

Relevance of Geophysics in Road Failures Investigation in a Typical Basement Complex of Southwestern Nigeria.

K.A.N. Adiat, M.Tech.^{*}, A.O. Adelusi, Ph.D., and M.A. Ayuk, M.Tech.

Department of Applied Geophysics, Federal University of Technology,
PMB 704, Akure, Nigeria.

^{*}E-mail: adiatnafiu@yahoo.co.uk

ABSTRACT

Electrical resistivity and electromagnetic methods were used in evaluating the subsurface integrity of a 3 km stretch of road from Igbara-Oke to Ibuji in southwestern Nigeria. A 3km Igbara-Oke-Ibuji road was geophysically investigated using Very Low Frequency Electromagnetic (VLF-EM) profiling and lateral resistivity profiling both at 10m intervals and twenty-one Schlumberger Vertical Electrical Sounding (VES).

The results from the VLF-EM study showed 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. Also, the lateral resistivity profile showed low resistivity zones that 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 four geologic layers which are: top soil, sand/lateritic sand, 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 shallowness of the aquiferous 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, civil engineering, road engineering, road failure)

INTRODUCTION

Incessant failure of highways has become a common phenomenon in many parts of Nigeria. The problem is apparently on the cut out section of roadways within the Precambrian basement complex terrain of the country. The present condition of most of the roads in the Precambrian basement complex of south western Nigeria has stimulated the interest of various stakeholders in the usage and maintenance of our road ways. Rehabilitating the road ways has become a financial burden on the Federal, State, and Local Governments, hence there is need to identify the causes of road failure and find a means of ameliorating the problem.

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.

The geological factors influencing road failures include the nature of soils (laterites) and the near surface geologic sequence, existence of geological structures such as fractures and faults, presences of laterites, existence of ancient stream channels, and shear zones. The collapse of concealed subsurface geological structures and other zones of weakness controlled by regional fractures and joint systems along with silica leaching which has led to rock deficiency

are known to contribute to failures of highways and rail tracks (Nelson and Haigh, 1990). The geomorphological factors are related to topography and surface/subsurface drainage system.

For the past two decades, geophysics has proved quite relevant in highway site investigations (Nelson and Haigh, 1990), geophysical methods like electrical resistivity has been used in mapping subsurface geologic sequence and concealed geological structures (Olorunfemi et al., 2004). Even the electromagnetic prospecting method has been used also in high way investigation along Akure-Ilesha road southwestern Nigeria (Akintorinwa et al., 2008) including geophysical investigation of Ilesha-Owena highway failure in the basement complex area of southwestern Nigeria (Momoh et al 2007). In the present study, geophysical investigation of causes and characteristics of road failure in Igbara-Oke-Ibuji, a basement complex area, has been carried out.

GEOLOGY OF THE STUDY AREA

The study area falls within the basement complex of southwestern Nigeria. The area falls within easting 0726836 (**5° 3' 18.39'' E**) to 0727120 (**5° 3' 27.77'' E**) and northing 0819608 (**7° 24' 38.76'' N**) to 0820447 (**7° 25' 6.02'' N**). The rock types in the area are low-lying undifferentiated migmatite gneiss and biotite granite (Figure 2 and 3).

SITE DESCRIPTION

Igbara-Oke is about 10km from Akure; however, the study area covered about 3km from Igbara-Oke end of Igbara-Oke-Ibuji road. The first 500m from Igbara-Oke end represents the stable segment of the road. The elevation above sea level ranges from 357m to 370m (Figure 1). The regional soils belong to the Ondo Association.

GEOPHYSICAL SURVEYS

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 road. A traverse of about 3000m (3km) length was established parallel to the road pavement. ABEM WADI was used for the VLF –

EM data collection along the road segment. The VLF transmitter operating at frequency of 17.6 KHz and located in Oxford, Great Britain was used for the investigation. The station to station interval of 10m was adopted for the survey.

The Electrical Resistivity method utilized Horizontal Profiling (HP) and Vertical Electrical Sounding (VES). Horizontal Profiling was carried out to know the lateral variation in ground apparent resistivity. Wenner electrode array configuration with electrode separation (a) of 10m was adopted for the horizontal profiling. The VES on the other hand entailed 1-D vertical probing of the subsurface. Owing to logistic problems, the VES investigation was restricted to the first 1050m portion of the investigated road and it was carried out at regular interval of 50m. The VES utilized Schlumberger electrode array configuration with maximum electrode separation (AB) of 200m. RD – 50 Resistivity meter was used for the resistivity investigation.

The HP was presented as profile where in the apparent resistivity values are plotted against the mid point of electrode spread (i.e. AB/2) on linear graph (Figure 5) and this was qualitatively interpreted.

The VLF-EM results were presented both as profiles (i.e. plot of raw real and filtered real against station) and as inverted pseudosections obtained by using KHFILT software. (Figures 4a-c).

The VES curves were interpreted quantitatively by partial curve matching and computer iteration technique using RESIST Software. The interpretation results were presented as sounding curves and geoelectric section (Figures 6 and 7, respectively).

RESULTS AND DISCUSSION

The VLF-EM Profiles

The plot of Raw Real (RR) and Filtered Real (FR) plotted against station distances is shown as profile. However, for clear and easy interpretation, the profile was presented in three segments shown in Figures 4a, 4b and 4c. The interpretation of this profile is mere qualitative and this involves visual inspection of the profile for points where the maximum peak of the Filtered Real coincides with the point of inflections of raw real as such

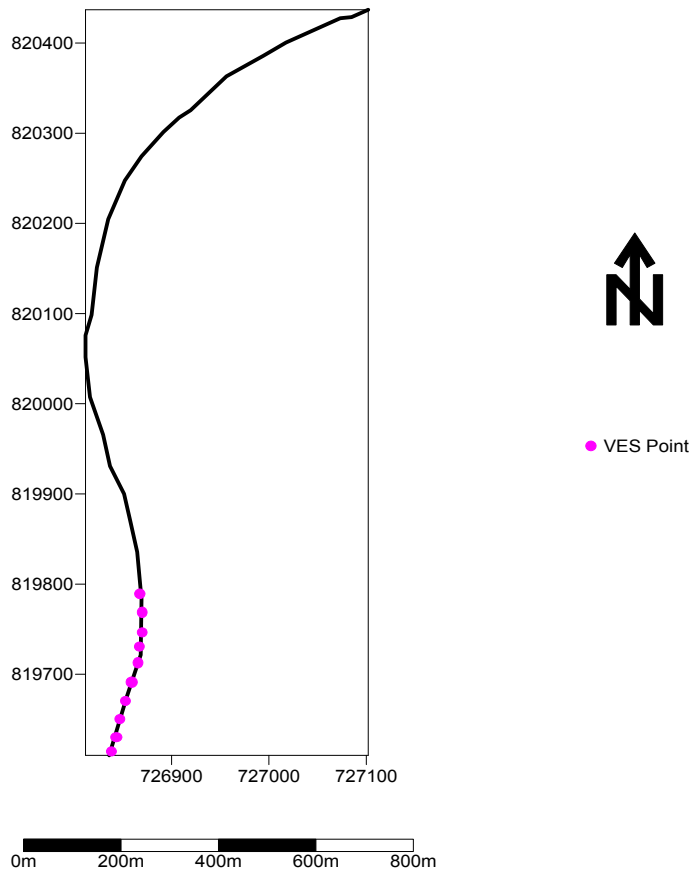


Figure 1: Basemap of the Study Area.

