Geophysical Studies of Highway Subsurface Integrity in a Typical Basement Complex of Southwestern Nigeria.

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ABSTRACT

Electrical resistivity and electromagnetic methods were used in evaluating the subsurface integrity of some major roads in Ibadan, southwestern Nigeria. Geophysical investigations involved the use of Very Low Frequency Electromagnetic (VLF-EM) profiling at 10m station intervals and ten Schlumberger Vertical Electrical Soundings (VES). The results from the VLF-EM study showed the presence of near surface linear geologic structures of varying lengths, depths, and attitude which suggest probable conductive zones that are inimical to the foundation of the road subgrade. These zones also coincide with most of the peak positive VLF-EM anomaly showing near surface clay materials and linear structures.

The quantitative interpretation of the VES results established the presence of three to four geo-electric layers which are: top soil, clayey soil, weathered basement, and basement with layers resistivity and thickness varying respectively from 88-553 Ω-m, 253-507 Ω-m, 63-308 Ω-m, 994-12208 Ω-m and 0.5-1.6 m, 2.4-2.6 m, 2.5-20.5 m, infinity. The unstable segment of the road is characterized by low resistivity of the near surface materials and shallow aquiferrous zone on which the road pavement was founded. Furthermore, the failure of the road is controlled mainly by geologic sequence and structures. The study further stressed the importance and relevance of geophysics in evaluating civil engineering structure such as roads.

(Keywords: geophysics, road subsurface, integrity, road pavement, road failure)

INTRODUCTION

Highway failures could be defined as a discontinuity in a road network resulting in cracks, potholes, bulges, and depression (Bagnold, 1941). Highways are very important in that they aid transportation of people, goods, and services from one place to another and also serve as links between cities and a means of disseminating information especially in places where other means of transportation remain undeveloped. The rate at which life and properties are being destroyed on the highway in many part of this country is alarming as a result bad road. Rehabilitating the road ways has become a financial burden on the Federal, State, and Local Governments, hence it become apparent to identify the causes of road failure and find a means of ameliorating the problem (Adiat, 2009).

Several factors are responsible for road failures, which include geological, geomorphological, geotechnical, road usage, construction practices, and maintenance (Adegoke–Anthony and Agada, 1980; Ajayi, 1987). Field observations and laboratory experiments carried out by Adegoke–Anthony and Agada (1980), Mesida (1981), and Ajayi (1987) showed that road failures are not primarily due to usage or design construction problems alone but can equally arise from inadequate knowledge of the characteristics and behavior of residual soils on which the road are built and non-recognition of the influence of geology and geomorphology during the design and construction phases. This is due to non-appreciation of the fact that proper design of highway requires adequate knowledge of subsurface condition beneath the highway route.

For the past two decades, geophysical investigation has proved quite relevant in highway site investigations (Nelson and Haigh, 1990). Geophysical methods particularly geo-electric method have been extensively used for a wide variety of engineering and environmental problems (Zohdy, 1974; Baker, 1980; Olorunfemi et al., 2005; Nigm, et al., 2008). Electromagnetic prospecting method has also been used in highway investigation along Akure-Ilesha and Ilesha-Owena highway, southwestern Nigeria by

Akintorinwa et al., 2008 and Momoh et al., 2008, respectively.

This research attempts to investigate the causes of failure of the highway pavement by using VLF-EM and electrical resistivity (Schlumberger technique) methods. This study will reveal the vertical discontinuity in the pavement subgrades so as to establish the highway integrity. It will also suggest some advice on remediation measures necessary to reduce the alarming rate of auto crashes and to minimize the expenditure of the government on reconstruction of failed portions of highways.

Geology of the Study Area

The geology of the study area can be explained within the context of the geology of the Precambrian basement complex of southwest Nigeria (Figure 2). It is divided into three parts; the first is located along Ibadan-Iwo Road between 7°25′35.5″ - 7°25′22.5″ and 3°59′43.2″ - 3°58′51.2″; the second is a location along Lagos-Ibadan Expressway between 7°24′59.5″ - 7°24′48.4″and 3°56′32.1″ - 3°56′34.9″; and the last location is along Aplleton Road, University of Ibadan, between 7°26′37.5″ - 7°26′18.5″ and 3°53′39.7″ - 3°53′38.7″. The elevations of the study areas above mean sea level are 208 – 224 m, 243 – 247 m and 210 – 225 m respectively. The geological map of Ibadan and the road map of Ibadan showing the study areas (Figure 1) revealed that L1 (Ibadan-Iwo road), L2 (Lagos-Ibadan expressway) and L3 (Aplleton road, University of Ibadan) are underlain by quartzite and banded gneiss.

