

Research Article

Geotechnical Assessment of Lateritic Soil for Subgrade and Sub-Base Applications in Road Construction: A Case Study from Akwa Ibom State, Nigeria

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Abstract

This study evaluates the geotechnical properties of lateritic soil from borrow pits in Ekit Itam II, Afia Nsit Atai II, and Ikot Ekpuk villages in Itu, Nsit Ibom, and Oruk Anam Local Government Areas, Akwa Ibom State, Nigeria, to assess its suitability for subgrade and sub-base applications in road construction. Laboratory tests, conducted in accordance with the Federal Ministry of Power, Works and Housing specifications, included particle size distribution, Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR). The results demonstrate that the soils meet the required standards for road foundation layers. Specifically, the liquid limits were 28%, 34%, and 28%, with plastic limits of 17%, 21%, and 16%, and plasticity indices of 11%, 13%, and 12% for samples L1, L2, and L3, respectively. The maximum dry densities ranged from 1.97 g/cm³ to 2.03 g/cm³, with optimum moisture contents of 8%, 9.89%, and 10.02%. CBR values for sub-base applications were 38.50%, 33.30%, and 65.40% (24-hour half-soaked) and for subgrade were 21.60%, 15%, and 40.60% (48-hour fully soaked). Particle size analysis revealed D₁₀ values of 0.08-0.09 mm, D₃₀ of 0.18-0.25 mm, and D₆₀ of 0.30-0.45 mm, with coefficients of uniformity (C_u) of 3.33-5.63 and curvature (C_c) of 1.00-1.74, indicating poorly graded clayey sand (SC) soils under the Unified Soil Classification System (USCS) and A-2-6 under the AASHTO classification. These properties confirm the lateritic soil's suitability for use as subgrade and sub-base materials, supporting sustainable road infrastructure development in Akwa Ibom State. The findings underscore the importance of thorough geotechnical assessments to ensure the quality and durability of pavement materials, contributing to improved regional connectivity and economic growth. Recommendations include ongoing research to characterize soil variability across borrow pits to guide material selection for construction projects.

Keywords

Lateritic Soil, Subgrade, Sub-base, Geotechnical Properties, Road Construction, Akwa Ibom, Nigeria

1. Introduction

It is necessary to have sufficient knowledge of the subsurface conditions and engineering characteristics of the earth material in order to construct the foundations of the majority of engineering structures [1, 9]. This is required so

that sound geotechnical characteristics can be used in the engineering planning, design, and building of such foundations [13]. Earth materials are usually understood to be the naturally occurring substances that are found on Earth and

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serve as the foundation for our global society. Minerals, rocks, soil, water, and metals are examples of earth materials [15].

The primary earth components utilized for the lower levels of road pavements are engineering soils. This study is particularly interested in them [11]. The main component of the foundation, subgrade, and even the further pavement layers is soil [6]. It is impossible to predict the engineering behavior and performance of soils used as subgrade and sub-base materials under natural consistency in time and space because they are typically heterogeneous and frequently anisotropic aggregates of mineral grains that vary greatly in composition and gradation [2]. In addition to other considerations like traffic stress, adequate earthwork, protection from floods and wave erosion, surface and subsurface drainage systems, cross drainage, etc., highway design has acknowledged the dependence of subgrade strength on the site's geology, which affects the pavement. According to [8], the most crucial elements in the structural design of pavements, whether they are rigid or flexible, are subgrade strength and traffic load.

Akwa Ibom State, located in the Niger Delta sedimentary basin, is characterized by lateritic soils formed through the long-term weathering of underlying rocks. Nigeria's geology comprises crystalline basement rocks and sedimentary basins, with the Niger Delta basin being one of the most prominent [16]. In this region, lateritic soils are commonly used in civil engineering due to their favorable mechanical properties when properly prepared. However, road construction in Akwa Ibom State faces region-specific challenges, including high annual rainfall exceeding 2,000 mm, frequent flooding, and erosion hazards exacerbated by climate change, which lead to soil moisture variations, increased pore water pressure, reduced shear strength, and seepage-induced failures in pavements [3]. These climatic effects, combined with poor drainage and soil instability in flood-prone areas, contribute to rapid road deterioration and necessitate robust geotechnical assessments to mitigate risks [15]. Consequently, the growing demand for social and economic development is reflected in Nigeria's rapid road infrastructure expansion, particularly in Akwa Ibom State. To enhance regional connectivity, extensive road networks have been developed in the Itu, Nsit Ibom, Oruk Anam, and Ukanafun Local Government Areas.

