DETERMINATION OF EMPIRICAL RELATIONS BETWEEN GEOELECTRICAL DATA AND GEOTECHNICAL PARAMETERS AT THE SITE OF A PROPOSED EARTH DAM.

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ABSTRACT

In order to establish empirical equations that relate layer resistivity values with geotechnical parameters for engineering site characterization, geotechnical tests comprising Standard Penetration Test (SPT), Atterberg limit, Triaxial Compression and Oedometer consolidation tests were conducted on soil samples collected from six boreholes drilled to a maximum depth of 20 metres along a proposed dam axis. The locations of the boreholes coincided with VES stations previously occupied along the axis. Atterberg limit test was conducted on the disturbed soil samples while the undisturbed samples were subjected to quick (undrained) triaxial and oedometer consolidation tests. The SPT blows (N) required for the 300 mm penetration following the first 150 mm penetration below the bottom of the borehole was taken as the penetration resistance of the soil.The geoelectrical data and geotechnical parameters were subsequently correlated. The study established that soil electrical resistivity increases with increase in bulk density but decreases with increase in plasticity index, cohesion and coefficient of compressibility. There seems to be no relationship between layer resistivity and Standard Penetration Test (SPT) blow counts, N. Where the correlation coefficients are significant (> 0.90), as for plasticity index, cohesion and coefficient of compressibility, the established empirical equations can be used to estimate geotechnical properties from subsoil resistivity values, thereby reducing the cost and duration of engineering site investigation.

Keywords: Electrical Resistivity, Site Characterization, Dam Axis, Correlation.

INTRODUCTION

Construction of large engineering structures requires prior investigation of the chosen site in order to derive a good knowledge of the subsoil characteristics. The information obtained usually guide the choice of suitable foundation type and provide information about the nature of construction materials available within and around the site. A major cause of dam failure is foundation failure which includes piping due to excess seepage through the foundation and settlement of foundation due to high compressibility of foundation soils. By far, the highest percentage of failures of foundations is due to settlement (Olayinka and Oyedele, 2001). The failure of a dam could wreak havoc on property and infrastructure and endanger the lives of the downstream population.

Detailed site investigation involves determining subsurface conditions by actually examining soil samples taken from various depths in exploratory boreholes drilled at closely-spaced points over the site. The boreholes are usually deep enough to penetrate all strata and terminate possibly on the bedrock. Both in-situ and laboratory tests are conducted on foundation soil, in order to obtain information about the subsurface geology and engineering properties. Such investigation is routinely done to ascertain the suitability, or otherwise, of the earth materials at such sites for proposed structures i.e. in terms of bearing capacity and/or hosting fitness (Olorunfemi *et al.,* 2005). Consulting engineering firms, due to financial constraints, drill only few widely-spaced boreholes at a number of discrete points and determine subsurface conditions between these points by correlation. In addition, the borings, most times, do not penetrate all strata. Therefore, in order to furnish adequate information for settlement prediction, the boring should be representative and should penetrate all strata that could shear or consolidate materially under the load of the structure (Olayinka and Oyedele, 2001). Such representative investigation can be very expensive. It is therefore imperative that an investigation technique that will reduce cost without compromising quality must be developed. Geophysical surveys have been shown to be efficient and cost effective in providing required geotechnical information (Gokhale and Dasari, 1984; Adeduro *et al.,* 1987; Ojo *et al.,* 1990; Olorunfemi *et al.,* 2000). Engineering geophysics involving electrical resistivity method has been found very useful in site investigation. The cost is cheap and its results can be related to geotechnical results (Fadugba and Olorunfemi, 2011, 2012)

This paper attempts to establish empirical relationships between geoelectrical and geotechnical data obtained along a proposed dam axis across River Ewawa, Okada area, Edo state, Nigeria (Fig 1). Such relationships will allow engineering deductions to be made and hence reduce the number of drilling and sampling required for site characterization. The area around Okada is underlain by the Upper Cretaceous Ajali Sandstone, Nssuka Formation and the Tertiary Imo Clay-Shale Group (Fig 2). The sediments of Ajali Sandstone and Nssuka Formation consist of a sequence of false-bedded sandstones, coal seams and shale while the Imo Clay-Shale group consists of well laminated clayey shales with grey to green colour. The shales contain occasional thin bands of calcareous sandstones, marls and limestone of Palaeocene age (Reyment, 1965). The study area is underlain by the rocks of Ajali Sandstone/Nssuka Formation. These sedimentary rocks are overlain by superficial deposits comprising clayey sand and sandy clay of varying thicknesses.

