Determination of Empirical Relations between Geoelectrical Data and Geotechnical Parameters in Foundation Studies for a proposed Earth Dam.

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ABSTRACT

In order to establish empirical equations relating layer resistivity 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 the subsoil in six boreholes drilled to a maximum depth of 20m 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 300mm penetration following the first 150mm 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 depths to geoelectrical interfaces (x) correlate strongly with the actual depths (y) obtained from drilling while the subsoil resistivity (ρ) weakly correlates with SPT, N values. The regression equations are: $y = 0.977x – 0.035$ and $N = 0.001\rho + 21.89$, while the coefficients of correlation are $r=0.95$ and $r=0.21$ respectively. There exists a positive correlation ($r=0.59$) between layer resistivity and bulk density (γ). The empirical equation: $\gamma = -8E\text{-}06\rho + 1.735$ shows increase in resistivity with increasing bulk density/subsoil compaction. Plasticity index (PI), cohesion (C) and coefficient of compressibility (M_v) decrease with increasing resistivity. While PI and C correlate strongly, M_v only correlates fairly. The empirical equations and the coefficients of correlation (r) are: $PI = 29.04–0.02\rho$ ($r=0.92$), $C = 304.9\rho^{-0.21}$ ($r=-0.98$) and $M_v = 3E\text{-}09\rho^2 – 3E\text{-}05\rho + 0.182$ ($r=-0.77$), respectively. The empirical equations established can be used to estimate geotechnical parameters from which relevant engineering deductions can be made.

(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 would 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 other than any other causes (Olayinka and Oyedele, 2001). The failure of a dam could wreck property and infrastructure and endanger the lives of the downstream population.

Detailed site investigation techniques involve 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 should be 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). Most times however, site investigations depending solely on borehole drilling are poorly planned. 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 do not penetrate all strata. In order to furnish adequate information for settlement prediction, the boring should penetrate all strata that could shear or consolidate materially under the load of the structure (Olayinka and Oyedele, 2001). Consequently, the results of such investigation are deficient and misleading.

Geotechnical boring gives point source (1-D) information and hence lack continuity in subsurface imaging which a geophysical method can provide. Geotechnical tests have limitation of depth of investigation. Such investigations can be very expensive if it has to be representative or detailed. Involvement of a cheaper method like surface geophysical method will reduce cost without compromising quality. Geophysical surveys have shown to be efficient and cost effective in providing the required geotechnical information (Gokhale and Dasari, 1984; Adeduro et al, 1987; Ojo et al, 1990; Olorunfemi et al, 2000). Electrical resistivity surveys can provide a rapid evaluation of subsurface conditions.

Empirical relationships were established between geoelectrical and geotechnical data along a proposed dam axis across river Ewawa, Okada area, Edo state, Nigeria (Figure 1). The study area is underlain by the Upper Cretaceous sedimentary rocks of the Ajali and Nssuka Formations and the Tertiary sedimentary rocks of the Imo clay-shale group (Figure 2). The sediments of the Ajali and Nssuka Formations 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 a grey to green colour. The shales contain occasional thin bands of calcareous sandstones, marls and limestone of Palaeocene age (Reymont, 1965). Such relationships will allow engineering deductions to be made and hence reduce the number of drilling and sampling required for site characterization.

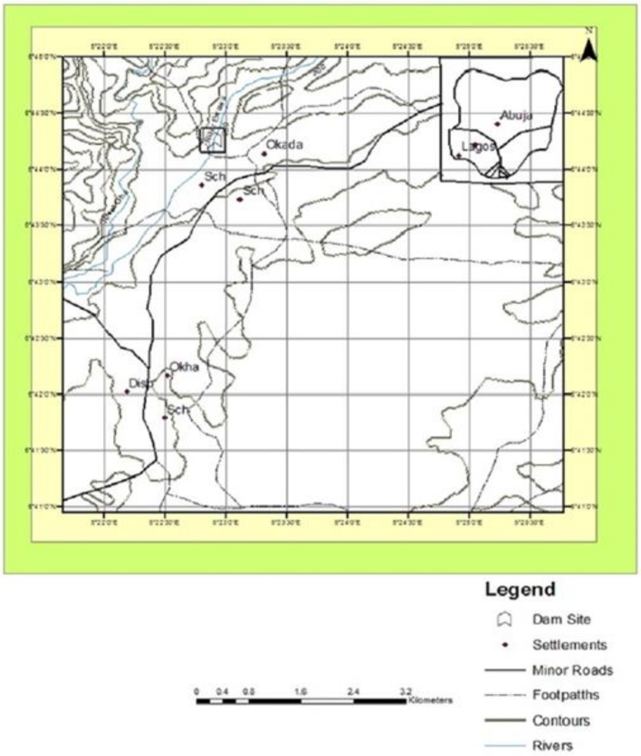

Figure 1: Location Map of the Proposed Dam Site.

