Integrating Geo-Electrical and Geotechnical Data for Soil Characterization

Fahad Irfan Siddiqui and Syed Baharom Azhar Bin Syed Osman

Abstract— **Precise determination of engineering properties of soil is essential for proper design and successful construction of any structure. The conventional methods for determination of engineering properties are invasive, costly and time-consuming. Electrical resistivity survey is an attractive tool for delineating subsurface properties without soil disturbance. Reliable correlations between electrical resistivity and other soil properties will enable us to characterize the subsurface soil without borehole sampling. This paper presents the preliminary results of an ongoing research on correlations of electrical resistivity with strength properties of soil. Soil investigations, field electrical resistivity survey (VES) and laboratory electrical resistivity measurements were conducted. From the data analysis, significant correlations have been obtained between resistivity and moisture content and angle of internal friction. Weaker correlations have been observed for cohesion and unit weight of soil.**

***Index Terms*—Correlations, electrical resistivity, geotechnical investigations, geophysics, shear strength, slope failures.**

I. Introduction

Stability of natural and engineered structures such as building, roads, tunnels, slopes, bridges, dams etc, is the most vital aspect of geotechnical engineering. Precise determination of engineering properties of soil is essential for proper design and successful construction of any structure [1]. The conventional method of obtaining these engineering parameters is laboratory investigations performed on soil samples acquired from site/field through borehole sampling. However, bore hole sampling is in general time-consuming and expensive. Soil properties are subjected to high spatial and temporal variations. For accurate assessment of soil properties, high-density sampling will be required but borehole sampling would be very costly and time-consuming option in such conditions [2].

Geophysical methods (geoelectrical, ground penetrating radar, seismic refraction, etc) have become increasingly practiced in engineering site characterization as being non-invasive, non-destructive, rapid and cost-effective method. Among these methods, geoelectrical survey is a very attractive tool for delineating subsurface properties without soil disturbance [3]. Electrical resistivity survey was first applied to oil/gas exploration and prospecting of conductive ore bodies, later it found applications in various engineering fields e.g. mining, agriculture, environment, archeology, hydrogeology and geotechnics.

Several attempts have been made by many researchers to explore the phenomenon of electrical resistivity in soils and its relationship with other soil properties; such as water content, thermal resistivity, salinity, CEC, hydraulic conductivity, ground water distributions etc [2], [4]-[15]. Few studies have been carried out to correlate electrical resistivity and geotechnical parameters of soil such as N-value SPT, moisture content, plasticity index, grain-size etc. [1], [15]-[18]. No research work has been carried out so far which actually correlates electrical resistivity with strength properties of soil (e.g. Cohesion, Angle of friction etc) quantitatively or qualitatively.

The aim of this research work is to propose a non-destructive, quick and low-cost method for the assessment of geotechnical problems, such as bearing capacity and factor of safety in soil slopes based on correlations of soil parameters such as cohesion, internal angle of friction, and unit weight with electrical resistivity values.

II. Material and Methods

The research methodology consist of both field and laboratory investigations. The study area is located at University Technology PETRONAS, Perak, Malaysia. Field investigations comprise of electrical resistivity survey (VES) and soil boring. The vertical electrical sounding or 1D survey was conducted at the location of borehole BH-01 and BH-02, using simple equipments and accessories in acquiring the electrical resistivity value e.g. Handheld multimeter, D.C. power source, Insulated wires, Measuring tapes, Stainless steel electrodes. The electrical sounding was conducted using wenner electrode configuration with electrode spacing ranging from 0.5 to 6 meters. Distance between borehole BH-01 and BH-02 was 30 meters

The inversion process generates a layered 1D model of subsurface soil based on variation in electrical resistivity and thickness. Soil samples from various depths were obtained by soil boring performed using percussion drilling set. Two boreholes BH-01 and BH-02 were drilled upto the depth of 3 meters. The obtained samples brought to the laboratory for soil characterization and electrical resistivity test in laboratory conditions. Laboratory tests were performed on the soil samples obtained from boreholes, such as moisture content, unit weight, and direct shear test as per methods suggested in British standards (BS).

Electrical resistivity of soil samples from various depths

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was measured in order to determined resistivity values in laboratory condition. Two disc electrodes were connected to both ends of cylindrical soil samples and also attached to DC power source and multimeter for current measurement. Potential difference varying from 30V, 60V, and 90V were applied and resulting variation in current were recorded. Submit your manuscript electronically for review.

III. Results & Discussions

A. Soil Investigations Results

Twelve (12) soil samples obtained from borehole BH-01 and BH-02 were brought to geotechnical laboratory for various soil tests (e.g. Moisture content, Unit weight, direct shear, and laboratory resistivity test). Table 1 shows detailed results of resistivity and geotechnical investigations. Moisture content of soil samples ranges from 18% to 52%. Direct shear test results indicates that all soil samples has more or less same shear strength parameters.

