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Geotechnical Investigation of Road Failure Along Abuja- Lokoja Road

Solomon Chijioke Agbo^{1*} | Akeem Amuda¹ | Musa Umar Kolo¹

¹Department of Civil
Engineering, Nile
University of Nigeria,
Abuja

ABSTRACT

A comprehensive investigation of soil properties along the Abuja-Lokoja Road, focusing on samples A and B located between KM51 + 300 to KM51 + 200 and KM45+100 to M51+000 respectively utilizing site analysis, laboratory testing, and comparative analysis, the study identifies critical distinctions in soil composition and engineering behaviours. Sample A, classified as CH (clay of high plasticity), exhibits a moisture content of 12.6% and a density of 1.940 g/cc in contrast, Sample B, classified as GM (gravelly material), has a higher moisture content of 13.8% and a denser structure at 2.100g/cc. Despite differing compositions, both samples demonstrate comparable load-bearing capacities, reflected in California Bearing Ratio (CBR) values at 100% moisture content. Sample A records 32.7% (unsoaked) and 24.6% (soaked), while Sample B exhibits 32.7% (unsoaked) and 26.2% (soaked), indicating similar strength under specific moisture conditions. Further analysis reveals a slightly higher Liquid Limit (LL) for Sample A at 41% compared to Sample B's 40%, with closely aligned Plasticity Index (PI) values, suggesting comparable plasticity characteristics. These findings align with established trends in cohesive and gravelly soils from past research. Recognizing these distinctions is crucial for informed construction practices. The study recommends tailored engineering strategies, based on precise soil characterization, to optimize infrastructure performance and longevity in diverse soil environments. The emphasis on soil analysis and tailored engineering approaches underscores their significance in enhancing infrastructure stability and durability across varying soil conditions.

KEYWORDS: Road Failure, CBR, Abuja, Highway & Transport

Corresponding Author's Name:

Solomon Chijioke Agbo

Corresponding Author's E-mail:

solomonchijioke27@yahoo.com



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1 | INTRODUCTION

The crucial role of roads in global trade and transportation, particularly in Africa where they are vital for accessing education, healthcare, and social services. The state of roads in Nigeria, specifically the Abuja-Lokoja Road, is highlighted, the link between road stability and the quality of soils is emphasized pointing to recurring failures and associated challenges [1].

The significance of geotechnical investigations in understanding subsurface conditions for road construction and maintenance is underscored. The Abuja-Lokoja Road serves as a case study, experiencing rutting issues, a common problem in Nigerian roads. Geotechnical engineering's role in addressing challenges such as expansive soils and unstable ground conditions is discussed. The research aims to conduct a comprehensive geotechnical investigation into the road failure along the Abuja-Lokoja Road. The study will involve field investigations, laboratory testing, data analysis, and geotechnical evaluation to identify the root causes of failure of the Abuja-Lokoja Road. The research is expected to contribute valuable insights to the field of geotechnical engineering, enhancing understanding and informing better road design, construction, and maintenance practices in similar geological conditions especially present improvement and future road works.

Presently, a significant portion of the major roads in Nigeria are in a state of disrepair, and efforts towards consistent road maintenance have yielded limited success [2]. The rehabilitation of roadways has imposed a substantial financial burden on various levels of government. Instability in roads is often attributed to factors such as heavy usage, inadequate maintenance, utilization of substandard construction materials, and practices that disregard the characteristics of the subsoil on which the roads are built [3].

The Abuja-Lokoja Road in Nigeria is a major transportation corridor that connects the capital city of Abuja with the northern regions of the country. The Abuja-Lokoja Road in Nigeria has been experiencing recurring road failures, leading to disruptions in traffic flow, increased maintenance costs, and compromised road safety. The causes of these failures, such as poor drainage systems, inadequate pavement design, substandard materials, weak subgrades, and heavy axle loads were identified [4]. There is a need for a comprehensive geotechnical investigation to understand the underlying geotechnical factors contributing to the road failures and develop appropriate mitigation strategies. However, a section of the road has been

experiencing suspected rutting, which poses significant challenges to its performance, safety, and efficiency.

