Geophysical and Geotechnical Characterization of Newly Constructed Abadina-Ajibode Road, University of Ibadan, Ibadan

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Abstract—The combination of geophysical and geotechnical methods in foundation investigation has shown to be invaluable in deciphering the depth to bedrock, characterizing the earth materials and extent of variation of allowable bearing pressure of foundation soils. Geophysical and geotechnical methods involving electrical resistivity and cone penetration test have been carried out to investigate the foundation conditions of a bridge site in Ajibode and the newly constructed Abadina-Ajibode Road, located in University of Ibadan, Ibadan, southwestern Nigeria.

Eleven vertical electrical sounding (VES) were carried out, seven at the investigated portion of the road and four at the bridge site. While four cone penetration tests were also carried out at the Bridge site. The vertical electrical sounding for investigated portion of the road revealed 2-4 different lithological layers. The first layers is topsoil which has resistivity ranges from 17-321Ωm with a mean of 220Ωm. The wide range in resistivity values of the topsoil can be due to different degree of compaction. The thickness of the topsoil ranges from 0.5-1.7m with a mean of 1.1m. The second layer resistivity from VES 1-VES 6 ranges from 19-46Ωm with a mean of 32Ωm. The resistivity of this layer is less than 100Ωm which is characteristics of clayey formation. The thickness of this layer ranges from 5.9-12.6m with a mean of 8.0m. For VES 7, the second layer is made up of lateritic pan with resistivity of 336Ωm and depth of 6.1m. The fractured/fresh basement layer resistivity ranges from 171-2364Ωm with a mean of 998Ωm and depth value ranges between 7.4-22.3m with mean depth of 10.9m. While for the investigated bridge site, the vertical electrical sounding revealed 2-3 geoelectric layers. The geoelectric layers include: the first layer is topsoil which has resistivity ranges from 31-320Ωm with a mean of 132Ωm. The wide range in resistivity of the topsoil can be due to different degree of compaction. The thickness of this layer ranges from 0.7m-2.5m with a mean of 1.5m. The second layer resistivity for VES 1-VES 2 ranges from 85-138Ωm with a mean of 116Ωm. The thickness of this layer ranges from 1.0-1.1m with a mean of 1.0m: this layer is characterized by weathered basement. The fresh basement layer resistivity ranges from 920-2853Ωm with a mean resistivity of 2067Ωm, is characterize with fresh bedrock. The cone penetrometer tests also revealed that the investigated bridge site has 2-3 different lithologies with cone resistance of 5-40Kg/cm^2 with a mean of 18Kg/cm^2 at depth range from 0.25-1.0m and at depth range of 1.25-1.7m, the penetrative resistance at CPT 1 and CPT 2 range from 25-250Kg/cm^2 with a mean of 148Kg/cm^2, this is a characteristics of competent materials which are weathered basement. CPT 3 and CPT 4 penetrative resistance range from 5-10Kg/cm^2 with a mean of 9Kg/cm^2 at depth range from 1.0-3.75m but from depth range between 4.0m and 5.0m, the penetrative resistance ranges from 200-250Kg/cm^2 with a mean of 225Kg/cm^2.

The results obtained from this study have emphasized the usefulness of geophysical methods in complementing geotechnical studies in variation in lithology accompanied by variation in the allowable bearing pressure of foundation soils.

Keywords: Ajibode, VES, Cone penetration test, Schlumberger configuration, Geotechnical survey, cone penetration test, pile foundation

INTRODUCTION

Major Nigeria roads are known to fail shortly after construction. Poor construction materials, bad design, usage factor, poor drainage network to mention few are some factors considered to be responsible for these failures. Geological factors are rarely considered as precipitators of road failure even though the road pavement is founded on earth surface. This is due to non-appreciation of the fact that proper design of road construction requires adequate knowledge of subsurface condition beneath the road route. The University of Ibadan's administration plans to create a road linking the two communities, Abadina and Ajibode located in the university premises. As part of the pre-construction process, it then became necessary to conduct an integrated geophysical and geotechnical survey, on the road to know the competency of the base material. The main objective of the investigation is to assess the near-surface geologic materials in terms of types, nature and bedrock structural disposition as possible causes of failure of roads. This is particularly germane to the success of the exercise because of the frequent usage of the road by the University staffs and community residents.

Electrical resistivity techniques have been extensively applied in wide areas of geological research among which are groundwater exploration, groundwater contamination, pollution mapping, material (gravel/sand) survey, archeological site investigations, landfill site investigation, dam site investigations and other engineering projects. The dominant of these however have been in groundwater exploration. The technique of groundwater exploration by the electrical resistivity method has been explained by Kollert (1969) and is widely applied in basement areas for groundwater exploration because it is less expensive than other geophysical techniques such as seismic (Shemang and Chaoka, 2003). It has been successfully utilized in assessing water supply potentials in basement aquifers (Chilton and Foster, 1995). Geophysical and geotechnical investigations of the subsurface are invaluable in characterizing subsurface geologic materials (Olorunfemi and Mesida, 1987; Sharma, 1997). Information such as soil type, load bearing capacity of materials, zone of weakness, resistance to penetration, compressibility, shrinkage limit, etc are often necessary in order to design a very good and strong foundation for the proposed bridge site. The investigation entailed geologic mapping of the area to determine rock types, geophysical investigation to differentiate subsurface layers using Vertical Electrical Sounding (VES) as well as in-situ geotechnical investigation to determine geotechnical properties of the earth materials at the bridge site on the newly constructed road.

Geophysical techniques that can be used to determine the depth to bedrock include gravity, magnetic, resistivity, ground radar, seismic refraction, seismic reflection (Sharma, 1997). It has also been shown that geophysical surveys are efficient and cost-effective in also providing the required geotechnical information (Gokhale and Dasari, 1984; Adeduro et al., 1987; Ojo et al., 1990; Olorunfemi et al., 2000).The application of electrical resistivity has largely been in the areas of hydrogeological investigation, ground water pollution studies and subsurface mapping. Olayinka (1990) and Ojo (1990) have employed resisitivity methods in the imaging the distribution of electrical properties for hydrogeological and dam-site investigation respectively. Olayinka (1991) described different methods of interpreting resistivity pseudo sections data and its application in the SW Nigeria basement complexes.

Geoelectrical sounding survey results as indicate that geophysics is able to provide a broad, composite picture of the subsurface over large areas with speed and economy not attainable by other means (Sharma, 1997).The use of cone penetrometer test as an in-situ test during subsoil investigation for structures such as building, dam, and bridge site has since gained popularity over the years (Adeyemi and Osammor, 2001). Some of the reasons for its increasing usage are its easy-to-use equipment, simple and reliable test result as well as relatively cheap nature of the test. Also measured parameters like cone resistance and sleeve friction are accurate and rapid to obtain coupled with its ability to delineate subsurface strata.

AIMS OF THE STUDY: The aims of the integrated investigation include:

- ✓ Determining the geoelectrical properties of the subsurface of Ajibode area.
- ✓ Delineating the different lithologies and the depth to bedrock.
- ✓ Determining the geotechnical properties of the earth materials and thus obtain information for foundation design of the proposed bridge along Abadina - Ajibode road.

LOCATION, DRAINAGE AND VEGETATION: The study area is the newly constructed road along Abadina and Ajibode community located in the ancient city of Ibadan, which is one of the largest urban centres in South Western Nigeria and Africa in general. The study area falls within longitudes 3^0 52^1 E and 3^0 55^1 E and latitudes 7^0 23^1 N and 7^0 25^1 N, in the North Eastern part of Ibadan. It has an area of about 10.08Km^2. (Figure 1). The study area is drained by the River Ona and its tributaries (figure 2). The river actually forms the boundary between the University campus and Ajibode village and it flows in a southwest direction. The river is linked by smaller rivers. The drainage pattern is dentritic. The "Oba – Dam" in the southern section of the campus also drains some of these rivers (figure 2 and 3). The volume of these rivers varies with season. The highest is during the peak of the rainy season between (April and October). The campus is characterized by gently undulating relief with topographic elevation ranging from 185 to 230m. (Figure 2). University of Ibadan falls within the humid climate peculiar with southwestern Nigeria. The rainy season starts in April and ends in November with short dry period in August. The dry season is generally between November and February. The mean annual rainfall varies from 788mm to 1884m.The vegetation in Ibadan typifies that of the tropical rainforest, but urbanization with its attendant increase in population has drastically reduced the forest into sparse vegetation

