International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:4, No:9, 2010

Electrical Resistivity of Subsurface: Field and Laboratory Assessment

Zulfadhli Hasan Adli, Mohd Hafiz Musa, M. N. Khairul Arifin

***Abstract*—**The objective of this paper is to study the electrical resistivity complexity between field and laboratory measurement, in order to improve the effectiveness of data interpretation for geophysical ground resistivity survey. The geological outcrop in Penang, Malaysia with an obvious layering contact was chosen as the study site. Two dimensional geoelectrical resistivity imaging were used in this study to maps the resistivity distribution of subsurface, whereas few subsurface sample were obtained for laboratory advance. In this study, resistivity of samples in original conditions is measured in laboratory by using time domain low-voltage technique, particularly for granite core sample and soil resistivity measuring set for soil sample. The experimentation results from both schemes are studied, analyzed, calibrated and verified, including basis and correlation, degree of tolerance and characteristics of substance. Consequently, the significant different between both schemes is explained comprehensively within this paper.

***Keywords*—**Electrical Resistivity, Granite, Soil.

I. Introduction

GROUND Resistivity survey methods have been widely used in order to solve engineering, archeology, environmental and geological problems in the last decades. [1] – [3] Subsurface resistivity distributions are measured by applying electrical current into the ground by using two current electrodes. The potential differences caused by the flow of current between any two points in linear line with the current electrodes are then measured by a pair of potential electrodes. From the measured voltage (V) and current (I) values, the resistance at the specified point in the subsurface can be determined.

In homogeneous ground, penetration depth is directly proportional to electrodes spacing, and changing the electrode's separation gives information on subsurface's stratification. [4] For 2D resistivity imaging, it is important to have a large set of data recorded along a survey line to effectively map the complex resistivity distribution of subsurface structure. The most practical way to acquire such large amount of data is by using automated multi-electrode data acquisition system.

In the interpretation of ground resistivity survey, it is important to differentiate between apparent resistivity and true resistivity. Apparent resistivity can be defined as the volumetric average of a heterogeneous half-space, except that the averaging is not done arithmetically but by a complex weighing function dependent on electrode's configurations. [5] In resistivity survey, true resistivity can only be measured in ideal condition where the ground is homogenous, which is almost never is the case. Advancement in computer forward modelling software (eg : Res2DINV, Resix) have made it possible to calculate numerous amount of data obtained from 2D resistivity survey in a short amount of time, and minimized the different between true and apparent resistivity for subsurface earth material by subdividing the subsurface into small rectangular cells where each cell has resistivity value close to the true resistivity of subsurface material. The principle is in determining the cell resistivity that provides a model response that fits well with the measured data. [6] However, this assumption is only true theoretically. Uncertainty still remains in the final obtained image even if the inversion is a quasi-automatic process. In practice, there are a lot of factors that can affect resistivity pseudo section imaging. Apparent resistivity is measured instead of true resistivity due to unknown near surface strata with different resistivity. This affects the conduction of current through earth material and thus affects the resistivity measurement.

Most of field resistivity surveys conducted by geophysicist are not always validated by laboratory measurement. The difficulty in obtaining the core sample, where the drilling works should be preceded by resistivity survey has made it difficult for geophysicist to analyse samples in laboratory. [7] Up to now, there are relatively few researches that had been done to study the comparison between rock resistivity obtained in laboratory and from field measurement. In this study, we measure the true resistivity of core samples collected from field resistivity survey, and compare it with apparent resistivity obtained from field measurement.

Zulfadhli Hasan is with Universiti Sains Malaysia(USM), 11800 Minden, Penang. Tel.:+ 604-0174188945; e-mail: zulfadhli87@ gmail.com

Hafiz Musa is with Universiti Sains Malaysia(USM), 11800 Minden, Penang. Tel.:+ 604-0195002235; e-mail: apis_musa@ yahoo.com

M. N. Khairul Arifin is with Universiti Sains Malaysia(USM), 11800 Minden, Penang. Tel.:+ 604-0194358683; e-mail: khaiarif@yahoo.com

