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RESEARCH ARTICLE

EVALUATING CAUSES OF ROAD FAILURE ALONG KM 5, ADO-IKERE-EKITI ROAD, SOUTHWESTERN NIGERIA

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ABSTRACT

A geophysical study of the failed portion of the Ado-Ikere-Ekiti road along Km5 was conducted to investigate the causes of its failure and proffer appropriate solutions to stop the failure. Vertical Electrical Sounding (VES), 2D Electrical Resistivity Tomography (ERT), and Electromagnetic (EM) impact survey using Schlumberger, Dipole-Dipole, and Gradient arrays respectively were employed for the study. VES data were interpreted quantitatively by partial curve matching and computer-assisted forward modeling using the IPI2Win(R) software. The geo-electric parameters obtained from the VES interpretation were used to generate a geo-electric section beneath the traverse. The 2-D subsurface resistivity structures of the failed portion of the road were obtained by processing and interpreting the data obtained from the ERT quantitatively employing the inverse modeling with DIPRO for Windows software. The EM survey electromagnetic fields were transmitted into the ground at varying frequencies to generate an output of frequency effect in percentage which is interpreted as apparent resistivity. The 1D EM geo-section generated by the instrument was used to delineate different formations like clayey/weathered, partly weathered, fractured basement, and fresh basement. The VES soundings produced different geo-electric curve types including the H, K, HA, HK, and KHA types. The geo-electric section revealed four subsurface geo-electric layers including the topsoil, weathered zone, fresh basement, and fractured basement. The topsoil resistivity values ranged from 249-685 ohms-m with a thickness range of 0.6 - 12.8 m. The topsoil is made up of lateritic-sandy soil. The second layer is the weathered zone with resistivity values ranging from 52 - 230 ohms-m and thickness from 0.7- 31.2 m. The third layer is the fresh basement with resistivity values ranging from 532-2866 ohms-m. The fourth layer constitutes the fractured zone of the study area with resistivity values of 269 – 422 ohms-m. The dipole-dipole arrangement revealed a hollow structure that suggested the possibility of a buried stream channel across the study area in an East-West direction. The EM survey confirmed the findings of the electrical resistivity surveys revealing highly weathered zones and the occurrence of deep fractured bedrock even at greater depth. It further confirmed the possibility of the buried river channel in the area. This study showed the possible causes of road failure to be the presence of a thin competent lateritic layer underlain by the thick weathered zone, the presence of fractured zones beneath the weathered zone, and lack of proper drainage at the road embankment. Suggested solutions to this problem include employing stabilization methods (compaction, grouting, or chemical stabilization) for the weathered zones, rock bolting, and grouting for the fractures and putting up drainage systems at the road embankments.

KEYWORDS

Failed portion, geo-electric parameters, varying frequencies, fractured basement, buried stream.

1. INTRODUCTION

Road infrastructure is critical for economic development and social connectivity. However, road failures can occur due to various factors, leading to costly repairs, inconvenience, and safety hazards (Ozegin et al., 2019a; Oyedele et al., 2020). Roads have been demonstrated worldwide to be the most effective and preferred mode of transportation for goods and persons (Owolabi, 2012; Oni and Olorunfemi, 2016). Road transport has gained popularity due to its ability to provide better accessibility through door-to-door services and its suitability for short haulage of passengers and freight. In Nigeria, road transport is the most affordable and efficient means of transport for the majority of people as other modes of transport are either too expensive or not fully developed, thus resulting in a rise in the construction of roads. Consequently, there are excessive axle loads on the majority of the roads. Nigerian roads are predisposed to structural failure after few years of performance and often before reaching design age (Adebiyi et al., 2018; Alo and Oni, 2018; Aigbedion et al., 2019a; Bawallah et al., 2019a; Adebo et al., 2019; Bawallah et al., 2021a; Aigbedion et al., 2021; Ajayi et al., 2022a). Komolafe (2006) stated that "the state of Nigerian roads stands out like a sore thumb and their national picture is simply scandalous". Reconstruction and rehabilitation of roads in Nigeria without even care to investigate the causes of the perpetual failure is very common. Akintorinwa et al. (2011) reported that several causes such as geotechnical, geological, geomorphological, hydrological, design, material selection, construction practices, maintenance, and usage factor can influence the performance of pavement structures. The prevalent deterioration and failure of Nigerian roads have been attributed to the indiscriminate use of lateritic soils without full knowledge of their limitations (Gidigasu, 1976). Various roads failed due to negligence of road maintenance, inadequacies in design and poor workmanship, poor soil

