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Geophysical Studies for Foundation Investigation in Basement Complex. Case Study of Iloko, Osun State, Nigeria

Ayodele, Moses Oyewole[1]; Adiela, U.P[2]; Yikarebogha, Y[3]

[1]Department of Geology, University of Port Harcourt, Nigeria
[2]Department of Petroleum Engineering, Nigerian Agip Oil Company, Port Harcourt, Nigeria
[3]Department of Drilling, NPDC, Benin, Nigeria

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

Geophysical methods generally provide very effective means of water content estimation, water qualify assessment and mapping of depth to the water table and bedrock. They are also used for mapping of subsurface structures like joints, fissures, shear zones, tracing of fresh, saline water interface and in the investigation for artificial groundwater recharge.

Although, various geophysical methods currently are being applied to explore and assess water resource as well as site foundation investigation, the electrical resistivity method remains the most powerful and cost-effective. Use of Wenner (Horizontal profiling) and schiumberger array (Vertical electrical sounding), and also, electrical tomography techniques have become very common in groundwater exploration and contamination studies. There are standard Published direct and indirect interpretation techniques specifically for VES data (e.g. Jupp and Vozoff, 1975, koefoed, 1979).

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

Review of Previous Study

Olorunfemi and Mesida (1987) used the electrical resistivity method to investigate a construction site in Ile-Ife area and the resistivity interpretation.

Ako and Osundu (1985) showed that a correlation exists between the measured Dar- Zarrouk parameters and hydrological parameters such as transmissivity, permeability and the specific yield of the aquifer mapped. They concluded that a zone with highest traverse resistance (T) values corresponds to the zone with the highest borehole yield.

Olorunfemi and Ajayi (1999) used the electrical resistivity method and borehole logging to delineate groundwater seepage into mill furnace and basement foundation in Osogbo area. It was concluded that the water seepage was primarily due to groundwater level increase during the raining season.

The topsoil is composed of clay, sandy clay, clayey sand and laterite, whereas the weathered layer is composed of clay which resulted in the failure of the foundation of the building by differential settlement the differential settlement precipitated by the flow of the clay at depth.

Recently, attempts have been made by researchers also to obtain hydraulic parameter from resistivity measurements (e.g. Brace, 1977; Biella et al. 1983). In porous media and alluvial1 transmissivity formation factor and permeability can be estimated using empirical I semi-empirical correlations (Kelly, 1977; Heigold et al. 1979; Schimschal, 1981; Urish 1981; Chen and Hubbad et al. 2001)

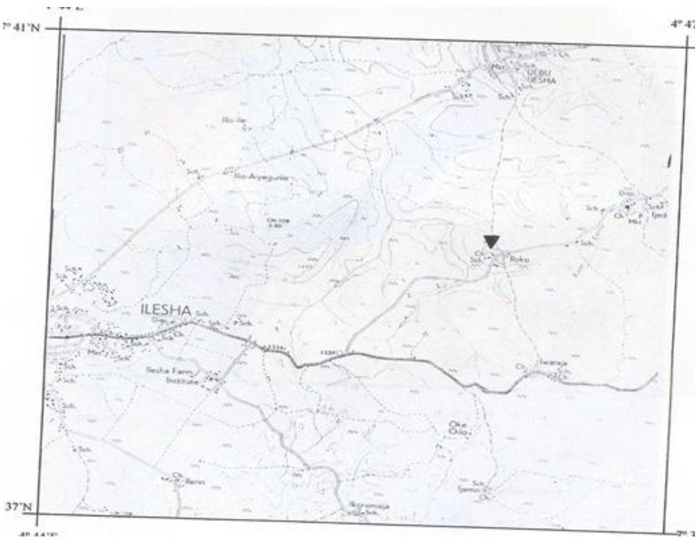

Fig. 1. Map of Ilesha South-East showing Iloko, the study Area and surrounding towns.

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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.

Methods of Study

The engineering parameters (coefficient of permeability, consolidation, and compressibility, liquid limit, moisture content, plasticity index, specific gravity) that were used in the survey area were provided geophysical lab. These data were determined at pit sites located along proposed main dam axis and two offset axes .