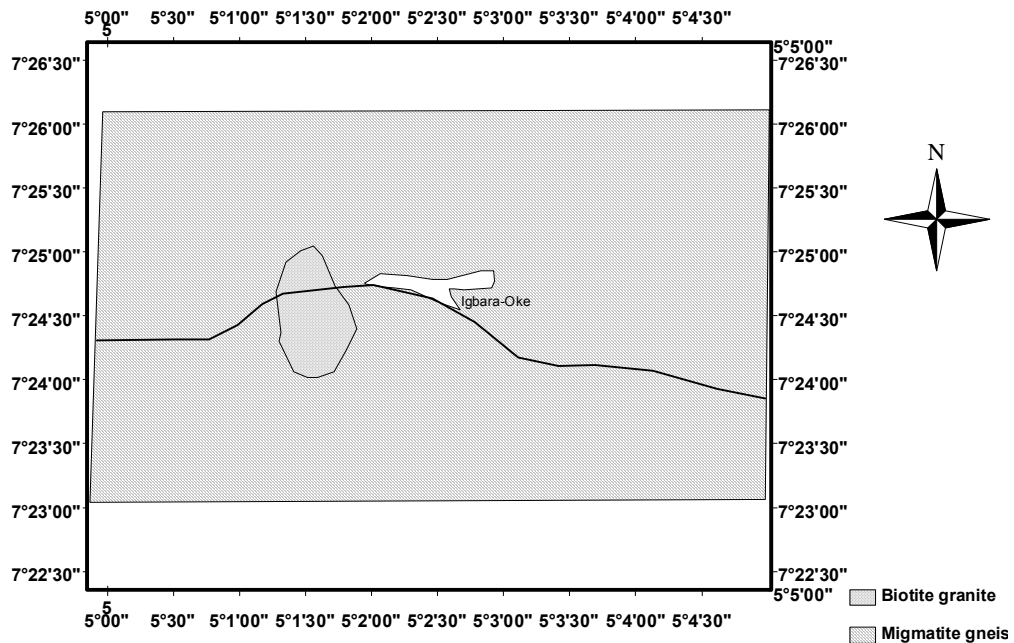


Figure 2: Geological map of the area .(After Geological Survey Agency of Nigeria,1967.)

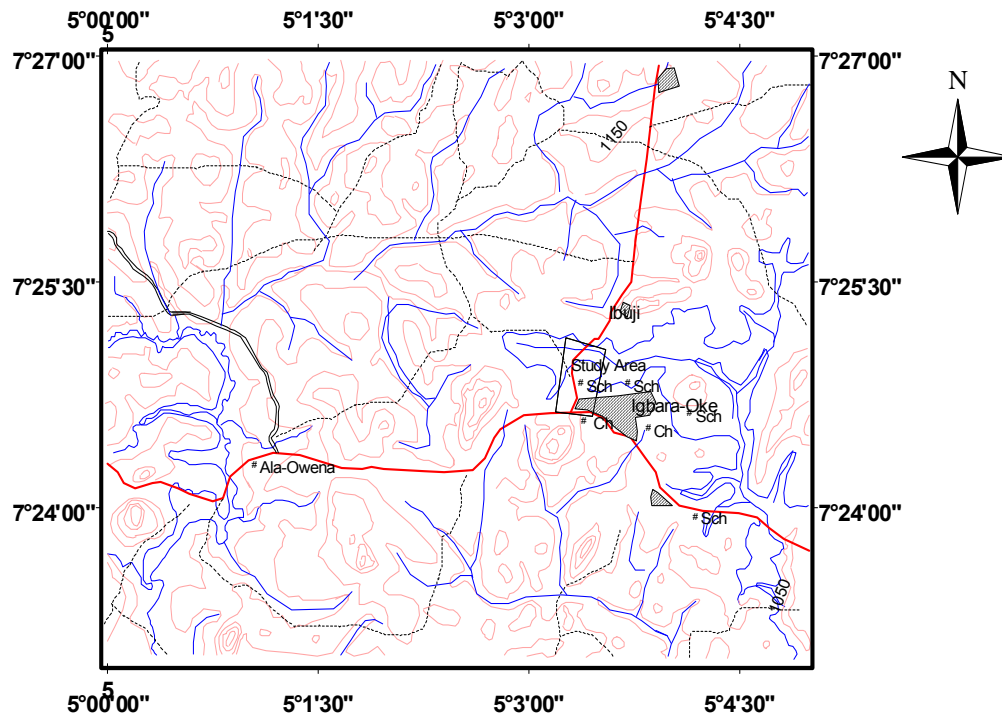


Figure 3: Topographical map of the area



points are usually suggestive of presence of conductive (weak) zones.

Several of such points were identified on the profiles; furthermore, the presence of multiple peak Positive filtered real anomalies (as observed on the profiles) is suggestive of inhomogeneity of near surface material.

The corresponding 2 – D models of the filtered real for each segment of the profile are as shown in figures 4a to 4c. The model shows that the study area is characterized with presence of linear features of different azimuthal direction (SE-NW, SW – NE etc) and of different conductivity ranges. 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.

