

# Micro-Resistivity Measurements, Near-Surface Sequence Delineation, and Empirical Relationships with Engineering Geotechnical Parameters.

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## ABSTRACT

This paper establishes empirical relationships between subsoil electrical resistivity and geotechnical parameters in a typical basement complex terrain of Nigeria. Two pits and two trenches were dug to a maximum depth of 3.0 m along and upstream of a proposed dam axis. Core cuttings (undisturbed soil samples) were collected at the base of the pits/trenches and the coefficients of Compaction, Compressibility, and Permeability were determined. Down-the-hole micro-resistivity measurements using Wenner and Pole-Dipole (Half-Wenner) arrays were made at 0.10 m interval from top to bottom of the pits/trenches with inter-electrode spacing of 0.10 m. On a linear-log plot, both coefficients of Consolidation and Compressibility increase with increase in subsoil resistivity values. The established empirical equations gave correlation coefficients that vary from 0.70 to 0.96. Beyond a threshold permeability value of around  $4 \times 10^{-5}$  mm/s, subsoil permeability increases with decrease in soil resistivity while below the threshold value, soil permeability tend to increase with increase in resistivity. The study demonstrates that engineering geotechnical parameters can be estimated from resistivity measurements provided the relevant empirical equations had been established for the area of interest.

(Keywords: micro-resistivity, geotechnical parameters, empirical equations)

## INTRODUCTION

Civil engineering structures are founded on or within the earth. One of the priority considerations in the design of the foundation of such structures

therefore, is the pre-construction investigation of the proposed site in order to ascertain the fitness of the host earth material. The pre-construction investigation may involve direct mechanical boring, pitting, and trenching for subsoil sequence delineation, groundwater table mapping, soil sampling and geotechnical laboratory analysis. It may also involve non-invasive geophysical investigation.

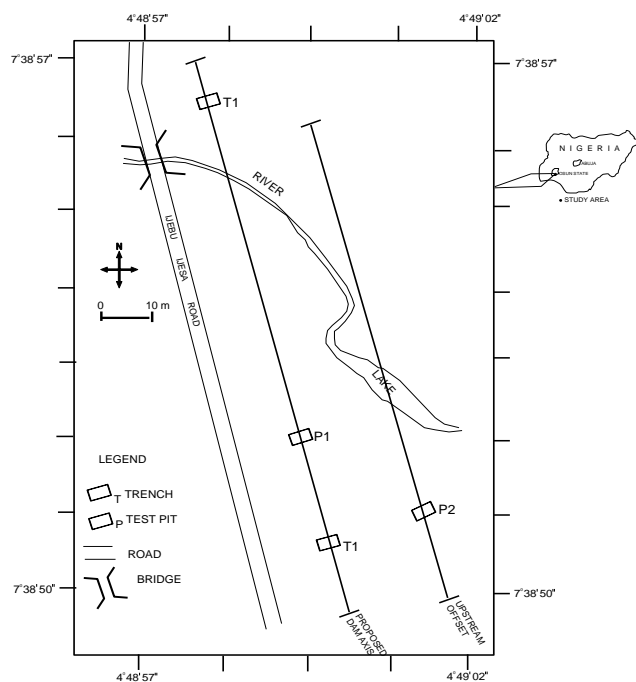
Where site investigation involves both geotechnical and geophysical investigations, it is often to reduce cost (by reducing the number of borings) and improve on the subsoil imaging through 1 and 2-D geophysical data gathering and modeling (Olorunfemi and Mesida, 1987; Barker, 1997; and Olorunfemi, 2008). The pre-construction investigation provides information on the subsurface lithologies and their thicknesses, identifies the competent bedrock and determines depths to its upper interface, establishes through geotechnical parameters, and examines the degree of competence of the foundation bedrock (Aina et al., 1996; Adewumi and Olorunfemi, 2005; and Idornigie et al., 2006).

