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GEOPHYSICAL INVESTIGATION OF PAVEMENT FAILURE ALONG JONATHAN BY-PASS - AKANSOKO AND ATIMBO - PARLIAMENTARY ROADS IN CALABAR METROPOLIS CROSS RIVER STATE, NIGERIA

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ABSTRACT
This study examined pavement failure in some roads in Calabar Metropolis using electrical resistivity tomography method. Seven (7) measurements were taken at the natural soil opposite the failed and stable segments of the road with the aid of Wenner electrode configuration at spacing of 5.0, 10.0, 15.0, 20.0, 25.0, 30.0 and 35.0m with spread length of 105m. The findings of this study revealed that along Jonathan by- pass – Lafarge – Akansoko road, low resistivity values were 8.0Ωm – 73.0Ωm at Akansoko a stable segment; 6.0Ωm - 17.0Ωm at Ukwua Itiat and 30.0Ωm - 94.0Ωm at Idundu market a failed segment. Along Atimbo - Jonathan – Parliamentary road, moderate/high electrical resistivity values in the range 331.0 Ωm – 1018.0 Ωm across the profile was obtained at Federal Government Girls' College by airport a control segment; 26.0 Ωm – 68.0 Ωm at opposite rice seedling site a failed segment and 49.0 Ωm – 74.0 Ωm at Message point Assembly Church. These results showed that the remote cause of road failure in the area is clay/shale/weathered geologic materials with low resistivity values. It was recommended that detailed geophysical investigation should always be conducted on any proposed site for road construction and/or rehabilitation before embarking on the project.

Keywords: Electrical resistivity tomography; clay; failed segment; Calabar

INTRODUCTION

Geophysical methods of exploration play important roles due to their extensive applications in exclusive fields of human endeavours. They have been efficiently implemented to resolve environmental, pollution, construction and engineering issues (Nelson and Haigh, 1990; Adiat et al., 2009).

The rampant failure of road network in Nigeria particularly in Cross River State according to Abong (2017) has become a grave concern both to the road users and government. It is not unusual to see potholes, cracks, depression and bulges at the roads and this result to hold up, opportunity for robbers to dispossess road users of their assets, crashes and death. Available information at the Federal Road Safety Corps (FRSC, 2011) revealed that Nigeria ranks 191 of 192 countries of the world with unsafe roads, and as a result 162 deaths per 10,000 populations occur from road crashes. Most accidents recorded in major high ways in Cross River State happened within the bad portions which are as a result of failure.

Ifabiyi and Kekere (2013) and Osemudiamen (2013) revealed that incompetence of subsurface geological substances, geology, usage, poor construction, poor renovation, insufficient information approximately the subsoil and geomorphology are answerable for the failure. Other factors in the opinions of Lebourg et al(2005), Fatoba et al(2010) and Adeyemo et al(2014) that could in all likelihood results in failure of the roads are capabilities like faults, sinkholes, cavities which are not considered by foundation and structural engineers before construction.

Several studies have employed unique strategies to investigate road failure. For instance, Ademila (2022) linked road failure to deep weathering bedrock of low resistive (<100Ωm) water saturated clayey subgrade. Weltime et al (2022) observed that resistivity of top layer <100Ωm is a sign of abundance of clay/shale substances which might be incompetent soils for road construction. Adenika et al (2018) connected failure of roads to clay under the toll road pavement and geologic elements. Okpoli and Bamidele (2016) attributed failure of the roads to weathered, low resistivity, water-absorbing substratum, joints and fracture zones, clayey soil and bad drainage system.

Atimbo - Parliamentary road is a major linking technical roundabout in 8miles and Lafarge –Akansoko, Calabar, Cross River State, Nigeria. The area is highly populated and the roads serve as great access to Parliamentary and surrounding areas. The greater populations in this part of the town are predominantly business people. Farm produce from neighboring communities hardly get to the outside market due to bad roads and commercial drivers charge very high transportation fare.

