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An Investigation of the Relationship between Electrical Resistivity (Wenner and Schlumberger Arrays) and Geotechnical Parameters in Foundation Investigation in Basement Complex Area of Iloko, Osun State, Nigeria

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Abstract— *Electrical resistivity survey involving both micro-resistivity and Vertical Electrical Sounding (VES) measurements was carried out at Iloko. This was to enable the generation of empirical equation relating the electrical resistivity with engineering parameters. The micro-resistivity measurements obtained down the hole and the VES interpretation results were plotted against each of the engineering parameters (Coefficient of Permeability, Consolidation and Compressibility, Liquid limit, Moisture content, Plasticity index, and Dry density).The results show that only few of the engineering parameters (Coefficient of Permeability and Consolidation) display non-linear relationship with (VES) electrical resistivity. Both the Coefficient of Permeability and Consolidation decreases with increase in electrical resistivity. The relevant empirical formulae were subsequently generated*.

I. INTRODUCTION

The engineering properties of soil and rock are useful in designing foundation under static loading. Hydraulic characteristic of subsurface aquifers are important properties for both groundwater and contaminated land assessments, and also for safe construction of civil engineering structures. Properties of particular interest to the foundation engineer include compaction, permeability, consolidation-swell, shear strength, stress-strain modulus and poison’s ratio.

In addition, hydraulic conductivity/permeability (K), transmissivity (T), and storativity (S) are all commonly applied hydraulic parameters in flow modeling (Freeze and Cherry, 1979; Fitts, 2002). Application of field hydrogeological methods of assessment is a standard technique for evaluating engineering parameter such as permeability (K), storativity (S), compressibility (My), transmissivity (T), consoIidation (C) and shear stress (a).

Therefore, in this context, there is an attempt to generate empirical formulae that relate engineering parameters and electrical resistivity, which can provide rapid and effective technique for site foundation investigation and aquifer evaluation.

Site Description

The survey area is located at Iloko in Oriade Local government Area of Osun State. The map of Nigeria showing Iloko and its environs is shown in figure 1.

The area lies between longitudes 7 038 50’ and 7 038’ 57” and latitudes 4 048’57”and 4. °49’ 02”..

The area is accessible through good roads and footpath networks to most of the area studied

Objectives of Survey

The main objective of this study is to generate empirical formulae between electrical resistivity and engineering parameters. Others include.

1) To delineate the subsurface layers and determine their resistivities and thicknesses

2) To evaluate the competence of the near surface soil on which engineering foundation is expected to be founded.

General Information on Resistivity

Resistivity is measured using an array of electrodes that measure the bulk resistivity of the soil around and between the electrodes. Bulk resistivity represents the total electrical resistance contributed from all sources (grains, matrix material and water). The most common electrical method used in hydrogeologic environmental and site investigation is the electrical resistivity method.

Electrical Conduction in Soils

In order to measure the electrical resistivity of soil, the electrical resistance must first be determined. This is accomplished by measuring the voltage (V) of a known current (I) across a pair of electrodes. Hence

$$R=V/I \quad (1)$$

Where R is resistance in ohms. I is current (A) in amperes and V is Voltage (V) in volts. The measured resistance is not a unique material property but a function of the cross-sectional area and length of the material being measured. Hence, resistivity, p, can be defined as

$$\rho = (A/L)\, R = I/\sigma \quad (2)$$

Where A is cross sectional area (m2),

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L is length (m) and σ is conductivity.v This formula shows that resistivity and conductivity inversely related (Campenella and Weemees 1990). Resistivity is measured in ohm meters while conductivity is measured in ms/meter or m mho/ meter.