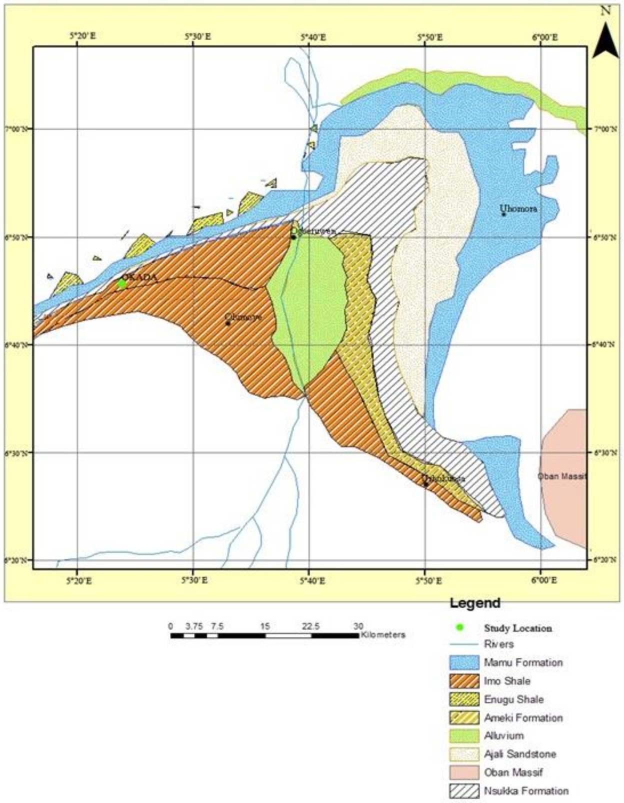

Figure 2: Geological Map showing the Study Area.

METHODOLOGY

Six boreholes were drilled along the proposed dam axis, each to a maximum depth of 20 meters. Standard Penetration Tests were carried out in the subsoil for each borehole. The total number of blows (N-values) required for 300mm penetration after the first 150mm 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 boreholes along the dam axis 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 near six of the VES stations previously occupied along the dam axis (Akinlabi and Oladunjoye, 2008) in order to allow 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 (Figure 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).