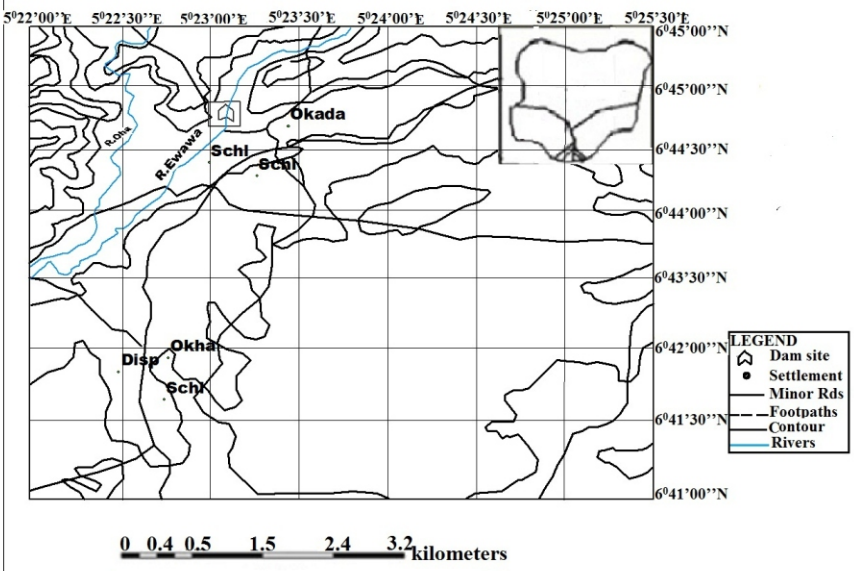

Fig. 1: Location Map of the Proposed Dam Site.

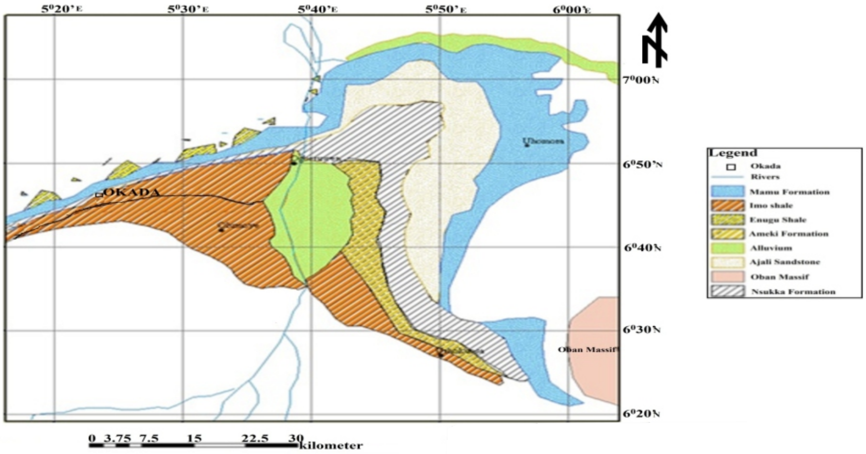

Fig. 2: Geological Map of the Area Around Okada.

METHODOLOGY

Six boreholes were drilled along the proposed dam axis, each to a maximum depth of 20 metres. Standard Penetration Tests were carried out in at the borehole sites. The total number of blows (N-values) required for 300 mm penetration after the first 150 mm penetration below the bottom of the borehole was taken as the penetration resistance of the soil. Undisturbed soil samples obtained from the cohesive strata in the boreholes were subjected to Triaxial Compression and Oedometer Consolidation tests in order to determine respectively, their shear strength parameters, and the coefficients of consolidation and volume compressibility. The detailed description of these tests are contained in the British Standards Institution Code of Practice (BS.1377:1990 – "Methods of Tests of soils for Civil Engineering Purposes").