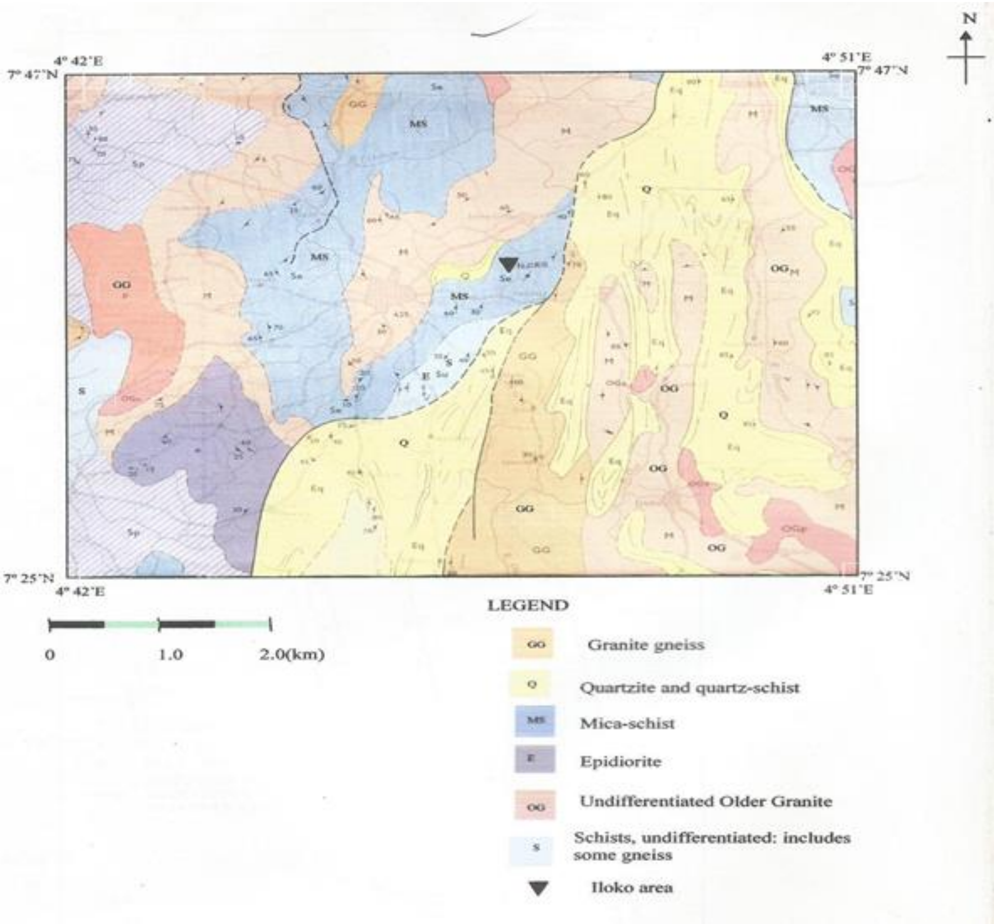

Fig. 1. The geological map of Iloko and its environs.

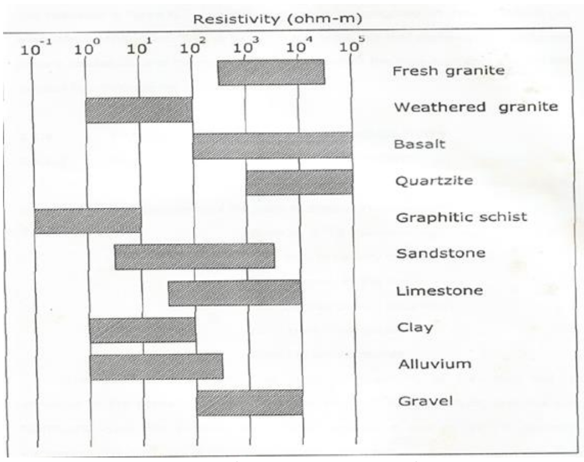

Fig. 2. Approximate Range of Resistivity values of common Rock Types (After Telford, 1990).

II. METHODS OF STUDY

Data Acquisition and Presentation Field Procedure

The electrical resistivity data ware acquired using ABEM SMS — 300Terrameter and SAS —2000 Booster, 2 pairs of electrode (2- potential and 2 — electrical electrode), connecting cables and hammer.

Survey Techniques

Two survey techniques are used in the electrical resistivity method,. They are
(i) Horizontal profiling
(iii) Vertical electrical sounding (VES)

The horizontal profiling techniques measures lateral variations in ground resisitvity. This technique is very useful in rock boundary mapping, fracture, joints and fault detection.

In the vertical electrical sounding technique, vertical variations in ground resistivity are measured with respect to a fixed center of array. The technique is suitable for subsurface layer delineation and detection of structures and faults.

Down the hole, micro resistivity measurements were obtained using Wenner and schlumberger configurations. These measurements were made at 10cm interval from top to bottom of the pit and trenches located in the survey area and data were presented as profiles. Micro resistivity values were plotted against engineering parameter in order to establish empirical formulae between electrical resistivity and engineering parameters.

