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# Geophysical Investigations of a Pavement Failure Along Akure-Ijare Road, Southwestern Nigeria

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**Abstract:** *Geophysical investigations were carried out along two failed segments of Akure-Ijare road, named locality 1 and locality 2, with the aim of establishing the cause(s) of the incessant pavement failure along the road. The geophysical investigations involved the Very Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity Methods. The VLF-EM measurements were taken at intervals of 10 m along traverses parallel to road pavements. Two techniques were adopted for the electrical resistivity method namely: the vertical electrical sounding (VES) and a combination of horizontal profiling and sounding using dipole-dipole configuration with inter stations separation (a) of 5 m and an expansion factor (n) that varies from 1 to 5. The Schlumberger configuration was used for the VES with AB/2 varying from 1 to 65 m. Nine (9) and twelve (12) VES were carried out at localities 1 and 2 respectively. The VLF-EM method revealed that the road pavement is founded on a weakly conductive material devoid of major geological structure. The Vertical electrical sounding curves range from A, H to KH. The geoelectric sections generally identified three to four geologic sequences that comprise topsoil, weathered layer, partly weathered/fracture basement and fresh basement. At locality 1, the topsoil/subsoil on which the road is founded are of low resistivity generally less than 100 Ω-m composed of clayey materials, while the road pavement along locality 2 is within the resistive topsoil or directly on bedrock. The bedrock along this locality is generally shallow (< 2 m) with an uneven interface. Therefore, from the results of the investigation the causes of road failure in the studied roadway are heterogeneity and clayey nature of the topsoil/sub-grade material, lack of proper drainage at the road embankment and poor construction material.*

**Keywords:** *failed segment, geophysical investigation, geological sequence, road failure, southwestern Nigeria*,

## I. Introduction

The statistics of failures of structures such as roads, buildings, dams and bridges throughout the nation has increased geometrically ([2]). Therefore the usefulness of geophysical investigation in engineering sector of our economy cannot be overemphasized. In recent years, many engineering professions such as civil, geotechnical and electrical engineers have come to realize that geophysical investigation is very important; as the information it furnishes assist these professionals in the design process of structure and utilities (e.g. dams, bridges, highways, communication masts).

Most highways in Nigeria are known to fail shortly after construction and far less than their life expectancy. Every year, millions of Naira are budgeted and expended on roads (Federal and State) but the same problem would resurface after some few months of rehabilitation or reconstruction. This incessant failure of our roads has now become a “thorn in the flesh” of our governments and that is why the geoscientists are working assiduously hard to provide a lasting solution to the problem. However, road structure like any other engineering structure, no matter how good its construction, needs routine maintenance to prevent rapid decline of the road structures caused by ageing of materials, variations in age, disuse, accidental damage, mismatch between design parameters and field condition during construction in order to serve its purpose optimally ([4]). The main aim of maintenance is to carry out protective and repair measures to limit the detrimental effects of these natural or imposed processes, and prolong the useful life of the roads. The non-maintenance scenario thus shortens the life span of these structures, resulting in high vehicular operating cost, public casualties from accident and later expensive rehabilitation reconstruction scheme ([1], [8], [10], [11], [15]).

The Akure-Ijare road, which is about 12 km in Ifedore local government of Ondo State “Fig. 1”, is the major road that links Akure and Ijare. It has greatly contributed to the socio-economic development of Ondo State and the country as a whole, as it helps in the movement of men and materials. Its incessant failure has both economic and social effects on the inhabitant of the suburb communities, because it makes transportation difficult and also restricts industries from moving into the region. The rate of accidents (human and material losses) and hold-up of vehicles along the roadway is increasing daily. Subsequently, this has impeded the rate of development and socialization in the area. Hence, the need to establish the cause(s) of road failure necessitated this study.

### 1.1 Description of the Project Environment

Akure-Ijare road lies within longitudes 5˚10ˡ E and 5˚09ˡ E and latitudes 7˚21ˡ N and 7˚17ˡ N. Expressed in the Universal Traverse Mercator (UTM) coordinates, the road is located within Northings 0806719 mN and 0812694 mN and Eastings 0738567 mE and 0739035 mE "Fig. 2". At the time of study, two segments of the road have failed (Orita-Obele axis and Ikota-Ijare axis) and these segments are named locality 1 and locality 2.