The boreholes were located parametrically to six of the VES stations previously occupied along the dam axis (Akinlabi and Oladunjoye, 2008) in order to allow for correlation to be carried out between geoelectric data and lithologic/geotechnical parameters. The distribution of the borehole points and VES stations are shown in Figure 3. Litho-geoelectric correlation was carried out by superimposing the borehole logs on the geoelectric section (Fig. 4) and empirical equations relating the geoelectrical data and geotechnical parameters were determined by crossplotting electrical resistivity with SPT blow counts (N), subsoil bulk density (γ), plasticity index (PI), cohesion (C) and coefficient of compressibility (M_v).

RESULTS AND DISCUSSION

The subsoils encountered in the 20 m deep boreholes drilled along the dam axis are essentially similar in lithology (Fig. 4). The stratigraphy is made up of three to four layers consisting of dark brown silty sand topsoil (0.40 m and 0.80 m thick); reddish-brown lateritic clay/ hard pan having thickness ranging between 1.00 m and 7.00 m; reddish-brown, soft-to-firm clayey sand about

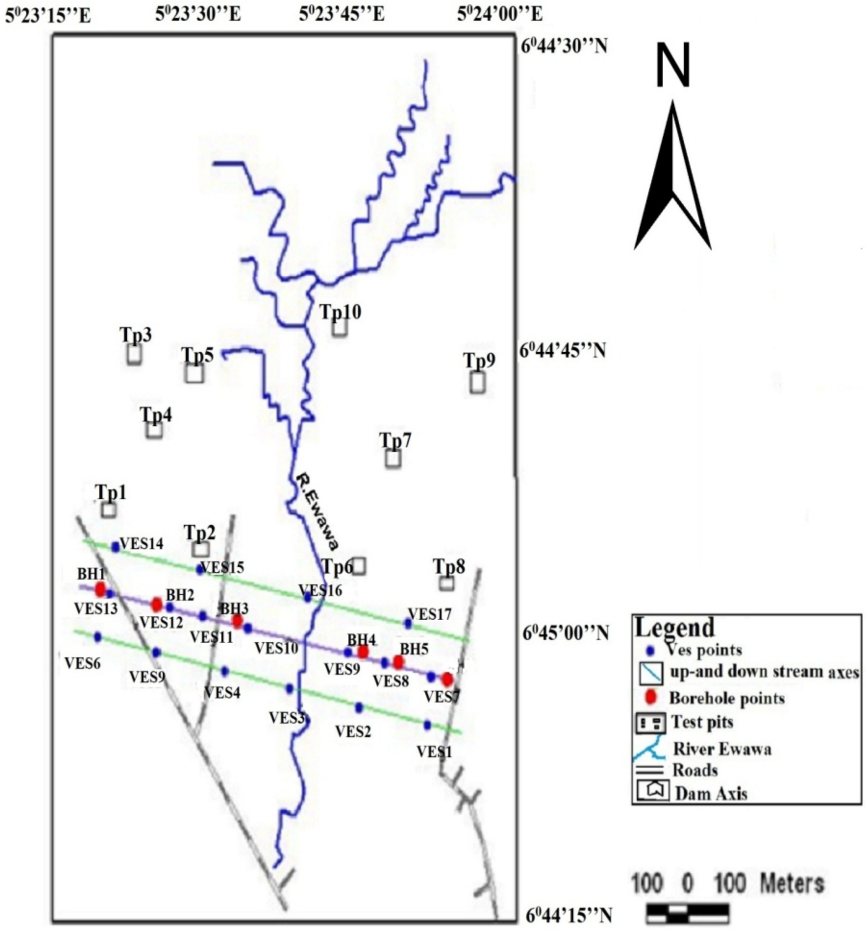

Fig. 3: VES Points, Borehole Points, and Test Pits in the Study Area.

