Subsurface investigation for road construction using electrical resistivity method along Oloko road, Apatapiti, Akure, Ondo State, Nigeria

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Subsurface Investigation for Road Construction Using Electrical Resistivity Method along Oloko road, Apatapiti, Akure, Ondo State, Nigeria

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Abstract

Evaluation of the shallow geologic materials in terms of types, nature, and bedrock structure as possible causes of pavement failure was carried out along Oloko road Apatatpiti, Akure, Nigeria, using Schlumberger vertical electrical sounding and 2-D imaging dipole-dipole techniques. Three lithological layers, namely thin top soil, weathered layer and weathered basement, were revealed by the 2-D resistivity structure. Vertical electrical soundings were made at locations with a very low resistive medium typical of linear features such as fractures/faults at some distances on the 2-D resistivity structure. Four geologic layers, namely the top soil, clay/sandy clay, fractured basement, weathered/fresh basement, were identified by the geoelectric section. The geoelectric section and the 2-D resistivity structure revealed that the upper 0-6m, which constitutes the subgrade, has a low resistivity (36 Ωm to 108 Ωm) characterised to be clayey materials and suggestive of weak zones that might impair the stability of the road. A relatively shallow depth, ranging from 3.7 m to 4.29 m, was the depth to the water table of the four wells close to the road. Therefore, the possible causes of pavement failure are the thick and low resistive layer, the near-surface linear features suspected to be fractures/faults, and the water table's shallow depth.
Keywords: 2-D Resistivity Structure, Geoelectric Section, Pavement Failure, Fractures, Water.

1.0 Introduction

Urban areas are potential growth engines, and governments should ensure cities are more economically viable (Burningham and Stankevich, 2005). Therefore, there is a need to create a good living and working environment, and for that to happen, infrastructure (e.g., roads) must be constructed and managed sustainably (Emeasoba, 2013). Local, State, and Federal Governments usually spend a huge amount of money on road construction each year in Nigeria, in which the most phenomenal one occurred between 1973 and 1980 (Ismail, 1987), after which more roads and other infrastructure have been built. Unfortunately, the roads in the country are plagued with potholes, pavement failure, failed bridges, and embankments; this has greatly increased the cost of moving goods to the consumers which causes an increase in price of commodities.

Road failures are hinged on usage, construction techniques, and maintenance (Adegoke-Anthony and Agada, 1980). Laboratory tests and field studies have proven, that poor understanding of the subsurface soil is among the factor of road failure (Ajayi, 1987). In Nigeria, the predominance of shrinkage and swelling of clays (Mesida, 1986; 1987), heterogeneity of the earth subgrade (Adeleye, 2005), presence of undetected linear features (Momoh et al., 2008) have been researched as causes of road failure.

Geoelectrical sounding studies have proven that geophysics can provide a broad, thorough description of the subsurface over large areas at a faster and lower cost than other methods (Sharma, 1997). Some portions of the Ogbomoso-Ilorin dual carriage road were investigated using integrated geophysical methods of electrical resistivity, very-low-frequency (VLF) electromagnetic, and ground magnetic (Adesola et al., 2017). The study revealed that clayey subgrade soil underneath the road pavement, lateral inhomogeneity, and near geological structures are responsible for the vulnerability of the road to failure. Schlumberger Vertical Electrical Sounding, 2-D imaging dipole-dipole technique, and ground magnetic method were used to assess the geological factors responsible for Highway pavement failure along Ibadan-Ife Highway, Nigeria (Adenika et al., 2018). The results showed that failed portions of the road pavement are underlaid by either very thick clay or linear structures. Electrical resistivity and screw driving sounding techniques were applied to evaluate a road failure in Ang Thong province, Thailand (Chaiyaput et al., 2021). The outcome suggested the two techniques can be used to investigate the stability of canal side roads. The electrical resistivity method estimated the shear strength of Bangkok clay as a primary appraisal for road construction (Chaiyaput et al., 2022).

This study employed vertical electrical sounding and dipole-dipole techniques and groundwater table measurements to evaluate the shallow geologic formation responsible for the pavement vulnerability to failure along Oloko road, Akure, Ondo State, Nigeria.