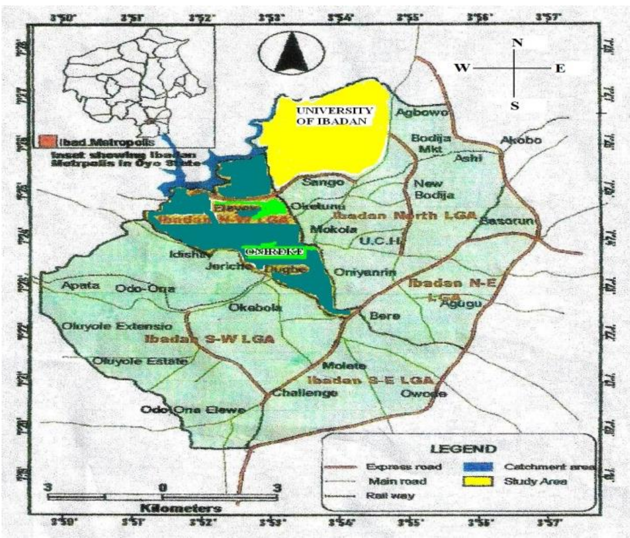

Figure 1: Diagram showing the location of the study area

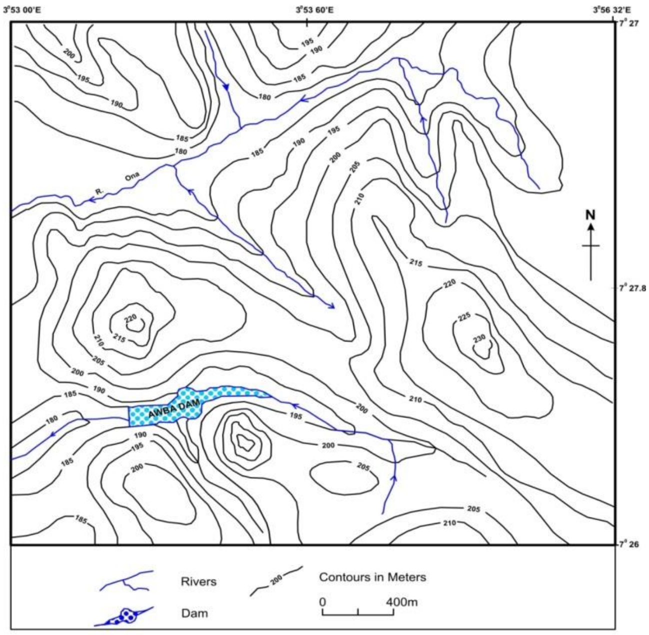

Figure 2: Physiographic map of University of Ibadan, Nigeria.

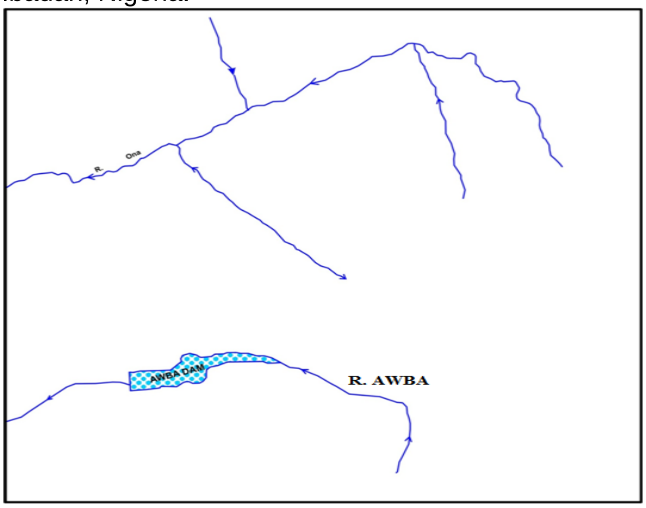

Figure 3: Drainage Map of Ajibode Area, University of Ibadan. Nigeria

REGIONAL GEOLOGY AND GEOLOGIC SETTINGS OF THE STUDY AREA (UNIVERSITY OF IBADAN) Half of Nigeria's land is composed of three main basement complexes located in the west, the north-west and the south-east. Between these massifs, sedimentary basins are aligned along a north-east axis from Lake Chad to the Niger Delta, i.e. along the length of the lower Niger –Benue river systems. The north-west/south-west trending Bida Basin follows the course of the Upper Niger River. In terms of regional setting, Nigeria is within the Pan Africa mobile provenance which is about 0.6 Ga (billion years). In the Nigeria sector of West-Africa region, the Precambrian complex domain constitutes three or four main rock units. Orogenic bodies were emplaced into the basement within the central part of Nigeria now constituting the younger granites. Major sedimentary basins have evolved within the Mesozoic on the basement sedimentary domain. Various lithofacies of sedimentary rocks varying from Cretaceous to recent in age are invariably distributed within this basin. Tertiary to recent complex includes igneous rocks and superficial deposits. The surface area of Nigeria (923,768 Km^2) is underlain in nearly equal proportions by crystalline and sedimentary rocks (Figure 4). The basement complex of Ibadan comprises Quartzites, banded and augen gneisses, granite gneiss and migmatite. The minor rocks include pegmatite, aplite, quartz veins and doleritic dykes (Grant, 1971; Oyawoye, 1972; Rahman, 1976).

(1) The University of Ibadan campus is underlain by quartzite, banded gneiss and augen gneiss (figure 4)

(2) The quartzites occupy the western part of the campus, while the eastern part is occupied by augen gneiss. Banded gneiss forms a strip between the quartzite and augen gneiss in a NW-SE direction (figure 4).

(3) Quartzites and augen gneiss outcrop in various parts of the campus with the former being highly weathered as evident from surface expression, foliation planes, which are well developed and strike in the NW-SE direction (figure 4).

(4) The study area (Abadina-Ajibode community road) is underlain mainly by augen gneiss with minor intrusions of pegmatites and quartz veins. This has been confirmed by boreholes drilled nearby.

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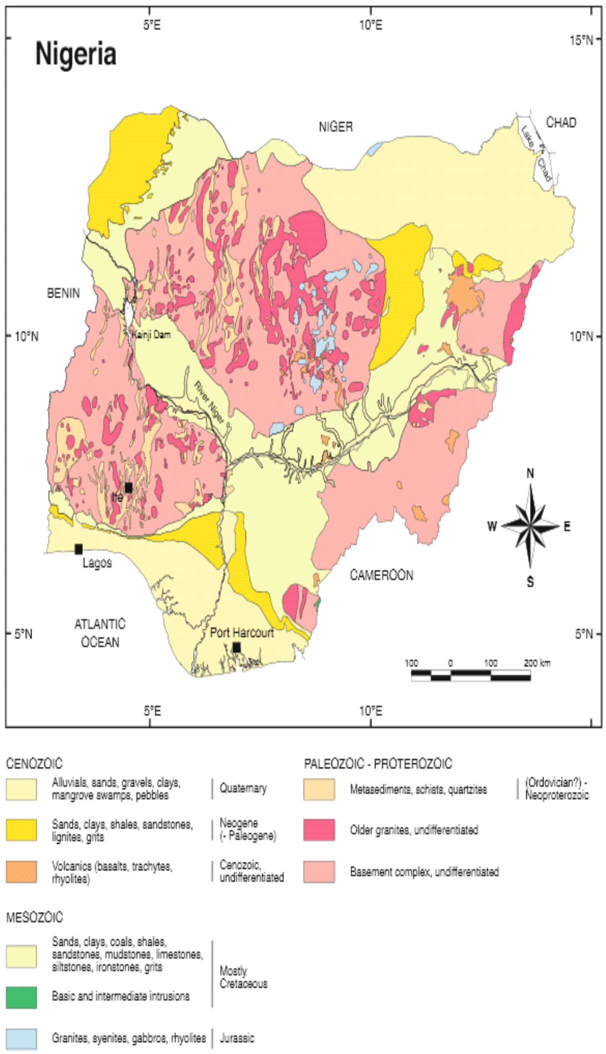

Figure 4: Geological map of Nigeria (modified after Okezie,

1974)

TABLE 1: GENERALIZED GEOCHRONOLOGY FOR THE BASEMENT ROCKS OFNIGERIA (ADAPTED FROM ANNOR, 1985)

Age (Ma)	Period (or epoch)	Activity	Remark
540±400	Late Pan-Africa	Uplift, cooling, faulting, high level magmatic activity	GOLD mineralization RARE-METAL pegmatites
650-580		Granitic intrusion, pegmatites and aplites development	Older Granite magmatism
550-850	Pan-African (Main phase)	Orogenesis: deformation, metamorphism, migmatisation and reactivitation of pre-existing rocks	
800-1000	Katangan	Geosynclinal deposition, intrusion of hypersthenes-bearing rocks	Katanganmetasediments
1900±2500	Eburnean	Granite intrusion, Orogenesis: folding, metamorphism and reactivation of preexisting rocks	Eburnea granites
2500	Birinian	Geosynclinal deposition	Birinianmetasediments
2800±2000	Liberian Cycle	Possible formation of banded gneiss complex near Ibadan	
>2800	Dahomean	Crystalline basement	

HYDROGEOLOGICAL POTENTIAL OF THE BASEMENT COMPLEX ROCKS

Davies and De West, (1966) revealed that crystalline basement complex rocks (igneous and metamorphic rocks) are unproductive aquifers due to their low primary porosity and permeability. Therefore groundwater exploration in the basement complex must target areas of secondary porosity and permeability which are formed by fracturing caused by earth movement and weathering of the crystalline basement rocks. There are few well very close to the newly constructed road dug by the people living there. Precisely three wells were visited and they are all productive which indicate that they are situated in highly weathered or fractured rock terrain. It is very important to know that localization of groundwater in highly weathered zone and fractured rock terrain makes the yield of the wells in crystalline bedrock terrain to be highly variable (Palacky et at., 1981). The stratigraphy of the weathered zone is much that the completely weathered layer is underlain by the moderately to highly weathered rock (transition zone) which is also underlain by the fresh basement rocks. The two topmost layers may be water bearing depending on the thickness as well as the product of the weathering. The wells visited were drilled through the weathered zone and are productive.