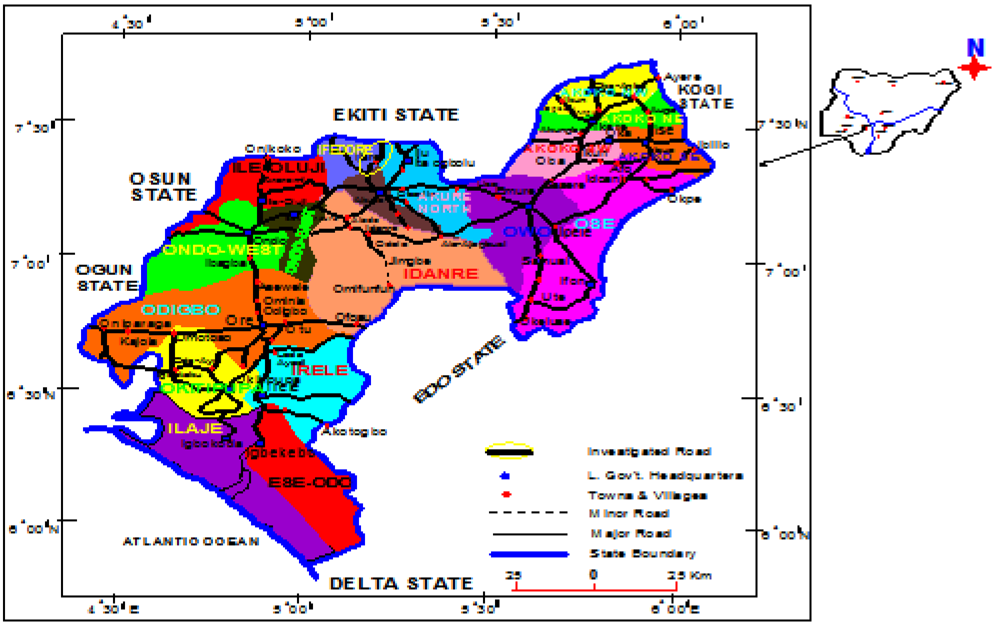



**Figure 1:** Road map of Ondo State showing the investigated road ([12])

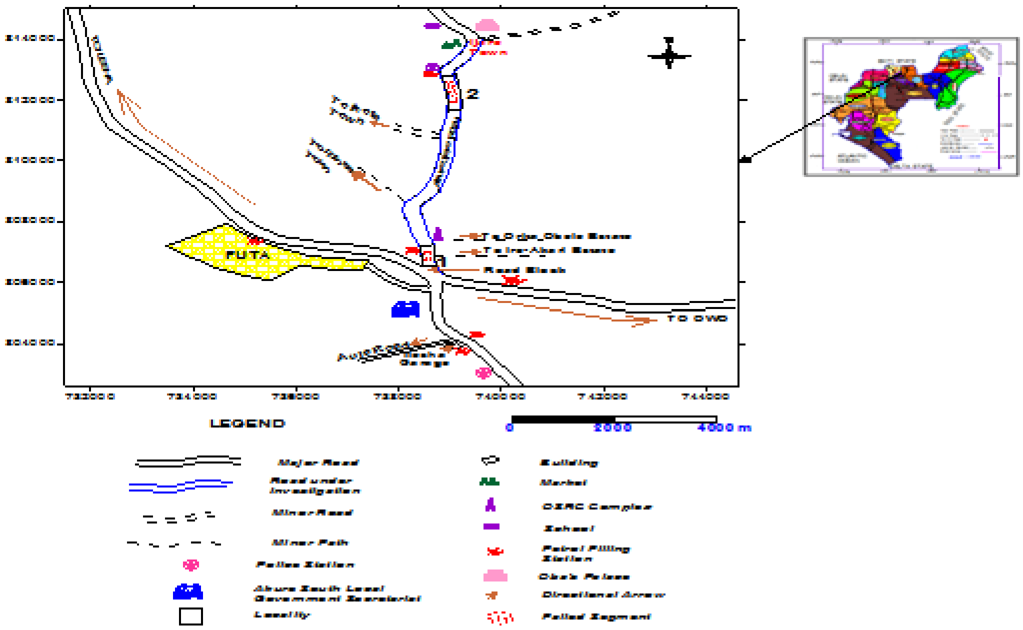



**Figure 2:** Road map of part of Akure-Ijare area showing the investigated road

The terrain of the road is relatively flat and it slopes gently from western to eastern part of the road "Fig. 3". The vegetation is of tropical rainforest and is characterized by thick forest of broad-leaved trees that are ever green. The vegetation of the area is dense and made up of palm trees, kolanut trees and cocoa trees.

### 1.2 Geology of the Area along the Studied Highway

The major rocks encountered in the study area are: migmatite gneiss, coarse porphyritic biotite hornblende granite, charnockite, quartzite, medium to coarse grained biotite-granite, fine to medium grained biotite granite gneiss and migmatite "Fig. 4". However, from the geological map the road cut across two rock units namely charnockite and medium coarse grained biotite-granite. However the major part of the road cut across charnockitic rock.

## II. Methods Of Study

At each of the established failed localities, one traverse each was made parallel to the road alignment. This cut across the classified stable? and the failed segments of the localities. The length of traverse at localities 1 and 2 are 170 m and 250 m respectively "Fig. 2".

### 2.1 VLF-EM Survey

The VLF - EM method utilized the inline profiling technique. The measurements were taken at 10 m intervals along each traverse "Fig. 5". The ABEM – WADI EM-VLF was used for the measurements. Although both real and quadrature components of the VLF-EM field were measured, the real component data, which are usually more diagnostic of linear features, were processed. The real and filtered real components were plotted against stations position using 'KHFFILT' software version 1.0 ([9]). The 2-D modeling of the filtered real component was carried out using the same software. The profiles were interpreted qualitatively by visual inspection of anomalies (conductor) that are diagnostic of possible geological structures in the bedrock while the 2-D modeling output was used for quantitative interpretation.