In geotechnique, subsoil competence is evaluated through series of tests which include compaction, triaxial, and consolidation tests. In geophysical prospecting, the Compressional (P) and Shear (S) wave velocities in earth materials can be used to evaluate subsoil competence through the determination of the bulk modulus (Sjogren et al., 1979 and Dutta, 1984). A compact subsoil is characterized by reduced porosity and moisture content with consequent increase in resistivity. It should therefore be possible to use resistivity measurements as indices of subsoil competence.

A pre-construction geotechnical and geophysical investigation was carried out at a proposed dam

site (Figure 1) in Iloko-Ijesha, via Ilesha, in Oriade Local Government area of Osun State, Nigeria. The site is underlain by mica-schist of the Precambrian Basement Complex (Rahaman, 1989).

The basement rock has undergone variable degree of weathering and laterization. This study attempts to establish empirical relationships between geotechnical parameters and micro-resistivity measurements. Such empirical relationships can be very useful in rapid reconnaissance engineering geotechnical investigation.



**Figure 1:** Geophysical and Geotechnical Data Acquisition Map of Iloko Investigated Area.

## METHODOLOGY

Two trenches (T1 & T2) and two pits (P1 & P2) were dug along and upstream of the proposed dam axis as shown in Figure 1. The logging pits were 1.5 by 1.5 m wide while the trenches at the ends of the proposed dam axis were each 2.4 by 4.0 m. The pits were dug to a maximum depth of 2.8 m while the trenches to a maximum depth of 3 m. Disturbed soil samples were collected at 0.50 m interval in the pits while both disturbed soil samples and core cuttings (undisturbed soil

samples) were collected at the base of the pits/trenches. Compaction tests were carried out on the recovered soil samples. Triaxial and consolidated tests were carried out to determine the shear and consolidation characteristics of the soil. The permeability of the undisturbed soil samples was also determined.

Down-the-hole micro-resistivity measurements using Wenner and Pole-Dipole (Half Wenner) arrays were made from top to bottom of the pits/trenches with inter-electrode spacing and measurement interval of 0.10 m. For both arrays, the electrodes were aligned parallel to the ground surface with the mid-point of the potential dipole located along the direction of measurement (down the hole).

## RESULTS

### Micro-Resistivity Measurements and Subsoil Lithological Differentiation

Figures 2 – 4 correlate the Wenner and Pole-Dipole micro-resistivity profiles with the pits/trenches lithological logs along the proposed dam axis. The lithological units, depth ranges and layer resistivity values are contained in Table 1.

Three subsoils were delineated beneath the investigated sites within the upper 3.0 m. These include the topsoil with variable composition that ranges from sandy clay to clayey sand; laterite (hard pan) and clay/lateritic clay.

The topsoil has thicknesses that range from 0.45 – 0.7 m and resistivity values of 182 – 656 ohm-m for the Wenner array and 140 – 652 ohm-m for the Pole-Dipole array.