The horizontal resistivity profile (HRP)

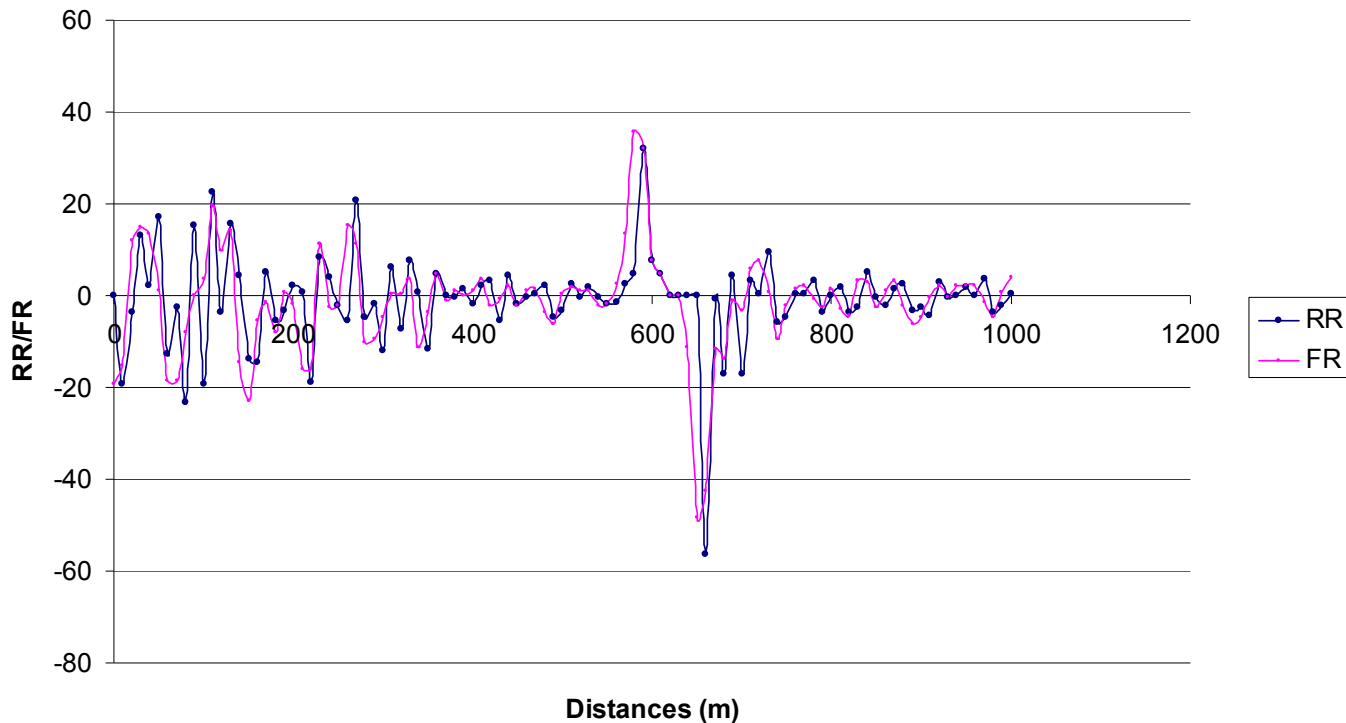
The plot of apparent resistivity against midpoint of the total electrode spread (i.e.AB/2) for each

measurement is presented as profile shown in Figure 5. The qualitative interpretation of the profile involves mere inspection of the profile for presence of low apparent resistivity as such points are indicative of conductive (weak) zones. The apparent resistivity values vary between 27 and 694 ohm-m. The presence of series of resistivity lows and highs observed on the profile is indicative of either lateral inhomogeneity in the geologic material underlay the road segment or presence of near surface features such as lineaments, fractures, joints, shear zones or clay etc.

Resistivity Sounding Curves and Goelectric Sections

Three resistivity sounding curve types were obtained from the surveyed area and these are the H, A and KH types with percentage frequency of occurrence of 52.38, 14.29 and 33.33% respectively. The results of the interpreted VES Curves are shown in table1 below while typical Curve types obtained from the area are shown in Figure 6.

Figure 4a: VLF profile for Segment 1 and Corresponding KH Section



Karous-Hjelt filtering
"IGBARA-OKE-IBUJI RD SEGMENT!"

