VOL. 11, NO. 8, APRIL 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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BEHAVIOR OF ELECTRICAL RESISTIVITY IN SANDY CLAY LOAM SOIL WITH RESPECT TO ITS STRENGTH PARAMETERS

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ABSTRACT

Precise determination of engineering properties of soil is important for the proper design of any geotechnical structure. In general, the most common parameters used in computing strength of soil as currently being practiced are the cohesion (c), internal angle of friction, (Φ), and standard penetration test (SPT-N) values. These parameters are normally obtained from actual soil boring and extraction of samples which are then brought to the laboratory for the appropriate testing. However, bore hole drilling and sampling method is in general time consuming and very expensive and so this paper presents the results of an ongoing research on correlations of electrical resistivity with strength properties of soil with the long term objective of partially replacing soil boring with geophysical methods. Soil drilling, 1D field electrical resistivity (VES) and seismic survey and laboratory tests results were together analyzed to look into the behavior or correlations between electrical resistivity against various strength parameters. From the data obtained, the soil could be generally classified as sandy clay loam and results show that for this particular soil type, an increase in electrical resistivity produces higher angle of friction and lower cohesion with regression values of $R^2 = 0.5586$ and $R^2 = 0.4693$ respectively, while correlation between electrical resistivity and SPT-N depicts a polynomial curve having both increasing and downward with a regression value of $R^2 = 0.8399$.

Keywords: electrical resistivity, internal angle of friction, cohesion, SPT-N, correlation.

INTRODUCTION

Soil properties such as cohesion (c), internal frictional angle (Φ), unit weight of soil (γ), are the crucial parameters for determination of bearing capacity of soil, factor of safety (FOS) in slopes and so forth. The most reliable method of obtaining these soil parameters that are used in actual calculation of geotechnical structures is by conducting laboratory tests on samples acquired from site/field through borehole sampling. However, borehole sampling is in general time consuming and is very expensive. For example, a regular checking of FOS in a certain stretch of slopes for the purpose of identification of risk/danger through borehole sampling would not be practical due to the above mentioned reasons. Several boreholes will be required to assess factor of safety (FOS) at different locations on a certain stretch of slope in order to determine the risk. The conventional methods of soil characterization mostly require disturbance, removing soil samples and laboratory analysis as opposed to the electrical geophysical methods which allow rapid measurement of soil electrical properties without soil disturbance [1].

Therefore, an alternate quick, non-destructive and less expensive method of obtaining especially soil strength properties is very essential so as to enable rapid and extensive measurements and calculation of the various geotechnical structures.

The aim of this research is to look into the behavior of electrical resistivity of the soil under study with respect to its strength parameters. This work is a part of some preliminary studies with the long term objective of establishing a quick method of acquiring soil strength parameters by replacing the conventional parameters such as cohesion and internal angle of friction with electrical resistivity values. Hence, eliminating the need of more elaborate borehole sampling. The initial stage of the project is to conduct field and laboratory tests involving the correlation of electrical resistivity with various soil parameters.

It is hoped that the obtained correlations will eventually lead to the actual design of geotechnical stuructures based on electrical resistivity results.

BACKGROUND

Electrical resistivity measurement

An electrical resistivity of soil is the measure of its resistance to the passage of current through it. The soil is a three phase heterogonous material consisting solid, liquid and gases. The solid and liquid plays a significant role in soil spontaneous electrical phenomena and in behavior of electrical fields, artificially generated in soil [2]. The electrical current flows in soil through electrolytic conduction; i.e. as a result of movement of ions in pore fluids.

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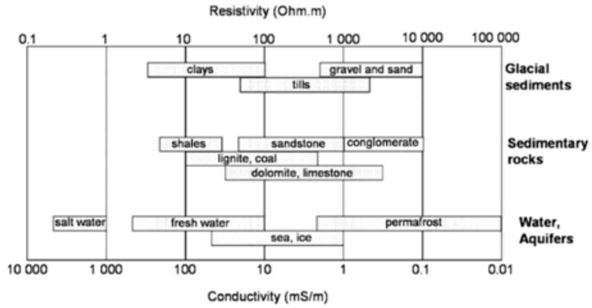

Figure-1. Typical ranges of electrical resistivity and conductivity of earth material [3].

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 one pair of electrodes by transmitting a controlled DC or AC current to another pair of electrodes. Typical range of electrical resistivity is given in Figure-1. There are different types of electrode arrays that can be used in actual field measurement of electrical resistivity such as Wenner, Schulumberger, Wenner- Schulumberger, Dipole-dipole, Pole-pole, Pole-dipole and square array.