8.5 m thick at both flanks; and light-to-yellowish brown silty sand with thickness ranging between 5.00 m and 15.50 m. The lithologic and geoelectric sections along the proposed dam axis are shown in Figure 4.

Table 1 presents the layer resistivity values and the corresponding SPT Blow counts (N) obtained beneath the proposed dam axis. Figure 5 shows a poor relationship between the resistivity values and N, with a correlation coefficient, r = 0.21. This is in agreement with the findings of Braga et al. (1999).

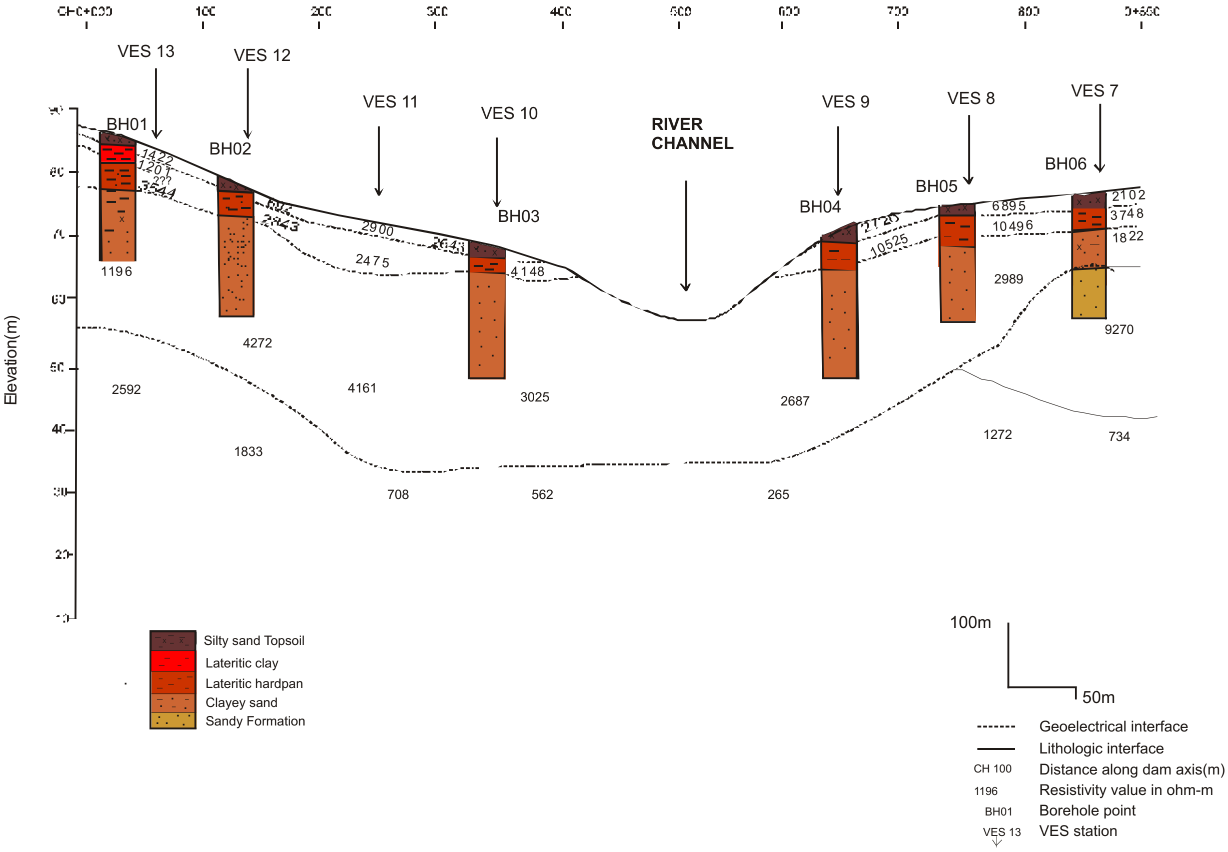

Fig. 4: Geoelectric and Lithologic Sections along the Proposed Dam Axis.

Table 1: Layer Resistivity values and corresponding with SPT, N Beneath the Proposed Dam Axis.