This has aroused the interest of the researcher to investigate road failure in Calabar Metropolis using electrical resistivity tomography method.

Location of the study area

The study area is located in Calabar Municipality Local Government area of Cross River State. The study area lies between the geographic coordinates (UTM) of latitudes N 04^{0} 55' 13.5" to N04^{0} 55' 15.6" and longitudes E008^{0} 19' 44.7" and E008^{0} 19' 45.7" The topographic elevation around the study area ranges from 6.0m to 66.0m (Table 1 and Fig.1).

Hydrogeology and geology of the study area

Calabar metropolis experiences peak rainfall in July and September of the year. The area has 3000mm of mean yearly rainfall and over 85% of relative humidity (Eni and Efiong, 2011). The three major rivers in the area include Akpayafe, Great Kwa and Calabar emptying into the main Cross River.

The geology is Coastal Plain sands known as the Benin formation

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and the lithology comprises alluvium, loose gravel, gravel, clay, lignite and gravel (Short and Stauble, 1967).

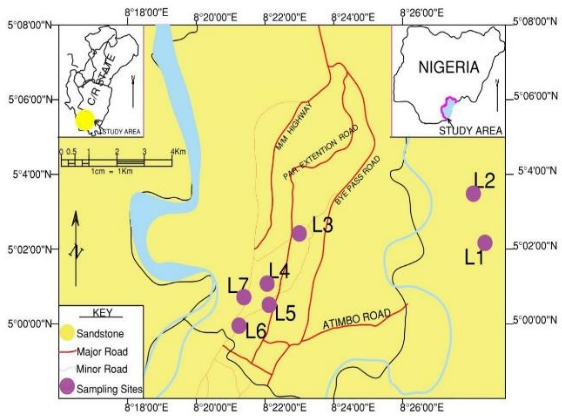

Figure 1 Geologic map of the study area (Drawing Unit (2023), Geology Department University of Calabar, Nigeria

MATERIALS AND METHODS

The major instrument used for data acquisition was a Resistivity Meter Model SSR-MP-ATS by IGIS (India) which can measure the earth resistance with an accuracy of 1μΩ and 24V rechargeable batteries. Accessories included twenty-one (21) electrodes, current and potential reels, measuring tapes, GARMIN 12 Global Positioning System (GPS), Hammers and Umbrella.

Table 1 Midpoint coordinates in the study area

S/N	Location	Label	Latitude	Longitude	Elevation (cm)	Segment
	Jonathan By- pass - Lafarge - Akansoko road					
1	Akansoko by market, Akpabuyo	L_1	N05°021’46.8”	E008°27’39.3”	8.0	Control
2	Ukwa Itiat, Akpabuyo	L_2	N5°03’15.0”	E008°27’17.1”	15.0	Failed
3	Idundu market , Akpabuyo	L_3	N05°00’53.9”	E008°23’45.1”	8.0	Failed
4	Jonathan By-pass close to bridge, Calabar	L_4	N05°00’44.3”	E008°22’45.4”	29.0	Failed
	Atimbo - Jonathan by-pass - Parliamentary road					
5	Federal Government Girls’ College, Calabar	L_5	N05°58’55.5”	E008°21’12.2”	66.0	Control
6	By Rice Seedling site Ayade Industrial Park, Calabar	L_6	N05°00’10.2”	E008°21’52.8”	41.0	Failed
7	By Message Point Assembly Church, Calabar	L_7	N05°00’51.0”	E008°22’00.9”	9.0	Failed

Data Acquisition

Seven (7) electrical resistivity tomography (ERT) measurements were carried out with five (5) at the different failed sections of the road and two (2) at the stable sections of the road which served as controls. In this method, twenty-one electrodes were arranged on a straight line, with current electrodes placed outside and the potential electrodes inside. Both current and potential electrode positions were aligned using constant electrode spacing (i.e. Wenner electrode configuration) with a separation of 5, 10, 15, 20, 25, 30 and 35m. The full procedure for conducting electrical resistivity tomography is described (Loke, 2000). The electrical resistivity tomography data after converting to apparent resistivity was imported into RES2Dinv software version 4.00.03.

