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Full Length Research Article

APPLICATION OF ELECTRICAL RESISTIVITY TOMOGRAPHY TO INVESTIGATING GEOLOGICAL CAUSES OF ROAD FAILURE IN TARABA STATE, NIGERIA

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ABSTRACT
The adverse effect of road failure in many parts of Nigeria has led to intense research on the possible causes of the persistent widespread road failures. In contribution to these investigations, a study was conducted in some failed portions of the Jalingo – Zing roads, located in Taraba State, Nigeria. The main purpose was to investigate the cause (s) of the perennial road failures on this road. The 2D electrical resistivity method, utilizing Electrical Resistivity Tomography (ERT) technique was adopted for the investigation. The ERT measurements were carried out on eleven profiles (two control and nine failed segments) of the roads using SSR-MP-ATS resistivity meter (IGIS, India). Results obtained revealed that the resistivity values in the top layers of all the eleven profiles were between 0 and 61.6 Ωm (i.e. < 100 Ωm). This clearly indicated the abundance of clay/shale materials on the top segments of the road, revealing the incompetence of top soils for road construction. It is recommended that the clay/shale deposits that exist below the pavement must be dug out to about four metres depth and replaced with more competent materials such as sandstone, granite and laterite before asphalt is laid. Geotechnical study is also recommended for a comprehensive result to be achieved.

Keywords: Electrical resistivity tomography; road failure; soil; clay; RES2DINV; Jalingo

INTRODUCTION

Road network is very important in the economies of many countries, especially the developing ones, like Nigeria, where most goods and services still need roads and highways for their transportation. But to maintain and construct good roads in Nigeria has become a big challenge. More worrisome is the fact that even the new roads that are constructed experience failures at different sections in less than six months or about a year. Lives and properties worth millions of naira are lost every year due to road crashes. Most accidents recorded in major high ways in Nigeria happened within the bad portions which are as a result of road failure. Traders on perishable goods often experience loss of goods and money as motorists had to spend several hours and even days before conveying goods from the producers to final consumers. This also, causes hike in the prices of commodities, causing more economic hardship to inhabitants. The activities of criminal elements such as armed robbers, pick pocketers and armed robbers thrives more around the failed portions of the road. This has become a source of worry and grave concern to researchers, resulting in the interest in assessing the causes of road failure.

A road network can be described as a smooth continuous stretch of asphalt that enhances smooth drive by vehicles. Any interruption or discontinuity on the road network is referred to as road failure. Road failure may exist as potholes, cracks, bulges and depression which make roads vulnerable and unmotorable to passengers (Aderemi and Adeola, 2021). Road failure can either be functional (occurring on the surface pavements) or structural (deep seated). On a general note, road failure may be caused by geological factors, engineering design failure and structural failure. Results from field and laboratory observations has proven that road failure may not only be linked to poor usage of road, slackness by road construction supervisors, substandard materials used for construction and unfaithfulness in obeying ethical design specification only, but lack of adequate knowledge of the geology of the construction site soils can also be a major contributory factor (Adiat et al., 2017). Most of the engineering structures are undertaken without consideration to the underlying soil characteristics and this has contributed in no small measures to the rampant cases of structural and foundation failures witnessed in the country (Momoh et al. 2008).

The geological causes of road failure include constitution/characteristics of soil, near-surface geological structures like shear zones, faults, fractures and old stream channels etc. (Hijab et al., 2012; Layade et al., 2017). It is advisable that these soil characteristics be investigated before carrying out any road construction. In Nigeria, several reasons have been provided as being the major causes of road failures. Some of the reasons are presence of vast clay coverage (Mesida, 1987); differences in the characteristics of the underlying (subgrade) materials (Adeleye, 2005); concealed linear structures like fractures and joints etc. (Momoh et al., 2008). Oladapo et al. (2008) and Adiat et al. (2009) also identified the geologic conditions as the major factor causing road failures in Nigeria.

In order to identify the possible causes of road failure, surface geophysical method has proven to be an important and reliable tool. Surface Geophysics has the advantage of being cheap, fast and non-destructive method for detecting discontinuity in road network resulting from cracks, bulges and depression (Ozegin, 2016). The effectiveness of geophysical methods for investigating highway failures has been confirmed by numerous studies (Adesina and Omosuyi, 2005; Ozegin et al., 2007; Soupious et al., 2007; Ofomola et al., 2009).

It is the success recorded by surface geophysical method that stimulated the adoption of geophysical method for this study. The road investigated has witnessed failure at some spots. Sometimes, the failures occurs soon after rehabilitation. Though Jalingo – Zing and Jalingo Mayolope roads are located in Taraba State road, they are Federal roads. This means that they are constructed and maintained by the Federal Government of Nigeria. The roads connects Taraba State with Adamawa State and it is through these roads that farm product produced in Zing and Yorro Local Government areas are transported to Jalingo the Taraba State capital. In recognition of the importance of these roads to the socioeconomic development of Taraba State and adverse effect of road failures on road users, that informed the choice of the roads for the present study. The objective of this study is basically to conduct geophysical investigation of some failed segments using electrical resistivity methods. The geophysical investigations were conducted at the various sites between 11th June and 19th June, 2018.

STUDY AREA

Location and areal extent

The area of study covers the basement complex area of Taraba State. It lies between latitude 6°30'N to 9°30'N and longitude 9°00' to 12°00'E and has an aerial extent of about 41,200 km^2. The area is generally hilly and is majorly drained by River Benue, Katsina Ala and Donga (Fig. 1). Taraba State has a tropical wet season (April to October) and dry season (November to March). Rainfall is approximately 8000 mm annually. The people of Taraba State are predominantly farmers and most of them are found in the rural areas.