Geotechnical investigation is a process of identifying and assessing ground conditions and soil properties to determine their suitability for a particular construction project. In the case of road failure, geotechnical investigation is typically conducted to identify the underlying cause of the failure, which could be due to factors such as poor soil quality, inadequate drainage, or unstable ground conditions [5]. The investigation typically involves drilling soil samples and testing to determine soil properties and to identify any weaknesses or potential hazards that could affect the stability of the road. Based on the results of the investigation, engineers can then develop an appropriate remediation plan to address the underlying issues and prevent future failures.

2 | REVIEW OF THE RELATED STUDIES

In Lokoja, North-central Nigeria, Akudo conducted a geophysical and geotechnical study to understand lithology, deformational features, and underlying geology affecting the road [5]. While the study successfully correlated geophysical and geotechnical results, it could benefit from a more critical analysis of the potential biases introduced by the chosen geophysical methods. Additionally, a deeper exploration of the specific impact of each identified geoelectric layer on road stability would provide a more critical understanding. Nwachukwu focused on the Mbaitolu-Ikeduru-Ahiara Mbaise highway in Imo state, southeastern Nigeria, conducting engineering tests on soil samples to assess subgrade properties. The study identified moisture fluctuations in the subgrade as a significant contributor to road failures, and while the recommended measures are practical, a more critical evaluation of their cost-effectiveness and long-term sustainability would enhance the study's applicability to real-world scenarios [6].

Conducting a geophysical investigation along the Lagos-Badagry expressway, Abiola et al. employed Two-dimensional (2D) electrical resistivity imaging to determine subsurface geological structures affecting the highway's stability [1]. The study successfully identified major contributors to road pavement collapse, but a more critical examination of the resolution limits of the imaging method and potential uncertainties in interpreting the subsurface structures would add depth to the findings.

Ademila's geotechnical investigation on the Owo-Ikare highway employed Very Low Frequency Electromagnetic (VLF-EM) and electrical resistivity

methods to identify causes of persistent road pavement failures [2]. The study successfully highlighted conductive subsurface structures, but a more critical discussion on the limitations of these geophysical methods in characterizing complex geological conditions and their impact on the study's conclusions would enhance the overall assessment.

Conducting a geotechnical investigation in Abakaliki, Nigeria, Babadiya and Igwe analysed the reasons behind the structural failures of road pavements, employing California Bearing Ratio (CBR) tests and in-situ density measurements [7]. While the study successfully revealed key soil properties, a more critical examination of the representativeness of the selected soil samples and potential variations in soil properties across different sections of the roads would strengthen the study's findings.

Ndanusa et al.'s geotechnical investigation on part of London Road involved CBR tests, sieve analysis, and compaction tests to evaluate the quality of subgrade materials, the study provided valuable insights into the properties of subgrade materials, a more critical analysis of the relevance of CBR values in predicting field performance, the potential influence of local variations on the results would enhance the study's credibility [8].

Alo & Oni's geological and geotechnical investigation in parts of Imo and Abia States identified complex deformations within geological formations [9]. The study successfully highlighted the importance of factors such as inadequate drainage, shallow water tables, and topographical variations, but a more critical examination of the specific contributions of each geological formation to road failures would provide a more comprehensive understanding.

Sangra et al. focused on investigating slope stability conditions along the Mughal Road in Jammu and Kashmir, India, employing Rock Mass Rating (RMRb), Slope Mass Rating (SMR), and kinematic analysis [10]. While the study successfully categorized slopes into different conditions with specific failure modes, a more critical discussion on ratings across diverse geological settings and potential limitations in predicting real-world slope stability would strengthen the study's broader implications.

The persistent structural failures on Nigerian roads have reached a critical juncture, becoming a distressing and commonplace occurrence. These failures can be attributed to a multitude of factors, including inadequate knowledge about the underlying soil layers within the pavement and local subsurface geological data. Obtaining accurate information regarding the root causes

of these failures is crucial in order to prevent this recurring issue and to efficiently allocate the limited resources towards effective, long-term solutions. The reliance on quick-fix remedies has proven insufficient in addressing this pressing problem [10].

In summary, while the reviewed studies contribute valuable insights to the understanding of road failures, a more critical examination of methodological limitations and a detailed analysis of specific findings would enhance the robustness and applicability of the research outcomes from previous research findings [11]- [15].