Using Wenner and Schlumberger arrays, micro-resistivity measurements were obtained down the hole. Data were presented as profiles and different lithologic boundaries were identified.

For vertical electrical sounding, schlumberger array was adopted. Five VES points were occupied and quantitatively interpreted by a method involving partial curve matching.

The VES interpretation results were later plotted against engineering parameters at specific depth. These were used to generate the empirical formulae between electrical resistivity and engineering parameter.

Geology of the Study Area

lloko area is underlain by the Pre-Cambrian Basement Complex rocks of Nigeria. Varying depths of weathered profiles which are in situ are observed and they lie directly over the fresh basement rock .The major rock types in the study area are granite —gneiss, quartzite/quartz schist, mica schist and amphibolites.

Granite Gneiss

This rock types was encountered in the south-western part of the studied area. It covers about 8% of the studied area. The granite gneiss is pinkish in colour. It is medium to coarse grained in texture. The rock contains feldspar, mafic minerals like pyroxene e.t.c. It is strongly foliated and its foliation is defined by mineralogical banding which is an alternation alkalis feldspar and mica minerals.

The granite gneiss in Iloko and its environs has been variously migmatised. The degree of migmatisation is not as strong as those of migmatitegneiss- quartzite complex of Rahaman (1976, 1988) classification of the Nigeria Basement Complex rocks. These granite gneisses are therefore probably ounger due to their granite composition, the granite gneisses are metamorphosed granites

Quartzite/Quartz Schist

This rock type is present along the Ilesha -Ijebu-Ijesha road, about 600 m along a footpath leading to Iloko- ljesha off Ilesha -Ijebu -Ijesa. This outcrop is low lying and has been quarried. They are also found intercalated within mica schist on a centimeter to decimeter scale, such that when more susceptible mica has been weathered off, it leaves behind the more resistant quartz rich bands.

The quartzite/ quartz schist range from white to purplish brown and show a resistant to weathering than the associated mica schist which occurs within. The pelitic mineral rich bands exhibit a schistose foliation which is defined by parallel alignment of platy mica minerals. A second type of foliation is parallel to the schistose and is defined by the lithologic banding in the rock.

Furthermore, the outcrop of the ridge has undergone more than one episode of deformation. The pelitic band shows this more than the pssammitic bands. Slickensides, striations and mineral lineation are common on the foliation surfaces associated within quartzite/quartz schist. This indicates that the rock has probably undergone a shear deformation episode. The rock is metamorphosed sandstone.

Mica Schist

This also covers a substantial amount of the area. It has undergone a high degree of chemical weathering such that most outcrops encountered are recognized based on the characteristic features of the weathered sample. It exhibits a characteristic low dip to the west, It usually occurs as low lying exposures along footpath and road cuts. It exhibits lateral and vertical variations in mineralogy and texture, which result in various types of the mica schist. It occurs with quartz rich bands intercalated within it. These quartz rich bands are usually on a millimeter to metric scale. The mica schist in the area is believed to be metamorphosed clay rich and sandy sediments.

II. METHODOLOGY

The Resistivity Method

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

$$R=V/I \tag{1}$$

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

$$\rho = (A/L)\ R = I/\sigma \tag{2}$$

Where A is cross sectional area (m2), L is length (m) and σ is conductivity.

This formula shows that resistivity and conductivity inversely related (Campenella and Weemees 1990). Resistivity

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is measured in ohm meters while conductivity is measured in ms/meter or m mho/ meter.

Basic Principle

The electrical resistivity method measures the bulk resistivity of the substance to determine geologic structure and I or physical properties of geological materials. An electrical current is introduced directly into the ground through current electrodes. The current and the potential electrodes are generally linearly.

The bulk resistivity of the soil is a function of both the resistivity of the pore fluid and the soil particles with their arrangements. Electrical measurements indicate not only the changes in the electrical properties of the soil and pore fluid due to the amount of total dissolved soils in the pore fluid, or the fluid conductance; but also due to the changes of soil type, or surface conductance (Weller *et al*. 1991).The two most important though related parameters in the electrical resistivity methods are the conductivity (a) and the resistivity (p).