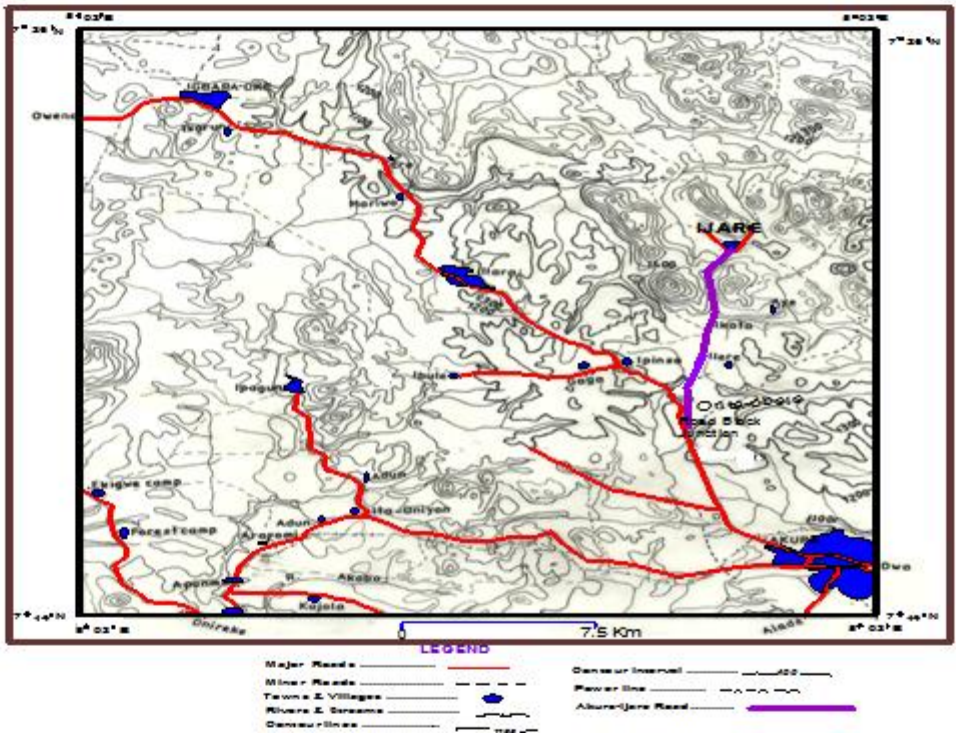



**Figure 3:** Topographical map of Akure-Ijare/Ifedore local government showing study highway ([6]).

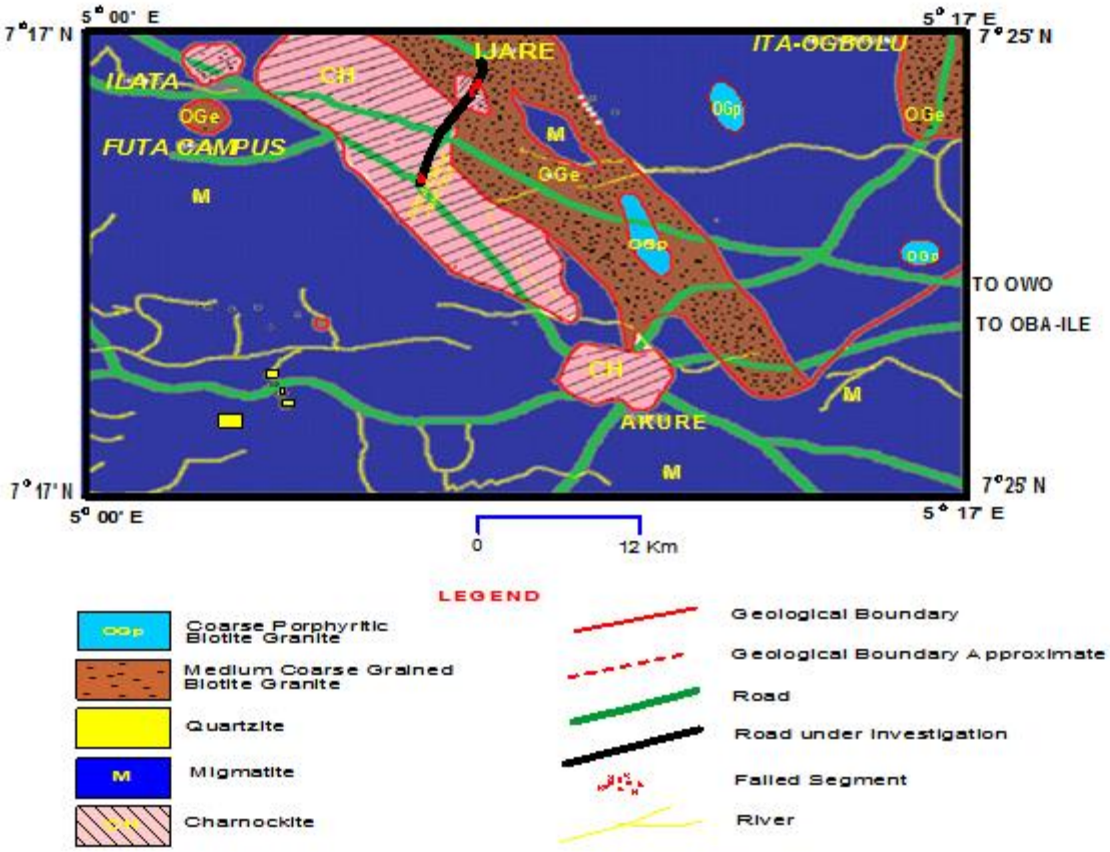



**Figure 4:** Geological map of Akure area showing the road under investigation ([7]).

## 2.2 Electrical Resistivity Survey

The electrical resistivity method utilized two field techniques - Vertical Electrical Sounding (VES) using the Schlumberger array and combined horizontal profiling and vertical electrical sounding (2-D electrical imaging) using dipole-dipole configuration. The same traverses were used in each locality as in VLF method. Sounding stations were marked and pegged along the traverses at 20 m interval. Nine (9) sounding stations were occupied at locality 1, while twelve (12) sounding stations were occupied at locality 2. The location of each sounding stations in both geographic and Universal Traverse Mercator (UTM) coordinates was recorded with the aid of the GARMIN 12 channel personal navigator - Geographic Positioning System (GPS) - unit. The instrument used for the resistivity data collection was the Omega. The current electrode spacing (AB/2) was varied from 1 m to 65 m. The apparent resistivity($\rho_a$) measurements at each station were plotted against electrode spacing (AB/2) on bi-logarithmic graph sheets. The resulting curves were then inspected visually to determine the nature of the subsurface layering. In each way, each curve was characterized depending upon the number and nature of the subsurface layers. Partial curve matching ([13]) was carried out for the quantitative interpretation of the curves.