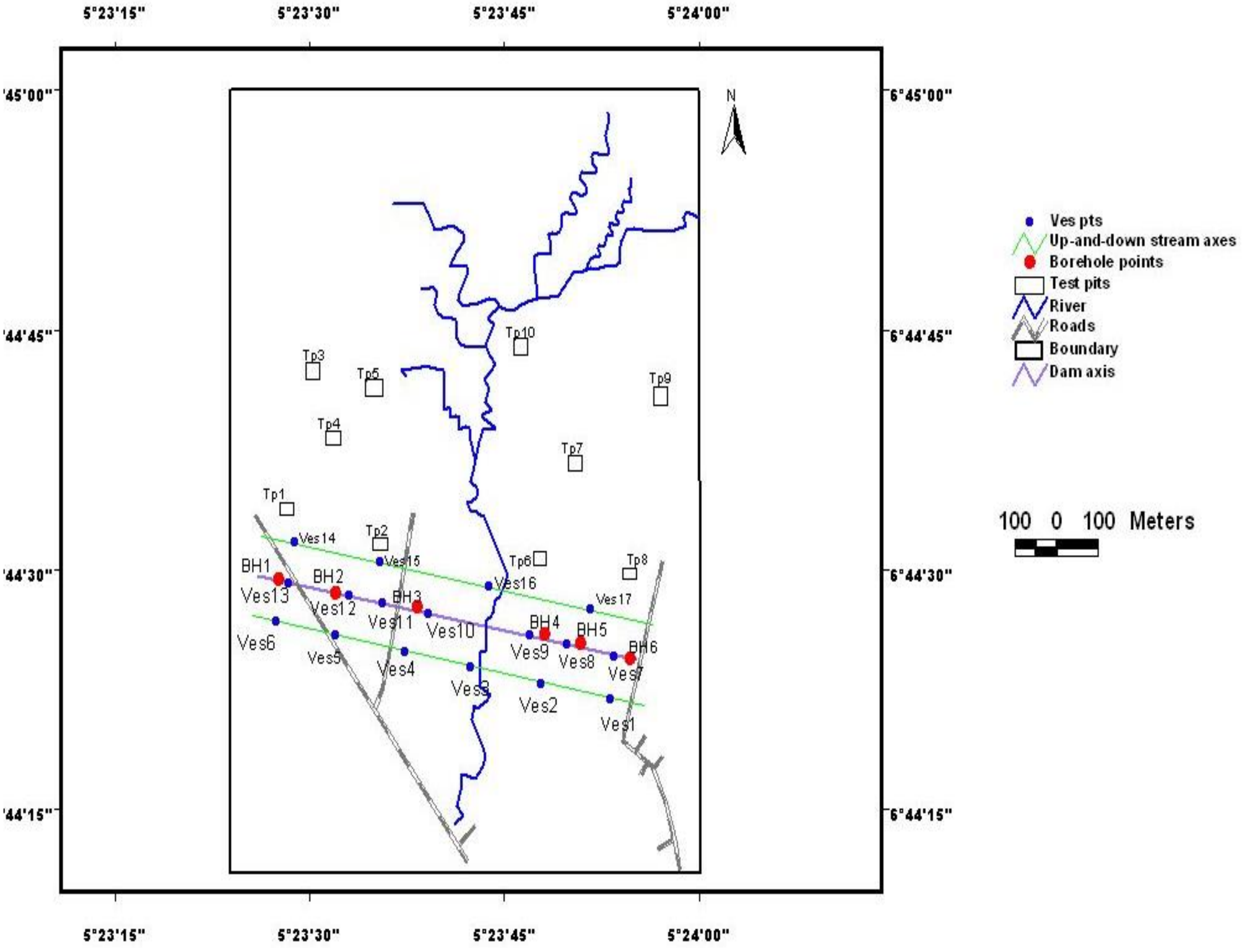

Figure 3: VES Points, Borehole Points, and Test Pits in the Study Area.

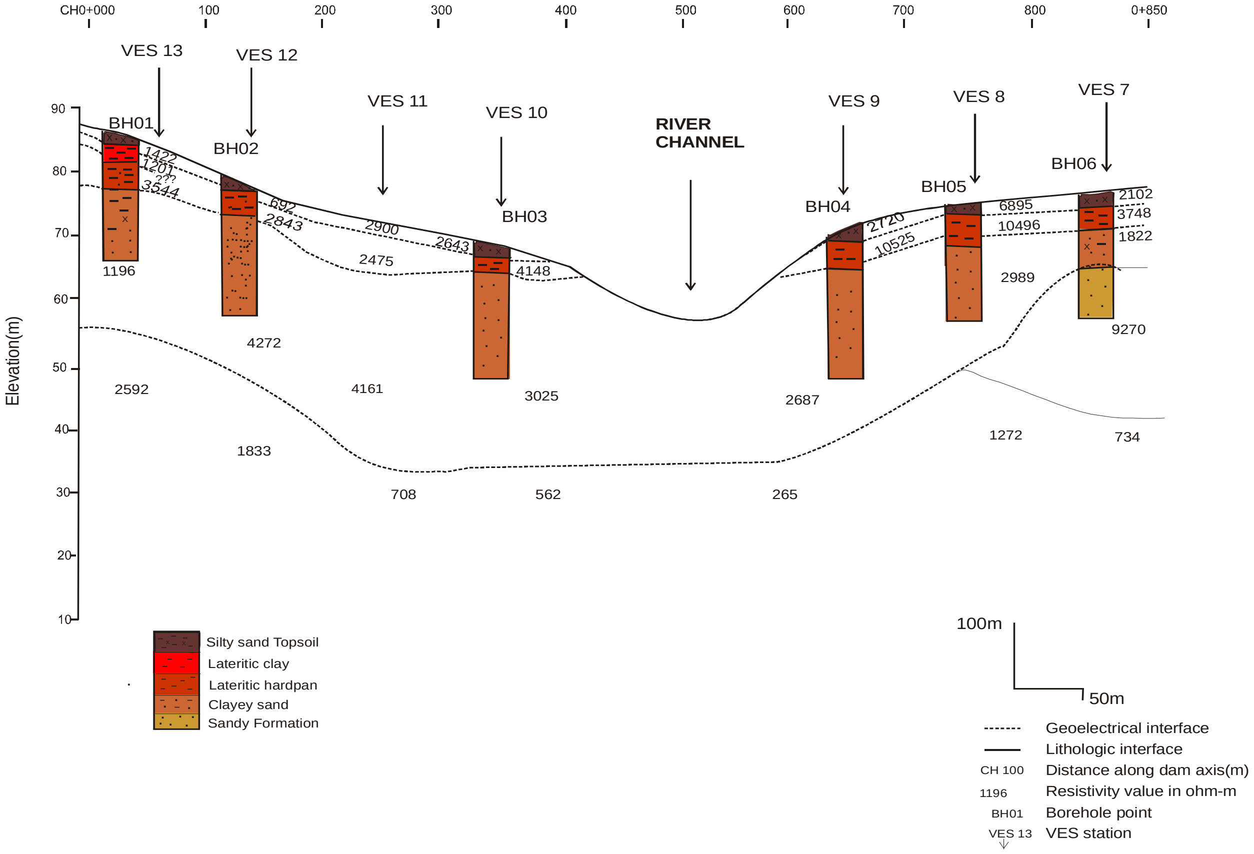

Figure 4: Geoelectric and Lithologic Sections along the Proposed Dam Axis.