For vertical electrical sounding, the schiumberger array was adopted and five VES points were occupied. The recorded data were plotted as depth sounding curve and these were

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qualitatively and quantitatively interpreted. The former involved visual inspection while the latter was effected by partial curve matching and computer iteration techniques.

Different types of VES curve can be obtained. These include, QH, Ak, type curve e.t.c. (See Figure 3)

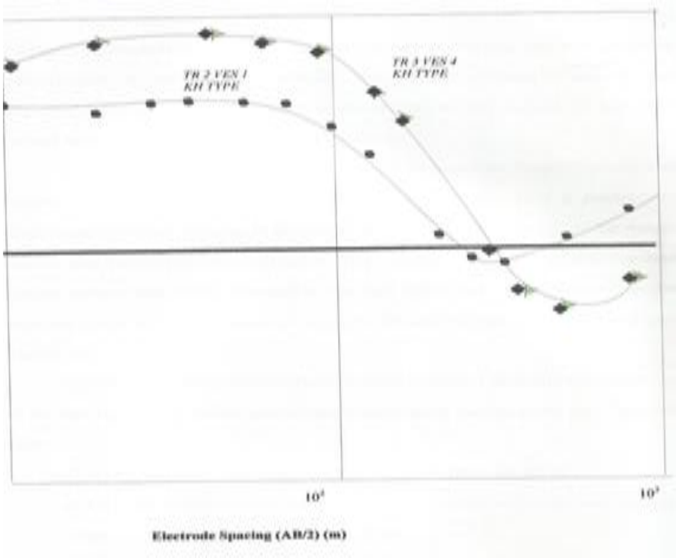

Fig. 3. Typical qh and ak Type curves.

Data Interpretation

The interpretation of the VES data was quantitative. The partial curve matching interpretation technique was employed in carrying out a quantitative interpretation of the sounding curves. The method involves a segment-by- segment matching of the field with a set of theoretically calculated two-layer curves and their corresponding auxiliary curves.

The field was superimposed on this set of two-layer master curves and moved around while keeping the respective axis paralle[, until a satisfactory match was obtained with one of the model curves and the origin (i) of the model curves was marked on the field curve. The resistivity ratio (ki) of the matched master curves was noted. Thereafter, the field curve was superimposed on the auxiliary curve with the cross-point (+,) and the appropriate auxiliary curve was traced out.

The vertical coordinates of the first cross point (+,) gave the thickness (m) of the first layer while the horizontal coordinates gave the resistivity (p) of the first layer:

The second layer resistivity (p) was calculated from equation:

$$\rho_2 = \rho_1 \times K_1 \quad (3)$$

Where ρ_2= resistivity of the second layer, ρ_1 resistivity of the first layer, K_1 = resistivity ratio of the master curve that matched the first segment of the field curve.

The second segment of the curve was matched when the K1 auxiliary curve was kept at the origin of the two-layer model curves and the axes were kept parallel until a satisfactory match was obtained. The new origin was marked on the field curved and the reflection coefficient K2 gave the replacement resistivity (P2g.) and the replacement thickness (h2r) of the second layer. The third layer resistivity was obtained from the equation

P3 =P2XK2.. (4)

Where

p3 resistivity of the third layer, P2 = resistivity of the second layer

K2 resistivity reflection coefficient of the master curve that matched the second segment of the field curve.

To obtain thickness (h2) of the second layers, the first cross point (i) was placed at the origin of the auxiliary curve while the axes curve kept parallel, the thickness ratio (Dn IDr)1 value was read of the location of the second crosspoint(+ 2). The second layer's thickness was obtained from the equation.

h2=(Dn)Xh1 (5)

Dr1

Where h1 thickness of the first layer

h2 thickness of the second layer

Dn /Dr1 is the value obtained at the location of the second cross-point.

For the quantitative interpretation of depth sounding curves with more than three layers, the procedures described above were repeated until the curves were completely matched.

Summation of successive thicknesses gave depths to resistivity interface. The layer resistivity values and thicknesses obtained from the vertical electrical soundings are presented in table1.

