The Correlation between Resistivity and Soil Properties as an Alternative to Soil Investigation

Hisyam Jusoh* and Syed Baharom Syed Osman

Department of Civil and Environmental Engineering, University Technology PETRONAS, 32160 Tronoh, Perak, Malaysia; hisyam.jusoh@yahoo.com, sybharom@petronas.com.my

Abstract

Objectives: To propose a possible assessment for soil investigation by correlating the resistivity values with soil properties. **Methods/Statistical Analysis:** Throughout the study, drilling work was carried out where samples were then brought to the laboratory and tested for the related properties. All the data were then analyzed and correlated. **Findings:** Experimental result (e.g.; resistivity and moisture content) from correlation and regression showed the coefficient of determination, R^2 were found to be 0.8168. **Application/Improvements:** The produced empirical formula with $w = 123.93 r_s^{-0.252}$ could be a possible assessment as an alternative to determine moisture content.

Keywords: Correlation, Geotechnical, Investigation, Resistivity, Soil

1. Introduction

The properties of soil are the most important aspect of ground engineering. In geotechnical engineering design, the most essential aspect that requires to be considered involve the soil moisture content, cohesion, friction angle, unit weight, saturation degree, porosity, plasticity index and size distribution. These properties are important elements especially in determination of bearing capacity and slope stability in soil.

Soil Investigation (SI) through borehole drilling and sampling offers the most dependable value of the relevant soil properties for the purpose of geotechnical design, however it is laborious, expensive and invasive. Therefore, an alternate quick, non-destructive and environmental friendly of assessing soil properties is very crucial so as to enable quick and widespread measurements and calculation of ground engineering design at different conditions of soil which is an essential factor in the prediction/mitigation of soil failures or landslides. As an alternate, geophysical method has been found to be an impressive tool for describing subsurface profile without disturb the soil structure.

Geophysical methods (electrical resistivity, geothermal, gravitational, magnetic etc.) have become widely known in engineering site characterization. Among these methods electrical resistivity survey is very impressive tools for describing subsurface profiles without disrupt the soil structure[1].

The electrical resistivity is potentially used as a non-destructive method to estimate soil compaction performance for highway embankments, earth dams, and many various fields of civil engineering. It is expected with further technical refinement where it could also be used to detect soil porosity or anomalous materials in soil[2]. This research proposes a resolution for soil investigation and properties identification by introducing electrical resistivity correlated with soil properties (moisture content, cohesion, friction angle and plasticity index). Possible correlations of various soil properties with electrical resistivity will bridge the gap between geotechnical and geophysical engineering and also enable geotechnical engineers to estimate geotechnical parameters from electrical resistivity data.

Electrical resistivity survey has been widely used by correlating the changes of subsurface resistivity with the

soil properties[3]. Most of the published reports are focusing on moisture content while in this study, by using cohesion (c) and friction angle (ø) is a new approach to correlate resistivity with soil properties. Resistivity can be defined in the context of current flow through a subsurface medium (soil) consisting of layers of materials with different resistivity[4]. The major purpose of soil resistivity is to determine the resistivity distribution of sounding in soil volume. The applied current in the soil indicates difference produced potential volume. The produced potential volumes with different values can represent the types of materials of soils including its properties. Thus, it's providing information with regards to soil profiles. In simple definition, the electrical resistivity survey can be a proxy for variability of soil physical properties.

The resistivity values shown in Figure 1 the soil component can be in different range because of certain factors; salinity, clay content, cation exchange capacity, clay mineralogy, pore size and their distribution, moisture content, and temperature[5]. Among these factors, moisture content and conductivity are the major controlling factors of bulk soil electrical resistivity due to main mechanism involved are current[6].
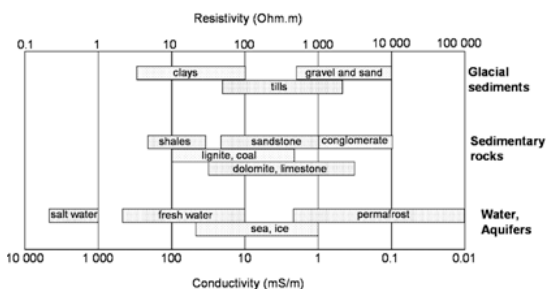

Figure 1. Typical resistivity and conductivity values in various earth materials.

The objective of this paper is to propose a possible assessment for soil investigation by correlating the resistivity values with soil properties (limited to all kind of soil in tropical area and not applicable on rock). Note that the effect of mineral composition in the soil is not taken into this study.

2. Materials and Methods

This study was carried out in two major phases; soil boring and laboratory work (soil properties and resistivity).