RESULTS AND DISCUSSIONS

The subsoils encountered in the 20m deep boreholes drilled along the dam axis are essentially similar.in lithology. The stratigraphy consists of three to four layers consisting of dark brown silty sand topsoil 0.40m and 0.80m thick; reddish-brown lateritic hard pan having thickness ranging between 1.00m and 7.00m; reddish-brown, soft-to-firm clayey sand about 8.5m thick at both flanks; and light-to-yellowish brown silty sand with thickness ranging between 5.00m and 15.50m. The Lithologic and geoelectric sections along the proposed dam axis are shown in Figure 4.

The relationship between depths to geoelectrical interfaces predicted from sounding and actual depths to lithological interfaces determined from drilling is presented in Table 1.

A statistically significant positive correlation ($r = 0.95$) exists between the two sets of data as shown by the correlation crossplot in Figure 5. The regression analysis produced the mathematical relationship $y = 0.977x – 0.035$ between the actual (y) and determined (x) depths.. This result indicates that geophysics is able to provide a broad, composite picture of the subsurface over large areas with speed not attainable by other means (Sharma, 1997).

The empirical relationship observed between Earth resistivities and SPT Blow counts (N) obtained from field measurements along the proposed dam axis is presented in Table 2 and Figure 6. The inverted resistivity correlates weakly with N, the correlation coefficient, $r = 0.21$ with the empirical equation $N = 0.001\rho + 21.89$. This is in agreement with the findings of Braga et al., (1999) who noticed variable and weak relationships between electrical resistivity and SPT blow counts in the Rio Claro and Corunbatai Formations within the sedimentary basin of Paran, Brazil.

Table 1: Relationship Between Depths to Geoelectrical Interfaces Predicted from Sounding and Actual Depths to Lithological Interfaces Determined from Drilling.

Sounding station	Depth to Geoelectrical interface, x (m)	Depth to Lithological interface, y (m)	Borehole No.
VES 7	0.7	0.6	BH 6
	2.1	1.6	
	9.7	9.8	
VES 8	2.0	0.6	BH 5
	4.1	6.0	
VES 9	0.5	0.4	BH 4
	2.7	4.3	
VES 10	0.9	0.5	BH 3
	6.3	4.9	
VES 12	0.2	0.4	BH 2
	7.1	5.6	
VES 13	0.8	0.8	BH 1
	2.4	2.8	
	8.9	9.4	