2.0 Experimental

The description of the study area

The road is located in Apatapiti, Akure South Local Government area of Ondo State, Nigeria. It is expected to link Apatapiti area to the University of Technology Akure. The study area is gently undulating with an elevation between 362m-369m above the sea level. It falls within Northings 806322 to 806577 and Eastings 737364 to 737415 expressed in Universal Traverse Mercator (UTM) coordinate geographic map location (Figure 1).

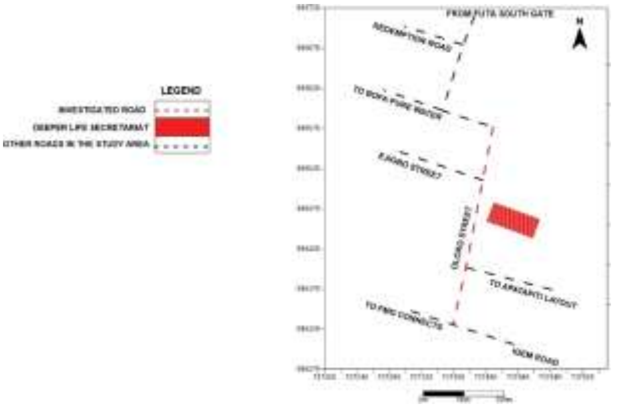

Figure 1: Base map of the study area

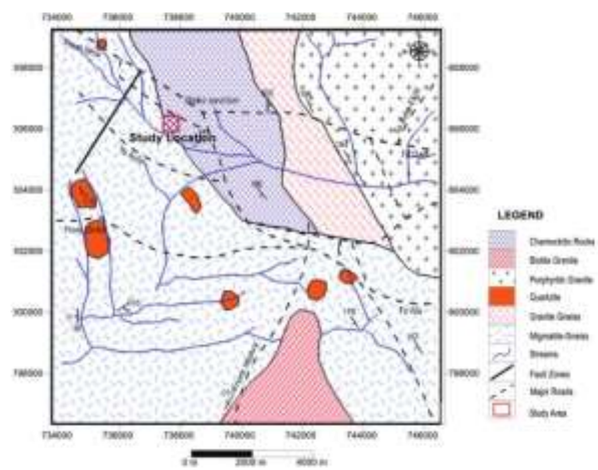

Figure 2: Geological map of Akure (After Owoyemi 1996)

Geology and hydrogeology of the study area

Akure geological mapping and associated studies have been done extensively by (Olarewaju, 1981), (Owoyemi, 1996) and (Sobogun, 2008). Akure comprises of four of the six petrological units of the Basement Complex of Southwestern Nigeria (Figure 2). These units include the Migmatite-Gneiss-Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites, and Unmetamorphosed dolerite dykes (Rahman, 1988).

The geological formations in Akure are folds, faults, foliation, schistosity, and joints and their structural trend is NNW-SSE (Ojo et al., 2014). These structural trends are oriented in the same direction as the main basement complex fracture direction (Oluyide, 1988). The east, south, and north central of Akure lie beneath granites and migmatite gneiss. However, the north central part lies beneath charnockites and has a small number of lineament and lineament junctions (Owoyemi, 1996). Charnockites and Migmatite-gneiss are the major rock types underlying the study area and a sequence of shallow quartzite rubbles in some areas (Adeyemo et al., 2014).

Field investigation and data processing

A reconnaissance of the area was carried out to determine the study area's local geology, outcrop and drainage pattern and generate the base map. GARMINI 12 channel personnel navigation Global Positioning System (GPS) was undertaken in the Universal Transverse Mercator (UTM) coordinates to construct the base map. Traverse was established perpendicular to the strike direction.

Geophysical investigation using electrical resistivity method was conducted along the traverse of 265m long established parallel to the road (Figure 3). Omega resistivity meter was used in acquiring the data, two dimensional (2-D) electrical imaging and vertical electrical sounding (VES) using Dipole-dipole and Schlumberger array respectively were employed.