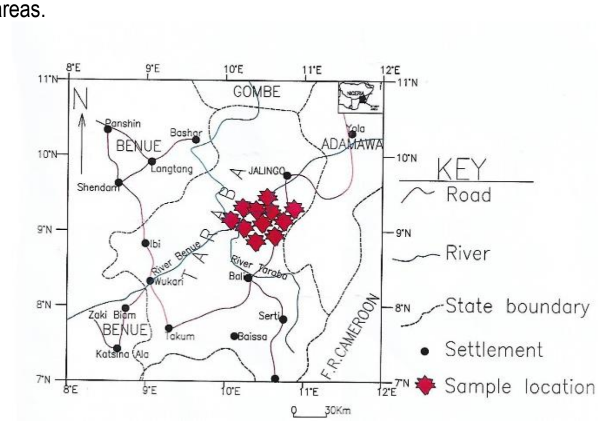

Fig. 1 Map of Taraba State showing profiles locations

Geology of the Study Area

The study area is underlain by the homogeneous Basement Complex rocks and are composed of older granites, gneiss and migmatites (Obaje, 2009). Tertiary to Recent basalts are also found in the study area (Fig.2). The homogeneous Basement Complex mainly the migmatites, generally vary from coarsely mixed gneisses to diffused textured rocks of different grain sizes and are usually porphyroblastic (Macleod et al., 1971). This rock unit forms mainly the homogeneous igneous and metamorphic rocks of Precambrian age (Grant, 1971).

There is also abundance of the Pan African Older Granites which appears either as basic or intermediate intrusive (Turner, 1964). Different kinds of textures ranging from fine to medium to coarse grains can be observed on the Older Granites (McCuurry, 1976). Other localized occurrences of minor rock types include some dolerite and pegmatitic rocks mostly occurring as intrusive dykes and vein bodies. These occurrences are common to both the undifferentiated Basement Complex and the Older Granite rocks (Carter, 1963; McCuurry, 1976).

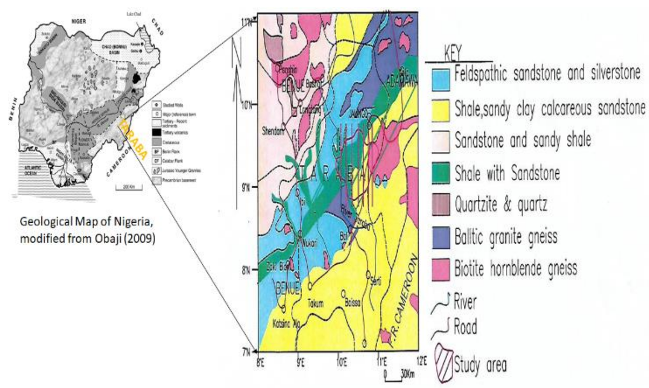

Fig. 2 Geologic map of the study area showing study location (adapted from Nigerian Geological Agency, 2006)

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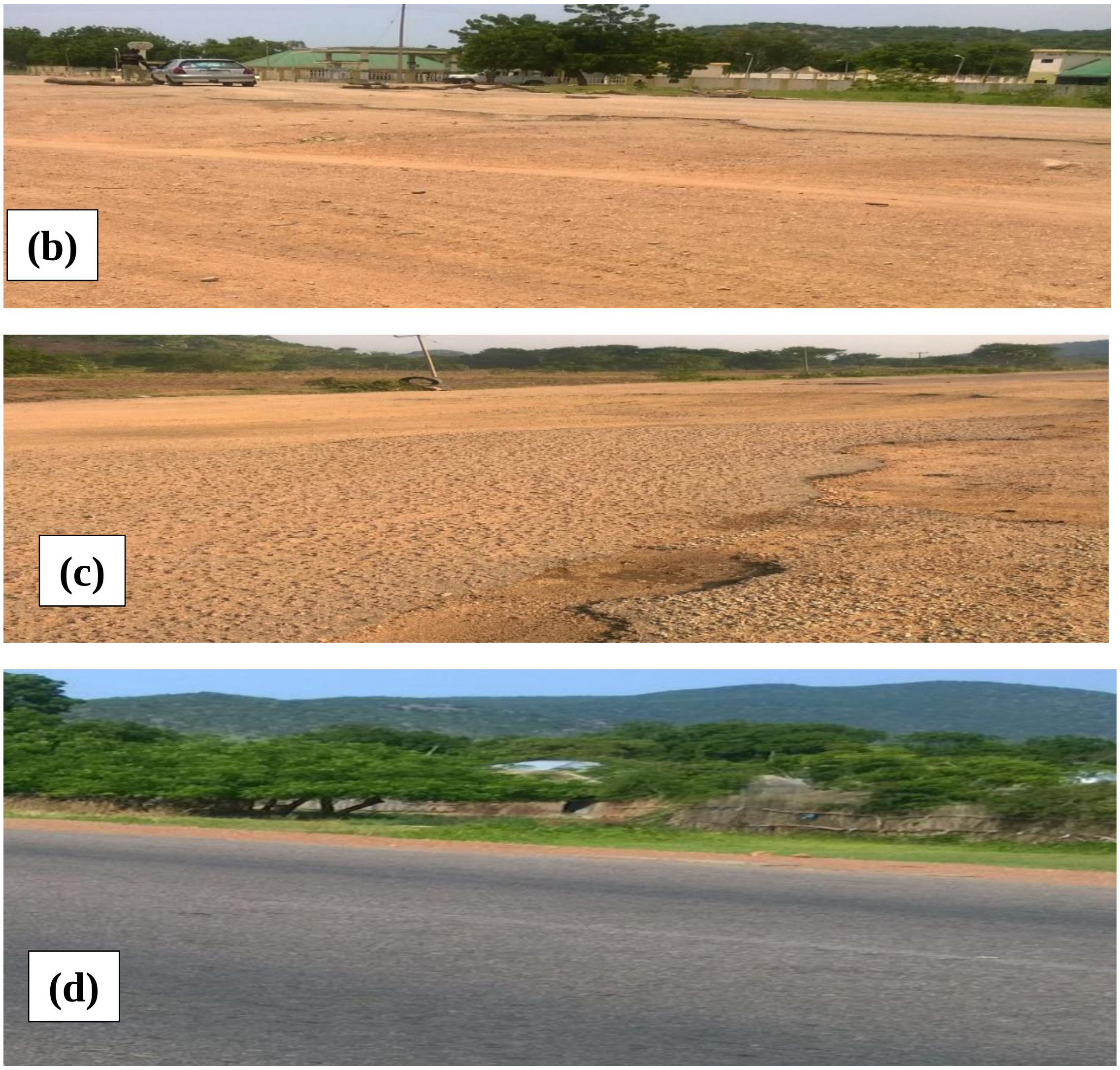