The apparent resistivity inversions results indicate that sub-surface soil have various layers or bands of different resistivity values and thickness. The resistivity value ranges from 1892.42 Ω-m to 17.40 Ω-m. The lower resistivity values for the last layer indicate the presence of water table which is further confirmed by borehole. Borehole data indicates the presence of water-table at 2.1 meters in BH-01 and 1.35 meters in BH-02.

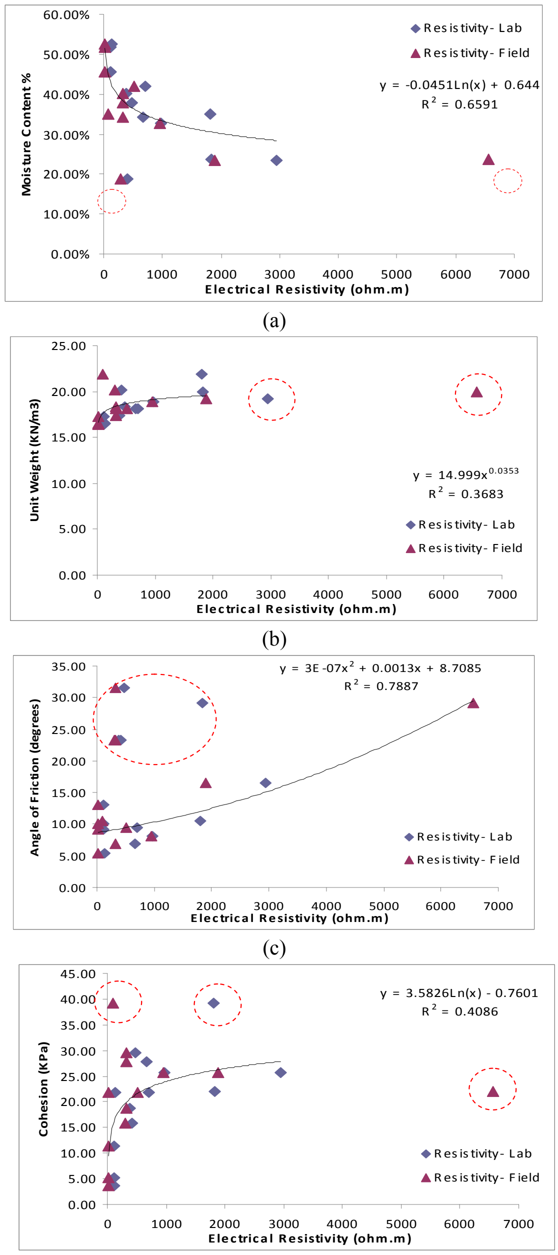
B. Resistivity Measurement Results

The soil samples obtained from borehole BH-01 and BH-02 were subjected to laboratory resistivity measurement in order to determine electrical resistivity of different samples under laboratory conditions. Samples were taken from the different depths of known resistivity values as determined from field resistivity survey, for instance at the depth of 0.574 meters, resistivity value is 1892.44 Ω-m according to field survey, therefore, the soil sample was also taken from 0.574 meters for laboratory resistivity test. Similarly, all the samples were taken from different depths.

In general, resistivity values obtained in laboratory is higher than those measured in field possibly due to various reasons such as change in saturations conditions, temperature difference and overburden pressure. The maximum percentage difference in resistivity values obtained at field and laboratory is 95% and minimum variation is 2.3%.

C. Correlations of Geotechnical and Resistivity Data

The results from electrical resistivity tests (field and laboratory) and soil characterization tests were analyzed together to understand the interrelation between electrical resistivity and various soil properties such as angle of friction, cohesion, unit weight, and moisture content of soil. Resistivity data from field and laboratory techniques were combined for reason of simplicity and generalization and correlated with various soil properties. Some of the data has been omitted from the final curve-fitting due to high deviation from the general trend. Bad data points indicated by red-circles in the graphs. The correlations between electrical resistivity and various properties of soil samples were evaluated using least-squares regression method. Linear, logarithmic, polynomial, exponential and power curve fitting approximations were applied and the best approximation equation with highest correlation coefficient was selected. Relationship between moisture content and resistivity values demonstrates non-linear logarithmic correlation with good regression co-efficient R^2=0.65 (as shown in fig. 1a). Electrical resistivity decreases with increasing moisture content in soils as reported in various previous studies [1, 2, 6, 9, 10, 16].



(a) (b) (c) (d)

Fig. 1. Correlations of electrical resistivity with (a) moisture content (b) unit weight (c) Angle of internal friction and (d) Cohesion of soil.

Higher moisture content facilitates conduction of electrical current through movement of ions in pore water. Fig. 1b indicates a weak exponential correlation between electrical resistivity and unit weight of soil with correlation coefficient R^2=0.36. It is also found that the electrical resistivity will increase with the increase in unit weight of soil. The weak correlation might be due to the fact that the unit weight of depends more on solid constituents than liquid portion of the soil. More soil samples will be tested to verify this behavior.