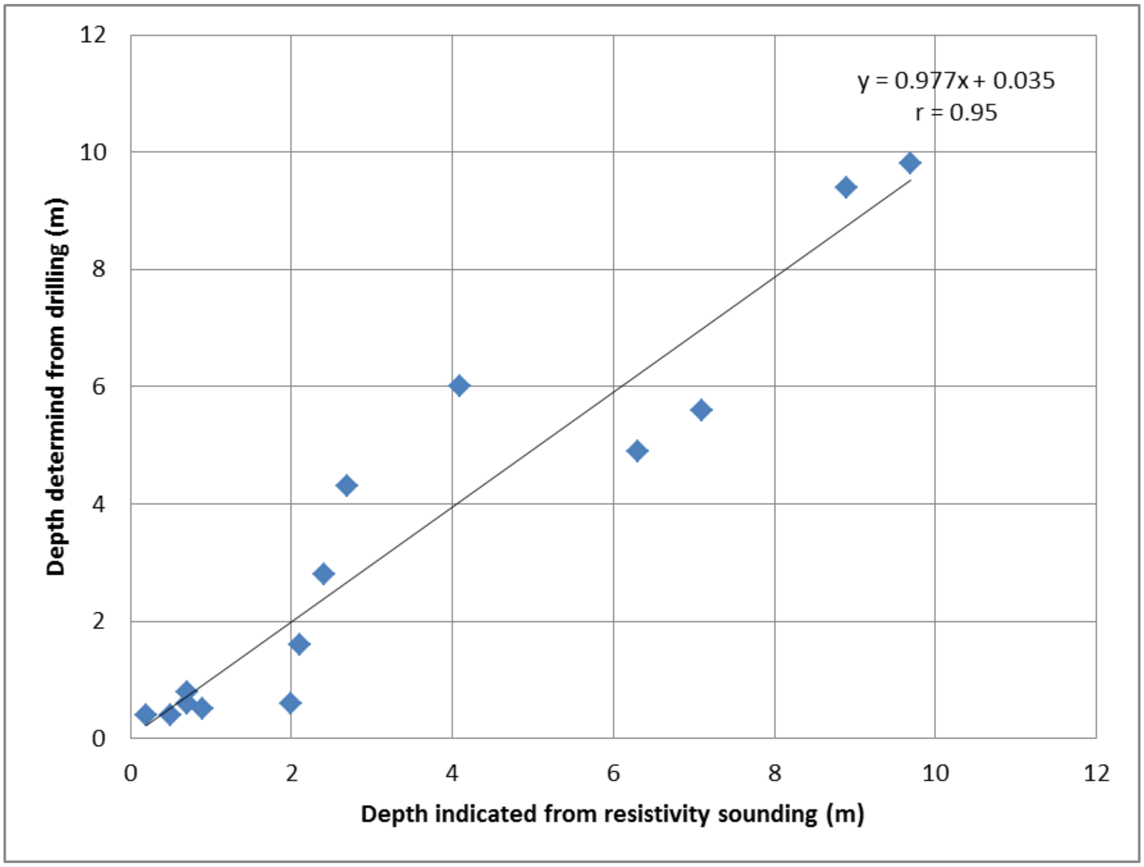

Figure 5: Correlation Between Depths to Geoelectrical Interfaces Interpreted from Sounding Data and Actual Depths confirmed in the Borehole Logs.

Table 2: Relationships of Electrical Resistivity 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	672	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	

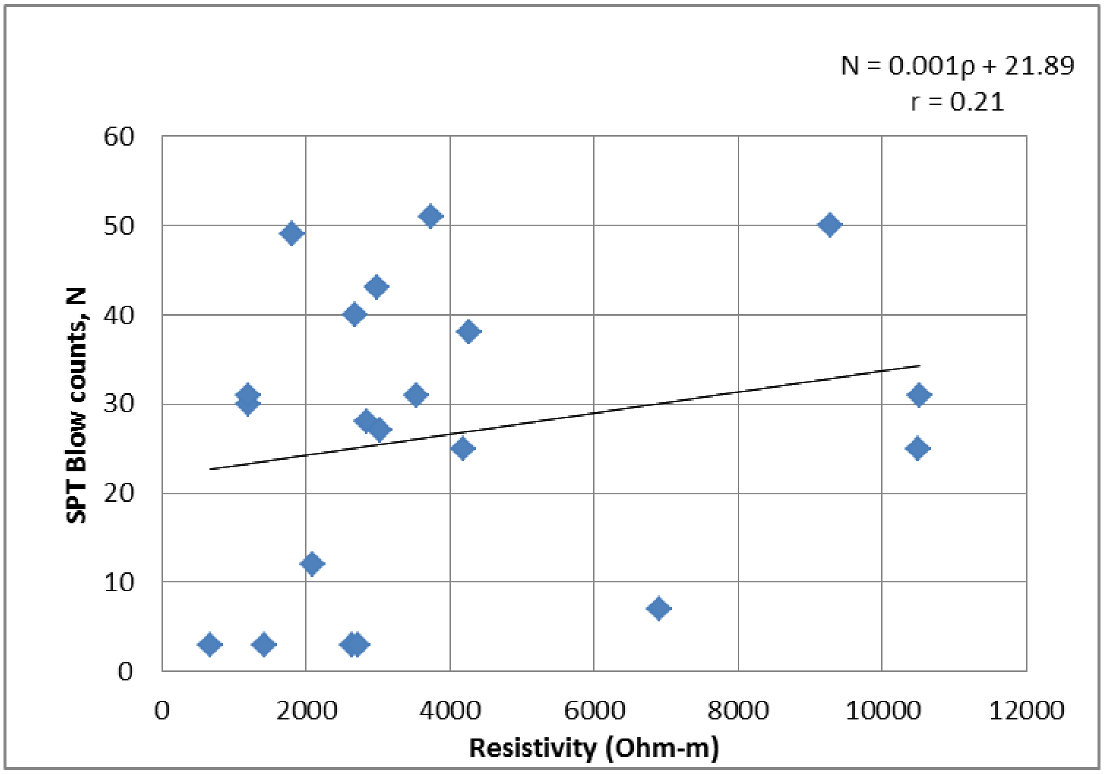

Figure 6: Empirical Relationship between Earth Resistivity, ρ and Standard Penetration Test (SPT) Blow Counts, N obtained from Field Measurements along Proposed Dam Axis.

