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Geophysical Investigation of Failed Portion (Km 2) along Iworoko - Are-Ekiti road, Southwestern Nigeria

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Abstract: The Iworoko-Are Road in Ekiti State, Southwestern Nigeria, has experienced persistent pavement failures despite repeated rehabilitation efforts. This study employs integrated geophysical methods to investigate the causes of the failures, focusing on the subsurface lithology, geological structures and soil properties. The research aims to provide actionable insights for sustainable road construction and maintenance in the study area. The investigation utilized dipole-dipole arrays method that combined horizontal profiling and Vertical Electrical Sounding (VES) and 2D electrical resistivity imaging to map the subsurface layers and identify the weak zones. The study also incorporated Electromagnetic method (EM) profiling to detect near-surface features such as fractures and faults. The geophysical survey revealed three to four geoelectric layers: topsoil (resistivity; 26.2–224Ωm), weathered layer (resistivity; 753 - 2543 Ωm), and fractured basement (resistivity; 75 -557 Ωm) and fresh bedrock (resistivity; 3,888 – 30,657 Ωm). The topsoil exhibited low resistivity with approximate depth of 10m, indicating clayey materials prone to water absorption and swelling, suggesting water saturation and weak zones. The significant fracture zone between 70 and 100m along the traverse that extends to depth of greater than 40m correlates severally with the severely failed portion of the road and represents a high – risk area for further deterioration. The EM results with four to five subsurface layers (clayey topsoil, a weathered layer, a partly weathered layer, a wet fractured/dry fractured zones and the fresh basement. Subsurface fractures and clayey top soil that is capable of differential settlement are responsible for the pavement instability and failure. The study concludes that the primary causes of road failure are the presence of water saturated clayey subgrade soils and subsurface fractures. These factors collectively undermine the structural integrity of the road pavement.

Keywords: Pavement failures, Rehabilitation efforts, Road construction, Geoelectric layers, Clayey materials

1. Introduction

Road infrastructure plays a critical role in the socio-economic development of any region, facilitating transportation, commerce and communication [1][2][3][4][5]. However, in Nigeria, road failures are a persistent challenge, disrupting transportation networks and imposing significant financial burdens on governments and communities [6][7]. These failures often occur due to a combination of geological, geotechnical, environmental and human-induced factors, making their investigation a multidisciplinary effort [8][9].

Several structural engineering problems have been recorded within Iworoko-Are Road Ekiti, South-western Nigeria. These problems have manifested in different forms, ranging from minor foundation cracks to major cracks on roads [10][11][12]. The problems have been addressed from the engineers' point of view which attributed the road failures to defective structural designs or poor construction practices such as the use of inferior construction materials and the involvement of unskilled/unqualified personnel during construction. There have been recommendations for the redesigning and reconstruction of such roads. No adequate measure has been adopted to unravel the reasons behind the road failures beyond the aforementioned engineers' views. It is important to note that the nature of the soil upon which engineering structures (buildings, dams, roads etc.) are constructed determines their sustainability [13][14][15][16].

Iworoko Ekiti, a rapidly growing town in Ekiti State, South-western Nigeria, is strategically located along major transport routes connecting it to neighboring towns and cities [17]. Despite its importance, a section of its road at km 2 along Iworoko-Are road has been pruned to structural failures. This has led to accidents, increased vehicle maintenance costs, and delays in transportation, all of which negatively impact the lives of residents and the local economy.

The causes of road failures in the region are multifaceted, ranging from poor construction practices, inadequate drainage systems, and heavy traffic loads to underlying geological structures such as weak subgrade soils or the presence of unstable geological formations [18]. These factors necessitate a detailed understanding of the subsurface conditions, which can be effectively achieved through geophysical investigations [19][20][21][22][23].