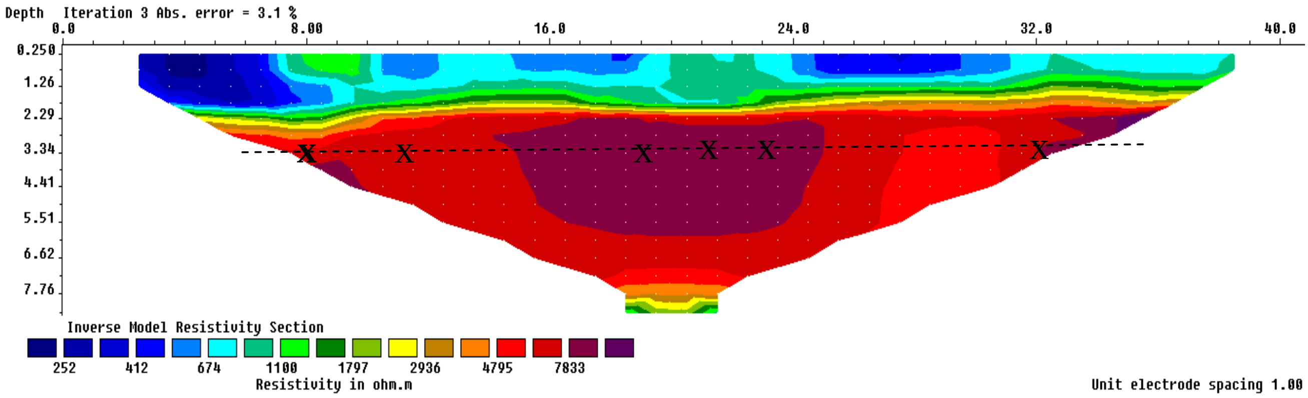

Fig. 1: Resistivity pseudo section image for survey area. 'x' is sample locations drilled for laboratory analysis.

II. THEORY

Electrical conduction in rock and earth material.

Electrical resistivity is known to be highly variable among other physical properties of rock. In some cases, different in extreme values of a single rock type can differ by a factor approaching several orders of magnitude.[8] Wide range of rock's resistivity parameter has always been the reason that makes it difficult to distinguish subsurface rock type if no information on the geological surroundings of field survey is available.

Electrical current flows through the earth material under subsurface through two methods, which are electrolytic and electronic conduction.[9] Electronic conduction, which is conduction through the rock's mineral compositions, occurs mainly through metallic ore minerals, providing that these minerals exist in dense enough concentration. However, most conducting minerals rarely exist in sufficient quantity in a rock composition, especially granite, to have considerable effect on the electrical properties of host rock. This conduction is controlled by matrix properties (semiconduction, lattice defects, and conductive accessories) which often resulted in very high resistivity values. [10] Thus, for dry rock, it is common to find the resistivity values to be higher than $10^4\,\Omega$.m

For most subsurface rock, electrical conduction occurs mainly through groundwater that exists in pores and cracks of the rocks. The flow of current in electrolyte conduction through rock is largely influenced by the porosity of the rock. Generally, for rocks that are still in their original conditions (in situ condition), rock with higher porosity have lower resistivity. Under any normal condition, the porous structure of rock is partly or completely filled with underground water, which usually carries salt solution and thus increasing the moisture content of the rock. It is not unusua for igneous rock to have moisture content less than 1%. However, even that small percentage of water is enough to affect the rock's resistivity considerably.[11] This can be explained by the fact that the resistivity of water, especially groundwater with salt solution is lower than most of the others constituents that make up a rock structure.

III. METHODS

Field Measurement and Interpretation.

Sites with visible strata of layering between top soil and bedrock were chosen for field survey. The purpose is so that we can compare the actual depth of bedrock and the depth that we obtain from resistivity survey. ABEM Terrameter SAS 4000 and a switcher unit were used to control the induction of current and potential readings from electrodes connected by multicore-cable along the survey line. A resistivity survey line with length 42 meters was setup by using Wenner-Schlumberger protocol, where spacing between each electrode was 1 meter. Wenner-Schlumberger protocol was chosen for field measurement as it provides moderately good horizontal and vertical subsurface resistivity coverage. [12]

Resistivity data were interpreted and analyzed by using software RES2DINV. Blocky constraint was used in data interpretation as it is the most suitable inversion method when subsurface internal resistivity values are separated by sharp boundaries. [13]