Fig. 3. Condition of the Investigated Jalingo – Zing Road. (a) – (c) are failed portions located at Lankaviri 2, Lankaviri 1 (near Custom office) and Pupule. (d) is a control road located at Mararaban Kunini

MATERIALS AND METHODS

Materials

The survey was conducted using the SSR-MP-ATS Resistivity meter manufactured by IGIS, India. The meter is capable of measuring earth resistances to an accuracy of one micro- Ohm (1 μΩ) and uses rechargeable batteries of 24V. In addition to the resistivity meter, electrodes (21), measuring tapes, hammers and GARMIN 12 Global Positioning System were utilized in the field work.

Methods

Electrical resistivity method was employed for the survey. The field survey lasted for a period of one week. The site selected for the Electrical Resistivity Tomography (ERT) measurement is shown in Fig.1. The Wenner array was utilized with a spread distance of 105 m. The initial electrodes spacing was 5 m and subsequently increased to 10, 15. 20, 25, 30 and 35 m respectively. The twenty-one electrodes were placed along the selected road profiles. Eleven (11) ERT profiles were taken to cover the area of interest. Out of the eleven ERT profiles, two profiles were used as control. Details of the midpoints of the survey profiles are show on Table 1. The observed data were converted to inverted resistivity tomogram with the aid of Res2DINV 3.54.44 software described in Loke and Barker (1996). Detail procedure on ERT measurements adopted for this study can be found in Loke (2000).

Table 1: Midpoint coordinates in the study area

S/N	Location	Segment	Latitude	Longitude	Elevation(m)
1	Lankaviri 1	Failed	N08^{0}59’57.8”	E011^{0}24’43.7”	329.0
2	Mararaban Zing close to bridge	Failed	N09^{0}06’15”	E011^{0}29’18.5”	226.0
3	Appawa	Failed	N09^{0}06’48.0”	E011^{0}30’20.5”	245.0
4	Mararaban Kunini by Primary School	Control	N09^{0}05’40.2”	E011^{0}28’14.5”	242.0
5	Lankaviri 2	Failed	N09^{0}00’49.6”	E011^{0}25’19.3”	288.0
6	Jimlari	Failed	N09^{0}04’03.7”	E011^{0}26’22.3”	271.0
7	Appawa Gadda 1	Failed	N09^{0}06’10.6”	E011^{0}29’35.4”	231.0
8	Pupule	Failed	N09^{0}01’50.7”	E011^{0}46’15.6”	355.0
9	Zing Town by College of Education	Failed	N08059’21.9”	E011^{0}46’15.6”	486.0
10	Zing Town by Immigration	Failed	N09^{0}00’05.6”	E011^{0}43’39.6”	537.0
11	Appawa Gadda 2 Zing Road Junction	Control	N09^{0}05’52.5”	E011^{0}29’47.9”	227.0

RESULTS

The 2D inverted resistivity of all the profiles are presented in Figs. 4 to Fig.13. The pseudo sections reveal features that may be responsible for the cause of road failure. Fig.4 shows three conductive zones in the profile and low resistivity zone (deep blue) layer with resistivity between 26.6 and 61.6 Ω m across the entire profile at a depth of 3.75 m. Underlain this layer is a moderate resistivity zone (light green) with resistivity from 331 Ωm to 768 Ω m at a depth between 3.75 m and 9.26 m. This can be interpreted as weathered granite. Below this is a very high resistivity layer (yellow to pink) with resistivity from 1782 Ωm to 9582 Ω m at a depth between 9.26 m and 19.8 m.

Fig.5 shows three pronounced zones across the profile with low resistivity zone (deep blue) with resistivity values between 11.9 and 35.4 Ωm across the entire profile at depths 9.26 m and 6.28 m. Below this layer is a moderate zone (light blue to yellow) with resistivity ranging 105 Ωm to 2748 Ωm at a depth between 9.26 m and 15.9 m and a high resistivity zone (red to pink) ranging from 8157 Ωm to 24213 Ωm at depths between 15.9 m and 19.8 m.

Fig.6 reveals three zones with low resistivity zone (deep blue) with resistivity values ranging from 1.40 to 4.39 Ωm occurring across the profile at depths 3.75m at surface points between 5.0 m and 60 m and at depth 12.4 m between the surface points 60.0 m and 95 m. Underlain this is a moderate resistivity zone (light blue to yellow) ranging from 14.0 Ωm to 420 Ωm and a high resistivity zone (red to pink) with resistivity ranging 1312 Ωm to 4102 Ωm at depths between 9.26 m and 19.8 m.

