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Geophysical Investigation of Soil Conditions for Foundation Study of Kukwaba, Abuja

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Abstract Geophysical investigation has been carried using Vertical Electrical Sounding (VES) at site in Kukwaba District, Abuja to examine the geophysical parameters that can be used to evaluate the structural competence of the subsurface for foundation. The Schlumberger array configuration was used for the Acquisition of the data. The electrical resistivity data were processed and interpreted using IP12win software package and Surfer 12. A total of 15 VES point was carried out with a maximum current electrode spacing (AB/2) of 100m. The results revealed maximum of five layer, the topsoil, the laterite, weathered layer, fractured basement and fresh basement. The resistivity value of the topsoil ranges between 85.1Ωm to 2416Ωm which is typical clay, clayed, sand, sandy clay and laterite with laterite being the most competent and clay being lest competent. From Geoelectric section, it is observed that the top layer resistivity of VES point 3, 11 and 15 with resistivity value less than 100Ωm are characterized by clay with high moisture content and therefore not competent, while VES point 12 and 14 are lateritic in nature; thus very competent and good for high rising building, while VES point 1, 2, 4, 5, 6, 7, 8, 9, 10, and 13 are moderately competent and can with stand small engineering construction.

Keywords: Layer, Laterite, Resistivity, Subsurface, Structural

Introduction

Engineering structures are designed and constructed with long life expectancy (Olorunfemi *et al.*, 2000). Apart from loss of huge financial investment, other consequences of structural failure can be very devastating. Lives and properties are lost; the cost of rehabilitation of such failed structural facilities can be enormous. In most cases, failed structures are completely redesigned and reconstructed at much higher cost. All structures erected on the earth have their own substructures (foundation). Foundation design depends on the characteristics of both the structures and the soil or rock (Akintorinwa *et al.*, 2011). Therefore, the nature (i.e. competence, strength and load capacity) of the soil supporting the super structure becomes an extremely important issue for safety, structural integrity, assessment and durability of the super structure. Hence, a detail examination of the subsoil is required by a none-intrusive technique such as geophysical method which gives the response of the heterogeneous soil particles to some physical parameters that governs the subsoil competency. Usually, civil and building engineers prefer drilling, cone penetrometer test and some other geo-technical methods in assessing the strength of materials for the support of infrastructures such as roads, buildings and Although, these techniques are good, they are expensive in terms of cost and might not give adequate information about the entire area and good depth of investigation may not be achieved. Therefore, it is imperative to complement these with cost effective geophysical method which are commonly applied in engineering site investigation.

Geoelectrical resistivity survey is the most common geophysical method used for site geotechnical investigation (Gowd, 2004). Various authors in literatures have integrated electrical resistivity and geotechnical data for characterization of the subsurface (Dahlin *et al.*, 2004). Apparent soil electrical conductivity (or resistivity) is influenced by a combination of several physico-chemical properties among which are clay content and mineralogy, soil water content, organic matter, and bulk density. Clay content can affect both strength and resistivity of the soil matrix in different degree.

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The Study Area

The study area is located in the central part of the Federal Capital Territory, Abuja, Nigeria (Figure 1.1). The Kukwaba district lies approximately between longitudes 60 46' and 70 37'E and latitudes 80 21' and 90 18' N. The study area covers an area of about 175,679m^2 of the 8000 km^2 is bounded by Dakibyu and Wuye to the north, Central Business District Area, to the east, Durumi and Kaura to the south and Airport road to the west.