The values of the layer resistivity and the corresponding subsoil bulk density along the dam axis are presented in Table 3. There exists a positive correlation of 0.59 with empirical equation: $\gamma = -8E\text{-}06\rho + 1.735$ showing increase in resistivity with increasing bulk density/subsoil compaction (Figure 7).This may be due to the fact that the bulk density of a soil will increase as the amount of voids and/or pore water within it (and hence its total volume) decreases.

The relationships between electrical resistivity and plasticity index, cohesion and coefficient of compressibility of subsoils at the study location is presented in Table 4. Electrical resistivity decreases with increasing Plasticity Index. 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 empirical equation demonstrates a linear fit (Figure 8) given as:

$PI = 29.04 – 0.02\rho$ with coefficient of correlation, $r = -0.92$.

Cohesion (C) correlates strongly with layer resistivity (ρ) by the power fit shown in Figure 9: $C = 304.9\rho^{-0.21}$ with coefficient of correlation, $r = -0.98$.

The subsoil resistivities at specific depths along the proposed dam axis and the coefficients of Compressibility, M_v determined in the laboratory at different pressure range 400– 800kN/m^2 presented in Table 4 while Figure 10 shows the established empirical relationship.

M_v decreases as ρ increases, according to the equation: $M_v = 3E\text{-}09\rho^2 – 3E\text{-}05\rho + 0.182$, with regression correlation coefficient, $r = -0.77$. This is due to the fact that the more compressible an earth material is, the higher is its porosity and the lower its electrical resistivity.

Table 3: Relationship between 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

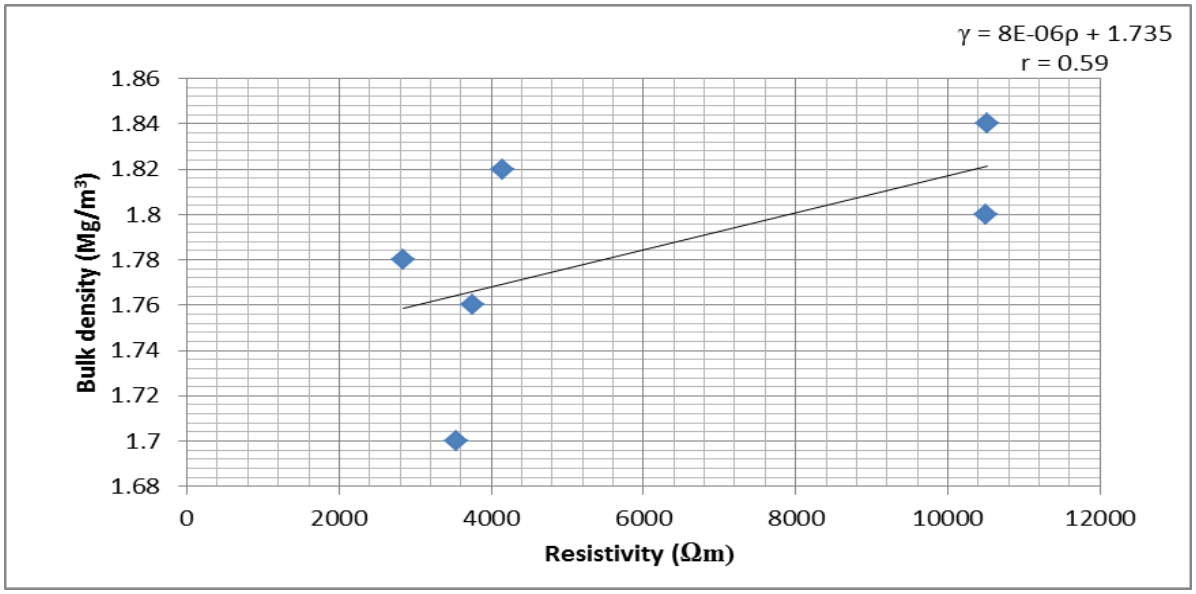

Figure 7: Correlation between layer resistivity and bulk density beneath the proposed dam axis.

Table 4: Values of Resistivity, Plasticity Index, Cohesion and Coefficient of Compressibility of Subsoils at the Study Location.