RESULTS AND DISCUSSION

The results from the field data resistivity, tomograms (2-D inverse model resistivity) of all the profiles in the study area are shown in (Fig.2 – Fig.8). These pseudo sections reveal features that may be responsible for the cause of the road failure in the study area.

Jonathan by- pass – Lafarge – Akansoko road

Fig.2 shows the inverted resistivity tomogram at Akansoko. The profile has a horizontal distance of 105m with a maximum depth of 19.4m with resistivity ranging from 8.0 Ωm to 182.0 Ωm and is a stable segment of the road. There is a moderate resistivity value ranging from 116Ωm to 182Ωm at the top of the profile to a depth of 8.86m which represents sandy clay across the entire profile. Beneath this is a low resistivity layer with resistivity ranging from 8.0Ωm to 73.0Ωm which represents clay. Though there are no failures in this profile, but the area is vulnerable to failure in future because the competent layer is seated on an incompetent layer. The moderate resistivity values are indication of moderately competent soils, while low resistivity values are indication of incompetent soils (Weltime et al, 2022).

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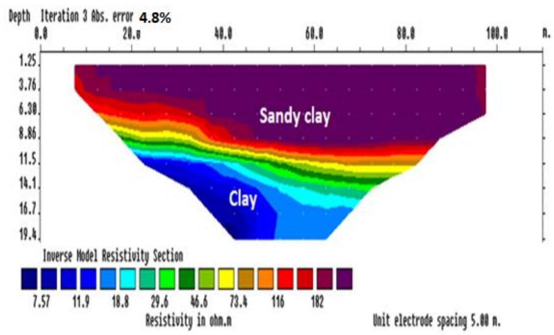

Figure 2 Inverted image of ERT 1 at Akansoko Calabar stable road section (control segment)

In Fig.3, the profile has a horizontal distance of 105m with apparent resistivity values ranging from ≤6.0Ωm to 265Ωm at a depth of 19.4m. The top layer has moderate resistivity values which represent clay ranged from 153 Ωm to 265 Ωm to a depth of 6.38m. Below the top layer is a low resistivity that lies in the range ≤6.0Ωm to 17.0Ωm at depths from 8.86.m to 19.4m. This indicates clayey clay. This implies that the road pavement is founded on an incompetent layer and is responsible for the road failure. Also it was observed that drainage was poor in this profile.

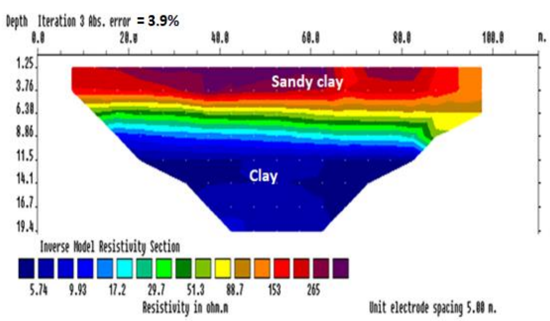

Figure 3: Inverted image of ERT 2 at Ukwa Itiat Calabar (failed segment

Fig.4 shows the electrical resistivity tomogram at Idundu market road section, failed section.
The resistivity values ranged from ≤30.0Ωm to 223.0Ωm and an approximate depth range of 19.4m. The layer is characterized with low resistivity ranged from ≤30.0Ωm to 94.0Ωm which is clay and is an indication of weak zone having approximate depths at about 14.1m and 8.86m and a lateral spread distance between 0.0m to 98.0m. A moderate resistivity occurred below the top layer with resistivity in the ranged 125.0 Ωm to 223.0Ωm which is represents sandy clay between the horizontal distance of 38.0m and 85.0m between the depths 8.86m and 19.4m. Since the area is dominated with clay, it is an indication of poor subgrade. The poor construction materials may have been the cause of the failure of the road, and also poor drainage system may have attributed to the failure of road.

