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Characterizations of Soil Profiles through Electric Resistivity Ratio

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Abstract: This paper presents how near surface soil characteristics are obtained through soil electric resistivity ratio from soil apparent resistivity profile. In recent advances of electrical sensors, soil apparent resistivity is implemented as nondestructive method for obtaining near surface soil profile. Although geo-electric techniques offer an improvement to traditional soil sampling methods, the resulting data are still often misinterpreted for obtaining soil characteristics through apparent electrical resistivity in the field. Because, soil resistivity as before rain and after rain are changeable due to the presence of more moisture contents in field investigations. In this study, the parameter of soil electric resistivity ratio is incorporated to obtain reliable near surface soil profiles from apparent resistivity of adjacent two layers in soil. The variations of potential differences are taken into account for using four probes method to get the soil apparent resistivity profile. The research is significant for simpler and faster soil characterizations using resistivity ratio of apparent resistivity in soil investigations.

Keywords: Soil apparent resistivity, Resistivity ratio, Depth of soil layers, Soil characteristics.

1. Introduction

Investigations of near surface soil profiles are necessary in geotechnical engineering, Highway and Road engineering and other division of civil engineering. The soil electrical resistivity are very important for determining the specific soil characteristics [8] including soil particle, soil compaction [6], salinity, porosity, temperature of soil corresponding to the depth and thickness of soil in geotechnical characteristics [1]. In this method, the current must be properly inserted into the soil medium through the voltage source connected with electric probes and the calculations of voltage differences are taken between other electric probes in soil [10].

Different soil electric resistivity test methods are seen considering the factor of probe numbers, lengths of cables required, efficiency of the measuring technique in near surface soil characterizations [2, 3]. Moreover, the test type are selected based on costs, reliability and ease of interpretation of the resistivity data. The common methods for soil resistivity investigations include Wenner method, Schlumberger array method and Driven Rod methods in geo-electrical model. The soil resistivity measurements are more commonly done by Wenner four probes methods [4, 13].

Seedher & Arora [18] obtained two-layer apparent resistivity profile with an optimal fit for two-layer soil structure. They included theoretical data with actual field data in their apparent resistivity model.

Takahashi and Kawase [9] shows the improvements in apparent resistivity profile where multi-layer earth structure is considered to show *ρ-a* curves for different layers. The instrument of measuring gauge is used to get apparent resistivity through Wenner four probes method. Using of the gauges in apparent resistivity measurements shows the limitations in coverage of all the situations of soil. Deep driven rod is needed to obtain essential earth parameters information from apparent resistivity profile in their model.

The optimization of apparent resistivity data is shown in the algorithm of Kang et al. [5]. The kernel function of Zou's method [21] is used to optimize the resistivity data. This proposed method is tedious and time consuming for the difficult derivatives of optimization expression in the measurements.

In addition, tomography technique is incorporated with soil apparent resistivity to show the 2-D profile of near surface soil. The computer software, Res2Dinv and Res3Dinv are used to get electrical resistivity tomography (ERT) from soil apparent resistivity data [4]. Researchers show the applications of ERT in hydrological applications [1, 6] and near surface soil characterizations [13].

Conventional techniques of soil apparent resistivity measurements do not allow the estimation of the short range variability [14]. The limitations are found especially in terms of the interrelationships between distance of probes and depth of soil profiles in soil apparent electrical resistivity (ρ) measurements.

Ozcep et el. [19] shows the relationship between soil electric resistivity and the moisture contents of soil. Moreover, soil electric conductivity can vary due to chemical compositions in near surface soil [12, 15]. Laver & Griffiths [20] shows that the soil electric resistivity changes according to the moisture contents, temperatures and other geological parameters. In conventional method, soil resistivity as before rain and after rain would not be same due to the presence of more moisture contents in field investigations. Moreover, using of only soil apparent resistivity data can influence decision based on site location with different installations of earthing electrode system. If the results obtained from the soil resistivity survey are unclear then it is suggested to repeat the soil testing in conventional method [7, 11].

For this reasons, soil resistivity ration is included in this model to overcome the influence of moisture contents and chemical contents on soil electric properties. The ability to calculate of soil resistivity ratio of different layers will perform layer-by-layer earth analysis for introduction of earth parameter information necessary in soil characterizations.

