PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 27 (8) 1687-1693 August 2023

Electrical Resistivity Tomography Survey of Some Failed Segments along Selected Major Highways in Cross River State, Southeastern Nigeria

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ABSTRACT: This study investigated some failed segments along Okuku – Okpoma and Abuochichie – Obanliku highways. Six (6) measurements employing electrical resistivity tomography (ERT) were conducted at the side of selected failed portions of the road and at the stable portions which served as controls. It was found that along Okuku – Okpoma road, the resistivity values of weak zones ranged from 25Ωm – 71Ωm at Okpoma and competent zones ranged from 840Ωm – 1376Ωm at Ugaga and 600Ω.m – 800Ωm at Ogbudu. Along Abuochichie – Obanliku road, the resistivity values of weak zones ranged from 25Ωm – 35 Ωm at Ukwutia and 78 Ωm – 90Ωm at Bukumanya and competent zones from 828Ωm – 1021Ωm at Amunga. The results further indicated that the remote causes of road failure are as result of geologic factors such as clay/shale materials/highly weathered materials at Okpoma, Ukwutia and Bukumanya where they occurred. It was recommended that geophysical surveys should be conducted prior to the construction of roads. Also clay materials as well as highly weathered geologic materials existing beneath the pavement should be excavated and replaced with competent materials such as sandy clay, clayey sand, sandstones, granite during construction of roads before laying the asphalt especially at Okpoma, Ukwutia and Bukumanya. Also there should be proper drainage system to prevent floods and washing of roads.

DOI: https://dx.doi.org/10.4314/jasem.v27i8.11

Cite this paper as: ABONG, A. A; GEORGE, A. M. (2023). Electrical Resistivity Tomography Survey of Some Failed Segments along Selected Major Highways in Cross River State, Southeastern Nigeria. *J. Appl. Sci. Environ. Manage.* 27 (8) 1687-1693

Dates: Received: 10 July 2023; Revised: 25 July 2023; Accepted: 14 August 2023 Published: 30 August 2023

Key word: Electrical resistivity tomography; failed segment; highway; road failure; competent zone.

Geophysical methods of exploration are gaining grounds as a result of their wide applications in different fields of human endeavours. They have been successfully applied to solve environmental, pollution, construction and engineering problems. The incessant failure of road network in Nigeria especially in Cross River State has become a source of worry both to the road users and government. It is common to see potholes, cracks, depression and bulges on the roads and this leads to traffic logjam and serve as avenue for robbers to dispossess road users of their belongings. Some researchers reported that factors such as incompetence of subsurface geological materials, geology, usage, poor construction, poor maintenance, insufficient information about the subsoil and geomorphology (Ifabiyi and Kekere, 2013 and Osemudiamen, 2013) may be responsible for the failure. Other factors according to Lebourg *et al*(2005), Fatoba *et al*(2010) and Adeyemo *et al*(2014) that may likely lead to failure of the road are features like faults, sinkholes, cavities which are not taken into consideration by foundation and structural engineers prior to construction. Many researchers have used different methods to investigate road failure. For instance, Adenika *et al* (2018) linked failure of roads to clay below the highway pavement and geologic factors. Okpoli and Bamidele (2016) attributed failure of the roads to weathered, low resistivity, water-absorbing substratum, joints and fracture zones, clayey soil and poor drainage system. Igwe (2015)

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reported the presence of huge amount of clay as one of the probable causes of road failure, as it could lead to differential settlement. Ibitomi *et al* (2014) reported failure of road due to low resistivity materials like clay, linear geological structures and partly fractured bedrock. Ozegin *et al* (2011) linked failure of the road to fracture zone and clay. Adiat *et al* (2009a) and Adiat *et al* (2009b) revealed failure of roads to geologic structures and sequence. Momoh *et al* (2008) revealed bad drainage system, geologic structures and clayey subgrade soil below the road. Aigbedion (2007) associated failure of the roads to clay, type of construction materials and drainage system. Olorunfemi *et al* (2005) observed that failure of road could happen due to subsurface materials of high clay content and low resistivity. Ademila (2022) considered the cause of road failure due to deep weathering bedrock of low resistive (<100Ωm) water saturated clayey subgrade. Similarly, Oloruntola *et al* (2022) attributed the failure of the road to subgrade soils with low resistivity (<100m) interpreted as clay. Also Weltime *et al* (2022) revealed that the resistivity of top layer <100Ωm is an indication of abundance of clay/shale materials which are incompetent soils for road construction. Few studies have carried out to study road failure in Cross River State. The only study conducted along some failed portions of highway in Cross River State was by Ilori *et al* (2014). Hence, this study on electrical resistivity tomography survey of some failed segments along some major highways in Cross River State, Southeastern Nigeria.

