Investigation of Road Failure at Ogun-Osun-Alabata Road, Nigeria, Using Vertical Electrical Sounding Technique

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Abstract

Electrical resistivity survey was carried out around Abeokuta area of Ogun State, Nigeria, to study the subsurface geologic layer with a view to investigating the failure in Alabata road that stretches about 1000 m. Vertical electrical sounding (VES) data were acquired with ABEM Terameter using Schlumberger electrode configuration at five (5) stations along the profile. The field data obtained was analysed using computer software (IPI2WIN) which gives an automatic interpretation of the observed apparent resistivity. The major lithologic units delineated beneath the study area are topsoil, sandy/sandy clay, and weathered basement layer. The resistivity of the topsoil layer varies from 120.7 to 392.4 ?m with thickness ranging from 1.1 -3.1 m. The sandy/sandy clay has resistivity values ranging from 22.3 - 206.0 ?m and thickness between 3.7 -20.6 m. The weathered basement has resistivity values ranging from 50.7 -1163.9 ?m with infinite depth. However, the depth from the earth's surface to the bedrock surface varies between 1.1-21.7 m. Results of the study have shown that the cause of road failure may be attributed to the sandy/sandy clay nature of the first layer.

Keywords: *Electrical resistivity, Vertical Electrical Sounding, Lithologic units, Road failure, Apparent resistivity*

Introduction

The statistics of failures of structures such as roads, buildings, dams and bridges throughout the nation has increased geometrically (Akintorinwa and Adeusi, 2009). Therefore the usefulness of geophysical investigation in engineering sector of our economy cannot be overemphasized. In recent years, many engineering applications (civil and geotechnical) involved geophysical investigation as it provided information in the design process of structure and utilities; as well as dams, bridges, highways and communication masts (Falowo and Akintorinwa 2015).

Road network is considered very vital in the economy of any country especially in developing states. Meanwhile, Nigerian roads contain lot of pot holes, faults and sometimes discontinuities. Major highways in Nigeria are known to fail shortly after construction and well before their design age because of absence of thorough subsurface investigations.

Geo-scientists are utilizing the advancement of geo-physical tools investigating the earth, which assist in oil, groundwater and mineral exploration. There are numerous methods available in field of geophysics and such include; electrical resistivity method, seismic method, gravity method, magnetic method and electromagnetic method, among which electrical method is commonly used for groundwater exploration. Resistivity method is one of the widely used methods to understand the formation characterization. The method involves the use of direct current, or alternating current with frequencies less than ten cycles per second (Battacharya and Patra 1969).

Road pavement failure can be defined as a discontinuity in a road network resulting from cracks, potholes, bulges and depression. A road network is supposed to be a continuous stretch of asphalt layer for a smooth ride. Visible cracks, potholes and depressions generally regarded as road failure may punctuate such smooth ride (Rahaman 1976, Aigbedion 2007). Flexible highway (i.e. good and well developed interconnectivity of roads) aids easy and smooth vehicular movement, and have been very useful for transportation of people, goods and services from one point to another, especially in developing countries where other means of transportation such as rail, underground tube, air, and water transportation systems have remained largely undeveloped. However, bad portions of road, many of which result from poor construction or incompetent sub-grade and sub-base materials had been found to do more harm than good. They have been responsible for many fatal accidents, wearing down of vehicles and waste of valuable time during traffic jams (Osinowo, 2011).

Geophysical survey incorporates the Vertical Electrical Sounding (VES) and Horizontal Profiling (HP) probes. The Vertical Electrical Sounding (VES) is currently very popular with groundwater investigations due to the ease in data acquisition and interpretations. This geophysical survey method is the detection of the surface effects produced by the flow of electric current inside the earth. It provides depth and thickness of various subsurface layers and their relative water yielding capacities (Okwueze and Ezeanyim, 1985).