Sampling Depth (m)	**Resistivity, ρ (Ωm)**	**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

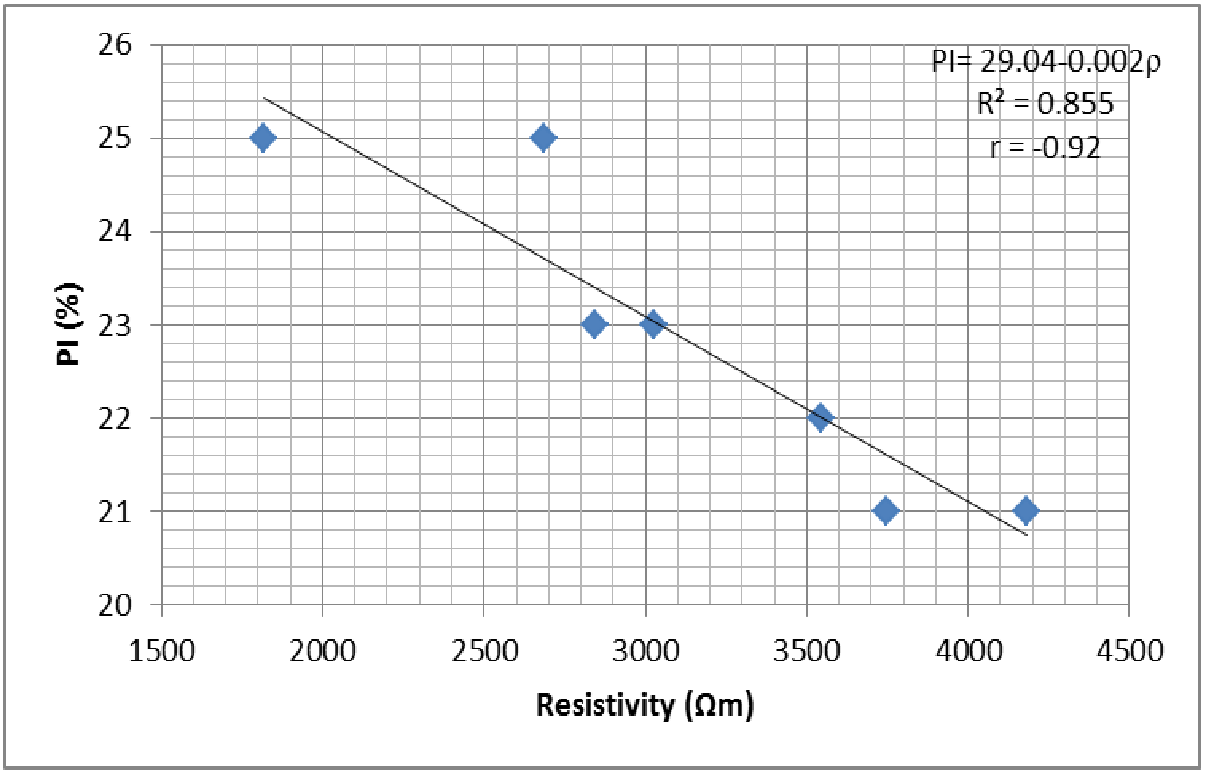

Figure 8: Relationship between Plasticity Index and layer resistivity at the study location.

