Relevance of Geophysics in Road Failures Investigation 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 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 Ωm, 253-507 Ωm, 63-308 Ωm, 994-12208 Ωm 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 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, 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

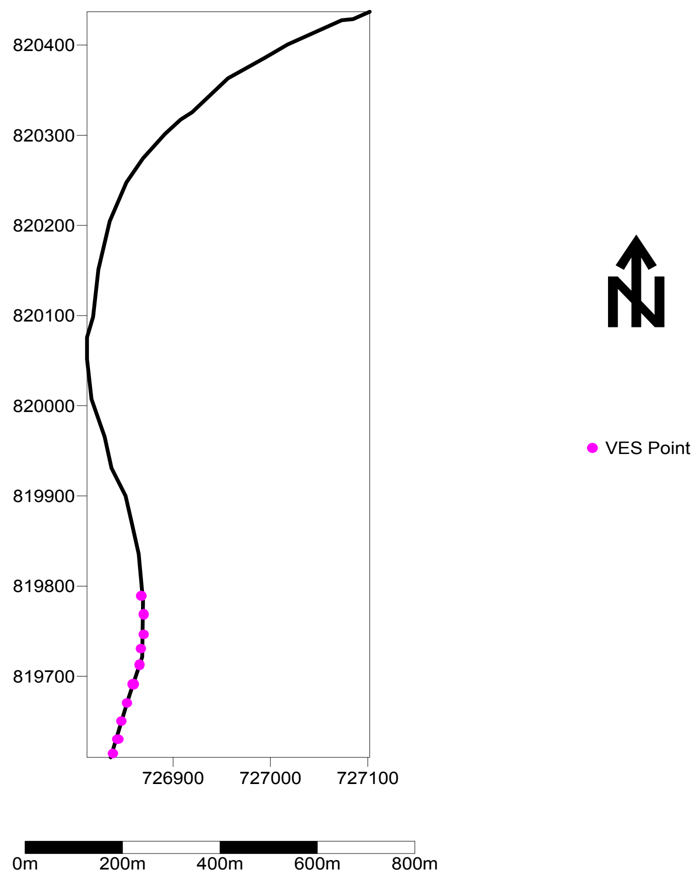


Figure 1: Basemap of the Study Area.

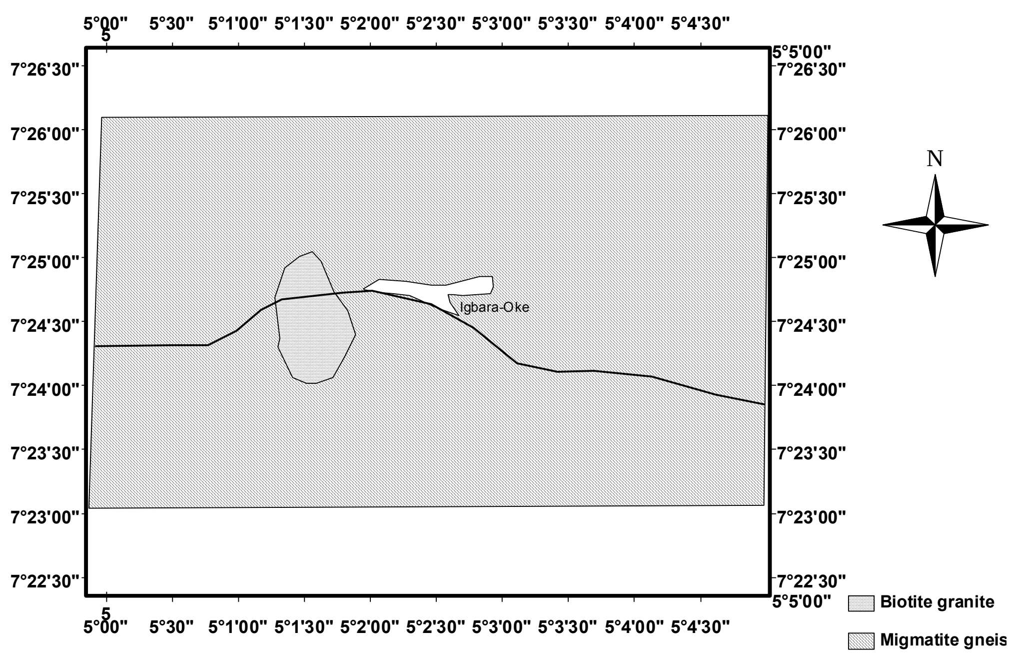


Figure 2: Geological map of the area .(After Geological Survey Agency of Nigeria,1967.)

