Possible Assessment of Slope Stability by Using Electrical Resistivity: Comparison of Field and Laboratory Results

Syed B. Syed Osman and Fahad I. Siddiqui

Abstract—**The stability of both natural and engineered slopes has always been a major concern of geotechnical engineers especially in recent years where an increasing number of development are encroaching into hillside areas. In tropical regions, soil slope failures due to frequent rainfall are quite common. One of the long term objectives of this whole research is to implement a quick method of assessing the factor of safety (FOS) in slopes by replacing the conventional soil parameters such as cohesion and internal angle of friction with electrical parameters such as resistivity. However, this paper is limited to the preliminary comparison of laboratory results obtained from controlled laboratory soil samples and results obtained from actual field samples. Results from both the laboratory controlled samples and actual field samples shows consistencies in the correlation between friction angle and electrical resistivity while correlations between moisture content and electrical resistivity shows a similar trend of decreasing moisture content with increase of electrical resistivity value.**

Index Terms—**Electrical resistivity, correlation, shear strength, slope stability.**

I. INTRODUCTION

For the past two decades or so, Malaysia has witnessed many failures in slopes and landslides causing extensive loss in properties and even to the extend of causing casualties. With the current implementation of risk management system and standard operating procedure (SOP) for sustainable hillside development developed by the respective parties, among the required elements to be implemented in the afore mentioned systems are:

- The identification of danger
- Quantifying hazard
- Determination of risk

One of the essential aspects to identify risk in slopes is to determine/calculate the factor of safety (FOS) which will indicate the stability of a certain slope. In the process of obtaining the FOS, among the crucial soil parameters to be obtained before calculating FOS are cohesion (c), internal frictional angle (ϕ), unit weight of soil (γ) etc. Since most of slope failures in Malaysia are mainly due to infiltration [1], the moisture content/pore water pressure also contributes to the FOS value. All these parameters are obtained for example

through bore hole sampling.

In general practice, soil investigation (SI) incorporating bore hole sampling perhaps will produce the most reliable value of the relevant soil parameters for the purpose of actual calculation on factor of safety in slopes. However, bore hole sampling is in general time consuming and very expensive. Conventional methods of soil analysis mostly require disturbing soil, removing soil samples and analyzing them in laboratory where else electrical geophysical methods on the contrary allow rapid measurement of soil electrical properties such as electrical resistivity and conductivity directly from soil surface to any depth without soil disturbance [2].

Gue [3] mentioned that among the critical element in SOP is the need of checking of slopes especially in hillside development, which could be done among others by checking the FOS. For a regular checking and calculation of FOS in a certain stretch of slopes for the purpose of identification of risk/danger for example, bore hole sampling would not be practical due to the above mentioned reasons. This is because many bore holes are required to check the factor of safety at different locations on the slopes in order to determine the risk/hazard. Hence an alternate quick and less expensive method of assessing FOS is essential so as to enable rapid and extensive measurements and calculation of FOS at different points in slopes.

Therefore, this future quick assessment method which is based on electrical resistivity method is to preliminary check the factor of safety (FOS) of any slopes on initial and regular basis. Any slope could be checked and if the FOS falls within a certain range of a "prescribed values" which indicates high risk, a further confirmation of the FOS will then be conducted through the actual soil boring sampling or any other extensive method.

The general approach behind this quick assessment system is to eliminate the usage of physical soil parameters such as cohesion (c), internal frictional angle (ϕ) and unit weight (γ) as is currently being practice for the calculation of FOS and replace these physical parameters with their correlated electrical parameters such as resistivity. Therefore the simplified method at site will require a few steel rods implanted in the soil/slope serving as the electrodes, a reel of electrical wires and an existing multi meter to generate the factor of safety calculated through a set of empirical formula, charts and graphs all to be determined from this research.

The works of researchers in past and recent years have included correlation of electrical resistivity with various soil properties. Hassanein [4] have studied the relationship of electrical resistivity in compacted clay with hydraulic conductivity and some index properties. Earlier research had suggested the possible correlation of electrical resistivity with hydraulic conductivity which serves as a nondestructive mean for evaluating the quality of compacted soil liner [5].