3| METHODOLOGY

3.1 Study Area and Site Selection

The research scrutinizes a specific stretch of the Abuja-Lokoja Road, where the prevalence of road failures has been a persistent challenge. The chosen area for investigation spans from CH.45+000 (Kwali) to CH.52+000 (Yangoji) in Nigeria. This careful selection ensures a focused examination of the region most affected by rutting road failures, providing a targeted understanding of the factors contributing to the road distress.

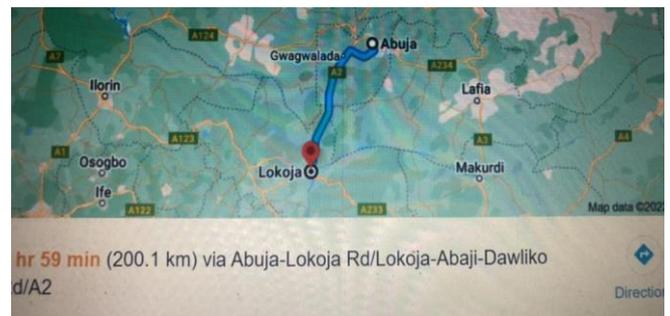


Figure 1: Site Location on map

3.2 Field Work and Sample Collection

The fieldwork conducted on October 14, 2023, involved a comprehensive Dynamic Cone Penetration Test (DCPT) at strategically identified locations within the problematic road section. from CH.45+000 (Kwali) to CH.52+000



Figure 2: Sample Collection

Simultaneously, the meticulous collection of undisturbed soil samples through trial pits provided

a direct representation of the soil's composition, aiding in subsequent laboratory analyses.

3.3 Laboratory Testing

The laboratory testing phase entailed thorough preparation of the soil samples obtained from the field. A multitude of tests, including Atterberg limit assessments, moisture content determinations, particle size distribution analyses through sieving and hydrometer methods, Proctor compaction tests to establish Optimal Moisture Content (OMC) and Maximum Dry Density (MDD), and California Bearing Ratio (CBR) evaluations after compaction and saturation, collectively offered a comprehensive characterization of the soil's physical and mechanical properties.

3.4 Atterberg Limit Analysis

The Atterberg limit analysis further delved into the intricate transitions between the various states of the soil, namely liquid, plastic, and semi-solid. This in-depth examination provided crucial insights into the soil's plasticity index, aiding in its accurate classification.



Figure 3: Atterberg Limit test

3.5 Moisture Content Determination

The determination of moisture content involved meticulous oven-drying processes, enabling a precise assessment of the water content in the soil. This crucial information contributes to an understanding of how the soil behaves under different moisture conditions.



Figure 4: dry can with sample for moisture content determination

3.6 Particle Size Distribution

The particle size distribution analysis employed both sieving and hydrometer methods, offering a detailed breakdown of the soil's composition. This granular insight serves as a foundational element for accurately classifying the soil and understanding its engineering properties.



Figure 5: particle size distribution (sieve analysis and hydrometer analysis)

3.7 Proctor Compaction Test

The Proctor compaction test unfolded the soil's compaction characteristics, providing essential data on Optimal Moisture Content (OMC) and Maximum Dry Density (MDD). This information is pivotal for comprehending the soil's load-bearing capacity and its response to compaction efforts.



Figure 6: weighing of compaction sample and compaction using automatic compaction machine

3.8 California Bearing Ratio (CBR) Testing

The California Bearing Ratio (CBR) testing process involved a meticulous classification and evaluation of the soil-subgrade and sub-base course material. The soaking of CBR samples after compaction ensured saturation, and adherence to standardized protocols guaranteed reliable results for pavement design considerations.



Figure 7: CBR Tests

4 | DATA ANALYSIS

The geotechnical investigation along the Abuja-Lokoja Road aimed to uncover factors contributing to recurrent road failures. This chapter provides a comprehensive analysis of data collected through various tests, including Dynamic Cone Penetration Tests (DCPT), Atterberg Limits, Moisture Content assessments, Particle Size Distribution analyses, Compaction Tests, and California Bearing Ratio (CBR) evaluations. The objective was to decipher the soil's behaviour and suitability for road construction.