The results of the curve matching (layer resistivities and thicknesses) were fed into the computer as starting model parameter in an iterative forward modeling technique using RESIST version 1.0 ([14]). From the interpretation results, geoelectric sections along the traverses were produced. The interpreted result was considered satisfactory since a good fit of RMS between the field curves and computer generated curves ranges from 1.4 - 2.9. The results were also used to generate layer parameter histograms.

## 2.3 2-D Electrical Imaging

The same traverses used for the VLF data acquisition were used. The Dipole-Dipole array ([3]) was used for the data acquisition. The inter-electrode spacing of 5m was adopted while inter-dipole separation factor (n) was varied from 1 to 5. 2-D inversion modeling of the dipole-dipole data was carried out using DIPRO for Windows ([5]) computer software.

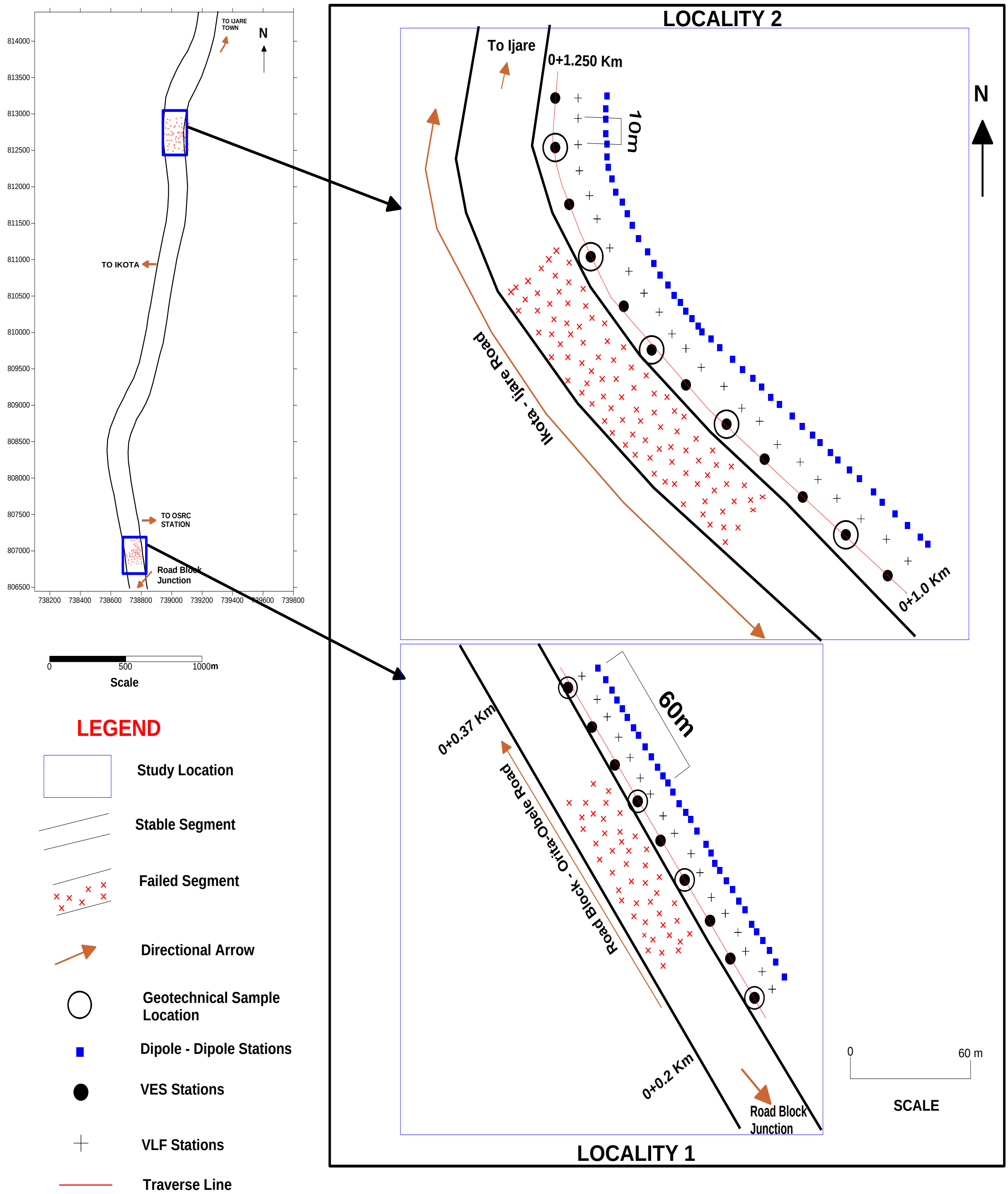



**Figure 5:** Field Layout at Locality 1 and 2 Showing VES Stations

## III. Results And Discussion

The summary of the interpreted VES curves is presented in Table 1 – 2. The curve types identified in the studied area are H, A and KH “Fig. 6”. The most occurring curve types are H-curve and A-type; with each having 43 % and KH-curve type has 14 % of the entire curve types identified “Fig. 7”. All the curve types in locality 1 are H-curve type. The curve shows that the lithologic sequence delineated are mainly 3 layers and 4 layers.