Geophysical Survey

Geophysical investigation involving the integration of VLF-EM and Electrical Resistivity methods were carried out along both the failed and stable segments of the study areas. The VLF-EM results were presented both as profiles (that is plot of filtered real against station) and as inverted pseudo sections obtained by using Karous-Hjelt filtering software (KHFILT). The Electrical Resistivity method utilized Vertical Electrical Sounding (VES). The VES was carried out on particular portions after the VLF-EM has mapped out possible linear features. The VES curves were interpreted quantitatively by partial curve matching and computer iteration technique using WINRESIST software.

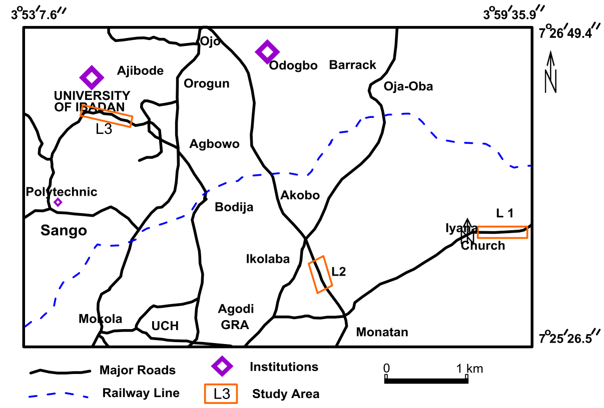

Figure 1: Base Map of the Study Area.

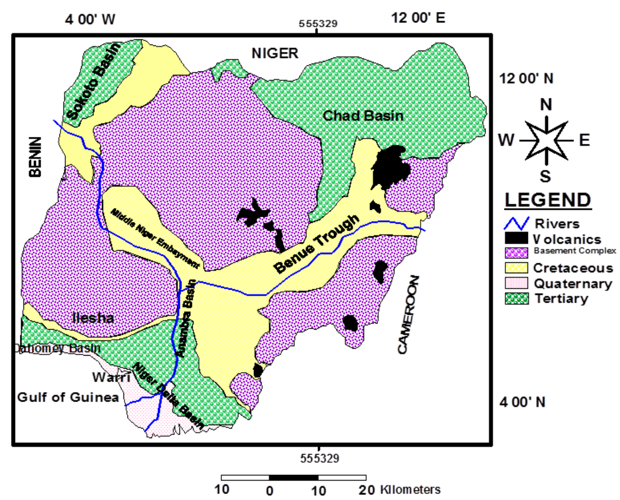

Figure 2: Geological Map of Nigeria showing Basement Complex and Sedimentary Terrain.

MATERIALS AND METHODS

Basic Theory

Geophysical investigation involving the integration of very low frequency Electromagnetic (VLF-EM) and Electrical Resistivity methods were carried out along both the failed and stable segments of the study areas. The electrical resistivity method utilized the Vertical Electrical Sounding (VES) techniques. The geophysical data were acquired with a resistivity meter (Geo-pulse Meter) which is a high quality earth science resistance meter capable of accurate measurements over a wide range of conditions. It contains both the transmitter unit, through which current enters the ground, and the receiver unit, through which the resultant potential difference is recorded. Other materials include: two metallic current and two potential electrodes, two black colored connecting cable for current and two red colored cable for potential electrodes; two reels of calibrated rope; a hammer for driving the electrodes in the ground; a compass for finding the orientation of the traverses; a cutlass for cutting traverses; and data sheets for recording the field data.

The Schlumberger array was adopted (Figure 3). In the first location, the electrode spread of AB/2 was varied from 1 to a maximum of 1110 m, in the second location from 1 to a maximum of 325 m and in the third location from 1 to a maximum of 420 m. The electrical resistivity data were processed by plotting the apparent resistivity values against the electrode spread (AB/2). This was subsequently interpreted quantitatively using the partial curve matching method and computer assisted 1-D forward modeling with WinResist 1.0 version software (Vander Velpen, 2004).