TABLE 1: Vertical Electrical Sounding Results

STATION POSITIONS	**DEPTH(M) D1/D2/D3**	**LAYER Resistivity P1/ p2/ p3/ p4 (ohmm)**	**GPS**	**curve**
TRENCH 1 TRAVERSE 2 VES 1	1.9/6.0/30.3	437/666/65/277	N07^{0}38.855^1 E004^{0}47007^1	KH
PIT 1 TRAVERSE 2 VES 5	0.5/3.2/25.7	186/110/87/994	N07^{0}38.874^1 E004^{0}48.999^1	KH
PIT 2 TRAVERSE 2 VES 8	0.4/1.9/25.3	1123/186/69/1808	N07^{0}38.887^1 E004^{0}48.991^1	QH
TRENCH 2 TRAVERSE 2 VES 14	1.3/5.0/17.3	40/90/48/1131	N07^{0}38.855^1 E004^{0}48.978^1	KH
PIT 4 TRAVERSE 3 VES 4	0.2/5.7/21.8	578/2022/103/180	N07^{0}38.501^1 E4^{0}49.04.0^1	KH

III. RESULT AND DISCUSSION

Geoelectric Sections.

In geoelectrical section, four geologic layers were delineated beneath the axis. The topsoil is composed of clay, sandy clay, clayey sand and laterite with layer resistivities of 40 — 1123 ohm-rn and thicknesses between 0.2 and 1 .9m. The second layer, which is lateritic clay, has resistivity values of 186 — 2021 ohm-rn with thicknesses between 1.0 and 6.0m

The clay, sandy clay weathered layer has resistivity values varying from 50 to 103 ohm-rn and thicknesses of between 16.1 — 28.5m. The fourth layer consists of the basement bedrock with resistivity values of 277 — 1808 ohm-rn.

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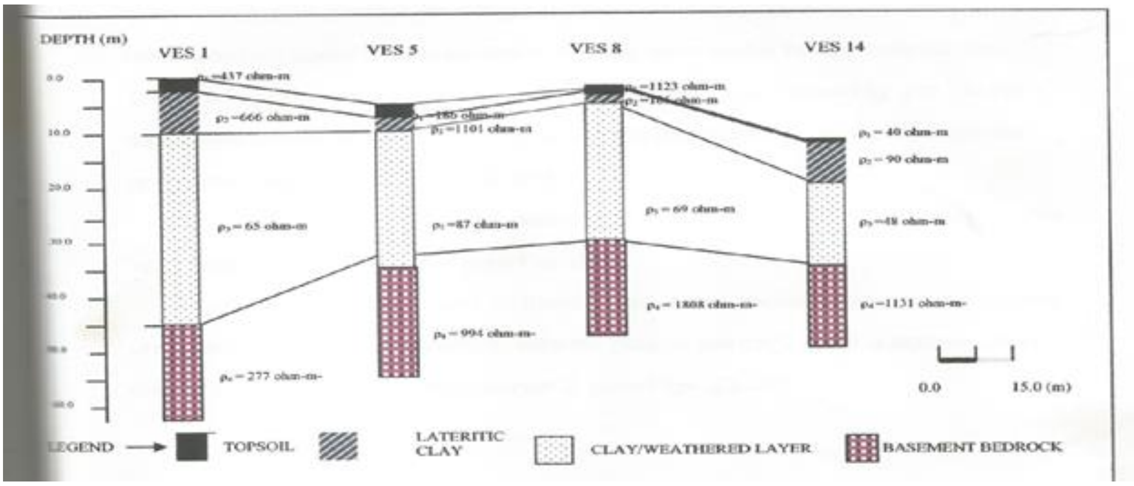

Fig. 4. Geoelectrical section along TR2.