Historically, pavement failures have often been attributed to inadequate subgrade preparation rather than surface defects [12]. This highlights the critical role of geotechnical investigations in road construction. For instance, [5] examined geotechnical characteristics of specific sub-base materials used in road construction, collecting samples from three sites and analyzing them in the laboratory. The soils were classified as fair to poor based on index properties, with CBR values ranging from 5% to 12%, indicating unsuitability as sub-base materials. The study concluded that low material quality was a primary cause of observed pavement failures. Similarly, [2] conducted a comprehensive assessment of subgrades and sub-base materials, revealing spatial variability

in residual soil properties and emphasizing the need for regular laboratory testing for quality control. Building on these, the present study differs by focusing on lateritic soils from specific borrow pits in Akwa Ibom State, incorporating both half-soaked and fully soaked CBR tests to simulate regional moisture conditions, unlike [5] which emphasized index properties without extensive soaking simulations. It also extends [2] by linking findings to local climate challenges, providing a more targeted evaluation for Niger Delta environments. Additional studies, such as [16] on tropical red soils in deltaic settings and [17] on lateritic soils in the western Niger Delta, report similar variability in geotechnical properties due to weathering, but this work uniquely assesses soils from active borrow pits used in ongoing projects like the Udo Ebong street, internal roads in Afia Nsit Atai, and the Ikot Ibritam-Ikot Ekeffe-Ikot Akpan Afaha road.

Soil samples from borrow pits used for pavement construction in the study areas were analyzed to determine their suitability for various pavement layers. The primary objective is to inform construction contractors about the variability of soil properties across the state and emphasize the need for comprehensive testing of soil strength parameters before use in pavements. This will aid stakeholders within and beyond Akwa Ibom State in selecting earthwork materials judiciously for pavement construction. The soil samples were subjected to laboratory tests including particle size distribution, Atterberg limits, compaction using British Standard Light (BSL) and British Standard Heavy (BSH) compactive efforts, and California Bearing Ratio (CBR) tests to characterize and evaluate the soils.

2. Materials and Methods

Three disturbed lateritic soil samples (designated L1, L2, and L3) were collected from borrow pits in Ekit Itam II, Afia Nsit Atai II, and Ikot Ekpuk villages, respectively. Samples were taken from one pit per site after removing the topsoil to a depth of 250-300 mm, with triplicate subsamples tested for each property to ensure reliability. All sample preparation and testing procedures adhered to BS 1377 Parts 1, 2, and 4 (1990). Soils were classified using the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) system. Tests performed included sieve analysis for particle size distribution, consistency (Atterberg) limits, compaction, and CBR.

For sieve analysis, air-dried samples were passed through a set of British Standard sieves (ranging from 75 μm to 2 mm) mounted on a mechanical shaker for 10-15 minutes to determine gradation (Figure 1). Atterberg limits were determined using the Casagrande apparatus for liquid limit (LL) via the fall cone method and thread rolling for plastic limit (PL), with plasticity index (PI) calculated as LL minus PL (Figure 2). Compaction tests employed standard Proctor

molds (1000 cm³ volume) and a 2.5 kg rammer for BSL effort (27 blows per layer) and a 4.5 kg rammer for BSH effort (62 blows per layer), measuring maximum dry density (MDD) and optimum moisture content (OMC). CBR tests used a CBR mold (150 mm diameter) and a loading machine with a penetration piston, applying loads at 1.25 mm/min after 24-hour half-soaking for sub-base simulation and 48-hour full soaking for subgrade, in accordance with Federal Ministry of Works and Housing (2016) specifications (Figure 3). All equipment was calibrated prior to testing, and tests were conducted at room temperature (25-28 °C).



Figure 1. Set of British Standard sieves mounted on a mechanical shaker for particle size distribution analysis.



Figure 2. Casagrande apparatus setup for Atterberg limit testing, showing the liquid limit determination.



Figure 3. California Bearing Ratio (CBR) testing machine with loading frame and penetration piston.

3. Results, Discussion, and Conclusions

The following presents results from tests on lateritic soil samples L1 (Ekit Itam II), L2 (Afia Nsit Atai II), and L3 (Ikot Ekpuk).

The results collected are summarized in Table 1.

Table 1. Summary of Index properties of the soil samples.

Property	L1	L2	L3
Liquid limit (%)	28.00	34.00	28.00
Plastic limit (%)	17.00	21.00	16.00
Plasticity Index (%)	11.00	13.00	12.00
Coefficient of uniformity (Cu).	3.33	5.25	5.63
Coefficient of curvature (Cc).	1.48	1.00	1.74
D10	0.09	0.08	0.08
D30	0.20	0.18	0.25
D60	0.30	0.42	0.45
Maximum dry density (g/cm ³)	2.00	2.02	1.97
Optimum moisture content (%)	8.11	9.89	10.02
C.B.R. Value (%) (24 hrs half-soaked).	38.50	33.30	65.40
C.B.R. Value (%) (48 hrs fully soaked).	21.60	15.00	40.60

Property	L1	L2	L3
Unified Soil Classification System (USCS).	SC	SC	SC
American Association of State Highway and Transportation Officials (AASHTO) classification	A-2-6	A-2-6	A-2-6

The results indicate that the soils from Ekit Itam II, Afia Nsit Atai II, and Ikot Ekpuk likely originated from similar weathering processes.