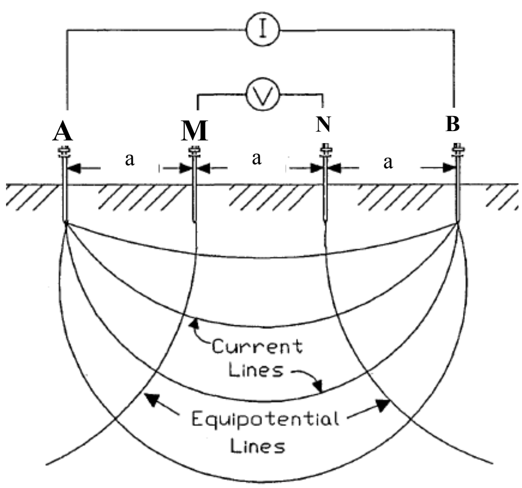

Figure-2. Arrangement of four electrodes to measure field electrical resistivity (Wenner configuration); after modified [4].

The basic concept of field electrical resistivity was first put forwarded in 1912 by Schlumberger brothers. In 1916, as shown in Figure-2, Wenner suggested the linear array of four equally spaced electrodes, still been widely used in all resistivity surveys. Resistivity methods were originally applied in petroleum and mining industries and afterward found use in archeological, hydrological, environmental, agricultural and geotechnical investigations.

Related work

Several attempts have been made by many researchers to explore the phenomenon of electrical resistivity in soils and its relationship with other soil properties. Water content and electrical resistivity of soil has been successfully correlated by various researchers [1, 2, 5, 6, 7, 8, 9, 10]. The obtained correlation models showed a clear correlation between soil moisture and resistivity.

Pozdnyakova and Pozdnyakova [1] thoroughly discussed all electrical geophysical methods and studied the effect of electrical resistivity in different types of soils with varying water content, salinity, humus content, clay mineralogy, and cation exchange capacity (CEC). Pozdnyakova *et al*. [11] also used electrical resistivity survey to locate groundwater table, salinity and other hydrological parameters of soil in urban areas where conventional soil sampling is not possible.

Electrical resistivity survey also were used for investigating chemical weathering index (CWI) [9], soil moisture determination for agricultural purposes [12, 13], foundation structure of old buildings [14], foundation stabilization work [15], detecting water seepage through earth dam [16], and groundwater movement [17].

Few studies have been carried out to correlate electrical resistivity and geotechnical parameters. Cosenza *et al*. [7] conducted 2D electrical resistivity survey to establish qualitative and quantitative correlations between resistivity and CPT values. No clear relationship between cone resistance and resistivity was observed. Sudha *et al*. [18] attempted to correlate SPT and resistivity and concluded that relationship is site-specific. Braga *et al*. [19] also obtained a poor correlation between SPT and electrical resistivity. A thorough study of geotechnical properties and resistivity of clayey soil is conducted by Giao *et al*. [20] and found poor correlation between plasticity index, unit weight and organic content.

Some investigations have been conducted to characterize the hydrogeological conditions in landslide region using 2D and 3D electrical resistivity tomography.

Studies covering some preliminary work has been carried out to correlate electrical resistivity with strength properties of soil (e.g. cohesion, angle of friction etc.) using a simple multi meter by Syed *et al*. [21]. Basic correlations between field electrical resistivity and various properties such as angle of friction, bulk density, SPT etc. have been obtained. Results of the research work are quite encouraging. It is also suggested to conduct extensive field and laboratory test in order to establish more precise correlations which ultimately would enable electrical resistivity to replace physical parameters in computations of FOS and bearing capacity of soil.

MATERIALS AND METHODOLOGY

This research work is consisted of two major phases; field work (soil drilling, 1D electrical resistivity and seismic surface wave) and laboratory work (soil resistivity, soil test). Data was then compiled for analysis.

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Vertical electrical sounding (VES) survey

Vertical Electrical Sounding (VES) or 1D survey was conducted for the study of sub-surface soil. This method is based on the measurement of voltage of electric field that was induced by electrodes embedded in soil. The method involves simple tools and accessories including 4 electrodes, power source (DC power supply), voltage meter or multimeter, insulated wires and measuring tapes which were easily prepared.

The VES survey was run at same location where the boreholes were drilled. The electrodes were placed between the boreholes at a distance of 0.5 meter and increased to 3 meters from each other using the Wenner array. Later the recorded values were calculated to determine apparent resistivity of soil, ρ_a (Ω.m) using equation (1).

$$\rho_a(\Omega.m) = 2\pi RL \tag{1}$$

R = resistance
L = distance from each electrode.