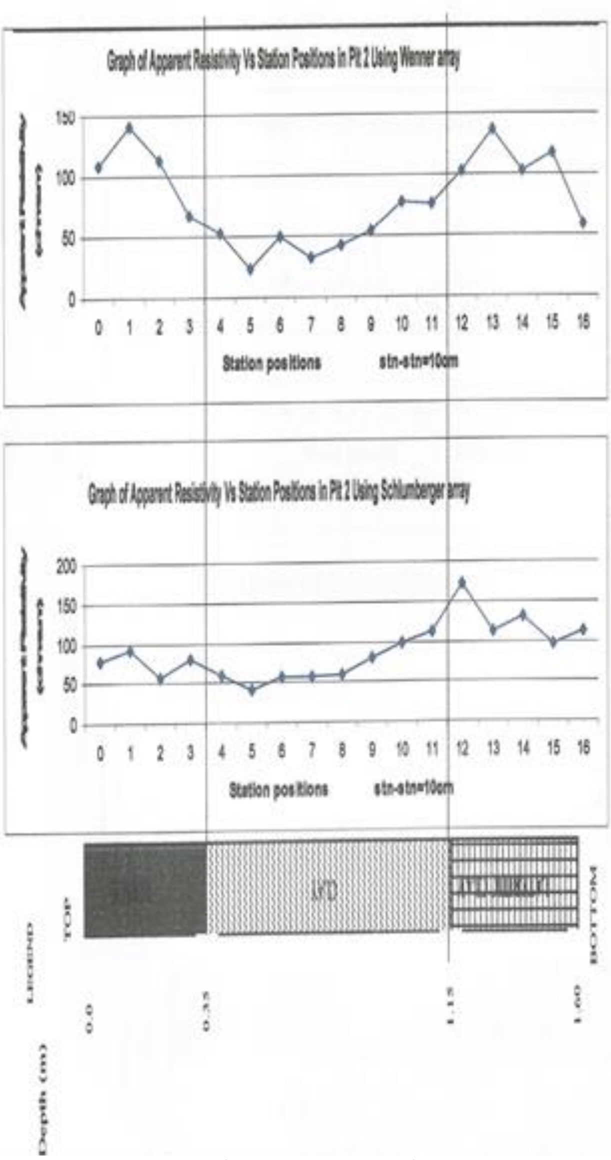

Fig. 5. Lithological log of micro-resistivity profiles using Wenner and Schlumberger array at pit 2 in Iloko Investigated area.

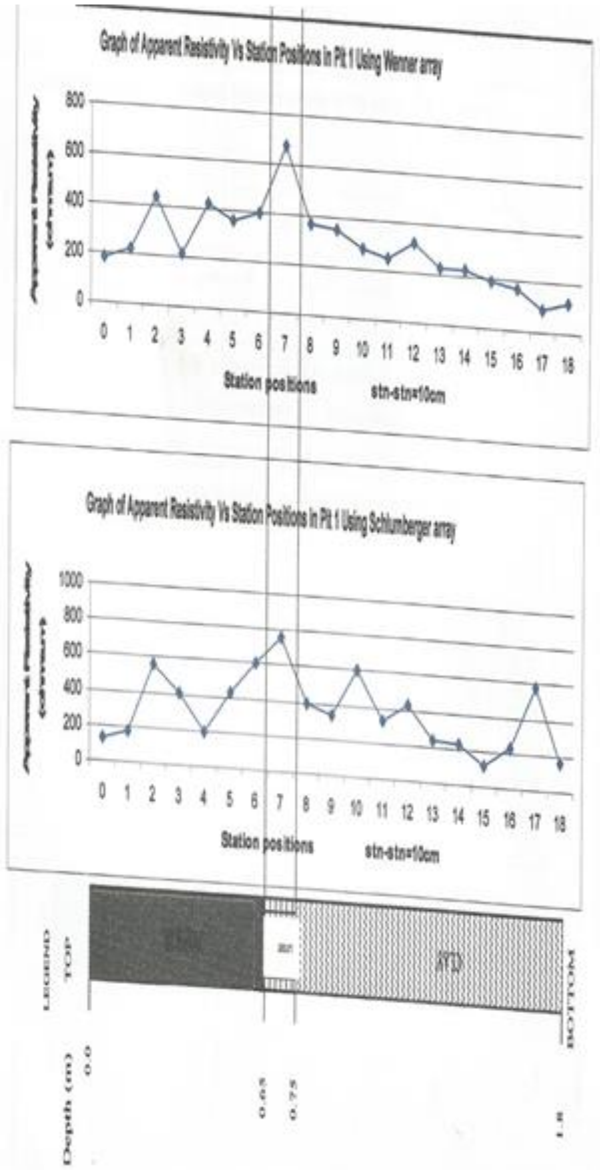

Fig. 6. Lithological log of micro resistivity profiles using Wenner and Sclumberger array at pit 1 in Iloko investigated area.

Micro-Resistivity Measurements.

Micro-resistivity measurements that were made using schiumberger array are presented as profiles (see Figures 5-6). At Pit 2, three layers were delineated-an upper topsoil underlain by clay layer and a bottom lateritic clay. The lithological interfaces occur between stations 1 and 9 (see Fig. 5). At Pit 1, three layers were delineated-an upper topsoil underlain by thin layer of laterite and bottom lateritic clay (see Fig. 6).

At Pit 4, three layers were delineated-an upper topsoil underlain by lateritic layer and a bottom hard pan.