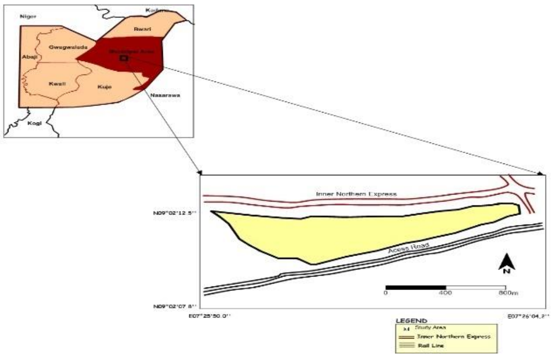

Fig.1.1 Location Map of the Study Area

The description of the Geology of the study area has variously been attempted in the works of Truswell and Cope (1963), Oyawoye (1970), McCurry (1970, 1976), ABU (1978), Turner (1978) and Alagbe (1979) to mention a few. The study area lies within the north central part of the Nigerian Precambrian Basement Complex which forms part of the Pan-African mobile belt placed in-between the West African and Congo Cratons (Black, 1980). Generally the Basement Complex of Nigeria is composed of four major petrolithological units namely: the Migmatite – Gneiss Complex; the Schist Belt (Metasedimentary and Metavolcanic rocks); the Older Granites (Pan African granitoids) and the Undeformed Acid and Basic Dykes. These basement rocks are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization corresponding to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African cycles (600 Ma). The basement rocks are intruded by the Mesozoic calc-alkaline ring complexes (Younger Granites) of the Jos Plateau and is unconformably overlain by Cretaceous and Younger Sediments (Figure 2). According to A.B.U. (1978), the rocks that underlie the study area include the metamorphosed supracrustal exogenetic rocks, migmatite complex, intrusive coarse grained granite, minor intusions such as rhyolites and dolerites and other small formations as quartzite, pegmatite and quartz vein (Figure 2). Structures such asfoliations in mica schist, migmatites and gneisses; layering and planar orientation of flat xenoliths in migmatitic complex; folds in migmatites and gneisses and sometimes schist; crenulation and elongation of mineral grains or aggregates in the schist belt; joins and faults trending NNW-SSE and SE-NW respectively have been mapped in the study area while intrusions in rock outcrops were reported as trending in the same direction as most of the joints.

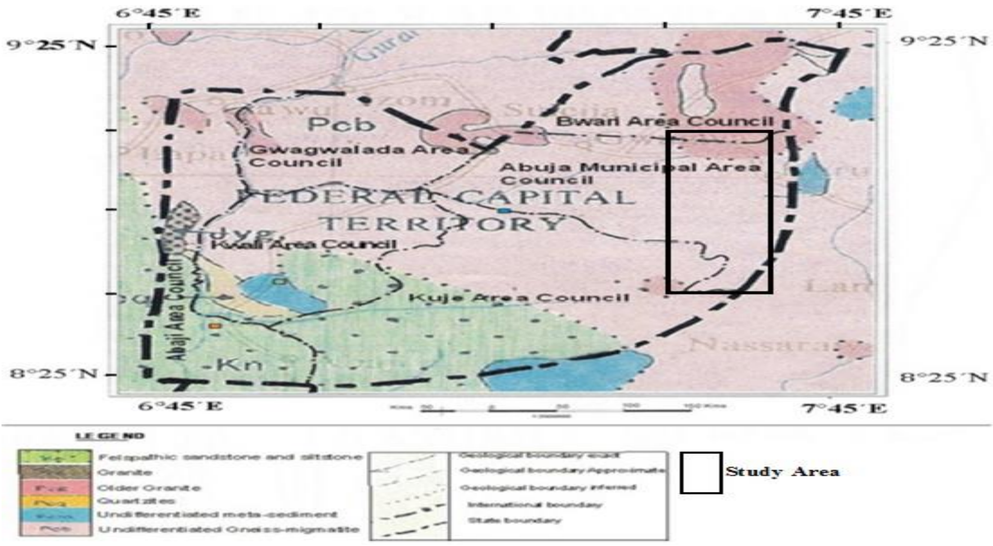

Figure 2: Geological map of the Study Area (NGSA, 2004)

Materials and Methods

ABEM Terrameter (SAS 3000) was used for the measurement of resistivity, Global Positioning System (GPS) was used for the location of VES points, Electrodes, Hammer, Data sheet with K- Value and a pen were as well used. A total of 15 vertical electrical sounding will be carried out using the Schlumberger electrode configuration with maximum current electrode spacing of 100m. A and B are current electrodes through which current will be driven into the ground, while M and N are two potential electrodes to record the potential distribution in the surface within the two current electrodes. The resultant ratio of the current and voltage is the measured data which is the ground resistance read off in the Terrameter. The ground resistance value was multiplied with Geometric Factor (K) to obtain the apparent resistivity using the following

$$\rho a = kR \quad (1)$$

Where k is the geometric factor given by $K = \pi\left(\frac{L^2}{2b}\frac{b}{2}\right)$ (2)

Where $L = \frac{1}{2}AB$ and $b = \frac{1}{2}$MN

Then the apparent resistivity value was plotted against the electrode spacing (1/2AB) on a log-log scale to obtain the VES sounding curves using an appropriate computer software, in this present study IPI2 Win was used, for the contour maps Surfer 12 was used.