Laboratory Measurement

Core samples at depth 3.34m of survey area were taken for later analysis in laboratory. The locations where each core sample was taken are marked in figure 1. Each core sample's length ranging from 4 cm to 8 cm with diameter 4.3 cm. The resistivities of the samples were measured by using Sample Core I.P Tester (SCIP). This device uses time domain (ON+, OFF, ON-, OFF) signal waveform with changing polarity of signal source. In this setup, 2 electrodes configuration was used, with both electrodes made up of copper disk. A cellulose sponge soaked with brine solution was used to hold the core sample between the electrodes. This enables the core sample to make full contact with the current source. Before the measuring process, it is important to ensure that the surface of the sample is fully dried so that no surface conduction of current through water layer on the sample takes place.

Method used to measure porosities is by weighing the sample in dry state and after saturating it with water. Samples were first dipped in water for at least a week to ensure they are fully saturated. Porosity is given by the weight different between these two conditions divided by the sample's saturated weight. Porosity values for each rock are shown in table 1.

IV. Result and Discussion

A. Field Assesment

Field data is obtained from resistivity survey over the hill at Bukit Jambul, Penang. This site was chosen as the geological formation of survey area such as depth of bedrock and thickness of top soil are clearly visible for easier interpretation during data processing. Bedrock consists of slightly weathered granite boulders. Wenner- Schlumberger electrode array was used with spacing 1 meter between each electrode. As shown in the resistivity pseudosection in figure 1, distributions of top soil and bedrock were very well-mapped. The high resistivity contrast at depth 2.29m between top soil and boulder are clearly shown as contour-colored image, with top soil resistivity ranging from 100 Ω.m to 800 Ω.m, and bedrock resistivity ranging from 1500 Ω.m to 9000 Ω.m. This corresponds well with the actual depth of bedrock as seen in the field. Auger method at distance 1 meter, 20 meter, and 39 meter of survey line shows that top soil from surface till depth 1.7m consists of dry soil with some presence of clay, and from depth 1.7m to bedrock, clayey soil with considerable amount of saprolite are present, indicating the boundary between bedrock and top soil.

B. Laboratory Assessment

Six core samples at distance 11m, 19m, 21m, 23m, and 32m of survey line were measured for its resistivity by using SCIP device. Figure 2 shows a clear comparison between apparent resistivity and true resistivity. The values of resistivity measured in laboratory, i.e., true resistivity, were plotted vs. its distance in survey line. Apparent resistivity, i.e. resistivity measured in field was also plotted in the same graph to show the comparison between both values. From the results, true resistivities of samples are generally higher than resistivity measured in the field. In subsurface condition, where rocks contain sufficient amount of moisture from underground water that exist in its cracks or pores, may be the reason for its lower apparent resistivity. Table 1 shows porosity percentage for all core samples as measured in laboratory, which are less than 0.5%. These values although very small, are not exactly

Table I

Percentage Difference Between Field And Laboratory Method

Sample's distance	*Results (Ω.m)* Field	Laboratory	*Percentage difference (%)*	*Porosity (%)*
8m	6558.40	7900.84	16.99	0.23
11m	7573.00	13616.19	44.38	0.27
19m	9167.40	10783.65	14.99	0.11
21m	9170.10	7132.63	22.22	0.16
23m	9117.00	11675.11	21.91	0.11
32m	6893.00	12318.31	44.04	0.26

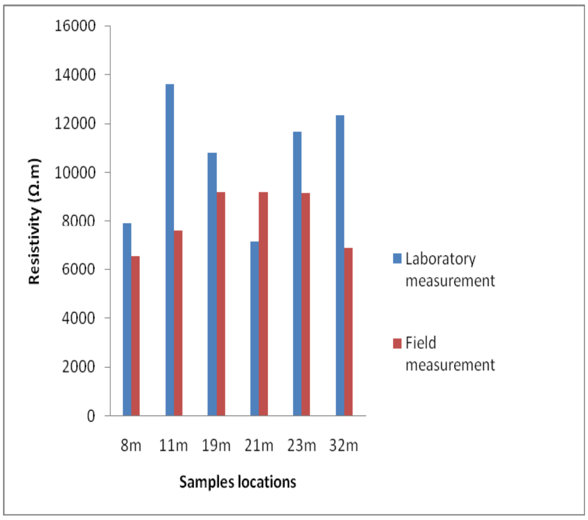

Fig. 2: Comparison between true and apparent resistivity at specific distance in survey line.

