

Geophysical Investigation of Road Failure in Federal College of Education (Technical) Asaba, Delta State, Nigeria Using Electrical Resistivity Imaging (ERI) Method

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Abstract: The study investigates the causes of road failure at the Federal College of Education (Technical), Asaba, Delta State, Nigeria using the Electrical Resistivity Imaging (ERI) method, a non-invasive approach to delineate subsurface features responsible for road failures. Surveys were conducted along failed road segments to characterize subsurface materials, moisture zones, and the depth to competent strata. Schlumberger array configuration was used to investigate the geotechnical causes of persistent road failure within the area. The research aimed to delineate subsurface geoelectric layers, identify weak zones, and assess their contribution to pavement instability. Five vertical electrical sounding (VES) stations were established along the failed road segments using an ABEM Terameter SAS 1000. The apparent resistivity data were processed and interpreted using RES2DINV and Surfer software to generate sounding curves and geoelectric section. The results revealed three to four distinct geoelectric layers: topsoil (50-300 Ω m), lateritic layer (150-3502 m), clayey/silty layer (38-9952m), and weathered basement/high resistivity (470-900 Ω m). The low-resistivity clayey/silty layer beneath the lateritic cap at depths of 5.8 m was identified and indicates the presence of weak zones, clay-rich formations, and high moisture content that contributes to pavement failures due to high plasticity in the study area. The Pseudo section results revealed that the road structure is founded on a near homogeneous substratum, indicating that the road is not situated on a better geology. Hence, the study concludes that geophysical techniques such as ERI are effective tools for subsurface characterization and can significantly reduce premature pavement deterioration in roads construction.

Keywords: Road Failure, Resistivity, Schlumberger Array, Characterization, Geoelectric, layers, , Zones, Substratum.

I. INTRODUCTION

Road pavement failure is the inability of a pavement to perform its intended structural and functional roles due to traffic loading, environmental effects, poor materials, inadequate design, poor construction or lack of maintenance. Understanding pavement failure mechanisms is essential for effective design, maintenance planning, and rehabilitation strategies Falade et al. (2021). Road failures significantly affect socio-economic activities in Nigeria, often leading to cracking, rutting, potholes, raveling, bleeding, depression and settlement, edge failure, etc. (Oyedele et al. (2019). Failure occurs when pavement distress becomes severe enough that the road can no longer economically carry traffic without major maintenance or rehabilitation (Oguntade and colleagues.,2022). Several Nigerian case studies have demonstrated Electrical Resistivity Imaging's (ERI) utility in diagnosing causes of road failure. Geophysical methods have proven useful in identifying weak subsurface zones and assessing geotechnical conditions before construction. Studies by Muhammad et al. (2021) demonstrated that low resistivity values correspond to clayey or silty layers that retain water, causing subgrade instability. Abdulsalam et al. (2021) also demonstrated that low resistivity values are often associated with clay-rich, water-saturated layers that reduce bearing capacity. Previous studies by Olorunfemi and Mesida (2019) have demonstrated the application

of electrical resistivity methods in road and foundation investigations that low resistivity values are commonly associated with clayey materials and high moisture content, both of which adversely affect subgrade stability. High resistivity values typically represent more competent lithology, such as sands and laterites.

Studies in southern Nigeria highlight the vulnerability of road infrastructure built over clayey or waterlogged substrata, reinforcing the need for detailed geophysical diagnosis before road construction. (Esiekpe et al., 2023). Falade et al. (2021) used integrated magnetic and Electrical Resistivity Imaging surveys to investigate pavement failure along the Ife–Osogbo highway, identifying clay-rich low-resistivity zones beneath failing pavement sections. However, this present research attempts to delineate the horizontal and vertical geological extent of the various lithological units, particularly the expected clayey layer, water-logged sands and also determine the depth to competent sandy layer using vertical electrical sounding (VES) and electrical resistivity imaging (ERI) method to investigate the underlying causes of recurrent road pavement failure at Federal College of Education (Technical), Asaba, Delta State, Nigeria and to recommend preventive strategies.