MATERIALS AND METHOD

Location and areal extent: The area of study is situated within the Obudu Plateau, which lies between latitudes $6^0$20’ and $6^0$40’North and longitudes $8^0$45’ and $9^0$15’ East (Fig.1). The study area includes: Abuochichie, Obudu – Obanliku and Okuku – Okpoma road.

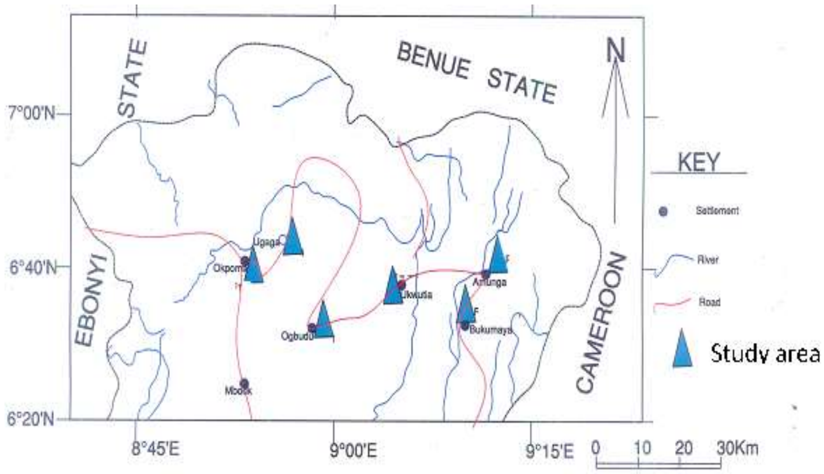

Fig. 1: Location map of the study area

Hydrogeology and geology and of the study area: The area of study is characterized by two seasons namely, wet season from April – October and dry season from November to March with an annual rainfall mean value of 1750mm – 2000mm. Akpanidiok (2010) and Edet *et al* (2011) reported that the area has high temperature with an average yearly temperature value of 27^0C to 29^0C. Holocene cretaceous and tertiary sediment controlled the geology of Cross River North which constitutes the lower Benue trough (Fig.2). According to Ekwueme (2013), the sediments lie unconformably on rocks of the Crystalline Basement (Oban – Obudu Massif). Abakaliki Anticlinorium, Anambra Basin, Calabar Flank, Afikpo Syncline and Mamfe Embayment are parts of the lower Benue Trough. The geological materials comprised shales and sandstones of Eze - Aku shale groups (Bulktrade & Investment Company Limited, 1989). Abakaliki formation which belongs to the group is associated with impervious shales with minor deltaic sediments of the Makurdi sandstone. The second group, Eze - Aku shale has transgressional sediment and comprises limestones, sandstones, marine deposits rich in pelagic micro - fauna and shales. Beneath the sedimentary rock formation is the Basement complex, especially granites and gneisses which have been weathered because of high tropical climatic factors.

Electrical resistivity measurements: Resistivity Meter Model SSR-MP-ATS by IGIS (India) with an accuracy of 1μΩ and its accessories was used to acquire data from the field. Six (6) measurements were taken using electrical resistivity tomography carried out at the side of selected failed portions of the road and at the stable portions which served as controls. A total of six (6) profiles were taken with four (4) at failed segments and two (2) at stable segments. Twenty one (21) electrodes were arranged in a straight line using Wenner array electrode configuration based on Loke (2000) techniques. A spacing of 5, 10, 15, 20, 25, 30 and 35m was employed for all profiles.