σ =1/p (3)

Where a = conductivity which is siemens per meter (s/m).

ρ = Resistivity in ohm-meter (R-m)

The large contrast in resistivity between ore bodies and their host rock is exploited in electrical resistivity prospecting, especially for minerals that occur as good conductor. Approximate range of resistivity values of common rock types

Data Acquisition and Presentation

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 resistivity. 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.

Different types of VES curve can be obtained. These include A — type, Q — type,. (see figure 2).

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 curve. The field was superimposed on this set of two-layer master curves and moved around while keeping the respective axis parallel, 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.

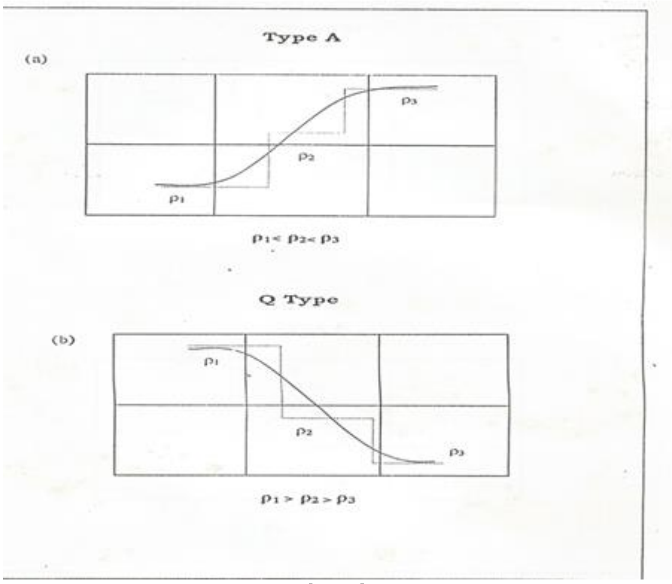

Fig. 2. Typical a and q type curves.

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:

$\rho_2 = \rho_1 \text{ x } K_1$ (1)

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 (2)

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 (3)
Dr1

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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 table 1.

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

Micro-Resistivity Measurements.

Micro-resistivity measurements that were made using Schiumberger array are presented as profiles 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. At Pit 1, three layers were delineated-an upper topsoil underlain by thin layer of laterite and bottom lateritic clay.

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 and laterite in trench 2.

Micro-Resistivity and Geotechnical Parameters

The micro-resistivity measurements were related with geotechnical parameters at Pit 4, Trench 1 and Pit 2. The geotechnical parameters used and the plot of micro-electrical resistivity against Coefficient of Compressibility does not give any definite relationship. For Coefficient of Consolidation and Permeability, the micro-electrical resistivity value decreases with increase in both Coefficient of Consolidation and Permeability.

However the Liquid limit, Plasticity Index and Moisture content increases with increase in micro-electrical resistivity. Meanwhile, the micro-electrical resistivity decreases with increase in Dry density.

