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Correlation of Electrical Resistivity with Some Soil Parameters for the Development of Possible Prediction of Slope Stability and Bearing Capacity of Soil using Electrical Parameters

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ABSTRACT

The long term objective of this research is to look into the possibility of replacing soil strength parameters such as cohesion and angle of friction with electrical resistivity value for the purpose of computing among others, factor of safety in slopes or bearing capacity of soil. This paper however is limited to the investigation of correlation between electrical resistivity with some selected soil parameters. Electrical resistivity tests, using a basic multi meter, steel moulds and other related equipment, were conducted in the laboratory on soil samples with variations in soil type, compaction energy and moisture content. The samples consisted of predominantly clay, silt and sandy size particles and were compacted in a 100 x 100 mm square mould, while the corresponding electrical resistivity tests were carried out using the disc electrode method in accordance to BS 1377. The values of the electrical parameters such as voltage, current and resistance, with the corresponding value of soil parameters such as cohesion, angle of friction and moisture content, were measured and recorded. The results of the tests produced some initial crude relationships between electrical resistivity and the selected soil parameters. The strongest correlation between electrical resistivity and angle of internal friction, φ, was obtained from the clay size samples with R^2 of 0.824, while the maximum correlation between electrical resistivity and moisture content again was obtained through the clay samples with R^2 of 0.818. From the other results and graphs analyzed, some consistencies and specific trends of behaviour observed gave some early indications that a more detail and precise correlation between electrical resistivity and soil strength parameters could be very well possible in future

Keywords: Electrical resistivity, correlations, shear strength, moisture content, compaction

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INTRODUCTION

In all occasions involving the aspects of design and checking of geotechnical structures, the shear strength parameters such as cohesive (c) and angle of internal friction (φ) are perhaps the two most important required parameters. The calculation of skin friction and bearing capacity for shallow and deep foundations to the calculation of Factor of Safety (FOS) for slope stability (including designing of retaining walls, c and φ along with some other parameters) is normally obtained through prescribed methods before the actual design and checking. In general practice, soil investigation (SI) incorporating bore hole sampling will perhaps produce the most reliable values of the relevant soil parameters for calculation purposes. 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 electrical geophysical methods allow rapid measurement of soil electrical properties such as electrical resistivity and conductivity directly from soil surface to any depth without soil disturbance (Pozdnyakov & Pozdnyakova, 2002).

Taking the case of standard operating procedure (SOP) for hillside development for example, among the critical element is to check the stability of the slopes which can be done by calculating FOS. For a regular checking and calculation of FOS in a certain stretch of slopes for the purpose of identification of risk/danger, 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 stretch of slope under consideration 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, the long-term objective of this research is to produce the correlations between electrical resistivity with especially strength parameters such as c and φ which will eventually make it possible for a quick assessment for FOS of any slope on initial and regular bases. Any slope could be checked and if the FOS falls within a certain range of a “prescribed value” which indicates high risk, a further confirmation of the FOS will then be conducted if needed through the actual soil boring sampling or any other extensive method. The correlation will also enable designing and checking of any geotechnical structure, as mentioned earlier.

The work of some researchers in the past and recent years has included correlation of electrical resistivity with various soil properties. For instance, Hassanein *et al*. (1996) studied the relationship of electrical resistivity in a compacted clay with hydraulic conductivity and some index properties. An earlier research had suggested the possible correlation of electrical resistivity with hydraulic conductivity which served as a non-destructive mean of evaluating the quality of compacted soil liner (Kalinski & Kelly, 1994). Meanwhile, an extensive work by Pozdnyakova *et al*. (2001) looked into the effects of electrical resistivity in different soil types with varying water contents, humus contents, salt contents and several other parameters. Other researchers have also studied the estimation of water content of soil using electrical resistivity (Kalinski & Kelly, 1993). Others have used the knowledge of electrical resistivity to estimate liquefaction of soil (Ronald & Ronald, 1982), detecting and locating geomembrane failures (Schulz *et al*., 1984), and estimation of soil salinity for agricultural activities (Shea & Luthin, 1961).