In vertical electrical sounding (VES) the goal is to observe the variation of resistivity with depth. The technique is best adapted to determining depth and resistivity for flat-lying layered rock structures, such as sedimentary beds, or the depth to the water table (Ikechukwu, 2014). The Schlumberger configuration is most commonly used for potential pairs of electrodes have a common mid-point, but the distances between adjacent electrodes differ. The mid-point of the array is kept fixed while the distance between the current electrodes is progressively increased. This causes the current lines to penetrate over greater depths, depending on the vertical distribution of conductivity (Lowrie, 1997).

The Schlumberger electrode array is commonly adopted in the Vertical Electrical Sounding (VES) technique due to its field logistic advantage of having to move only two electrodes at a time. This reduces the man power requirement thereby minimizing survey cost. Where large depth of investigation is required, large electrode spacing is adopted. This is also the case when the substratum is very conductive due to high clay content or saline water intrusion and current flow lines converge, leading to shallow depth of investigation (Telford et al., 1990).

The study applied vertical electrical sounding to investigate the cause of the road failure along Alabata road. Momoh *et al.*, 2008 used VES among other methods to examine the geological factors responsible for highway failure in basement complex terrain of southwestern Nigeria. The result identified suspected geological features and the clayey sub-grade soil below the highway pavement as the major geologic factors responsible for the highway failure

Ifabiyi and Kekere (2013) examine some of the factors responsible for road failure along Ilorin-Ajase Ipo road, Kwara State Nigeria. The results showed that poor foundation materials and poor Engineering Construction have affected the rate of failure of the road along Ilorin-Ajase Ipo road. Osuolale *et al*., 2012 investigated that the pressure causes of the highway failure along Ibadan-Iseyin road, Oyo-State Nigeria. The results revealed that some samples of subgrade and sabbage materials do not conform to Federal Ministry of Works specifications for road work and this may be responsible for the road failure.

In their work, Layade *et al.,* (2017) investigated the causes of road pavement failure along Ibadan-Lagos dual carriage road. The results revealed that, the topsoil and weathered layer are composed of clay and sandy clay formation and the fractured bedrock is linked to the lithology contacts whose high porosity and permeability allows the flow of water to the surface which can be absorbed by the clay at the topsoil. However, the road structural failure may also be caused by the use of substandard construction materials and unethical construction practices.

The Study Area

The road investigated in this study is a portion of Alabata road, Abeokuta. The study area of about 1000 m lies between longitude 3^0 26' 22.61" and 3^0 26' 13.81"E and latitude from 7^0 11' 54.75" to 7^0 11' 26.01"N. Alabata road is a road that links the Federal University of Agriculture, Abeokuta (FUNAAB) with the outside world (Figures 1). The economic, educational and political sections of the university depend solely on this road. Some years ago, the road was constructed to allow easy movement to and fro the campus.

Also, the lack of drainage system along the study area has resulted in the flooding and washing away of the pavement. Over the years, the road experienced lots of failure (pot holes, faults, cracks, etc.) which affected the academic and economic growth of the institution to date.

Figure 1: Failed portion along Alabata road

Methodology

Vertical Electrical Sounding (VES) using Schlumberger array was carried out in the study area. The principal instrument used to obtain VES data from the field is ABEM (Signal Averaging System. (SAS 300) Terrameter. The Terrameter in the resistivity surveying mode operates with battery power, a resistivity meter (with an output display sufficient for current electrode separation of 1000 m).