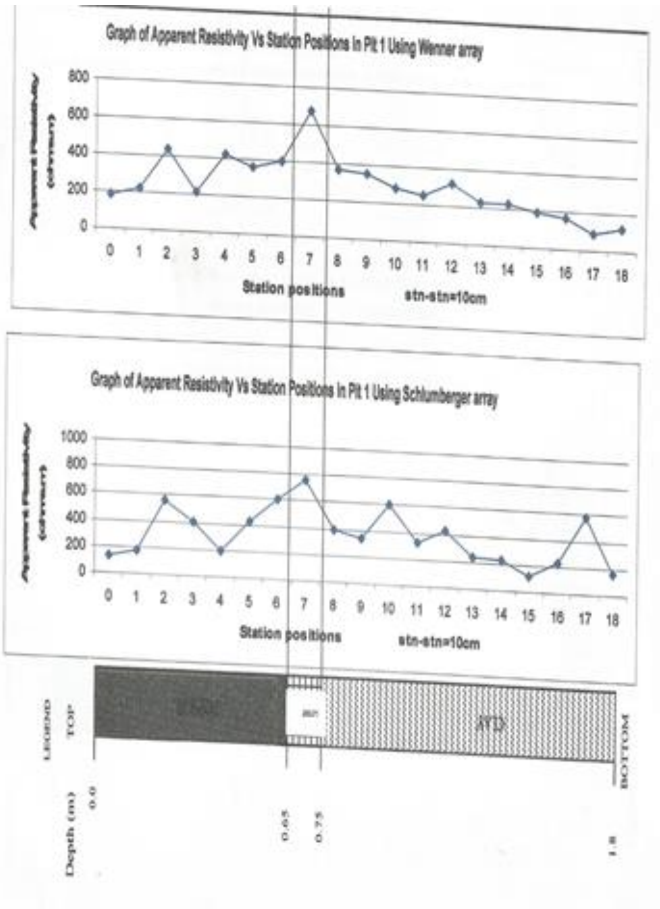


Fig. 3. Lithological log of micro resistivity profiles using Wenner and Sclumberger array at pit 1 in Iloko investigated area.

Geotechnical Parameters and VES Data

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.

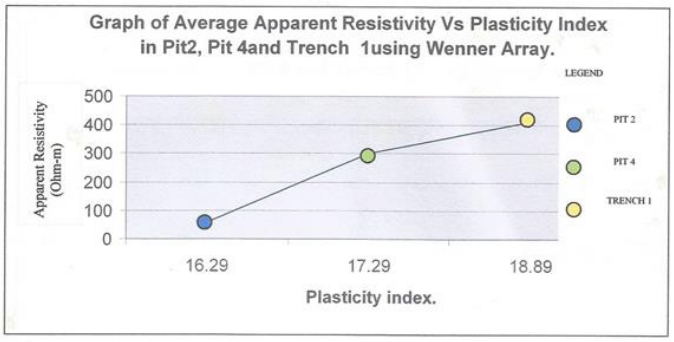
Meanwhile, nonlinear relationship exists between Coefficient of Permeability and Consolidation with (VES) electrical resistivity.

Coefficient of Consolidation

The coefficient of consolidation (Cv) decreases exponentially with increase in resistivity (p). The generalized equation that exists between p and C, is of the form:

$$p = Ae^{BCV}$$

Where p resistivity of the soil
Cv coefficient of consolidation
A and B are constants, they are derived in below:



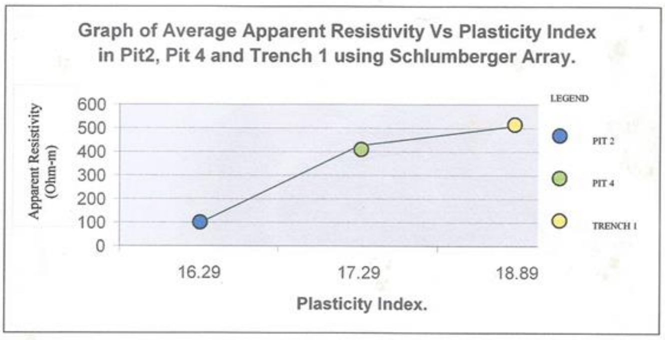


Fig. 4. Graph showing the Relationship between Plasticity Index and Micro-Resistivity measurements usinig Wenner and Sublumberger Array in Iloko Investigated Area.

From the graph, (see figure 4), the following equation are derived.

2020 = Ae°692 (4)
666 = Ae916 (5)
186 = Ae3°788 (6)
Recall equation 63
2020 = AeO6O2B
A = 2020 (7)
e°692
Recall equation
666 = Ae1 91 6B
Substitute A as in equation 5 in equation (8)
666 = 2020 x e19
666 =
2020 e0692B
0.3297 = e19168 + eO.692B
0.3297 = e1916 0.6928
0.3297 = e148
Take the natural log of both side
In (0.3297) = logeet224B
-1.109572 = 1.224B B = -1.109572
1.224
B = -0.906513 (9)
Recall equation
1 86 = Ae3°78
Substitute B as equation in equation 65
186 = Ae3°78 X O9O65l 3 186 = Ae279025
A = 186
e29025
A= 186
0.061406043 A = 3029

Therefore, the equation that exist between resistivity and Coefficient of Consolidation (Cv) is:

p = 3029e°9065 Cv
p = 3.029 x I 03e°9065 CV

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

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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