Applied Sciences, Computing and Energy, 2(2), 181-190

Foundation Feasibility in Lokoja: Geotechnical Perspectives

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Received: 25 December 2024/Accepted: 27 March 2025/Published: 04 April 2024

Abstract: *This geotechnical study aimed to analyze the soil characteristics in certain areas in Lokoja with an emphasis on the durability of foundations for civil engineering projects. To identify important engineering parameters, the study used soil sampling, laboratory analysis, and geological mapping. The majority of the soil types were found to be unstable, with high clay content, poor compaction, and limited bearing ability. Granulometric research revealed that in unstable areas, over 50% of grain sizes had a diameter of less than 0.3 mm, signifying a high concentration of silt and clay. The optimal moisture content ranged from 10.4% to 12.2% in compaction assessment, indicating medium compaction levels susceptible to risks from rainfall. In unstable areas, Atterberg limit tests showed considerable plasticity, with plasticity indices ranging from 7.9% to 16.92%. According to California Bearing Ratio (CBR) measurements, unstable regions have low bearing capacity, with values between 2.0% and 3.31%, whereas stable regions had values between 21.9% and 28.7%. Based on these results, the subsoil is typically inappropriate for sustaining structures, which also explains the observed building cracks. Incomparable geological settings, our research highlights the importance of detailed geotechnical investigations for accurate foundation design and construction.*

Keywords: *Insitu-testing, soil composition, bearing capacity, foundation design, site characterization.*

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1.0 Introduction

The stability of engineering structures, including buildings, roads, and bridges, heavily depends on the geotechnical properties of the underlying soil (Hussain *et al*., 2022). Soil, as a fundamental construction material, exhibits varying engineering behaviours influenced by its composition, compaction, permeability, shear strength, and load-bearing capacity (Holtz *et al*., 2011). The ability of a soil mass to support structural loads without undergoing excessive settlement or failure is a critical consideration in foundation engineering (Salahudeen & Sadeeq, 2016).

Lokoja, the confluence town of Nigeria, has witnessed rapid urban expansion and infrastructural development in recent decades. However, the region is characterised by complex geology comprising alluvial deposits, lateritic soils, and residual formations derived from crystalline basement rocks (Onivefu, 2024). These geological variations influence the geotechnical properties of soils in Lokoja, making site investigations imperative for sustainable construction practices (Adekoya et al., 2019). Despite the strategic importance of Lokoja, inadequate geotechnical assessments have contributed to structural failures, including foundation settlements and pavement failures (Oyelami & Van Rooy, 2016). Understanding the geotechnical behavior of soils in this region is essential for mitigating risks associated with poor foundation performance.

Several studies have emphasized the necessity of geotechnical investigations to ensure structural stability and durability. According to Chatrabhuj (2024), soil testing before construction prevents potential failures and reduces maintenance costs in the long run. Geotechnical parameters such as Atterberg limits, shear strength, and consolidation properties are crucial in determining soil suitability for foundations (Dimitrova & Yanful, 2012). In Nigeria, research on soil competency has shown that lateritic soils, which dominate much of the country, exhibit variable engineering behaviour based on environmental factors and parent material composition (Oyelami & Van Rooy, 2016).

Foundation failures have been extensively reported across different geologic terrains. For example, Exe *et al*. (2023) identified improper soil characterization as a primary cause of foundation distress in southwestern Nigeria. Similarly, Almuaythir *et al*. (2024) demonstrated that high plasticity and low bearing capacity in clay-rich soils contribute to excessive settlement in civil engineering structures. In Lokoja, subsurface heterogeneity exacerbates foundation-related challenges, necessitating localized studies to inform construction practices (Ibrahim et al., 2021).

The application of modern technologies, including geophysical methods and in-situ testing, has improved soil investigation accuracy. Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) have been employed to delineate subsurface anomalies and assess soil competency (Olabode *et al*., 2020). These advancements provide better insights into soil behavior compared to conventional laboratory tests alone. Furthermore, emerging trends in smart materials and nanotechnology offer potential solutions for enhancing soil properties through stabilization techniques (Mohamed, 2025).

Despite existing studies on geotechnical properties in Nigeria, there remains a paucity of research focused on the soil conditions in Lokoja, particularly in relation to foundation design and construction challenges. While Sadeeq & Salahudeen. (2017) provided preliminary assessments, a comprehensive evaluation of soil classification, compaction characteristics, shear strength, and load-bearing capacity specific to Lokoja is still lacking. Moreover, limited studies have integrated geotechnical, geological, and geophysical approaches for site characterization in this region. Addressing these gaps is essential for developing location-specific foundation solutions.