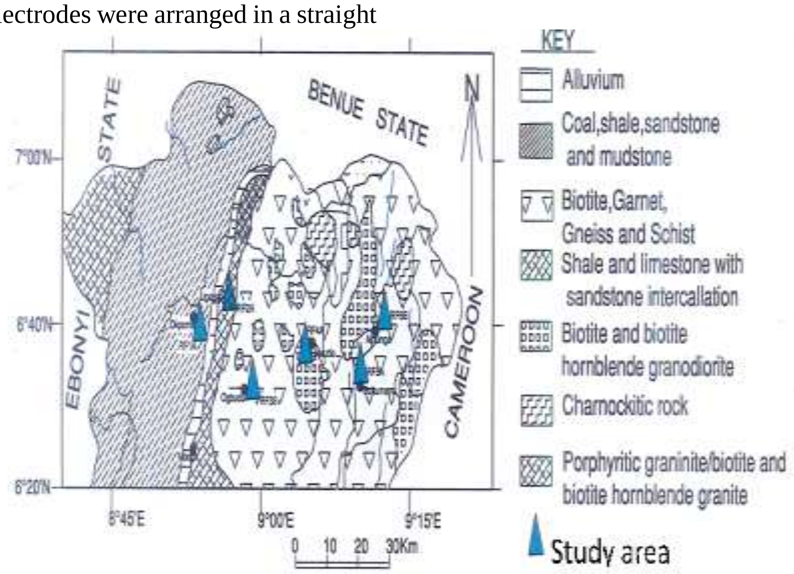

Fig.2 Geologic map of the study area

Table 2. Coordinates of midpoints in the study

Location	Label	Latitude	Longitude	Elevation(m)
Okpoma, Yala	RF_{1A}	N06^{0}37'04.7"	E008^{0}39'44.5"	75.0
Ugaga, Yala	RF_{2A}	N06^{0}41'22.6"	E008^{0}44'22.9"	117.0
Ogbudu, Yala	RC_1	N06^{0}33'07.1"	E008^{0}40'56.7"	103.0
Ukwutia, Obudu	RF_{3A}	N06^{0}36'38.11"	E009^{0}02'31.3"	143.0
Bukumanya,Obanliku	RF_{4A}	N06^{0}36'34.0"	E009^{0}11'58.0"	252.0
Amunga, Obanliku	RC_2	N06^{0}38'42.6"	E009^{0}12'28.2"	251.0

RF: Road Failure; RC: Road Control

RESULTS AND DISCUSSION

The processed results are as shown in Fig. 3 - Fig. 7. The pseudo sections reveal features that may be responsible for the causes of road failure. In ERT 1 and Fig.3, resistivity values >405Ωm between lateral distances 27.0m – 50m with a thickness of 2.50m constitutes the top soil considered to be clayey sand. Beneath this is a resistivity that ranged from 123.0Ωm - 272Ωm considered to be sandy clay. Below it is a low resistivity layer that ranged from 25Ωm – 83.0Ωm across the profile with thicknesses between 6.38 – 12.4m and 3.75m – 11.0m. This low resistivity is considered as clay/shale intercalation. The low resistivity characterized by clay/shale intercalation accounts for the failure of this segment. In ERT 2 and Fig.4, a high resistivity at the top layer 840Ωm – 1376Ωm but with thicknesses 3.75m – 6.0m and 6.50m indicates sandstone with mudstone intercalation. Underlain this layer is a low resistivity material with resistivity ranging from 44Ωm – 71Ωm found between lateral distances 20m – 33m and 45m – 75m with thickness between 10m – 12m. The low resistivity range is considered to be clay and is responsible for the road failure in the segment. In ERT 5 and Fig.5 which served as a control, show a relatively moderate resistivity material 600Ωm – 800Ωm between lateral distances 30m– 70m with thickness 1.25m forms the topsoil interpreted as lateritic topsoil. Below this is a very high resistivity material 1646Ωm – 1942Ωm across the entire profile. The high resistivity underlying the road pavement which indicates typical of sandstones, granite and laterite are responsible for the stability of this segment. In ERT 6 and Fig.6, a resistivity value in the range 200Ωm – 284Ωm was observed between lateral distances 60m – 80m interpreted as lateritic topsoil. Underlying this topsoil layer is a low resistivity material with resistivity range from 25Ωm – 35Ωm with thicknesses 9.0m, 11.0m and 6.38m – 11m respectively across the profile between lateral distances 7m – 83m. The low resistivity range is considered to be clay materials and is responsible for the road failure in the segment.