The soil boring was operated by using petrol-operated percussion drilling set model: CobraTT, Atlas Copco equipped with 1-meter tube sampler for sampling process. The bore holes were drilled to a certain depth for undisturbed samples. The undisturbed samples were kept in plastic cylinder and capped tightly and numbered according to the boreholes and depths.

2.1 Soil Analysis

The laboratory tests on selected soil properties (moisture content, shear strength and plasticity index) were conducted on samples acquired through drilling and then brought to the laboratory. Then, soil samples from various depths were analyzed for its resistivity value in laboratory condition according to BS 1377: Part 3: 1990: 10.2 where two electrodes disk will be mounted on each side of soil samples. The disks will be clamped to make sure the disk and soil resist before the electrical potential (30, 60 and 90 volts) applied. The soil resistivity can be calculated based Equations (1) and (2).

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

$$r_s = (A/L) \times R \tag{2}$$

Where:

R = resistance calculated from applying volts divide captured current from soil

A = is cross sectional area

L = length of the sample, L

r_s = resistivity value

2.2 Correlation and Regression

The correlation analysis was measured in order to interpret the strength of a linear or nonlinear relationship between two continuous variables. Meanwhile, simple regression analysis is to evaluate the relative impact of a predictor variable on a particular outcome[7]. The correlation and regression was conducted by using Microsoft Excel. The equation produced from correlation and regressions particularly use of Pearson method to obtain coefficient of determination, R^2 where the value is square of correlation coefficient, r[8,9].

The interpretation of coefficient can be found as listed in Table 1 order to determine the strength and rank of the correlation[10].

**Table 1.** Interpretation size of correlation coefficient

Size of correlation	Strength of correlation
0.9 – 1.0	Highly Perfect/ Very strong
0.7 – 0.9	Perfect/ strong
0.5 – 0.7	Moderate
0.3 – 0.5	Weak
0.0 – 0.3	No association

3. Results and Discussion

Relationship between moisture content and resistivity values obtained from laboratory work for all type of soil is demonstrated shown in Figure 2. The regression shows strong correlations between these two variables with coefficient of determination $R^2 = 0.8168$. From the regression line of moisture content and resistivity values, the empirical formula is developed for the soil samples investigated;

$$w = 123.93r_s^{-0.252} \tag{1}$$

Previous studies have showed resistivity value decreases with growing soil moisture content[11,12]. Through movement of ions in pore water at low value of moisture content tends to reduce the conduction of electrical current.
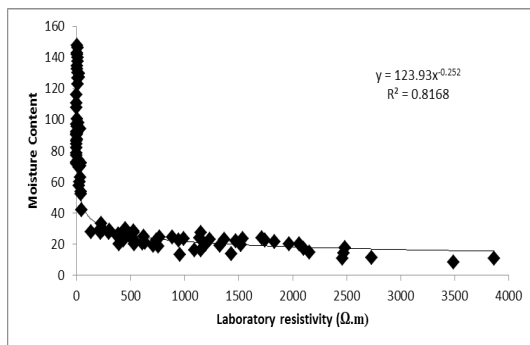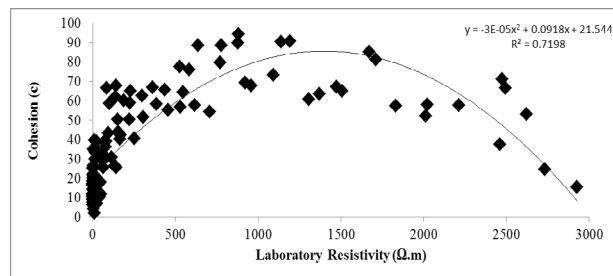

Figure 2. Correlation laboratory resistivity and moisture content.

The moisture-resistivity relationship shown in Figure 3 obtained by the current research was compared with an established relationship in published report[6,13–15]. The obtained relationship model depicts similar trend where resistivity value increases in function with decrement of the moisture content.
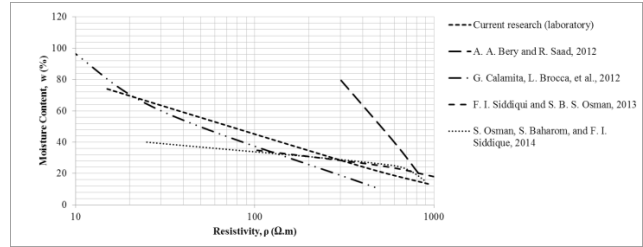
Figure 3. Correlation laboratory resistivity and moisture content.