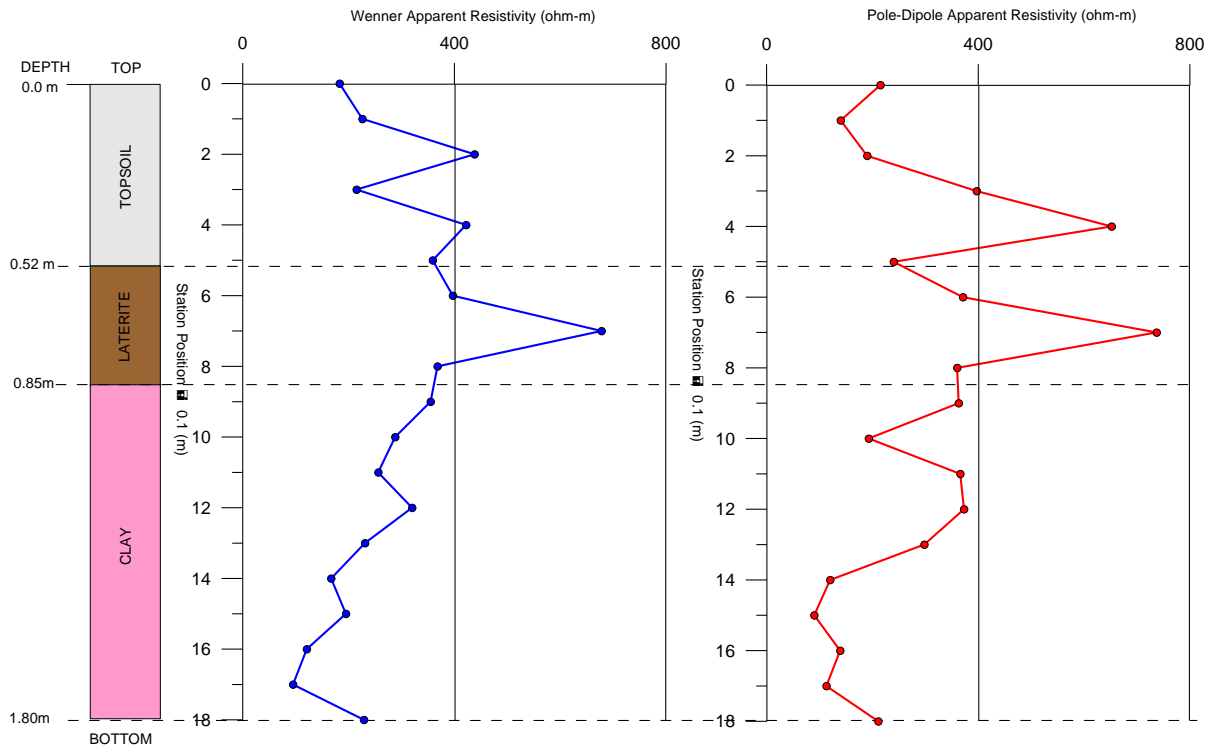
The lateritic layer has thickness of between 0.1 and 1.6 m and resistivity values of 678 – 2963 ohm-m and 602 – 2934 ohm-m for the Wenner and Pole-Dipole array, respectively.

The clay/lateritic clay layer has resistivity range of 95 – 542 ohm-m and 90 – 956 ohm-m for the Wenner and Pole-Dipole array, respectively.

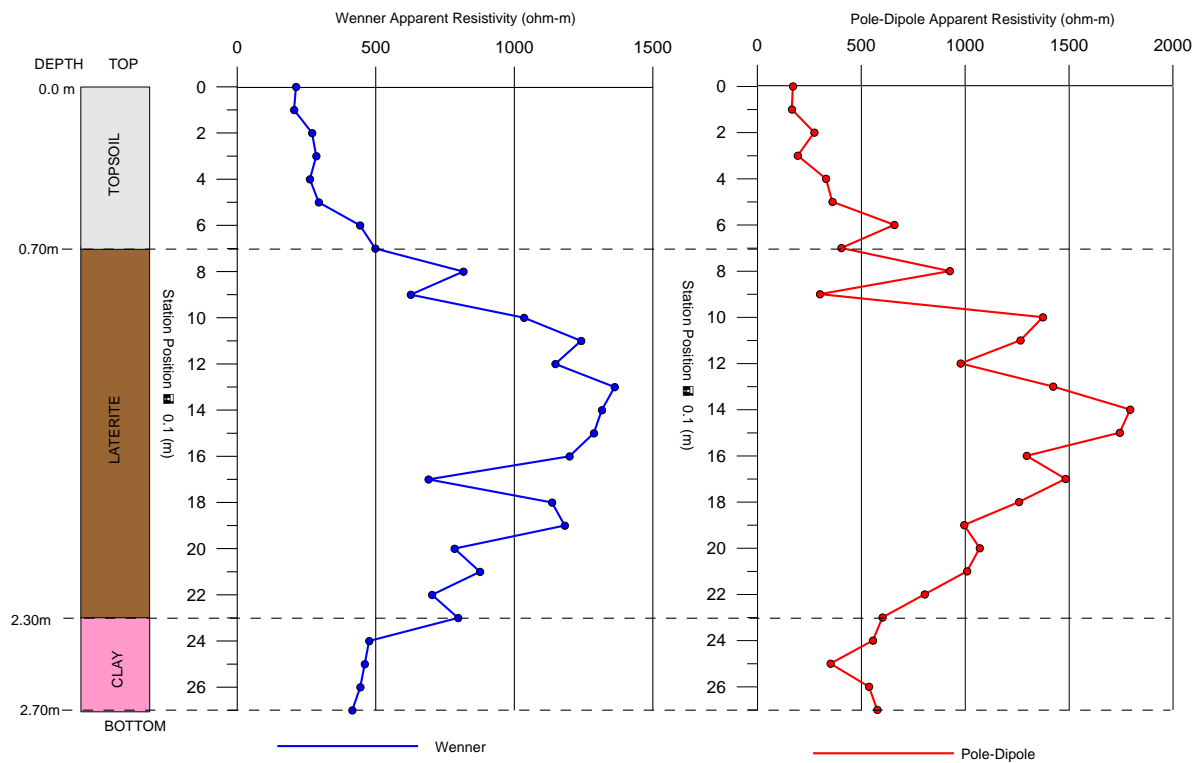
The resistivity profiles clearly resolve the near-surface layers due to small electrode spacing and sampling interval. The Pole-Dipole resistivity values are, however, in most cases slightly higher in amplitude than the Wenner equivalent.