Geophysical methods provide non-invasive techniques to study subsurface properties and identify the root causes of road failures [24][25]. Methods such as electrical resistivity, seismic refraction and ground-penetrating radar have proven effective in mapping soil properties, detecting voids, and assessing the integrity of underlying layers [26]. This study was carried out employing electrical resistivity imaging using dipole-dipole configuration of combined horizontal profiling and vertical electrical sounding to reveal the subsurface condition of the failed portion of the Ado-Are road.

2. Location and Accessibility

The study area is located at Km2, Iworoko-Are Road, Ekiti state, South-western Nigeria. Iworoko-Ekiti is approximately 15 kilometers northeast of Ado-Ekiti, the state capital (Figure 1), within Latitude: 7°43'3" N and Longitude: 5°15'48.2" E. Iworoko is connected to major towns including Are-Ekiti, Ado-Ekiti, Ifaki-Ekiti through road networks (Figure 1.). The study area is characterized generally, by undulating terrain with gently sloping hills and valleys with the elevation ranging approximately from 300 to 400 meters above sea level.

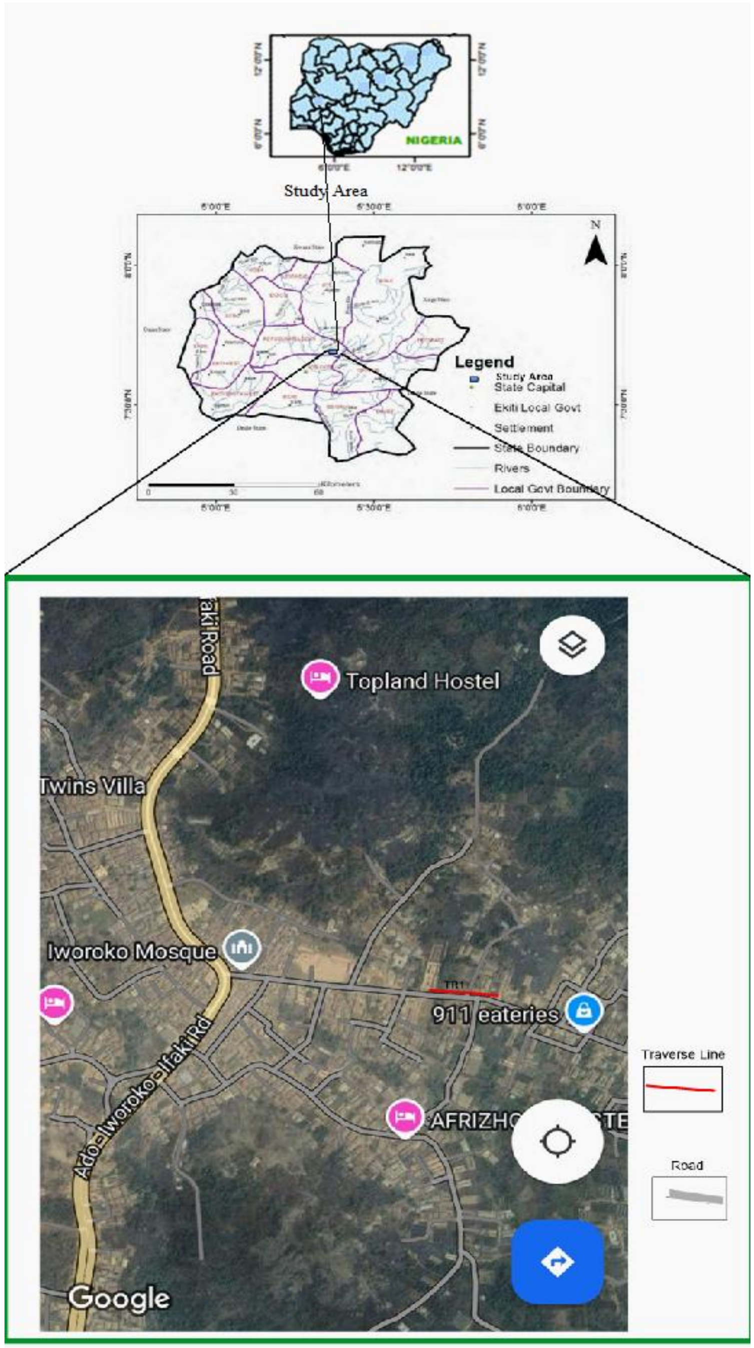

Figure 1: Location of study

The Iworoko-Are Road is situated on a relatively flat or gently sloping area mainly in a low-lying region within the broader undulating landscape. This type of topography is common in many parts of the South-western Nigeria, where the landscape is dominated by rolling hills, valleys, and floodplains. The area is prone to water logging and erosion during heavy rains which makes it particularly susceptible to infrastructural challenges, including road failures. The drainage system in the area is usually marked with the proliferation of many smaller streams which are dry for many months, especially from Nov – May. There is a major river in the study area called river Oke ode, which flows from the north to the southern part of the area. The drainage pattern typical of the study area is trellis which is controlled by the structures [27]. The study area is within the tropical rain forest with two distinct seasons (wet and dry). The wet season ranges from April to October while the dry season is from November to March each year. The average annual rainfall ranged from 1500 – 2000mmm while that of the temperature is between 22°C - 32°C [28]. There may be little variation in the climatic variables arising from recent climate change.

3. Methodology

Electrical Resistivity (ER) using Ohmega Ω Resistivity Meter Rev. F 0609 and Electromagnetic Survey employing PQWT S300 Electromagnetic Equipment were carried out to investigate the road failure along Iworoko-Are-Ekiti. These techniques were chosen for their effectiveness in characterizing subsurface conditions, particularly in detecting variations in soil properties, moisture content and structural anomalies.

