of earthworks containing soils. Despite some recent developments (i.e., Yu and Drnevich, 2004), commonly used compaction quality control methods obtain total density using one procedure and the water content using another procedure. The conventional approach towards the measurement of bulk density is to remove a known volume of soil and measure its oven dry weight and volume. The core, clod (McKeague, 1978), excavation (Blake, 1965), and gamma radiation methods essentially use this approach, differing in sampling method. However, the reference method for water content is the standard oven dry method.

Geophysical methods have potential to assess compaction quality too. For example, electrical resistivity (resistance per unit length times cross-sectional area) of soils and porous rocks has been described to be sensitive to pore-fluid resistivity, matrix resistivity, pore-space morphology as well as density and water content (Jackson et al., 2002). The use of electrical resistivity to characterize soils has been investigated by many authors (Smith-Rose 1935, Croney et al. 1951, McCarter 1984, Mualem and Friedman 1991).

For example, Kalinski and Kelly (1993) performed a series of laboratory measurements using a small plastic rectangular box with metal ends and two pins inserted along the length. Soil specimens were compacted into the box, and the metal pins were inserted into the specimen. Due to the geometry of the box, the resistivity of the specimen in ohm-cm is equal to the measured resistance in ohms.

In another research, Abu-Hassanein et al. (1996) widely studied the relationships between electrical resistivity, hydraulic conductivity, compaction conditions and index properties for various clayey geomaterials. Using an apparatus developed by the authors, they mainly concluded that (a) lower electrical resistivity is obtained for compaction and greater compactive effort or higher water content (b) there is an unique relationship between electrical resistivity and saturation degree that is independent of compactive effort (c) there is unique relationship between electrical resistivity and hydraulic conductivity for some soils (d) higher liquid limit shows lower electrical resistivity. The apparatus proposed by the authors might have been constructed mainly due to simulate a conductor rod having ‘r’ radius and ‘L’ length to readily use the Ohm’s law. In that figure, the potential drop (ΔV) is measured between the copper rods inserted at the third point. The current flow lines will be parallel to the axis of the cylinder with the equipotential lines at right angles to these flow lines. The electrical resistance ‘R’ is computed using Ohm’s law (equation 1) assuming that electrical field is one-dimensional. The vertical electrical resistivity ‘ρ’ is then computed from the equation 2.

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

$$\rho = \frac{RA}{L} \tag{2}$$

Where ΔV is the potential difference between the copper rods, I is the electrical current through the end electrodes, L is length through electrical current flows, and A is the cross-sectional area.

However, this approach does not seem to allow flexibility in the procedures necessary to develop a relationship between electrical and hydraulic properties of soil in-situ. Therefore, this study attempts to describe the use of an alternative to the approach already available by performing numerical investigating of electrical resistance because of its simplicity and availability. For this purpose, a mathematical approach that is based on the numerical integration of the conventional compaction mould is introduced. The compaction mould having ‘h’ height and ‘r’ radius has been modelled by slicing perpendicular to the h axis, as well as perpendicular to the r axis.

DEVELOPMENT OF A MODEL

Most published studies on the electrical resistivity of soils concentrate on the experimental procedures to assess the compaction quality. The usefulness of accurate experimental study to define compaction quality is undisputed. However, in this study, it has been decided to present a numerical approach that can be implemented in a finite elements approach. The objective of the modelling is to show the potential-drop measurements between two points at the edge of a compaction mould, which are assumed to be placed on a straight line.

Based on the assumption of evenly travelling of electrical current among the path described, a right-circular cylinder solid having a base in diameter ‘2r’ and in height ‘h’ has been considered to represent the conventional compaction mould. Here, a right-circular cylinder is defined as a solid that can be generated by translating a circular plane region along a line or axis perpendicular to the region. The right-circular cylinder solid can be divided into thin slices by parallel planes perpendicular to the r-axis. Each slice is rectangular of height, where the height is the height of cylinder ’h’. Consider a typical slice S_i (Figure 1). If the slice is very thin, the cross section of the slice S_i will be approximately the same as the cross section at r_i, and we can approximate slice S_i by a thickness Δr_i and cross sectional area A (r_i). If the cross-sectional area of each slice is known, its length and average area necessary to compute resistivity ‘ρ’ using the equation 2 can be determined, which is unique for each soil under specific conditions.