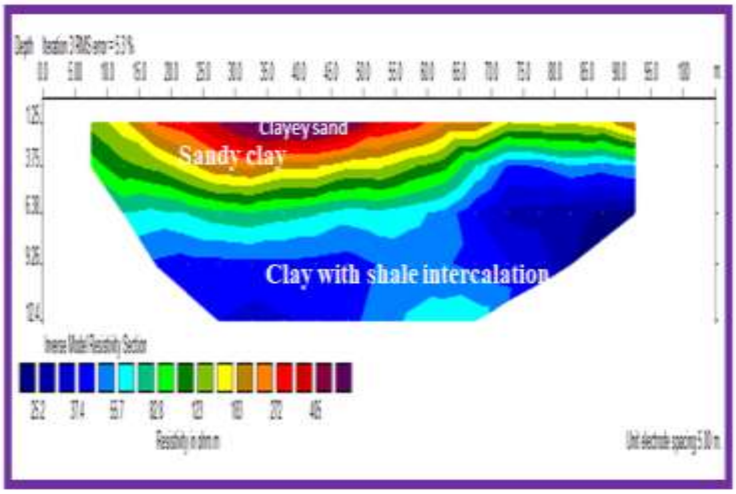

Fig. 3 Inverted 2D least square inversion apparent resistivity pseudo-section for ERT 1 at RF1A Okuku – Okpoma road

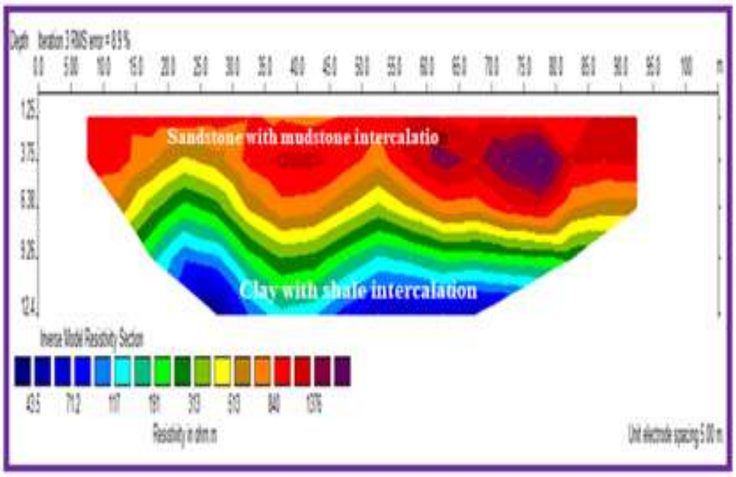

Fig. 5. Inverted 2D least square inversion apparent resistivity pseudo-section for ERT 2 at RF2A Okuku – Okpoma road

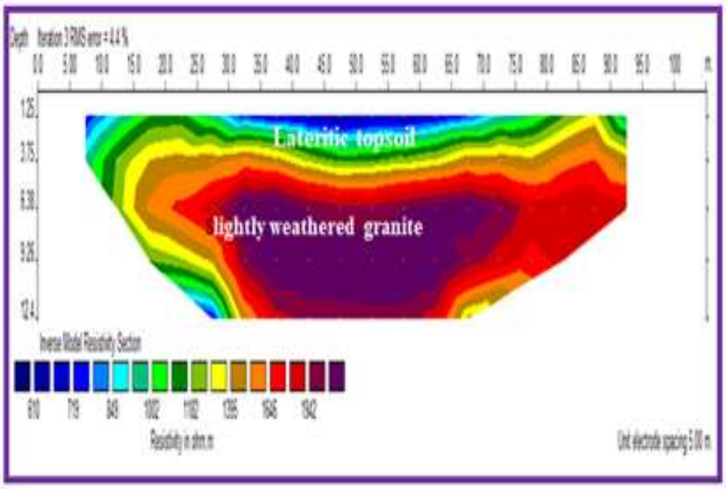

Fig. 5 Inverted 2D least square inversion apparent resistivity pseudo-section for ERT 3 at RF3B Okuku – Okpoma road