The calculated apparent resistivity values were inverted by using IX1D software. The sounding curves produced from software were then interpreted to determine the true soil resistivity and the thickness of various layers.

Seismic (surface wave) survey

The seismic imaging process was conducted using surface wave method which reads the S wave velocity of the ground. Geophones were set up by firmly installed into the ground and positioned at the specific distance from each other. The trigger switch was connected with remote cable and mounted on hammer head. The trigger level was checked at the seismograph unit. The seismograph data were used in the Seisimager/SW software to convert S wave velocity into N value of SPT. This method of acquiring SPT values from shallow seismic was used in this research due to the availability and reliability of the seismic equipment. Reliability of the method is based on the fact that very strong correlation was established between wave velocity and N values obtained from the traditional SPT method. [22].

Soil boring

Samples were collected by boring the selected area. The soil boring was performed using a petrol-operated percussion drilling set (model: CobraTT, Atlas Copco) equipped with 1 meter core sampler to collect subsurface soil samples. Percussion drilling set was used in this research as it is very handy and mobile and was able to take reasonably undisturbed samples using the correct attachments. The boreholes were drilled at the same spots where field resistivity surveys were done. Boreholes were drilled to 3 meter depths. The undisturbed samples were kept in plastic cylinder and capped tightly to avoid the loss of moisture content. The samples were then numbered according to their respective boreholes and depths.

Laboratory soil electrical resistivity

The laboratory resistivity was conducted by using approximately 100 mm long and 50 mm in diameter of cylindrical soil samples extruded from the sampling tube. The soil samples from various depths were analysed for its resistivity value in laboratory condition according to disk electrode method (BS 1377: Part 3: 1990: 10.2) where two electrodes disk are mounted on each side of the soil samples. The disks were clamped to the soil before the electrical potential (30, 60 and 90 volts) were applied. The soil resistivity can be calculated based on equations (2) and (3).

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

V = voltage applied
I = the applied current

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

ρ = electrical resistivity
A = cross sectional area of soil sample
L = length of soil sample
R = resistance across soil sample

Laboratory soil analysis test

The obtained samples were brought to the laboratory and extruded for soil characterization (moisture content. particle size distribution, density, plasticity index, shear strength, etc.) and electrical resistivity test in laboratory condition.

RESULTS AND DISCUSSIONS

Soil properties, resistivity (field and laboratory) and SPT-N value

The soil properties of 24 samples were investigated according to the depth of boreholes ranging from 0.5 m to 3.0 m from BH 1 to BH 4. The moisture content of soils at BH 1 was found to be from 16% to 24% while at BH 2 the moisture content was higher than BH 1 varying from 21% to 43%. Moisture content at BH 3 at BH 4 was found in the range of 18% to 24% and 16% to 26%, respectively.

The particle size distribution indicates percentage of soil particles of the 24 samples. The tests were conducted by using hydrometer test, wet and dry sieving. The size of particle from BH 1 and BH 2 shows the percentage of sand, silt and clay on the average are 40%, 30% and 20%, respectively. BH 3 and BH 4 soils show the average of sand, silt and clay are 45%, 30% and 25%, respectively. From the distribution it was found that the soils are of sandy clay loam type according to United

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States Department of Agriculture (USDA) Textural Soil Classification method.

The 24 soil samples obtained from all boreholes (BH 1 to BH 4) were subjected to laboratory resistivity measurement by using disk electrode method. The laboratory resistivity values in BH 1 show a range of 800 Ω.m to 1700 Ω.m as shown in Figure-3. The resistivity of BH 2 samples in Figure-4 shows the values are 700 Ω.m to 2900 Ω.m. In BH 3, the resistivity values vary from 29 Ω.m to 140 Ω.m (Figure-5) while the resistivity in BH 4 is almost identical with BH 3 where the values are from 55 Ω.m to 145 Ω.m as shown in Figure-6.

The vertical electrical sounding (VES) results found in Figure-3 to Figure-6 shows the various range of field resistivity values. These values were inverted from apparent resistivity data obtained from 1D field work. The lowest and highest value can be found at 29.39 Ω.m and 642.20 Ω.m, respectively. Soil from BH 1 to BH 4 shows that the field resistivity for each borehole exhibit a relatively small difference of electrical resistivity from 0.5 to 3.0 meter depth implying an almost same soil type throughout the depth.