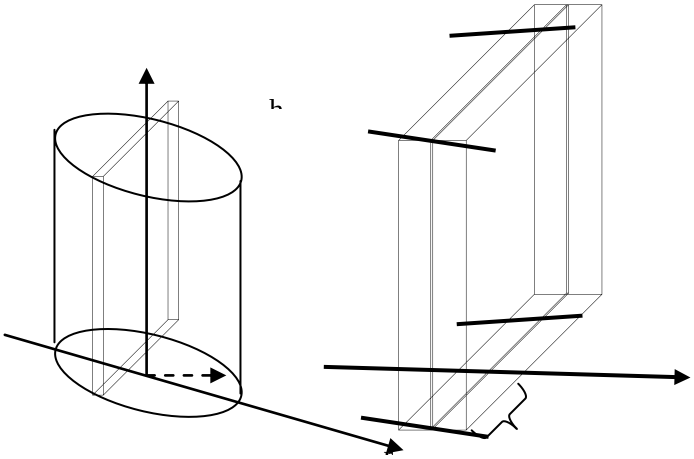

Figure 1: Schematic representation for the approach proposed.

To be specific, suppose that the solid M shown in Figure 1 lies between planes perpendicular to the r-axis at positions a=-r and b=+r and that the cross-sectional area of M in the plane perpendicular to the r-axis is a known function A(r), for $a<r<b$. The author assumes that A(r) is continuous on [a, b]. If $a= r_0< r_1< r_2 <r_3\ldots< r_n= b$, then $C= \{r_0, r_1, r_2, r_3, \ldots\ldots,r_n\}$ is a partition of [a, b] into n subintervals, and the planes perpendicular to the r-axis at the $r_1, r_2, r_3, \ldots\ldots r_{n-1}$ divides the solid into n slices of which the i^{th} has thickness $\Delta r_i= r_i- r_{i-1}$.

Thus, the area $A(r_i)$ of the slice S_i is approximately

$$A(r_i) = 2x_i h \tag{3}$$

and the sum of the entire slices in solid M is approximately

$$A = A_1 + A_2 + \ldots + A_n \approx \sum_{k=1}^{n} 2x_i h \tag{4}$$

If we now increase the number of slices in such way that max $\Delta r_i \rightarrow 0$, then the slices will become thinner and thinner and the approximation will get better and better. As the thickness of each slice tends to zero, the sum becomes a definite integral. Thus, intuition suggests that approximation (4) will approach the exact value of the area A of the solid between a=-r, and b=+r, as max $\Delta r_i \rightarrow 0$, that is,

$$A = \lim_{\max \Delta ri \longrightarrow 0} \sum_{i=1}^{n} 2x_i h \tag{5}$$

Since the right side of (5) becomes a definite integral, then we are led to the following result

$$A = \int_0^r A(r)dr \tag{6}$$

then, by inserting ‘x’ in to the equation (6) becomes,

$$A = 2 \cdot h \cdot \int_0^r \sqrt{r^2 - (r - l)^2}\, dr \tag{7}$$

RESULTS AND DISCUSSION

The electrical resistance approach to the modelling of compacted soils provides a theoretical basis for the analysis of compaction quality. A fairly simple integration model for this approach is applied to generate an understanding of the relationship between electrical resistance and compacted soils. A series of modelling have been performed on laboratory compacted specimens of a CH soil having different resistivity properties as reported by Kalinski and Kelly (1993). The applicability of the proposed model to predict the relationship of compacted soils and electrical resistance is judged based on this data set.

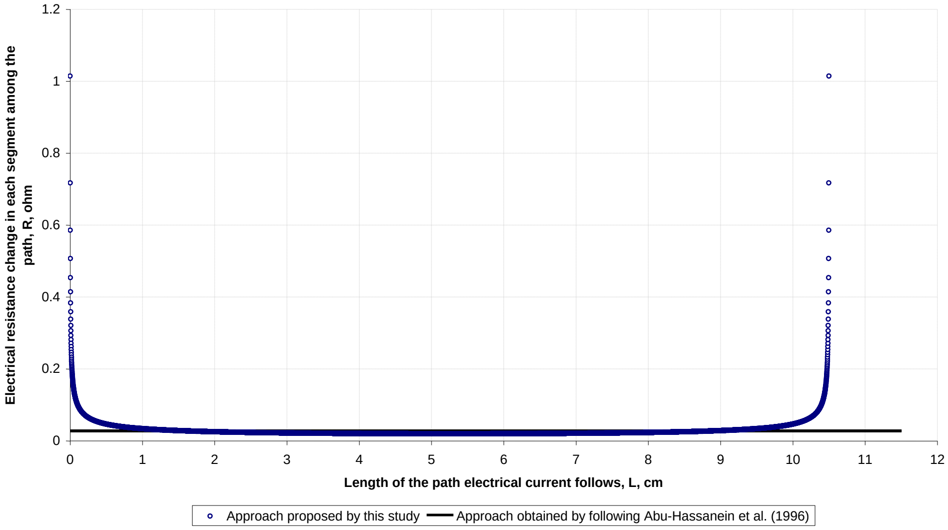

Figure 2: Change in electrical resistance through each segment having 0.001 cm length.