An extensive work by Pozdnyakov [6] have looked into the effects of electrical resistivity in different soil types with varying water content, humus content, salt contents and several other parameters. Other researchers have also studied on estimation of water content of soil using electrical resistivity [7]. Others have used the knowledge of electrical resistivity to estimate liquefaction of soil [8], detecting and locating geomembrane failures [9], estimation of soil salinity for agricultural activities [10], etc. Syed *et al.* [11] investigated the relationship of the electrical resistivity with soil parameters on homogeneous samples of sand, silt and clay at laboratory scale. Moisture content found to have strong relationship with resistivity. Poor correlations were observed between cohesion and friction angle with electrical resistivity for sand and silt samples, whereas clays samples showed a good correlations between shear strength parameters and resistivity. Syed and Zuhar [12] conducted some preliminary field work on actual slopes in the effort to find correlation of electrical resistivity and various soil parameters including friction angle and *N* value from Standard Penetration Test (SPT). Findings from the these two previous work were quite encouraging and therefore warrants for more field and laboratory investigations in order to establish more precise relations between resistivity and soil properties.

In this paper a relook into the results obtained from previous laboratory and field works are conducted, compared and presented in order to highlight the feasibilities and uncertainties of this research. Recommendations are then proposed in order to keep the momentum going hopefully in the right direction.

II. MATERIALS AND METHODS

The research methodology consist of both field and laboratory investigations. The study area is located at University Technology PETRONAS, Perak, Malaysia as shown in Fig. 1. Field investigations comprise of electrical resistivity survey (VES) and soil boring. Laboratory investigations consist of soil characterization tests and electrical resistivity test.

Fig. 1. Locations of boreholes around University technology petronas, Malaysia.

A. Vertical Electrical Sounding

The vertical electrical sounding or 1D survey was conducted at the locations of boreholes (BH-01 to BH-10), 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 3 meters. The apparent electrical resistivity of soil (ρa) is determined by equation (1).

$$\rho_a = 2\pi RL \qquad (1)$$

The obtained apparent electrical resistivity values were inverted to true resistivity values using *Ipi2 win* software and were used for interpretation. *IPI2 win* is an open-source algorithm freely distributed by Moscow State University. The procedure for inversion involves automatic and manual technique. Initially automatic inversion were selected in order to get initial model and later on inversion models were refined or fine-tune using manual method until least RMS error was obtained.

B. Soil Boring

Soil boring was performed using percussion drilling set CobraTT equipped with 1meter core sampler. Depth of all boreholes (BH-01 to BH-10) was 3 meters. Prior to drilling PVC pipe was fixed in core sampler for easy and smooth recovery of soil samples from the core barrel. The obtained samples were then brought to the laboratory for soil characterization and electrical resistivity test in laboratory conditions.

C. Laboratory Tests on Index and Engineering Properties

The basic idea behind this research is to estimate various soil properties using resistivity values. Therefore various soil characterization tests were performed to determine engineering properties of soil. Laboratory tests were performed on the soil samples obtained from boreholes, such as moisture content, unit weight, direct shear, sieve analysis, hydrometer test, liquid limit, plastic limit etc. as per methods suggested in British standards (BS).

Fig. 2. Setup for laboratory electrical resistivity measurement.

D. Laboratory Resistivity Test on Field Samples

Electrical resistivity of soil samples from various depths 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 multi meter for current measurement. Potential difference varying from 30V, 60V, and 90V were applied and resulting variation in current were recorded. Laboratory temperature during electrical resistivity test was recorded as 24^0C. Fig. 2 shows experimental setup for resistivity measurement in laboratory conditions.

The electrical resistivity of soil samples were determined by equation (2) and (3). Where *V* is voltage in volts, *I* is current in amperes, *R* is the resistance in ohms, *A* is the cross-sectional area of soil sample in meters, *L* is the length of soil sample in meters and *ρ* is the resistivity in ohms meter

$$R = \frac{V}{I} \tag{2}$$

$$\rho = \left(\frac{A}{L}\right)R \tag{3}$$

E. Laboratory Resistivity Test on Controlled Laboratory Samples

Dry soils of separate sandy and silt size particles obtained from soil supplier were each mixed with 25%, 30%, 35% and 40% of distilled water in the laboratory. Mixing was done by means of a soil mixer and the samples were then left aside for at least 24 hours in the mixing bowl wrapped with plastic. Prior to the compaction process, the internal perimeter of the mold was lined with a thick plastic material. The specimens were then compacted in three equal layers using standard proctor hammer that delivers blows ranging from 15 to 45 blows per layer. The measurement of the electrical resistivity was done in the same manner conducted on the field samples.