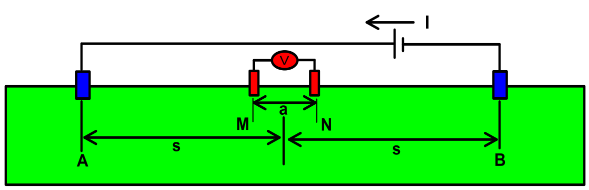

Figure 3: Sketch Diagram of Schlumberger Array.

The VLF-EM data were processed by downloading the raw real and filtered real components from the Abem-Wadi VLF-EM equipment. The data were presented as profiles (Figure 4). The Abem-Wadi measures the field strength and the phase displacement around the fracture zone. The EM data was interpreted and inversed into a 2-D section using the Karous-Hjelt filtering (Karous and Hjelt, 1983). The anomaly inflections appear as peak positive anomalies and false VLF anomaly inflections as negative anomalies (Reynolds, 1977) of the profiles.

RESULTS AND DISCUSSION

<u>The VLF-EM Profiles</u>

The plot of Filtered Real (FR) against station distances were presented as profiles and the corresponding 2D-models of the filtered real for each segment of the profiles was also presented. The presence of multiple peak positive filtered real anomalies is suggestive of inhomogeneity of near surface material. The presence of these near surfaces cross cutting linear structures is indicative of weak/incompetent geologic formation upon which the road pavement was founded which consequently accounts for its failure.

For clear and easy interpretation, Profile 1 was presented in five segments, Profile 2 in one segment, and Profile 3 in two segments (Figures 4-6). The interpretation of these profiles involves visual inspection of the profile for points where the maximum peak of the filtered real coincides with the positive anomaly from the 2D-section which suggests the presence of fractures (weak) zones.

Anomalies were delineated at twenty-four locations along Profile 1 which were labelled A1, A2, A3 …to A24. Majority of these fractures were delineated around the failed portion of this road although some occur at the stable portions of this highway. The results show that about 60% of the identified fractures on this profile underlain the intensely failed portion while 40% underlain fairly stable portion.

On Profile 2, five linear features B1, B2 … to B5 were delineated. Fractures B1, B3, to B5 occurred at the failed portion whereas B2 and B4 were detected at the fairly stable portion of the highway. This shows that about 60% of the identified fractures underlain the failed portion while 40% underlain stable portion.

Profile 3 revealed nine major fractures (C1 – C9). Fractures C1, C2, C3, C4, C5 and C6 occurred at the failed portion whereas C7, C8 and C9 were at the stable portion of the highway.

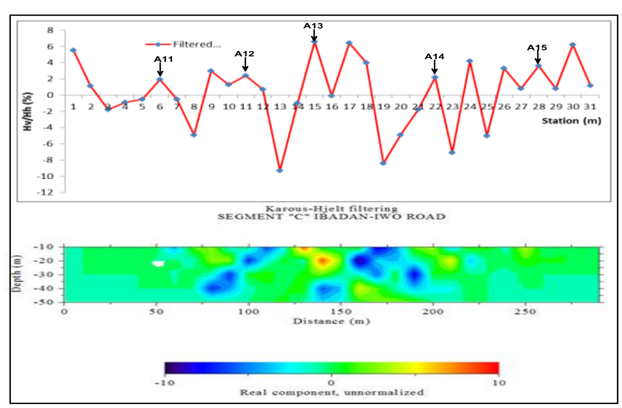

Figure 4: Typical VLF Profile and Corresponding 2-D Section.

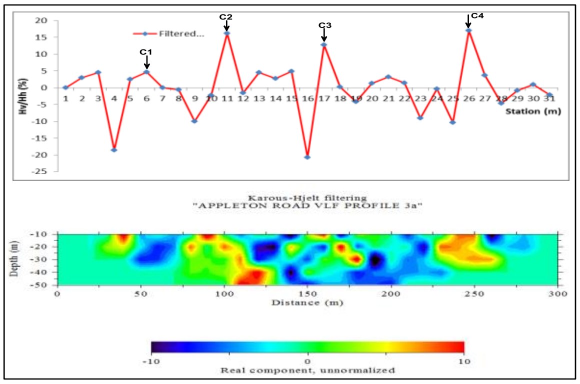

Figure 5: Typical VLF Profile and Corresponding 2-D Section.