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properties like low California Bearing Ratio (CBR) and high liquid limits, etc. among others (Ogundipe, 2008). Various failed highway pavement assessments have been conducted by several researchers using geophysical methods, which has drawn the conclusion that some geological factors such as the near-surface geologic sequence, existence of geological structures like fractures and faults, presence of laterites, the existence of ancient stream channels, and shear zones influence road failures (Momoh et al., 2008; Adiat et al., 2009; Bawallah et al., 2019b, Aigbedion et al., 2019b; Bawallah et al., 2021b; Akinlabi and Adegboyega, 2021, Bawallah et al., 2022). Every year, millions of Naira are budgeted and expended on roads (Federal and State) but the same problem would resurface after a few months of rehabilitation or reconstruction. This incessant failure of roads has now become a “thorn in the flesh” of governments prompting the geoscientists to work assiduously hard to provide a lasting solution to the problem. However, road structures like any other engineering structure, no matter how good its construction, need routine maintenance to prevent the rapid decline of the road structures caused by aging of materials, variations in age, misuse, accidental damage, mismatch between design parameters and field condition during construction to serve its purpose optimally (Anyanwu, 1990, Falowo and Akintorinwa, 2020). 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 costs, public casualties from accidents, and later expensive rehabilitation reconstruction schemes (Abam et al., 2000, Jegede, 2000, Oladapo, 1997 and Omange, 1997). The incessant structural failures on Nigerian roads are becoming alarming and have become a common phenomenon which the failures can be linked to so many factors such as inadequate information on underlying soil layers in the pavement and the local subsurface geologic data (Ilugbo et al., 2018a; Bawallah et al., 2020; Adebo et al., 2021; Ajayi et al., 2022b). Adequate information on the actual causes of failure will greatly assist in avoiding this perennial problem hence curbing the wastage of the limited economic resources on quick-fix solutions that have failed in tackling the problem (Ilugbo et al., 2018b, Ozegin et al., 2019b). Ado-Ikere-Ekiti Road is one of the busy roads in Ekiti state as it connects the state to the neighboring Ondo State. The deplorable status of the road has resulted in accidents that have caused considerable damage to human lives and properties. This has reduced the movement of people and goods, thus reducing the rate of socio-economic growth and development in the corridor. Along Km 5, Ado-Ikere Ekiti Road, there have been recurrent road failures, including pavement cracks, subsidence, and sinkholes. These failures have resulted in traffic congestion, economic losses, and safety concerns for road users and nearby communities. The exact causes and extent of the subsurface issues contributing to the road failures remain unclear, necessitating a comprehensive geophysical evaluation to identify the underlying geologic and hydrogeological factors responsible for the instability. Geophysical evaluation provides a cost-effective and non-destructive approach to assess the subsurface without the need for extensive excavation or drilling. This study, therefore, aims to investigate the causes of road failure along Km 5, Ado-Ikere-Ekiti Road in Southwestern Nigeria using geophysical techniques. The study provides non-intrusive means to assess subsurface conditions and potential causative factors, enabling effective remediation strategies and informed decision-making for road rehabilitation. The findings from this study will contribute valuable insights into the geological and hydrogeological factors that contribute to road instability, offering a scientific basis for engineering solutions and reducing the risk of future road failures in the area.

1.1 Location of Study

A portion of the road linking Ado-Ekiti to Ikere-Ekiti Southwestern Nigeria located along Km 5 is slated for this study. The failed portion of the road is located within latitudes 7º 30’ 00” N and 7º 35’ 00” N and longitudes 5º 10’ 00” E to 5º 20’ 00” E (Figure 1). The road serves as a link between the State capital of Ekiti State and the neighboring Ondo State. The road connects facilities like the Fayose housing estate, farm settlements, and the Hausa Shasha community market. Ado-Ikere highway is a busy road serving as a link to the road that connects Ado-Ekiti to the Northern part of Nigeria. The road is in the tropics experiencing similar dual wet and dry seasons as Ikere-Ekiti (Adebayo, 1993). The yearly rainy season lasts from April to October and the dry season from November to March. The mean annual temperature is 27°C while the mean annual rainfall is 1,367mm (Ogundare, 2016). The study area is underlain by the Precambrian basement complex comprising mainly of migmatite-gneiss with granitic and charnockitic rock intrusion in some places. The underlying rocks weathered into clay which may be dangerous and serve as the basis for the road failure.