The distance covered by the survey was about 1000 m and a total of five (5) VES data set were obtained across the failed segments of the roadway. The resistance readings at every point were automatically displayed on the digital readout and recorded. The geometric factor, G, was first calculated for all the data stations. The values obtained were then multiplied with the resistance values to obtain the apparent resistivity,

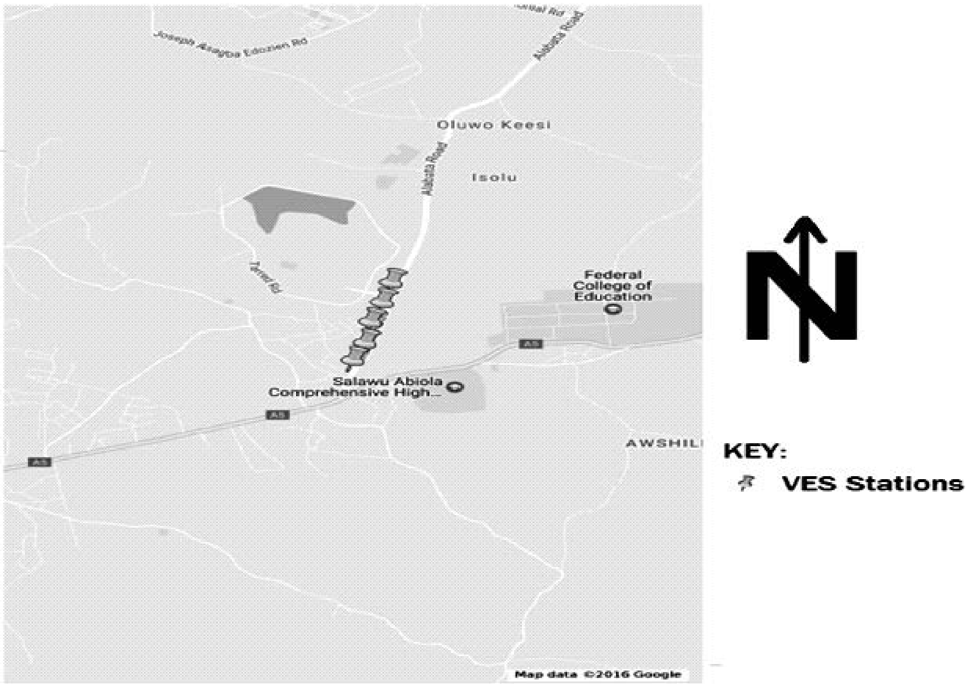

Figure 2: Study area showing the VES points

The advantages of the Schlumberger array are fewer electrodes need to be moved to each sounding and the cable length for the potential electrode is shorter. Schlumberger sounding generally have better resolution, greater probing depth, and less time-consuming field deployment than the wenner array. The disadvantages are that long current electrode cable is required, the recording instrument needs to be very sensitive, and the array may be difficult or confusing to coordinate in the field (Keller, 1966).

Discussion of Results

Vertical Electrical Sounding Profiling

VES 1 is located at latitude 7^{0} 11 '54.75" and longitude 3^{0} 26' 22.61". The curve type of VES 1 is H with three geo-electric layer. The first geo-electric layer of this figure is comprised of topsoil with resistivity values 0f 148.8 ?m and the thickness is 3.1 m and the depth of 3.1 m as shown in Table 1. The second geo-electric layer composed of sandy clay with resistivity values of 22.3 ?m and thickness is 20.6 m. The third geo-electric layer is composed of fractured basement with resistivity value of 718.5 ?m (Figures 3 and 8a).

The curve type of VES 2 located at latitude 7° 11' 47.42" and longitude 3° 26' 20.55 is KH with four geo-electric layers. The first geo-electric layer is composed of topsoil with, resistivity values of 275.7 ?m and thickness of 2.1 m and of depth 2.1 m respectively (Table 1). The second geo-electric layer is composed sandy clay with resistivity values of 109.2 ?m and thickness 10.3 m and depth of 12.4 m. The third geo-electric layer is composed of saturated sandy clay with resistivity of 19.3 ?m and thickness of 30.9 m. The fourth geo-electric layer is composed of the weathered fractured basement layer with resistivity value 341.2 ?m. (figures 4 and 8b)

In the VES 3 located at latitude 7° 11' 40.22" and longitude 3° 26' 17.91", the curve type of VES 3 is H with three geo-electric layer VES 4 has 3 geo-electric layer. The first geo-electric layer of this V.E.S is composed of topsoil with resistivity values 0f 392.4 ?m and the thickness is 1.7 m and the depth of 1.7 m. The second geo-electric layer composed of sandy clay with resistivity values of 206.0 ?m and thickness is 18.8 m (Table 1). The third geo-electric layer is composed of fractured basement with resistivity value of 71163 ?m as shown in Figures 5 and 8c respectively.