In this study, the soil resistivity properties are measured along the depth based on the measured electric current and voltage difference with the thickness of soil layers. Fig. 1 shows the different layers of soil where resistivity ratio is obtained from apparent resistivity measured of adjacent two layers. The measurements consist of the reading taken at the depth of last point of the layers. Subsequent reading is obtained with the penetration of probes in the soil. Apparent resistivity is considered according to the changes of the distances between two adjacent probes.

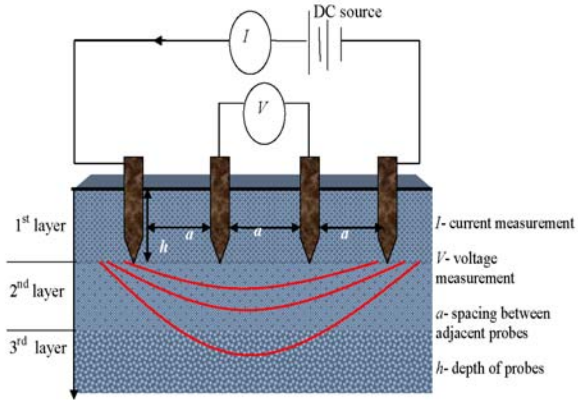

Fig. 1. Soil characterization with apparent resistivity model.

The model based on soil electric resistivity ratio can significantly reduce the complexity of estimation of depth and thickness corresponding soil resistivity profile. The aim of the research is demonstration of reliable and faster soil characterizations with depth and layer thickness using parameter of soil resistivity ratio in near surface soil resistivity profile.

2. Methodology

The research on soil electric resistivity is carried out in the Faculty of Engineering and Built Environment, University Kebangsaan Malaysia (UKM). The apparent resistivity of near surface soil is measured using Earth ground tester, model no. Fluke 1625 as four probes Wenner method in soil profile. The study and the analysis on soil electric resistivity ratio is performed using MATLAB 2009 in Geotechnical Laboratory, UKM.

Fig. 2 shows the using of earth ground tester at construction site to obtain soil near surface soil profile. In the earth ground tester, testing voltage is set as standard value, 48 V to pass current in the soil.

The options of Automatic Frequency Control (AFC) shown four measuring frequencies in the devices as 94 Hz, 105 Hz, 111 Hz and 128 Hz. The criteria of AFC ensure the reduction of feasible interference during measurements.

Fig. 2. Four probes method at site in UKM.

Fig. 2 shows how instrument is equipped to measure the resistance of surface soil. The potential differences between two inner probes are obtained to measure the apparent resistivity of soil. Islam and Chik [16] show the theoretical derivation to use soil electric resistivity ration as shown in Fig. 3. The model for a horizontally stratified multi-layer earth structure is shown in Fig. 3 where the thickness is defined as h_1, h_2………h_n.

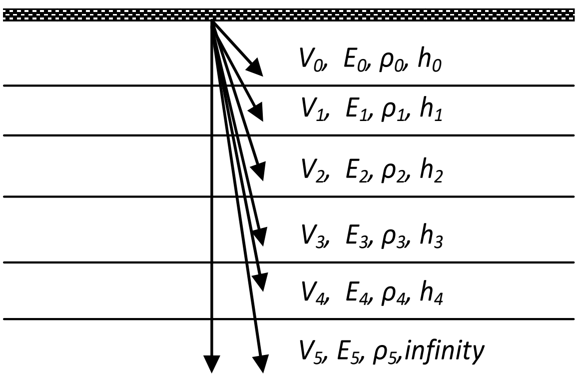

Fig. 3. Soil electric properties at different layers.

A general solution on scalar potential can be written as (1).

$$\psi = \int_0^{\infty} F(\lambda) R(\lambda, r) Z(\lambda, z) d\lambda \,, \qquad (1)$$

where the electric potential and electric intensity varied according to depth is considered as a function of z and λ is the separation constant.