This study aims to evaluate the geotechnical properties of soils in Lokoja, Nigeria, to provide insights into their suitability for foundation engineering. The specific objectives are:

(i) To determine the classification and index properties of soils in Lokoja.
(ii) To assess the compaction characteristics and shear strength parameters.
(iii) To analyze the bearing capacity and settlement potential of the soils.
(iv) To correlate geotechnical properties with geological formations in the study area.
(v) To recommend foundation design strategies based on the soil characteristics.

By addressing these objectives, this research will contribute to the knowledge base on geotechnical engineering in Nigeria and aid in mitigating foundation-related failures in Lokoja and similar geologic settings.

2.1 Geological Setting

The study location is located in Crusher, Lokoja, Kogi State, which is in the Precambrian Basement Complex in north-central Nigeria. The Niger and Benue Rivers, respectively, split the region's noticeably undulating topography (Odunuga et al. 2015). In Lokoja, there are two distinct seasons: the rainy season, which lasts from May to September and is characterized by heavy rainfall in August and September, and the lengthy dry season, which lasts from October to April annually. Iwena (2012) asserts that the region falls under the category of a Basement Complex, characterized by significant compositional variability. This variation results from the different pressure-temperature (P-T) conditions encountered during metamorphic processes as well as the varied nature of the antecedent rocks (protoliths), which are classified as igneous, psammitic, or pelitic. The three main types of rocks found in the research region are gneisses, granitic rocks, and migmatites. The granitic group consists of porphyritic granites, medium-grained types, and aplites that are identified by textural and mineralogical traits. According to Obaje (2009), magmatites are complex mixtures of light and dark-colored crystals that originate from both granitic and non-granitic rocks through metamorphism.

2.0 Materials and Methods

This investigation used geological mapping to characterize the stable and unstable parts of the site and to determine the lithological units. Soil sample points were built and distributed to cover the perimeter and other important sections of the research site. Seven soil samples were collected in a methodical manner over the research area. These samples were taken between 0.5 and 1.5 meters below the surface. A GPS device was used to meticulously record the height and coordinates of each sampling location. Following the proper labeling of the samples, they were packed in polyethylene bags and sent to the laboratory for analysis. The moisture content was ascertained as soon as they arrived. For seven days, the samples were left to air dry in the laboratory. Any clumps that remained were then carefully torn apart. After that, a series of experiments were run to assess the soil's engineering and index qualities. These tests included grain size distribution, specific gravity, linear shrinkage, consistency limitations, and specific gravity. Furthermore, the California Bearing Ratio (CBR) and other engineering parameters were ascertained. While certain tests followed the guidelines in British Standard Methods for Civil Engineering Purposes (BS 1377, 1990) and ASTM Standard D1557 (2009), the Atterberg limits tests were conducted in accordance with ASTM D (2017) standards.

3.0 Results and Discussion

The following are the geotechnical analysis data obtained; Grain Size Analysis, Compaction and moisture content, California Bearing Ratio and Atterberg Limit.

3.1 Granulometric Analysis Result

The granulometric analysis of the soil samples reveals significant differences between the unstable and stable portions of the study area. The unstable portions, represented by samples SAM 1 to SAM 5, exhibit a higher percentage of fine particles compared to the stable portions, SAM 6 and SAM 7. The weight percentage of coarse particles passing through the 10mm, 5mm, and 2.5mm sieve sizes remains high across all samples, indicating that the soils contain substantial amounts of gravel and sand. However, at the 2.5mm sieve, the stable portions show a noticeable reduction in particle retention, with values of 88% and 86%, whereas the unstable portions maintain a higher percentage averaging 98% (Table 1).

As the sieve size decreases, the difference between the two soil types becomes more pronounced. In the intermediate fractions at 1.25mm and 0.6mm, the unstable portions retain higher percentages of passing particles, ranging from 84% to 93% at 1.25mm and 72% to 78% at 0.6mm. In contrast, the stable portions show significantly lower percentages, with only 45%–48% passing at 1.25mm and 18%–20% at 0.6mm. This suggests that stable soils have a coarser structure with fewer fines, making them less prone to moisture retention and associated instability (Table 1).

The presence of fine particles becomes even more evident in the 0.3mm and 0.15mm sieve fractions, where the unstable portions continue to retain higher proportions of fines. The percentage passing through the 0.3mm sieve ranges from 37% to 49% in unstable portions, while the stable portions exhibit much lower values of 6% and 5%. Similarly, at the 0.15mm sieve, the unstable samples retain 15%–22%, whereas the stable portions contain only 1%–3% (Table 1). This high fine content in unstable portions contributes to their lower bearing capacity and increased susceptibility to structural failures. The percentage passing the smallest sieve confirms this trend, with unstable portions showing traces of extremely fine particles (1%–2%), while the stable portions have none.