The 2-D electrical imaging was first conducted along the single traverse established parallel to the road. 2-D electrical imaging gives both the vertical and lateral variations of resistivity of the subsurface simultaneously. This technique was used as reconnaissance to delineate possible weak zones along the road, the inner electrode spacing was 5m and inter dipole expansion factor (n) ranges; each VES point was recorded in Universal Traverse Mercator (UTM) coordinates with the aid of Global Positioning System (GPS), and Dipro Software was employed for 2-D modelling. It gives high-resolution colour images of the field data, the theoretical pseudosection, and the 2-D resistivity structure used for the quantitative interpretation.

Vertical electrical sounding was adopted to investigate electrical resistivity changes with depth. In this technique, vertical variations in the ground apparent resistivity were measured with respect to a fixed array centre by gradually increasing the electrode spacing.

A total of five VES points revealed linear features by the 2-D modelling were sounded with a maximum current electrode separation of 40m-65m since most engineering investigations are shallow. The apparent resistivity data were treated to partial curve matching to provide a quantitative interpretation of the curves, which show the number of layers, layer resistivity, and layer thickness. Thereafter, qualitative interpretation using computer iteration with the aid of Wein resist software. Surfer 12 software was utilised to generate the geoelectric cross-sections using the enhanced geoelectric parameters. The four wells located close to the road were also sampled to determine the depth to the water table.

3.0 Results and discussion

Electrical resistivity Pseudo-section

The 2-D resistivity structure (Figure 4) obtained from the inversed dipole-dipole data revealed three lithological layers; thin top soil (greenish-yellow and red colour), weathered layer (green and red colour) and weathered basement (green, red and purple colour). It also revealed fractured/fault as a blue colour. Due to its small thickness, the topsoil layer was frequently subsumed by the weathered layer. The profile showed predominantly low resistivity values (<100 Ωm) at many locations at 5m depth.

The lower resistivity value represented by green and yellow colour indicates a clayey material. The overburden thickness between 100m-120m station is about 8m, and the resistivity of the basement (purple/red colour) ranges from 168 Ωm to 261 Ωm; the shape suggests a rock boulder at the ascertained location. However, the segment is likely to fail because of the thick, low resistivity clay overburden.

Towards the southwestern part of the traverse, i.e. station, 180m-190m is resistive geology to a depth of about 10m from the surface. Station 215m-235m showed weathered strata at a depth of about 8m. In addition, indicative of linear features such as faults and fractured zones with surface expressions at distances 45-55m; 120-130m; 155-160m; and 195-205m.

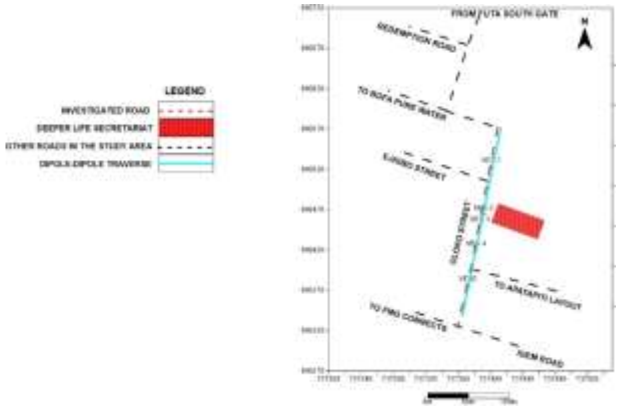

Figure 3: Data acquisition layout

Sounding curves

Classification of the five sounding curves are H, A and KH. The curves are shown in Figures 5 to 9. They suggest three possibilities (Adiat et al., 2017). The first possibility is that the study area depicted a shallow depth of fresh basement (Figure 8). The second possibility is that three geoelectric layers lie beneath various parts of the study area; the second layer is the weathered basement layer. This increases the road's vulnerability because the depth to the weathered basement layer may be shallow, indicating that the layer is saturated with water (Figures 5, 7 and 8). The third possibility depicts the occurrence of a fractured basement, as shown in the third geoelectric layer (Figures 6 and 9). If not appropriately addressed during construction, the presence of a fractured basement can also jeopardise the road's stability. The summary of the geoelectric parameters at different locations is shown in table 1.