3.1. Electrical Resistivity Method

A single geophysical traverse was established along the eastern-western orientation, covering critical failed sections of the road. The traverse spanned a total length of 210 m with measurement stations spaced at 10 m intervals. This setup provided adequate resolution to capture subsurface variations related to road failure. The 2D electrical resistivity imaging was conducted using the dipole-dipole array configuration, a method that combines horizontal profiling and vertical electrical sounding. The data acquired were inverted using DIPRO software to generate 2-D image structure. This approach allows for high-resolution imaging of subsurface resistivity variations, which are indicative of lithological and structural features. Five movements of the electrode array were carried out along the traverse, with an inter-electrode spacing of 10 m. The electrode configuration and spacing were designed to achieve a maximum investigation depth of approximately 50 m. This depth was sufficient to evaluate the underlying strata for anomalies such as voids, fractures, or water intrusion that could contribute to road failure.

3.2. Electromagnetic Method

The Electromagnetic (EM) geophysical method employed in this study was an impact-based EM technique designed for subsurface investigation along the 210 m long traverse. The traverse was established for data acquisition with an inter-station spacing of 5 m and an electrode separation (MN spacing) of 10 m. The survey utilized the PQWT-TC150 Electromagnetic instrument, known for its efficiency in detecting subsurface conductivity anomalies. The starting point of the traverse was designated at 0 m, where the equipment setup included two non-polarizing electrodes which were placed equidistantly at a separation of 10 m, connected by a transducer bar and cables. After each measurement, the distance between the electrodes (MN) was incrementally increased by 5 m along the traverse. This was used to reveal the weak/porous portions of the subsurface which are revealed as conductive layers of the constructed subsurface of the road from a 2D-geosection processed by the program in-built in the instrument. This is also a function of natural charges and magneto telluric current readily generated within the subsurface.

4. Results and Discussion

Electrical resistivity and Electromagnetic impact methods of geophysics were adopted in this study and their results are presented as 2D-Electrical Resistivity Structure, tables and geo-sections.