Sounding Station	Resistivity, ρ (ohm-m)	SPT Blow counts, N	Borehole No.
VES 13	1422	3	BH 1
	1201	30	
	3544	31	
	1196	31	
VES 12	692	3	BH 2
	2843	28	
	4272	38	
VES 10	2643	3	BH 3
	4184	25	
	3025	27	
VES 9	2720	3	BH 4
	10525	31	
	2687	40	
VES 8	6895	7	BH 5
	10496	25	
	2989	43	
VES 7	2102	12	BH 6
	3748	51	
	1820	49	
	9270	50	

(Layer resistivity values are from (Akinlabi and Oladunjoye, 2008)

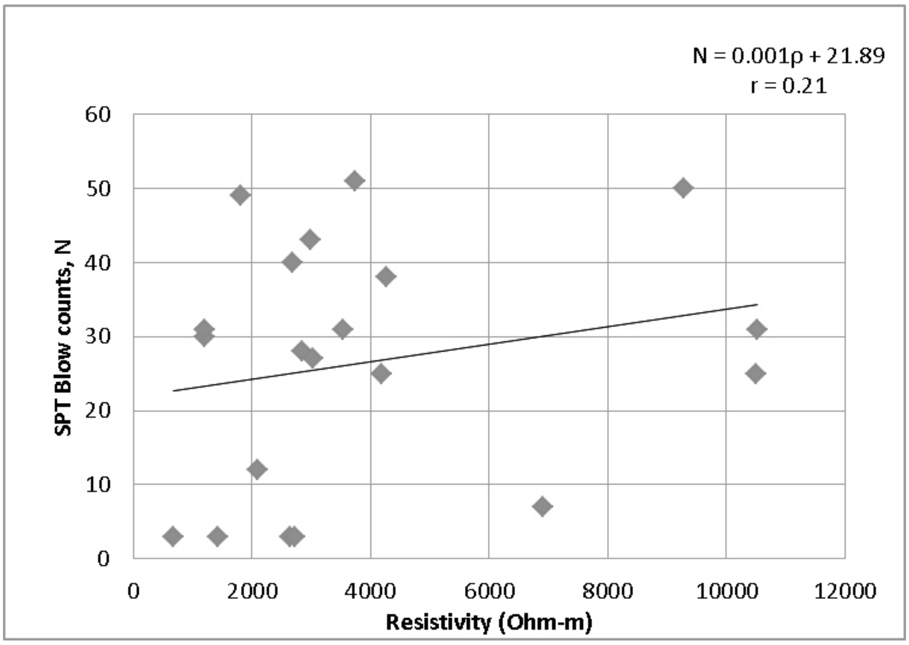

Fig 5: Correlation of Subsoil Resistivity, ρ and Standard Penetration Test (SPT) Blow counts, N.

The layer resistivity values and the corresponding subsoil bulk density along the dam axis are presented in Table 2. Figure 6 shows that the resistivity increases as the bulk density increases.The coefficient of correlation r = 0.59. This is not unexpected because as the bulk density of a soil increases, the amount of voids and/or pore water within it (and hence its total volume) decreases, the degree of compaction increases and the resistivity will increase. Table 3 contains the observed layer resistivity, plasticity index (PI), cohesion (C) and coefficient of compressibility of subsoils at the study location. The layer resistivity decreases with increase in Plasticity Index (Fig. 7). Plasticity index for a particular soil material is a measure of the cohesive qualities of the binder resulting from the clay content. It is also an indication of the amount of swelling or shrinkage that will result from the wetting or drying of a portion of the soil. The relationship can be expressed in terms of an empirical equation:

$PI = 29.04 - 0.02\varrho$ (coefficient of correlation, $r = -0.92$)

where ϱ is the layer resistivity.
Cohesion (C) also increases with decrease in layer resistivity (ϱ) (Fig. 8). The empirical relationship can be expressed with equation:

$C = 74.64 - 0.006\varrho$ (coefficient of correlation, $r = -0.95$)

The subsoil resistivities at specific depths along the proposed dam axis decrease as the coefficients of Compressibility (M_v) increases (Fig. 9). The empirical relationship is expressed as:

$M_v = 0.157 - 10^{-5}\varrho$ (correlation coefficient, $r = -0.76$)

This is not unexpected as the more compressible an earth material is, the higher is its porosity and the lower its electrical resistivity.