Results, Interpretations and Discussion

The results of vertical electrical sounding (VES) are often interpreted quantitatively as a series of curves using computer assisted iterative software packages, also as a series of contour map when using gridded data. The IPI2win software package was used to produce the curves from the field data while the contouring package surfer 12 was used to produce the maps from the values obtained from the curves. Figure 2 shows the geological map of the study area showing the VES point.

The result of the Fifteen (15) VES carried out in the study area showed that the subsurface is made up of five (5) layers, being top layer, lateritic layer, weathered layer, fractured basement and the fresh basement. The result of the VES across the study area is summarized in Table 1.

The VES curves are composed of H, HA, HK, KH, AK, QH QHK and HKH type with three to five Geoelectric layer combinations. Typical VES curves are shown in Figure 3-6, KH curves types predominates, consisting of 26.6 % of the total, the H and HK consisting of 20% and AK, HA, QH, QHK, HKH constitute 6.67 % each. The characteristic curve types in each VES station are summarized in Table 2. Table 3 shows the soil competency rating.

Table 1: Summary of VES result across the study area

VES No.	ρ1	ρ2	ρ3	ρ4	ρ5	T1	T2	T3	T4	d1	d2	d3	d4	Curve Type
1	122	17.1	5439	4.78	-	1.09	1.38	4.42	-	1.09	2.47	6.89	-	HK
2	105	63.3	3511	28.3	-	1.38	4.85	17.3	-	1.38	6.24	23.5	-	HK
3	29.9	5.5	8028	-	-	0.57	5.5	-	-	0.57	6.07	-	-	H
4	179	10.9	62531	-	-	1.18	1.82	-	-	1.18	3.0	-	-	H
5	142	82.2	326	43973	-	0.56	3.48	15	-	0.56	4.04	19	-	HA
6	155	71.7	43369	-	-	0.31	6.41	-	-	0.31	6.72	-	-	H
7	113	864	47.1	93609	-	0.34	5.17	6.53	-	0.34	5.51	12	-	KH
8	127	965	64	93253	-	0.44	4.49	8.58	-	0.44	4.93	13.5	-	KH
9	205	766	37.4	3005	-	1.86	2.64	5.11	-	1.86	4.5	9.6	-	KH
10	110	81	501	21.4	9559	0.75	1.82	3.63	14.1	0.75	2.57	6.2	20.3	HKH
11	70.73	89.17	3844	10.63	-	1.78	5.86	18.09	-	1.78	7.64	25.7	-	AK
12	2416	332	90.8	9687	89.9	0.43	0.84	9.79	18	0.43	1.27	11.1	29.1	QHK
13	346	2827	31.3	59082	-	0.36	0.58	2.46	-	0.36	0.94	3.4	-	KH
14	1272	408	38.9	1297	-	2.05	4.42	6.9	-	2.05	6.47	13.4	-	QH
15	85.1	37.9	12720	89	-	0.88	3.88	8.98	-	0.88	4.76	13.7	-	HK

ρ1 - ρ5 are the resistivity of the 1st – 5th layer respectively, T1 – T4 are the thicknesses of the 1st – 4th layer respectively and d1 – d4 are the depth of the 1st – 4th layer respectively.

Table 2: Characteristic curve types in the area with their frequency and percentage

S/No	Curve Types	Curve Characteristics	Curve Frequency	% Curve Type
1	H	ρ1> ρ2< ρ3	3	20
2	HA	ρ1> ρ2< ρ3< ρ4	1	6.67
3	HK	ρ1> ρ2< ρ3> ρ4	3	20
4	KH	ρ1< ρ2> ρ3< ρ4	4	26.60
5	AK	ρ1< ρ2< ρ3> ρ4	1	6.67
6	QHK	ρ1> ρ2> ρ3< ρ4> ρ5	1	6.67
7	HKH	ρ1>ρ2< ρ3> ρ4< ρ5	1	6.67
8	QH	$\rho 1 > \rho 2 > \rho 3 < \rho 4$	1	6.67

Table 3: Soil Competence Rating

Apparent Resistivity (Ω-m)	Lithology	Competence Rating
<100	Clay	Incompetent
100 – 350	Sandy Clay	Moderately Competent
350 – 750	Clayed Sand	Competent
>750	Sand/Laterite	Highly Competent