**Table 1:** Near-Surface Lithological Units and Wenner and Pole-Dipole Micro-Resistivity Values along the Proposed Dam Axis.

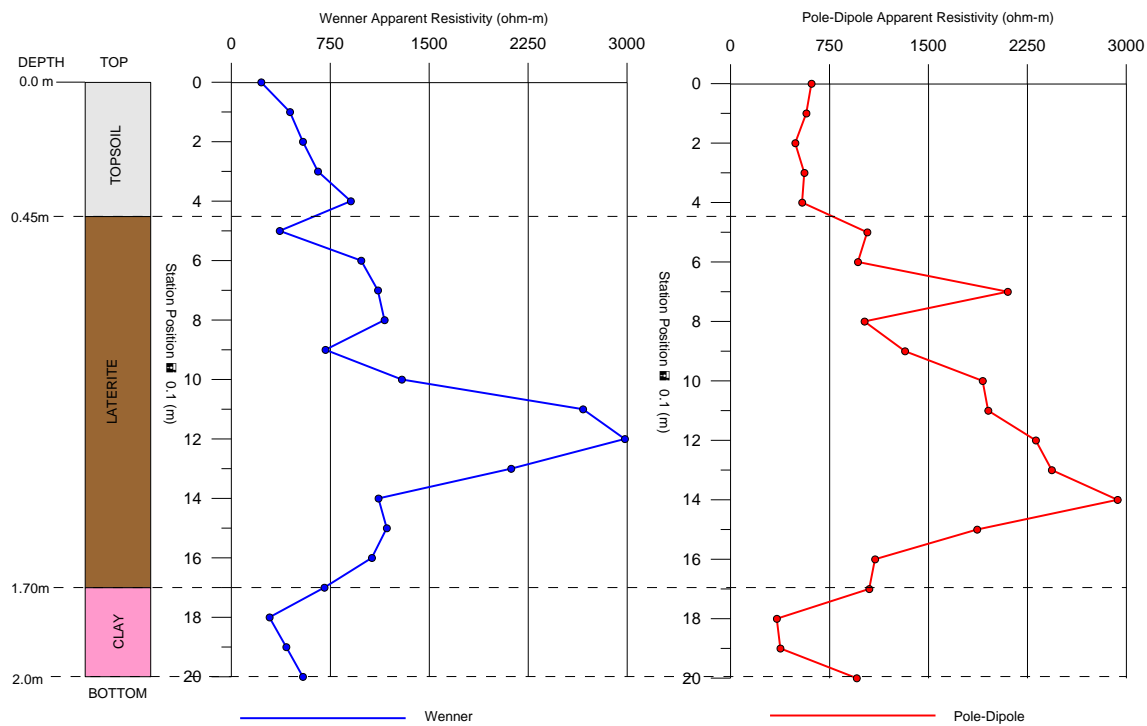
Sample Point	Lithology	Depth Range (m)	Micro-Resistivity Values (ohm-m)	
			Wenner	Pole-Dipole
Trench, T2	Topsoil	0 – 0.45	226 – 656	490 – 613
	Laterite	0.45 – 1.7	705 – 2963	965 – 2934
	Lateritic Clay	1.7 – 2.0	289 - 542	330 – 956
Pit, P1	Topsoil	0 – 0.52	186 – 438	140 – 652
	Laterite	0.52 – 0.85	678	737
	Clay/Lateritic Clay	0.85 – 1.8	95 - 368	90 – 373
Trench, T1	Topsoil	0 – 0.5	205 – 443	166 – 404
	Laterite	0.7 – 2.3	690 – 1362	602 – 1794
	Lateritic Clay	2.3 – 2.7	415 - 476	352 – 577