At locality 1, both the topsoil and the subsoil (weathered layer) in the upper 0 - 5 m are clayey within the failed and the classified stable segments on both flanks “Fig. 8a and 8c”. The 2-D resistivity structure correlates well with the geoelectric section displayed in “Fig. 8a”. The 2-D resistivity structure shows evidence of basement depression at distance between 35 and 45, 55 and 70 m and 110 and 125 m. As revealed by the resistivity structure, the bedrock topography is uneven “Fig. 8a and 8c”.

The VLF-EM 2-D model “Fig. 8b” identified weakly conductive (faint-yellow colour) targets typical of clay material or possible linear features with pockets of fairly resistive material (blue colour) as shown on model. Their depth extents are generally within the upper 20 m on both the classified stable? and the failed segment. However, the 2-D resistivity structure shows some discontinuities in the basement such as fracture/fault, lithological contact e.t.c. that can act as a weak zones, which might have resulted to the failure of the road between distances 35 and 45 m, 55 and 65 m, and 113 and 127 m. The locations of these geological features are generally within the failed segment.

The overburden thickness along the failed segment is generally very thin. From the above it can be concluded that, both the failed and the classified stable? segments are founded on topsoil/subsoil of very low resistivity (< 100 Ω-m) which is typically clay, and both segments contain geological features such as fractures, faults, lithological contact e.t.c which are zones of weakness that may increase porosity and fluid permeability of the subsoil and hence decrease the engineering capability of the road pavement. Therefore road pavement failure at this locality may have been precipitated by the incompetent clayey topsoil/subsoil, geological features and thin over and thin overburden thickness.

At locality 2, both the topsoil and the weathered layer in the upper 0-3 m are composed of clay, sandy clay, clayey sand and laterite beneath the failed and the classified stable? segments “Fig. 9a and Fig. 9c”. This indicates high degree of heterogeneity in the upper layer. The geoelectric section and the 2-D resistivity structure confirm the shallow nature of the basement bedrock (generally less than 2 m) along the failed segment of the road compared to the classified stable? segments which shows an appreciable overburden thickness (generally greater than 2 m) at both flanks. However, the geoelectric, 2-D VLF-EM model and 2-D resistivity show no indication of geological features such as fractures/faults and lithological contacts in the bedrock, but the bedrock mostly outcrop along the failed segment.

The failure at this locality may have been precipitated by the heterogeneity and clayey nature of the upper layer. Also, lack of proper drainage at the road embankment and poor construction material may have enhance the failure at this locality since the road is expected to be stable due to shallow nature of the bedrock.

## IV. Conclusions

It can be concluded from the study that, the possible causes of pavement failure along the studied highway are: incompetent clayey topsoil/subsoil; heterogeneity nature of the upper layer; lack of proper drainage at the road embankment; and poor construction material, since the road is expected to be stable due to shallow nature of the bedrock at locality 2.

This research work has made the following contributions to knowledge:

(i) it has provided information on the cause(s) of the failed segments of the investigated road;

(ii) it has served as a guide to road engineers; as information it provided assists during rehabilitation or reconstruction of roads; and

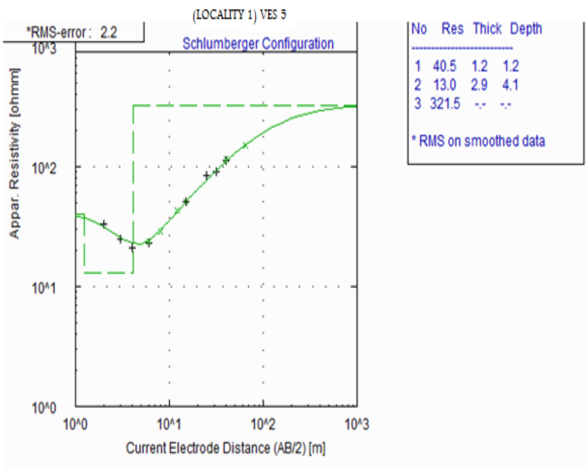
(iii) it has served as an indispensable tool for road engineers that geophysical survey is essential for preconstruction/design activities.