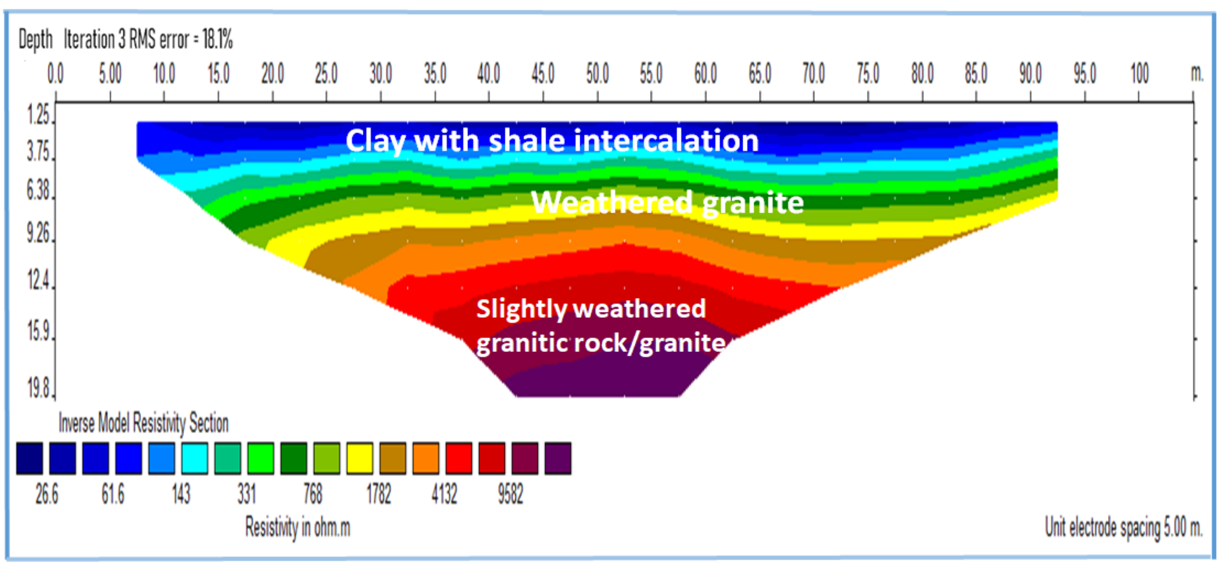

Fig. 4 ERT1 Lankaviri 1

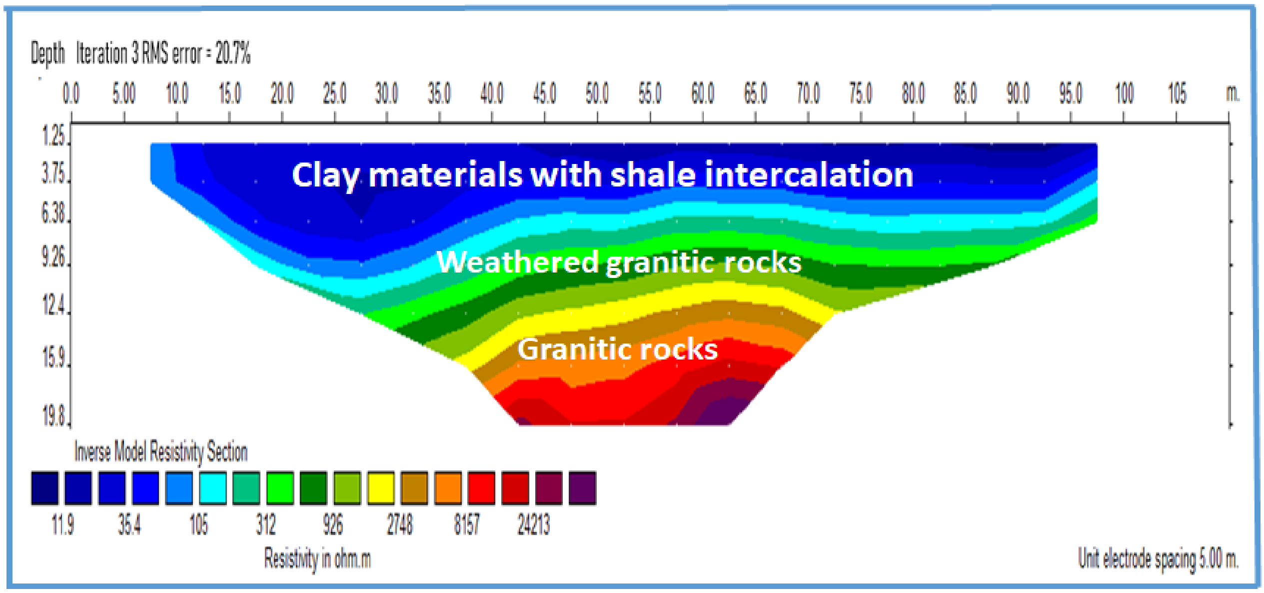

Fig. 5 ERT 2 Mararaban Zing

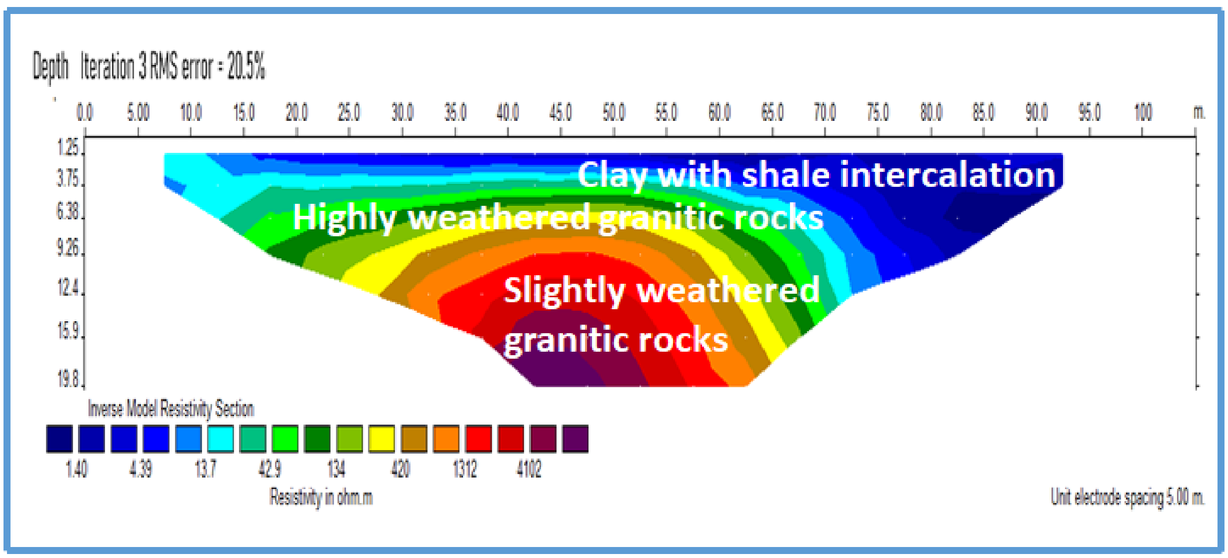

Fig. 6 ERT 3 Apawa

Fig.7 shows three conductive zones with low resistivity zone (deep blue) less than having values from 47.9 to 151 Ωm at a depth of 1.30 m across the entire profile. Below this layer is a high zone (light blue to yellow) with resistivity ranging from 473 Ωm to 1465 Ωm at depth between 1.30m and 6.38m. Underlain this layer is a very high resistivity zone (red to pink) with resistivity ranging from 45991 Ωm to 144429 Ωm at depths between 6.38 m and 19.8 m.