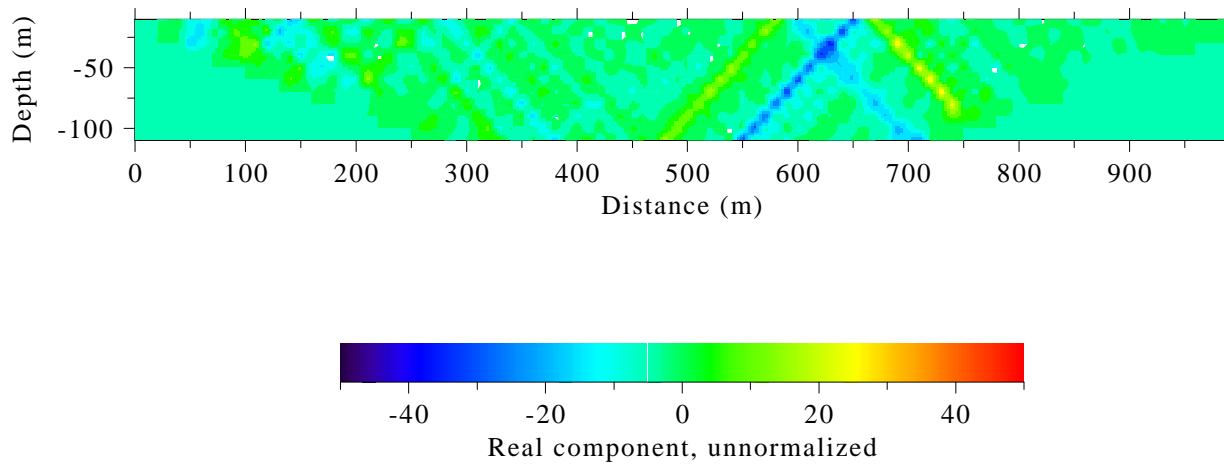
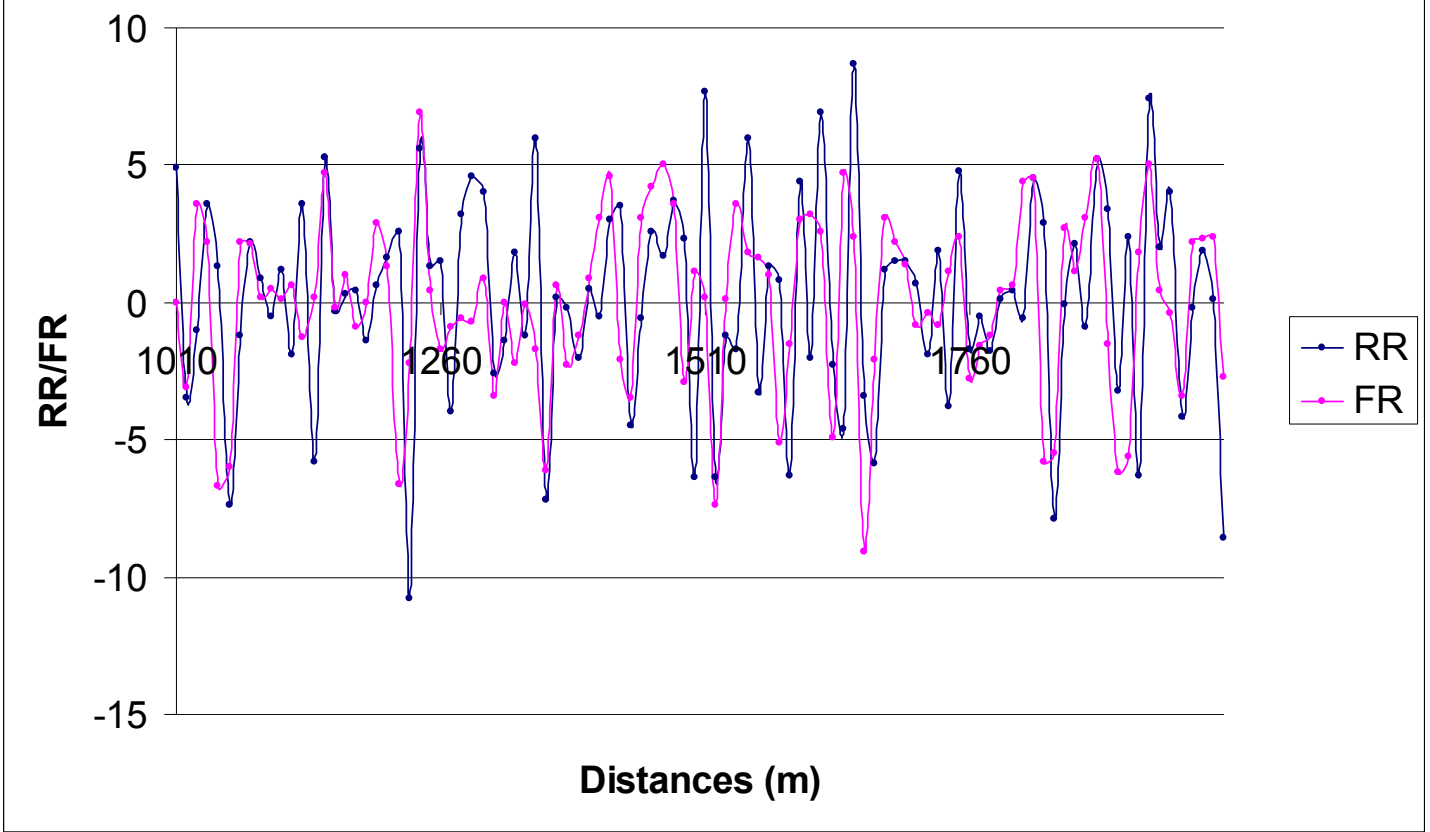


Figure 4b: VLF profile for Segment 2 and Corresponding KH Section



Karous-Hjelt filtering
"IGBARA-OKE-IBUJI RD SEGMENT 2"