Geoelectric Section

The geoelectric section (Figure 10), taking along the traverse, connects the study area's geoelectric sequence. Four subsurface geologic layers were delineated: the top soil, clay/sandy clay, fractured basement, weathered/fresh basement. The top soil has a resistivity that varies between 36 Ωm and 108 Ωm, and thickness ranges from 0.5m to 1.1m.

These resistivity values indicate a clayey substance. The majority of the top soil has a quite low resistivity (<100 Ωm), indicating weak areas that could jeopardise the road's competence. The clay/sandy clay layer has a resistivity that varies from 60 Ωm to 113 Ωm, and thickness ranges from 3.8m to 26.5m. This layer is a substandard

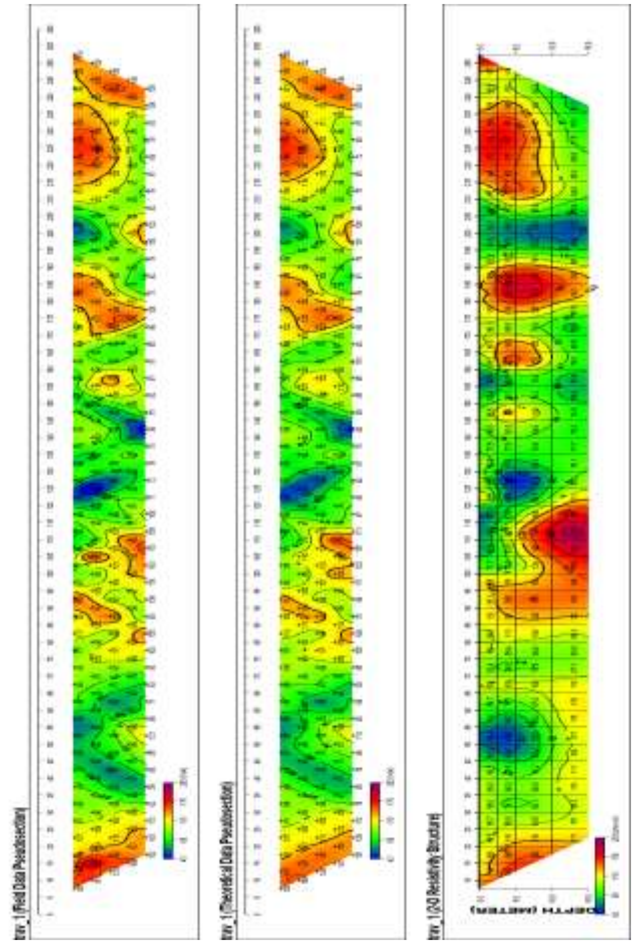

Figure 4: The inverse model resistivity section for the traverse