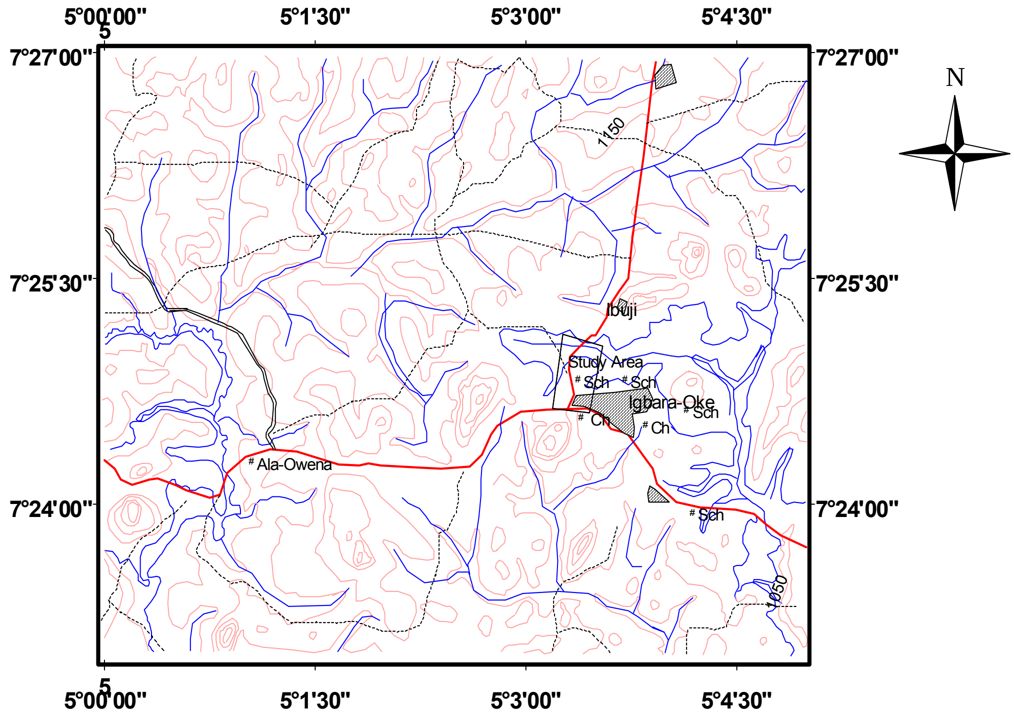


Figure 3: Topographical m ap of the area

0 4 8 Kilometers

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.

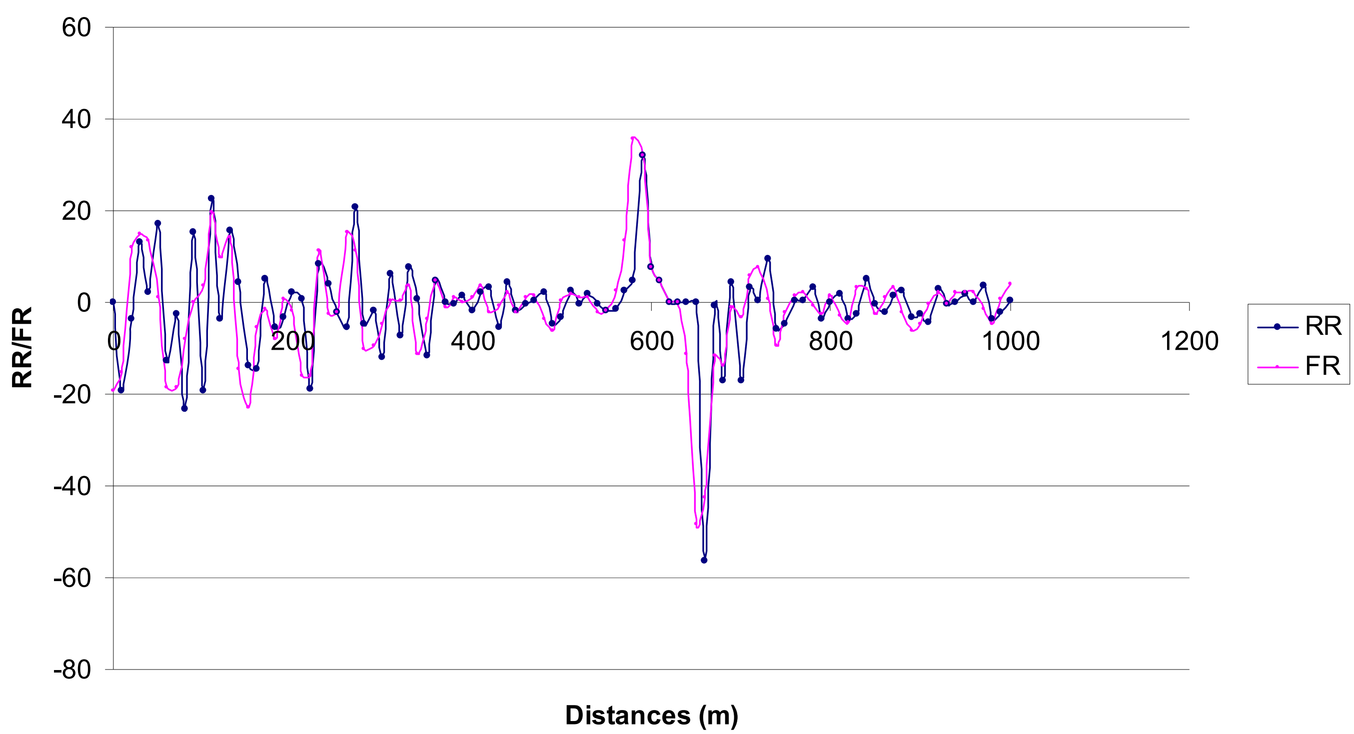
The horizontal resistivity profile (HRP)