In ERT 7 and Fig.7, the top layer has resistivity ranging from 180Ωm – 207Ωm between lateral distances 7m – 20m, 30m – 53m with thickness of about 2m which indicates weathered granite. A low resistivity of value ranging from 78Ωm – 90Ωm was found at lateral distances 40m – 50m, 60m – 93m respectively interpreted as clay materials and are responsible for the failure of this segment. In ERT 8 and Fig.8, a very high resistivity material 828Ωm – 1021Ωm and moderate resistivity 440Ωm – 671Ωm at lateral distances 7m – 60m and 60m – 85m with thicknesses 9.0m and 11.0m spread across the entire profile. This can be interpreted as granitic rocks/weathered granitic rocks and the absence of clay material in the profile shows that the area is highly resistive and competent.

This study found that the remote causes of failure of roads in the study areas are due to geologic factors such as clay/shale materials/highly weathered materials. It was also found that along Okuku – Okpoma road, the resistivity values of weak zones ranged from 25Ωm – 71Ωm at Okpoma and competent zones ranged from 840Ωm – 1376Ωm at Ugaga and 600Ωm– 800Ωm at Ogbudu and along Abuochichie – Obudu – Obanliku road, the resistivity values of weak zones ranged from 25Ωm – 35Ωm at Ukwutia and 78Ωm – 90Ωm at Bukumanya and competent zones from 828Ωm – 1021Ωm at Amunga. The weak zones in these areas may be responsible for the road failures at Okpoma, Ukwutia and Bukumanya where the clay/shale/highly weathered materials occurred. These findings are in consonance with Olorunfemi *et al* (2005) who observed that failure of road could happen due to subsurface materials of high clay content and low resistivity.

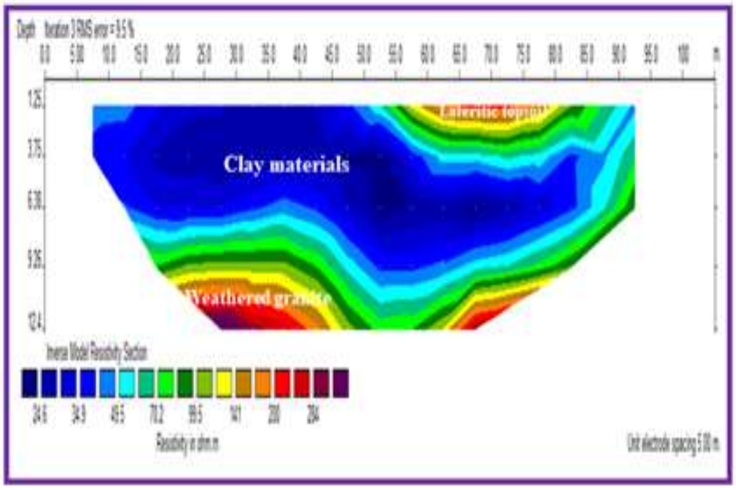

Fig.6. Inverted 2D least square inversion apparent resistivity pseudo-section for ERT 4 at RF 4A Abuochiche – Obudu – Obanliku road