4.1. Electrical Resistivity 2D-Image Result

Figure 2 presents the subsurface resistivity profile along the 210 m traverse established over the failed portion of the road. The topsoil, characterized by clayey formations, extends to a depth of approximately 10 m across the study area. This layer exhibits resistivity values ranging from 26.2 to 224 ohm-m, indicating a highly conductive zone spanning the entire traverse from 0 to 210 m. The resistivity data reveal four distinct subsurface formations which are Clayey/weathered topsoil with resistivity values between 26.2 and 224 ohm-m, indicating a weak, moisture-retaining layer, partly weathered layer with resistivity values between 753 and 2543 ohm-m representing transitional material with moderate consolidation, fractured layer with resistivity values between 75 and 557 ohm-m, indicating structural weaknesses that could facilitate water infiltration and fresh basement which have a resistivity values between 3888 and 30,675 ohm-m, corresponding to competent unweathered bedrock.

A significant fracture zone is evident between 70 and 100 m along the traverse, extending to depths greater than 40 m. This fractured section correlates with the severely failed portion of the road and represents a high-risk area for further deterioration. If timely mitigation measures are not implemented, this could lead to total collapse of the road that may require substantial financial resources for reconstruction. Clayey subgrade and fractures compromise pavement performance by facilitating moisture buildup, lowering bearing capacity and triggering volume changes that can result in various structural failures.

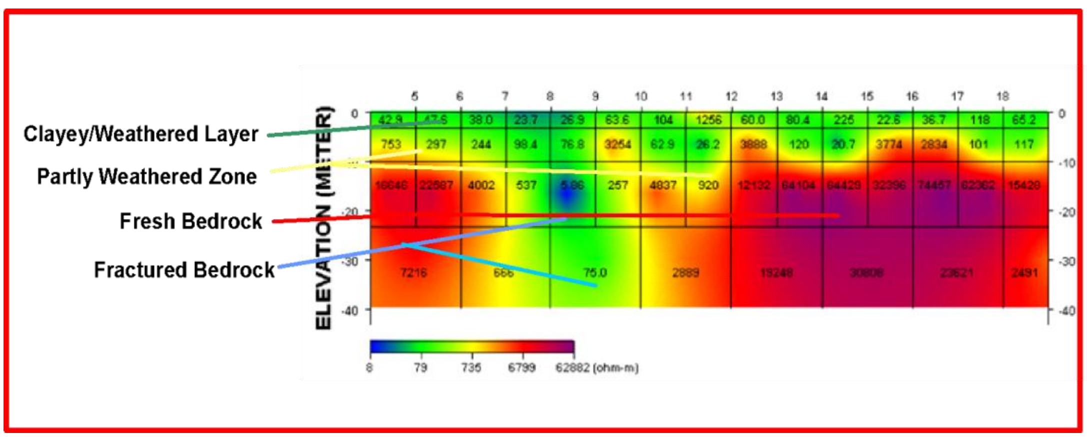

Figure 2: Electrical resistivity 2D-image structures

4.2. Electromagnetic Result

Profile responses of 19 varying frequencies of electromagnetic fields were analyzed to characterize shallow, medium, and deep subsurface formations. Fig.3 displays the frequency response profiles of the electromagnetic fields, where low-response trends correspond to highly conductive zones, while high-response trends indicate highly resistive zones.

The electromagnetic survey delineated many formations, including clayey topsoil; a conductive layer that contributes to road instability, a weathered layer; which consists of moderately conductive zones indicative of partially decomposed materials, a partly weathered formation representing transitional zones with varying consolidation, a wet fractured zone characterized by saturated layer that weaken the subsurface and fresh bedrock which comprises highly resistive and competent zones at greater depths. Also, a dry fractured zone that lacks significant moisture is observed. The dry fracture zone still impacts the subsurface stability of the road.

The results reveal that the clayey topsoil extends across significant portions of the traverse, indicating its critical role in the road's instability. The presence of the saturated fractured and weathered formations within the subsurface significantly weakens the mechanical integrity of the foundation, making it unable to withstand the downward forces from vehicular and heavy-duty lorry loads. The basement complex is the only competent zone with high bearing capacity that is ideal for road stability.