**Table 1: VES Interpretated Results from Locality 1**

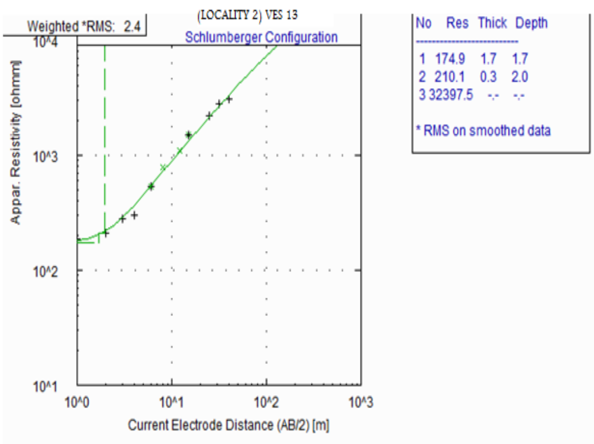
| VES NO | RESISTIVITY (ρ) (Ω-m) | | | THICKNESS (h) (m) | | CURVE TYPE |
|---|---|---|---|---|---|---|
| | $\rho_1$ | $\rho_2$ | $\rho_3$ | $h_1$ | $h_2$ | |
| 1 | 99 | 11 | 229 | 1.0 | 3.6 | H |
| 2 | 53 | 25 | 729 | 0.7 | 4.1 | H |
| 3 | 81 | 20 | 490 | 0.7 | 6.2 | H |
| 4 | 67 | 17 | 280 | 0.6 | 1.8 | H |
| 5 | 41 | 13 | 321 | 1.2 | 2.9 | H |
| 6 | 44 | 12 | 301 | 1.1 | 2.6 | H |
| 7 | 52 | 17 | 270 | 0.8 | 1.5 | H |
| 8 | 75 | 21 | 1004 | 1.2 | 4.8 | H |
| 9 | 74 | 25 | 1075 | 1.2 | 5.5 | H |

**Table 2: VES Interpretated Results from Locality 2**

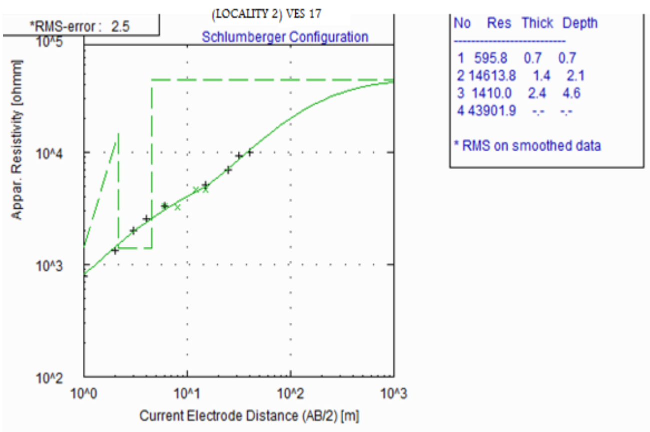
| VES NO | RESISTIVITY (ρ) (Ω-m) | | | | THICKNESS (h) (m) | | | CURVE TYPE |
|---|---|---|---|---|---|---|---|---|
| | $\rho_1$ | $\rho_2$ | $\rho_3$ | $\rho_4$ | $h_1$ | $h_2$ | $h_3$ | |
| 1 | 148 | 353 | ∞ | | 1.6 | 0.7 | | A |
| 2 | 148 | 191 | ∞ | | 1.3 | 0.9 | | A |
| 3 | 28 | 775 | ∞ | | 0.3 | 0.2 | | A |
| 4 | 175 | 210 | ∞ | | 1.7 | 0.3 | | A |
| 5 | 87 | 6591 | 1719 | ∞ | 0.4 | 0.7 | 3.5 | KH |
| 6 | 243 | 661 | ∞ | | 0.6 | 0.5 | | A |
| 7 | 64 | 6533 | ∞ | | 0.3 | 0.4 | | A |
| 8 | 596 | 14614 | 1410 | ∞ | 0.7 | 1.4 | 2.4 | KH |
| 9 | 588 | 5066 | 6586 | | 0.9 | 9.2 | | A |
| 10 | 119 | 3321 | 2751 | ∞ | 0.5 | 9.5 | 2.6 | KH |
| 11 | 98 | 439 | ∞ | | 1.0 | 0.1 | | A |
| 12 | 141 | 2854 | ∞ | | 1.5 | 0.2 | | A |




(a)




(b)




(c)