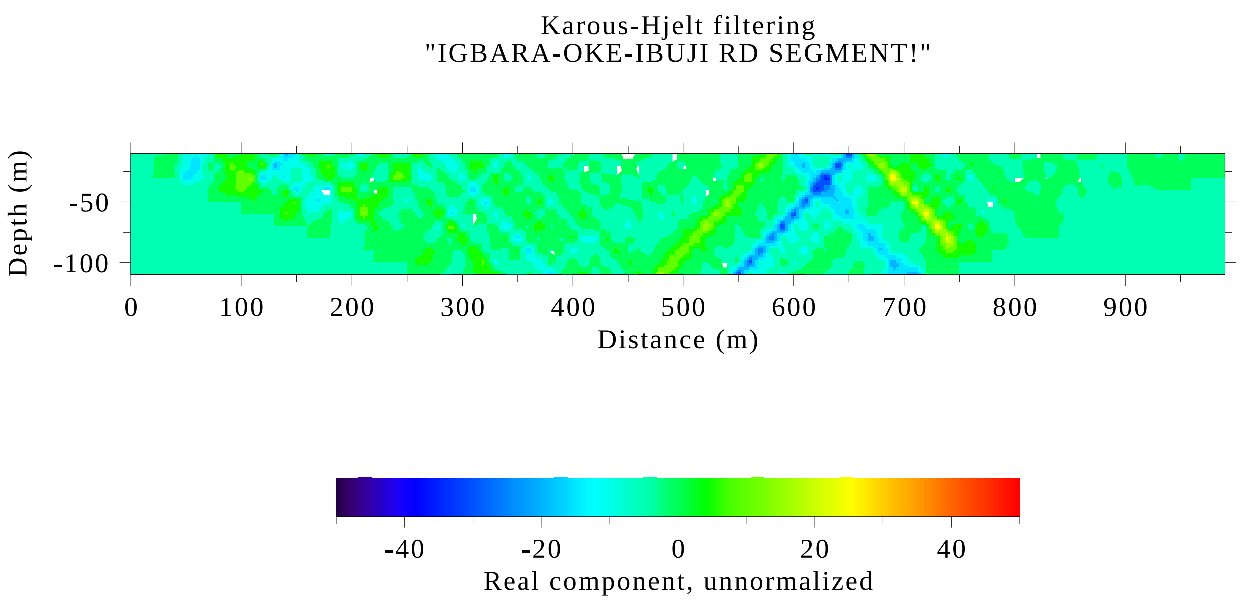
The plot of apparent resistivity against midpoint of the total electrode spread (i.e.AB/2) for each measurement is presented as profile shown in Figure 5. The qualitative interpretation of the profile involves mere inspection of the profile for presence of low apparent resistivity as such points are 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 Geoelectric 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