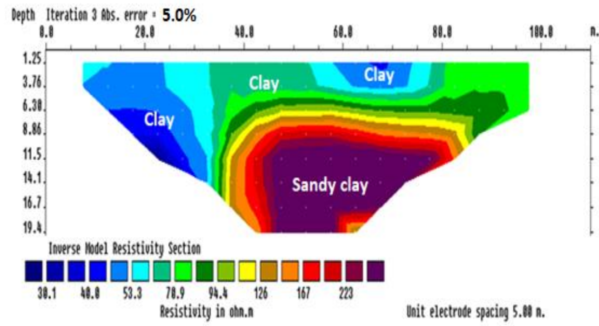

Figure 4: Inverted image of ERT 3 at Idundu market Calabar (failed segment)

Fig.5 shows the electrical resistivity tomogram at Jonathan by-pass close to the bridge road, failed section. The area has resistivity values ranged from ≤ 1.0Ωm to 237Ωm and a depth range of 19.4m. The competent layer has moderate resistivity in the range of 106.0Ωm to 237.0 Ωm and it represents sandy clay at depths of about 3.76m and 2.51m at a lateral distance of between 0.0m to 65.0m. The incompetent layers are characterized with low resistivity range of 1.0Ωm to 47.0Ωm which represents clay with depth range of 6.30m to 19.4m. Since the area is predominated with clay, this may have been the causes of the road failure due to infiltration between the two layers.

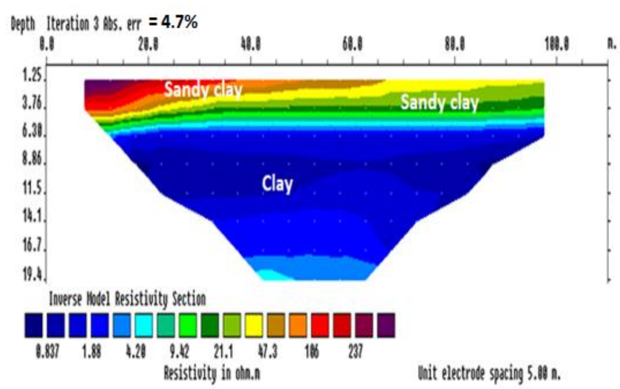

Figure 5 Inverted image of ERT4 at Jonathan by- Pass close to bridge Calabar (failed segment)

Atimbo - Jonathan by-pass - Parliamentary road
Fig.6. shows the tomogram at Federal Government Girls' College, Calabar which served as a control. The profile has a lateral distance of 105m with electrical resistivity characterized by electrical resistivity ranged from 331.0Ωm to 1018.0Ωm. The subsurface below the ground in the control is characterized by moderate resistivity values from 331.0Ωm to 739.0Ωm which represents clayey sand and high resistivity >739.0Ωm to 1018Ωm which represents laterite /sand across the profile. The moderate and high resistivity values are indicative that there are no failed portions or sections of the road at the control. This implies that the soils at the control are competent and good for construction of pavement roads.

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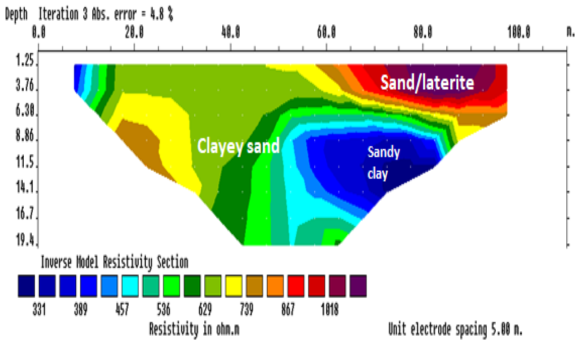