2. Methods

This study was carried out employing 2 distinct geophysical methods; the Electrical Resistivity and the Electromagnetic Impact methods respectively. For the two methods, a single north-south geophysical traverse was established along the roadside at Km 5, Ado-Ikere-Ekiti road. Thereafter, Vertical Electrical Sounding (VES) and 2-Delectrical Resistivity Tomography (ERT) techniques were adopted for the study. The electrical resistivity method employed Schlumberger arrangement for vertical electrical sounding technique and dipole-dipole array for the 2D electrical imaging. The VES technique was purposely employed to determine the subsurface stratification/layering within the occupied traverse to provide a clue for the 2-D imaging. Five (5) VES stations were occupied with inter-VES separation of 50 m on the only traverse along the road up to a maximum distance of 300m (Figure 1). Half current electrode spacing (AB/2) was varied from 1 m to a maximum of 150 m for the VES locations. VES data were interpreted quantitatively by partial curve matching and computer-assisted forward modeling using the IPI2Win(R) software (Bobachev, 1990). The geoelectric parameters (thicknesses and resistivities) obtained from the VES interpretation were used to generate a geoelectric section beneath the traverse. The 2-D subsurface resistivity structures of the failed portion of the road were obtained by processing and interpreting the data obtained from the ERT quantitatively employing the inverse modeling with DIPRO for Windows software. Generally, in Electromagnetic surveys, an electric current is transmitted through the Earth and the response of the current as it travels back out of the Earth is measured. Conductivity and resistivity are the inverse of each other. Resistive zones will return a weak response whereas conductive zones will return a strong response. In this study, the electromagnetic impact method utilized the gradient array technique with inter-electrode space of 10m and 1m movement which involves the transmission of electromagnetic fields into the ground at varying frequencies to generate an output of frequency effect in percentage which is interpreted as apparent resistivity. The 1D EM section generated by the instrument was used to delineate different formations like clayey/weathered, partly weathered, fractured basement, and fresh basement.

3. Results and Discussion

A total of 5 VES locations across the single traverse were occupied in the study area (Figure 1). Data obtained from the VES soundings were processed and interpreted, resulting curve types were examined and classified while the various subsurface lithologic units were established, and the plotted geoelectric section was employed in deciphering the causes of the road failure. The results are presented in Table 1, geoelectric curves (Figure 2), and section (Figure 3).

The observed depth-sounding curves were classified into different curve types. Curve types identified in the study area are H, K, HA, HK, and KHA, varying between three to five geoelectric layers along the traverse. Each of the five curves type constitutes 20% of the study area which implies that the study area is very heterogenous as seen in Fig. 2 a-d. Curve types can be classified into four distinct classes as follows: Class 1 type curve, represents a subsurface condition in which there is an increase in resistivity values from the topsoil to the basement rock, example is the A-type curve. In class 2 curve types, the upper horizons when not leached are usually clayey and of low resistivity. Immediately underlying this usually low resistivity, high porosity, low specific yield, and low permeability aquiferous zone is the fresh basement. This classic architecture of the profile produces an H-type curve signature. Curve types of class 3 are typical of a succession of relatively low and high resistivity layers. The K type is found where a highly resistive lateritic layer underlies low resistivity clayey topsoil and a weathered zone in turn underlies the former. Or it may result from where the basement, fractured at depth, underlies the topsoil. In the curve type in class 4, the succession of the subsurface layers starts with a highly resistive topsoil followed by a more conductive horizon and then another less conductive layer underlies the latter, an example is the HKH-type curve (Olorunfemi and Olorunniwo, 1985, Idornigie and Olorunfemi, 1992, Olayinka and Olorunfemi 1992).