unexpected for granitic rock. Water absorbed in pore volume of rocks though at very small percentage could affect resistivity measurement, especially considering that underground water contains certain amount of salinity which usually originated from geo-chemical weathering of rock and parent materials of soil. The effect of layered earth with different resistivity can also affect the propagation of current through subsurface, and thus resistivity value may be affected. In laboratory analysis, the impossibility to simulate the exact condition in which the sample was in under subsurface is the reason for the different in resistivity. It is also important to consider that in laboratory assessment, effect of inhomogeneities in the samples does not represent the entire geological formation due to the small size of samples tested. Result shows that values from field and laboratory measurement, although do not tally perfectly, are still comparable where the difference between both values does not exceed 50%. This percentage different signifies that straightforward interpretation of subsurface geological compositions based on field measurement alone is difficult to achieve in resistivity survey due to different in actual resistivity of rock and field measurement.

V. CONCLUSION

Field electrical resistivity method has successfully mapped the resistivity distribution of granite bedrock in subsurface, and gives its apparent resistivity within 1500 Ω.m to 9000 Ω.m. Laboratory measurement produced resistivity value of rock samples that differ from field measurement by less than 50%, a relatively small difference in resistivity survey application. Field measurement which gives generally lower resistivity than laboratory analysis can be attributed to the presence of underground water in pores and cracks of subsurface rock. This study suggests that the true resistivity of rock is generally higher than apparent resistivity, which can be associated to the effect of moisture contain by underground water and minerals, and unknown near-surface strata with different resistivity on the value of field resistivity.

REFERENCES

[1] Michael van Schoor, "Detection of sinkholes using 2D electrical resistivity imaging," Journal of Applied Geophysics 50 (2002),pp. 393–399.

[2] Ettore Cardarelli, Michele Cercato, Antonio Cerreto and Gerardina Di Filippo, "Electrical resistivity and seismic refraction tomography to detect buried Cavities**,"** *Geophysical Prospecting,* 2009**,** pp. 1–11

[3] I. B. Osazuwa and E. Chii Chii, "Two-dimensional electrical resistivity survey around the periphery of an artificial lake in the Precambrian basement complex of northern Nigeria," Journal of Physical Sciences Vol. 5(3), pp. 238-245, March 2010

[4] T. Dahlin," The development of DC resistivity imaging techniques," Computer & Geosciences 27 (2001), pp. 1019 – 1029.

[5] Vincenzo Compare, Marilena Cozzolino, "Resistivity probability tomography imaging at the Castle of Zena, Italy," EURASIP Journal on Image and Video Processing, Volume 2009.

[6] F.Nguyen, S. Garambois, "Image processing of 2D resistivity data for imaging faults," Journal of Applied Geophysics 57 (2005), pp.260 – 277.

[7] P.H. Giao, S.G. Chung, " Electric imaging and laboratory resistivity testing for geotechnical investigation of Pusan clay deposits," Journal of Applied Geophysics 52 (2003), pp. 157 – 175.

[8] F.S. Grant, G.F. West, " Interpretation Theory in Applied Geophysics," Mcgraw-Hill Book Company (1965), pp. 393.

[9] Dr. M.H.Loke, Tutorial, " 2-D and 3-D electrical imaging surveys"(2004), pp. 13.

[10] J.H. Schon, "Physical Properties of Rocks,Fundamentals And Principles of Petrophysics, Handbook of Geophysical Exploration" (1996), pp. 401.

[11] E.I.Parkhomenko, "Electrical Properties of Rocks," Plenum Press, (1967), pp. 121.

[12] Pazdîrek O. & Bláha V, "Examples of resistivity imaging using ME-100 resistivity field acquisition system." 58th EAGE conference, Amsterdam, The Netherlands, Extended Abstracts, P050(1996).

[13] M.H loke, Ian Acworth, T. dahlin, "A comparison of smooth and blocky inversion methods in 2D electrical imaging surveys," Exploration geophysics (2003) 34, pp. 182 - 187