Figure 6 Inverted image of ERT 5 at Federal Government Girls College Calabar by Airport (Control segment)

Fig.7 shows the tomogram at rice seedling site, Calabar where there was a big pothole (failed segment). The profile has resistivity in the range of 26.0Ωm to 19259.0Ωm at a lateral distance of 105m and a depth of 19.4m. The top layer has a low resistivity ranged from 26.0Ωm to 68.0Ωm which represents clay with shale intercalation at depths 16.7m, 14.1m and 11.5m respectively across the entire profile. Beneath the top layer is the second layer with moderate resistivity values ranged from 173.0Ωm to 444.0Ωm and represent sandy clay/clayey sand at depths 14.1m and 16.7m and the third layer with very high resistivity values ranged from 1140.0Ωm to 19259.0Ωm which represents laterite/sand. The low resistivity value is an indication of clay with shale intercalation which may be responsible for road failure. The moderate and high resistivity layers are indications of competent materials such as sandy clay, clayey sand, laterite/sand and lateritic soils which are good construction materials.

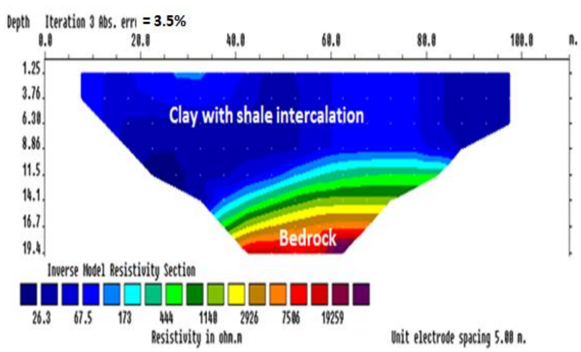

Figure 7. Inverted image of ERT 6 at rice seedling site Calabar (failed segment)

Fig.8 shows the inverted resistivity tomogram at Message Point Assembly Church, Calabar where there was a big pothole (failed segment). The profile has a resistivity in the range 49.0 Ωm to 975.0Ωm at a lateral distance of 105m and a depth of 19.4m. The top layer has a low resistivity ranged from 49.0Ωm to 74.0Ωm which represents clay with shale intercalation at depths 3.76m and 6.30m respectively across the entire profile. Beneath the top layer is the second layer with moderate resistivity values ranged from 114.0Ωm to 635.0Ωm which represents sandy clay/clayey sand at a depth between 6.30m and 8.06m and the third layer with very high resistivity values ranged from > 975.0Ωm which represents laterite/sand. The top with low resistivity value is an indication of clay with shale intercalation which may be responsible for road failure and is seated on competent layers. The moderate and high resistivity layers are indications of competent materials such as sandy clay, clayey sand, laterite and lateritic soils which are good construction materials.

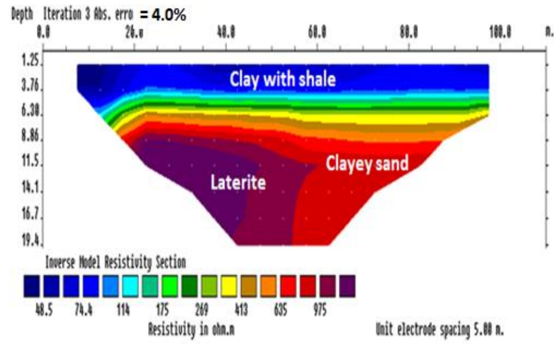

Figure 8. Inverted image of ERT 7 at Message Assembly Church Calabar (failed segment)

DISCUSSION OF FINDINGS

The findings of this study revealed that along Jonathan by pass – Lafarge – Akansoko road, low and moderate resistivity values were 8.0Ωm – 73.0Ωm and 116.0Ωm - 182.0Ωm at Akansoko, a stable segment that served as a control. At Ukwua Itiat a failed segment, the low and moderate resistivity values were 6.0Ωm - 17.0Ωm and 153.0Ωm – 265.0Ωm. At Idundu market a failed segment, the low and moderate resistivity values were 30.0Ωm - 94.0Ωm and 125.0Ωm – 223.0Ωm. Also at Jonathan bye-pass, low and moderate resistivity values were 1.0 Ωm – 47.0 Ωm and 106.0 Ωm – 237.0 Ωm.

