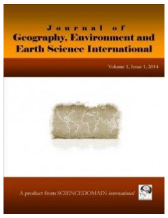

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# Characterization of Subsurface Using Schlumbeger Electrical Resistivity Method and Dynamic Cone Penetration Tests

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***Authors' contributions***

*This work was carried out in collaboration between all authors. Author SON undertook the geophysical fieldwork and wrote the first draft of the manuscript. Authors FAM and KS performed the geotechnical fieldwork. Authors BO and KO performed the laboratory tests and analysis of the geotechnical data. All authors read and approved the final manuscript.*

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## ABSTRACT

Geophysical and Dynamic Cone Penetrometer Test (DCPT) were conducted at a site to characterize the subsurface as part of a near surface studies designed to determine the strength properties of the soil for a building foundation design. 1-D resistivity method involving the Schlumberger array was carried out at the proposed building site. Soil strength properties and grain size distribution were obtained by DCPT and laboratory analysis of soil samples respectively. Qualitative interpretation of the resistivity data suggested an A- type curve (where layer resistivity; $\rho_1<\rho_2<\rho_3$), showing increasing resistivity with depth. The layer boundaries were not well defined due to poor resistivity contrast between the layers at depth. A 2-layer earth model is suggested with the average resistivity values $\rho_1$ of 521.76 ohm-m and $\rho_2$ of 819.94 ohm-m topping a bottom layer of a higher resistivity $\rho_3$. Qualitative interpretation of the soundings estimated the first and second layer boundaries at 5 m and 10 m below ground respectively. Correlation of resistivity values with

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characteristic soils resistivity suggested a material composed of clayey, silt on the surface and sand with admixture of gravel and cobbles dominant at depth which accounted for the high resistivity. Conductive moist clay on top could account for the low resistivity values. DCPT results showed an increase in average bearing capacity from 300 to 500 kPa, to the depths of 1-2 m and decreasing from 250 to 160 kPa from 4-5 m, this suggested that the survey area is characterized by a relatively thin (1-2 m) competent top formation overlying non-cohesive materials. The non-cohesive material correlated with increasing resistivity values with depth from 4m below ground surface. These methods discussed have suggested alternatives to the more expensive and time consuming procedures of soil characterization, as well as provide preliminary field data to limit the number of confirmatory drill holes in site investigations.

*Keywords: Geophysics; dynamic cone penetration; soil properties; resistivity; conductivity.*

## 1. INTRODUCTION

Integration of geophysical and geotechnical data to characterize a site for civil works is gaining notable recognition within the global engineering and construction community. This is desirable because it facilitates the qualitative and to some extent quantitative evaluation of the subsurface, both of which have beneficial cost and environmental implications. Depending on the engineering problem at hand, of the several methods, the Electrical Resistivity Imaging and Dynamic Cone Penetration Tests (DCPT) have received some considerable attention due to the methods ability to quickly and economically identify lithological types and determine the strength properties of the soils for foundation designs.

The Dynamic Cone Penetrometer Test is used to measure the variability and strength of unbound layers of soil and granular materials. The DCP Test computes the resistance (N-value) of the soil from the penetration of the cone in terms of the number of blows per 10 cm of penetration into the soil. The test is inexpensive, results are simple to interpret and several correlations to more widely known strength measurements have been published. The DCPT results quickly generate a continuous profile of in situ materials with depth. DCPT can be done during preliminary soil investigations to quickly map out areas of weak materials. [1] discusses the use of DCPT to locate potentially collapsible soils. By running an initial DCPT, and then flooding the location with water and running another test, a noticeable increase in the Penetration Index (less shear strength) might indicate a potentially collapsible or moist soil that would warrant a more detail investigation.

Electrical Resistivity Imaging on the other hand relies on measuring subsurface as variations of electrical current flow which are manifest by an increase or decrease in electrical potential between two electrodes. The working principle of this method is based on the conduction phenomenon of soil. This is represented in terms of electrical resistivity which may be related to changes in rock or soil types both in the vertical and lateral directions. The ERT provides a continuous image of the subsurface and data can be used to qualitatively study subsurface.