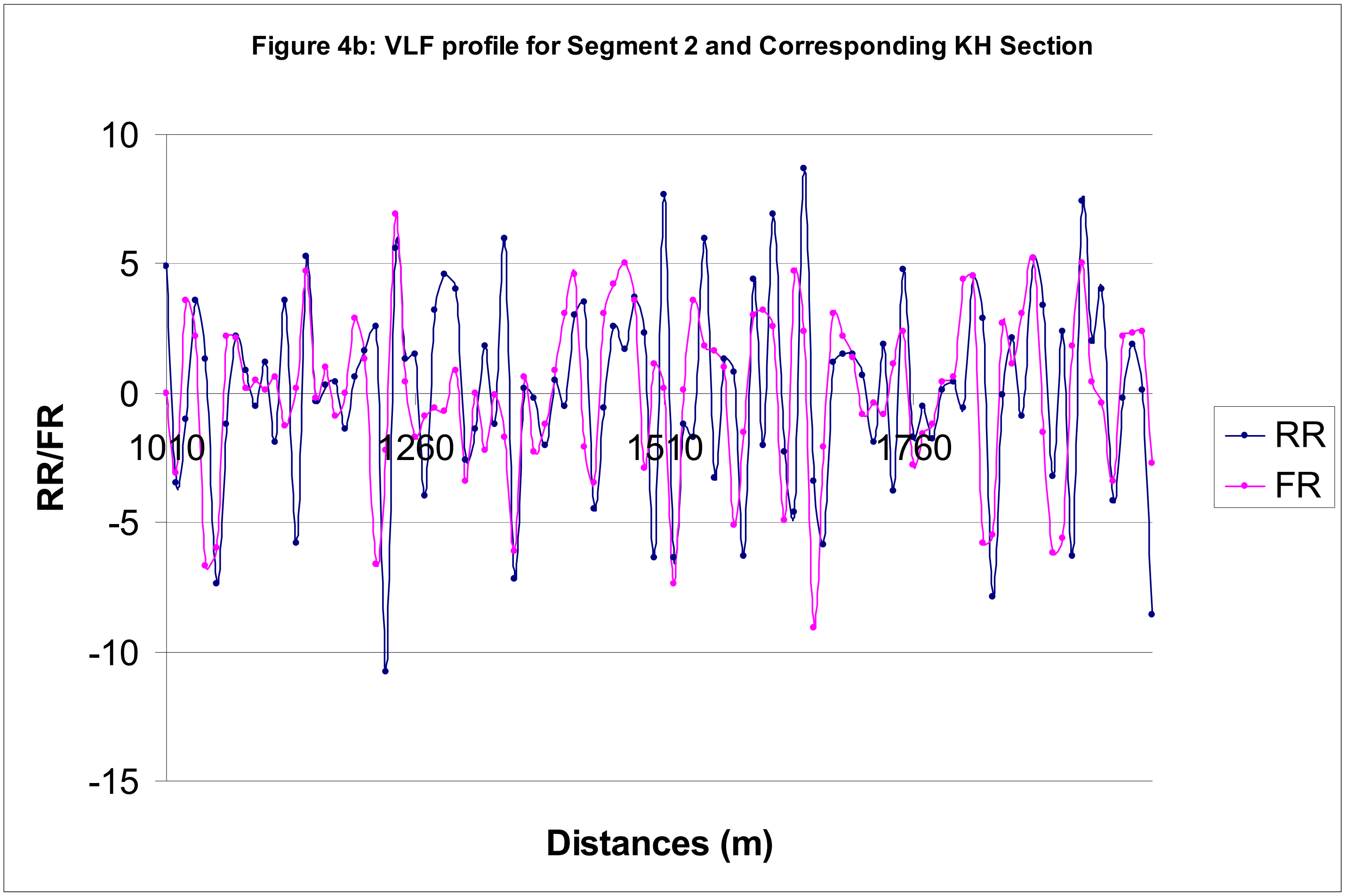


Figure 4b: VLF profile for Segment 2 and Corresponding KH Section
10
5
0
-5
-10
-15
1010
1260
1510
1760
RR/FR
Distances (m)
RR
FR