Now, the potentiality equation can be derived from (1) and using Bessel function theory for layer 1 and 2 as,

$$\psi_1' = \frac{I\rho_1}{2\pi}\int_0^{\infty}\left[f_1(\lambda)e^{-\lambda z} + g_1(\lambda)e^{\lambda z}\right]J_0(\lambda r)d\lambda \,, \qquad (2)$$

$$\psi_2' = \frac{I\rho_1}{2\pi}\int_0^{\infty}\left[f_2(\lambda)e^{-\lambda z} + g_2(\lambda)e^{\lambda z}\right]J_0(\lambda r)d\lambda \,, \qquad (3)$$

where ρ is the indication of soil resistivity. Thus, $f_1(\lambda)$ and $g_1(\lambda)$, $f_2(\lambda)$ and $g_2(\lambda)$ can be solved with following boundary conditions.

At $z \to \infty$, $\psi_2 \to 0$

At $z \to 0$, $\frac{\partial \psi_1}{\partial z} = 0$

At $z = h$, $\psi_1 = \psi_2$

Now, $f_1(\lambda)$ is solved as,

$$f_1(\lambda) = \frac{Ke^{-2\lambda h}}{1 - Ke^{-2\lambda h}} \,, \qquad (4)$$

where reflection coefficient, K is defined as

$$K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \qquad (5)$$

The results of theoretical analysis including resistivity ratio are shown through Fig. 4 for multi-layer earth structure on soil characterizations.

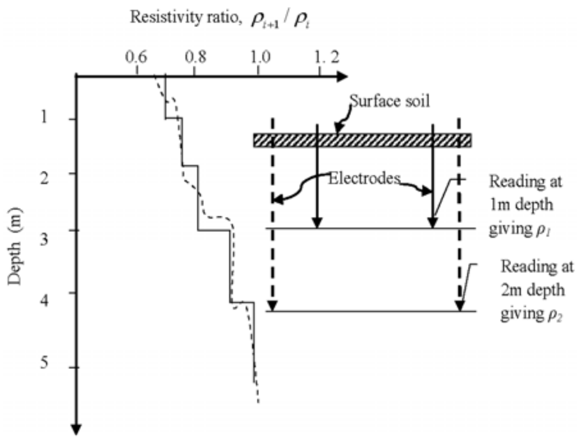

Fig. 4. Depth corresponding resistivity ratio in soil investigations.

The results of theoretical analysis including resistivity ratio are shown through Fig. 4 for soil characterizations. The resistivity ratio, ρ_2 / ρ_1 is demonstrated as 0.73, where resistivity, ρ_1 is 0.38 Kilo Ohm-m and ρ_2 is 0.28 Kilo Ohm-m in the soil characterizations. The resistivity of third layer ρ_3 is given as 0.22 Kilo Ohm-m and thus the resistivity ratio is $\frac{\rho_3}{\rho_2} = \frac{0.22}{0.28} = 0.78$. Thus resistivity ratio from soil electric properties is considered in the model aim to obtain reliable soil characteristics of near surface soil.

3. Results and Discussions

Soil resistivity measurements are far simpler than other nondestructive method to investigate near surface soil properties. Different techniques are discussed in background study to obtain soil apparent resistivity of surface soil. In existing resistivity model, there are empirical relations between probe distance, a and depth to obtain corresponding soil resistivity profile [9] which can be changed due to the effects of moisture contents and chemical contaminations of soil [8, 11, 15].

This paper would be helpful in obtaining the reliable soil profile from apparent resistivity measurements in soil investigations. Islam and Chik [17] shows the improved near surface soil characterizations using multilayer resistivity model where true resistivity profile is compared with multichannel analysis of surface wave (MASW) method. Though true resistivity is necessity for reliable soil characterizations it is time-consuming to show deeper soil profile. Therefore, the resistivity ratio is measured from apparent resistivity profile in soil characterizations. Soil apparent resistivity is obtained including the measurements of soil resistance, area of the surface, length between two probes of tester for soil site investigations.

Fig. 5 shows one of the apparent resistivity profiles at SPT site which is located at near of Engineering Faculty of UKM. The profile of soil apparent resistivity and resistivity ratio are obtained in this SPT site in UKM.