Characterization of soils using in-situ geotechnical methods (e.g SPT and DCPT) and electrical resistivity imaging have been reported in literature. In practice quantitative parameters have been derived from geotechnical data, whilst resistivity imaging provided qualitative evaluation of the subsurface. Currently attempts are being made to predict site specific geotechnical parameters by correlating geo-electrical data with standard penetration test [2,3,4,5,6]. Results however had not been translated directly to geotechnical knowledge due to the absence of site specific mathematical transformations.

[7] performed site characterization using Schlumberger–Wenner Configuration, Standard Penetration Test (SPT) and Dynamic Cone Penetration Test. Results indicated no specific correlation between SPT and resistivity, however linear correlation was observed when SPT was plotted against the transverse resistance and concluded that the correlation is site specific and solely dependent on the geologic environment of the study period.

Similar studies [6] conducted in the Rio Claro, Sao Paulo Brazil; using VES DC resistivity and Standard Penetration Test have also suggested the contribution of the local geology and the methods capability for soil characterization for soils in locations having similar lithology for preliminary geotechnical investigation.

[8] also reports on correlation of geo-technical properties with Resistivity Imaging (RI) of several fundamental geotechnical parameters of clayey soils. For example a decrease in resistivity of soils with high PI and LL tends to be a power function of electrical resistivity [9], the only exception being for samples with high coarse fractions. Soils with 47% coarse fraction showed high resistivity. Further studies have indicated that the trend of decreasing resistivity with increase LL and PI is also consistent with the mineralogy of samples. Other interesting relationships between other geotechnical properties such as the shear strength, moisture susceptibility, resilient modulus, and electrical properties of base course aggregates are being developed [10]. This paper attempts to characterize the subsurface of a building site using the dynamic cone penetrometer and the Schlumberger electrical resistivity methods.

## 1.1 Geological Setting of Project Area

The study area, Abankro in the Ejisu municipality of Kumasi, is located on latitude 6 ° 43’ 0’’ North and longitude 1°28’0’’ West. The general geology (Fig. 1) of the project area is associated with the Birimian Systems, comprising of the Upper and Lower Birimian [11]. The Lower Birimian consists of great thicknesses of intercalation of shales, phyllites, greywacke and argillaceous beds with some tuffs and lavas. Slates and phyllites have been commonly altered to quartz-biotite schist close to granite intrusion. The Upper Birimian overlies the lower Birimian conformably and is volcanic in origin.

The series consist of great thicknesses of basaltic andesitic lavas, beds of agglomerate, tuff and tuffaceous sediments. The basic volcanics and pyroclastics have been altered largely to chloritised and epidotised rocks that are loosely grouped together as greenstones. Where the greenstones have been subjected to dynamothermal metamorphism, they have converted to hornblende schists and amphibolites. The Upper Birimian rocks are usually fractured and sheared presenting mylonitic textures in places. Due to the intrusive relationship with granitoids, they are usually strewn with quartz veins. The water-bearing and yielding capacity is high due to the faults, fractures and quartz veins. The Birimian formation is greatly intruded by large masses of granites and basic intrusive of uncertain age but probably of post-Birimian and Pre-Tarkwaian. The geological setting of the study area is mainly granitioids with considerable thick weathered overburden where ground conditions are spatially uniform.