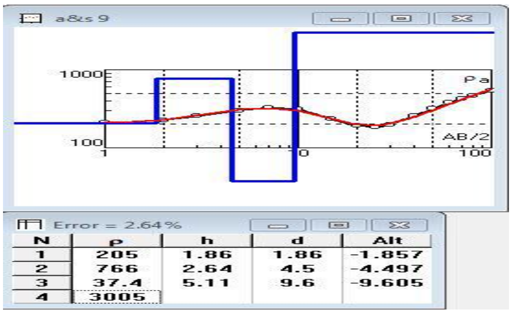

Figure 3 Typical KH- type in the Study Area

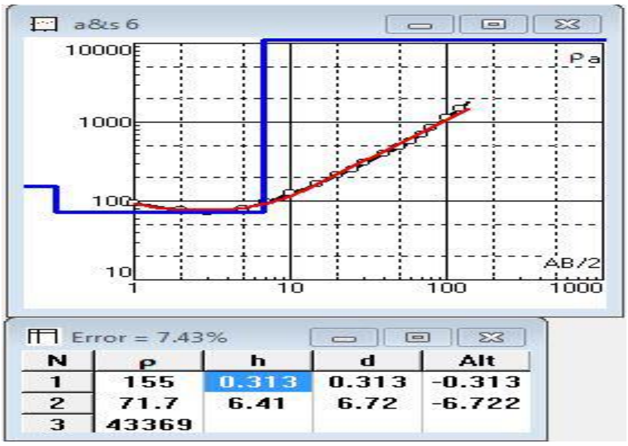

Figure 4: Typical H- type in the Study Area

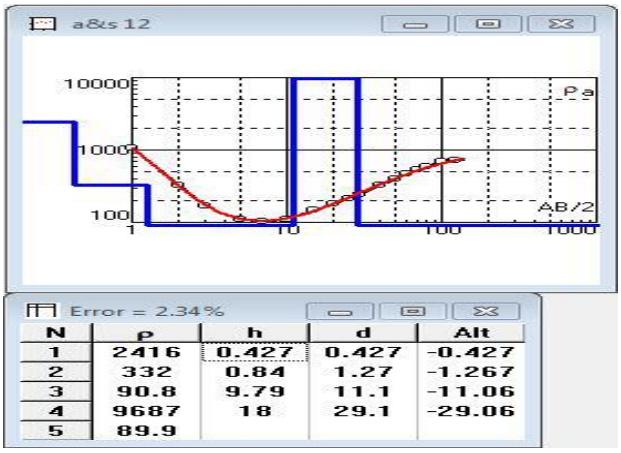

Figure 5: Typical QHK-Type Curve in the study area

Top Layer Resistivity

Figure 6 shows the resistivity map of the soil. The resistivity value of the top soil in the study area mostly varies from 85.1Ω-m to 2416Ω-m typical clay, clayed, sand, sandy clayed and laterite. The values of the top layer resistivity were obtained by taking the resistivity of the first layer in each VES station. Higher resistivity values may indicate area with high competence for foundation, while lower resistivity values indicate areas with low competence. The 2D contour Map in Figure 6 shows that the North- East and the West typified by bluish coloration have low resistivity while the brownish coloration is area with high resistivity.

Overburden Thickness

The overburden thickness map, also known as the isopach map is the depth to fresh basement in the area. It is made up of all the layers from the top layer to the fractured layer. This was obtained by compiling the values of the depth to basement in all the VES stations. The area with thick overburden indicate high competency while area with thin overburden indicate low competency. The overburden thickness map in Figure 7 shows that the central to North East portion of the area has thick overburden as indicated by dark brownish coloration with a thickness ranging from 7.5 to 14.5m while the Western region to South West of the study area has thin overburden ranging from 1 to 4.5m. The depth to basement in the study area ranges from 3.4m to 29.1m with a mean depth of 14.81m as shown in the Figure 8.