III. RESULTS AND DISCUSSIONS

A. Soil Samples Description

A total of 79 soil samples were obtained from 10 boreholes (BH-01 to BH-10). Resistivity results and soil boring indicates different geological profiles ranging from silty sandy soils to sandy soils. Grain size analysis shows that soil samples from BH-01 to BH-06 are classified as "silty-sand" whereas soil samples obtained from BH-07 to BH-10 are mostly "sandy" soil samples according to British Soil Classification System (BSCS). Based on grain size distribution analysis, it can be concluded that 43 soil samples are silty-sand and 36 soil samples are course-grained sandy soils.

The controlled samples which were prepared in the laboratory as mentioned earlier were comprised of separate silt and sandy size particles and later data from the two separate sizes were combined for analysis.

B. Correlations between Friction Angle and Electrical Resistivity

In order to establish relationship between electrical resistivity and various soil properties, simple regression analysis technique was used. Separate analysis for field and controlled laboratory samples was performed. The correlations between electrical resistivity and various properties of soil samples were evaluated using least-squares regression method. Linear, logarithmic, polynomial (quadratic and cubic), exponential and power curve fitting approximations were applied and the best approximation equation with highest correlation coefficient was selected.

The relationship between friction angle and field resistivity and laboratory resistivity (from samples obtained from field) indicates increasing logarithmic trend with R^2=0.33 and R^2=0.25 respectively for all soil samples as shown in Fig. 3 and Fig. 4. The obtained behavior is quite understandable due to the fact that shear strength of soil increases with decreasing moisture content [13]. This phenomenon could be clearly observed from the relationship between moisture content and electrical resistivity as shown in Fig. 5 and Fig. 6. The regression values of R^2=0.59 and R^2=0.54 respectively indicate the strong relationship between

electrical resistivity and moisture content. Decrease in moisture content, increases electrical resistivity of soil. Hence, at higher resistivity values, higher friction angle will be observed. Another possible reason for this increasing trend might be due to the decreasing saturation of the soils. Since nearly saturated pores form bridges between particles and greater particle-to-particle contact [14], therefore decreasing saturation reduces particle-to-particle contact. Thus, lower and higher electrical resistivity associated with friction angles are results of decreasing or increasing electrical conductivity or resistivity in the pores and along the solid surface.

It should be noted here that besides being dependent to the amount of water and saturation, electrical resistivity also depends on other properties such as porosity, mineralogy, particle shape and orientation and so forth. However, the author believes that the effect of all these properties in all the above tested samples were minimal.
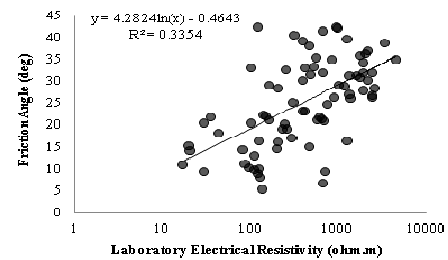

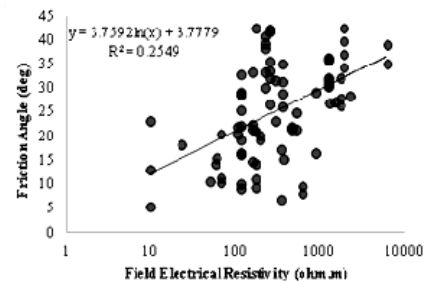Fig. 3. Correlation of friction angle and laboratory resistivity for all field soil samples.

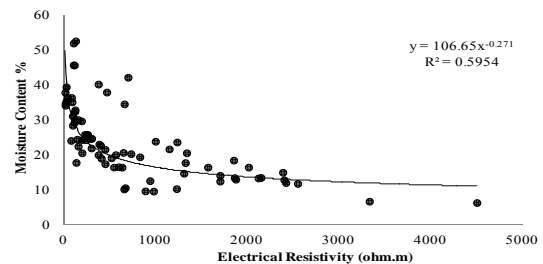Fig. 4. Correlation of friction angle and field resistivity for all field soil samples.