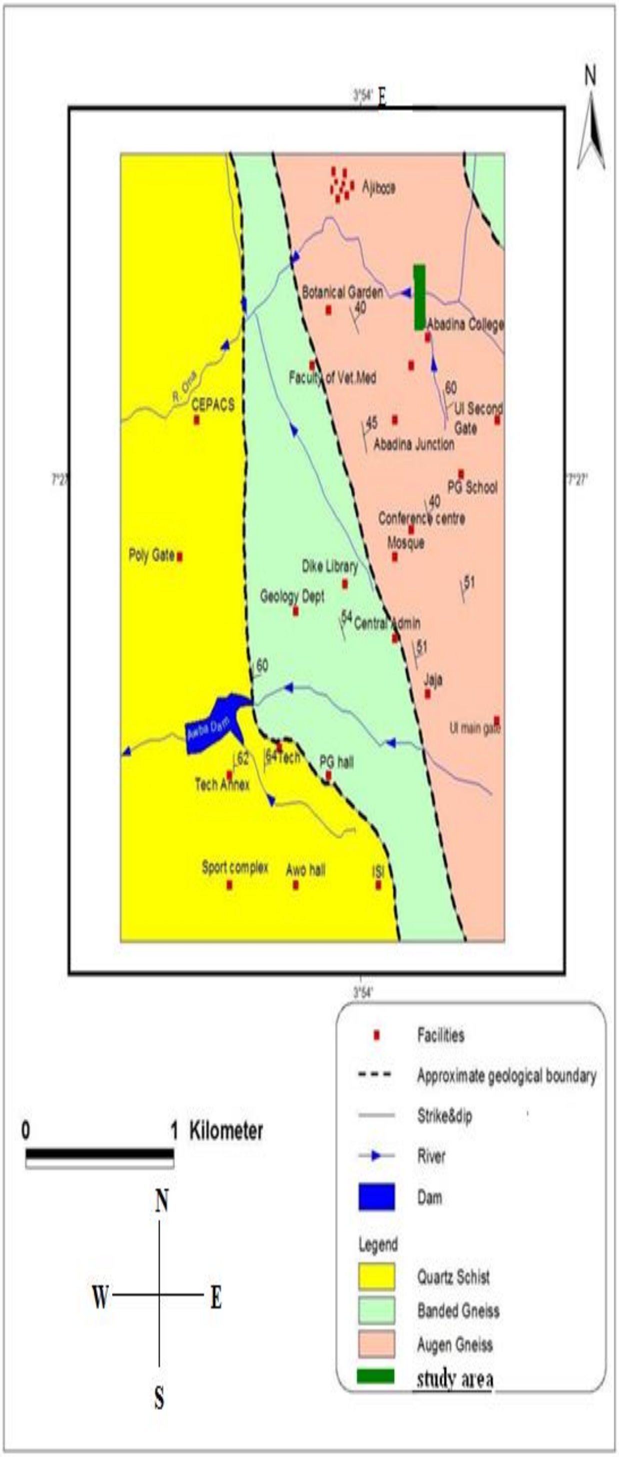

Figure 5: The Geological map of University of Ibadan Campus (After Oladunjoye, 2010).

METHODOLOGY OF RESEACH

1. GEOPHYSICAL INVESTIGATION: ELECTRICAL RESISTIVITY METHOD

The Electrical resistivity method is widely used in the study of lateral and vertical variations in conductivities of the sub-surface layer and also in the detection of 3-dimensional bodies of anomalous electrical conductivity. The application of this method in geophysical prospecting involves the measurement of potential difference across two measuring electrode when current flows through the subsurface between two current electrodes on a generalized four electrode system of various configuration. The potential created can be from natural earth field or created artificial by passing a d.c electric current into the ground. Natural potentials are associated with oxidizing sulphide ores, corrosion of metals, water of different chemical composition in contact through pores and any other electrochemical sources. The electrical resistivity method employs the use of artificial potentials that drops across two potentials electrodes in a four electrode system in determining the resistivity of the sub-surface formation. The resistivity of a material can be defined as the resistance of conducting cylinder with a cross section of unit area (A) and with a unit length (L)

$\rho \propto A/L$

$\rho = RA/L$

Where R= electrical resistance, ρ= resistivity in ohm-meters. The electrical property of natural earth material particularly its resistivity varies and it is governed solely by their content (water). The resistivity of rock is therefore a function of porosity and chemical properties of the water filling the pore spaces rather than the conductivity of the mineral grains that the rock itself is composed. Thus, massive rocks such as granites are poor conductors (unless they are fractured) while gravels and clean sands have a relatively lower resistivity if filled with water and sands saturated with saline water have lowest resistivity.

There are several methods of geophysical survey but the electrode configuration used for this project is the schlumberger array. This makes use of four electrodes. The arrangement is as shown in figure 6. Here, measurement of apparent resistivities is made by keeping the potential electrodes fixed about the mid-point of the array while the current electrodes are systematically spaced in opposite directions. As a result of its simplicity in interpretation and poor sensitivity to lateral variation of resistivity, it is used for Vertical Electrical Sounding (VES).

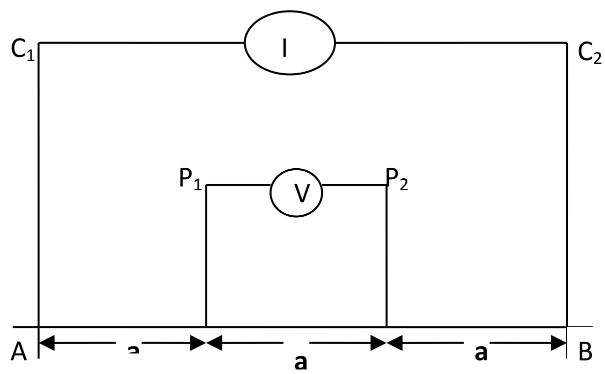

Figure 6 : Schlumberger array configuration Diagram

$$\text{K–Schlumberger} = \frac{2\pi}{\frac{1}{a-\frac{b}{2}} - \frac{1}{a+\frac{b}{2}} - \frac{1}{a-\frac{b}{2}}}$$

The resistivity measured in a homogenous and isotropic layer (ρa) is obtained by multiplying the ∆v/I value by a geometric factor that depends on electrode configuration. This is the weighted average of the resistivities of all the formations through which the current is passing, ρa is expressed in ohm-meters (Ωm). It is worth mentioning that in reality, the subsurface ground does not conform to a homogeneous medium and thus the resistivity obtained is no longer the 'true' resistivity but the "apparent resistivity" (ρa). The apparent resistivity is not a physical property of the subsurface media, unlike the true resistivity. Consequently, all field resistivity data are apparent resistivity while those obtained by interpretation techniques are true resistivities. The analysis of the apparent resistivity variations makes it possible to draw conclusions about the subsurface conditions.

The two main methods of electrical resistivity survey used for the purpose of this survey are the Horizontal profiling method and Vertical Electrical Sounding (VES). The Horizontal profiling method is used to study the lateral variation in resistivity of an area while the VES studies variation in resistivity with depth.

Constant seperation treversing (cst): The principle of horizontal profiling is based on the fact that the subsurface is inhomogeneous and that electrical properties vary from one place to another over an area thus, the lateral variation can be studied. The resistivity measurement is carried out by the use of collinear four electrode array configuration in which the entire electrode array is moved after taking measurement to successive stations. The depth of investigation in resistivity surveying is proportional to electrode spacing. The choice of electrode array and spacing is often based on consideration of the ease of measurement and time, depth of investigation and the sensitivity to lateral variations and anomaly resolution (Baker, 1979).

Vertical electrical sounding (ves): This is used to study the variation of resistivity with depth. It is important in studying the horizontal geological layering of an area where the electrical properties of the sub-surface material vary primarily with depth. The procedure involves taking a succession of apparent resistivity measurement with increasing electrode spacing while maintaining a fixed centre between the measuring potential electrodes. This is based on the fact that larger spacing between the current electrodes corresponds to increase in depth of investigation.

INSTRUMENTS: The instruments used in electrical resistivity survey are quite simple; occur in sets and locally sourced except for the resistivity meter. They include: sets of cable reels, electrode, hammers, measuring tapes and resistivity meter (Terrameter).

Cables and reels: These are wires (cables) wound round a cylindrical metal (reels). They consist of a set of four and are used to complete electrical circuit between the electrodes and the resistivity meter.

Electrodes: These are metals with sharp pointed mouth driven into ground with the aid of hammer from which current are introduced to the ground and potential difference is created. Electrodes are generally good conductors; two are used as current electrodes and two are used as potential electrodes.