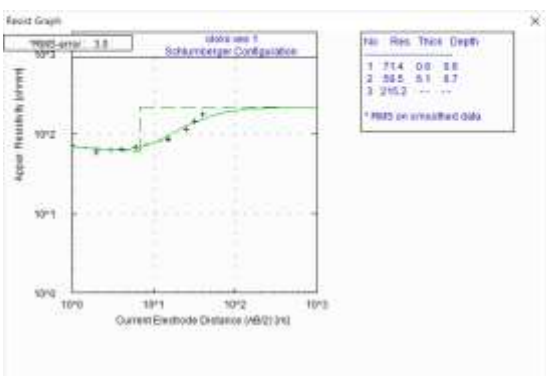

Figure 5: H Curve Type

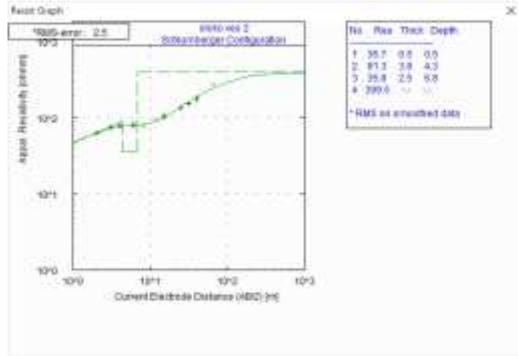

Figure 6: KH Curve Type

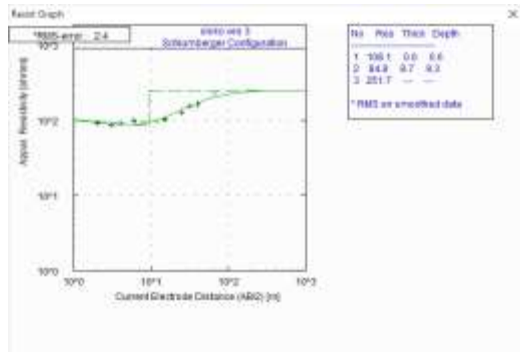

Figure 7: H Curve Type

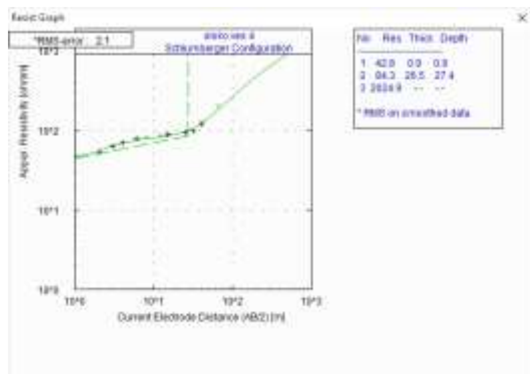

Figure 8: A Curve Type

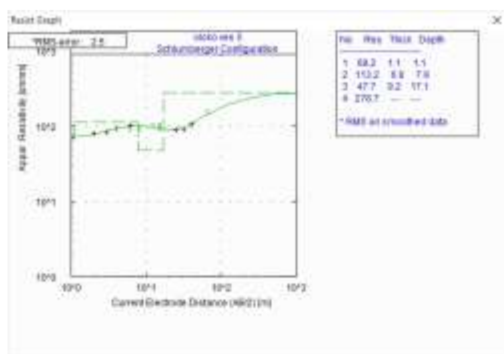

Figure 9: KH Curve Type

Table 1: Summary of geoelectric parameters

VES	Location	No of layers	Curve type	Resistivity (Ωm)	Thickness (m)	Depth(m)
1	53m	3	H	71.4 59.5 215.2	0.6 6.1 -----	0.6 6.7 -------
2	118m	4	KH	35.7 91.3 35.8 399.5	0.9 3.8 2.5 ------	0.5 4.3 6.8 ------
3	128m	3	H	108.1 84.8 251.7	0.6 8.7 -------	0.6 9.3 -------
4	158m	3	A	42.8 84.3 2024.9	0.9 26.5 -------	0.9 27.4 -------
5	200m	4	KH	68.2 113.2 47.7 278.7	1.1 6.8 9.2 -------	1.1 7.9 17.1 -------