The regression trend of cohesion and soil resistivity is shown in Figure 4. The result presents a strong relationship between cohesion and resistivity with coefficient of determination $R^2 = 0.7198$ as shown in figure 4. Referring to obtained relationship, it can be concluded that resistivity value increases with increasing of cohesion. However, the cohesion values tend to decrease as resistivity values increase. The reason behind this phenomenon due to soil becomes sandy and at this point the cohesion will be less[16]. Hence, the moisture content will also be less. This is associated with its density, compression of clay particle and bonding between the particles of very fine clay[17].

Figure 4. Correlation laboratory resistivity and cohesion.

The produced empirical formula for cohesion(*c*) calculation from resistivity is given as follow;

$$c = -3E-0.5r_s^2 + 0.0918r_s + 21.544 \tag{2}$$

where, r_s is the electrical resistivity (Ω.m) and *c* is cohesion (kPa).

The correlation between angle of friction and soil resistivity values is depicted in Figure 5. The produced regression trend shows a moderate relationship with the coefficient of determination, R^2 was equal to 0.6337. The potential reason that attributes to the high friction angle is due to the low moisture content. It is understandable that soil shear strength reduces corresponding to high

moisture content. An increment in soil moisture turns the resistivity to be decreased. Hence, at higher friction angle, lower moisture will be observed corresponds with higher resistivity. Additional factor to the increment angle of friction value is due to high percentage of sand composition and hence, triggers the resistivity to be increased. Moreover, soil porosity could also the reason for this increasing trend. Generally, porosity will affect the pore size and air voids volume which in turn the saturation degree to be lower or higher. Saturated pores can create bridges between particles and develops particle contact[18,19]. Thus, lower and higher resistivity in function with friction angle of soil material is the results of the mentioned statement.

The equation to calculate friction angle from resistivity is given as follow;

$$\phi = 4.7036ln(r_s)+6.6297 \tag{3}$$

where, r_s is the electrical resistivity (Ω.m) and ø is friction angle.
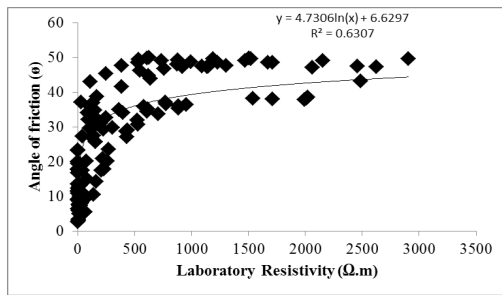
Figure 5. Correlation laboratory resistivity with friction angle.

The moderate relationship between plasticity index and soil resistivity value is illustrated shown in Figure 6. The result indicates a degree correlation between PI and soil resistivity with coefficient of determination $R^2 = 0.6337$.
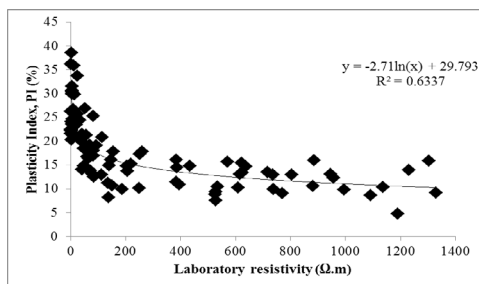
Figure 6. Correlation laboratory resistivity with Plasticity Index (PI).

From the relationship between plasticity index and resistivity values, the following equation is obtained;

$$PI = -2.71ln(r_s)+29.793 \tag{4}$$

where, r_s is the electrical resistivity (Ω.m) and PI is plasticity index (%). This phenomenon shows that soil with higher PI, a higher percentage of fines, or a lesser granular grains generally have lower resistivity values.

4. Conclusion

The findings in this study offer a significant data and research materials regarding soil resistivity. The results from laboratory work were analyzed together to cognize the interrelation among soil properties and electrical resistivity. The relationship between moisture content and resistivity values has demonstrate a strong correlation ($R^2 = 0.8168$) as published in numerous reports. A strong correlation was found among cohesion and resistivity with R^2 was found to 0.7198. The regression produced an empirical formula $c = -3E-0.5r_s^2+0.0918\ r_s+21.544$. More data collection is needed in order to understand the relation between friction angle and plasticity index (PI) with resistivity whereby a moderate correlation was obtained in this study. The empirical formula was in form of $\phi = 4.7036ln(r_s)+6.6297$ and $PI = -2.71ln(r_s)+29.793$, respectively. From produced empirical formulas, this study intends to assist geotechnical engineers in determining the site suitability in a short period of soil investigation work. Also, it is hoped that this study will be helpful for the existing ground engineering design for the enhancement purpose. Although new, the obtained data in this study has been consistent and supports most of the results by previous researchers. Nevertheless, this work can be improved by having varies research sites, longer period of observing and data recording for the purpose of generating more accurate correlation.