In spite of the many research done as mentioned above, none has actually looked into the aspects of correlation of electrical resistivity with strength properties such as *c* and *φ*. The general approach behind this quick assessment system is to eliminate the usage of physical soil parameters such cohesion (*c*), internal frictional angle (*φ*) and unit weight (*γ*), as is currently being practice for the calculation of FOS or bearing capacity of soil and replacing these physical parameters with their correlated electrical parameters which include resistivity, conductivity and voltage. Therefore, the future 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 multimeter to generate the factor of safety or bearing capacity that is calculated through a set of empirical formula, charts, and graphs to be developed in several phases of research.

Electrical Resistivity Measurement

The electrical resistivity of soils varies between different geological materials and soil types, and is dependent on many factors which will be explained later in this paper. Resistivity measurement and method of soil investigation can thus be used to identify layers of zones with different electrical properties.

The electrical resistivity of the soil is determined by measuring the resistance between two points in the soil and this is done by measuring voltage across a pair of electrodes by transmitting a controlled DC or AC current (*I*) between two electrodes pushed into the ground, while measuring the potential (*V*) between two other electrodes. The setup for the measurement of electrical resistivity is shown in Fig.1.

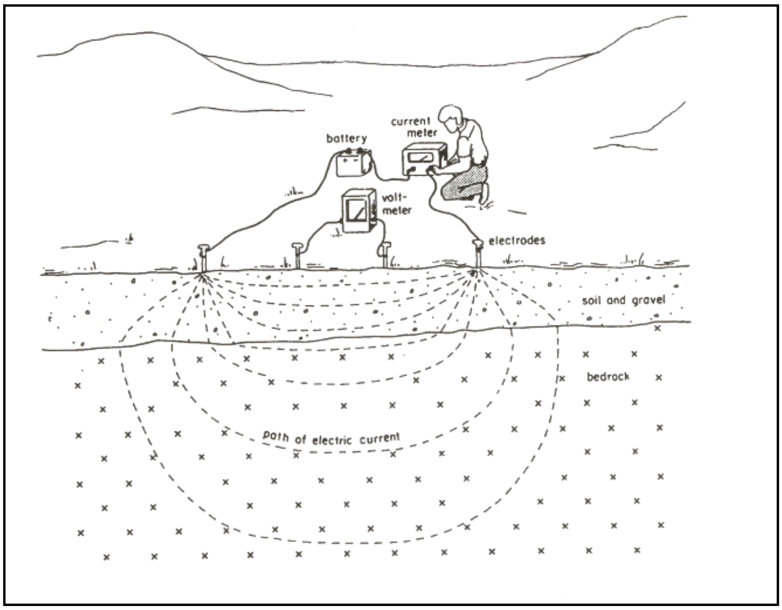

Fig.1: Principle set-up for direct current resistivity measurement (Robinson & Coruh, 1988)

The resistance (*R*) is calculated using Ohm's Law as given in Equation (1).

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

where, *V* is voltage (V) and *I* is current (amp).

For the case of a pair of electrodes in homogeneous, isotropic conducting media, the relationship between resistance and resistivity is linear and the material resistivity (ρ) can then be defined as in the following Equation (2):

$$\rho = 2\pi RL \tag{2}$$

where, *L* is the length (m) between electrode and *R* is resistance (Ω).

In the actual field measurement of electrical resistivity, there are many different kinds of electrode arrays or configuration that one could adopt. Some of the typical electrode arrays are Wenner, Schlumberger, Dipole-dipole and Pole-pole. In this research, however, disc electrode method in accordance to BS 1377 was adopted to enable undisturbed or disturbed samples of soil to be measured in the laboratory. By using this disc electrode method of measurement, the resistivity of the soil (ρ) in .m is determined by the formula given in Equation (3).

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

where, *A* is cross sectional area (m2) of the sample, *L* is length (m) and *R* is resistance (Ω).

Factors Affecting the Electrical Resistivity of Soil

For most common minerals forming soils and rocks, the resistivity is high in a dry condition and therefore the resistivity of soils and rocks generally depends on the amount and type of water in the pore spaces and fractures. Meanwhile, the connection between cavities and fracture is also an important factor in the final value of resistivity. The amount of water in a material depends on porosity, which may be divided into primary and secondary porosity. Primary porosity consists of pore spaces between the mineral particles, and occurs in soils and sedimentary rocks. Secondary porosity consists of fractures and weathered zones, and this is the most important porosity in crystalline rocks such as granite and gneiss (Instruction manual for LUND, 1999).