In Fig.8, three pronounced zones with very low resistivity zone (deep blue) with resistivity varying from1.16 to 4.50 Ωm across the top of the profile at depths 12.4 m, 9.26 m and 6.38 m were revealed. Underlain this is a low resistivity zone (light blue to lemon green) with resistivity ranging from 17 Ωm to 260 Ωm at depths between 12.4 m and 15.9 m, 6.38 m and 6.38 m and 9.26 m. And a high resistivity zone (yellow to pink) with resistivity ranging from 1004 Ωm to 14993 Ωm at depths between 15.9 m and 19.8 m, 12.4 m and 19.8 m.

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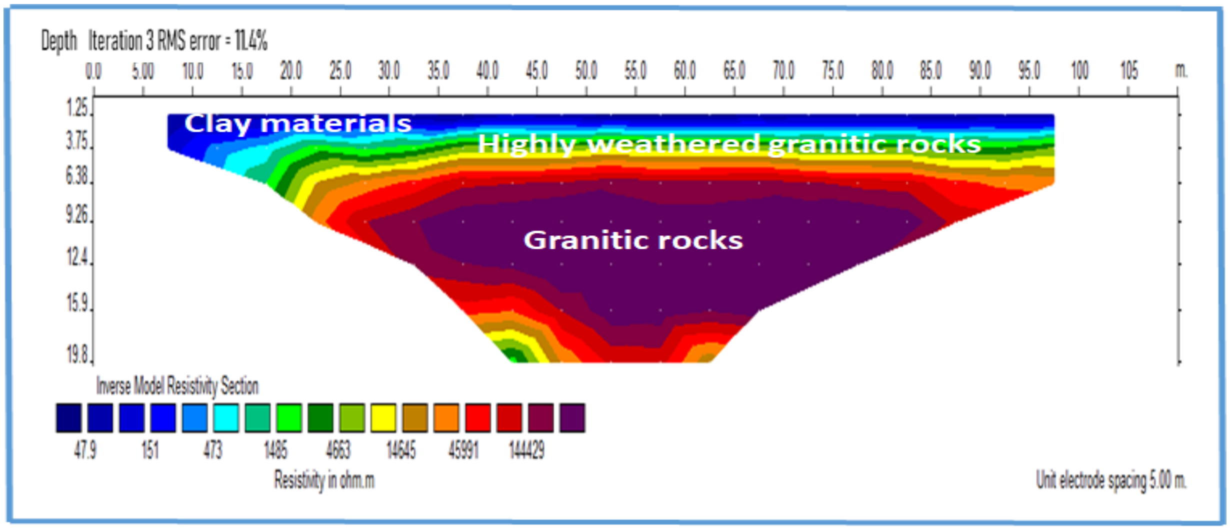

Fig.7 ERT 4 Mararaban Kunini (Control)

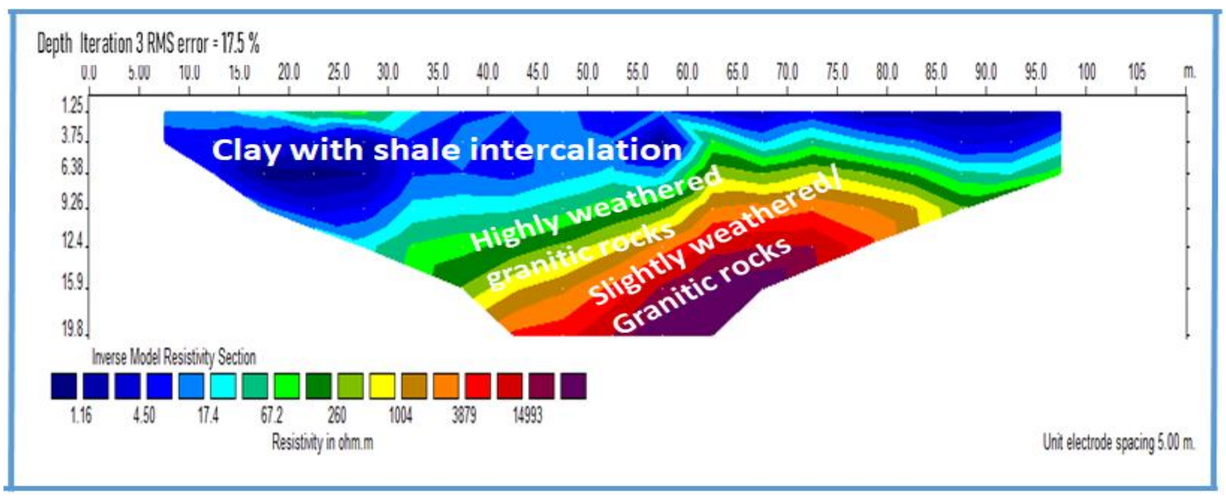

Fig. 8 ERT 5 Lankaviri 2

Fig.9 shows three zones with very low resistivity (deep blue) with resistivity varying from 5.83 to 7.30 Ωm at the surface points 5.0 m and 100.0 m at depths 1.25 m and 3.75 m. Underlain this is low resistivity zone (light blue to lemon) with resistivity ranging from 33 Ωm to 575 Ωm at depths between 3.75 m and 9.26 m. And a high resistivity zone (yellow to pink) with resistivity ranging from 2411 Ωm to 42398 Ωm at depths between 15.9 m and 19.8 m.