**Figure 6:** Typical curve types obtained in the Study Area (a) H curve (b) A curve (c) KH curve

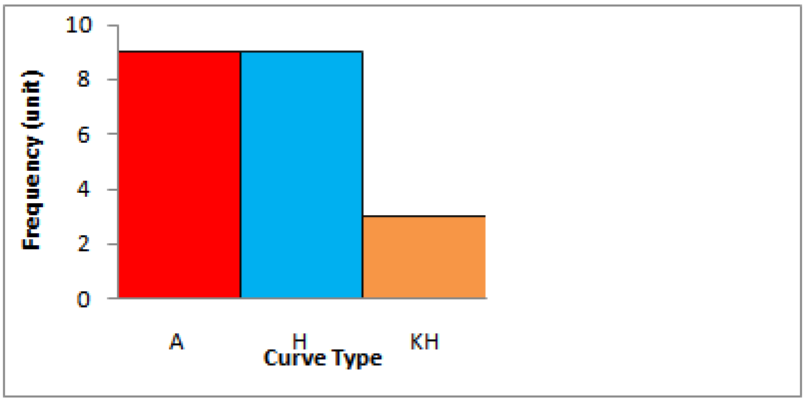
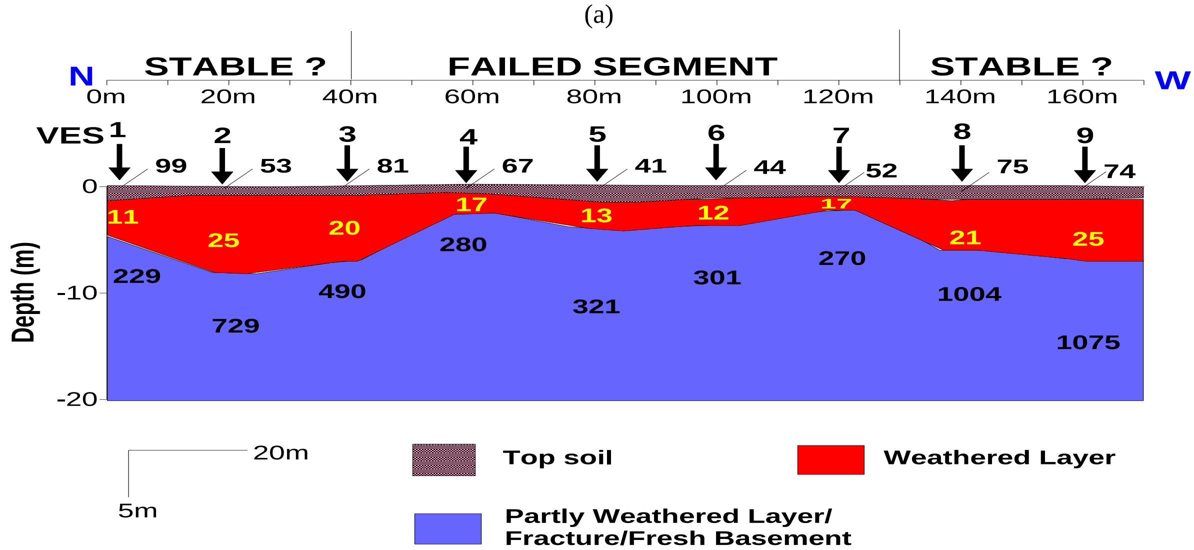



**Figure 7**: Histogram of Curve Types in the Studied Localities 1 and 2.

(a)

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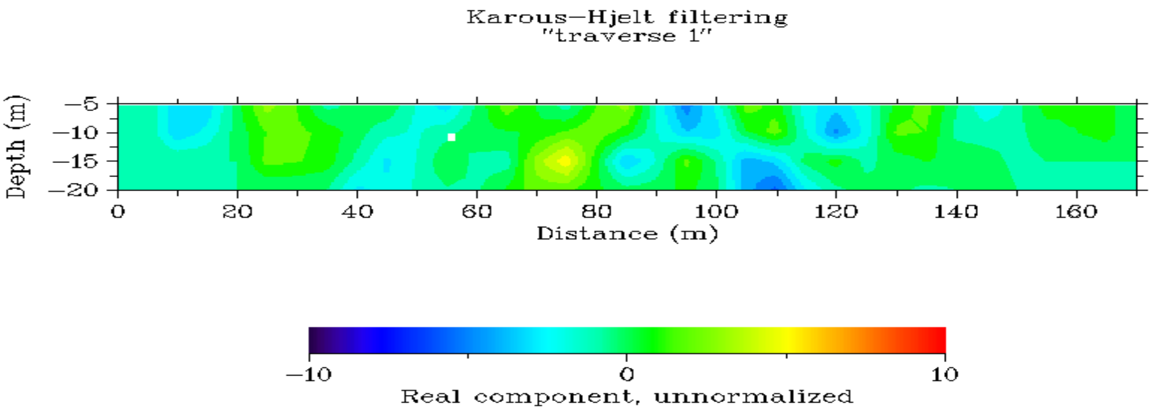