However, the basic mechanism affecting conductivity in moist soils and water bearing rocks occurs as a result of the movement of ions, while the ability to transmit ions is governed by electrical resistivity which is a basic property of all materials (Hassanein *et al*., 1996). Besides being dependant to the amount and type of water and porosity, electrical resistivity also depend on other properties such as type of material, particle shape and orientation, mineralogy, as well as the amount of clay content and electrical resistivity of the pore fluid. The presence of clay minerals strongly affects the resistivity of sediments and weathered rock. This is due to the fact that clay minerals are electrically conductive particles having the ability to absorb and release ions and water molecules on the surface through an ion exchange process (Parasnis, 1986).

Therefore, it is worthwhile to mention here that in clean sands and gravels, electrical conduction occurs primarily in the pores (Jackson, 1975), while in clayed soils and clay-bearing rocks, electrical conduction occurs in the pores and on the surfaces of electrically charged particles (Rhodes *et al*., 1976). Mitchell (1993) supports the above statements by adding that surface conductance in clays can be a significant factor affecting the bulk electrical resistivity of soil. Other factors which indirectly affect the electrical resistivity are frequency of the current, geometry, spacing and type of electrodes used (Erzin *et al*., 2010). Temperature also plays an important role in the electrical resistivity of soil in the sense that increasing the temperature increases the mobility of the ions and this decreases the electrical resistivity of soil (Hassanein *et al*., 1996).

The statements above exhibit the complexities in correlating resistivity with the different factors associated with soil, rocks and pore fluid. However, one could start off with the variations of resistivity and some common types of material found in many tables as an initial assistance in determining what material one is working with. An example is given in Table 1 below.

TABLE 1
Variations of resistivity with some common materials (Jackson, 1975)

Material	Ohm Meter
Clay and marl	1 to 100
Loam	5 to 50
Top soil	50 to 100
Clayey soils	100 to 500
Sandy soils	500 to 5000
Typical mine water	1 to 10
Typical surface water	5 to 50
Shale	10 to 80
Limestones	80 to 1000
Sandstones	50 to 8000
Coal	500 to 5000

MATERIALS AND METHODS

Soils

Three types of soil were used for this research. The soils were purchased from a soil processing factory according to their grades, namely, KM80, KM200 and L2B20. Brief specifications for each are given in Table 2.

From Table 2, it could be seen that the three soil types used were predominantly of kaolinite and quartz mineralogy and the main variation is in the grain sizes. In this research, the author designated grade KM80 as clay, KM200 as silt and L2B20 as sand, which are in accordance to their respective predominant particle sizes.

TABLE 2
Specifications of the soil types used

Type/Grade	Particle size	pH	Predominant Mineralogy	PI	Predominant particle size
KM80	1.0-3.0 µm	3.5-5.5	kaolinite	30.6	clay
KM200	44-250 µm	3.5-5.5	kaolinite	10.6	silt
L2B20	300-2000 µm	3.5-5.5	quartz	3.8	sand

Basic Procedure and Tests

All soil samples were stored in airtight containers so as to reduce the absorption of moisture. Basic tests comprising of sieve analysis, plastic limit and liquid limit tests were then conducted to ascertain some basic properties of the soil samples. Following this, the samples were then prepared for the second phase tests, which consisted of the electrical resistivity and the direct shear tests.

Electrical Resistivity Tests

The apparatus used for this electrical resistivity test consisted of the following:

1. Standard 100 x 100 mm concrete cube mould
2. Soil mixer
3. Standard Proctor hammer
4. Two 100 mm aluminium electrodes
5. 200 volts DC power supply
6. Hand held multimeter
7. Other basic apparatus

For every specimen, 3 kg of soil were mixed with a certain amount of distilled water according to the percentage of moisture content required that ranged between 10 % - 45 % as shown in Table 3. Mixing was done by means of a soil mixer and the samples were then left aside for at least 24 hrs in the mixing bowl wrapped with plastic.