The SPT-N values calculated from seismic surface wave in borehole logs are also shown in Figure-3 to Figure-6. The SPT-N values in BH 1 were found to be 15 to 30 blows while in BH 2, the SPT-N is higher than BH 1 with a range from 40 to 50 blows. However, in BH 3 and BH 4, SPT-N values are very low where the obtained blows are from 5 to 16 blows as shown Figure-5 and Figure-6.

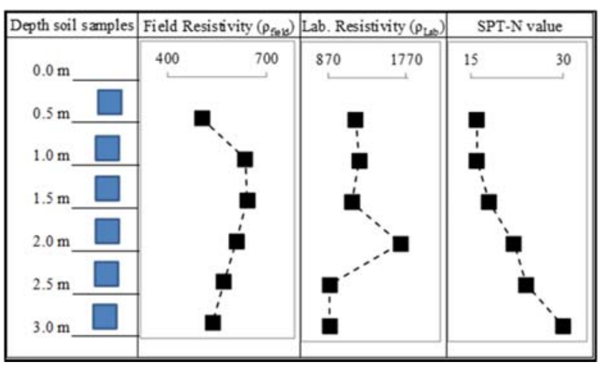

Figure-3. Borehole 1 details of resistivity and SPT.

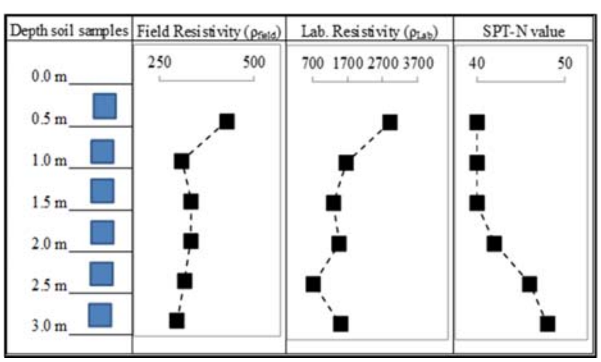

Figure-4. Borehole 2 details of resistivity and SPT.

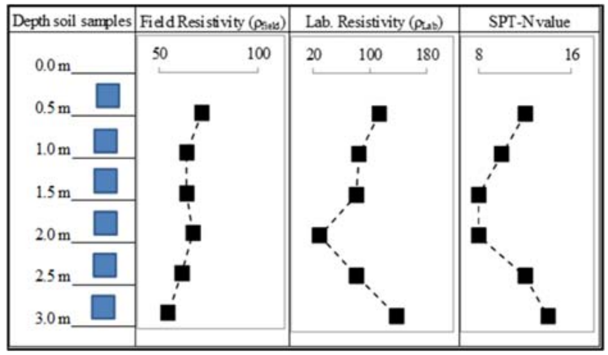

Figure-5. Borehole 3 details of resistivity and SPT.

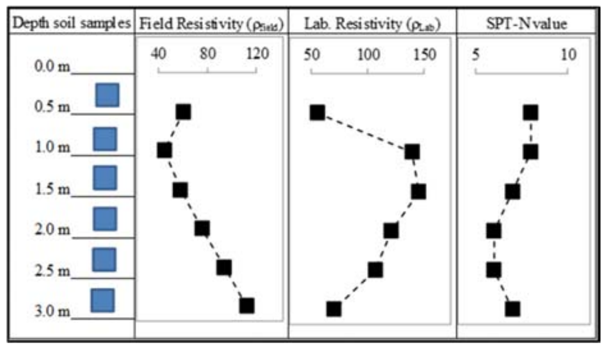

Figure-6. Borehole 4 details of resistivity and SPT.

Correlation studies by simple regression between soil properties and field resistivity

The power trend correlation between field and laboratory resistivity in Figure-7 shows a strong relation for these two variables. The regression value, R2, is 0.8248 where it can be assumed that the field resistivity value could be used for measuring purpose without taking the samples and the equation developed is $\rho_{lab} = 0.4287\rho_{field}^{1.2977}$.

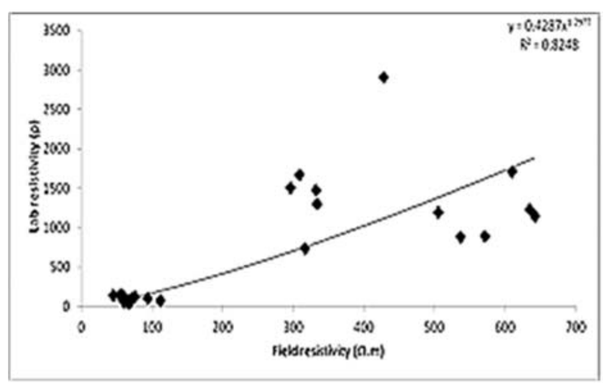

Figure-7. Correlation between lab. resistivity and field resistivity.