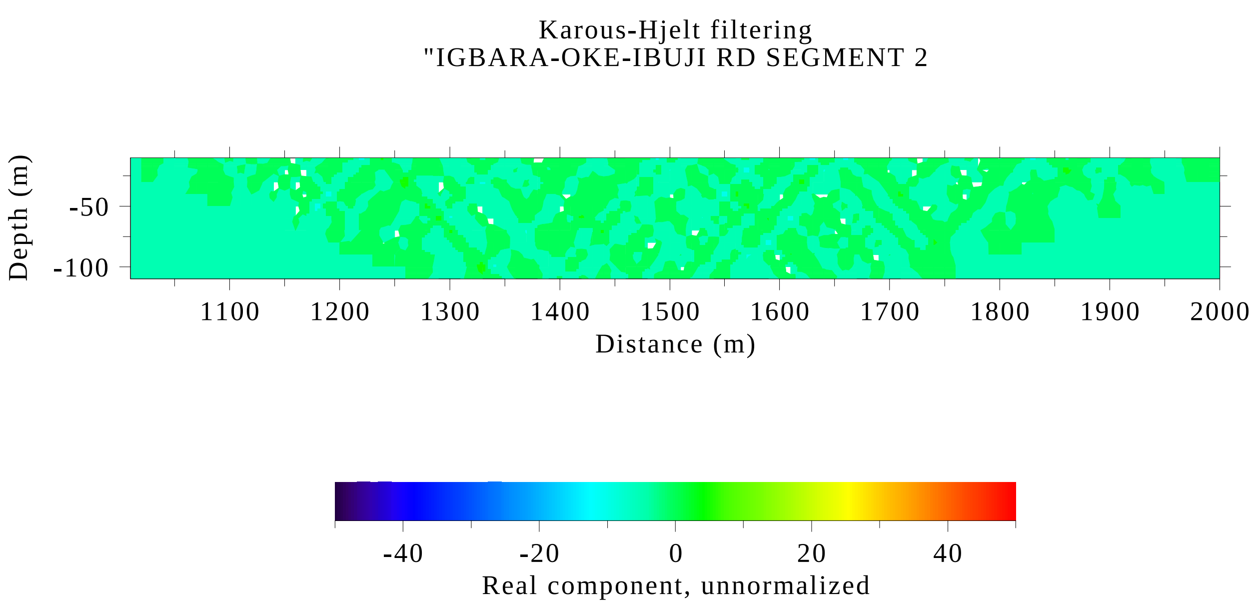
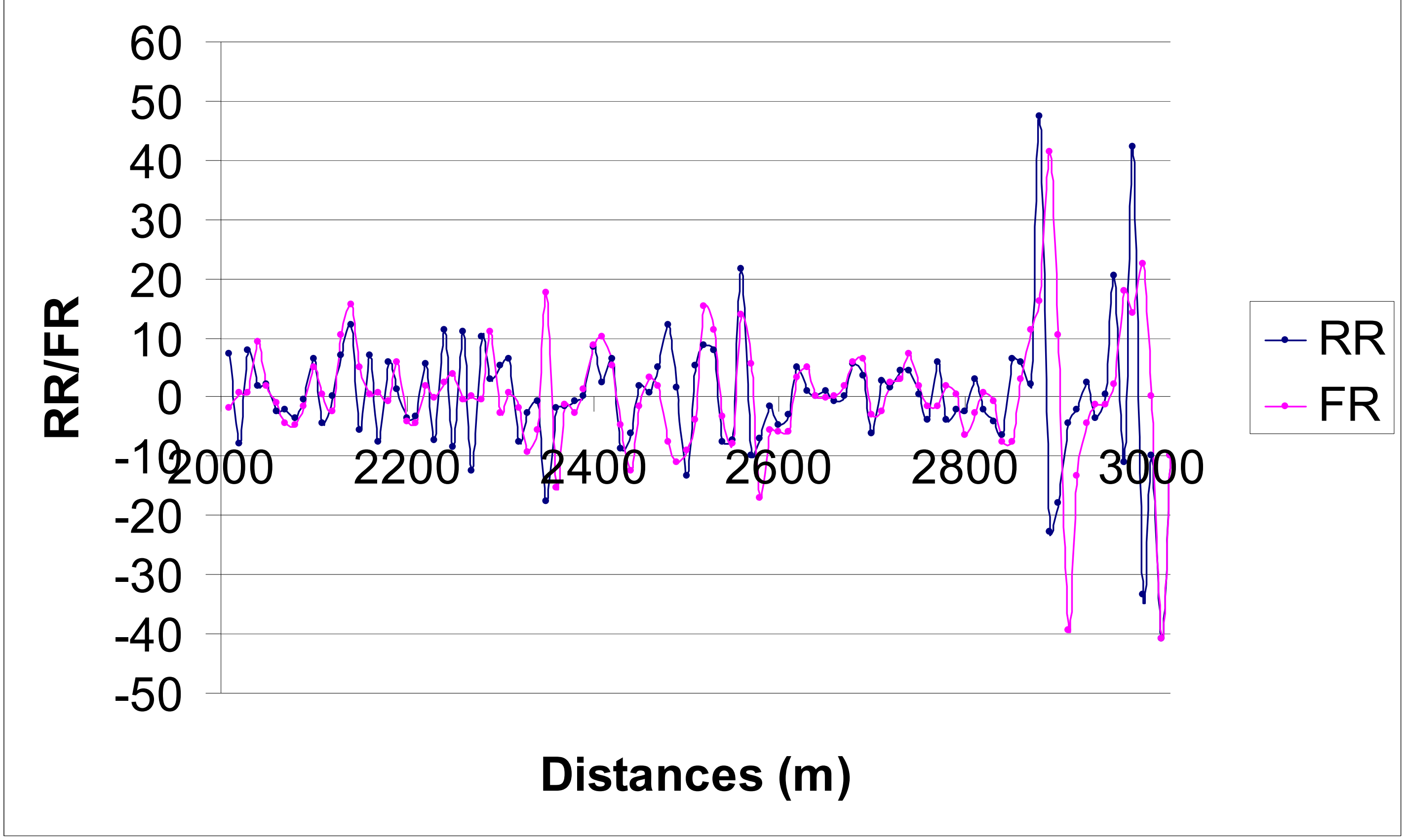