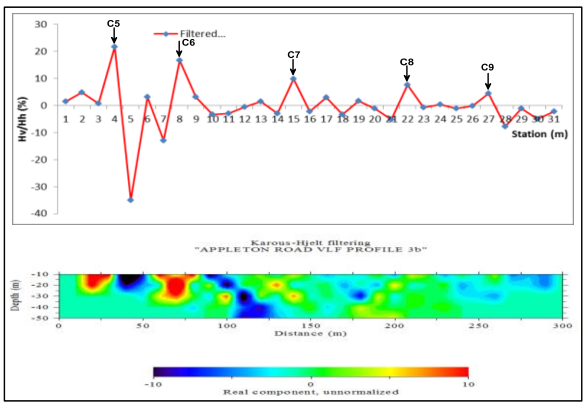

Figure 6: Typical VLF Profile and Corresponding 2-D Section.

Resistivity Sounding Curves and Geoelectric Sections

The geoelectric parameters (resistivity and depth) obtained from the curve-matching and iteration of the electrical resistivity sounding data were presented as a bar chart. The apparent resistivity values calculated were presented as sounding curves for all the VES points using WinResist. Six curve types have been identified within the study area. These are A-, H-, HA-, KH-, HQ and QH types with the H type as the predominant curve type (Figure 7).

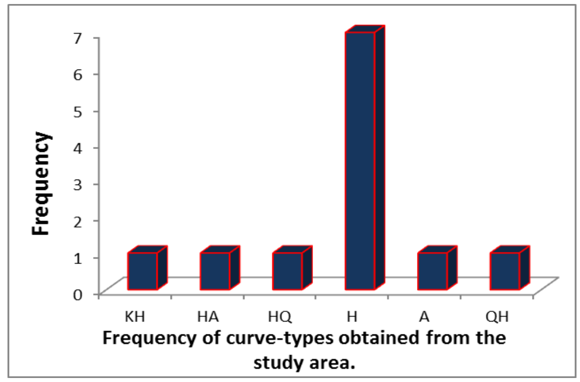

Figure 7: Frequency of Curve-Type Obtained within the Study Area.

Geo-electric Method

Electrical resistivity methods primarily reflect variations in ground resistivity (Omosuyi et. al., 2008). These variations are due to observable contrast between geo-electric boundaries within the subsurface. The 2-D view of the geo-electric parameters (resistivity and thickness) obtained from the electrical resistivity sounding data was used to delineate the mineralized layers.

The geo-electric section of part of Ibadan – Iwo road under investigation is approximately in east-west direction (Figure 8). Three to four subsurface geo-electric layers were delineated i.e. the topsoil, clayey soil, weathered layer and the basement. The topsoil has resistivity values ranging from 26.2 – 158.1 Ω-m and thickness between 0.6 – 1.1 m. It is however observed from the geo-electric section that VES 1, 3 and 5 (the extremely bad portion of the road are characterized with top soil of low resistivity values of between 88 - 109 Ω-m suggesting clayey top soil with possibly high moisture content.

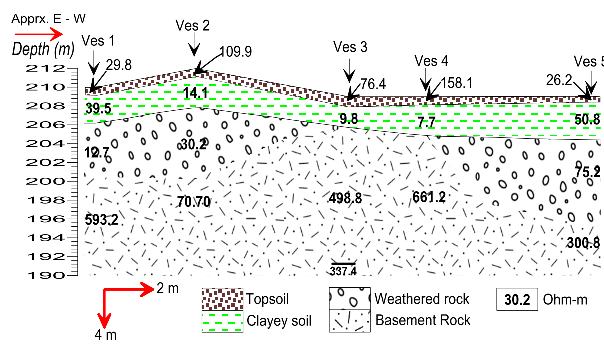

Figure 8: Geo-electric Section along L1 (Ibadan-Iwo Road).

The second layer manifest as clayey soil and has resistivity values of between 7.7 – 50.8 Ω-m and thickness between 2.1 – 4.0 m. This layer is highly porous and also corroborate high failure rate. The third layer is the weathered basement which appeared under VES 1, 2, and 5 with resistivity values ranging between 12.7 – 75.2 Ω-m and thickness 5.7 – 9.1 m. The presence of this layer explains why the road is unstable at these segments (i.e. under VES 1, 2 and 5) it is however relatively stable under VES 3 and 4 with a near surface basement structure. This layer suggests a high degree of saturation which corresponds to the aquiferrous zone in the area.