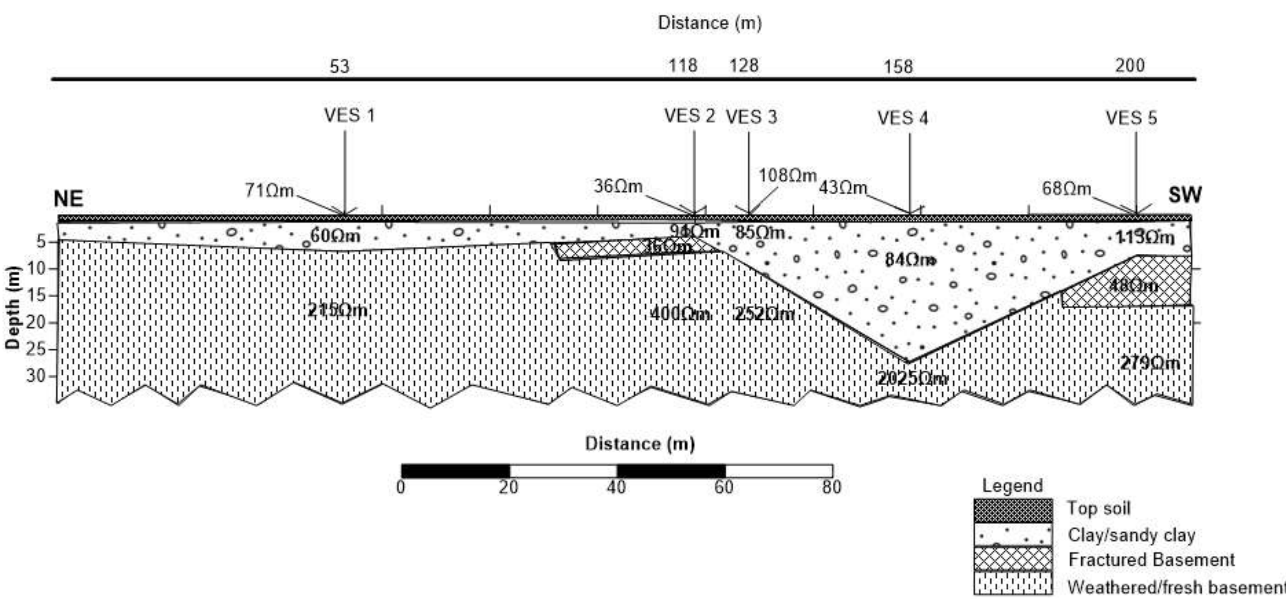

Figure 10: The Geoelectric section along the traverse

substandard engineering material that may be detrimental to the road's stability. The fractured basement has a resistivity value that ranges from 36 Ωm to 48 Ωm, and thickness ranges from 2.5m to 9.2m. This layer constitutes weak zones and reduces the bed rock's bearing capacity. The weathered/fresh basement has a resistivity value that ranges from 215 Ωm to 2025 Ωm. The depth to the weathered/fresh basement is more than 27 m in some places in the southwestern parts of the section, while it is shallower in the Northeastern part of the section (<9 m). Characteristics of depressions observed in the southwestern section should be considered during the road structure design.

Depth to the water table

The depth to the water table in the area ranges from 3.7m to 4.29m, and this relatively shallow depth of the water table will exacerbate road base failure due to groundwater saturation or high moisture content from capillary suction.

Correlation of Results

The results from the two field techniques have a similar relationship in their lithology and stratigraphy. The 2-D resistivity structure reveals that the subsoil in the upper 0-6 m across the traverse has a low resistivity characterised to be clayey materials; this correlates with the geoelectric section obtained from the vertical electrical sounding, which has a weathered layer or plastic clay lithologic units at this depth. Even at about 15m, the 2-D resistivity structure reveals no fresh basement. This also correlates with the geoelectric section in which the only fresh basement delineated at VES point 4 is at a depth of 27 m. The blue colour band identified on the 2-D resistivity structure and delineated to be linear features are also indicated on VES points 2 and 4. The delineated linear features have a depth extent of about 7m, indicating geological features such as fractures/faults. The relatively high resistivity areas on the 2-D resistivity structure represent competent sub-base, i.e. places with a resistivity greater than 150 Ωm can still be regarded as good road construction and the area that fall within the low resistivity areas, i.e. resistivity lower than 150 Ωm are considered to be bad and incompetent for road construction.

4.0 Conclusion

The two electrical resistivity techniques revealed the clayey nature of the topsoil and subsurface to a depth of about 6m on which the road pavement would be founded. Clay, which is extremely porous but less permeable due to inadequate pore connection, holds water without releasing it, causing it to bloat and eventually road failure. The results also show the presence of near subsurface linear features suspected to be faults/fractures; because of their depth (>5m), they are structurally vulnerable areas that encourage groundwater accumulation and, as a result, pavement failure. In addition, the depth to the water table in the area, which ranges from 3.7m to 4.29m, would make the road vulnerable. Therefore, the following measures must be taken during the road construction: the topsoil and some part of the layer underneath it (i.e. depth of about 2m) must be excavated and filled with competent engineering materials before laying asphalt. The portion suspected to be underlain by linear features such as fractures/faults should be reinforced or grouted. A good drainage channel should also be constructed at the embankment; this will prevent the accumulation of runoff on the pavement embarkment.

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Conflict of interest

There are no conflicting interests.

Author's contributions

Conception: [SSO]

Design: [SSO]

Execution: [SSO]

Interpretation: [SSO]

Writing the paper: [SSO]

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