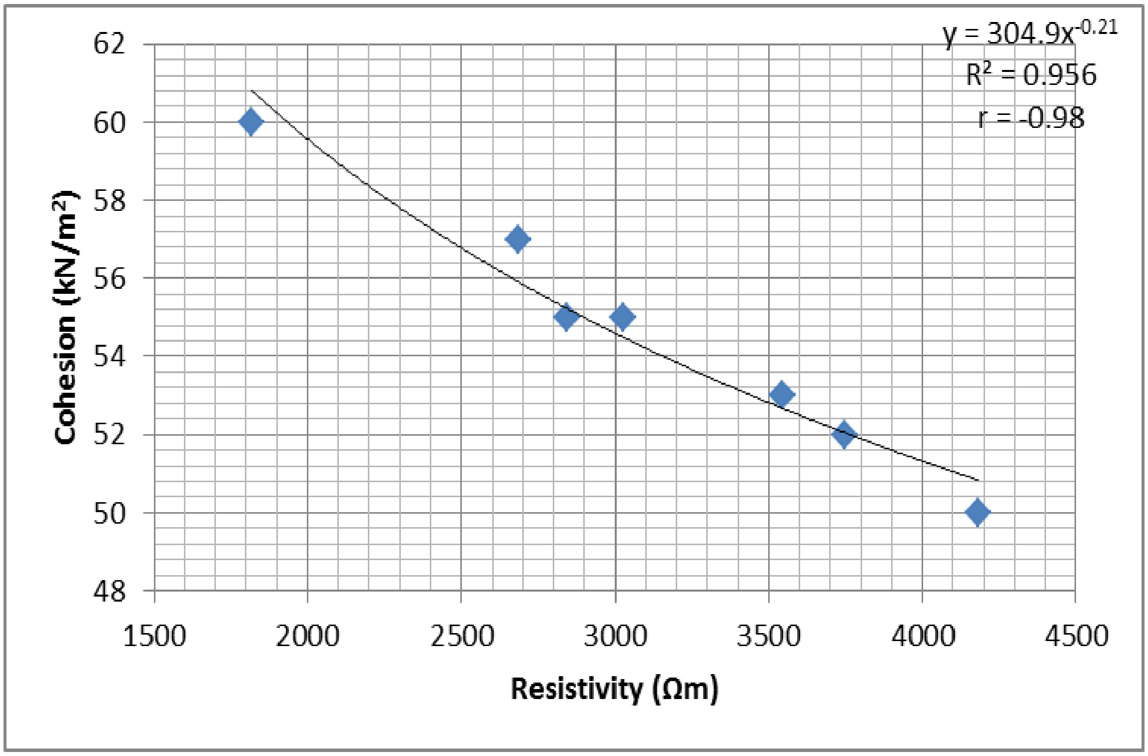

Figure 9: Relationship between Cohesion and Earth Resistivity at the Study Location.

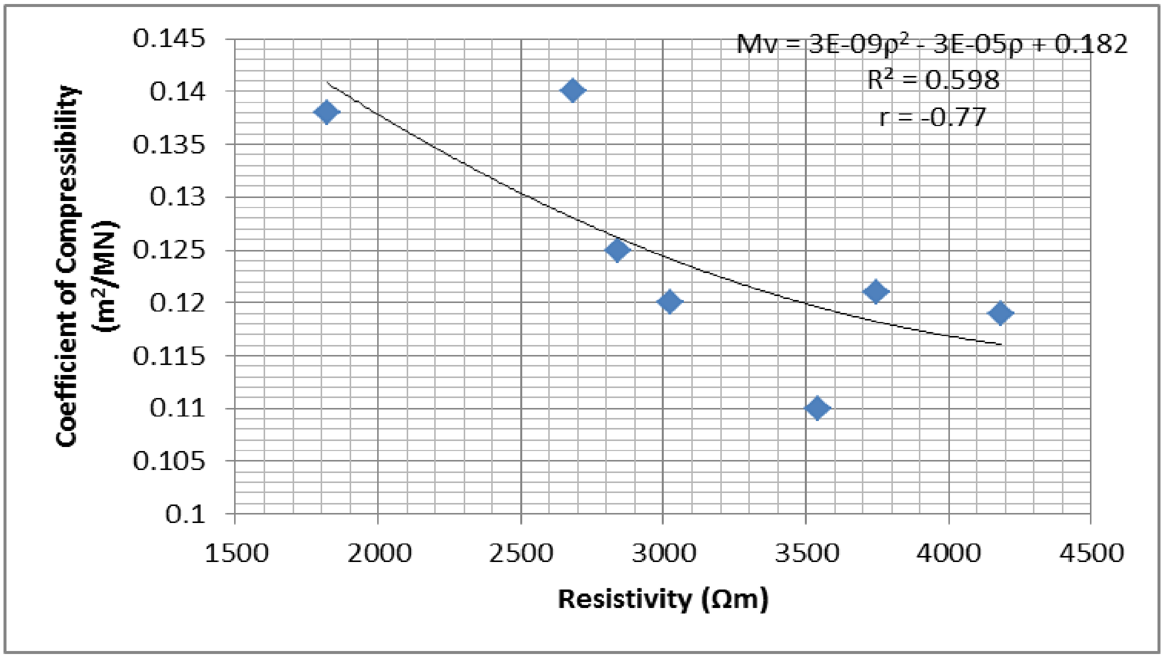

Figure 10: Correlation between ρ and M_v of Subsoils at the Study Location.

CONCLUSIONS

Quantitative correlations have been established between geoelectrical and geotechnical data acquired at the proposed dam-site. The strong positive correlation (r =0.95) established between the depths to the different lithologic units obtained from the resistivity sounding data and those measured in the boreholes indicates that 1-D geoelectrical sounding can provide close estimation of subsurface geology for foundation studies. The inverted resistivity values weakly correlate with the Standard Penetration Test (SPT) blow counts, N. The plot gives low correlation coefficient for linear regression of 0.21.

The empirical relationships of electrical resistivity with bulk density, plasticity index, cohesion and coefficient of compressibility gave correlation coefficients of 0.59, -0.92, -0.98 and -0.77 respectively. A consideration of these empirical relationships will allow engineering deductions to be made from resistivity data in site characterization and thus reduce the cost and duration of investigation appreciably.

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