These findings suggest that the unstable portions contain a significant proportion of silt and clay, which affects soil stability by increasing water retention and reducing load-bearing capacity. The plasticity index of these soils indicates a high potential for expansion and contraction, which can lead to foundation instability. In contrast, the stable portions exhibit a coarser texture with better drainage properties, making them more suitable for construction. The high California Bearing Ratio (CBR) values recorded for the stable portions further confirm their superior bearing capacity. Given the moisture susceptibility of the unstable portions, structures built in these areas require soil stabilization techniques such as compaction, chemical treatment, or deep foundations to mitigate the risks of settlement and failure. The findings underscore the necessity of detailed geotechnical investigations before construction in order to ensure appropriate foundation design and soil improvement measures (Table 1).

Fig. 1 presents the granulometric analysis plot, which illustrates the relationship between the percentage passing and the sieve sizes on a semi-logarithmic scale. The distribution curves provide insight into the gradation characteristics of the soil samples, highlighting differences in particle size composition between the stable and unstable portions. The plotted curves exhibit a steep slope, indicating a relatively uniform grain size distribution among the samples. The transition from coarser to finer particles occurs within a narrow range, suggesting that the soil contains a significant proportion of sand and finer particles.

Table 1: summary of the Sieve analysis result for the seven samples

Sample ID	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**	**% Wt. Passing**
Sample Name	**SAM 1 (unstable portion)**	**SAM 2 (unstable portion)**	**SAM 3 (unstable portion)**	**SAM 4 (unstable portion)**	**SAM 5 (unstable portion)**	**SAM 6 (stable portion)**	**SAM 7 (stable portion)**
10mm	100	100	100	100	100	100	100
5mm	100	100	100	100	100	96	97
2.5mm	98	99	96	98	99	88	86
1.25mm	84	90	91	93	90	45	48
0.6mm	73	72	75	77	78	20	18
0.3mm	49	41	46	37	49	6	5
0.15mm	22	18	20	15	18	1	3
passing	1	2	0	0	0	0	0
Σ	100	100	100	100	100	100	100

Variations in the curves suggest differences in stability, as the unstable portions show a higher percentage of finer particles compared to the stable portions. This observation aligns with the data presented in Table 1, where unstable samples retained a greater proportion of fines at sieve sizes below 1.25 mm.

The grain size distribution curves further provide an understanding of the engineering behavior of the soils. Soils with a higher fraction of fine particles generally have lower permeability, higher plasticity, and increased susceptibility to swelling and shrinkage, which may compromise structural stability. Conversely, well-graded soils with a more balanced mix of coarse and fine particles exhibit better compaction properties and improved load-bearing capacity. The steep slopes observed in the curves suggest that the soils may be poorly graded, with limited variation in particle sizes, potentially requiring stabilization for construction purposes.

Also, the positioning and spread of the curves indicate differences in soil texture between the stable and unstable portions. The curves corresponding to the unstable portions extend further toward the finer fraction, reinforcing the conclusion that they contain a higher clay and silt content. In contrast, the curves associated with the stable portions terminate more rapidly, reflecting a dominance of coarser grains that contribute to improved stability. This confirms the earlier interpretation that the unstable portions may require soil improvement strategies to enhance their structural performance (Fig. 1).

The plotted grain size analysis of the soil samples taken at seven different locations at a depth of 1.5 meters is displayed in the above chart. Plotting the sieve sizes (phi values) versus the cumulative weight % was done. More than 50% of the grain sizes in samples 1 through 5 (the unstable portion of the research regions) are less than 0.3 mm in diameter, suggesting the presence of silt and clay. In contrast, samples 6 and 7 demonstrate that 80% of the grain sizes are less than 0.6 mm in diameter. Grain distributions were even, making them appropriate for use in civil engineering projects.

3.2 Geological Characterization of the Study Area

The study area is characterized by two predominant rock types: porphyroblastic gneiss and migmatite, as identified through geological mapping. These rock formations consist largely of mafic minerals, which undergo weathering to form a clay-rich topsoil. This clayey topsoil significantly influences the geotechnical properties of the subsoil, which in turn affects foundation stability.

The crystalline basement complex terrain in the study region is known for its heterogeneous nature, often leading to variable engineering properties of the underlying soil.