Fig. 5. Correlation of moisture content and laboratory resistivity for all field soil samples.

The relationship between friction angle and controlled laboratory samples is shown in Fig. 7. A regression value of R^2=0.22 was obtained demonstrating the same trend of increasing friction angle with increasing resistivity. Again, the effect of increase in electrical resistivity and hence friction angle due to decrease in moisture content could be clearly seen from Fig. 8 where the regression value increase to R^2=0.62 as a result of variations of moisture content from 25% to 40%. The variation in the compaction blows ranging from 15 to 45 blows resulted in the changes of degree of saturation and could have certainly contributed significantly

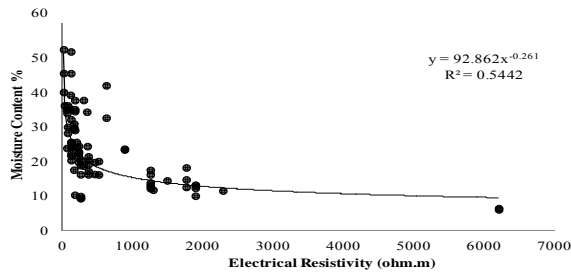to the behavior as depicted in Fig. 8.

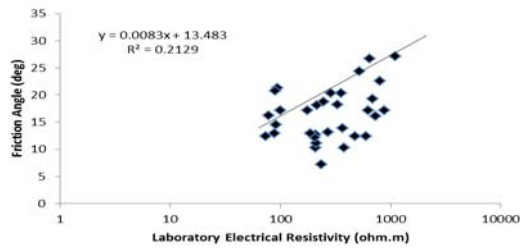Fig. 6. Correlation of moisture content and field resistivity for all field soil samples.

Fig. 7. Correlation of friction angle and laboratory resistivity for controlled laboratory soil samples.
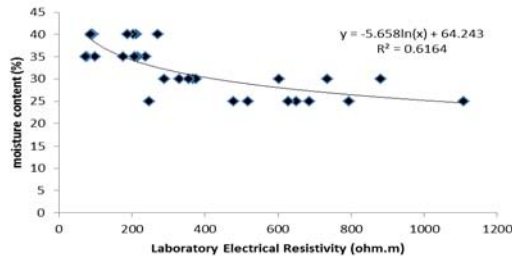

Fig. 8. Correlation of moisture content and field resistivity for controlled laboratory soil samples.

IV. CONCLUSIONS

In this study, it was observed that the relationship between friction angle and electrical resistivity shows an increasing trend for both the field samples and controlled laboratory samples. Although the points plotted are scattered and the regression values are relatively low, nevertheless, a clear trend of increasing friction angle with increase in electrical resistivity provide an early indication of the possibility to eventually arrive to a better correlation. It is identified here that the behavior displayed is attributed to the increase in moisture content and degree of saturation in all the samples where results of moisture content versus electrical resistivity show strong correlations with significant regression values.

It is suggested here that the framework and focus of the future research should include obtaining enough data covering various types of soils with different moisture content and properties. Since many geotechnical design procedures require engineers to choose formula based on sand or clay material, correlations should be divided into two main types of soils which are coarse grain and fine grain soils, each having sub divisions for different range of moisture content. Correlations between cohesion and electrical resistivity should also be covered. It is hopeful that with

correlated graphs for geotechnical design purpose.

enough data and strong correlations, friction angle (ϕ) and cohesion (c) values could eventually be extracted from the

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Syed Baharom Azahar bin Syed Osman is a senior lecturer at the Department of Civil Engineering, Universiti Teknologi PETRONAS, and Malaysia. He is a chartered engineer with the engineering council of UK. He received a doctorate degree from the Universiti Teknologi PETRONAS, Malaysia, and research interests include electrokinetic soil slopes stabilization, geotechhis nical engineering, electrical resistivity of soil.

Fahad Irfan Siddiqui is a lecturer at the Department of Mining Engineering, Mehran Universiti of E&T Pakistan. He received his master degree in civil engineering from Universiti Teknologi PETRONAS, Malaysia and his research interests include soil slopes, geotechnical engineering, electrical resistivity of soil.