Federal College of Education (Technical), Asaba (Fig.1) lies within (longitude 6° 12', latitude 6°45'E). The area has a humid tropical climate, characterized by intense rainfall and seasonal flooding conditions that exacerbate subsurface instability and accelerate road deformation. The underlying geology consists of weathered basement rocks, lateritic soils, clay-rich deposits, and sandy substructure. These geological settings influence the stability of road pavements in the area. The subsurface lithological units are made up of about 25–30 m thick alluvium, which represents the aquifer in the area; the alluvium is Pleistocene to Recent; this was followed by a succession of the Eocene Ogwashi–Asaba formation and the the Oligocene–Miocene Ameki formation.

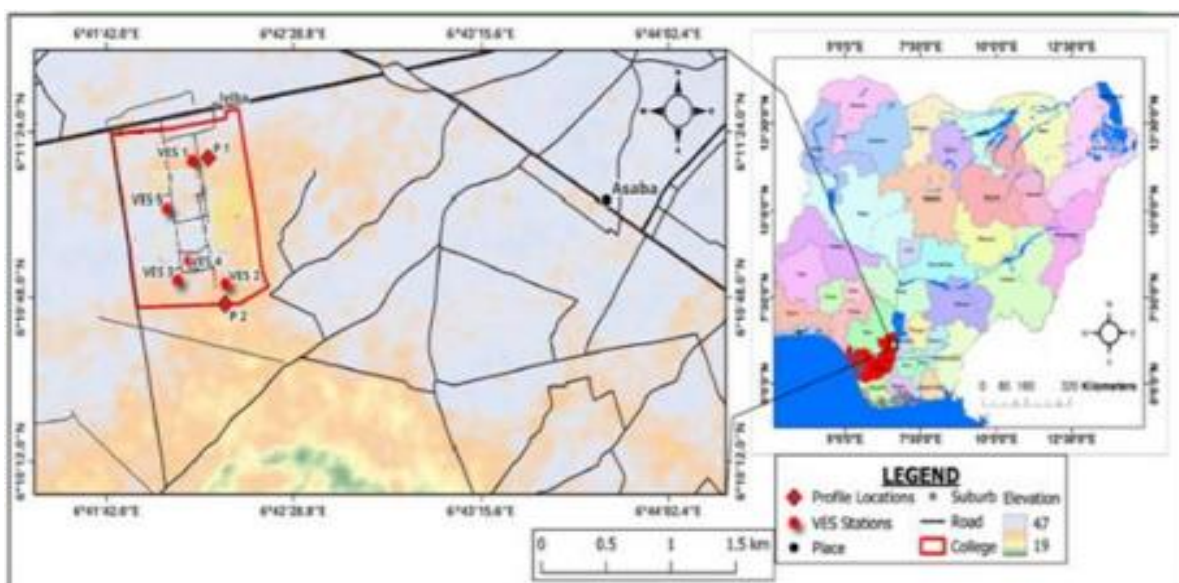


Fig.1: Map of study area showing VES points and Schlumberger array Profiling



Fig.2: Failure portions of the Road segment identified at Federal College of Education (Technical), Asaba, Delta State.

II. MATERIALS AND METHODS

The research investigation was carried out to ascertain the causes of road failure at the Federal College of Education (Technical), Asaba, Delta State, in order to establish accurate results of the measurement. 2D resistivity profiles were established using the Schlumberger array configuration with electrode spacing up to 100 m. In this research study, resistivity was measured using ABEM SAS 1000 (Signal Averaging System) to acquire field data and to perform automatic recording of both voltage and current. The resistivity involved Vertical Electrical Sounding (VES) with Schlumberger array configuration and horizontal profiling. Five (5) soundings and two (2) profiling were performed in the study area as shown in Fig. 1. The VES data was measured with current electrode spacing (AB/2) varying from 1 to 100 m. The resistivity measured was converted to apparent resistivity (ρ_a) using equation (1) below. Horizontal profiling was carried out using electrode Spacing of $a = 5\text{m}, 10\text{m}, 20\text{m},$ and 30m , which implies that as the electrode spacing increases, the number of measurements decreases. Datasets were generated, processed, and inverted using RES2DINV software. The Surfer® 10, which is a grid-based graphics program, was used to produce pseudo-sections. The inversion generated 2D resistivity models of the subsurface, which were interpreted in terms of lithology, moisture content, and structural integrity. Zones of anomalous low or high resistivity were identified and correlated with observed road conditions. The apparent resistivity (ρ_a) for the Schlumberger configuration is:

$$\rho_a = \frac{k\Delta V}{\Delta I}$$

ρ_a = apparent resistivity, ΔV = voltage, ΔI = current, and K = geometric factor

$$K = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{2MN} \right]$$

III. RESULTS AND DISCUSSION

Table I: Layer Resistivity Model and Lithology Interpretation Units

VES Point	Layer No	Resistivity (Ω)	Thickness (m)	Depth to Bottom (m)	Lithology Interpretation
VES 1	1	85	1.0	1.0	Topsoil clayey
	2	200	0.4	5.5	Lateritic layer
	3	60	3.0	12.5	Clayey/silty layer (Poor bearing)
	4	470	–	–	Weathered basement
VES 2	1	80	1.0	1.0	Topsoil (clayey)
	2	210	1.5	6.0	Lateritic sand layer
	3	395	2.5	10.8	Clayey subsoil layer
	4	750	–	–	Weathered basement
VES 3	1	60	0.7	0.7	Topsoil clayey
	2	215	1.7	6.0	Laterite Layer
	3	38	2.6	5.8	Plastic clay (weak zone)
	4	900	–	–	Weathered basement
VES 4	1	300	0.9	0.5	Topsoil (sandy)
	2	330	2.0	3.0	Lateritic layer
	3	980	–	–	Weathered basement/ high resistivity
VES 5	1	50	0.6	0.4	Topsoil (sandy)
	2	150	1.5	4.5	Lateritic sand
	3	995	–	–	Weathered basement/ High resistivity