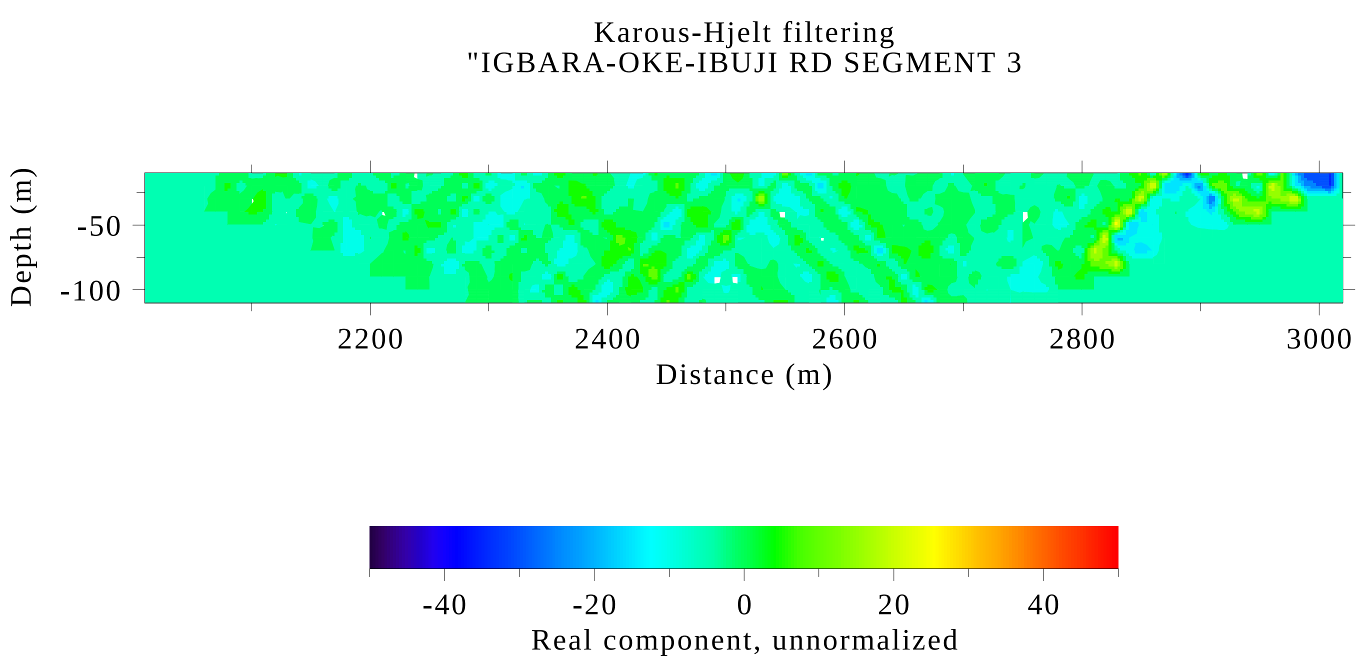
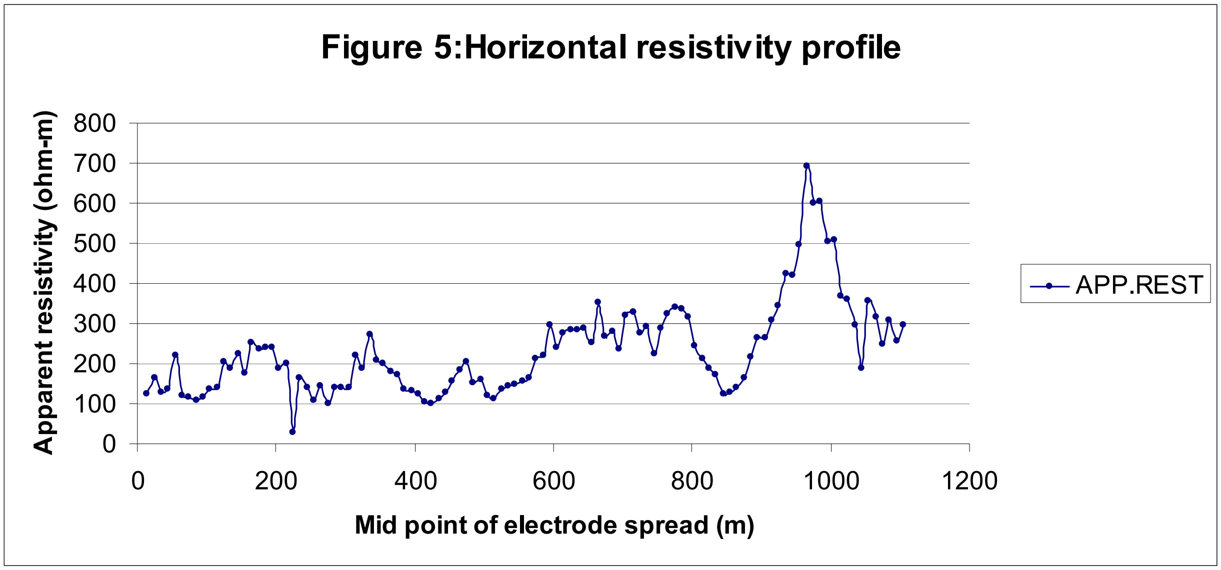