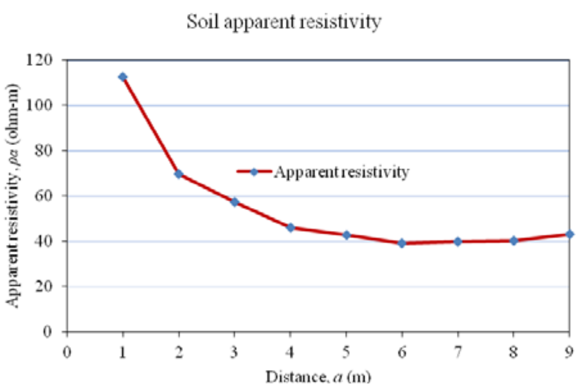

Fig. 5. Soil apparent resistivity at SPT site in UKM.

In the results of Fig. 5, the resistivity is stable after 6 m depth in field investigations where the resistivity curve decreases steeply before 4 m in soil profile. Since the probe distance, *a* is not multiplied in the resistivity profile, the changes of apparent resistivity curve shows the significance of using resistivity ratio in measurement of near surface soil characteristics.

At the same site, soil resistivity ratio is also obtained using earth ground tester modeled as Fluke 1625 shown in Figure 6. Resistivity ratio of the soil is 0.55 to .80 up to the depth of 4 m in soil site investigation shown in Figure 6. This is a soft soil with sand and clay up to the depth of 4 m as shown in the soil resistivity profile. Hence, the range of soil resistivity ratio is 0.8 to 0.9 at the depth of 4 m to 6 m. According to the classification of soil layers, this is a layer of clayey sand soil at the depth 4 m to 6 m in the resistivity profile.

Fig. 6 shows the resistivity ratio is more than 1 after 7 m depth in near surface resistivity model. Based on the results of resistivity ratio, there are harder soils after 7 m depth at soil site investigations.

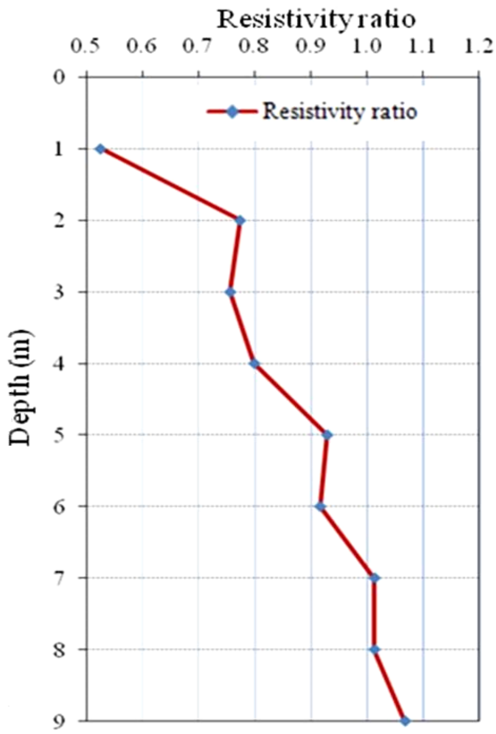

Fig. 6. Soil resistivity ratio at SPT site in UKM.

Soil resistivity profiles before rain and after rain are changed in surface soil investigations as discussed in background study. According to the case study on SPT site in UKM, the resistivity ratio for the adjacent two layers is able to show reliable soil properties where effects of moisture content and chemical contents at specific site are less influential in obtaining soil characteristics. Since the resistivity of hard soil is higher than the resistivity of soft soil that contains more clay and silt. Profile of resistivity and resistivity ratio are both utilized in this study to obtain more accurate near surface soil characterizations.

4. Conclusions

Soil characterizations are obtained through soil resistivity ratio which is taken from apparent resistivity profile of adjacent two layers in soil investigations. Due to the variations of moisture contents, it is difficult to characterize near surface soil profile through existing apparent resistivity model. The case study on implementations of soil resistivity ratio is carried out at SPT site in UKM. The explained relationships between soil electrical resistivity ratio with soil layer profiles are crucial to obtain reliable soil properties in geo-electric engineering. Soil resistivity ratio incorporating with apparent resistivity model is able to perform layer-by-layer earth analysis with boundary conditions in geoelectric formations. Future studies will focus on the results of applying more test data in particular applications of geotechnical engineering.

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