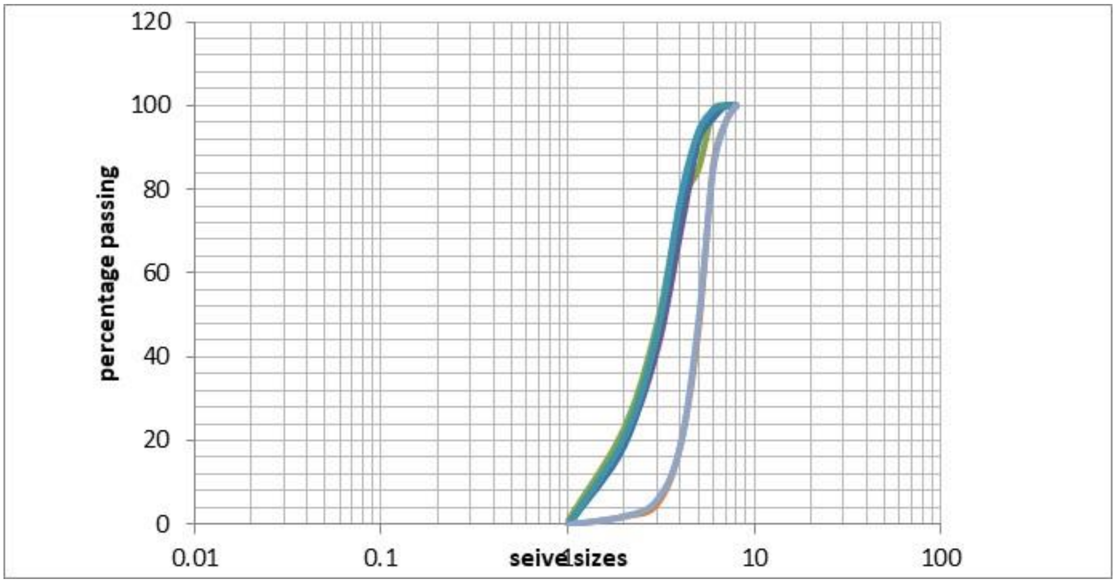

Fig. 1: Granulometric analysis plot showing plotted percentage passing against sieve sizes

3.3 Geotechnical Properties of Soil Samples

To assess the foundational integrity of the soil, various geotechnical tests were conducted, including moisture content determination, grain size analysis, Atterberg limits, and linear shrinkage tests.

3.3.1 Optimal Moisture Content (OMC)

The optimal moisture content (OMC) of the soil samples ranged from 10.5% to 12.2% (Table 2).

Table 2: Optimal Moisture Content (OMC) of Soil Samples

Sample ID	Depth (m)	OMC (%)
S1	1.5	10.5
S2	1.5	11.3
S3	1.5	12.2

According to Jegede (2000), this range suggests that the soil at a depth of 1.5 m is naturally medium compacted but may become highly susceptible to excessive rainfall. The OMC is influenced by rainfall amount, sampling depth, and soil texture. This indicates that in periods of heavy rain, the soil may experience excessive moisture retention, leading to foundation instability.

3.3.2 Grain Size Distribution

The results of grain size analysis showed that the percentage of finer particles passing through the sieve ranged from 70.9% to 75.5% (Table 3), with an average value of 72.76%.

Table 3: Grain Size Analysis

Sample ID	% Finer Passing
S1	70.9
S2	74.3
S3	75.5
Average	**72.76**

This indicates a poorly graded soil with a significant proportion of fine particles, primarily clay and minor amounts of silt. The presence of high clay content can contribute to shrink-swell behavior, making it less suitable as a foundation material.

3.3.3 Atterberg Limits and Plasticity Index

The Atterberg limits, including the liquid limit, plastic limit, and plasticity index (PI), were evaluated to determine the soil's engineering properties. The calculated average PI for the samples was 10.4% (Table 4). Barbosa *et al*., (2023) suggested that soil with a PI within 20% can be classified as poor to fair for foundation use.

Table 4: Atterberg Limits and Plasticity Index

Sample ID	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
S1	35.1	25.0	10.1
S2	34.8	24.3	10.5
S3	35.3	24.6	10.7
Average	**35.06**	**24.63**	**10.4**

This classification implies that while the soil has some plasticity, it is not highly expansive but still may pose challenges for shallow foundation applications.

3.3.4 Linear Shrinkage

The linear shrinkage (LS) values ranged from 1.81% to 5.75%, with an average of 3.65% (Table 5).