Karous-Hjelt filtering
"IGBARA-OKE-IBUJI RD SEGMENT 2
Depth (m)
-50
-100
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Distance (m)
-40
-20
0
20
40
Real component, unnormalized

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







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 Ωm 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 Ωm suggesting clayey top soil with possibly high moisture content.

The second layer has resistivity values of between 253 - 285 Ωm (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 Ωm 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 Ωm 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 aquiferrous zone in the area. However, there is an indication of very high degree of saturation (63 - 158 Ωm) 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/aquiferrous layer. It is shown from the table that the depth to the top of the aquiferrous 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 Igbara-oke – 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

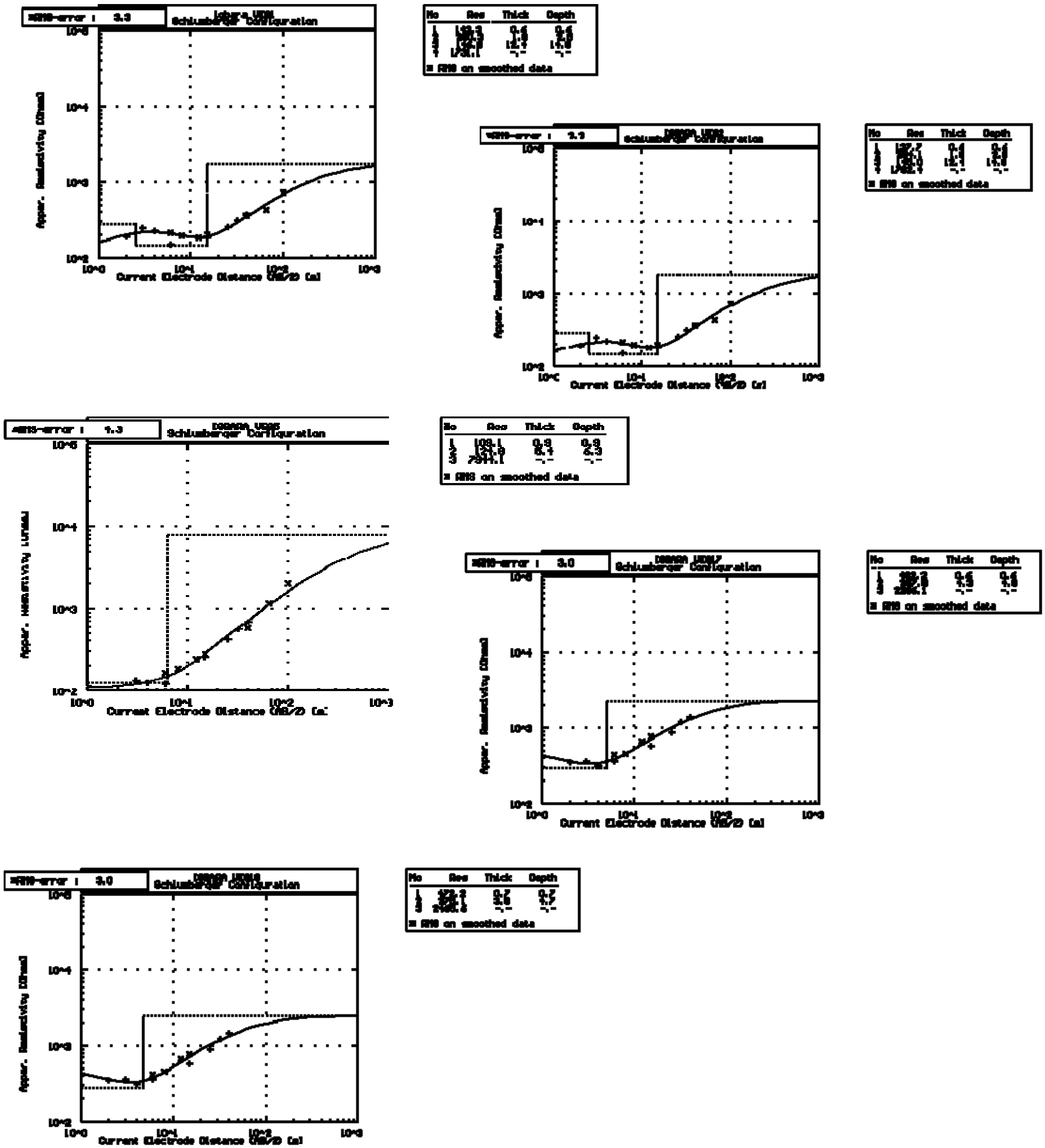


Figure 6: Typical Curve Types Obtained from the Study Area.