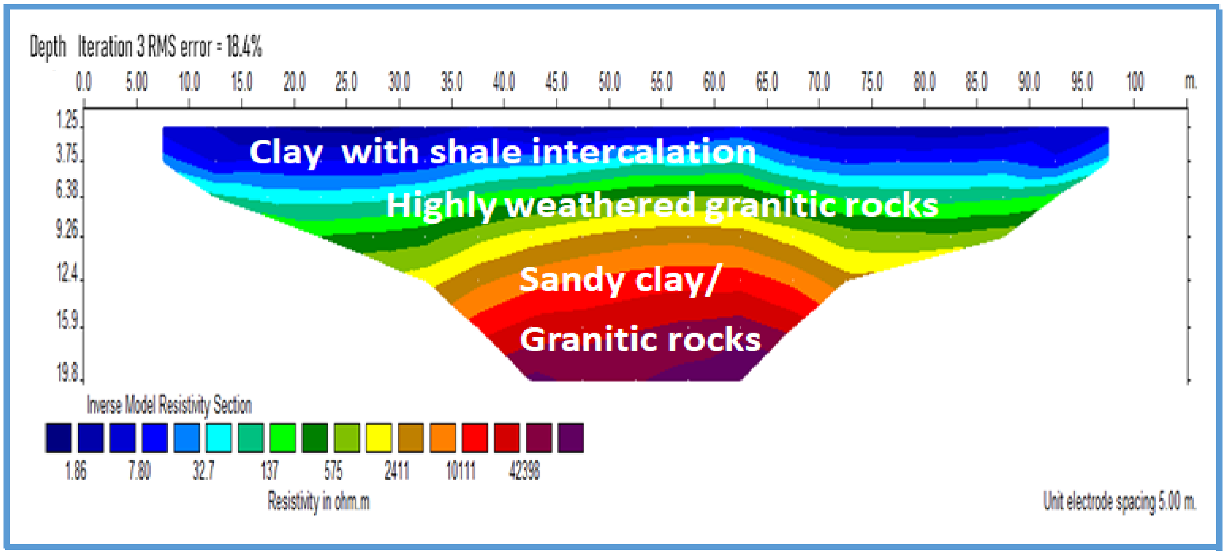

Fig. 9 ERT 6, Jimlari

ERT 7 (Fig. 10) reveals three resistive zones with a very low resistivity (deep blue) having resistivity varying from 5.83 to 10.20 Ωm at a depth of 3.75 m across the profile. Underlain this layer is a low resistivity zone (light blue to lemon green) with resistivity ranging from 18 Ωm to 55 Ωm at depths between 6.38 m and 9.36 m. Below this is a high resistivity zone (yellow to pink) with resistivity ranging from 96 Ωm to 295 Ωm across the profile with depths between 9.26 m and 19.8 m.

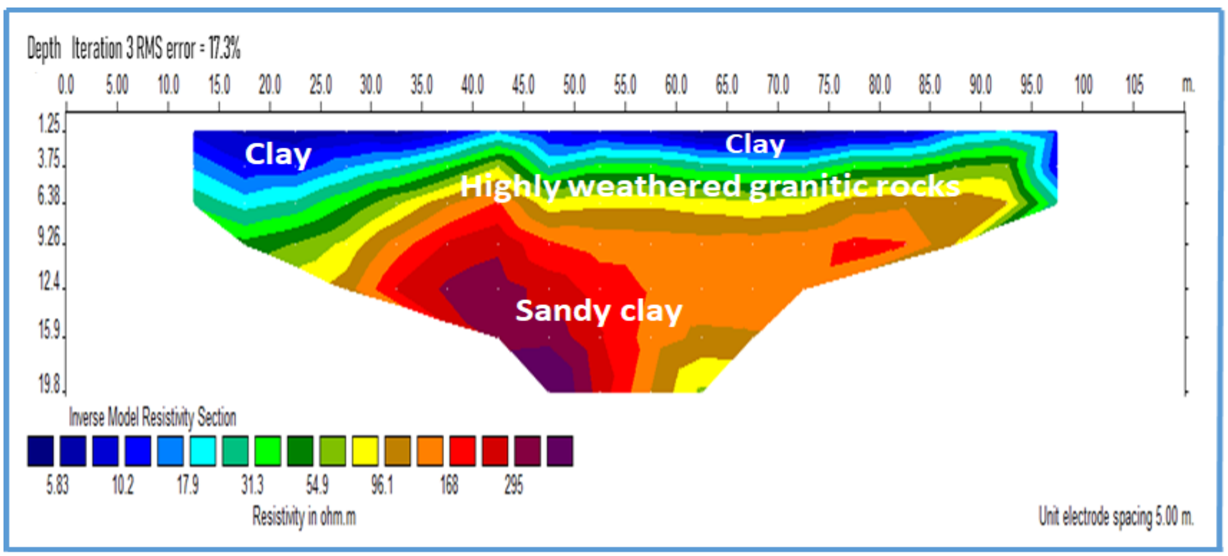

Fig.10 ERT 7 Appawa Gadda

ERT 8 (Fig. 11) shows two pronounced resistivity zones with very low patches of resistivity zone (deep/light blue) at surface points 10.0 m to 25.0 m, 40.0 m to 50.0 m and 58.0 m to 69.0 m with resistivity ranging from 0 Ωm to 1 Ωm. Below this zone is a low resistivity zone (lemon/yellow colour) with resistivity values ranging from 1 Ωm to 3 Ωm. Underlain this zone is a moderate zone (red/pink) with resistivity ranging from 9 Ωm to 17 Ωm.