Table 5: Linear Shrinkage Values

Sample ID	Linear Shrinkage (%)
S1	1.81
S2	3.39
S3	5.75
Average	**3.65**

The presence of high clay content, which is characteristic of the topsoil in the study area, contributes to increased shrinkage potential, affecting foundation stability. Compared to the Federal Ministry of Works and Housing (1972) standards, which recommend a minimum of 8% LS for a good foundation material, the obtained values indicate that the soil does not meet the required criteria for structural stability.

3.4 Implications for Structural Stability

The geotechnical properties evaluated from the soil samples indicate that the subsoil in the study area exhibits poor engineering characteristics for foundation purposes. The high percentage of fine-grained material, low plasticity index, and inadequate linear shrinkage values suggest that the soil has a high potential for expansion and contraction. This contributes to foundation instability and the observed cracking in structures.

Furthermore, compared to the Federal Ministry of Works and Housing (1972) recommendations, the evaluated soil parameters exceeded the acceptable limits for foundation materials, particularly in terms of percentage finer grain size, liquid limit, plastic limit, and plasticity index. The standard limits for good foundation material are 35% maximum finer grain size, 50% liquid limit, 30% plastic limit, and a plasticity index of no more than 20%. The observed values indicate that the subsoil fails to meet these engineering criteria, justifying the observed foundation failures.

3.5 Comparison with Previous Studies

The findings of this study align with those of Jegede (2000), who identified similar geotechnical deficiencies in crystalline basement complex terrains. The study confirms that the presence of clay-rich soil layers significantly impacts foundation stability. Additionally, Olaniyan et al. (2018) found that migmatite-derived soils exhibit high plasticity and low strength, leading to frequent structural failures in affected areas. Given the geotechnical constraints, the following recommendations are proposed to mitigate foundation failures in the study area:

- **Deep Foundations:** The use of deep foundations, such as piles, can help bypass the weak clayey topsoil and anchor structures to more competent subsoil layers.
- **Soil Stabilization:** Chemical stabilization using lime or cement can

improve soil strength and reduce shrink-swell potential.

- **Proper Drainage Systems:** To minimize moisture fluctuation and prevent excessive soil swelling, proper drainage systems should be implemented.
- **Geosynthetics Reinforcement:** The use of geotextiles and geogrids can enhance the mechanical properties of the soil and provide additional stability.

The results of this study highlight the poor geotechnical properties of the subsoil in the study area, which contribute to structural instability. The high clay content, poor grading, and low shrinkage values indicate that the soil is unsuitable for shallow foundations without proper stabilization measures. To ensure long-term structural integrity, appropriate engineering solutions, such as deep foundations and soil stabilization, should be adopted.

4.0 Conclusion

The study investigated the geotechnical properties of subsoil materials in a crystalline basement complex terrain to determine their suitability as foundation materials. Geological mapping identified porphyrolastic gneiss and migmatite as the dominant rock types, with weathering producing a clay-rich topsoil. Geotechnical analysis revealed that the optimal moisture content ranged from 10.5% to 12.2%, indicating that the soil is naturally medium compacted but susceptible to instability under heavy rainfall. Grain size analysis showed that the percentage of finer particles passing through the sieve ranged from 70.9% to 75.5%, confirming a significant clay content. The plasticity index had an average value of 10.4%, suggesting poor to fair engineering properties, while linear shrinkage values varied between 1.81% and 5.75%. The findings further showed that the evaluated parameters exceeded the Federal Ministry of Works and Housing standards, reinforcing the conclusion that the soil is relatively weak as a foundation material. The study concluded that the subsoil in the study area exhibits high porosity, low permeability, and low resistivity, which are characteristics of clayey formations with poor load-bearing capacity. These unfavorable geotechnical properties are the primary reasons for the structural cracks observed in buildings across the region. The results confirmed that the subsoil lacks the necessary strength and stability to support structures effectively, making it unsuitable for shallow foundations.

To mitigate the challenges posed by the weak subsoil, proper foundation design modifications should be adopted. Engineering interventions such as soil stabilization, deep foundations, and drainage control should be considered to enhance soil strength and reduce moisture-related instabilities. It is recommended that construction projects in the area be preceded by detailed geotechnical investigations to determine the appropriate foundation type for long-term structural integrity. Further studies should focus on advanced soil treatment techniques and their effectiveness in improving the engineering properties of clayey soils in basement complex terrains.

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Compliance with Ethical Standards Declaration

Ethical Approval

Not Applicable

Competing interests

The authors declare that they have no known competing financial interests

Funding

The authors declared no external source of funding

Author's Contributions

All the authors were involved in the fieldwork, writing of the manuscript, editing and corrections