VES 4 is located at latitude 7° 11' 32.44" and longitude 3° 26' 16.61". The curve type of VES 4 is KH with four geo-electric layers. The first geo-electric layer of this VES is composed of topsoil with, resistivity values of 120.7 ?m and thickness of 1.1 m and of depth 1.1 m. (Table 1). The second geo-electric layer is composed of sandy clay with resistivity values of 94.4 ?m and thickness 3.7 m and depth of 4.8 m. The third geo-electric layer is composed of saturated sandy clay with resistivity of 14.2 ?m and thickness of 17.1 m. Figures 6 and 8d show the fourth geo-electric layer composed of the fractured basement layer with resistivity value 597.8 ?m.

The location of VES 5 is found at latitude 7° 11' 26.01" and longitude 3° 26' 13.81". The curve type of VES point is QH geo-electric layers. The first geo-electric layer of this VES is composed of topsoil with, resistivity values of 356.8 ?m and thickness of 2.1 m and of depth 2.1 m. The second geo-electric layer is composed clayey soil with resistivity values of 142.0 ?m and thickness 7.4 m and depth of 9.5 m. The third geo-electric layer is composed of lateritic soil with resistivity of 632.2 ?m and thickness of 17.1 m. The fourth geo-electric layer is composed of the fractured basement layer with resistivity value 50.7 ?m in figures 7 and 8e.

Table 1: The results of VES stations (1-5) of the study area

VES station	Resistivity (?m)	Thickness (m)	Depth (m)	Number of layers/Curve	Lithology
1	148.8 22.3 718.5	3.1 20.6	3.1 23.7	3 H	Top soil Sandy Basement rock
2	275.7 109.2 19.3 341.2	2.1 10.3 18.5	2.1 12.4 30.9	4 KH	Top soil Sandy clay Saturated sandy clay Weathered basement
3	392.4 206.0 1163.9	1.7 18.8	1.7 20.5	3 H	Top soil Sandy clay Basement rock
4	120.7 94.4 14.2 597.8	1.1 3.7 12.3	1.1 4.8 17.1	4 KH	Top soil Sandy clay Saturated sandy clay Weathered layer
5	356.8 142.0 632.2 50.7	2.1 7.4 12.3	2.1 9.5 21.7	4 QH	Top soil Sandy clay laterite Weathered basement

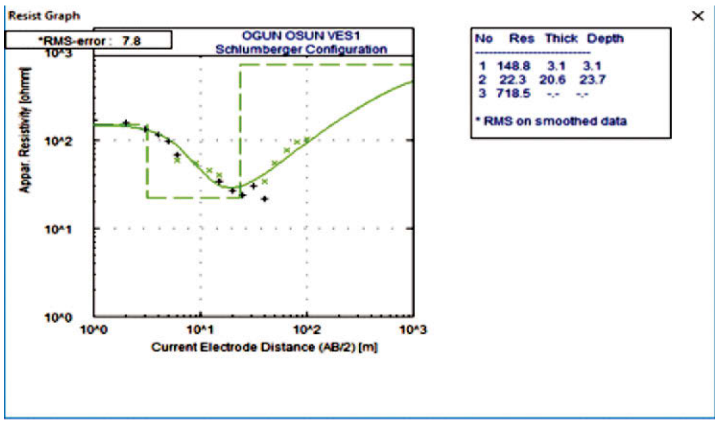

Figure 3: Interpreted Schlumberger depth sounding curve for VES 1.