Prior to the compaction process, the internal perimeter of the mould was lined with a thick plastic material for easy removal of the specimen once the mould had been disassembled. The specimens were then compacted directly in a 100 x 100 mm square mould in three equal layers using the standard proctor hammer that delivered blows ranging from 15 to 45 blows per layer. The procedure for compaction is the same as prescribed in BS 1377, except for the fact that the mould is square instead of the standard round mould and the number of blows varies from 15 – 45 blows as mentioned earlier. The mould was disassembled upon completion of compaction and the specimen cubes were placed between two circular aluminium electrodes for the purpose of determining electrical resistivity using the disc electrode method according to BS 1377. The specimens, along with the aluminium discs, were connected to both the negative and positive terminals of a DC power supply and also connected to a multimeter, where an initial potential with varying voltages from 30V, 60V, and 90V were applied (Fig.2). The resulting values of the current in miliampere were then recorded. The electrical resistant and resistivity of the samples were calculated from Equations (1) and (2) respectively.

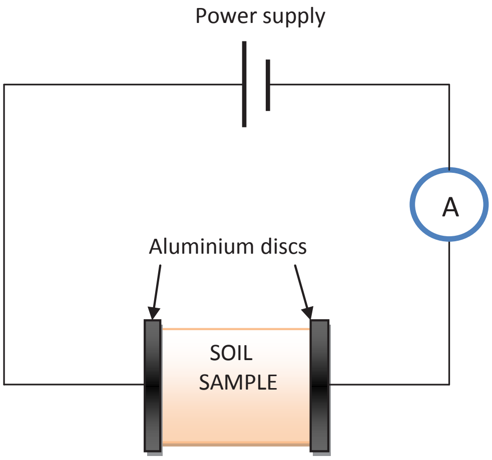

Fig.2: Electrical resistivity test set-up

The cube specimens were then sliced into 3 portions, where they were placed in a direct shear box assembly with subsequent loadings of 10 kg, 20 kg and 30 kg. Finally, the three Mohr circle diagrams from each sample were constructed and both the cohesion and angle of friction were also recorded. A summary of all the 48 tests conducted with their variations is given in Table 3 below.

For example, in tests 1 to 3, the weight of dry soil used was 3.0 kg for each sample. The soil samples were mixed with 0.75, 0.3 and 0.75 kg of water to produce the corresponding moisture content of 25%, 10% and 25% for sand, silt and clay sample respectively. The no. of blow for in tests 1 to 3 was set to 15 blows per layer. The same process was repeated for the rest of the tests in Table 3.

TABLE 3

A summary of the tests for all the samples

Test No.	Wt. of dry soil (kg)	Moisture content for sand samples (%)	Moisture content for silt samples (%)	Moisture content for clay samples (%)	No. of blows per layer
1-3	3.0	25	10	25	15
4-5	3.0	25	10	25	25
6-9	3.0	25	10	25	35
10-12	3.0	25	10	25	45
13-15	3.0	30	15	30	15
16-18	3.0	30	15	30	25
19-21	3.0	30	15	30	35

TABLE 3 (*continue*)

Test No.	Wt. of dry soil (kg)	Moisture content for sand samples (%)	Moisture content for silt samples (%)	Moisture content for clay samples (%)	No. of blows per layer
22-24	3.0	30	15	30	45
25-27	3.0	35	20	35	15
28-30	3.0	35	20	35	25
31-33	3.0	35	20	35	35
34-36	3.0	35	20	35	45
37-39	3.0	40	25	40	15
40-42	3.0	40	25	40	25
43-45	3.0	40	25	40	35
46-48	3.0	40	25	40	45

RESULTS AND DISCUSSION

Variation of Electrical Resistivity with Moisture Content

The curves of moisture content against electrical resistivity plotted in Fig.3, Fig.4 and Fig.5 are the combination of points resulting from the tests where different moisture contents and different blows were used. For simplicity reason, the effect of blows on electrical resistivity will not be discussed in detail here other than the fact that different numbers of blow were found for the same moisture content that resulted in different values of electrical resistivity for all soil types (sand, silt and clay). This is due to the changes of porosity in the soil samples. It was also found that the effect of the number of blows (which causes changes in electrical resistivity) is much more prominent in samples with lower moisture content rather than the samples with higher moisture content.