The fourth layer is the basement whose resistivity values vary from 300.8 – 661.2 Ohm-m and it is of infinite depth. Depth to the bedrock varies from 4.1 – 17.8 m.

The road pavement in this location is founded on an incompetent (weak) layer which account for the incessant failure being observed along the road.

Figure 9 shows the geo-electric section of location 3 (Aplleton Road) which delineates only three geo-electric layers drawn in the south - north direction cutting across VES points 8, 9, 10, 11, and 12. The topsoil on this section has resistivity values ranging from 65.3 to 1038.6 Ohm-m with thickness between 0.9 to 2.3 m. It is however observed from the geoelectric sections that VES 10 is underlain by a topsoil of low resistivity (65.3 Ohm-m) suspected to be clayey soil with possibly high moisture content. This portion is porous and also underlain by a thin weathered aquiferous layer, which explains why this portion failed. Beneath the topsoil layer is the weathered layer with resistivity values ranging between 26.2 and 242.9 Ohm-m and layer thickness which ranges from 2.9 to 19.0 m.

This layer forms the major aquifer unit around this area due to its high degree of saturation with highest potential under VES 11 and VES 12 forming a basement depression (a water collection center). The basement unit with resistivity values ranging from 259.4 to 2447.7 Ohm-m is identified as the fresh bedrock along the section and is of infinite depth. Depth to the bedrock varies from 4.0 - 20.4 m. The groundwater in the area is mostly located in the weathered layers. In most of the unstable sections, the groundwater level is found to be close to the surface. This suggests that the road pavement in the unstable section is founded on an incompetent layer which accounts for the incessant failures being observed along the road sections.

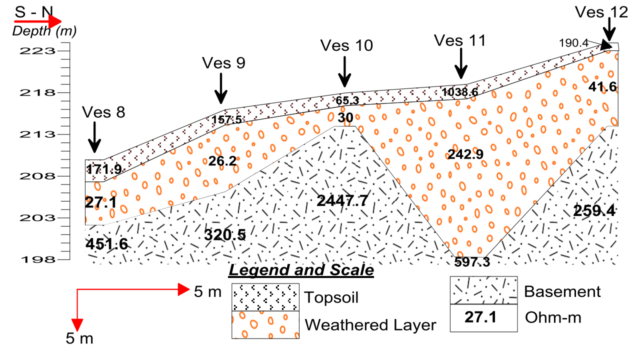

Figure 9: Geo-electric Section along L3 (Appleton Road, University of Ibadan).

CONCLUSION

Integrated geophysical methods have been used to investigate the courses of incessant road failure along some major roads in Ibadan environment, southwestern Nigeria. Results from the geophysical survey identified the causes of the road failure to include the clayey nature of the topsoil on which the road pavement is founded. Clay is highly porous but with low permeability due to poor connectivity of its pores. Therefore, it has the ability to retain water without releasing it, leading to swelling and collapse at the exertion of pressure, subsequently leading to road failure.

The presence of structurally weak layer(s) due to near surface linear features such as fractured zones, fissures and joints, etc., which underlay the road pavement results in high groundwater accumulation and hence pavement failure.

Weathered/aquiferrous layer in most places is close to the surface which implies that the road pavement is resting within water table. This also contributes to road failures among other reasons.

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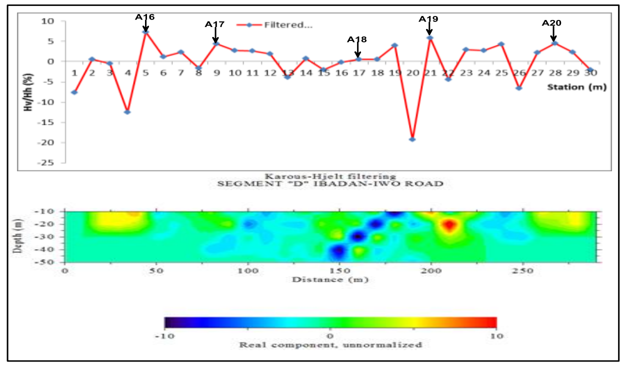
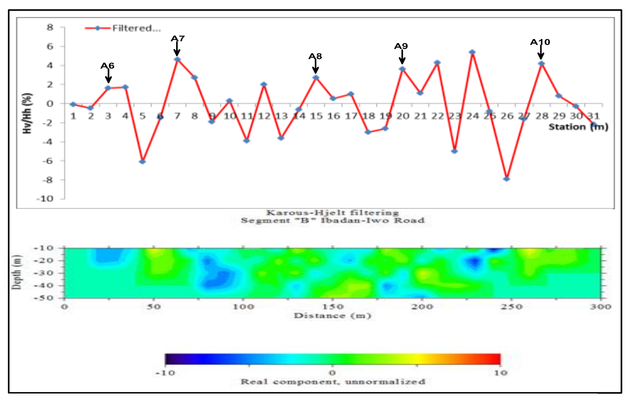
APPENDIX