Fig.12 shows low resistivity values (deep blue) with resistivity varying from 5.90 to 20.1 Ωm at surface points 5.0 m and 60.0 m with depths 9.0 m and 6.38 m between surface points 70.0 and 85.0 m at depth 5.0 m. This can be interpreted as clay with shale intercalation. Beneath this layer is moderate resistivity zone (lemon colour) with resistivity values ranging from 37-69 Ωm with a portion at surface points between 63.0 m and 70.0 m. Underlain this layer is a high resistivity zone with resistivity ranging from 126 Ωm to 430 Ωm.

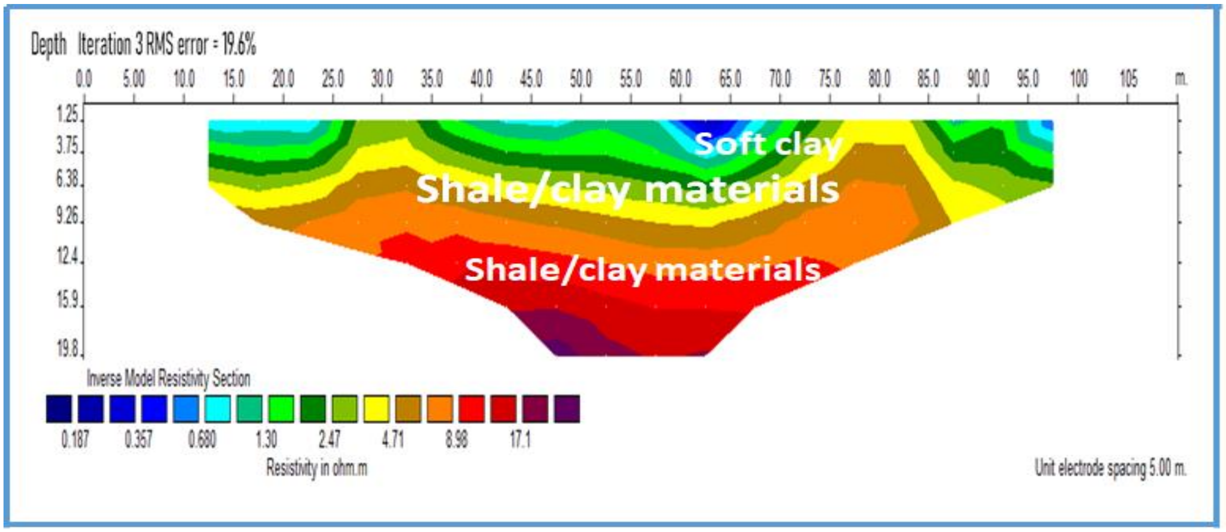

Fig. 11 ERT 8 Pupule Zing

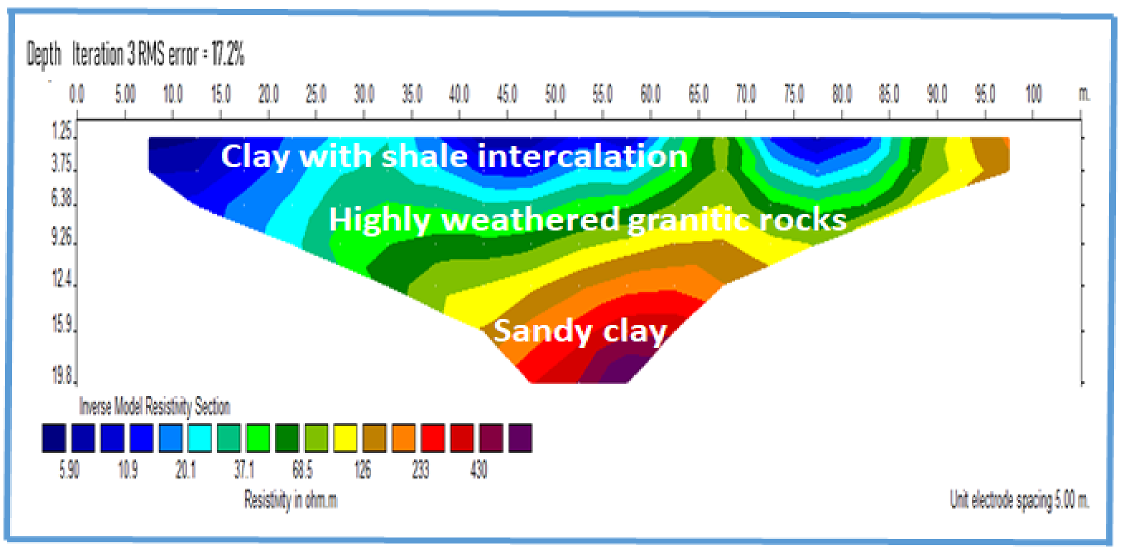

Fig. 12 ERT 9 Zing Town by College of Education

Fig. 13 displays patches of very low resistivity zone (deep blue) at surface points between 15.0 m -25.0 m, 40.0 m-70.0 and 77.0 m-100 m. In between and beneath this layer is low resistivity layer (lemon colour) with resistivity ranging from 6 Ωm to 21 Ωm. Underneath this layer is moderate resistivity zone (yellow to pink) with resistivity values ranging from 60 Ωm to 550 Ωm.
Fig. 14 shows a very low resistivity zone (blue) with patches at surface 5.0 m to 30.0 m and 80 m to 100 m with resistivity ranging from 0 - 6 Ωm. In between and beneath this layer is a low resistivity zone (lemon colour) with resistivity ranging from18.0 Ωm to 59 Ωm at depths 9.0 m and 6.0 m. Underlain this layer is a high resistivity zone (yellow to pink) with resistivity values ranging from 192 Ωm to 2019 Ωm.