Fig.3 shows that the electrical resistivity for the sand samples, regardless of the number of blows, ranges between 188 ohm.m at 40% moisture content to the maximum 1108 ohm.m at 25% moisture content, which is within the range of the specified electrical resistivity value for sandy material (see Table 1). As for the silt samples, Fig.4 shows that the electrical resistivity values range between 78 ohm.m at 20% moisture content and 881 ohm.m at 15% moisture content, whereas the clay samples exhibit a range of electrical resistivity between 9.31 ohm.m to 37.7 ohm.m at the moisture content of 40% and 25% respectively (see Fig.5). Once again, the values of electrical resistivity for both silt and clay samples are within the specified range.

All the curves in Figures 3, 4 and 5 indicate strong correlations between moisture content and electrical resistivity for all types of soil. This is in agreement with the findings from many past researchers who found that moisture content and ionic content in pore fluids are more important than the conductivity of the constituent mineral grain of the soil or rock in governing resistivity of the sample (Kizlo & Kanbergs, 2009). By comparing the curves obtained for the sand, silt and clay samples, it is obvious that the moisture content for clay has the strongest correlation with electrical resistivity, i.e. with a regression coefficient, R^2, of 0.818, while silt exhibits the lowest correlation with the R^2 value of 0.694. The higher correlation of electrical resistivity against moisture content in clay could be well contributed by the smaller range of electrical resistivity values for clay compared to sandy particles which limit the variation in the values of electrical resistivity in clay. In addition, the homogeneity of the sizes of the sand particles which varies from 300 – 2000 µm might again affect the range of measured electrical resistivity values and hence the correlation. However, it should be noted that the weak correlation in silt might be due to the fact that lower moisture contents (10% to 25%) were used in the silt samples and therefore, further experiments should be conducted to verify this. The combined curve for silt and clay shown in Fig.6 revealed an even better correlation, suggesting that the samples with fine grain soils produced better correlation of moisture content with electrical resistivity.