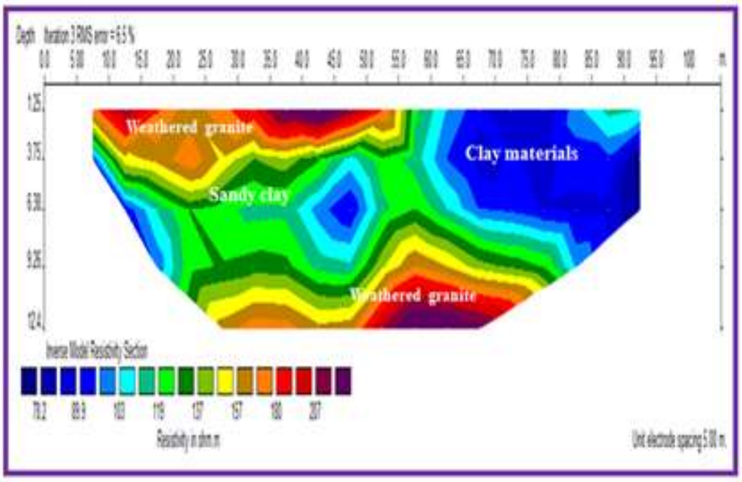

Fig.7. Inverted 2D least square inversion apparent resistivity pseudo-section for ERT 5 at RF 5A Abuochiche – Obudu – Obanliku road

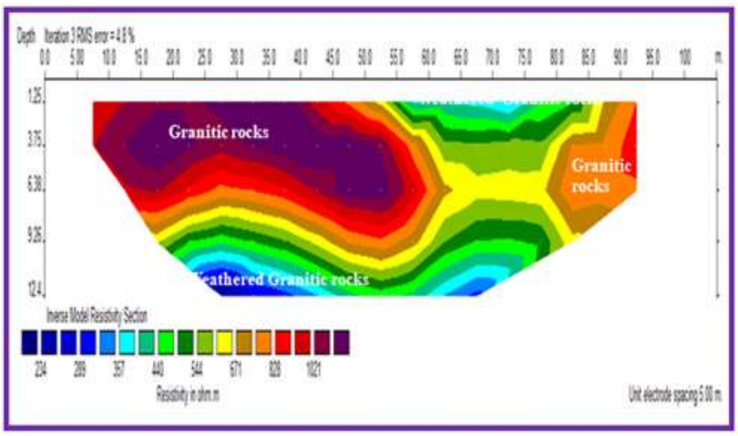

Fig.8. Inverted 2D least square inversion apparent resistivity pseudo-section for ERT 6 at RF 6A Abuochiche – Obudu – Obanliku road

Also Ozegin *et al* (2011) linked failure of the road to fracture zone and clay. These zones are weak due to fractures and create room for seepage of groundwater and accumulation which leads to failure of the roads. The findings are also in line with Aigbedion (2007) who found that majority of roads failed because clay was used as construction materials. Clay soil has the ability to swell due to moisture content and as moisture content changes, the volume of the clay changes as well and this will reduce its shear strength. According to Fatoba *et al* (2010), subgrade failure occurs when road is constructed in an area with soft clay beneath the top layer. The low resistivity materials such as clayey subgrade soil with resistivity value <100Ωm swells and accumulate water. Also geological features such as faults and fractures served as weak regions cause accumulation of water giving rise to road failure (Adenika *et al*, 2018). Similarly, the findings are in agreement with the findings of Ademila (2022) who attributed road failure to deep weathering bedrock of low resistivity(<100Ωm) water saturated clayey subgrade. Also Oloruntola *et al* (2022) linked the failure of the road to subgrade soils with low resistivity (<100Ωm) interpreted as clay. In addition, Weltime *et al* (2022) corroborated that the resistivity of top layer <100Ωm is an indication of abundance of clay/shale materials which are incompetent soils for road construction. It therefore means that low and very low resistivity values at the top layer and bottom layer in the failed segments are incompetent to withstand the load of heavy and always busy traffic on the surface of the road pavement. The moderate, high and very high resistivity values in the failed and control segments showed competent geologic materials. According to Akintorinwa and Adeusi (2009), as the resistivity of a given layer of soil increases the more competent and stable the layer is.

Conclusion: Geophysical investigation of the failed segments revealed that the major causes of the failure of roads are due to geologic factors such as clay/shale materials/highly weathered materials. These may be responsible for the road failures at Okpoma, Ukwutia and Bukumanya where the clay/shale/highly weathered materials occurred. It was recommended that geophysical surveys should be conducted prior to the construction of roads. Also clay materials as well as highly weathered geologic materials existing beneath the pavement should be excavated and replace with competent materials such as sandy clay, clayey sand, sandstones, granite should be used during construction of roads.

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