Along Atimbo - Jonathan – Parliamentary road, electrical resistivity tomography measurement taken at Federal Government Girls' College by airport which served as a control was characterized with moderate/high electrical resistivity values in the range 331.0 Ωm – 1018.0Ωm across the profile. At opposite rice seedling site a failed segment, low and moderate/high resistivity values were 26.0Ωm – 68.0Ωm and 173.0Ωm – 19259.0Ωm. At Message point Assembly, low and moderate/high resistivity values were 49.0Ωm – 74.0Ωm and 114.0Ωm – 975.0Ωm. These results showed that the remote cause of road failure in the area is clay/shale/weathered geologic materials with low resistivity values. The moderate/high values of resistivity are indications of competent soils such as sandy clay, laterite, and lateritic soils which are good construction materials. Though there was no failure at the control segment at Akansoko, but the low values of resistivity in the segment indicates that segment is vulnerable to failure in future. The findings in this study are in agreement with the findings of Adiat et al(2017), Ademila (2022), Akinlabi and Adegboyega (2021) and Jekayinfa and Osinowo (2021) who reported that the causes of road failure is due to clayey materials which have low resistivity values and areas with clay are weak zones that are unable to withstand the loads. Clays swell and shrinks during seasons and this give rise to several cracks and deformations on the road leading to failure because of reduced shear strength and incompressibility ((Egwuonwu et al., 2011 ; Eebo and Abiodun, 2021). The findings are also in consonance with the findings of Ebhohimen (2013) who revealed

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that highly resistive soils are competent zones and low resistive zones are incompetent zones. Also Nnamdi et al(2019) corroborated the present findings and observed that moderate and low resistivity values correspond to partially stable and failed sections of the road.

Conclusion
Geophysical investigation of the failed segments of roads in Calabar Metropolis indicated that the remote causes of road failure in the study area are due to geologic factors such as clay/shale materials/highly weathered materials especially at top layer. These are responsible for the road failures at Ukwa Itiat, Idundu market, Jonathan by-pass, rice seedling site and by Message point Assembly Church. It was recommended that the clay/shale deposits as well as highly weathered geologic materials existing beneath the pavement should be excavated and replaced with more competent materials such as granite, laterite, clayey sand and sandy clay before laying the asphalt at Ukwa Itiat, Idundu market, Jonathan by-pass, rice seedling site and Message point Assembly Church. Also Suitable drainage channels should be constructed at all locations to prevent flood and washing away of road pavement.

REFERENCES
Abong, A.A(2017). Geophysical investigation of some failed segments of major highways in Cross River State, Southeastern Nigeria. PhD Thesis, University of Calabar, Calabar, Nigeria.

Ademila, O(2022). Engineering geophysical investigation of Oka-Isualbillo highway failure;remedy and road sustainability in Nigeria. *J. of Sci. Res. of the Banarus Hindu University*, 66(1), 41 – 52.

Adenika , C.I, Ariyibi, E.A, .Awoyemi , M.O, Adebayo, A.S, Oluwaseyi, A, Dasho, O.A & Olagunju, E.O (2018). Application of geophysical approach to highway pavement failure: a case study from basement complex terrain southwestern Nigeria. *Geo-Eng,* 9{8), 1-22.

Adeyemo, I. A, Omosuyi, G.O, Olayanju, G.M & Omoniyi, G.K(2014). Hydrogeologic and geoelectric determination of groundwater flow pattern in Alaba-Apatapiti layouts, Akure, Nigeria. *Intern. J. of Eng. Sci*, 3, 44–52.