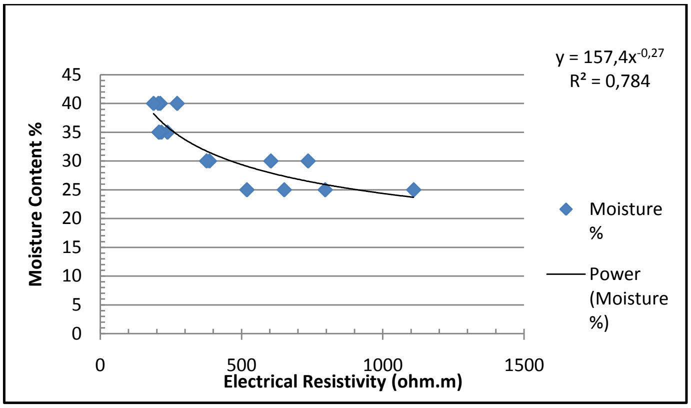

Fig.3: Moisture content vs. electrical resistivity for sand

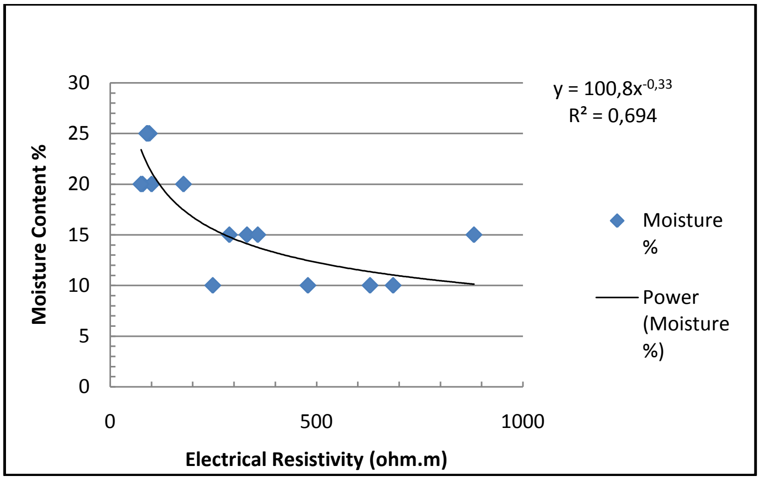

Fig.4: Moisture content vs. electrical resistivity for silt

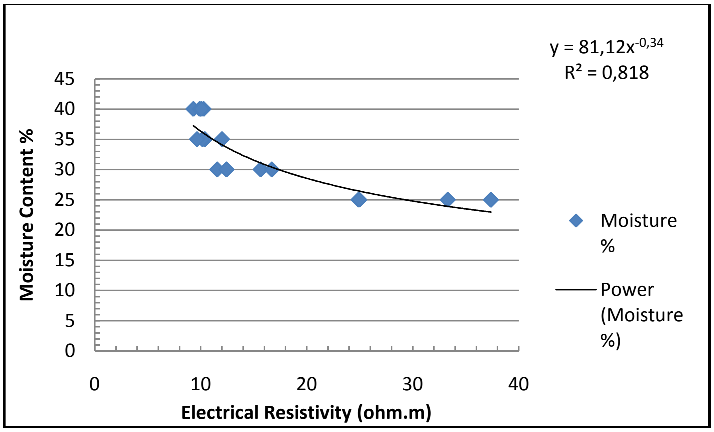

Fig.5: Moisture content vs. electrical resistivity for clay

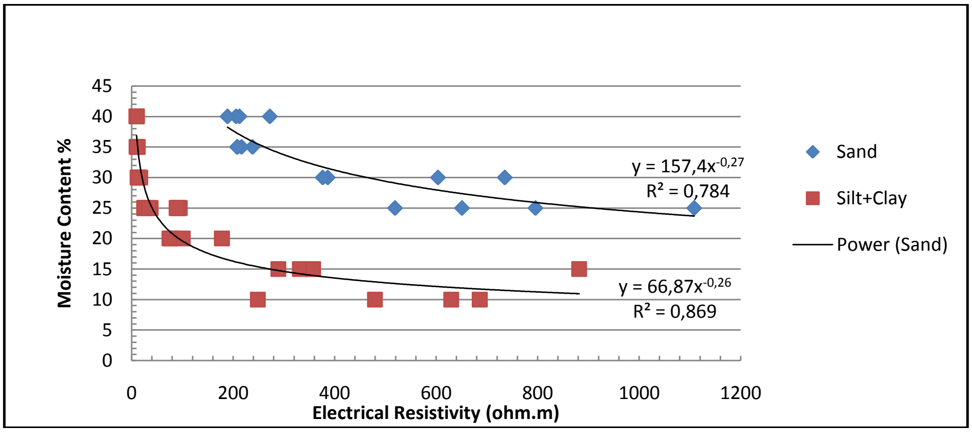

Fig.6: Moisture content vs. electrical resistivity for sand and silt+clay

Variation of Electrical Resistivity with Angle of Friction

All the values of angle of frictions φ presented in the following figures were obtained from the small shear box tests conducted on the remoulded soil samples. Along with the angle of frictions, φ, cohesive values, c, were also obtained. However, only the results obtained for φ are presented in this paper.

Fig.7, Fig.8, Fig.9 and Fig.10 show the correlations between the angle of friction and electrical resistivity. It is interesting to note that the trend of the curves indicates that the values of internal friction φ increase with the increase in the electrical resistivity. It is also interesting to find out that the correlation between φ and electrical resistivity for clay soil shown in Figure 9 gives the strongest correlation with a coefficient of regression, R^2, of 0.824, i.e. with the silt soil type having the least R^2 value of 0.012. The combined points for all the soil types are then plotted in Figure 10, with the trend of increasing φ with the increase in the electrical resistivity persists, while the value of regression, R^2, is 0.338. Nevertheless, this paper does not attempt to hypothesize the reasons of such a relationship.

If what was obtained here is the true representation of the relationship between φ and electrical resistivity, then further tests would need to be carried out to establish the governing mechanisms. Note that it is very important to establish a strong and reliable correlation between electrical resistivity and strength parameters such as φ, which is one of the main parameters used in the calculation of factor of safety (FOS) in slopes and bearing capacity of soils. A particular measurement of the electrical resistivity in the field if correlated correctly could produce a reasonable value of FOS for slope stability assessment and bearing capacity of soils for foundation design. Therefore, the related factors to look for are probably in the fabric structure or particle arrangement of the fine particles and the reduction of porosity in coarse particles, where both factors contribute to the strength of the soil samples and affect the ability in the transmission of fluid or ions in the soil, which will in turn affect electrical resistivity. Robain *et al*. (2003) and Ozcep *et al*. (2005) pointed out that solid soil components are generally insulators but electrical conductivity and resistivity lie in the fluid content in both the macro and micro voids. Porosity generally affects the pore size and volume of air voids, which will in turn increase or decrease the degree of saturation. Nearly saturated pores form bridges between the particles and greater particle-to-particle contact (Sadek, 1993). Thus, lower and higher electrical resistivities associated with φ are the results of decreasing or increasing the electrical conductivity or resistivity in the pores and along the solid surface.