Hammers: They are used to drive the electrodes into the ground to make a good contact with the ground layer. The surface soils are mostly hard and difficult to penetrate hence the need to hammer the electrode into ground for better contact.

Measuring tapes: These are used to measure station distances or points at which resistance is taken on the field and to measure equally the electrode spacing. Measuring tapes are generally used in horizontal profiling to ensure accurate inter-electrode spacing as well as accurate movement during survey.

Resistivity meter: The instrument used for this survey is the Campus Tigre Resistivity meter which measures the resistance of the ground layers. It makes use of direct current (d.c) mode passed across two current electrodes. The instrument is portable and light fixed with a rechargeable battery. Factors influencing resisitivity values is majorly electrical resistivity of its pore fluid and the geometry of the pore spaces in the soil by the relationship:

$$P = a\pi\rho w n^{-m}$$

Where n= porosity of the soil, and a & m are constants that depend on the type of soil or rock (Abu-Hassanein et al. 1996). Others are soil type, ionic content of pore fluid, hydraulic conductivity, compaction variables, saturation values, particle size distribution, temperature and anisotropy.

2 GEOTECHNICAL INVESTIGATION: CONE PENETRATION TESTS

Penetration test basically involves pushing or driving a steel tube or cone into the subsurface and monitoring the resistance to penetration distance in the soil (Meyerhoff, 1956). A site investigation is always required before building any structure and the investigation may range from simple examination of surface material to investigation of materials at considerable depth below the surface. These investigations commonly involve in-situ and laboratory tests on the materials encountered. The extent of the work depend on the importance and foundation arrangement of the structure, the complexity of the soil conditions and the information, which may be available on the behavior of existing foundations on similar soils. Determining the shear strength or density of soils in-situ is a valuable means of investigating subsurface material. For this project the tests used are cone penetration test which is widely used for both cohesionless and cohesive soils. The cone end has a base area of 1000mm^2 and apex angle of 60^0.The Dutch cone penetrometer was used for the field investigation of subsurface material at the bridge site of the road. The machine consists of a steel frame carrying driving head which houses a hydraulic pressure capsule mounted on a movable frame with four tyres. The diving head is raised or lowered by motor driven hydraulic ram. Dutch cone penetration test (DCPT) involve pressing a hardened steel cone continuously into the ground using a system of outer sounding tubes, a signal cable connecting the cone and a mounted data logger to measure the resistance to penetration. Tests are normally carried out in accordance with the principle outlined in British Standard BS 5930:1981, “Codes of Practice for site Investigation” (BS 5930, 1981). A 2.5 tonne Dutch Cone Penetrometer (DCP) was utilized to determine the penetration resistance necessary for the determination of bearing capacity of the soils from layer to layer. This strength was measured at every 0.25m depth interval. The measurement was terminated at refusal, which is when the maximum capacity (250Kg/cm2) of the machine was attained. A plot is then made of penetration resistance to depth of penetration to determine competent layers. A total number of four stations were carried out at the bridge site. This is as shown in figure 7

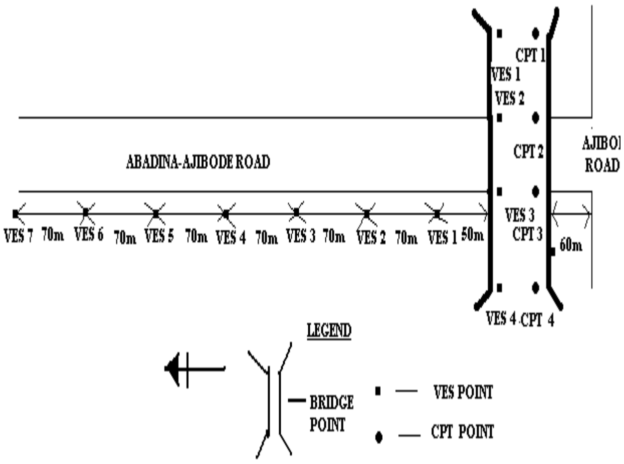

Figure 7: Diagram showing the VES & CPT points in the study area

DATA PRESENTATION AND INTERPRETATION FOR GEOPHYSICAL (VES) SURVEY

Qualitative interpretation of schlumberger vertical electrical sounding data: The apparent resistivity data are plotted against half electrode spacing (AB/2) on a bi-logarithm graph paper. The points are jointed and the overall shape of the resultant curve is noted. If the curve is taken to be a three layered curve, it can be determined if it falls into one of the four types of curves namely H-type ($\rho_1>\rho_2<\rho_3$), K-type ($\rho_1<\rho_2>\rho_3$), A-type ($\rho_1<\rho_2<\rho_3$), or Q-type ($\rho_1>\rho_2>\rho_3$). (Figure 8), where there are more than three layers, we have combination curves. For n-layers the letter combination is n-2, for example, a four-layer curve has 2-letter combination like HA (($\rho_1>\rho_2<\rho_3<\rho_4$) as illustrated in figure 9. Knowledge of the type of curve enhances which of the theoretical master curves will be used for curve matching.

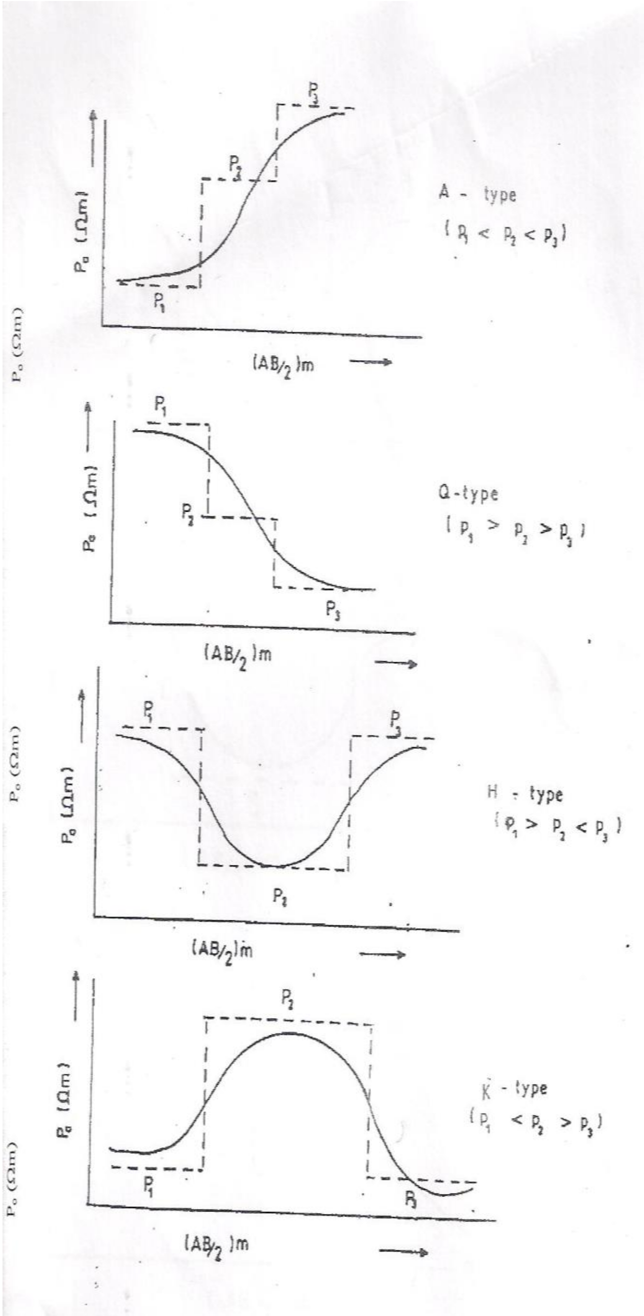

Figure 8: Curves types for a 3-layer Earth Model

Curve matching: This involves comparing successive portions of the field curve with Schlumberger theoretical master curves of similar shapes. Apparent resistivity is plotted against half-electrode spacing on transparent bilogarithm paper of the same modulus as the theoretical master curves. It is then superimposed on and shifted over the master curves while keeping the co-ordinate axes of both the field and master curve parallel until a reasonable match is obtained with one of the master curves or with an interpolated curve. This procedure was done for the eleven Vertical Electrical Sounding data obtained. This preliminary investigation provides the geo-electric parameters (resistivity and thickness) which will be used as starting models/ data for the computer aided iteration program used for complete curve matching. The computer iteration is carried out with a very efficient computer program (Winresist version 1.0) with very low RMS error. It entails inputting the field data and model parameter obtained from partial curve matching, an iteration process is then commenced until a near perfect match is obtained between the field and the computer curves. Usually, the obtained root mean square (rms) error of below 5% is considered satisfactory.