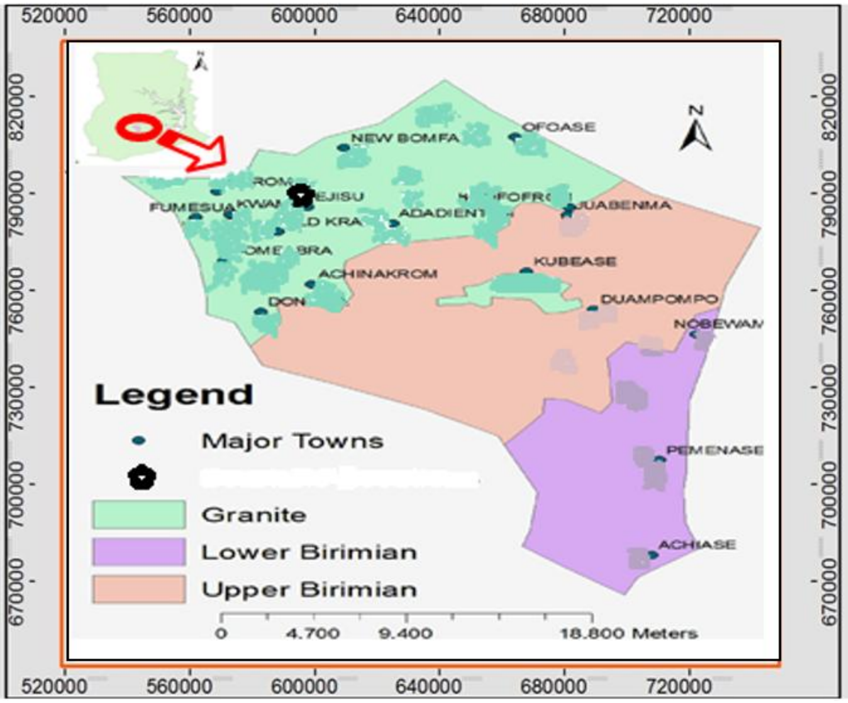

Fig. 1. Schematic geology of the study area

## 2. MATERIALS AND METHODS

The layout of the project site is present in Fig. 2 is a schematic diagram of the project site and covers an area approximately 30m wide and 60m long. Geophysical traverse line is indicated as $G_1G_2$, Dynamic Cone Penetrometer Tests positions as DCP and TP represents test pit locations. Horizontal Electrical Profiling (HEP) was carried in the Schlumberger configuration close to DCP1, DCP4 and DCP9 and depth sounding conducted using Vertical Electrical Sounding (VES) mode close to DCP9.

In the HEP mode current electrode spacing (AB) was 10 m and 20 m, at 1 m potential electrode (MN) separation. These respectively probed approximate horizontal depths of 5 and 10m respectively i.e. approximately ½ of current electrode separation (AB/2) The VES on the other hand investigated pseudo depths up to 10 m at station 30 m.

Dynamic Cone Penetration Tests (DCPT) using the Dutch type (DIN) apparatus conducted at 9 locations at the site. These were conducted to determine the stiffness of the soil formation and to provide geotechnical parameters (bearing capacity) for foundation design.

Test pits were excavated with a pick axe and shovel to a depth of 2 m at different locations to study the soil profile. Laboratory tests were carried on ddisturbed samples based on the BS [12] specifications to determine the Moisture content, Grading including hydrometer, Atterberg Limit, Specific Gravity for the soil classification. The test pits and the laboratory test served as geological control over the interpretation of the geophysical.

## 3. RESULTS AND DISCUSSION

The summary of all major results are presented in the following Figs. 3 – 5.