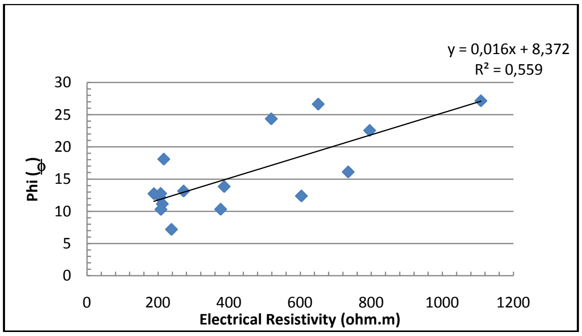

Fig.7: Angle of friction (Phi) vs. electrical resistivity for sand

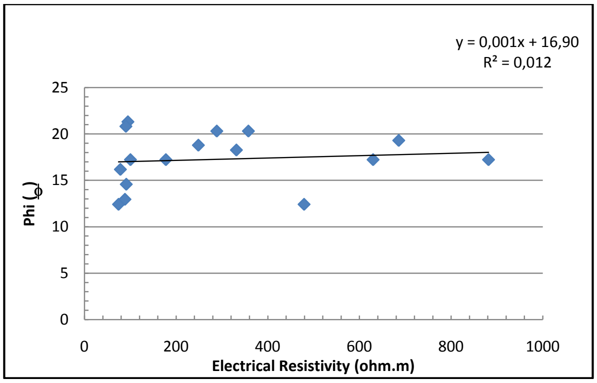

Fig.8: Angle of friction (Phi) vs. electrical resistivity for silt

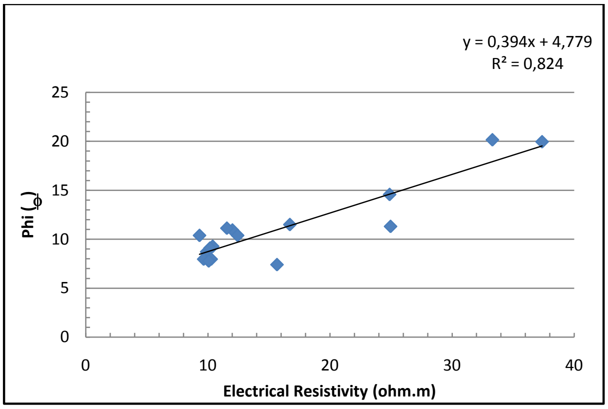

Fig.9: Angle of friction (Phi) vs. electrical resistivity for clay

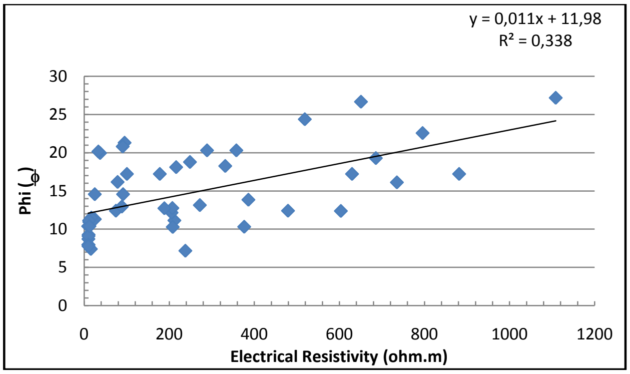

Fig.10: Angle of friction (Phi) vs. electrical resistivity for all soil samples

CONCLUSION

The trend and reliability of relationships between moisture content and angle of friction with electrical resistivity were established from this research. Relationship between moisture content and electrical resistivity shows that higher moisture content causes electrical resistivity to be lowered with the strongest coefficient of regression, R^2 was obtained in the clay soil samples. On the other hand, relationship between φ and electrical resistivity reveals that higher value of φ caused electrical resistivity to be higher with again the strongest R^2 was from the clay samples. The mechanism which governs the correlations mentioned above needs to be understood and verified through further tests which hopefully will pin point to the factors contributing to such relationship or trend. For this purpose, the author suggested to initially focus on the aspects of structural arrangement in fine grained soils and porosity in course grained soils, both of which affects the transmission of ions which has direct bearing on the value of electrical resistivity.