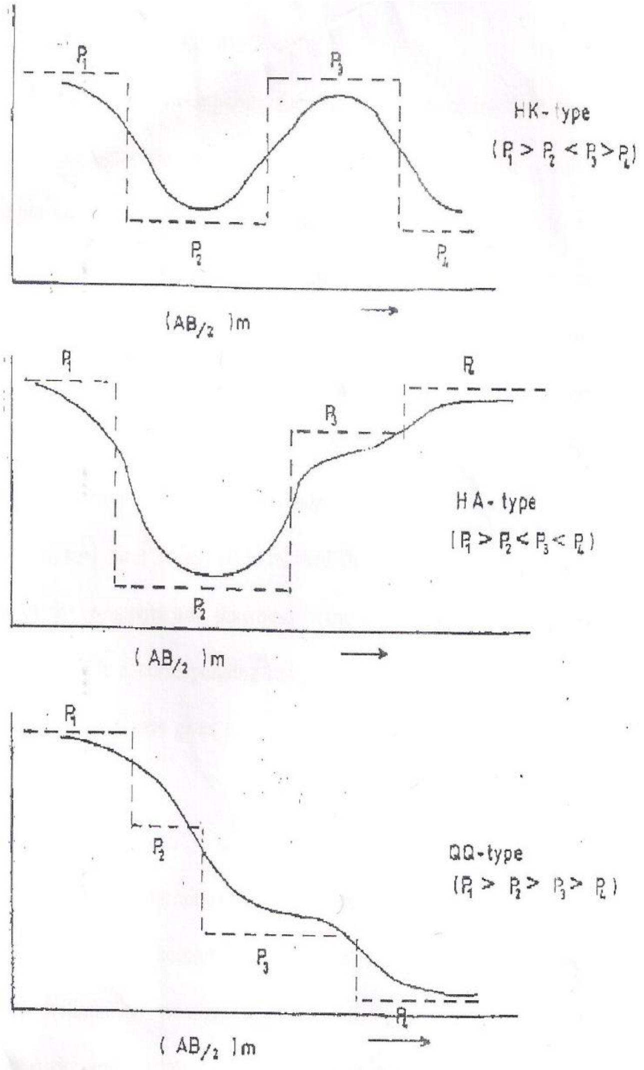

Figure 9: Curves types for a 4-layer Earth Model

Data presentation

The sounding curves for VES 1-7 carried out on the investigated portion of the road are shown in Figures 10-16. For VES 1-6 it is three geo-electric layers (figure 10-15) and four geoelectric layers for VES 7 (figure 16). The curve is made up of H, A and KH as illustrated in Table 2. The geoelectric sections include: the first layer is topsoil which has resistivity ranges from 17-321Ωm with a mean resistivity of 220Ωm. The wide range in resistivity values of the topsoil can be due to different degree of compaction. The thickness of the topsoil ranges from 0.5-1.7m with a mean of 1.1m. The second layer resistivity from VES 1-VES 6 ranges from 19-46Ωm with a mean resistivity of 32Ωm. The resistivity of this layer is less than 100Ωm which is characteristic of clayey formation (Hazell et al., 1992; Aina et al., 1996).The thickness of this layer ranges from 5.9-12.6m with a mean of 8.0m. For VES 7, the second layer is made up of lateritic pan with resistivity of 336Ωm and depth of 6.1m. The basement layer resistivity ranges from 171-2364Ωm with a mean resistivity of 998Ωm and depth value ranges between 7.4-22.3m with mean depth of 10.9m.