Change in electrical resistance in each segment through the r-axis, for ρ= 2390 ohm-cm, is seen in Figure 2, where the solid M representing the conventional compaction mould has been divided into segments, each having 0.001 cm length. When graphing equations of the form R=f (L), the author has been keeping the L-axis horizontal and the R-axis vertical, where R=f (L) is said to define R explicitly as a function of L. Following the concept by the Abu-Hassanein et al. (1996), Figure 2 also shows an application of slicing method to the h-axis. As can be seen from the figure, the approach proposed in this study exhibits a set of points in the plane equidistant from L-axis (the directrix) and a point not on the line (the focus), which could be described as a parabola. The segments having the smaller areas, which are at the two ends of the r-axis in Figure 1, show higher resistance values than the segment having larger areas, which are between the two ends.

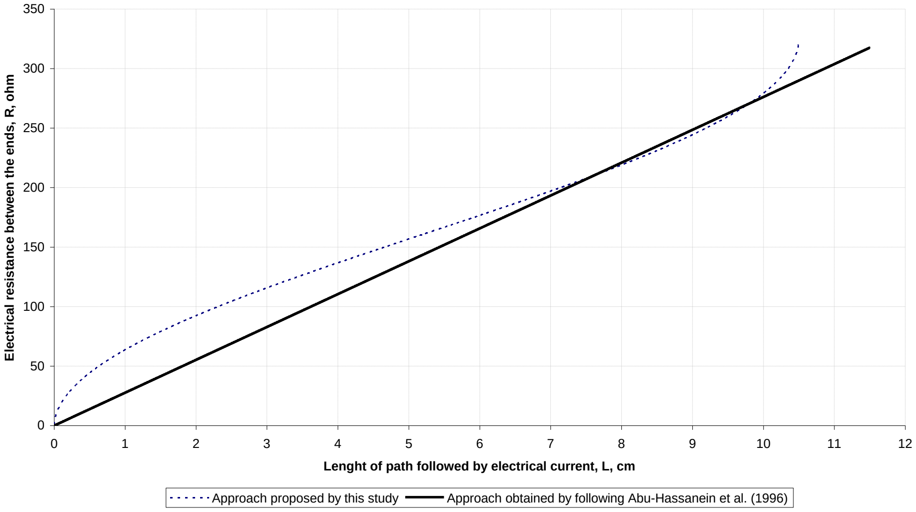

Figure 3: Electrical resistance in the whole section.

Figure 3 displays the evolution of the predicted electrical resistance as a function of distance from one end to rest of the points for both approaches. The evolution of the predicted electrical resistance is related to the fact that corresponding area varies among the path followed by distance from the end. Among the path, the relation obtained by following Abu-Hassanein et al. (1996)'s approach is linear; whereas the other approach is non-linear.

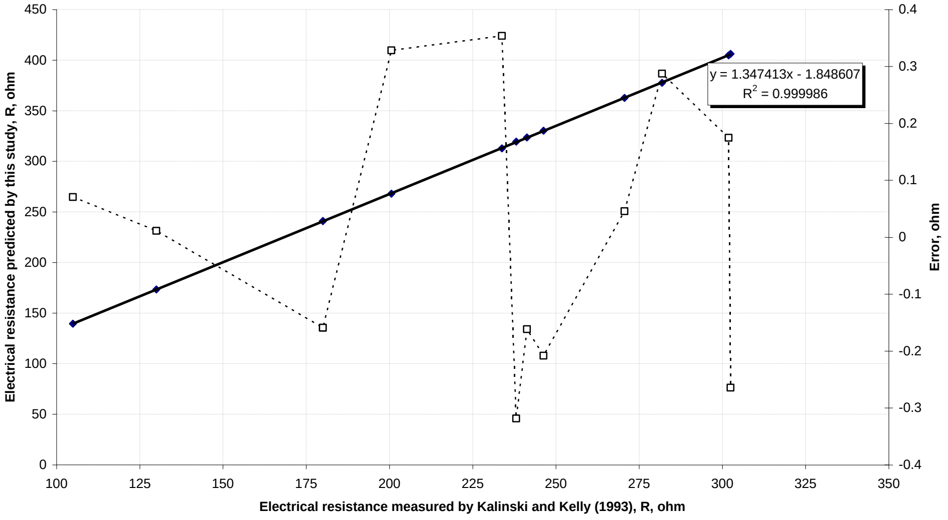

Figure 4: Comparison of measured and predicted electrical resistance.