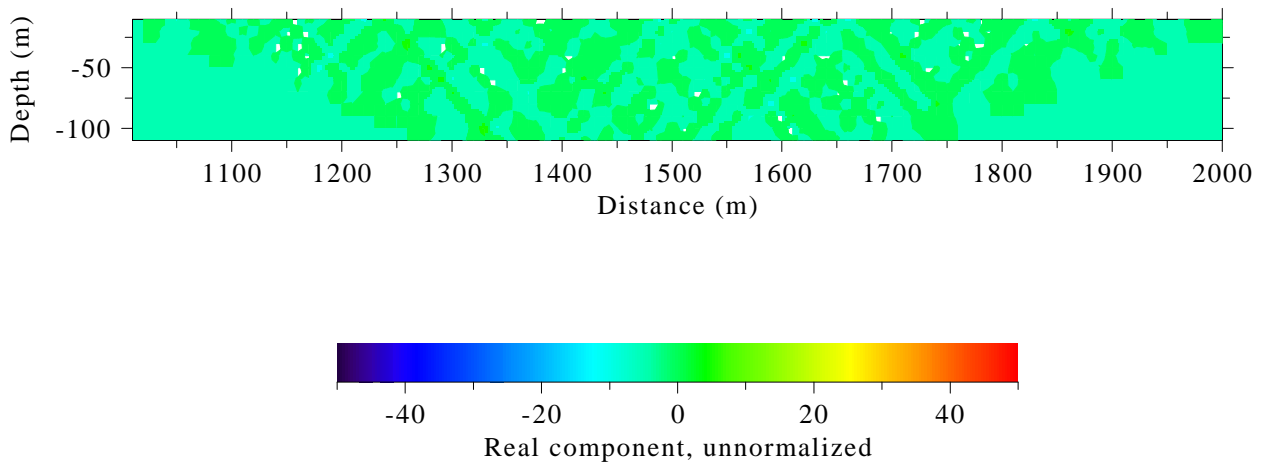
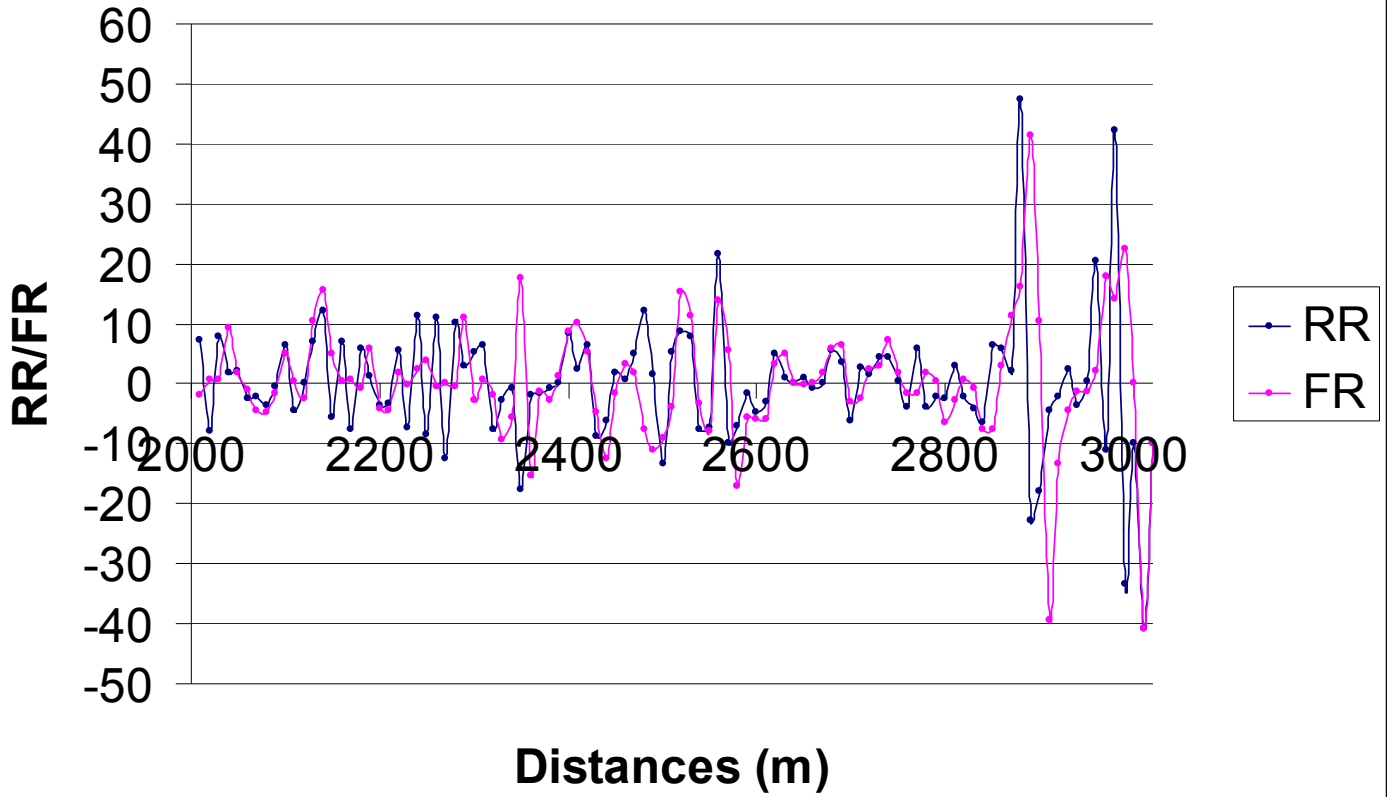
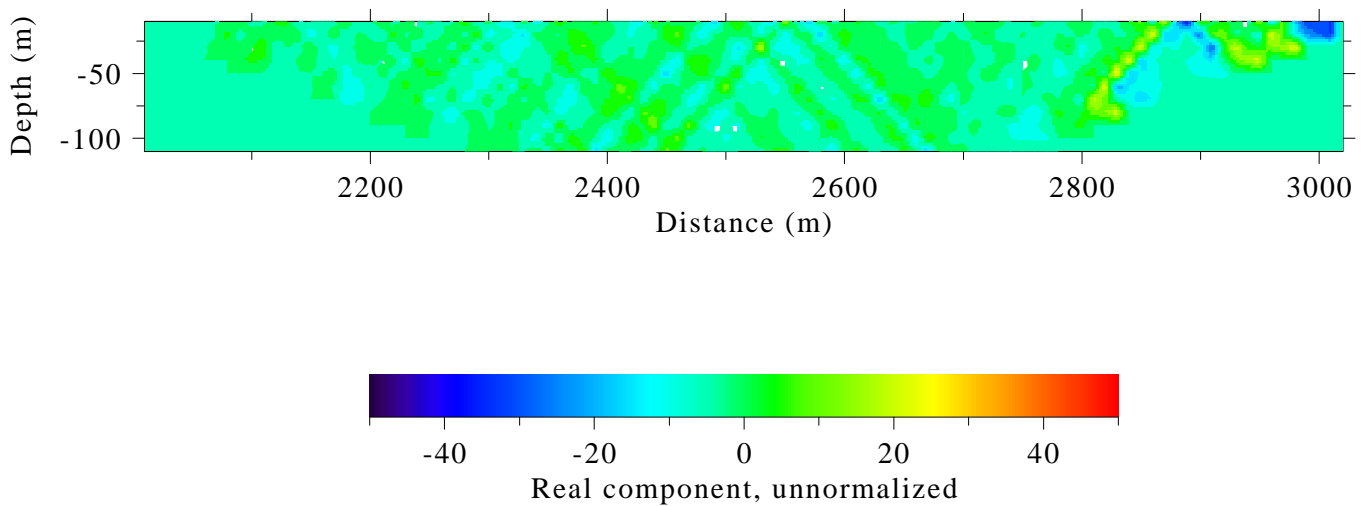
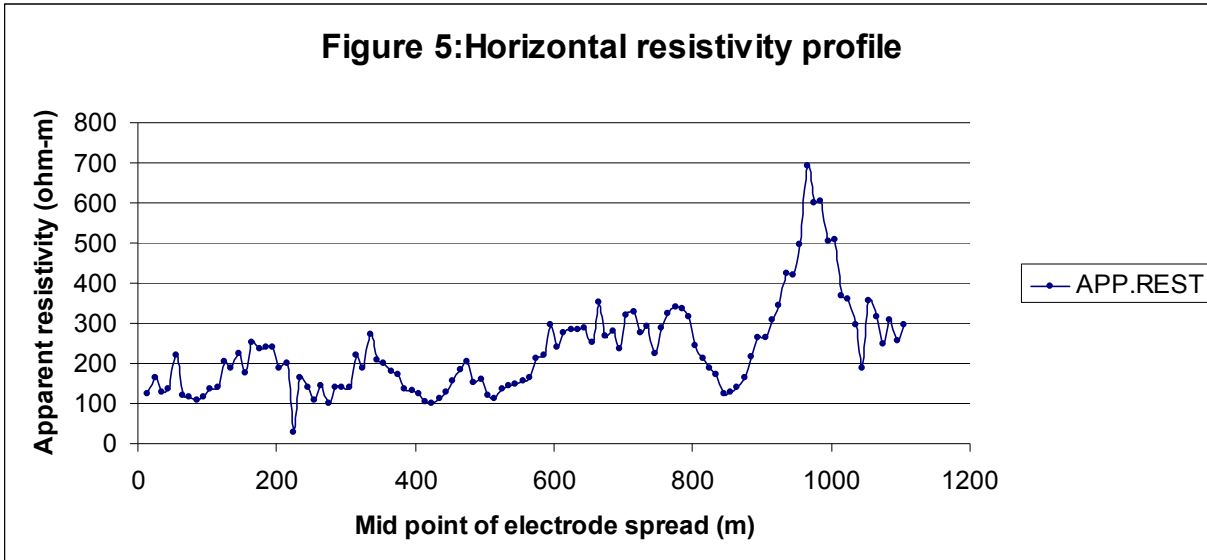


Figure 4c: VLF profile for Segment 3 and Corresponding KH Section



Karous-Hjelt filtering
"IGBARA-OKE-IBUJI RD SEGMENT 3





The geoelectric section as shown in Figure 7 delineates four subsurface layers which are the topsoil, the Sand/lateritic sand, the weathered layer and the presumably fresh basement.