The relationship between angle of internal friction and resistivity indicates that the friction angle increases with increase of electrical resistivity (as shown in fig. 1c). Angle of internal friction has a good correlation with regression co-efficient R^2=0.62. The mechanism behind such good relationship is yet to be explored through extensive testing. It could not be elaborated at this point of time as it is beyond the scope of current research paper. Cohesion has weak relationship with resistivity of soil. Fig.1d shows logarithmic relationship between cohesion and electrical resistivity. The trend of the curve indicates that the cohesion increases with increase of electrical resistivity.

IV. Conclusion

Significant quantitative and qualitative correlations have been obtained between resistivity and moisture content, angle of internal friction and plasticity index. Weaker correlations have been observed for cohesion and unit weight of soil. It is also observed that presence of water-table notably affect correlations models as below water-table obtained resistivity values are much lower. More field and laboratory tests needed to be conducted in different geological environments in order to establish more precise and generalized correlation between strength properties and electrical resistivity of soil.

References

[1] P. Cosenza, E. Marmet, F. Rejiba, Y. Jun Cui, A. Tabbagh, and Y. Charlery, "Correlations between geotechnical and electrical data: A case study at Garchy in France," *Journal of Applied Geophysics,* vol. 60, pp. 165-178, 2006.
[2] A. Pozdnyakova and L. Pozdnyakova, "Electrical fields and soil properties," *Proceedings of 17th World Congress of Soil Science, Thailand,* vol. 14-21, pp. 1558, August 2002.
[3] A. Samouëlian, I. Cousin, A. Tabbagh, A. Bruand, and G. Richard, "Electrical resistivity survey in soil science: a review soil and tillage research," vol. 83, pp. 173-193, 2005.
[4] Z. S. Abu-Hassanein, C. H. Benson, and L. R. Blotz, "Electrical resistivity of compacted clays," *Journal of Geotechnical Engineering - ASCE,* vol. 122 (1996), pp. 397-406
[5] Y. Erzin, B. H. Rao, A. Patel, S. D. Gumaste, and D. N. Singh, "Artificial neural network models for predicting electrical resistivity of soils from their thermal resistivity," *International Journal of Thermal Sciences,* vol. 49, pp. 118-130, 2010.
[6] R. J. Kalinski and W. E. Kelly, "Estimating water content of soils from electrical resistivity," *Geotechnical Testing Journal,* vol. 16, pp. 323-329, 1993.
[7] R. J. Kalinski and W. E. Kelly, "Electrical-resistivity measurements for evaluating compacted-soil liners," *Journal of Geotechnical Engineering - ASCE*, vol. 120, pp. 451-457, 1994.
[8] W. J. McCarter, "Electrical resistivity characteristics of compacted clays," *Geotechnique,* vol. 34, pp. 263-267, 1984.
[9] F. Ozcep, O. Tezel, and M. Asci, "Correlation between electrical resistivity and soil-water content," *Istanbul and Golcuk International Journal of Physical Sciences,* vol. 4, pp. 362-365, 2009.
[10] F. Ozcep, E. Yildirim, O. Tezel, M. Asci, and S. Karabulut, "Correlation between electrical resistivity and soil-water content based artificial intelligent techniques," *International Journal of Physical Sciences,* vol. 5, pp. 47-56, 2010.
[11] L. Pozdnyakova, A. Pozdnyakov, and R. Zhang, "Application of geophysical methods to evaluate hydrology and soil properties in urban areas," *Urban Water,* vol. 3, pp. 205-216, 2001.
[12] B. F. Schwartz, M. E. Schreiber, and T. Yan, "Quantifying field-scale soil moisture using electrical resistivity imaging," *Journal of Hydrology,* vol. 362, pp. 234-246, 2008.
[13] Y. Son, M. Oh, and S. Lee, "Estimation of soil weathering degree using electrical resistivity," *Environmental Earth Sciences,* vol. 59, pp. 1319-1326, 2009.
[14] S. Sreedeep, A. C. Reshma, and D. N. Singh, "Generalized relationship for determining soil electrical resistivity from its thermal resistivity," *Experimental Thermal and Fluid Science,* vol. 29, pp. 217-226, 2005.
[15] G. L. Yoon and J. B. Park, "Sensitivity of leachate and fine contents on electrical resistivity variations of sandy soils," Journal of Hazardous Materials, vol. 84, pp. 147-161, 2001.
[16] P. H. Giao, S. G. Chung, D. Y. Kim, and H. Tanaka, "Electric imaging and laboratory resistivity testing for geotechnical investigation of Pusan clay deposits," *Journal of Applied Geophysics,* vol. 52, pp. 157-175, 2003.
[17] S. Oh and C. G. Sun, "Combined analysis of electrical resistivity and geotechnical SPT blow counts for the safety assessment of fill dam," *Environmental Geology,* vol. 54, pp. 31-42, 2008.
[18] K. Sudha, M. Israil, S. Mittal, and J. Rai, "Soil characterization using electrical resistivity tomography and geotechnical investigations," *Journal of Applied Geophysics,* vol. 67, pp. 74-79, 2009.

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