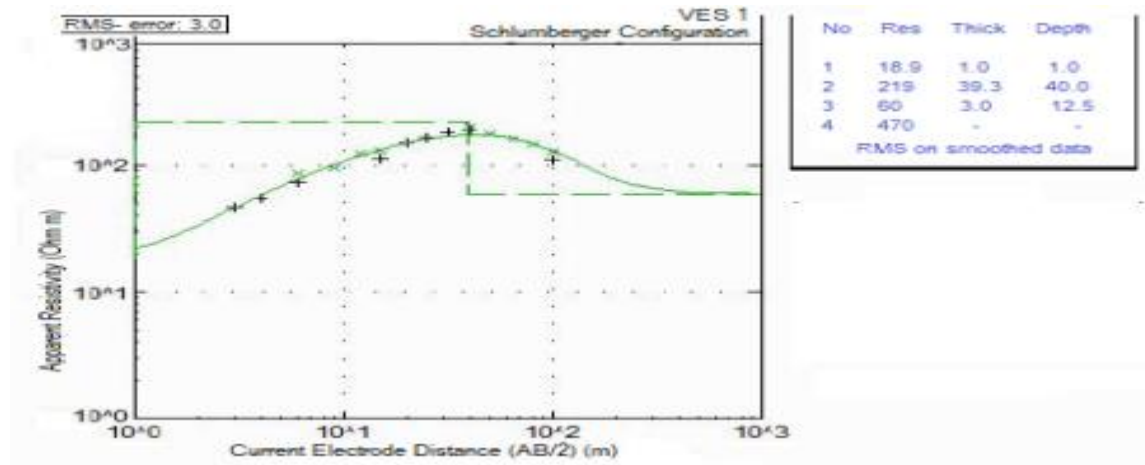


Fig 2: Sample of sounding curve for VES 1

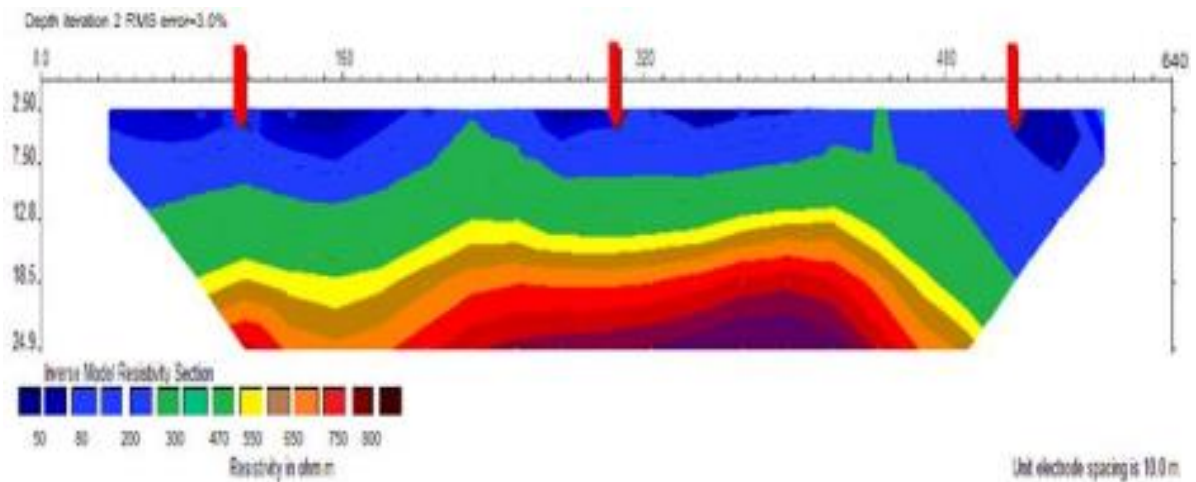


Fig 3. Pseudo-section plot of Lithology Interpretation showing stratified colour layers VES 1, VES 2 and VES for Federal College of Education (Technical), Asaba, road profile. The arrows depicted regions with very low resistivity represented blue colour. The pseudo sections above is computer interpreted iterated inverse model.

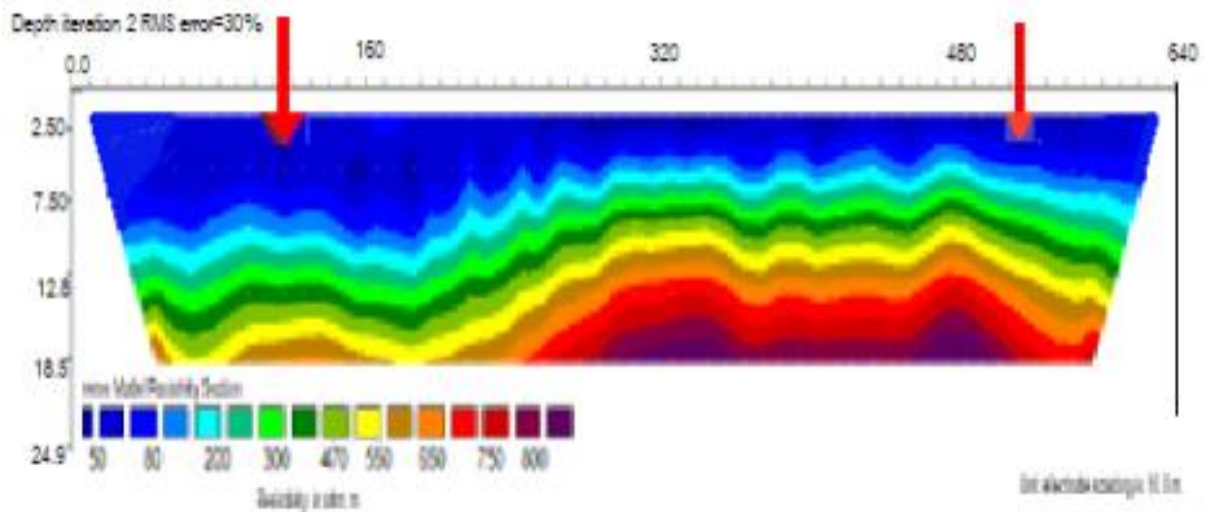


Figure 4. Pseudo-section plot of Lithology Interpretation showing stratified colour layers VES 4 and VES 5 for FCE (T) Asaba road profile. The arrows depicted regions with very low resistivity represented blue colour. The pseudo sections above is computer interpreted iterated inverse model.