The topsoil has resistivity values ranging from 88-553 Ω m corresponding to clay and clay sand respectively; the top soil thickness varies between 0.5 – 1.6 m. It is however observed from the geoelectric section that VES 5 – 8 (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.

The second layer has resistivity values of between 253 - 285 Ω m (sand) at VES 1 – 3 and thickness values of between 1.5 – 3.0m. This layer manifest as lateritic sand at VES 14, 15, and 16 with resistivity values of between 444 - 507 Ω m and thickness of between 2.4 – 2.6m. The presence of this layer explains why the road is relatively stable at these segments (i.e. between VES 1 – 3 and VES 14 – 16).

The third layer is the weathered basement with the resistivity and thickness values varying between 63 - 308 Ω m and 2.5 – 20.5m respectively. The resistivity values of this layer suggest a high degree of saturation which in other words might suggest that the layer corresponds to the aquiferous zone in the area. However, there is an indication of very high degree of saturation (63 - 158 Ω m) between VES 1 – 8 suggesting

why the segment of the road between VES 4 – 8 is extremely bad with the presence of sand layer reducing the failure between VES 1 – 3.

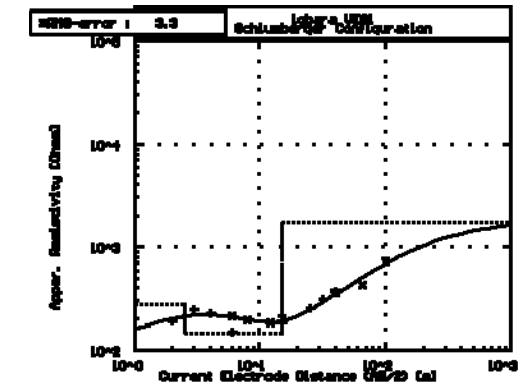
The fourth layer is the presumably fresh basement whose resistivity values vary from 994 – 12, 208 ohm-m and it is of infinite depth. However, depth to the bedrock varies from 3.3 – 21.8m.

Table 2 below shows that the depth ranges to the top of the weathered/aquiferous layer. It is shown from the table that the depth to the top of the aquiferous layer is between 0.5 – 3.5m in all the VES position. This suggests that road pavement is founded on an incompetent (weathered) layer which account for the incessant failure being observed along the road.

CONCLUSION

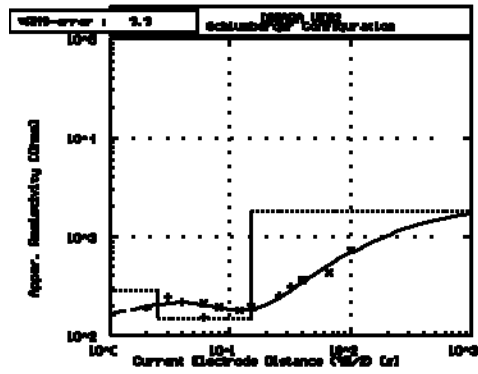
In this study, integrated geophysical methods have been used to investigate the courses of incessant road failure along some parts of Igbaraoke – Ibuji road – southwestern Nigeria. Results from the geophysical survey identified the causes of the road failure to include:

- Clayey nature of the topsoil / subgrade soil on which the road pavement is founded. Clay, though highly porous but less permeable owing to poor connectivity of its pores, retains water without releasing it thus makes it swell



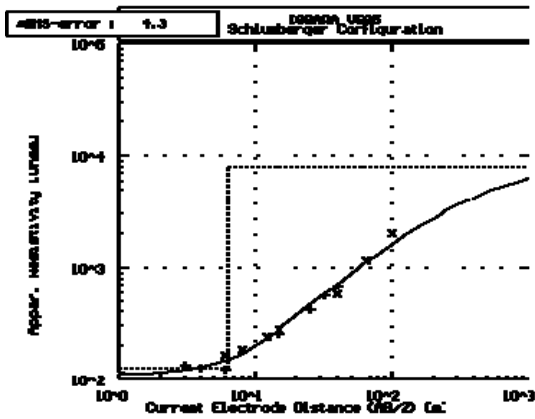
| No | Res | Thick | Depth |
|----|-------|-------|-------|
| 1 | 100.0 | 0.3 | 0.3 |
| 2 | 200.0 | 1.2 | 1.2 |

■ RRS on smoothed data



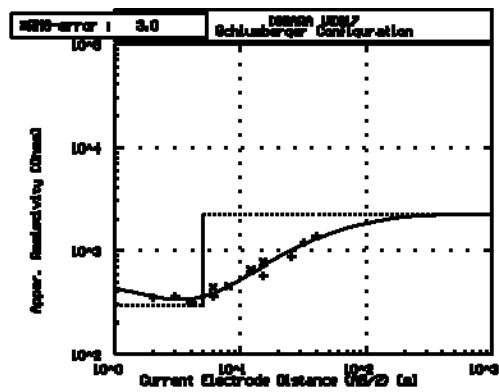
| No | Res | Thick | Depth |
|----|-------|-------|-------|
| 1 | 100.0 | 0.3 | 0.3 |
| 2 | 200.0 | 1.2 | 1.2 |

■ RRS on smoothed data



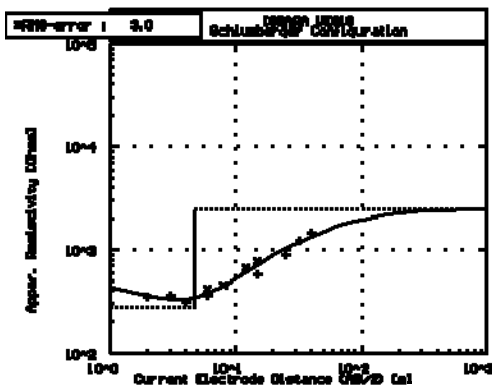
| No | Res | Thick | Depth |
|----|-------|-------|-------|
| 1 | 100.0 | 0.3 | 0.3 |
| 2 | 200.0 | 1.2 | 1.2 |

■ RRS on smoothed data



| No | Res | Thick | Depth |
|----|-------|-------|-------|
| 1 | 100.0 | 0.3 | 0.3 |
| 2 | 200.0 | 1.2 | 1.2 |

■ RRS on smoothed data



| No | Res | Thick | Depth |
|----|-------|-------|-------|
| 1 | 100.0 | 0.3 | 0.3 |
| 2 | 200.0 | 1.2 | 1.2 |

■ RRS on smoothed data

Figure 6: Typical Curve Types Obtained from the Study Area.