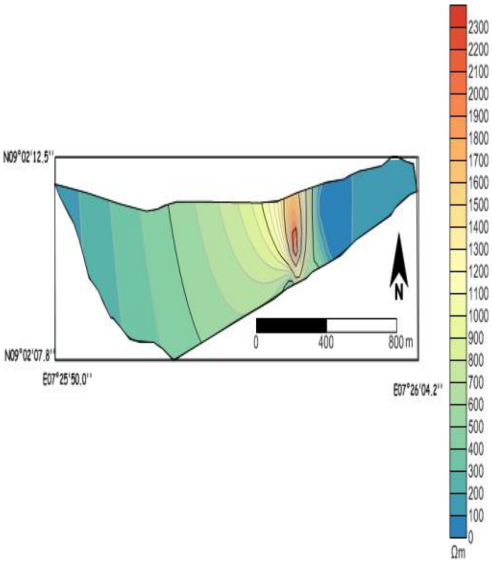

Figure 6: Resistivity Map of the study area

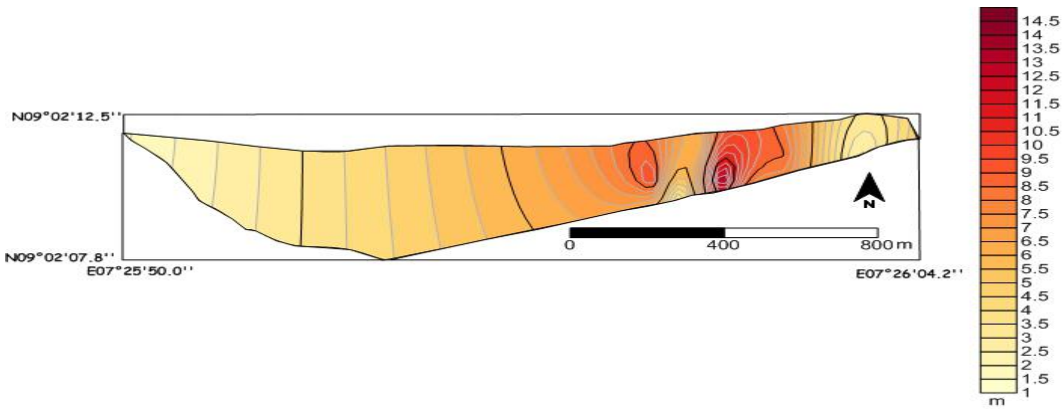

Figure 7: Overburden thickness map

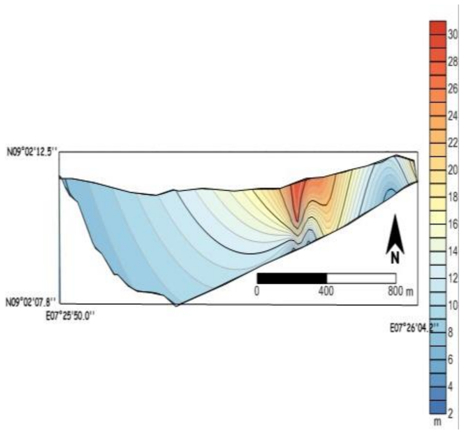

Figure 8: Depth to Basement Map

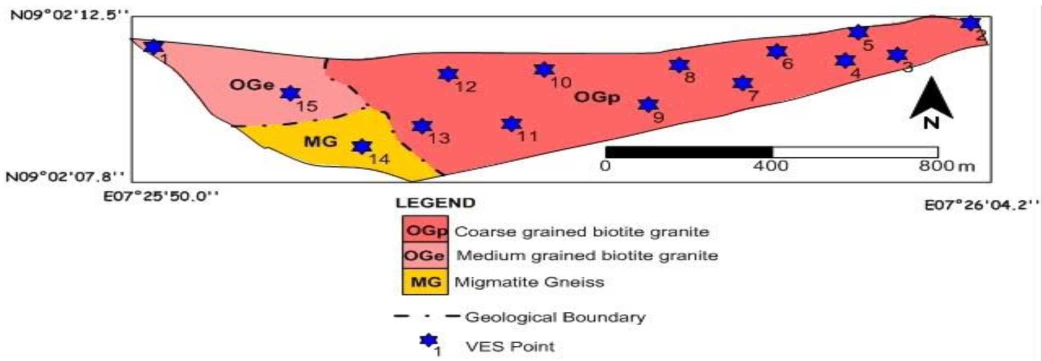

Figure 9: Geological map showing the VES point

Subsoil

Evaluation of the Study Area

There are no indications of any major linear structure such as fracture or fault that could aid building subsidence. The Geoelectric sequences beneath the area is composed of thin layer of top soil ranging from 0.35m to 2.05m, the laterite layer, the weathered layer, fractured layer and the fresh basement. The top soil constitutes the layer within which small civil engineering structures can be constructed (Jatau & Patrick, 2012). From the table of resistivity values (Table 1) the top soil is composed of clay, sandy clay, clayed sand and laterites. Engineering competence of the subsurface can be evaluated from the layer resistivity. The higher the resistivity value the higher the competence of the layer, hence from the point of view of the resistivity value therefore laterite is the most competent, followed by clayey sand and sandy clay with clay being the least competent. Figure 10 to Figure 12 below shows the Geoelectric section, it is observed that VES 3, 11 and 15 are mostly clay characterized by moisture content and therefore not competent VES point 12 and 14 are lateritic nature which is very competent and good for high rising building, while VES point 1, 2, 4, 5, 6, 7, 8, 9, 10, and 13 are moderately competent and can withstand small engineering construction.