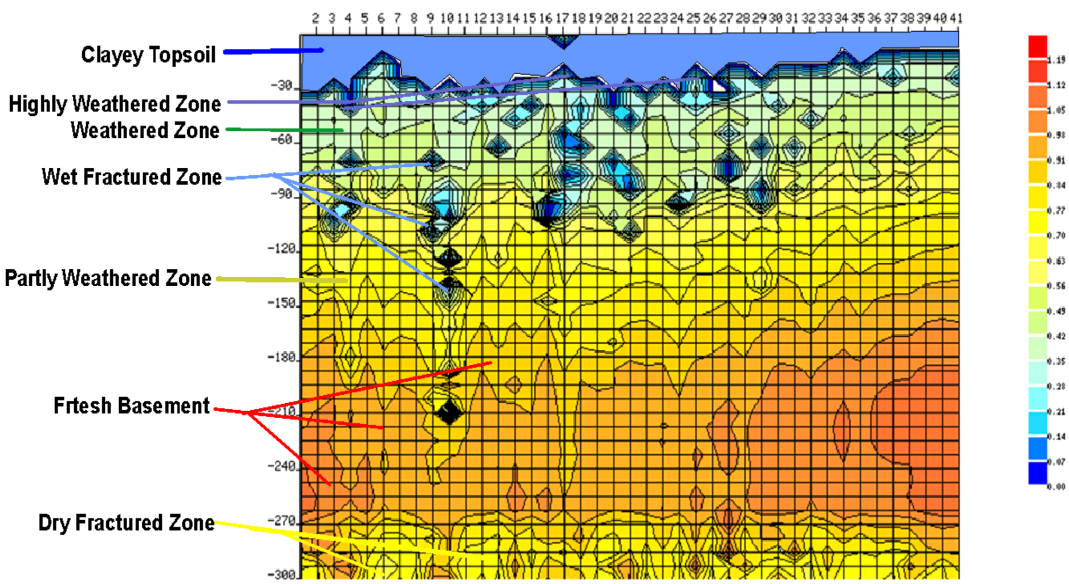

Figure 3: EM anomaly map of the study area along the single traverse

This method successfully probed depths of up to 300 m, providing a detailed understanding of the subsurface conditions. The 2D-geosection highlights critical weaknesses along the road; from 0 to 210 m with weaknesses evident at shallow depths exceeding 40 m. Additional responses indicating fractures and highly weathered formations are observed from 0 to 155 m along the traverse.

These findings underscore the importance of addressing subsurface weaknesses, particularly in the clayey and fractured zones, to improve road stability and durability. The Electromagnetic Survey corroborates the Electrical Resistivity survey as areas of the failed portion of the road are linked to low resistivity and geological flaws especially clayey and wet fracture zones. The stable areas generally correspond with higher resistivity and uniform substrate; remediation requires removing unsuitable materials and installing competent fill and effective drainage systems.

The study revealed that the clayey topsoil, characterized by low resistivity (26.2–224 ohm-m), is moisture-retaining and prone to instability. A significant fractured layer, with resistivity values ranging from 75–557 ohm-m, was identified between 70 and 100 meters along the traverse and extending to depths exceeding 40 meters. This fractured section aligns with the most severely failed portions of the road, posing a high risk for further deterioration.