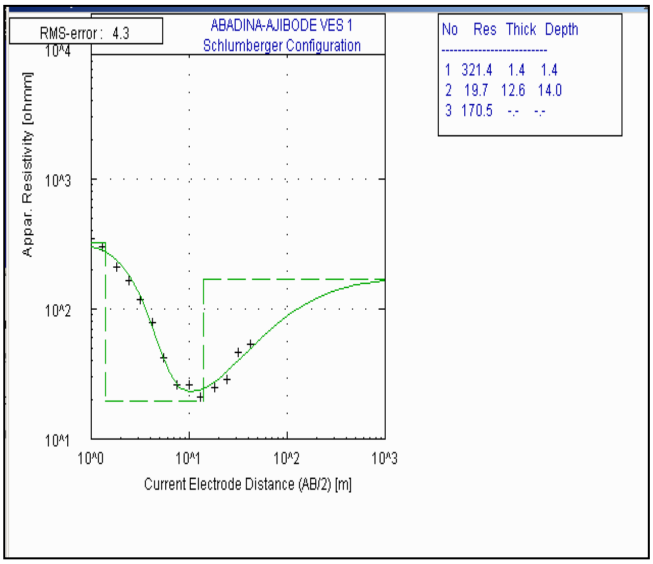

Figure 10: Geoelectric Curve for Abadina-Ajibode Road VES 1

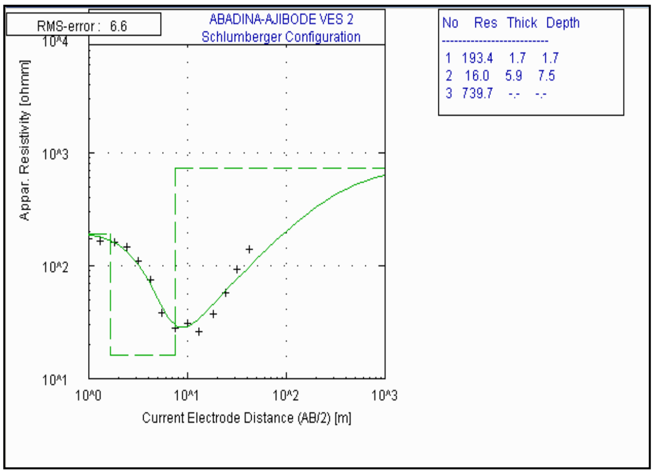

Figure 11: Geoelectric Curve for Abadina-Ajibode Road VES 2

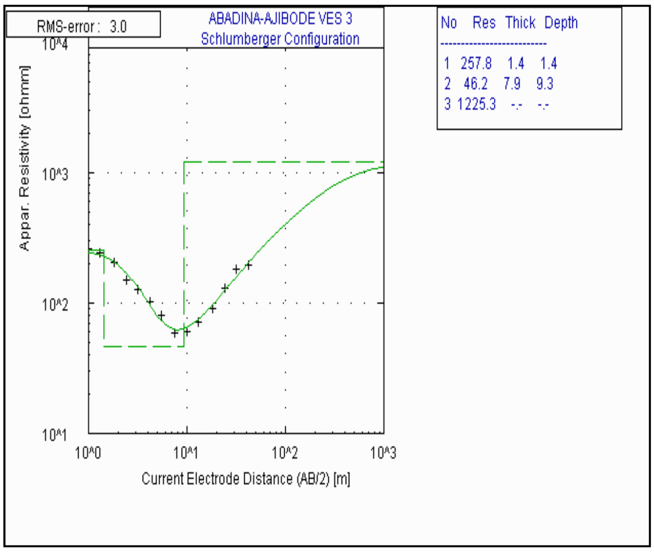

Figure 12: Geoelectric Curve for Abadina-Ajibode Road VES 3

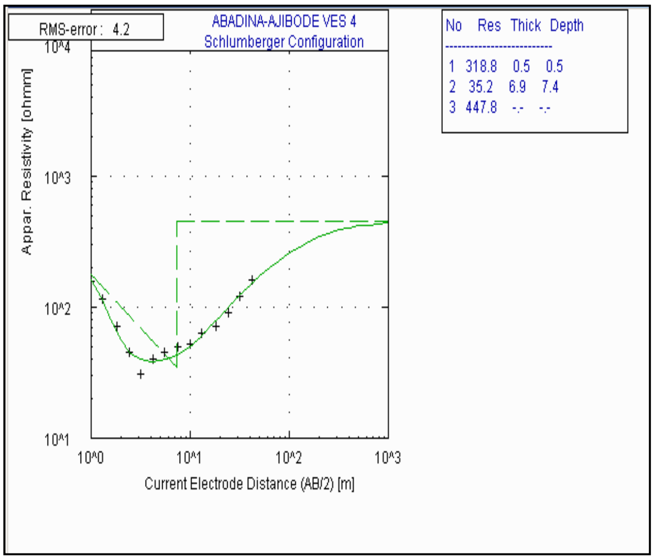

Figure 13: Geoelectric Curve forAbadina-Ajibode Road VES 4

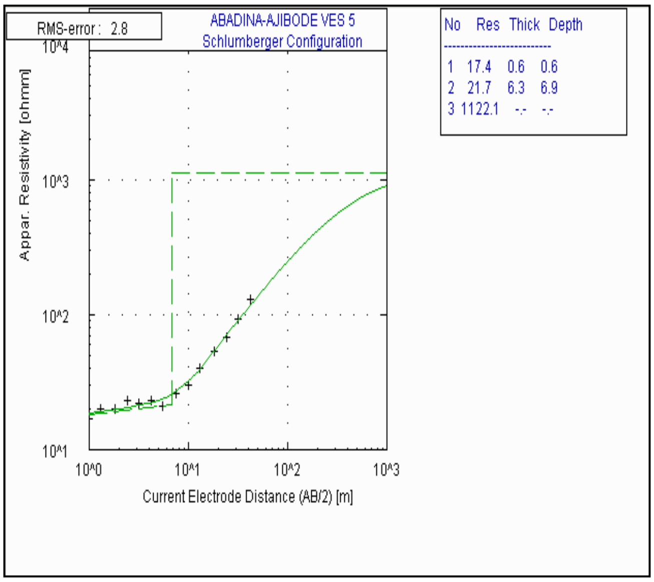

Figure 14: Geoelectric Curve for Abadina-Ajibode Road VES 5

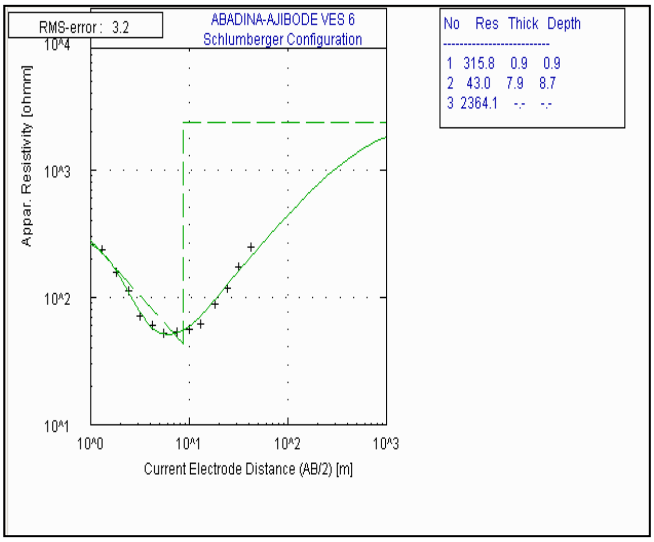

Figure 15: Geoelectric Curve for Abadina-Ajibode Road VES 6

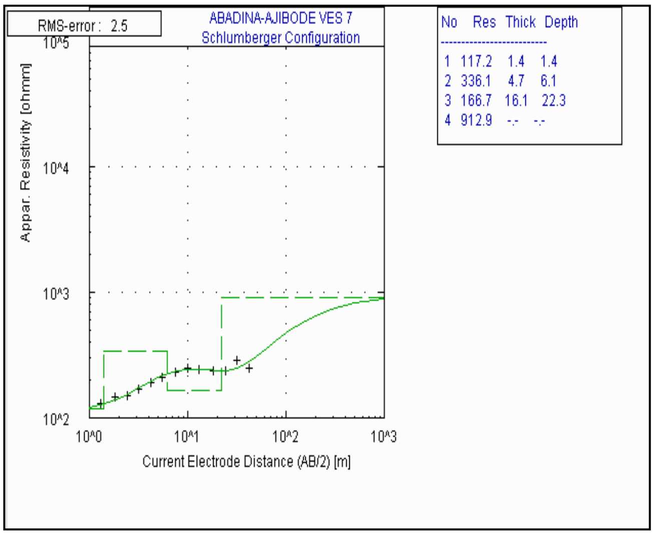

Figure 16: Geoelectric Curve for Abadina-Ajibode Road VES 7

TABLE 2: SUMMARY OF GEOELECTIC CURVE INTERPRETATION OF THEVES FROM ABADINA AJIBODE ROAD

Layer	Resistivity (Ω-m)	Thickness (m)	Depth (m)	Probable Lithology	Types of curve
VES 1					
1	321	1.4	1.4	Top soil	H-type
2	19	12.6	14	Weathered basement (clayey)	
3	171	-	-	Fractured basement	
VES 2					
1	193	1.7	1.7	Top soil	H-type
2	16	5.9	7.5	Weathered basement (clayey)	

3	740	-	-	Fresh basement	
VES 3					
1	258	1.4	1.4	Top soil	H-type
2	46	7.9	9.3	Weathered basement (clayey)	
3	1225	-	-	Fresh basement	
VES 4					
1	319	0.5	0.5	Top soil	H-type
2	35	6.9	7.4	Weathered basement (clayey)	
3	448	-	-	Fractured basement	
VES 5					
1	17	0.6	0.6	Top soil	A-type
2	22	6.3	6.9	Weathered basement (clayey)	
3	1122	-	-	Fresh basement	
VES 6					
1	316	0.9	0.9	Top soil	H-type
2	43	7.9	8.7	Weathered basement (clayey)	
3	2364	-	-	Fresh basement	
VES 7					
1	117	1.4	1.4	Top soil	KH-type
2	336	4.7	6.1	Lateritic pan	
3	167	16.1	22.3	Weathered basement	
4	913	-	-	Fractured basement	

BRIDGE SITE: The sounding curves for VES 1-4 carried out on the Ajibode bridge site are shown in Figures 17-20. There are three geoelectric layers for VES 1 and VES 2 and two geoelectric layers for VES 3 and VES 4. The curve is made up of H and A types as shown in Table 3. The geoelectric sections include: the first layer is topsoil which has resistivity ranges from 31-320Ωm with a mean resistivity of 132Ωm. The wide range in resistivity values of the topsoil can be due to different degree of compaction. The thickness of the topsoil ranges from 0.7-2.5m with a mean of 1.5m. The second layer resistivity for VES 1-VES 2 ranges from 85-138Ωm with a mean resistivity of 116Ωm. The thickness of this layer ranges from 1.0-1.1m with a mean of 1.0m; this layer is charactertized by weathered basement. The basement layer resistivity ranges from 920-2853Ωm with a mean resistivity of 2067Ωm, is characterize with fresh bedrock.