**Figure 2:** Correlation of Micro-Resistivity Profiles (Wenner and Pole-Dipole) with Pit 1 (P1) Lithological Log.



**Figure 3: Correlation of Micro-Resistivity Profiles (Wenner and Pole-Dipole) with Trench 1 (T1) Lithological Log.**



**Figure 4: Correlation of Micro-Resistivity Profiles (Wenner and Pole-Dipole) with Trench 2 (T2) Lithological Log.**

**Subsoil Engineering Parameters and Relationships with the Resistivity Values**

The coefficients of Permeability, Consolidation and Compressibility and the resistivity values at specific depth levels are shown in Table 2.

Figures 5 – 7 show the graphical representation of the relationships between soil resistivity and the coefficients of Consolidation, Compressibility and Permeability. On linear-log plot, both the coefficients of Consolidation and Compressibility increase with increase in resistivity values (Figures 5 and 6). This is not unexpected since consolidation/compression decreases porosity and volume of fluid saturation with consequent increase in resistivity. The relationships are described by the empirical equations:

$$C_v = 2.2101\text{Ln}(\rho_w) - 11.548 \quad (R = 0.96) \quad (1)$$

$$C_v = 1.3831\text{Ln}(\rho_{pd}) - 7.0047 \quad (R = 0.96) \quad (2)$$

$$M_v = 0.0627\text{Ln}(\rho_w) - 0.1548 \quad (R = 0.78) \quad (3)$$

$$M_v = 0.0353\text{Ln}(\rho_{pd}) - 0.0019 \quad (R = 0.70) \quad (4)$$

where  $C_v$ ,  $M_v$ ,  $\rho_w$  and  $\rho_{pd}$  are as defined in Table 2 and R is the regression correlation coefficient.

Figure 7 displays a somewhat curvilinear relationship between soil resistivity and coefficient of Permeability. It appears that beyond a threshold permeability value (around  $4 \times 10^{-05}$  mm/s) soil permeability increases with decrease in soil resistivity. Below this threshold, soil permeability increases with increase in soil resistivity. The second order polynomial equations are of the form:

$$\rho_w = -4E+11K^2 + 3E+07K + 160.48 \quad (R = 0.90) \quad (5)$$

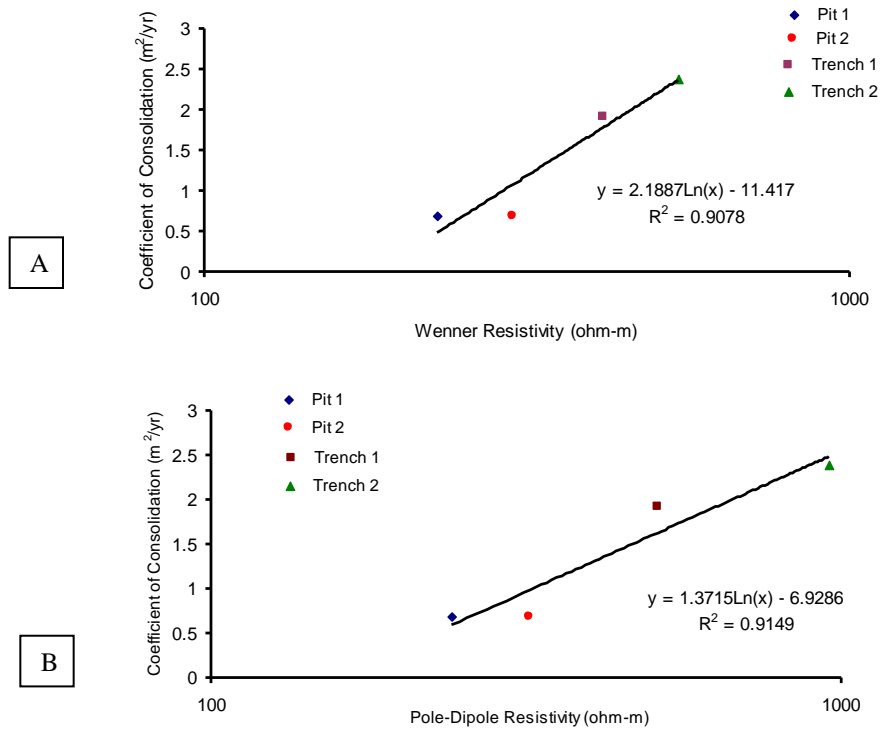
$$\rho_{pd} = -9E+11K^2 + 7E+07K + 15.44 \quad (R = 0.79) \quad (6)$$

where K is as defined in Table 2.

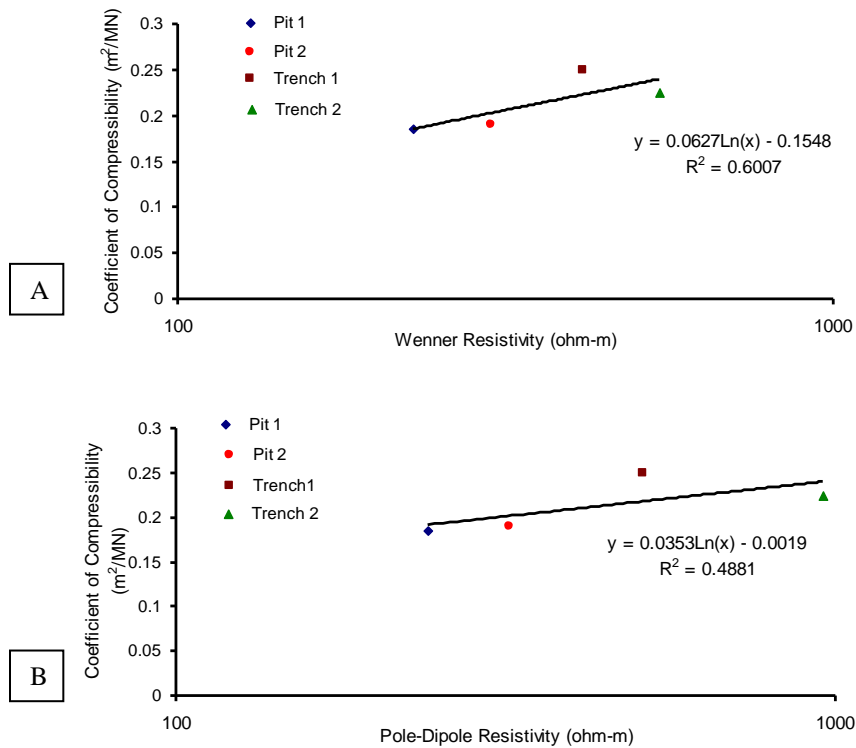
**Table 2:** The Coefficients of Permeability, Consolidation, Compressibility and Resistivity Values of the Soil Samples at the Base of Log Pits in the Investigated Area.

Sample Point	Depth of Core Cutting /Sampling (m)	Engineering Parameters			Micro-Resistivity, $\rho$ (ohm-m)	
		K (mm/s)	$C_v$ ( $m^2/yr$ )	$M_v$ ( $m^2/MN$ )	Wenner Array, $\rho_w$	Pole-Dipole Array, $\rho_{pd}$
Pit (P1)	1.80	$7.42 \times 10^{-05}$	0.669	0.186	229	241
Pit (P2)	2.80	$5.23 \times 10^{-06}$	0.692	0.190	300	320
Trench (T1)	2.70	$1.29 \times 10^{-05}$	1.916	0.250	415	510
Trench (T2)	2.00	$1.21 \times 10^{-05}$	2.383	0.225	542	956