The relationship between friction angle (ø) and field resistivity indicates an increasing linear trend with R^2=0.5586 for sandy clay loam soil as shown in Figure-8. On the other hand it is found that relationship of field resistivity and cohesion (c) has a decreasing relationship

(R^2=0.4693) as plotted in Figure-9. The linear equations developed for both parameters are ø = 0.0458ρ + 29.929 and c = -0.1042ρ + 109.43, respectively. The same trend of increasing friction angle with increasing electrical resistivity and decreasing cohesion with increasing electrical resistivity were observed on combination of silty sand and sandy soil by Siddiqui *et al*. [23]. Although some simple explanation was concluded by previous researchers, a more elaborate study is required to fully understand the behaviour.

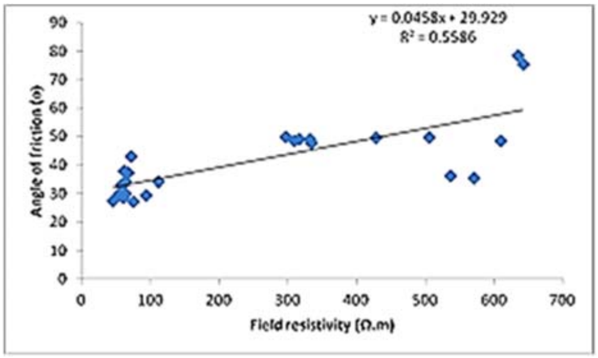

Figure-8. Correlation between angle of friction (ø) and field resistivity.

The relation between SPT-N values with resistivity in Figure-10 produces strong correlation with R^2=0.8399. The polynomial regression depicts both increasing and decreasing trend and the polynomial equation gives SPT = $-0.0003\rho^2 + 0.2553\rho - 6.2856$.

However, the author believes that the actual correlation should not be as such since it should only exhibit either an increasing or a downward trend. More samples are required to obtain a well distributed points in Figure-10. Previous preliminary work by Syed and Zuhar [3] and Syed and Siddique [24] shows an increasing trend for electrical resistivity against SPT-N values.

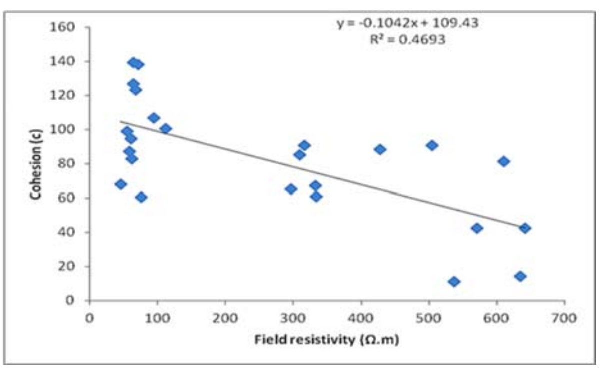

Figure-9. Correlation between cohesion (c) and field resistivity.

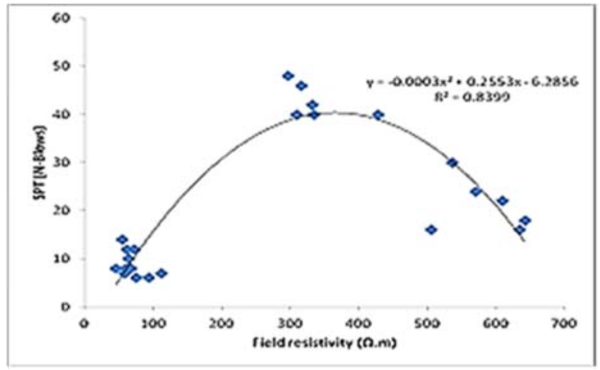

Figure-10. Correlation between SPT-N value and field resistivity.

CONCLUSIONS

This study was conducted in order to look into the relationship between electrical resistivity and some strength parameters on clay loam soil type. The observed overall regression of R^2=0.4693 to R^2=0.8399 show significant correlations which could be improved by having more data and samples. Although a long way to go, once a well define and reliable correlation are established, actual prediction of soil strength parameters using the correlated electrical resistivity values is possible. This will definitely contribute significantly to the reduction of time and labour in soil investigation works. Further study is also required to understand the mechanism of behaviour of electrical resistivity against the various soil strength parameters.

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