4.1 DATA ANALYSIS

The dataset from DCPT-01 to DCPT-05 reveals intriguing insights into soil characteristics at different depths along the road. Load-bearing capacity, relative density, CBR, and compaction percentages exhibit variations, emphasizing the diverse and heterogeneous nature of soil properties. These findings underscore the need for a new approach in road construction strategies to address localized disparities in soil behavior. DCPTs conducted at different locations along the road sections illustrates variations in load-bearing capacity, relative density, CBR, and compaction percentages. The observed differences emphasize the need for tailored construction strategies considering local geology, moisture content, and specific compaction techniques for optimal road performance.

Table 1. SITE DATA ANALYSIS for sample A (DCPT – 01, KM51 + 300 to KM51 + 200)

S/N	Depth (m)	No of blows	Qa (KNm2)	Dr (%)	Avg. compaction (%)	CBR (%)	
1	0	0	0	0			
2	0.1	19	211	125	104	17	29
3	0.2	19	212	125			
4	0.3	17	190	122			
5	0.4	14	158	117			
6	0.5	10	114	112			
7	0.6	11	126	113	102	25	
8	0.7	9	105	110			
9	0.8	7	83	107			
10	0.9	13	150	118			
11	1	9	107	110			
12	1.1	8	88	109	102	45	
13	1.2	8	88	109			
14	1.3	8	89	109			
15	1.4	11	120	113			
16	1.5	15	180	119			

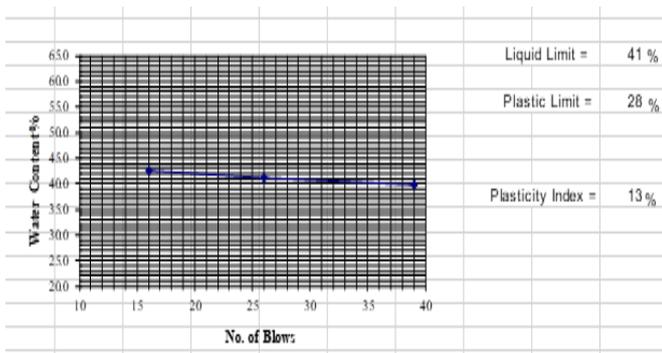


Figure 12: Moisture content Sample A

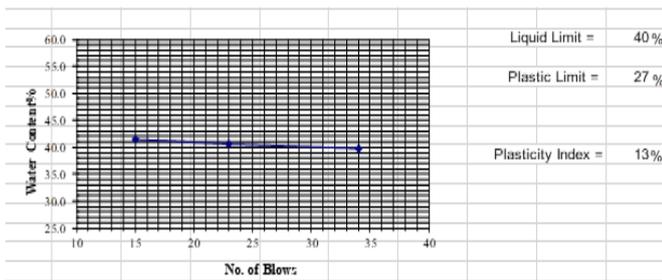


Figure 13: Moisture content Sample B

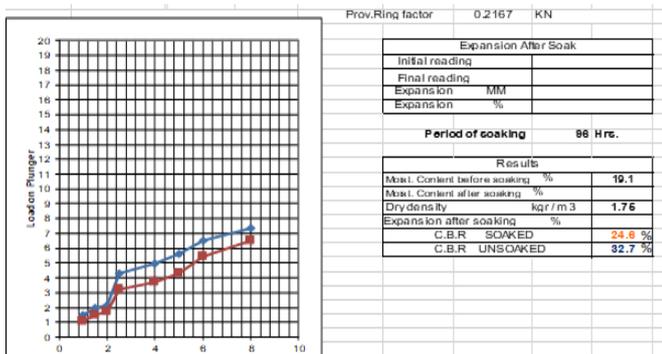


Figure 14: CBR Sample A

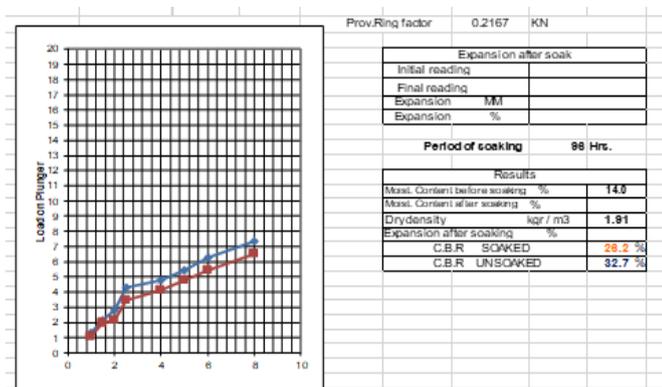


Figure 15: CBR Sample B

The CBR values indicated load-bearing capacity under specific moisture conditions.