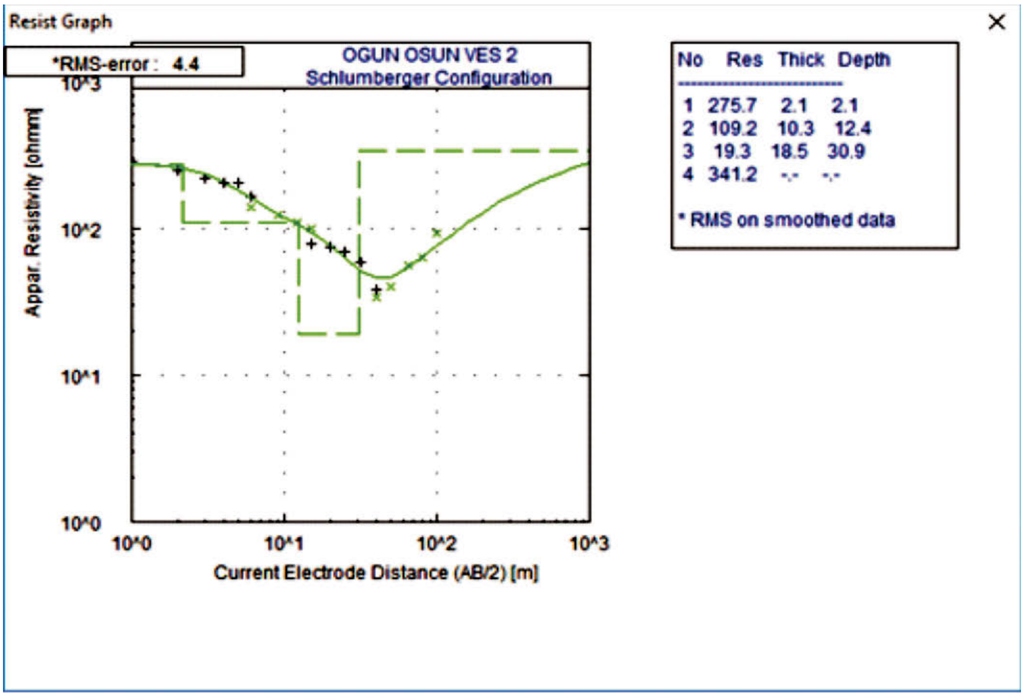

Figure 4: Interpreted Schlumberger depth sounding curve for VES 2.