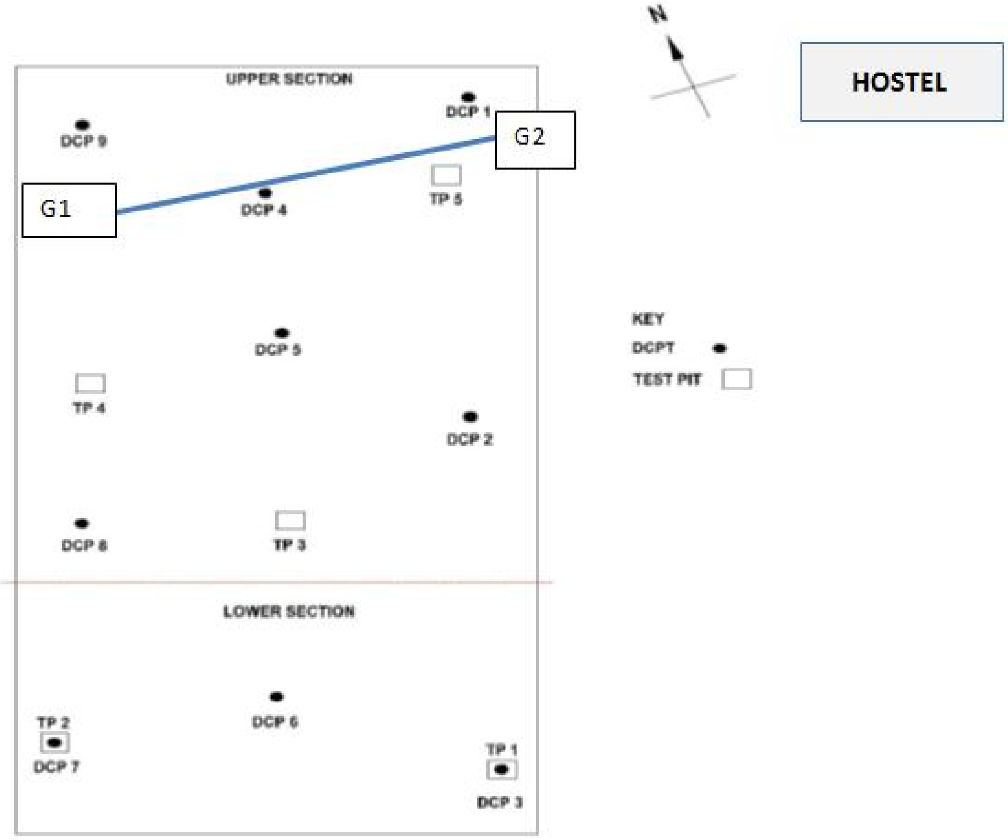

Fig. 2. Location of the tests pits and DCPT

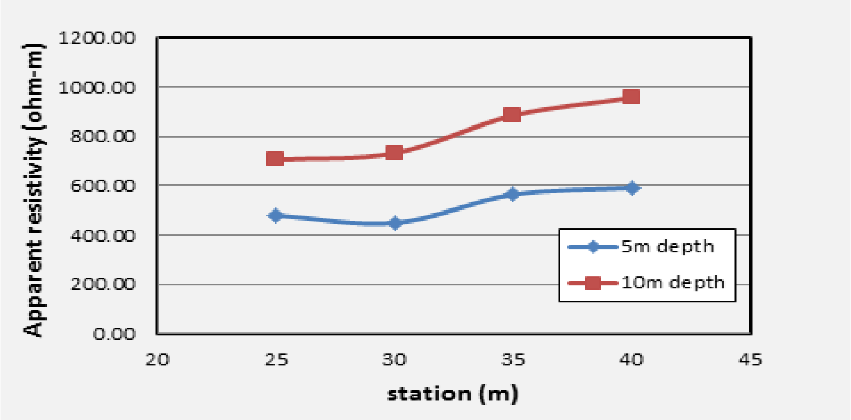

Fig. 3. HEP (Schlumberger) at 5 m and 10 m depths, Abankro Ejisu

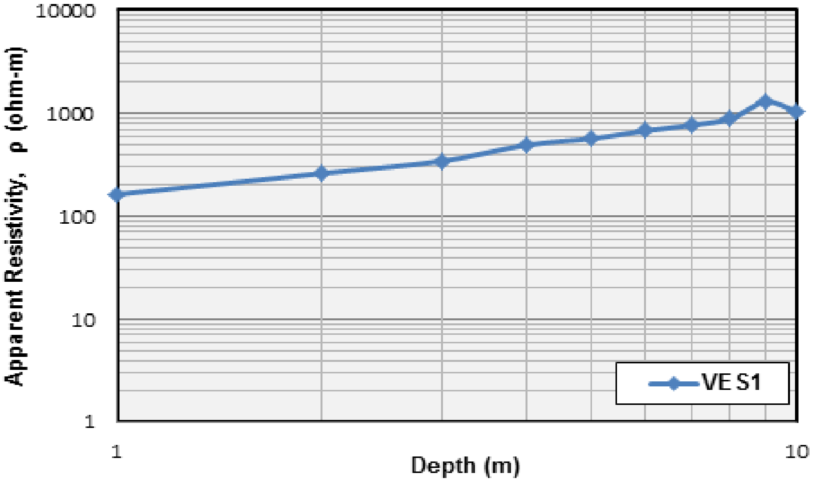

Fig. 4. VES (Schlumberger) at station 30 m, Abankro Ejisu

### 3.1 Analysis and Interpretation

From Fig. 3, the range of resistivity values at the 5 m pseudo-depth was from 481.24-591.64 ohm-m, ($\rho_1$ ave. 521.76 ohm-m) this overlay a moderately resistive formation with resistivity ranging from 705.99-955.73 ohm-m ($\rho_2$ average of. 819.94 ohm-m) and estimated to extend below 5 m from ground surface to the depth of 10 m. This layer is considered to separate the low resistivity top formation from a suspected high resistive bottom layer $\rho_3$. The indicted resistivity profile reflects an A-type sounding curve of Fig. 4 (where layer resistivity; $\rho_1<\rho_2<\rho_3$), but without well-defined boundaries due to poor resistivity contrast between the layers at depth. The horizontal variations in the resistivity values from station to station also suggested some degree of material inhomogeneity but without significant resistivity contrast to suggest the presence of isolated features. In theory a homogenous material shows a well-defined resistivity value, as resistivity is a physical property. However, geologic materials are known to be very heterogeneous, necessitating assignment of a wide range of resistivity values. There are cases in which the resistivity of an earth material will fall outside of the accepted range of resistivity values for that material, in such instances; additional data analysis is needed to produce meaningful data interpretation. Fig. 8 lists some geologic materials along with the industry accepted ranges of electrical resistivity for those materials. According to [13] the resistivity values observed were correlated with the accepted ranges for the interpretation presented in this paper.

From Fig. 8 it can be seen that clays, sandstones, shales, saprolites etc. lie in the region of relatively low resistivity which increases in value as material become less porous, reduction in the moisture content and other complex factors The range of resistivity values observed (160-1200 ohm-m) for depth soundings did not suggest the approach of the basement rocks which could generally be expected to be high, usually above 5,000 ohm-m (Kristern et al. 2012). It can therefore be suggested that the bedrock is deep seated in the area of the study and any significant deviation could be an isolated feature and not the general trend in the area. It was observed that the resistivity data collected in the survey area had subsurface resistivity values of an order of magnitude generally accepted for the existing geologic material in the area. The soil encountered at the site could be described as weathered materials derived from igneous rocks and predominantly clay, silt and sand with some admixture of gravel and cobbles (Fig. 9).