3.1 Geoelectric Session Results

The geo-electric parameters derived from the five VES stations were used to generate the geo-electric section of the study area. The geoelectric section (Fig.3) shows the variations of resistivity and thickness values of layers within the depth penetrated in the study area at the indicated VES stations. Four subsurface geo-electric layers which are; the topsoil, weathered zone, fresh basement, and fractured basement. The topsoil resistivity values ranged from 249-685 ohms-m with a thickness range of 0.6 - 12.8 m. The topsoil is made up of lateritic-sandy soil. The sands originated from the weathered quartzite formation of the study area.

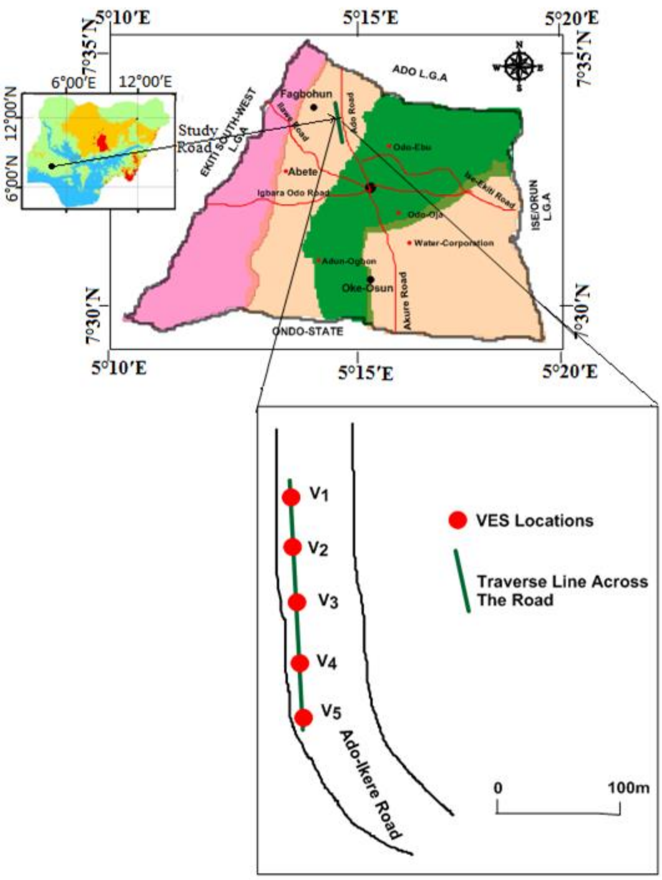

Figure 1: Location Map

Table 1: Summary of the Interpreted VES Curves						
VES	**RESISTIVITY (Ωm)**	**THICKNESS (m)**	**DEPTH**	**CURVE TYPE**	**NO OF LAYERS**	**REMARK**
1	249	2.4	2.4	H	3	Topsoil
	145	31.2	33.6			Weathered Layer
	506	--	---			Fresh Basement
2	163	0.7	0.7	KHA	4	Topsoil/ Weathered Layer
	283	1.7	2.5			Fresh Basement
	116	41.2	43.6			Fractured Basement
	2856	---	---			Fresh Basement
3	507	0.6	0.6	HA	4	Topsoil
	62	2.9	3.5			Fractured Basement
	230	12.1	15.6			Fresh Basement
	532	---	---			Fresh Basement
4	119	12.8	12.8	K	3	Topsoil/Weathered Layer
	1231	22.0	34.8			Fresh Basement
	269	---	---			Fractured Basement
5	685	0.7	0.7	HK	4	Topsoil
	66	7.8	8.5			Weathered Layer
	603	16.5	25.0			Fresh Basement
	422	---	---			Fractured Basement