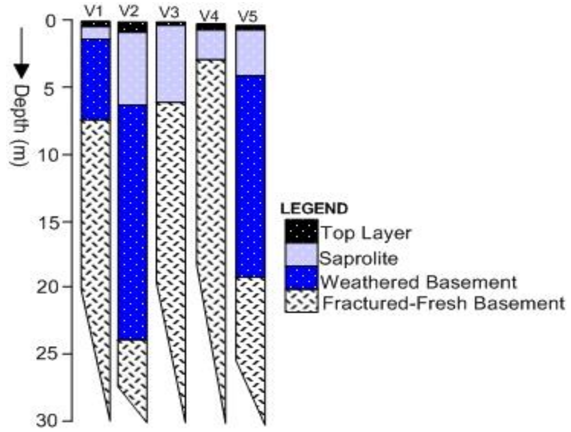

Figure 10: Geoelectric Section of VES 1-5

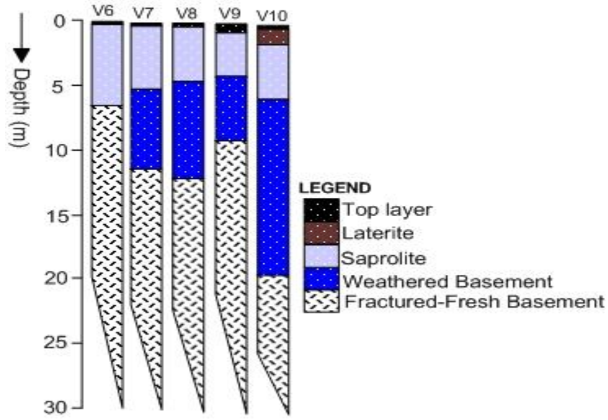

Figure 11: Geoelectric Section of VES 6-10

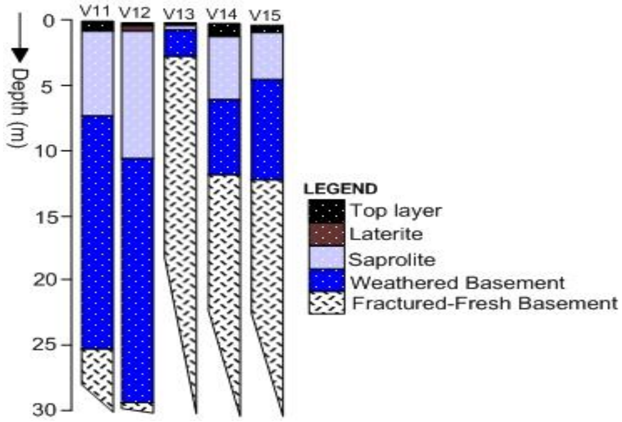

Figure 12: Geoelectric Section of VES 11-15

Conclusion

From the interpretation of the Vertical Electrical Sounding (VES), four major layers were delineated from the study area which comprise topsoil which are mainly clay, clayed sand and sandy clay, laterite, sand, weathered formation, fracture layer and fresh basement. At the north east and north south part of the study area, the topsoil is mainly clay, which means that the topsoil has to be excavated beyond the depth of 0.5m for the choice of shallow foundation in the study area. For building development in the study area, the topsoil must be excavated to a reasonable depth in between the lateritic layer at which the soil is adequately competent to bear the load because lateritic soil has a greater load bearing capacity.

Based on the interpretation of the data and field results obtained, I would like to make the following recommendations

i. Excavation of soil to a depth at which the soil is lateritic in nature (adequately competent and highly consolidated) to sustain the structure of any kind.
ii. Shallow type of foundation such as strip footing in the competent area of high bearing capacity and raft foundation in the area of less competence are recommended.
iii. High rise buildings can be built in the study area because there is no near surface geologic structure and the choice of foundation materials should be carefully chosen and deep type of foundation should be employed at a reasonable depth.

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