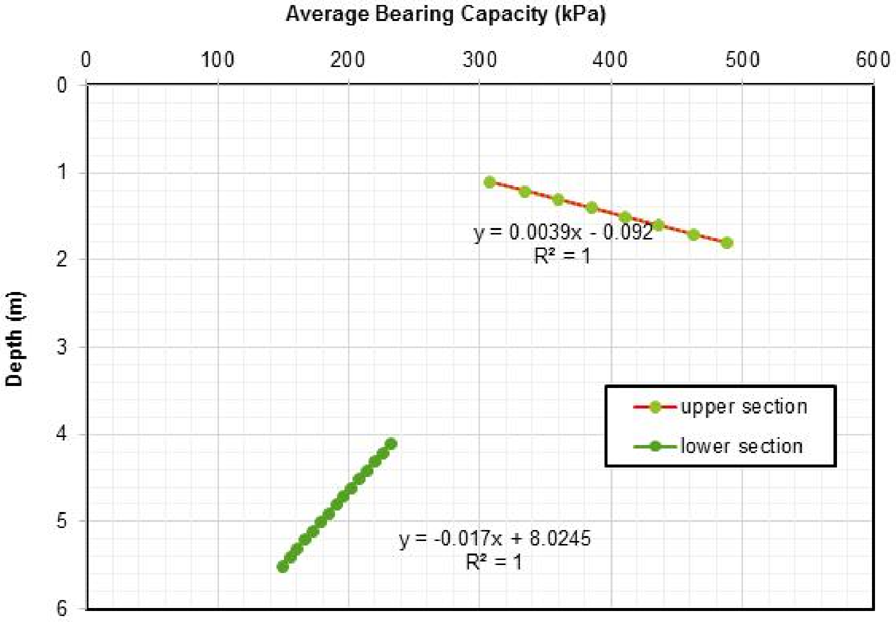

Fig. 5. Average bearing capacity against depth over project area

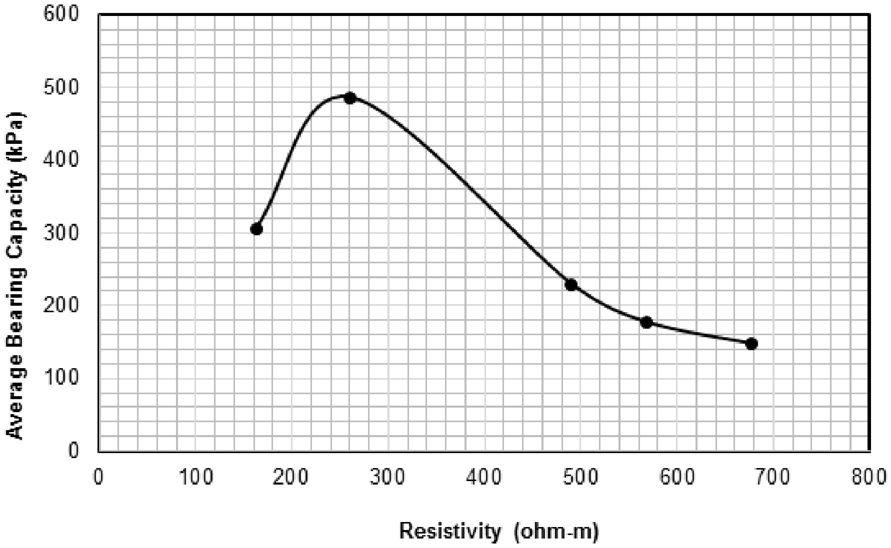

Fig. 6. Average bearing capacity against apparent resistivity

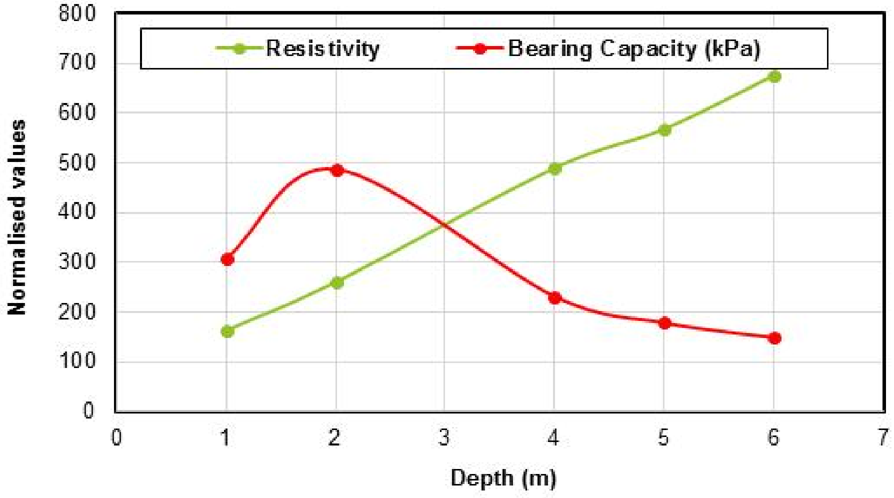

**Fig. 7. Normalised plot of average bearing capacity, apparent resistivity against depth**

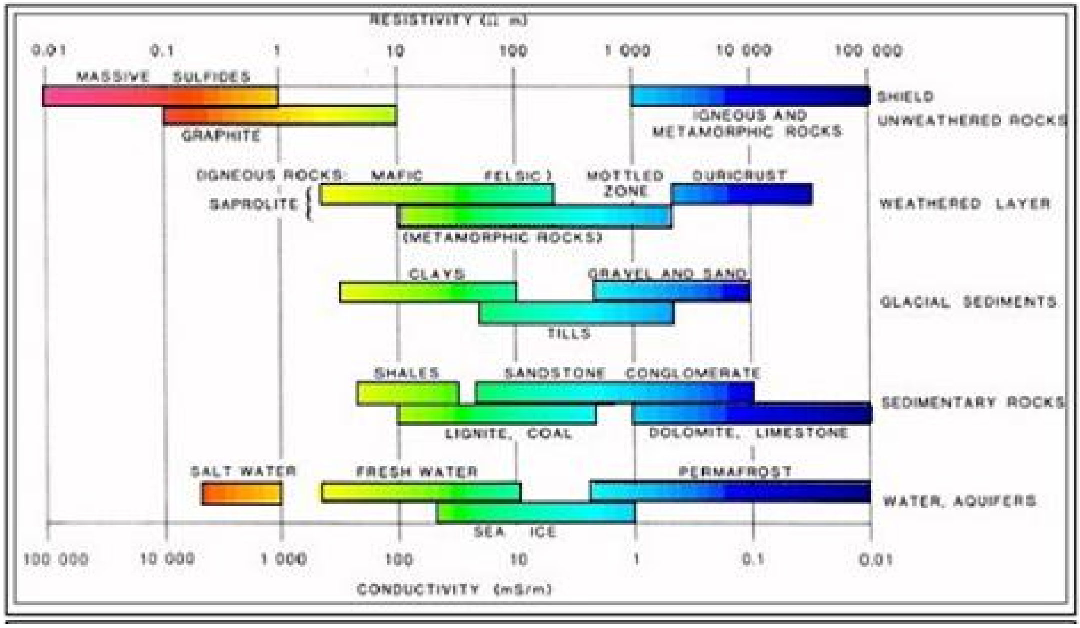

**Fig. 8. Industry accepted resistivity values for common geologic materials (adapted from Kristern et al. 2012)**

Conductive moist clayey material on the surface of the project area could account for the low resistivity. Fig. 5 shows an increase in the average bearing capacity from 300 to 500 kPa, from depths of 1-2 m and decreasing from 250 to 160 kPa between 4-5 m thus characterizing the survey area as relatively thin (1-2 m) competent top formation overlying non cohesive material. On the resistivity curves in Fig. 6, the non-cohesive zone is shown as the relatively high resistive segment of the curve. Visual inspection of test pit materials at location (TP 5) close to the geophysical traverse line identified the soil as silty, gravelly clayey SAND. Laboratory classification of soils samples from tests pits (Fig. 8) and index properties summarized and presented in Table 1 as well as particle size distribution curves shown in Fig. 10 indicated that the soils encountered in each of the test pits were mainly clayey SAND with minor gravel and silt, supporting earlier characterization of the soil by the geophysical electrical method. The laboratory tests also showed that, the soils have an average plasticity index of 23.23% with an average liquid limit of 48.76. The average moisture content is 14.17%. From Fig.7 generally no linear correlation could be established between the bearing capacity and the resistivity data and this probably may be due to insufficient data coverage of the DCPT below 5 m on site to allow for any definite interpretations to be made.