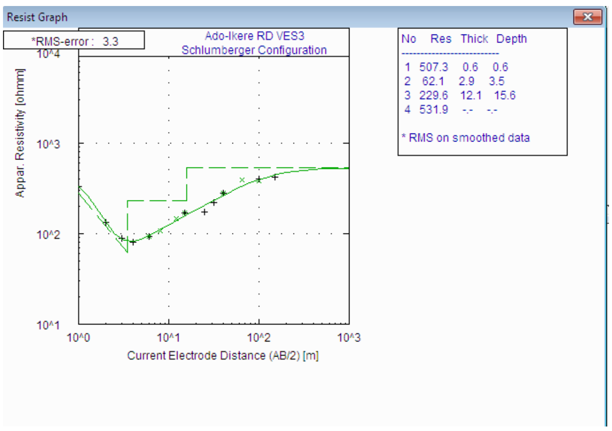

Figure 2a: Resistivity Curve of VES 1

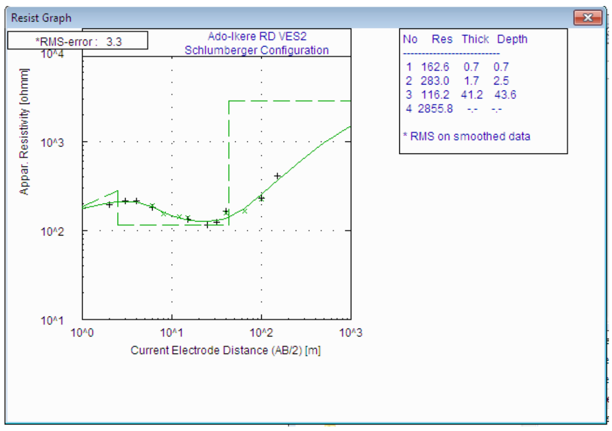

Figure 2b: Resistivity Curve of VES 2

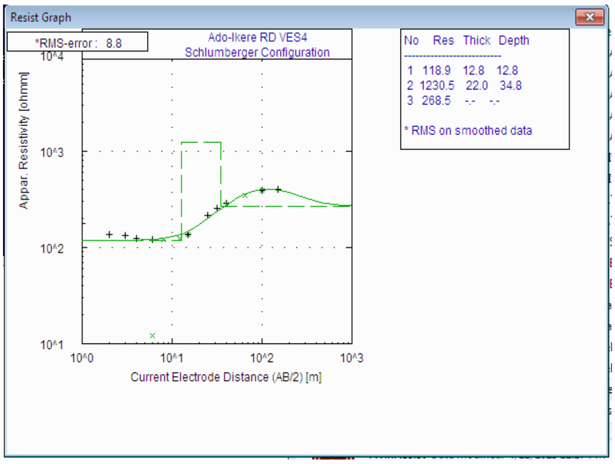

Figure 2c: Resistivity Curve of VES 3

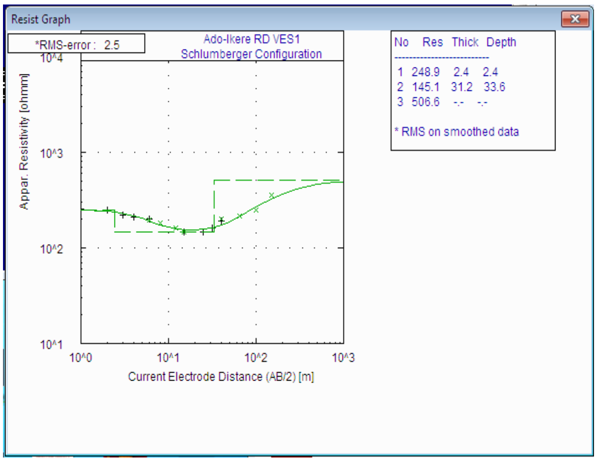

Figure 2d: Resistivity Curve of VES 4

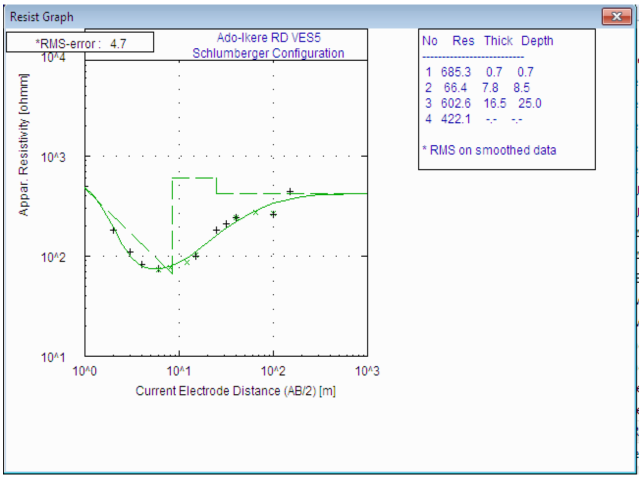

Figure 2e: Resistivity Curve of VES 5

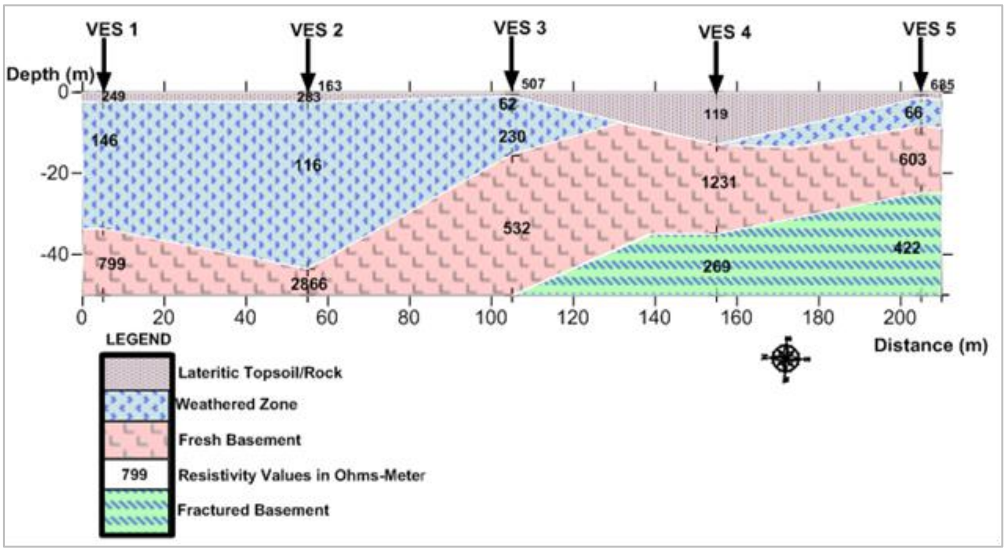

Figure 3: Geoelectric Section along the Studied Road

The second layer is the weathered zone with resistivity values ranging from 52 - 230 ohms-m and thickness from 0.7- 31.2 m; the weathered formation can be observed in VES 1, 2, 3, and 5. The third layer is the fresh basement with resistivity values ranging from 532-2866 ohms-m. The fourth layer constitutes the fractured zone of the study area with resistivity values of 269 – 422 ohms-m. The study revealed that the partly competent lateritic topsoil is very thin along distances 0 to 100 m; which was underlain by a highly thick 10 to 40 m weathered formation. These have rendered the road reconstruction work ineffective. The quantity of hardcore to fill a 40 m depth is not economical. Also, the fractured zone underlying the stable bedrock has contributed to the failing of the road uphill along distances 105 to 210 m of the study area as a result of the weight of heavy-duty vehicles plying the road. It was noted during the study that the drainage system of the road is not adequately taken care of. The blockage has also aggravated the continuous failure of the road.

The 2-D pseudo-section was produced along the single traverse (Fig. 4). The blueish color represents a highly weathered/clayey zone, the green color indicates a weathered formation, the yellow color shows a partly weathered formation while the red color signifies fresh basement with resistivity values ranging from 36-160, 161-847, 848-4511 and 4512-5554 ohm-meter respectively (Fig. 4). The study has revealed weathered formation at the depth ranging from 0-20 m. Very deep fractured formation was also observed within distances 110 to 160 m which could not be captured by the VES approach. This hollow-fractured formation revealed by the dipole-dipole arrangement has suggested the possibility of a buried stream channel across the study orientation in an East-West direction.