Table 2: Layer Resistivity and Subsoil Bulk Density Beneath the Proposed Dam Axis.

Borehole No.	Sampling Depth (m)	**Bulk density, γ** (kN/m^3)	Layer Resistivity, ρ (ohm-m)	VES Station
BH 1	3.90	1.7	3544	VES 13
BH 2	1.90	1.78	2843	VES 12
BH 3	2.00	1.82	4148	VES 10
BH 4	2.00	1.84	10525	VES 9
BH 5	2.40	1.8	10496	VES 8
BH 6	2.00	1.78	3748	VES 7

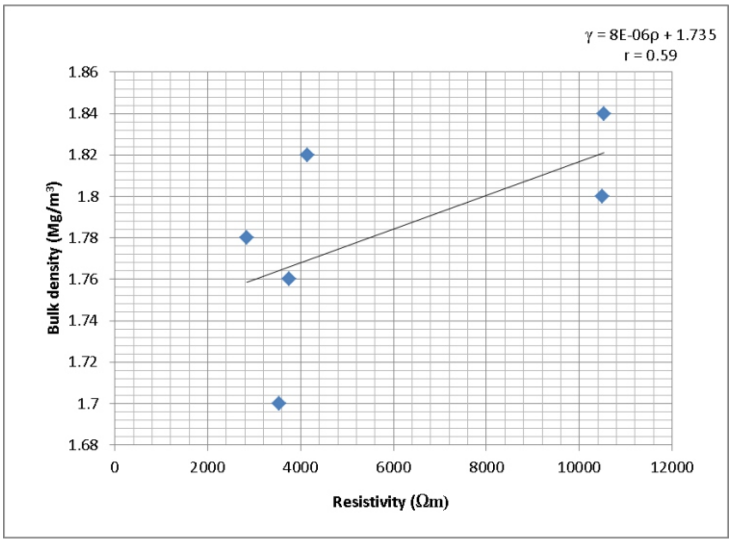

Fig. 6: Correlation Between Layer Resistivity and Bulk Density Beneath the Proposed Dam Axis.

Table 3: Layer Resistivity, Plasticity Index, Cohesion and Coefficient of Compressibility of Subsoils at the Study Location.

Sampling Depth (m)	Layer Resistivity ρ (ohm-m)	PlasticityIndex, PI (%)	Cohesion, C (kN/m^2)	Coefficient of Compressibility, (M_v)
2.40	1820	25	60	0.138
3.00	2687	25	57	0.140
1.90	2843	23	55	0.125
6.30	3025	23	55	0.120
3.90	3544	22	53	0.110
2.00	3748	21	52	0.121
2.00	4184	21	50	0.119

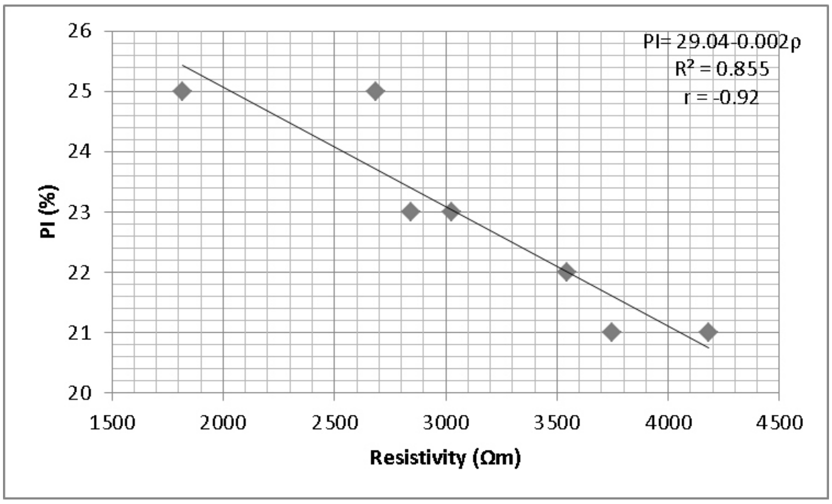

Fig 7: Relationship Between Plasticity Index and Layer Resistivity at the Study Location.