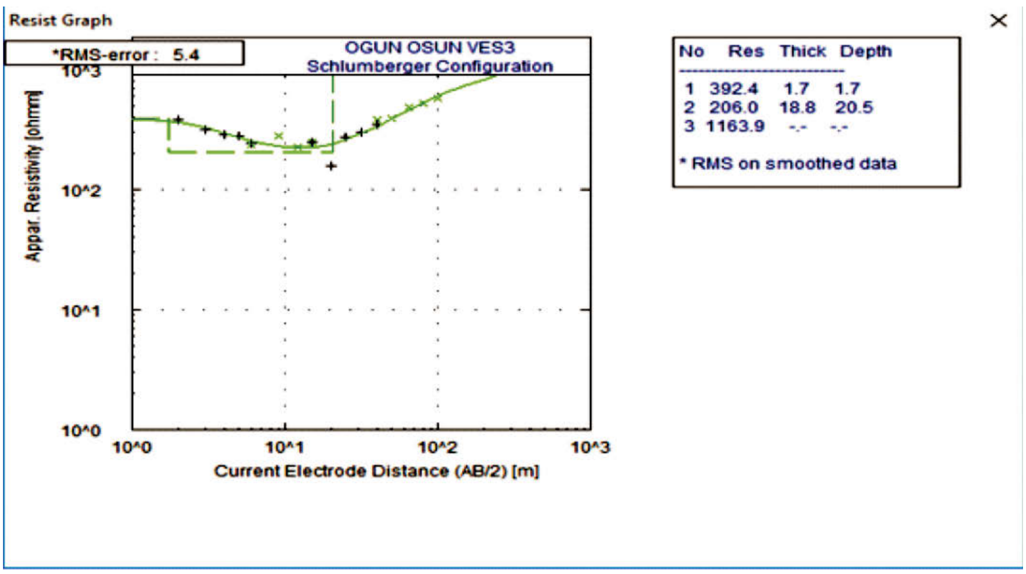

Figure 5: Interpreted Schlumberger depth sounding curve for VES 3

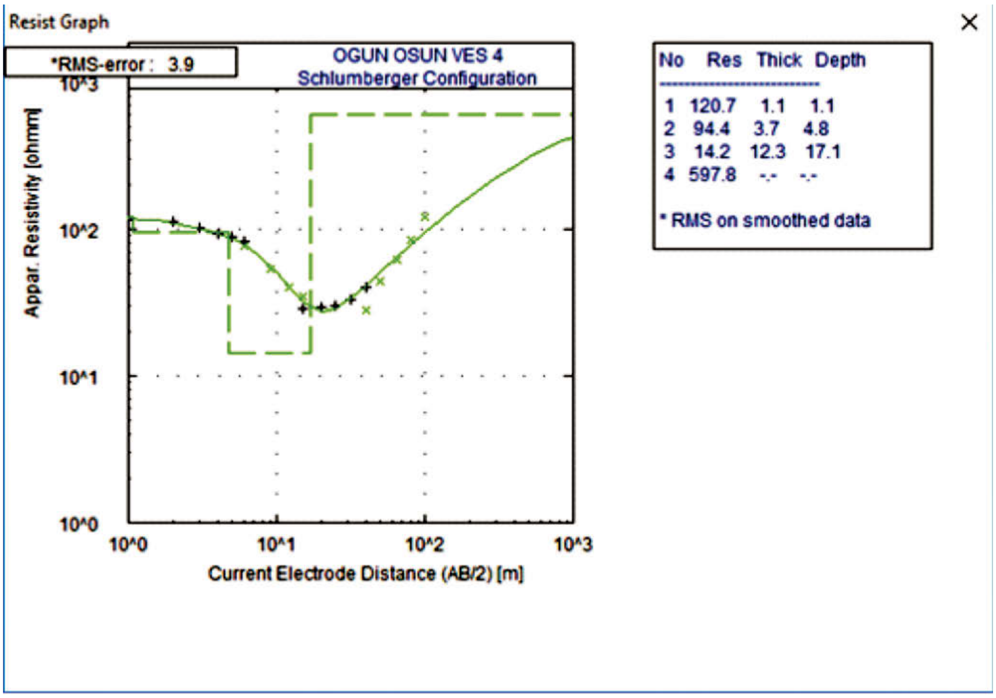

Figure 6: Interpreted Schlumberger depth sounding curve for VES 4

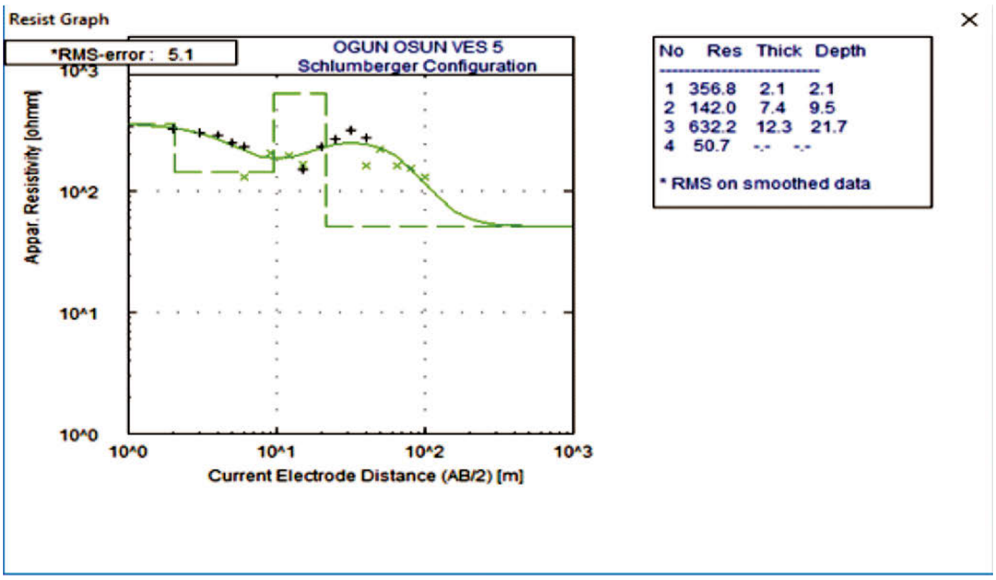