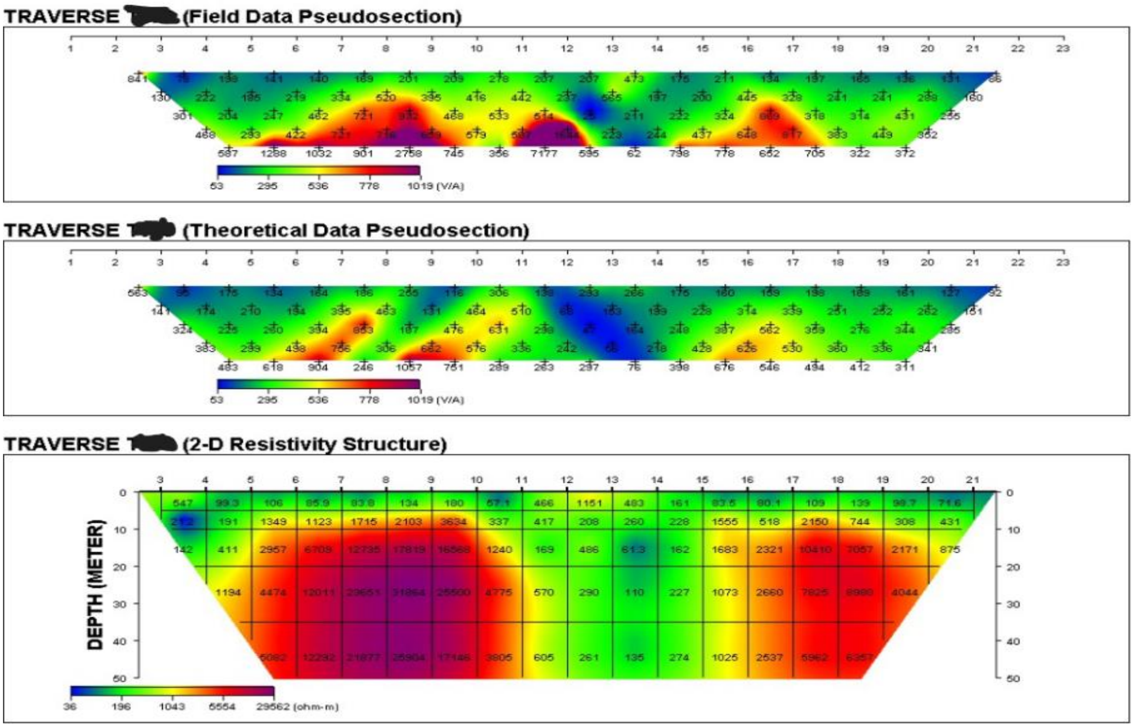

Figure 4: The 2D resistivity structure of the study area

3.2 Electromagnetic Method Result

The electromagnetic Impact method was also used with Gradient Array techniques to unravel the causes of road failure along Km5, Ado-Ikere – Ekiti road. Fig. 4. Indicating electromagnetic spectra revealed a highly weathered zone with blue coloration reflecting conductive zones with frequent effect percentage(FEP) range of 0 - 10% representing the clayey zone,11-36% with greenish color representing the fairly weathered zone and yellowish to reddish zone signifying the fresh basement/stable bedrock with above 36% FEP.