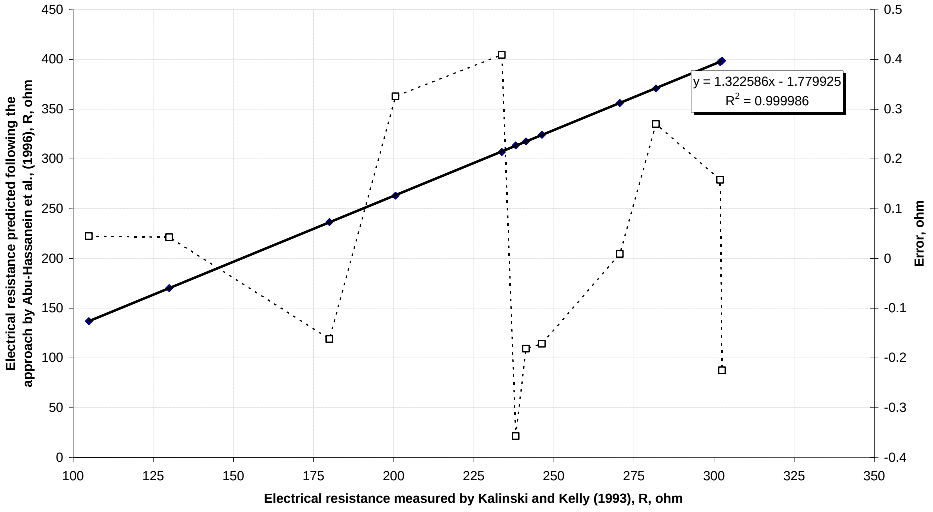

Figure 5: Comparison of measured and predicted electrical resistance.

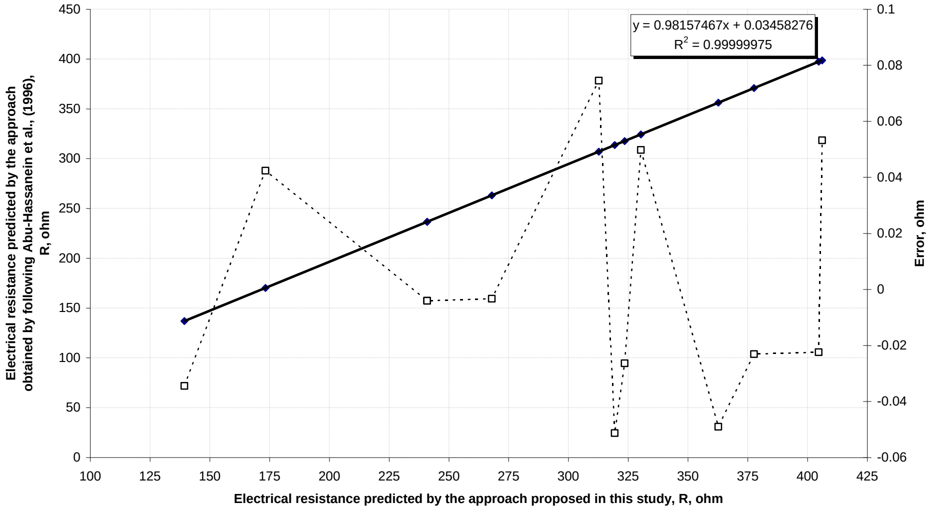

Figure 6: Comparison of predicted electrical resistance obtained different approaches.

The theoretical estimates from the two different approaches are also plotted in Figures 4, 5, and 6 for comparison. In Figures 4 and 5, electrical resistance of the specimen having various resistivity (ρ) values could be predicted with a maximum error approximately 0.35 ohm in the approach proposed by this study and a 0.41 ohm in the approach obtained following Abu-Hassanein et al. (1996). Figure 6 shows the comparison of predicted electrical resistance obtained different methods and the errors.

CONCLUSIONS

The purpose of this investigation was to study the electrical resistance of compacted soils for use in numerical approach. The author proposed a geometrical model based on the numerical integration of the conventional compaction mould. This relation was shown by computations performed over a series of laboratory measurements reported by Kalinski and Kelly (1993). The author then presented general comparisons between the approach proposed here in this study and the approach obtained by following Abu-Hassanein et al. (1996) as well as the study by Kalinski and Kelly (1993). Qualitative evidence was found for the approach proposed in the study. A main advantage of this technique is that compaction quality could be made without the need for numerous procedures. Experiments over the study are going to be under way for comparison with numerical simulations in order to evaluate more specifically the influence of water content and compaction degree on the electrical resistance.

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