Comparisons between Samples A and B and their classifications under USCS and AASHTO systems reveal distinct differences in compositions and engineering properties. Despite divergent compositions, both samples exhibited similar load-bearing capacities under specific moisture conditions. These findings emphasize the importance of considering variations in soil characteristics for optimal construction practices.

The comparison between Sample A and Sample B highlights differences in soil compositions but similar load-bearing capacities. Despite higher clay content in Sample A, both samples exhibited comparable plasticity characteristics and CBR values. This underscores the necessity of precise consideration of soil variations for optimal construction practices. The geotechnical investigation along the Abuja-Lokoja Road has provided valuable insights into soil behaviour and its implications for road construction. The data analysis highlights the need for tailored construction strategies to address the diverse and heterogeneous nature of soil properties. These findings contribute to informed decision-making in road construction and maintenance, emphasizing the importance of a holistic understanding of soil behaviour.

5 | CONCLUSION

This study conducted a thorough analysis of road failures and geotechnical conditions, aiming to address critical factors contributing to road instability. Through meticulous field investigations and laboratory tests, including Dynamic Cone Penetration Testing (DCPT), the research delineated diverse soil compositions and their engineering properties in Sample A and Sample B. Findings underscored discrepancies between measured parameters using DCPT and low California Bearing Ratio (CBR) values, particularly in high-traffic sections, signalling potential engineering oversights. The study advocates for tailored engineering solutions, advanced geotechnical investigations, hydrological assessments, long-term monitoring, innovative material selection, adaptive road design, collaborative research initiatives,

community engagement, climate impact assessments, and policy development to rectify identified issues. Proposed interventions, such as construction of weigh bridges, use of crushed stone, provision Laboratory Control Test - Sample A:

Sample A, classified as cohesive soil (CH), exhibited clayey characteristics. Laboratory tests revealed moisture content, density, CBR values, and plasticity indices. The findings align with prior research on cohesive soils, emphasizing their plasticity and low permeability. CBR values indicated load-bearing capacity under specific moisture conditions.

Laboratory Control Test - Sample B:

Sample B, characterized as gravelly soil (GM), displayed gravelly attributes. Laboratory analysis unveiled moisture content, density, CBR values, and plasticity indices. The results align with established literature on gravelly soils, showcasing improved of macadam, geotextile materials, scarification of existing asphalt, and road redesigning, are recommended to bolster road durability and stability. These insights aim to inform sustainable road construction practices and mitigate the influence of dynamic soil behaviour on road integrity. Inconsistencies in relative density pointed to non-uniform soil consolidation. *The CBR are below and at close range to 30%*, It was noted that soils with CBR values below 30% exhibits limited bearing capacity when compared to the Sub base CBR value specified in FMWH (1997) specifications for roads and bridges in Nigeria

6 | RECOMMENDATIONS

Based on the aforementioned conclusions, the following recommendations are advice or suggested: -

- i. Customized Engineering Solutions: Tailor construction plans to accommodate the specific soil properties identified in Sample A and Sample B for improved stability and performance.
- ii. Advanced Geotechnical Investigations: Conduct additional geotechnical studies to explore deeper layers and assess the potential impact on road integrity.
- iii. Hydrological Assessments: Investigate the influence of water flow and drainage patterns on soil stability to mitigate erosion and flooding risks.

- iv. Long-Term Monitoring: Establish continuous monitoring systems to track soil behavior and assess structural responses over time.
- v. Innovative Material Selection: Explore novel construction materials suitable for varying soil types to enhance road durability.
- vi. Adaptive Road Design: Develop flexible road designs capable of accommodating soil variations to minimize maintenance requirements.
- vii. Collaborative Research Initiatives: Foster partnerships between engineering entities to share findings and develop standardized practices.
- viii. Community Engagement: Involve local communities to gather indigenous knowledge about soil behavior and integrate it into engineering strategies.
- ix. Both subbase and base should be made of crushed stone

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