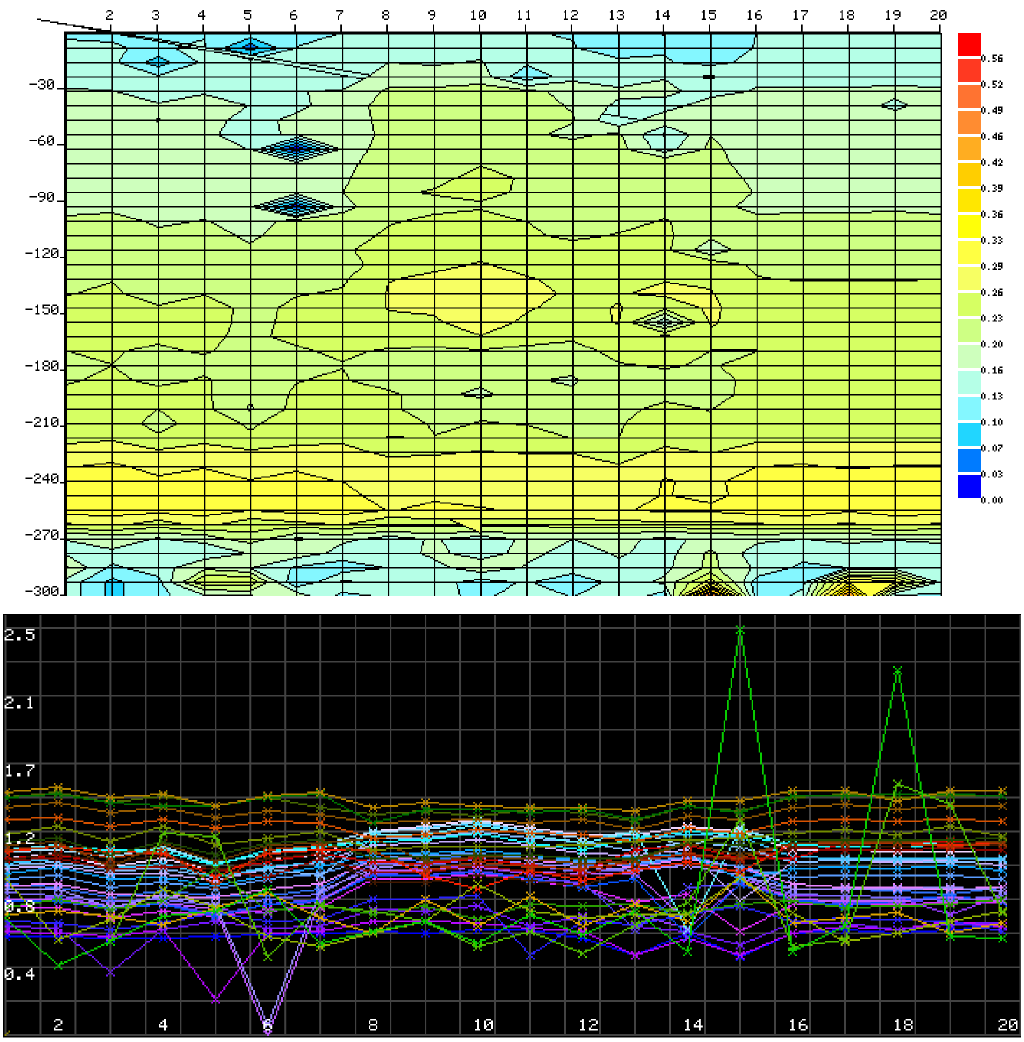

Figure 5: Pseudo-Section of the Frequency Effect Ratio Percentage of the Electromagnetic Waves and the Generated Profile Map along the Study Area.

Also, some fractured formations were revealed at distances 50, 60, and 140m at 5, 60 - 90 m, and 91-110m depth respectively. The frequency effect percentage represents the apparent resistivity variations within the subsurface. This approach captured 300 m depth of the study area. It revealed the occurrence of fractured bedrock at the depth of 47- 63 m, 86 - 100 m, and 270 to infinity along the traversed path of the road. The Electromagnetic method further revealed the possibility of the buried river channel at a depth of 270 m and above across the study area.

4. Conclusion

This research was undertaken to employ the electrical resistivity method and electromagnetic point survey to unravel the underlying causes of road failure along Km5, Ado-Ikere- Ekiti road Southwestern Nigeria. The VES showed complex geo-electric curves including H, K, HA, HK, and KHA. Three to four geoelectric layers were found along the traverse comprising the topsoil, weathered zone, fresh basement, and fractured basement. The complexity of the subsurface layers with partly thin competent lateritic topsoil underlain by thick (10 – 40 m) weathered zone is responsible for the road failure as it is not economical to fill 40 m depth with quantity of hardcore.

In addition, the fractured zone underlying the stable bedrock has contributed to the failing of the road uphill towards the western end of the failed portion. The drainage system of the road was not adequately addressed resulting in the blockage that has also aggravated the continuous failure of the road. The Dipole-dipole arrangement revealed a weathered zone as well as a hollow-fractured formation indicating the possibility of a buried stream channel across the study area in the East-West direction. The Electromagnetic point survey confirmed the findings of the electrical resistivity surveys revealing highly weathered zone and occurrence of deep fractured bedrock even at greater depth. It further confirmed the possibility of a buried river channel at a depth of 270m and above across the study area. Conclusively, the possible causes of road failure along the studied highway are; the presence of a thin competent lateritic layer underlain by the thick weathered zone, the presence of fractured zones beneath the weathered zone. And the lack of proper drainage at the road embankment. This research work has provided information on the causes of the failed segments of the investigated road which will serve as a guide to road engineers during rehabilitation or reconstruction. It has equally shown that geophysical survey is essential for pre-construction/post-construction of roads. Suggested solutions to this problem include employing stabilization methods (compaction, grouting, or chemical stabilization) for the shallow weathered zones, rock bolting and grouting the fractures, and putting up drainage systems at the road embankments.

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