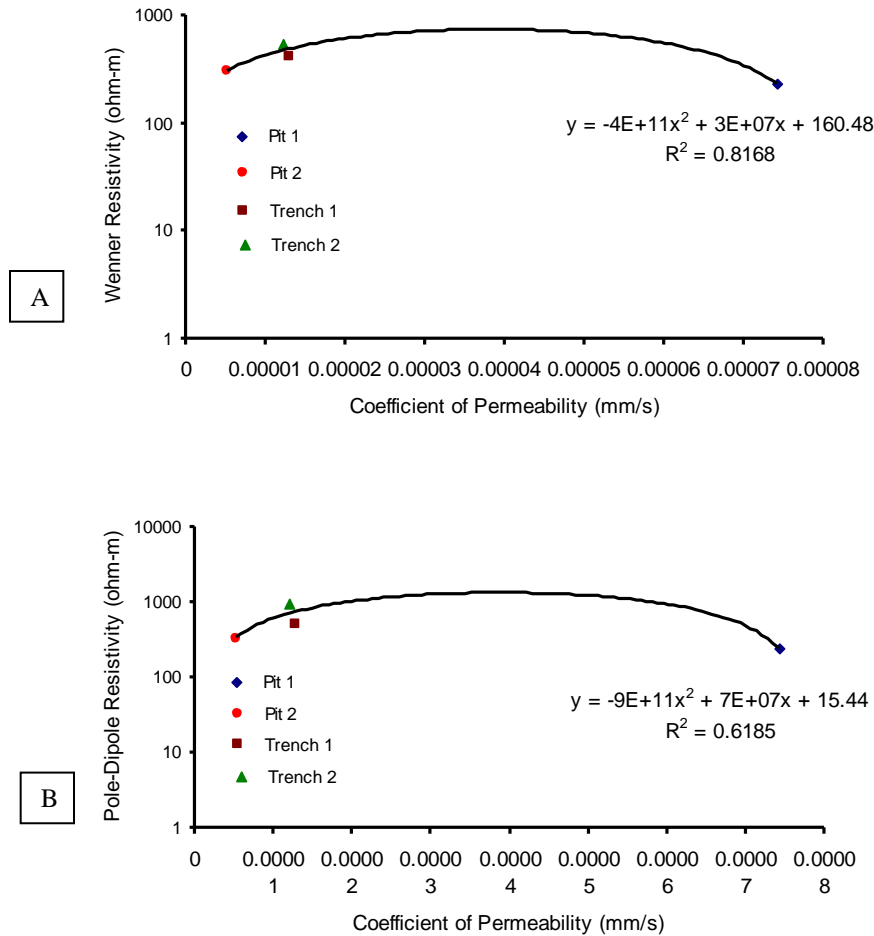
Note:  $K$ : Coefficient of Permeability  
 $C_v$ : Coefficient of Consolidation  
 $M_v$ : Coefficient of Compressibility



**Figure 5:** Plot of the Coefficients of Consolidation against (a) Wenner Resistivity and (b) Pole – Dipole Resistivity Values.



**Figure 6:** Plot of the Coefficients of Compressibility against (a) Wenner Resistivity and (b) Pole – Dipole Resistivity Values.



**Figure 7:** Plot of (a) Wenner Resistivity and (b) Pole –Dipole Resistivity Values against Coefficients of Permeability.

**CONCLUSIONS**

The subsoil resistivity values display a linear relationship with coefficients of Compaction and Compressibility. On a linear-log plot, both coefficients increase with increase in resistivity values. The empirical equations gave correlation coefficients that range in value from 0.70 to 0.96.

Beyond a threshold permeability value of around  $4 \times 10^{-5}$  mm/s, subsoil permeability increases with decrease in soil resistivity while below the threshold value, soil permeability tend to increase with increase in resistivity.

The above demonstrates that engineering geotechnical parameters can be estimated from resistivity measurements provided the relevant empirical equations had been established for the area of interest.

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