Table 1: The Results of the Interpreted VES Curves.

| VES NUMBER | THICKNESS(M) | LAYER RESISTIVITY(Ω M) | REMARKS | CURVE TYPES | NUMBER OF LAYERS |
|------------|--------------|--------------------------------|--------------------------|-------------|------------------|
| 1 | 0.6 | 143 | TOP SOIL(CLAYEY SAND) | KH | 4 |
| | 1.9 | 280 | WEATHERED LAYER | | |
| | 12.4 | 147 | FRACTURED BEDROCK | | |
| | | 1731 | FRESH BEDROCK | | |
| 2 | 0.6 | 137 | TOP SOIL(CLAYEY SAND) | KH | 4 |
| | 1.9 | 284 | WEATHERED LAYER | | |
| | 12.4 | 145 | FRACTURED BEDROCK | | |
| | | 1792 | FRESH BEDROCK | | |
| 3 | 0.5 | 141 | TOP SOIL(CLAYEY SAND) | KH | 4 |
| | 3.1 | 253 | WEATHERED LAYER | | |
| | 8.6 | 112 | FRACTURED BEDROCK | | |
| | | 994 | FRESH BEDROCK | | |
| 4 | 0.7 | 140 | TOP SOIL(CLAYEY SAND) | KH | 4 |
| | 0.8 | 383 | WEATHERED LAYER | | |
| | 18.2 | 158 | FRACTURED BEDROCK | | |
| | | 1900 | FRESH BEDROCK | | |
| 5 | 0.9 | 109 | TOP SOIL(SANDY CLAY) | A | 3 |
| | 5.4 | 125 | WEATHERED LAYER | | |
| | | 7944 | FRESH BEDROCK | | |
| 6 | 0.6 | 93 | TOP SOIL(CLAY) | A | 3 |
| | 3.9 | 106 | WEATHERED LAYER | | |
| | | 7280 | FRESH BEDROCK | | |
| 7 | 0.8 | 103 | TOP SOIL(SANDY CLAY) | H | 3 |
| | 2.5 | 63 | WEATHERED LAYER | | |
| | | 9181 | FRESH BEDROCK | | |
| 8 | 0.5 | 88 | TOP SOIL(CLAY) | A | 3 |
| | 3.9 | 96 | WEATHERED LAYER | | |
| | | 4355 | FRESH BEDROCK | | |
| 9 | 0.5 | 359 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 5.6 | 201 | WEATHERED LAYER | | |
| | | 2378 | FRESH BEDROCK | | |
| 10 | 1.6 | 547 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 17.2 | 226 | WEATHERED LAYER | | |
| | | 2256 | FRESH BEDROCK | | |
| 11 | 0.8 | 344 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 9.6 | 284 | WEATHERED LAYER | | |
| | | 3625 | FRESH BEDROCK | | |
| 12 | 0.8 | 355 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 9.9 | 292 | WEATHERED LAYER | | |
| | | 6697 | FRESH BEDROCK | | |
| 13 | 0.7 | 349 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 11.6 | 283 | WEATHERED LAYER | | |
| | | 12208 | FRESH BEDROCK | | |
| 14 | 0.6 | 231 | TOP SOIL(SAND FORMATION) | KH | 4 |
| | 2.6 | 444 | WEATHERED LAYER | | |
| | 14.5 | 134 | FRACTURED BEDROCK | | |
| | | 4218 | FRESH BEDROCK | | |
| 15 | 0.6 | 240 | TOP SOIL(SAND FORMATION) | KH | 4 |
| | 2.5 | 472 | WEATHERED LAYER | | |
| | 14.5 | 148 | FRACTURED BEDROCK | | |
| | | 5177 | FRESH BEDROCK | | |
| 16 | 0.7 | 221 | TOP SOIL(SAND FORMATION) | KH | 4 |
| | 2.4 | 507 | WEATHERED LAYER | | |
| | 8.8 | 122 | FRACTURED BEDROCK | | |
| | | 2775 | FRESH BEDROCK | | |

| | | | | | |
|----|------|------|--------------------------|---|---|
| 17 | 0.6 | 482 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 4.3 | 298 | WEATHERED LAYER | | |
| | | 2286 | FRESH BEDROCK | | |
| 18 | 0.6 | 506 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 4.9 | 308 | WEATHERED LAYER | | |
| | | 3173 | FRESH BEDROCK | | |
| 19 | 0.7 | 472 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 3.9 | 275 | WEATHERED LAYER | | |
| | | 2466 | FRESH BEDROCK | | |
| 20 | 1.6 | 546 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 19 | 190 | WEATHERED LAYER | | |
| | | 3421 | FRESH BEDROCK | | |
| 21 | 1.3 | 553 | TOP SOIL(SAND FORMATION) | H | 3 |
| | 20.5 | 247 | WEATHERED LAYER | | |
| | | 4949 | FRESH BEDROCK | | |