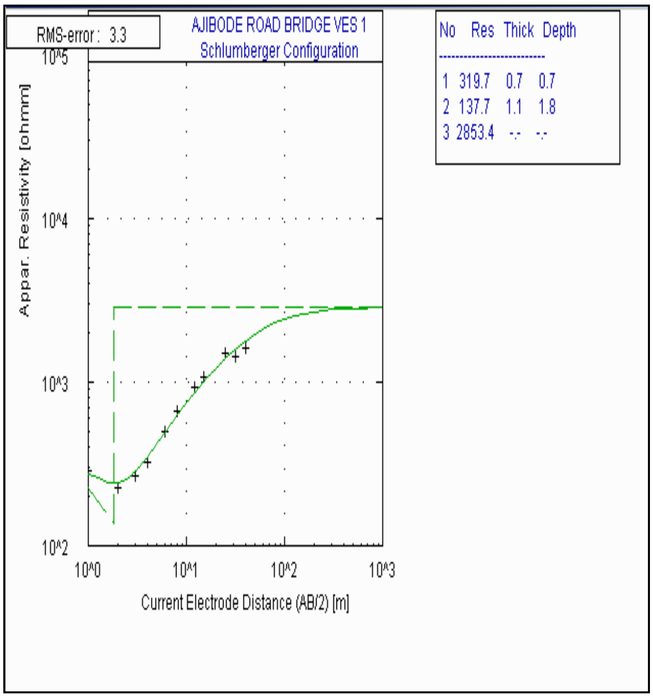

Figure 17: Geoelectic Curve for Bridge site VES 1

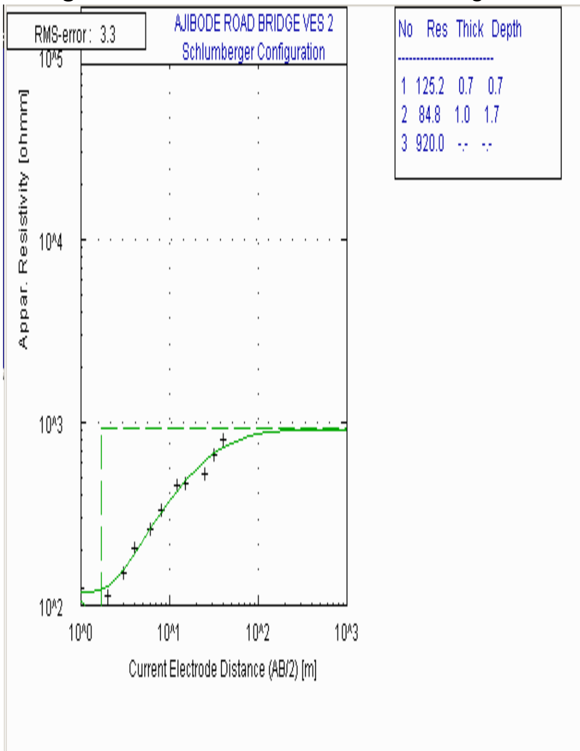

Figure 18: Geoelectic Curve for Bridge site VES 2

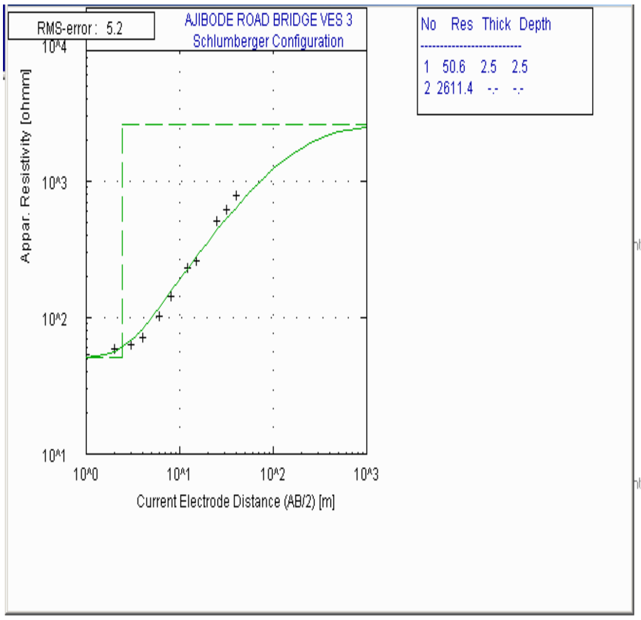

Figure 19: Geoelectic Curve for Bridge site VES 3

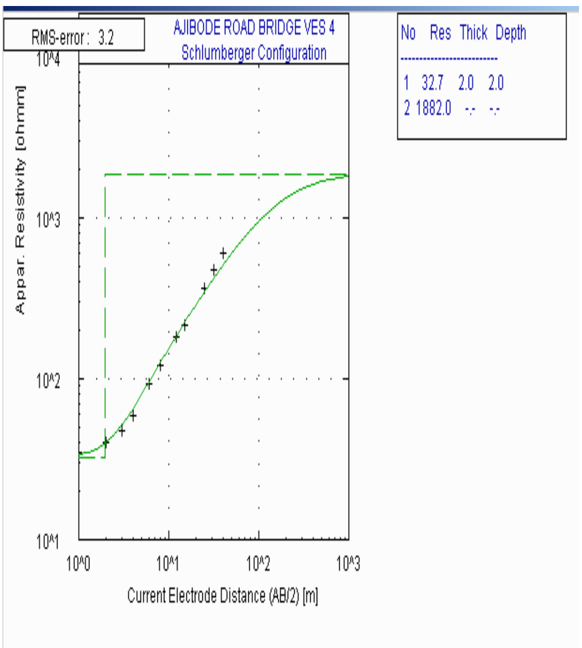

Figure 20: Geoelectic Curve for Bridge site VES 4

Table 3: Summary of geo-electric curve interpretation of the VES of Ajibode road bridge

Layer	Resistivity (Ω-m)	Thickness (m)	Depth (m)	Probable Lithology	Types of curve
VES 1					
1	320	0.7	0.7	Top soil	
2	138	1.1	1.8	Weathered basement	H-type
3	2853	-	-	Fresh basement	
VES 2					
1	125	0.7	0.7	Top soil	H-type
2	85	1.0	1.7	Weathered basement (clayey)	
3	920	-	-	Fresh basement	
VES 3					
1	51	2.5	2.5	Top soil	A-type
2	2611	-	-	Fresh basement	
VES 4					
1	33	2.0	2.0	Top soil	A-type
2	1882	-	-	Fresh basement	

GEOELECTRIC SECTION: Geoelectric section for the study area was drawn along VES 1-VES 7 for the road (figure 21) and for VES 1-VES4 at the bridge site (Figure 22). The geoelectric section for the road is characterize by relatively thin layer of topsoil, thick highly weathered basement (clayey) and fractured/fresh bedrock layer except for VES 7, where lateritic pan and weathered basement is observed. (Figure 21). The excavated portion along the investigated road is as shown in figure 23

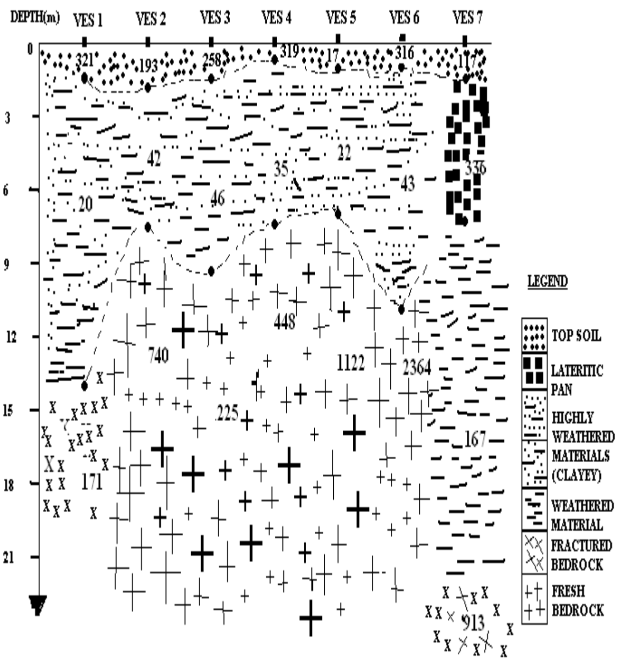

Figure 21: Geoelectric Section from VES 1-VES 7 along Abadina-Ajibode Road.

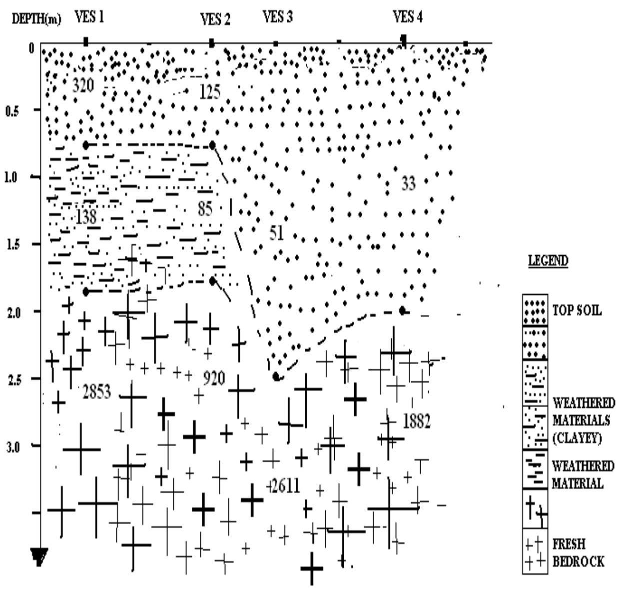

Figure 22: Geoelectric Section from VES 1-VES 4 for Ajibode bridge site.

Figure 23: Excavated portion along the investigated road

DATA PRESENTATION AND INTERPRETATION FOR DUTCH CONE PENETROMETER TEST

A penetrometer is similar to a miniature pile foundation that forces the soil aside in a complex pattern of shear. While the force required to advance the point, Q_0, is related to shear strength, many other factors are involved, similar to those of importance in pile bearing capacity. The most significant factors are:

1 c and Φ of soil.
2 Overburden stress, λ Z
3 Neutral stress μ
4 Geometry of penetrometer
5 Method of driving
6 Effect of driving on μ, Φ, c.

For a clay which a strength can be approximated by a single penetrometer tests that is independent of changing confining stress and changing hydrostatic neutral stress, μ, the resistance Q_0 can be approximated by

$Q_0 = N_p . A$

$S = Q_0 = N_p . A$

In this expression the dimensionless penetrometer factor, N_p, embodies the shape of the device and the mode of driving, and A is the projected area in the direction driven. For the Dutch cone, values of N_p range between 5 for very sensitive soils to 9 for medium plasticity clays of low sensitivity. For dynamic penetrometers, the energy of the hammer of weight W, falling a distance h with a total mechanical efficiency of m is mWh. If the distance penetrated by N hammer blows is S, then the static and dynamic resistance are related:

$Whm = Q_0 S$

$Q_0 = \underline{WhmN}S$

$Q_0 = {}_sN_pA$

$S = \underline{WhmN}SN_pA$

The summary of the Cone Penetrometer Test values is given in Table 4, showing the penetrative resistance (P.R), the allowable bearing pressure (qa), the ultimate bearing capacity (qu) and probable materials present.The cone penetrometer test curves for CPT 1-CPT 4 are shown in Figures 24-27. It consists of two layers which include competent layers and non-competent layer. The penetrative resistance in CPT 1-CPT 4 range from 5-40Kg/cm^2 with a mean of 18Kg/cm^2 at depth range from 0.25-1.0m (table 4). This is a characteristic of non-competent materials which is topsoil. At depth range of 1.25-1.75m, the penetrative resistance at CPT 1 and CPT 2 range from 25-250Kg/cm^2 with a mean of 148Kgcm^2, this is a characteristic of competent materials which is weathered basement. CPT 3 and CPT 4 penetrative resistance range from 5-10Kg/cm^2 with a mean of 9Kg/cm^2 at depth range from 1.0-3.75m but from depth range between 4.0m and 5.0m, the penetrative resistance ranges from 200-250Kg/cm^2 with a mean of 225Kg/cm^2. It is a characteristic of fresh basement rock, which is competent. However, there is a fair correlation between the CPT and VES carried out at Ajibode bridge site with the depth to bedrock determined by CPT 1 and CPT 2 ranges from 1.25-1.75m and VES 1 and VES 2 determined depth to fresh bedrock ranges from 1.0-1.8m. While CPT 3 and CPT 4 depth to bedrock is 4.0-4.5m and that of VES 3 and VES 4 ranges from 2.0-2.5m.