Figure 7: Interpreted Schlumberger depth sounding curve for VES 5

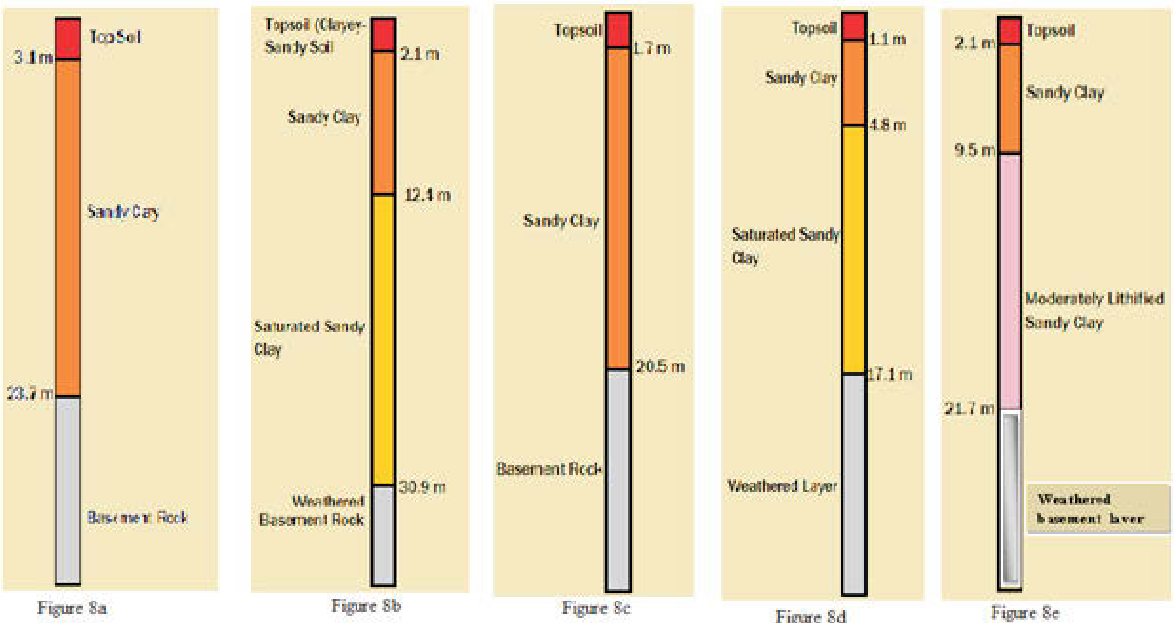

Figure 8: (a) Inferred lithology of VES 1, (b) Inferred lithology of VES 2, (c) Inferred lithology of VES 3,(d) Inferred lithology of VES 4,(e) Inferred lithology of VES 5.