At both trenches I and 2, three layers were delineated-an upper topsoil, underlain by laterite in trench I, lateritic clay in trench 2, and a bottom lateritic clay in trench 1, and laterite in trench 2.

The vertical electrical sounding resistivity data were also related to engineering parameters such as Moisture content, Dry density, Plasticity index, Liquid limit, Coefficient of Consolidation, Permeability and Compressibility.

Some of the engineering parameters do not show appreciable relationship with (VES) electrical resistivity and these are Coefficient of Compressibility, Dry density, Plasticity Index, Moisture content and Liquid limit.

Meanwhile, nonlinear relationship exists between Coefficient of Permeability and Consolidation with (VES) electrical resistivity.

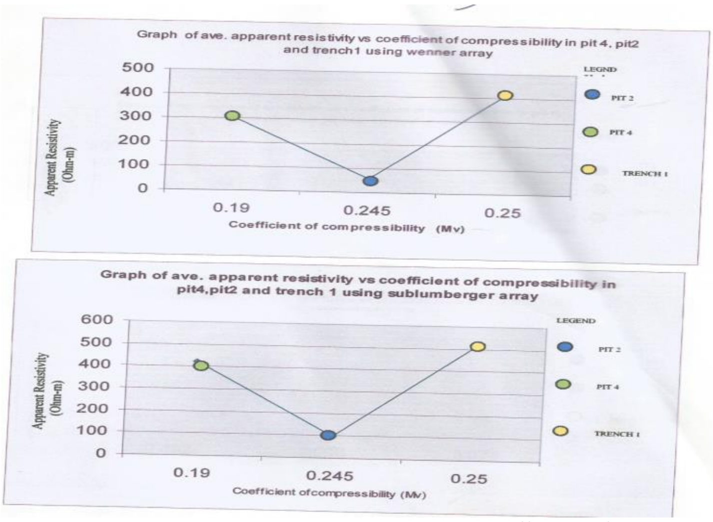

Fig. 7. Graph showing the Relationship between Coefficients of Compressibility and Micro—Resistivity measurements using Wenner and Sublumberger Array in loko Investigated Area.

Coefficient of Permeability

The coefficient of permeability (K) exponentially decreases with increases in resistivity. The generalized equation between K and p is of the form.

p = Ae< (after Singh, 2005.)

Where p = resistivity of the soil

K = coefficient of permeability

A and B are constants.

These constants can be derived as follows;

From the graph,

2020 = AeB':°0000047) (6)

666 = AeBOOOOl29) (5)

186 = Ae6°°oo°°255 (6)

From equation 56

A= 2020 = e°°°°°°478 (7)

recall equation 5

666 = Ae°°°°°°129

— 666 = 2020 x e°°°°°°1298 / e°°°°°°47

666 OOOOO1298

2020 e°°°°°°478

0.329703 = e°°°°°°1298 +

0.329703 = e0000001298 - 0.00000478

0.329703 = e°°°°°°

Taking natural logarithms of both side

7/

Taking natural logarithms of both side

ln(0. 329703) =

-1.10956303 = 0.0000082B

0.0000082B = -1.10956303

B = -1.10956303

0.0000082

B = -135,313

B = -1.35 x 60

Recall equation 5

186 = Ae°°°°°°255 X -135313

186 = Ae3°5

A = 186

e34505

A = 186 = 5861.96

0.03173

A = 5862

A = 5.862 x103 (8)

Therefore, the equation existing between electrical resistivity and coefficient of permeability is:

p = 5.862 x e135313k (9)

Coefficient of Compressibility

There is a non-linear relationship between both micro-electrical resistivity and VES data with coefficient of compressibility

Liquid Limit

This engineering parameter does not give any linear relationship with electrical resistivity (VES).

IV. CONCLUSION

The present study reveals that both micro-electrical and vertical electrical sounding (VES) resistivity values inversely vary with coefficient of consolidation and permeability.

The established empirical formulae between electrical resistivity and

coefficient of permeability (K) and consolidation (Cv) are;

p = 5.862 x 10 e3S3l3k

p = 3.029 x I 03e°9065 Cv

Where p = resistivity of the soil

K = coefficient of permeability

Cv coefficient of consolidation

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There are no well defined relationship between the other engineering parameters and electrical resistivity. Such engineering parameters are plasticity index, moisture content, dry density e.t.c

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