Adiat, K.A.N., Akinlalu, A.A & Adegoroye, A.A(2017). Evaluation of road failure vulnerability section through integrated geophysical and geotechnical studies. *NRIAG Journal of Astronomy and Geophysics*, 6(1), 244 – 255.

Adiat, K.A.N. Adelusi, A.O. & Ayuk, M.A (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.

Akinlabi , I.A & Adegboyega, C.O (2021). Engineering geophysical investigation of road failure in a basement complex terrain, Southwestern Nigeria. *Journal of Geography, Environment and Earth Sciences International*, 25(2), 40-51.

Drawing Unit (2023). Geology Department University of Calabar, Nigeria

Ebhohimen, V.O(2013). Geophysical investigation of road failure using electrical resistivity imaging method, a case study of Uhiele – Opoji road Edo State. An MSc thesis Department of Geology, Faculty of Physical Sciences, University of Nigeria, 1-115.

Eebo, F. O & Abiodun, O(2021). Geophysical investigation of causes and characteristics of road failure along part of Ilara-Ipogun, Ondo State, Nigeria. *Global Scientific Journals*, 9 (7), 27 – 38.

Egwuonwu, G. N., Ibe, S.O & Osazuwa, I.B. (2011). Geophysical assessment of foundation depths around a leaning superstructure in Zaria Area, Northwestern Nigeria using electrical resistivity tomography. *The Pacific Journal of Science and Technology,* 12(1), 472 - 486.

Eni, D.I & Efiong, J(2011). Seasonal variations in hydrochemical parameters of groundwater in Calabar South, Cross River State, Nigeria. *British Journal of Arts and Social Sciences*, 3(1), 85-97.

Fatoba, J.O, Alo, J.O & Fakeye, A.A (2010). Geoeletrical imaging for foundation failure investigation at Olabisi Onabanjo University mini campus, Ago-Iwoye, Southwestern Nigeria. *J. of Appl. Sci. Res,*.62, 192–8.

Ifabiyi, I.P & Kekere, A.A.(2013). Geotechnical investigation of road failure along Ilorin Ajase – Ipo road Kwara State, Nigeria. *J. of Environ. and Earth Sci*., 3(7), 91-95.

Jekayinfa, S & Osinowo, O(2021). Geophysical and geotechnical investigation of road pavement failure in part of Ibadan Metropolis southwestern Nigeria *Asian Journal of Geological Research,* 4(4), 17-31.

Lebourg, T, Binet, S, Tric, E, Jomard, H & El Bedoui, S(2005). Geophysical survey to estimate the 3D sliding surface and the 4D evolution of the water pressure on part of a deep seated landslide, *Terra Nova*, 17399 – 406.

Nelson, R.G & Haigh, J.H(1990). *Geophysical Investigation of in Lateritic Terrain*. Geotechnical and Environmental Geophysics. Ward, S.H. (Ed), (Geotechnical), SEG, Tulsia. 2, 133 – 154.

Nnamdi, J.A, Zander, C.C.A & Osita, C.O(2019). Geophysical and geotechnical investigation of failed section of Orsu-Ihiala Road Southeastern Nigeria. *International Journal of Scientific & Engineering Research*, 10(6), 461-467.

Okpoli, C.C & Bamidele, A.A(2016). Geotechnical investigation and 2D electrical resistivity survey of a pavement failure in Ogbagi road, Southwestern Nigeria. *Intern. Basic and Appl. Res. J.,* 2(7), 47- 58.

Osemudiamen, E.V(2013). Geophysical investigation of road failure using electrical resistivity imaging method, a case study of Uhiele-Opoji road Edo State. M.Sc Thesis University of Nigeria, Nsukka, Nigeria.

Short, K. C & Stauble, A.J.(1967). Outline geology of Nigeria Delta. *American Association ofPetroleumGeologist*,51,761-779.