VLF profile and Corresponding 2-D Section of part of Ibadan - Iwo road.



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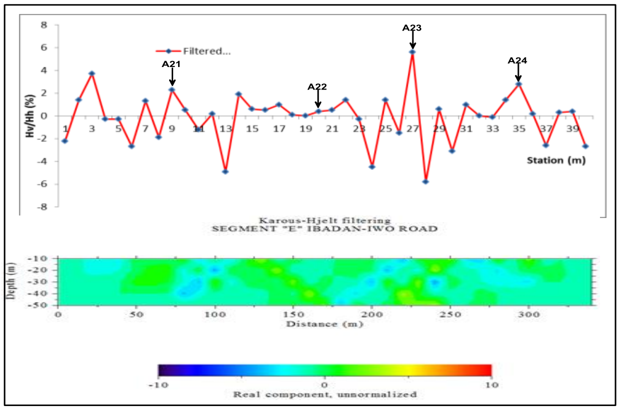

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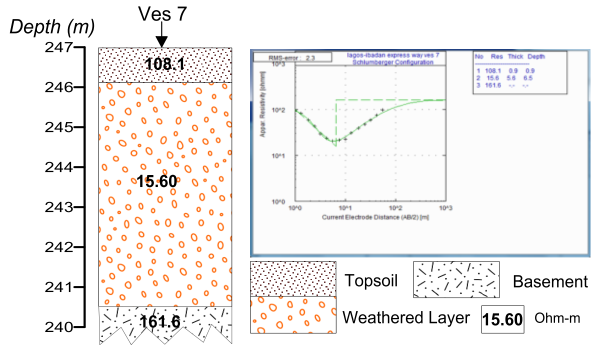
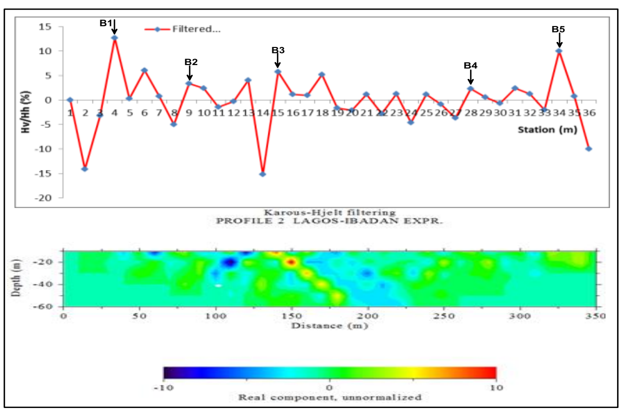
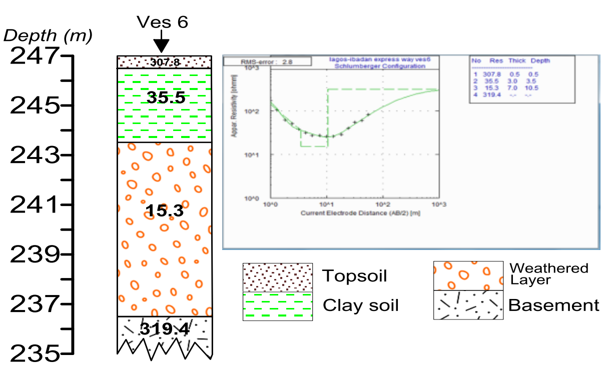


Geo-electric section along L2 (Lagos-Ibadan Way) – VES 7.



VLF profile and Corresponding 2-D Section of part of Lagos – Ibadan highway.



Geo-electric section along L2 (Lagos-Ibadan Way) – VES 6.

SUGGESTED CITATION

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