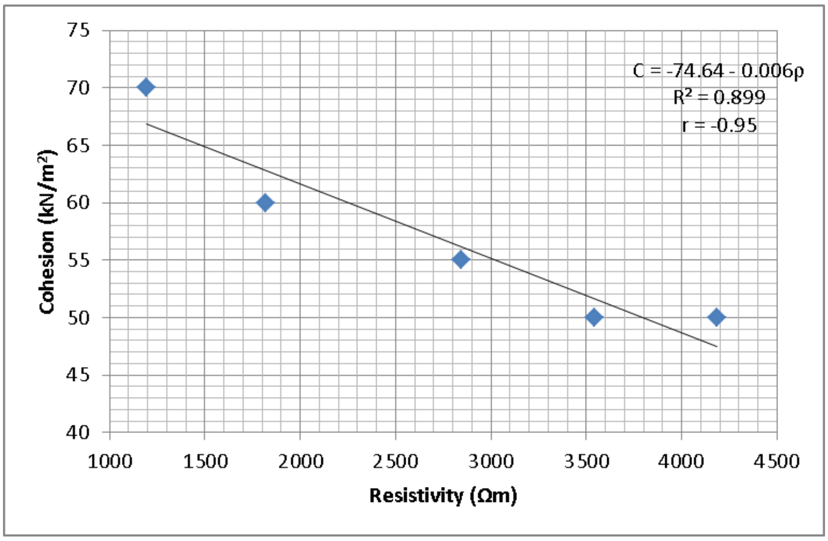

Fig 8: Relationship Between Cohesion and Layer Resistivity at the Study Location.

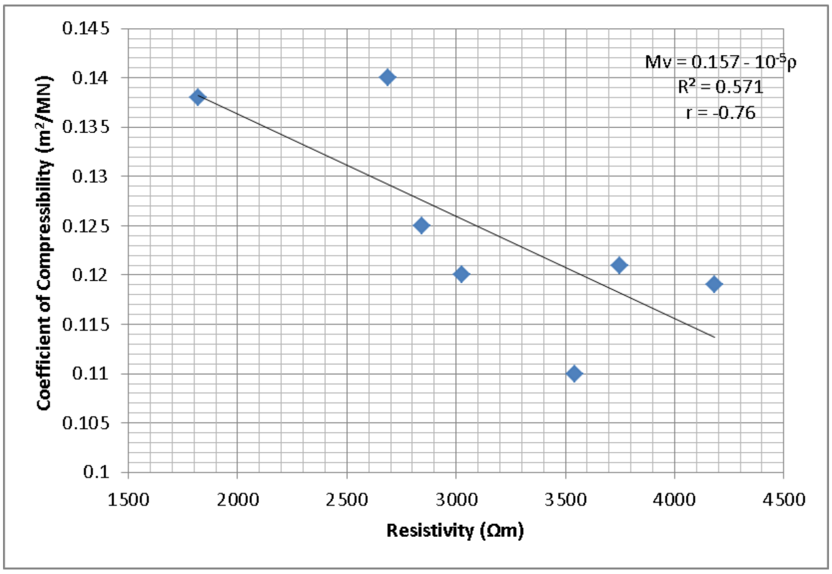

Fig. 9: Correlation Between Layer Resistivity and Coefficient of Compressibility of Subsoils at the Study Location.

CONCLUSION

The study establishes that soil electrical resistivity increases with increase in bulk density but decreases with increase in plasticity index, cohesion and coefficient of compressibility. There seems to be no clear relationship between layer resistivity and Standard Penetration Test (SPT) blow counts, N. Where the correlation coefficients are significant (> 0.90), as for plasticity index, cohesion and coefficient of compressibility, the established empirical equations can be used to estimate geotechnical properties from subsoil resistivity values, thereby reducing the cost and duration of engineering site investigation.

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