Table 1: The Results of the Interpreted VES Curves.

VES NUMBER	THICKNESS(M)	LAYER RESISTIVITY(ΩM)	REMARKS	CURVE TYPES	NUMBER 0F 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		

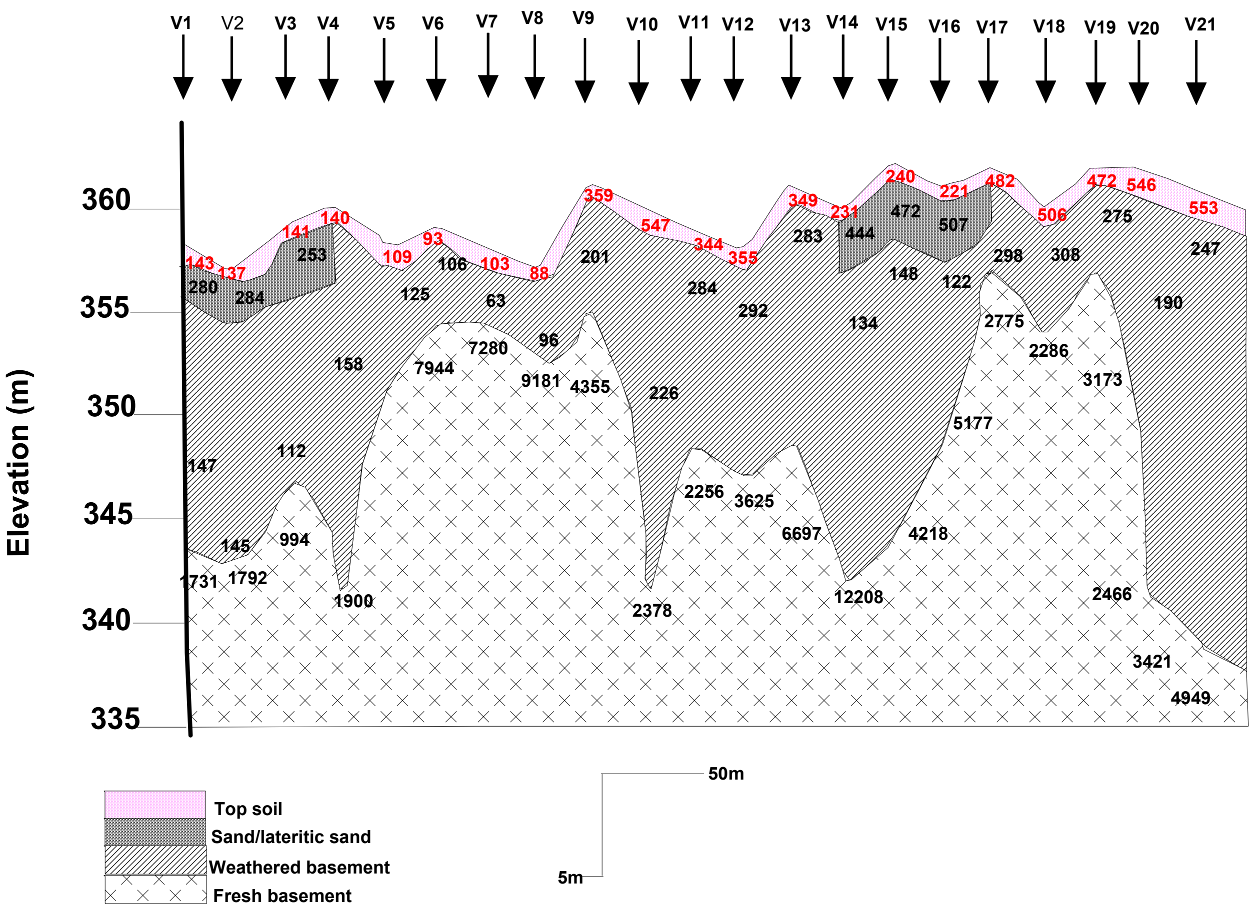


Figure 7: Geoelectric Section along the Investigated Road.

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.

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