The electrical resistivity data acquired were interpreted, and the results were displayed as 2-D pseudo-sections and sounding curves (Figure 2) along with their corresponding models. From the result, four to five geo-electric layers were delineated, which is topsoil, lateritic, clayey/silty, and weathered basement/high resistivity (Table 1). The resistivity, which indicated incompetent geologic material colors and competent geologic material colors, is shown on the pseudo sections as blue representing very poor rocks, green representing poor rocks, yellow representing fair rocks, red representing good rocks, and purple representing very good rocks. The first layer is made up of topsoil (clayey sandy), which has resistivity ranging from 50 Ωm to 300 Ωm with thickness between 0.5 m and 1.7 m. The resistivity is within that of clayey sandy lithology, which suggests a high moisture content composition.

The second layer shows resistivity values of about 150 Ωm - 330 Ωm , which possibly made the resistivity fall within the lateritic formation with thickness ranging from 0.4 to 2.0 m. The third layer has resistivity values from 38 Ωm to 995 Ωm , which suggests a clayey/silty layer that acts as the major weak zone of poor bearing capacity of the road failure with thickness ranging from 2.1 m to 3.0 m. The fourth layer has high resistivity values from 470 Ωm to 900 Ωm for the weathered basement layer with unknown thickness due to the inability of the current injected to exceed the layer thickness theoretically down infinitely. These indicated that a weathered basement with high resistivity has more competent/stable road foundation materials.

The results in VES 1, VES 2, and VES 3 in table 1, represented in the pseudo section in Figure 3, indicate very low resistivities and the presence of a clayey, water-bearing layer with high moisture retention and plasticity at a depth of 5.8 m, which leads to water infiltration, weakening the pavement foundation and leading to progressive structural failure of the road segment in the study area. While VES 4 and VES 5 in Table 1 represented in the pseudo section in Figure 4 exhibit higher resistivities in deeper layers, indicating more competent geologic materials (sandy to lateritic), suitable for supporting road foundations after proper compaction and drainage. These results are consistent with field observations and support the conclusion that high-resistivity zones are suitable for pavement foundations. As a result, for a stable road foundation building in the study area, the topsoil must be excavated at least to the weathered basement competent (competent layer) to avoid road pavement deformation. Hence, any engineering structure built on them will cause differential settlement and instability foundations and possibly lateral deformation under pavement

. Secondly, lack of proper drainage system which may cause gutter not to drain away excess water on the surface of the roads also increases the moisture content of the clay underneath the asphalt. This causes the Asphalt to cave in, causing the cracks and the potholes on the road surfaces observed. These findings corroborate earlier geotechnical observations that clay-rich and water-saturated layers are the dominant contributors to pavement instability in the study area.

IV. CONCLUSION

It was concluded that the causes of road failures observed in the study areas are as a result of the presence of clay in the top soil and inability of the engineers to excavate to the appropriate depth that causes the recurrent of pavement failure such as weak and highly conductive clayey subgrade materials, which are correspond geotechnically unsuitable for road foundations, and poor drainage condition is also a major contributor. Therefore, it is recommended that proper subsurface investigations such as ERI and geotechnical testing should be conducted prior to any future road construction or rehabilitation within the college. In addition, effective surface and subsurface drainage systems should be incorporated into road design to minimize water infiltration and improve the long-term stability of the pavement structure. Hence, this research emphasizes the importance of geophysical methods, particularly for diagnosing and mitigating road failures in geologically sensitive environments like Asaba, Delta State.

This paper therefore recommends that the engineers should endeavor to excavate at least 2m of the top soil and fill them with a more competent material such as laterite (red soil) to ensure good bedrock or foundation. More importantly, that proper drainage system should be constructed on both sides of the roads to avoid road pavement failure and finally that construction engineers should endeavor to carry out proper ERI geophysical surveys before road construction to avoid pavement failure.

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