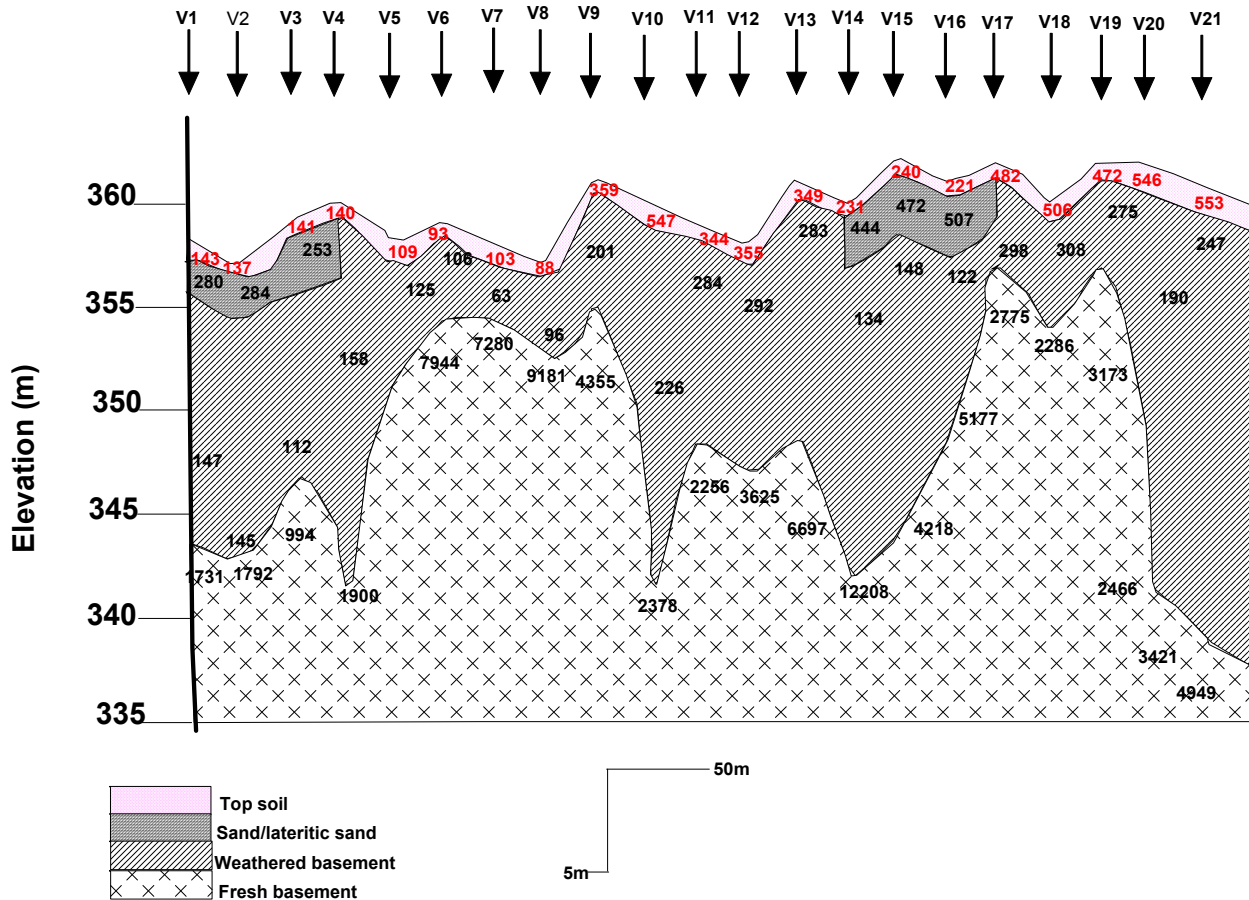


Figure 7: Geoelectric Section along the Investigated Road.

Table 2: Depth to the Top of Weathered (Aquiferrous) Layer.

| Depth range (m) | Frequency | Percentage (%) |
|-----------------|-----------|----------------|
| 0.5 – 1.0 | 12 | 57.14 |
| 1.0 – 1.5 | 2 | 9.52 |
| 1.5 – 2.0 | 2 | 9.52 |
| 2.0 – 2.5 | 2 | 9.52 |
| 2.5 – 3.0 | 0 | 0 |
| 3.0 – 3.5 | 3 | 14.29 |
| Total | 21 | 99.99 |

up and collapse at the exertion of pressure and this subsequently lead to road failure.

- Presence of near surface linear features such as faults, fractured zones, fissures and joints etc. in the subsoil beneath the road pavement as this creates structurally weak zones that enhance groundwater accumulation and hence pavement failure.
- The closeness of the weathered/aquiferrous layer to the surface implying that the road pavement is resting within water table.
- Poor drainage pattern at the two of road pavement thereby leading to its ponding.

REFERENCES

1. Adegoke–Anthony, W.C. and O.A. Agada. 1980. "Geotechnical Characteristics of Some Residual Soils and their Implications on Road Design in Nigeria". Technical Lecture. Lagos, Nigeria. 1 – 16.
2. Ajayi, L.A. 1987. "Thought on Road Failures in Nigeria". *The Nigerian Engineer*. 22 (1): 10 – 17.
3. Akintorinwa, O.J. 2008. "Geophysical Investigation of Highway Failure along Akure-Ilesha Road South-Western Nigeria". Unpublished Ph.D. Thesis. Federal University of Technology Akure.
4. Mesida, E.A. 1981. "Laterites on the Highways – Understanding Soil Behaviour". *West African Technical Review*. 112 – 118.
5. Momoh, L.O., Akintorinwa, O., and Olorunfemi, M.O. 2008. "Geophysical Investigation of Highway Failure- A Case Study from the Basement Complex Terrain of Southwestern Nigeria". *Journal of Applied Sciences Research*. 4(6): 637-648.

6. Nelson, R.G. and J.H. Haigh. 1990. "Geophysical Investigation of in Lateritic Terrain". *Geotechnical and Environmental Geophysics*. Ward, S.H. (Ed), (Geotechnical), SEG, Tulsa. 2: 133 – 154.
7. Olorunfemi, M.O., Idornigie, A.I., Coker, A.T., and Babadiya, G.C. 2004. "Assessment of Anomalous Seepage Conditions in the Opa Dam Embankment, Ile-Ife South- Western Nigeria". *Global Journal of Geological Sciences*. 2(2):191-198.

ABOUT THE AUTHORS

K.A.N. Adoat, M.Tech. is an Assistant Lecturer in the Department of Applied Geophysics, School of Earth and Mineral Sciences, Federal University Of Technology, Akure, Nigeria. He specializes in the application of Remote Sensing and geophysical methods in mineral and groundwater explorations and environmental studies.

A.O. Adelusi, Ph.D. is a Senior Lecturer in the Department of Applied Geophysics, School of Earth and Mineral Sciences, Federal University of Technology, Akure, Nigeria. He specializes in the potential fields and application of magnetic and electromagnetic methods in groundwater and environmental studies in crystalline basement terrain.

M.A. Ayuk, M.Tech. is a Lecturer 1 in the Department of Applied Geophysics, School of Earth and Mineral Sciences, Federal University of Technology, Akure, Nigeria. He specializes in seismic exploration and borehole logging methods.

SUGGESTED CITATION

Adoat, K.A.N., A.O. Adelusi, and M.A. Ayuk. 2009. "Relevance of Geophysics in Road Failures Investigation in a Typical Basement Complex of South Western Nigeria". *Pacific Journal of Science and Technology*. 5(1):528-539.



[Pacific Journal of Science and Technology](http://www.akamaiuniversity.us/PJST.htm)