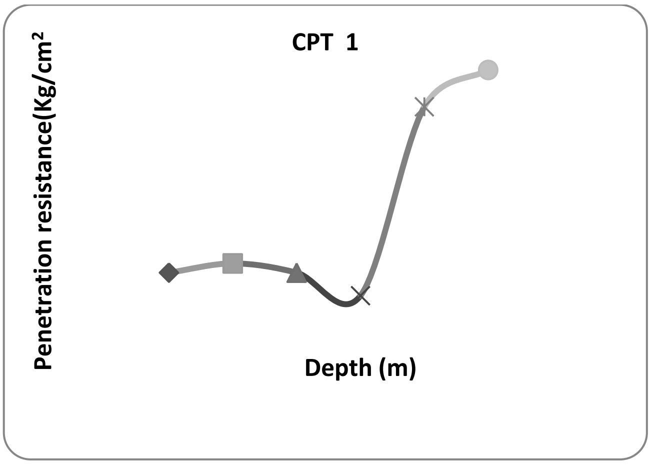

Figure 24: CPT curve for Ajibode bridge site CPT 1

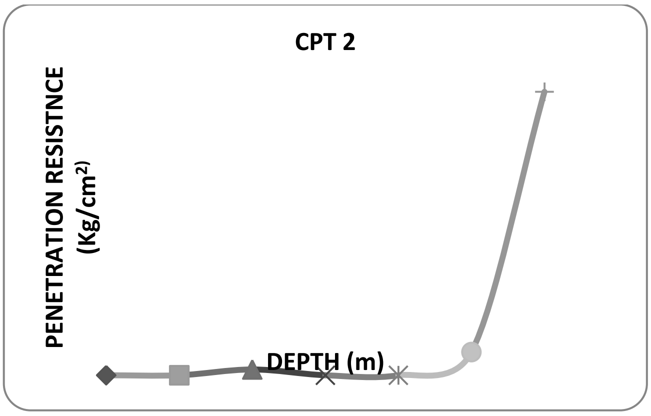

Figure 25: CPT curve for Ajibode bridge site CPT 2

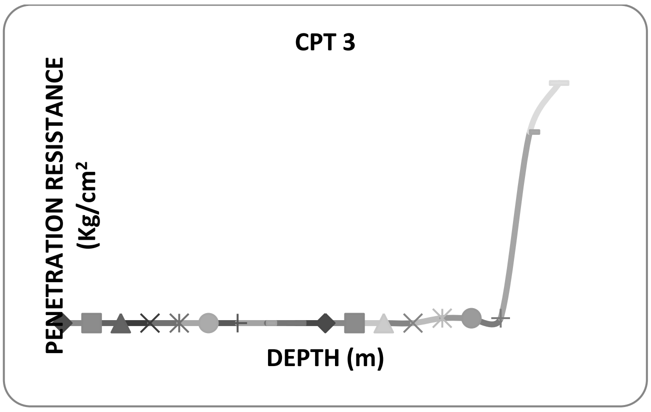

Figure 26: CPT curve for Ajibode bridge site CPT 3

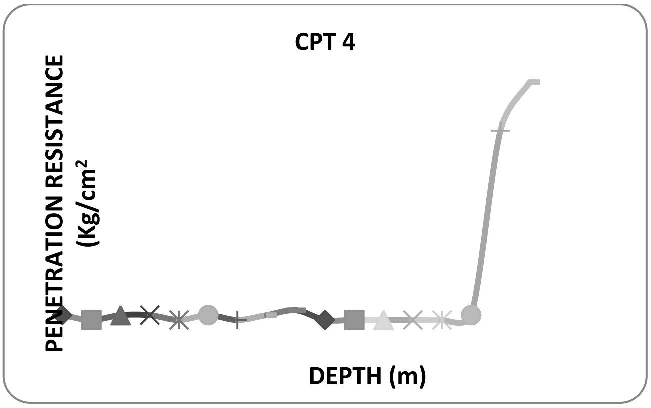

Figure 27: CPT curve for Ajibode bridge site CPT 4

Table 4: CPT table of values for the ultimate bearing capacity of the bridge site

CPT 1	DEPTH (m)	P. R. ((Kg/cm2)	Qa ((Kg/cm2)	qu (Kg/cm2)	qu (KN/m2)	MATERIAL PRESENT
	0.25	30	81.00	243.00	23814.0	Non-competent
	0.50	40	108.00	324.00	31752.0	
	0.75	30	81.00	243.00	23814.0	
	1.00	5	13.50	40.50	3969.0	
	1.25	210	567.00	1701.00	166697	competent
	1.50	250	675.00	2025.00	198450	
CPT 2	0.25	5	13.50	40.50	3969.0	Non-competent
	0.50	5	13.50	40.50	3969.0	
	0.75	10	27.00	81.00	7938.0	
	1.00	5	13.50	40.50	3969.0	
	1.25	5	13.50	40.50	3969.0	
	1.50	25	67.50	202.50	19845.0	
	1.75	250	675.00	2025.00	198450	Competent
CPT 3	0.25	5	13.50	40.50	3969.0	Non-competent
	0.50	5	13.50	40.50	3969.0	
	0.75	5	13.50	40.50	3969.0	
	1.00	5	13.50	40.50	3969.0	
	1.25	5	13.50	40.50	3969.0	
	1.50	5	13.50	40.50	3969.0	
	1.75	5	13.50	40.50	3969.0	
	2.00	5	13.50	40.50	3969.0	
	2.25	5	13.50	40.50	3969.0	
	2.50	5	13.50	40.50	3969.0	
	2.75	5	13.50	40.50	3969.0	
	3.00	5	13.50	40.50	3969.0	
	3.25	5	13.50	40.50	3969.0	
	3.50	10	27.00	81.00	3969.0	
	3.75	10	27.00	81.00	3969.0	
	4.00	10	27.00	81.00	3969.0	
	4.25	200	540.00	1620.00	158760	Competent
	4.50	250	675.00	2025.00	198450	
CPT 4	0.25	10	27.00	81.00	7938.0	Non-competent
	0.50	5	13.50	40.50	3969.0	
	0.75	10	27.00	81.00	7938.0	
	1.00	10	27.00	81.00	7938.0	
	1.25	5	13.50	40.50	3969.0	
	1.50	10	27.00	81.00	7938.0	
CPT 4	1.75	5	13.50	40.50	3969.0	Non-competent
	2.00	10	27.00	81.00	7938.0	
	2.25	15	40.50	121.50	11907.0	
	2.50	5	13.50	40.50	3969.0	
	2.75	5	13.50	40.50	3969.0	
	3.00	5	13.50	40.50	3969.0	
	3.25	5	13.50	40.50	3969.0	
	3.50	5	13.50	40.50	3969.0	
	3.75	10	27.00	81.00	7938.0	

	4.00	200	540.00	1620.00	158760	Competent
	4.25	250	675.00	2025.00	198450	

CONCLUSION

The geophysical and geotechnical methods of foundation investigation carried out in the study area have been effective in characterizing the sub-surface materials that underlies the study area as well as depth to bedrock. The results obtained from the Vertical Electrical Sounding (VES) carried out on the Abadina-Ajibode road, shows 3 to 4 geoelectric layer which include: topsoil, highly weathered basement (clayey formation), slightly weathered basement/weathered material and fresh bedrock (basement). There is an exception in VES station 7 which have a lateritic pan. While for the bridge site there is appreciable correlation between the VES results and the CPT results obtained, which revealed 2-3 geoelectric layer: the topsoil, weathered basement and fresh bedrock. For road construction purposes, the highly weathered basement (clayey formation) cannot be used. Therefore it has to be excavated and fill with lateritic materials which are more stable. For the Bridge site, the high resistive layer envisaged for resting the Bridge foundation is the fresh bedrock which is suitable and coincides with 1m thick overburden. This is because the depth of foundation for any engineering structure should be greater than 1m, which is almost the same with the thickness of the overburden of the Ajibode Bridge site which implies the bridge will rest on competent bedrock beneath the soil subsurface.

RECOMMENDATION

The highly weathered basement/ clay formation is not good as sub-base over which construction can be made. It is recommended that for any building/construction purposes, the clayey materials should be excavated away because of their unstable characteristics and the land re-filled with high stability lateritic materials. For the bridge site, pile foundation may not be necessary since the foundation (greater than 1m) would have entered into the bedrock. However if pile foundation is used, the length of the pile may be short.

ACKNOWLEDGEMENTS

My unreserved appreciation goes to Almighty Allah for his countless mercies and protection throughout my undergraduate days, and my entire life. (Al-Hamdullahi). I specially thank my supervisor Dr. M.A. Oladunjoye, whose excellent supervision led to the successful completion of this research work. I also appreciate his patience, guidance, kindness and fatherly advice throughout the task. My utmost appreciation goes to my parents Alhaji Mohammed-Rabiu Agboola Farinde and AlhajaFatimotAdenikeAdunni Farinde as well as my wife Tawakalit Adeoti-Farinde

My acknowledgements goes to my dad and mum in person of Overseer and Deaconess M. O Oni. My appreciation also goes to Dr Olugbenga A. Ehinola of department of geology, University of Ibadan, Oyo state.

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