Geoelectric Section

Geoelectric section for the study area was drawn along VES 1-VES 5 for the road (Figure 9). The geoelectric section for the road is characterized by layers of topsoil, sandy clay (clayey), saturated sandy clay and fractured basement layer except for VES 5, where there is sandy clay (laterite) and weathered basement. The first layer is topsoil which has resistivity ranges from 392.4 Ωm with thickness ranging from 1.1-3.1 m. The second layer resistivity (sandy clay) ranges from 22.3 -206 Ωm and the thickness ranging from 3.7-20.6 m. The fractured basement layer have resistivity ranging from 50.3 -1163.9 Ωm. The saturated sandy clay which is found in VES 2 and VES 4 have resistivity ranging from 14.2 -19.3 Ωm and thickness from 12.3-18.5m.

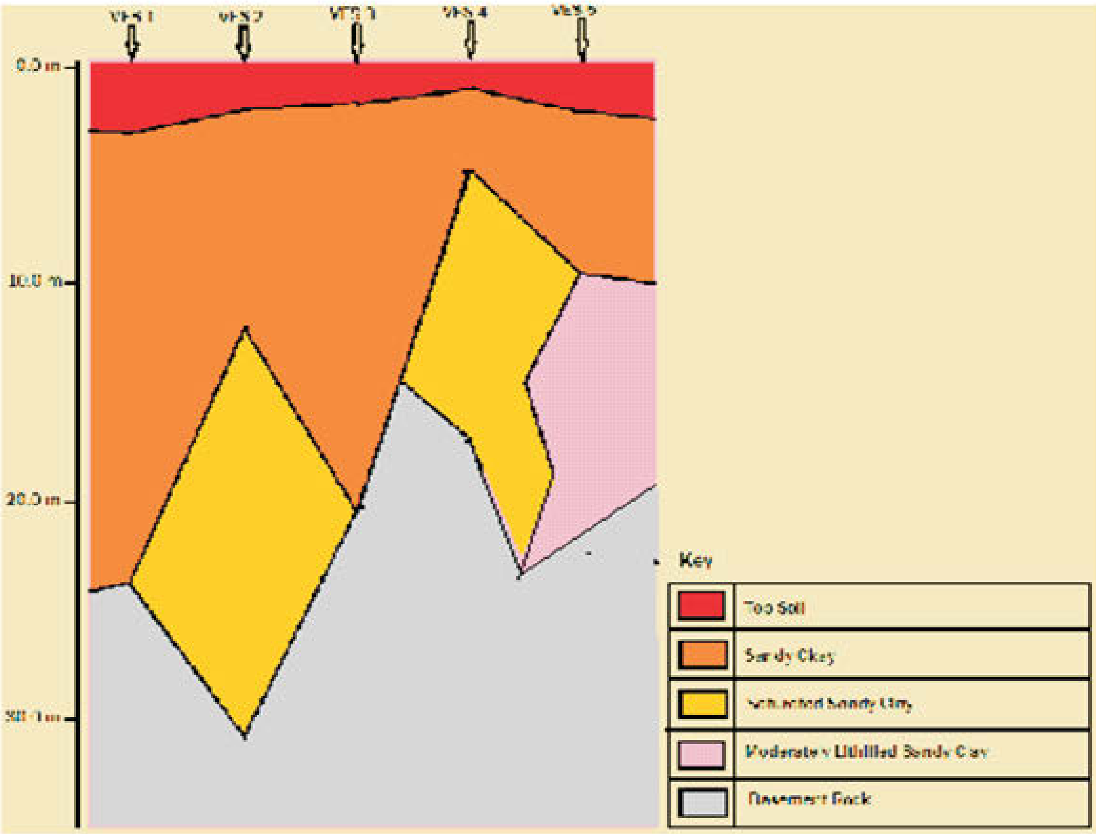

Figure 9: The Geoelectric section of the VES.

Conclusion

The geophysical investigation carried out in the study area has been effective in identifying 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 Ogun-Osun portion of Alabata road; reveal three to four geo-electric layers which include: topsoil, sandy clay (clayey formation), slightly weathered basement/weathered material and fractured basement. Base on this result, the layer with low resistivity (sandy clay) basement cannot be used for road construction purposes. Therefore it has to be excavated and fill with lateritic materials which are more stable.

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