REFERENCES

Erzin, Y., Rao, B. H., Patel, A., Gumaste, S. D., & . Singh, D. N. (2010). Artificial Neural Network Models For Predicting Electrical Resistivity of Soils from Their Thermal Resistivity. *International Journal of Thermal Science*, *49*, 118-130.

Hassanein, Z., Benson, C., & Blotz, L. (1996). Electrical Resisitivity of Compacted Clay. *Journal of Geotechnical Engineering*, *122*(*5*)(May Issue), 397-406.

Instruction Manual for LUND Imaging System (1999). ABEM Instrument AB, Bromma, Sweden. Chapter 2, 1-21.

Jackson, P. (1975). An Electrical Resistivity Method for Evaluating the In-situ Porosity of Clean Marine Sands. *Marine Geotechnol*., *1*(2), 91-115.

Kalinski, R. J., & Kelly, W. E. (1993). Estimating Water Content of Soils From Electrical Resistivity. *Geotechnical Testing Journal*, *16*(3), 323-329.

Kalinski, R. J., & Kelly, W. E. (1994). Electrical Resistivity Measurements for Evaluating Compacted Soil Liner. *Geotechnical Testing Journal*, *120*(2451) 451-457.

Kizlo, M., & Kanbergs, A. (2009). The Causes of the Parameters Changes of Soil Resistivity. *The 50th International Scientific Conference, Power and Electrical Engineering*, 43-46.

Mitchell J. (1993). *Fundamentals of Soil Behavior (2nd ed.)*, New York: John Wiley and Sons.

Ozcep, F., Asci, M., Tezel, O., Yas, T., Alpaslan, N., & Gondogdu, D. (2005). Relationships Between Electrical Properties (in Situ) and Water Content (in The Laboratory) of Some Soils in Turkey. *European Geosciences Union General Assembly*, Wien, Austria.

Parasnis, D. S. (1986). *Principles of Applied Geophysics*. Chapman & Hall.

Pozdnyakova, L., Poznyakov, A., & Zhang, R. (2001). Application of Geophysical Methods of Evaluate Hydrology and Soil Properties in Urban Areas. London, UK. *Urban Water*, *3*, 205-216.

Pozdnyakov, A., & Pozdnyakova, L. (2002). *Electrical Fields and Soil Properties.* In *17th WCSS*, Thailand, Paper 1558, 1-11.

Robain, H., Camerlynck, C., Bellier C., & Tabbagh, A. (2003). Laboratory Measurements of Electrical Resistivity Versus Water Content on Small Soil Cores. *Geophysics Research Abstract*, 5.

Robinson, E. S., & Coruh, C. (1988). *Basic Exploration Geophyics.* John Wiley & Sons.

Rhodes, J., Raats, P., & Prather, R. (1976). Effect of Liquid Phase Electrical Conductivity, Water Content, and Surface Conductivity on Bulk Soil Electrical Conductivity. *Soil Science Society of American Journal, 40*, 651-655.

Ronald, A. E., & Ronald, C. G.(1982). Electrical Resistivity Used To Measure Liquefaction of Sand. *Journal of Geotechnical Engineering*, *108*, *GT5*, 779-782.

Sadek, M. (1993). *A Comparative Study of the Electrical and Hydraulic Conductivities of Compacted Clay*. *Phd Thesis*, Dept. of Civil Engineering, University of California at Berkeley, Berkeley, California.

Schultz, D. W., Duff, B. M., & Peters, W. R. (1984). Performance of An Electrical Resistivity Technique for Detecting and Locating Geomembrane Failures. *International Conference on Geomembrane*, Denver, USA, 445-449.

Shea, P. F., & Luthin, J. N. (1961) An Investigation of The Use of The Four Electrode Probe For Measuring Soil Salinity In Situ. *Soil Science*, *92*, 331-339.