5. Acknowledgement

Teknologi PETRONAS; Mr. Mohd. Redzuan, Mr. Zaaba, Mr. Azran, Mr. Iskandar, Mr. KhairulAnuar, Mr. Ruzaimi and Mrs. IzzatulImma for their passions and help in the field and laboratory work.

6. References

1. Samouëlian A, Cousin I, Tabbagh A, Bruand A, Richard G. Electrical resistivity survey in soil science: A review. Soil and Tillage Research. 2005; 83(2):173–93. https://doi.org/10.1016/j.still.2004.10.004

2. Islam T, Chik Z. Improved near surface soil characterizations using a multilayer soil resistivity model. Geoderma. 2013; 209–210:136–42. https://doi.org/10.1016/j.geoderma.2013.06.015

3. Drahor MG. A review of integrated geophysical investigations from archaeological and cultural sites under encroaching urbanisation in İzmir, Turkey. Physics and Chemistry of the Earth, Parts A/B/C. 2011; 36(16):1294–309. https://doi.org/10.1016/j.pce.2011.03.010

4. Herman R. An introduction to electrical resistivity in geophysics. American Journal of Physics. 2001; 69(9):943–52. https://doi.org/10.1119/1.1378013

5. Zhu J-J, Kang H-Z, Gonda Y. Application of Wenner Configuration to Estimate Soil Water Content in Pine Plantations on Sandy Land. Pedosphere. 2007; 17(6):801–12. https://doi.org/10.1016/S1002-0160(07)60096-4

6. Calamita G, Brocca L, Perrone A, Piscitelli S, Lapenna V, Melone F. Electrical resistivity and TDR methods for soil moisture estimation in central Italy test-sites. Journal of Hydrology. 2012; 454–455:101–12. https://doi.org/10.1016/j.jhydrol.2012.06.001

7. Puth M-T, Neuhäuser M, Ruxton GD. Effective use of Pearson's product–moment correlation coefficient. Animal Behaviour. 2014; 93:183–9. https://doi.org/10.1016/j.anbehav.2014.05.003

8. Zou KH, Tuncali K, Silverman SG. Correlation and simple linear regression. Radiology. 2003; 227(3):617–28. https://doi.org/10.1148/radiol.2273011499 PMid:12773666

9. Cheng C-L, Garg G. Coefficient of determination for multiple measurement error models. Journal of Multivariate Analysis. 2014; 126:137–52. https://doi.org/10.1016/j.jmva.2014.01.006

10. Mukaka M. A guide to appropriate use of Correlation coefficient in medical research. Malawi Medical Journal. 2012; 24(3):69–71. PMid:23638278 PMCid:PMC3576830

11. Osman S, Baharom S, Harith T, Zahir Z. Correlation of electrical resistivity with some soil properties in predicting factor of safety in slopes using simple multi meter. Conference on Sustainable Building and Infrastructure, Kuala Lumpur; 2010.

12. Pozdnyakov A, Pozdnyakova L, Karpachevskii L. Relationship between water tension and electrical resistivity in soils. Eurasian Soil Science. 2006; 39(1):S78–S83. https://doi.org/10.1134/S1064229306130138

13. Osman S, Baharom S, Siddique FI. Correlation of electrical resistivity with some soil parameter for the development of possible prediction of slope stability and bearing capacity of soil using electrical parameters. Pertanika Journal Science and Technology. 2014.

14. Bery AA, Saad R. Tropical clayey sand soil's behaviour analysis and its empirical correlations via geophysics electrical resistivity method and engineering soil characterizations. International Journal of Geosciences. 2012; 3:111–6. https://doi.org/10.4236/ijg.2012.31013

15. Siddiqui FI, Osman SBABS. Simple and multiple regression models for relationship between electrical resistivity and various soil properties for soil characterization. Environmental Earth Sciences. 2013; 70(1):259–67. https://doi.org/10.1007/s12665-012-2122-0

16. Fenton GA, Griffiths D. Bearing-capacity prediction of spatially random c φ soils. Canadian Geotechnical Journal. 2003; 40(1):54–65. https://doi.org/10.1139/t02-086

17. Kemper W, Rosenau R, Dexter A. Cohesion development in disrupted soils as affected by clay and organic matter content and temperature. Soil Science Society of America Journal. 1987; 51(4):860–7. https://doi.org/10.2136/sssaj1987.03615995005100040004x

18. Nimmo J. Porosity and pore size distribution. Encyclopedia of Soils in the Environment. 2004; 3:295–303.

19. Santamarina J, Cho G. Soil behaviour: The role of particle shape. Advances in geotechnical engineering: The skempton conference [Internet]. [cited 2015 Jun 19]. Available from: http://www.icevirtuallibrary.com/doi/abs/10.1680/aigev1.32644.0035?src=recsys.