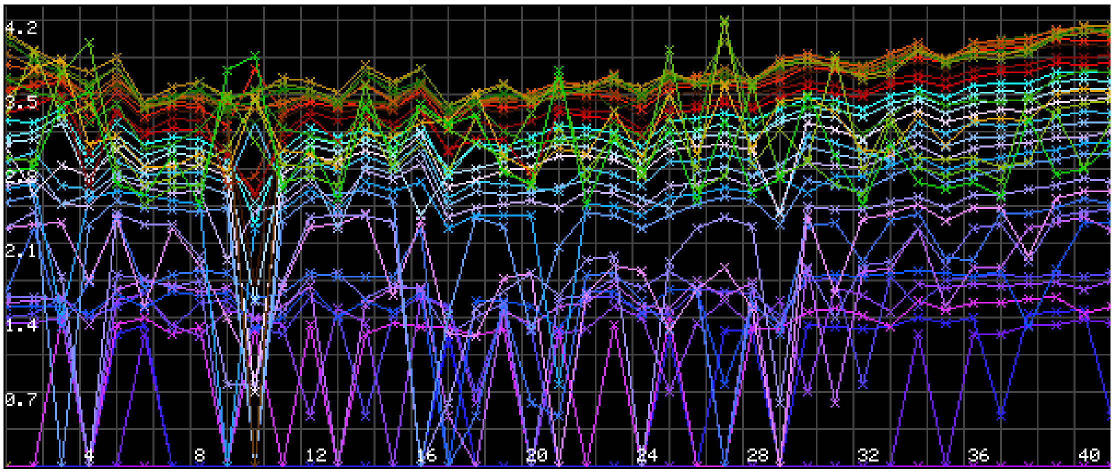

Figure 3: Profile plot at varying frequencies of the resistivity of the study area along the traverse

The hydro-geotechnical clay layer is capable of swelling and shrinking at varied weather conditions and traffic loads thereby responsible for the failed road portion of the study area. The partially weathered layer is more geotechnically competent compared to the weathered layer. Both layers are capable of differential settlement which equally enhances road failure. The fractured zones serve as conduit to water passage which can lead to water saturation of the subgrade which contributes significantly to the failed portion of the road.

The electromagnetic profiles corroborated these findings, showing that highly conductive zones correspond to clayey formations and water-saturated fractures, while resistive zones indicate stable formations like the fresh basement rock (3888–30,675 ohm-m). The fractured and weathered formations, extending from 0–155 meters along the traverse, significantly weaken the road's foundation, particularly under heavy vehicular loads. The presence of saturated fractures exacerbates this degradation, making the subsurface unable to withstand downward forces, and without timely intervention, these weaknesses could lead to a total road collapse, requiring costly reconstruction.

To address these issues, the study recommends reinforcing weak zones with appropriate engineering materials, particularly in the clayey and fractured areas, and improving drainage systems to prevent water infiltration. Additionally, sustainable construction practices that account for local geological conditions and regular geophysical surveys to monitor subsurface integrity are essential for ensuring the road's durability and resilience against environmental challenges.

5. Conclusion

The investigation of road failure along Iworoko-Are Road in Ekiti State, Southwestern Nigeria, utilized geophysical techniques (Electrical Resistivity 2D-Imaging and Electromagnetic Methods) to identify geological weaknesses and provide recommendations for remediation and future construction.

The study has provided critical insights into the root causes of its failure. Weak clayey topsoil, fractured layers, and weathered formations have been identified as the primary contributors to the road's instability. These subsurface weaknesses, coupled with inadequate drainage, have rendered the road foundation unable to support the forces exerted by vehicular and heavy-duty traffic. The fractured zones, particularly between 70 and 100 meters along the traverse, represent a significant risk area for further deterioration. Without timely intervention, the road may experience total collapse, resulting in substantial financial and logistical challenges. This study underscores the need to understand the subsurface geology and hydrogeology of the study area before an effective road can be constructed. Reinforcement of the weak zones by strengthen the clayey and fractured sections with appropriate engineering materials, such as compacted granular fill or stabilizing agents to improve subsurface stability is recommended as remediation measures in this study. Also, efficient drainage system along the road should be implemented to minimize water infiltration into the subsurface, particularly in areas prone to water saturation.

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Authors' Contributions Statement

A.O. Talabi: Conceptualization, Writing – original draft, Visualization, Investigation, Resources, Supervision, Project administration. O.O. Akinola: Writing – original draft, Software, Visualization, Resources, Supervision. S.A. Adeoye: Writing – original draft, Visualization, Resources, Supervision.

Declaration of Competing Interest

The authors hereby declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Statement

This work is our own original idea and it has not been previously published or is not currently being considered for publication elsewhere. The paper is a reflection of our research findings without any encumbrances.

Fundings

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