**Fig. 9. Typical tests pits excavated at the site**

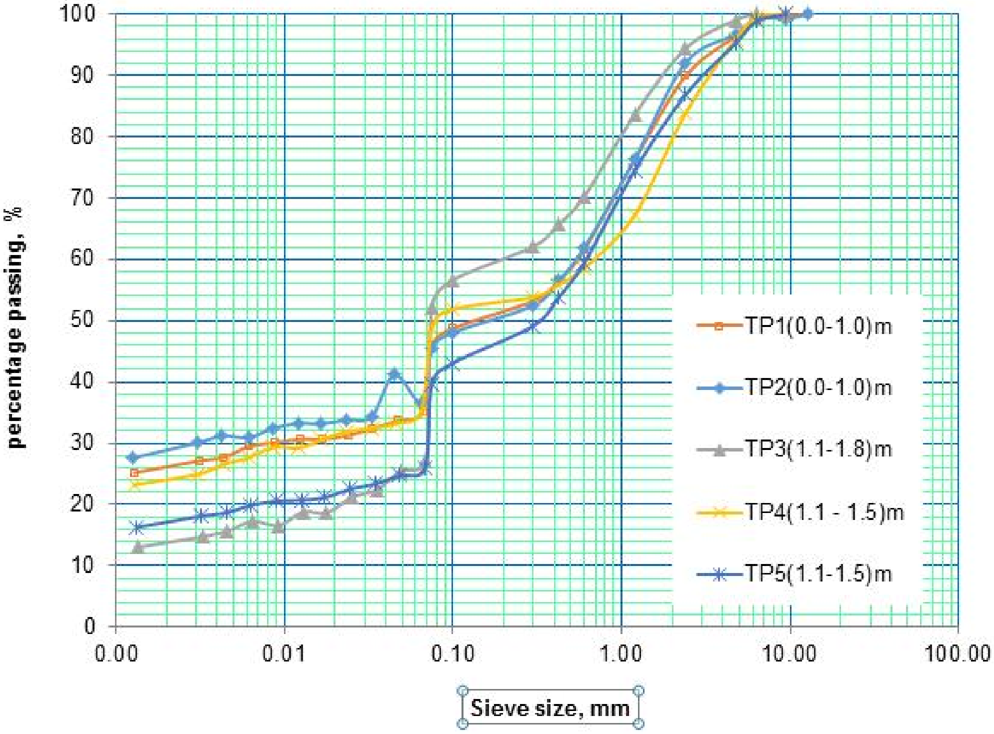

**Fig. 10. Particle size distribution curve**

**Table 1. Summary of laboratory results**

| Sample ID | Depth (m) | M.C (%) | Specific Gravity, $G_s$ | Atterberg limits (%) | | | Particle size distribution (%) | | | | Consolidation | | | Soil type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LL | PL | PI | Clay (C) | Silt (M) | Sand (S) | Gravel (G) | $e_o$ | $e_f$ | $C_c$ | |
| TP 1 | 0.0 – 1.0 | 13.71 | 2.64 | 47.8 | 25.3 | 22.5 | 26.3 | 7.8 | 53.1 | 12.8 | | | | *Silty, Gravelly, Clayey,* SAND |
| TP 2 | 0.0 – 1.0 | 13.48 | 2.48 | 48.6 | 21.8 | 26.8 | 29.3 | 8.3 | 50.9 | 11.5 | | | | *Silty, Gravelly, Clayey,* SAND |
| TP 3 | 0.0 – 1.1 | 17.84 | 2.64 | 48.3 | 27.0 | 21.3 | - | - | - | - | | | | - |
| | 1.1 – 1.8 | 15.67 | 2.64 | 49.7 | 29.3 | 20.4 | 14.0 | 11.1 | 67.2 | 7.7 | 1.3 | 0.78 | 0.040 | *Gravelly, Silty, Clayey,* SAND |
| TP 4 | 0.0 – 1.1 | 12.27 | 2.48 | 59.4 | 27.1 | 32.3 | - | - | - | - | | | | - |
| | 1.1 – 1.5 | 13.56 | 2.51 | 56.4 | 19.5 | 36.9 | 24.3 | 9.7 | 45.8 | 20.2 | | | | *Silty, Gravelly, Clayey,* SAND |
| TP 5 | 0.0 – 0.9 | 13.52 | 2.55 | 41.5 | 23.1 | 18.5 | - | - | - | - | 0.65 | 0.47 | 0.013 | - |
| | 1.1 – 1.5 | 13.34 | 2.55 | 38.4 | 31.3 | 7.1 | 17.7 | 6.7 | 59.8 | 15.8 | | | | *Silty, Gravelly, Clayey,* SAND |

## 4. CONCLUSION

This study has shown the effectiveness of the Dynamic Cone Penetrometer Test (DCPT) and the Schlumberger Resistivity methods to characterize the subsurface of a construction site. The DCPT identified different layers when the penetration rate (mm/blow) is plotted versus penetration depth and provided data on soil strength for foundation designs. Bearing capacity is site specific and changes in values as soil is penetrated and different lithological units are encountered. The dynamic cone penetration test characterized the soil into bearing capacity and depth relations, the top 2m indicated a bearing capacity between 300-500 kPa and is classified as clayey Sands with admixture of silt and gravel overlaying 160-250 kPa probably consisting of non-cohesive Sand derived from the weathering of the parent rock (granitoids). The apparent resistivity results identified a fairly non homogeneous sub-soil increasing in resistivity with depth. Apparent resistivity indicated the presence of conductive moist clay with average resistivity of 521.76 ohm-m at depths 0-4m overlying moderately resistive non-cohesive clayey sands (average resistivity 819.94 ohm-m) below 4 m depths. This assumed resistivity profile correlated with high bearing capacity on the surface and relatively low bearing capacity at deeper depths. The suggested model also did not differ significantly from laboratory test on the soils which indicated the site to be underlain by dry clayey SAND at depth. As a result of non-uniqueness the ideal concept that higher bearing capacity values corresponds to higher apparent resistivity, and lower the bearing capacity and lower the resistivity values are linearly correlated may not always be the case. In such field situations few exploratory holes are needed over anomalous zones to confirm and delineate lithological layers to provide additional data for the ground investigation.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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