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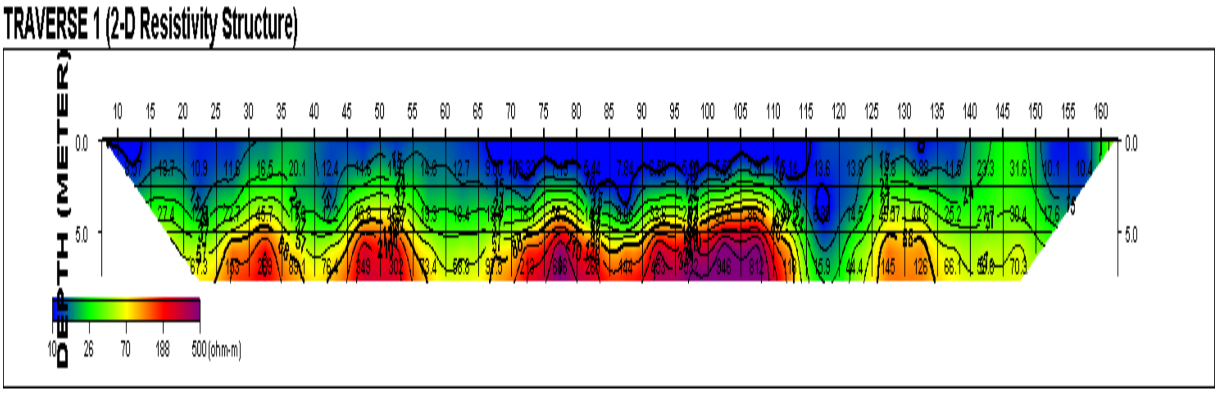
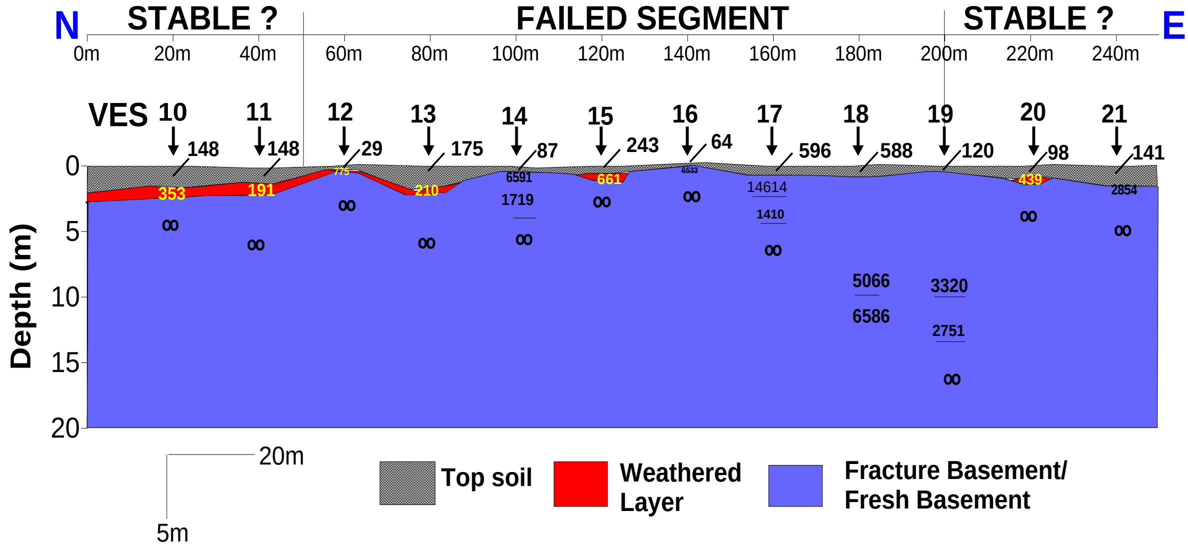
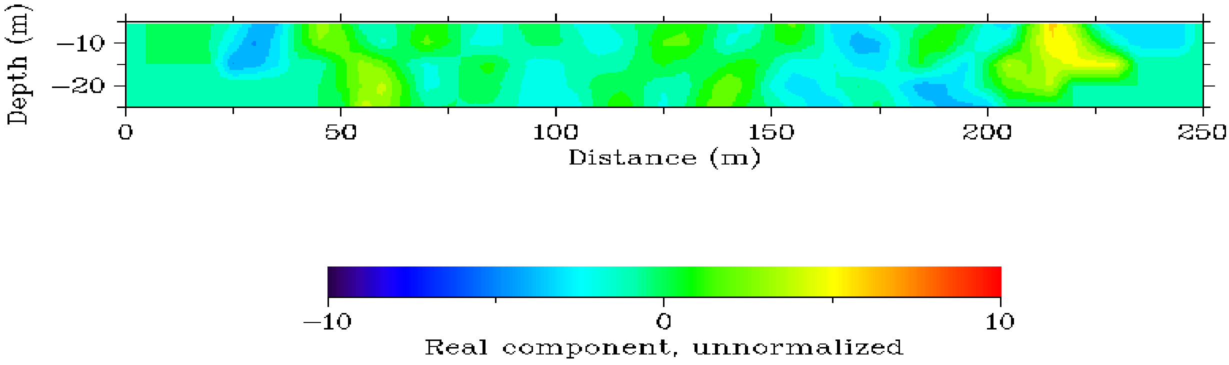


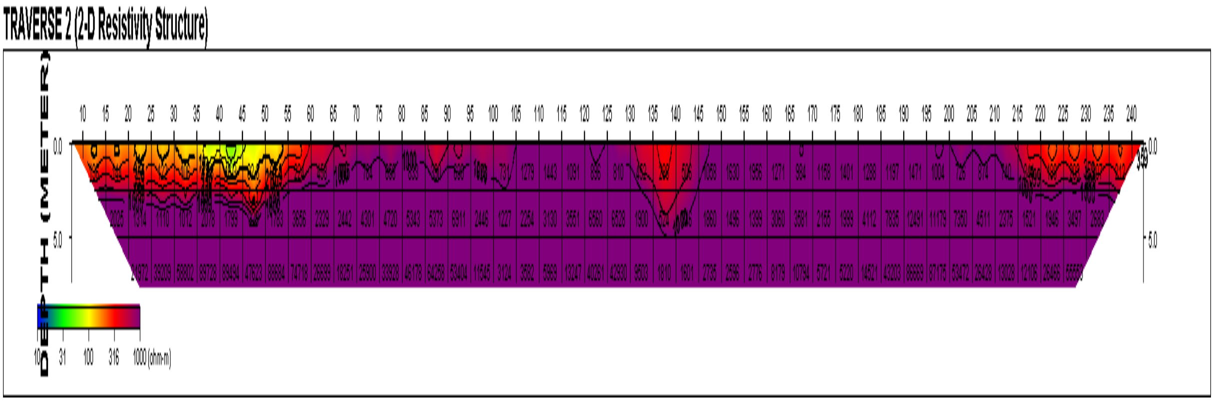

**Figure 8:** (a) Geoelectric Section, (b) 2-D Inversion Model and (c) 2-D Dipole-Dipole Resistivity Structure at Locality 1.




(a)




(b)




(c)

**Figure 9:** (a) Geoelectric Section, (b) 2-D Inversion Model and (c) 2-D Dipole-Dipole Resistivity Structure at Location 2.

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