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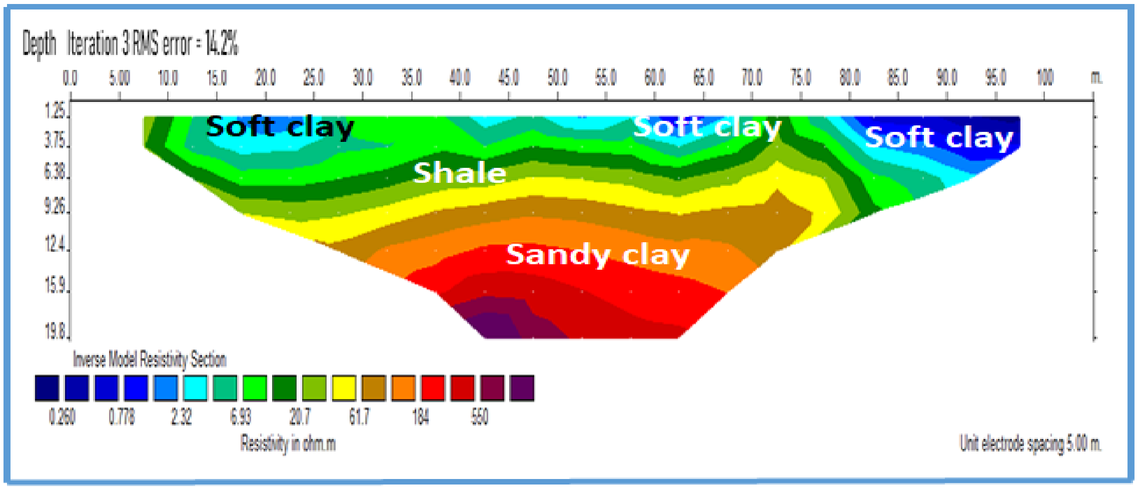

Fig. 13 ERT 10 Zing Town by immigration office

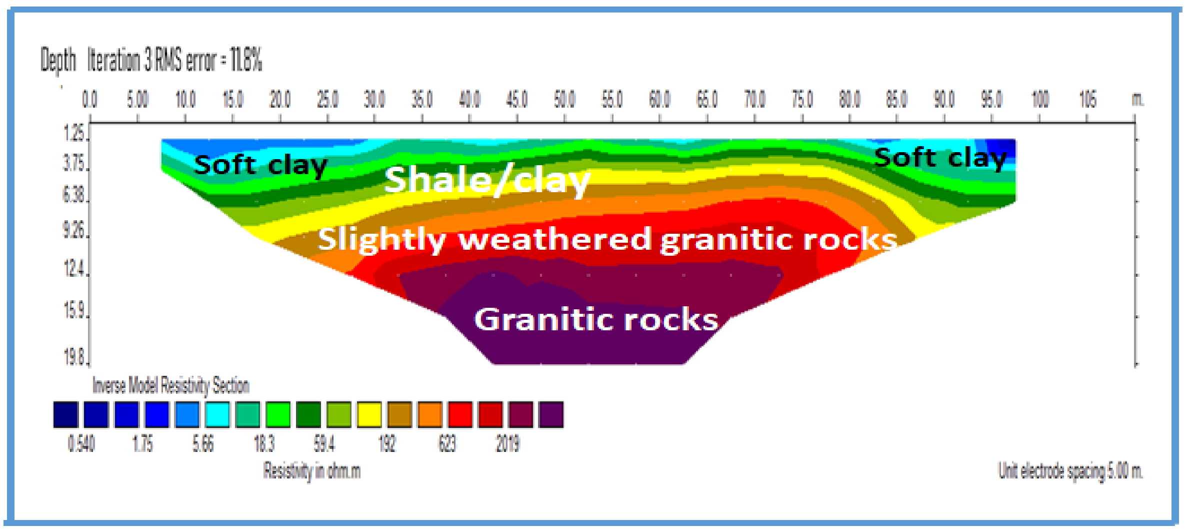

Fig. 14 Zing road after PHC ERT 11 (Control)

DISCUSSION

The competence zones of the study were differentiated using the Idornigie and Olorunfemi (2006) model which used soil resistivity values to rate the competence of various lithologies. The model is shown in Table 2.

Table 2: Soil competence Rating (Idornigie and Olorunfemi, 2006)

Apparent Resistivity(Ωm)	Lithology	Competence Rating
<100	Clay	Incompetent
100-350	Sandy clay	Moderately competent
350-750	Clayey sand	Competent
>750	Sand/laterite/Bedrock	Highly competent

Based on this classification, it is observed that the resistivity of the top layer of all the profiles in the study area were less than 100 Ωm (specifically, between 0 and 61.6 Ωm) indicating that the layers are incompetent. This was evidenced in all the failed portions of the roads. But ERT 4 and ERT 11 which served as controls in the study area showed no failure. This is because the incompetent layer lies on a very high resistive zone as shown in the tomogram. The depth of the low resistivity (top layer) varies from one profile to the other. In ERT1 (0 - 6.0 m); ERT2 (0 - 9.26 m); ERT3 (0 - 12.4 m); ERT4 (0 - 3.75 m); ERT5 (0 - 12.4 m); ERT6 (0 - 6.38 m); ERT7 (0 - 6.38 m), ERT8 (0 - 6.38 m); ERT9 (0 - 6.38 m); ERT10 (0 - 6.38 m) and ERT11 (0 - 3.75 m) with an average overburden thickness of 6.66 m. Similar investigations conducted in different parts of Nigeria by Momoh et al. (2008), Onoja et al. (2016) and Layode et al. (2017) obtained low resistivity values (less than 200 Ωm) in the failed portions of the roads and high resistivity values in the stable portions.

Conclusion

The study reveals that the remote cause of road failure in the study area is as a result of clay/shale materials at the top layer of the road segments. The top layers of all failed segments of the roads in the study area are incompetent. Thickness of overburden materials was observed to be variable ranging from 0 to 12.4 m. Average overburden thickness was observed to be 6.66 m.

Recommendations

Based on the findings of the study it is recommended that:

i) Geophysical surveys are very important and therefore always be used as reconnaissance tools in road construction.

ii) The clay/shale deposits that exist below the pavement must be dug out to a depth of about 4 m and replaced with more competent materials such as sandstone, granite and laterite before asphalt is laid.

iii). Suitable drainage channels should be constructed with a view to resolving the problems of flooding and washing away of the pavement in all locations.

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