3.1. Particle Size Distribution Test Results and Analysis

The test facilitated soil classification. No gravel was observed at any site. Sand particles constituted up to 90% of all samples. Under USCS, the soils classify as SC (clayey sand), reflecting a mix of sand and clay. Per AASHTO, they are A-2-6. C_u values were 3.33 (L1), 5.25 (L2), and 5.63 (L3); C_c values were 1.48, 1.00, and 1.74, indicating poorly graded soils with non-uniform particle distribution (Figures 4-6). Compared to other regional studies, these C_u values are lower than those reported for lateritic soils over quartz schist in southwestern Nigeria (C_u up to 10), suggesting less gradation variability but similar poor grading due to weathering. In the Niger Delta, [14] noted comparable sand dominance in coastal laterites, but this study's soils show higher clay content, enhancing cohesion for sub-base use.

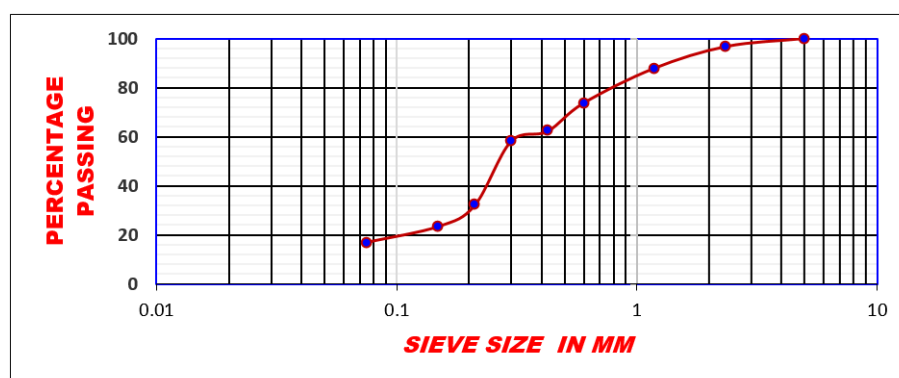


Figure 4. Particle size distribution curve for soil sample L1, showing poorly graded characteristics.

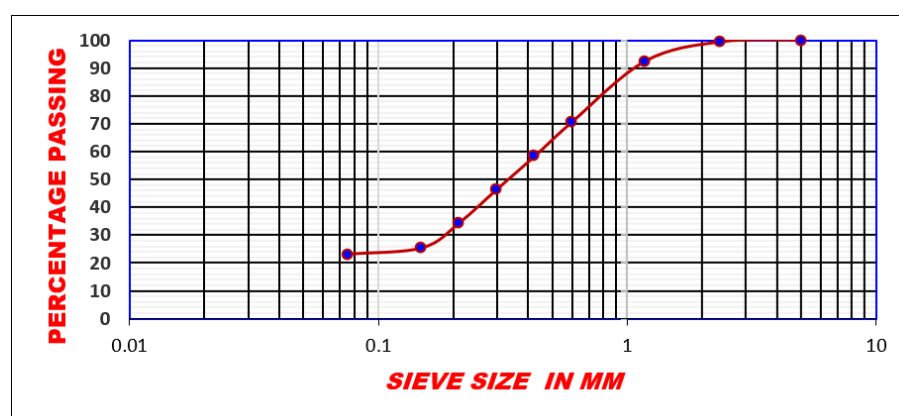


Figure 5. Particle size distribution curve for soil sample L2, showing poorly graded characteristics.

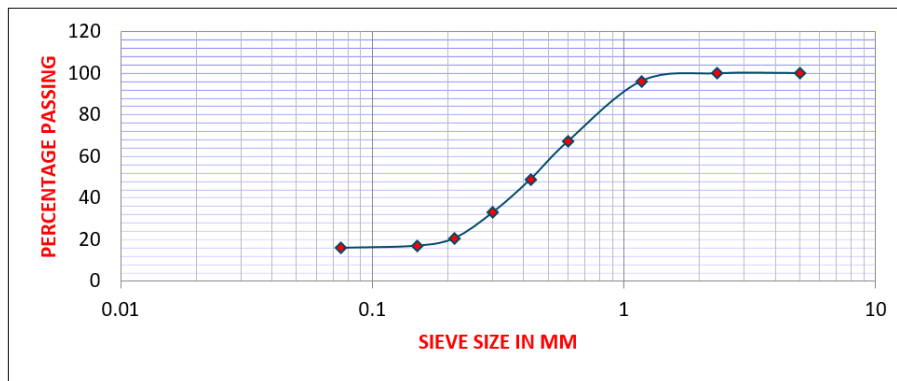


Figure 6. Particle size distribution curve for soil sample L3, showing poorly graded characteristics.

3.2. Atterberg Limits Test Results and Analysis

The soils exhibit medium plasticity, with PI averaging 11-13% and LL 28-34%. These meet Federal Ministry of Works and Housing standards ($LL \leq 30\%$, $PI \geq 10\%$ for sub-base/subgrade). Figures 7-9 display liquid limit curves.

Relative to [6] on southeastern Nigerian laterites (PI 10-20%), these values indicate moderate swell potential, suitable for regions with moisture fluctuations but requiring drainage to prevent expansion. Unlike [10] in southwestern Nigeria (higher PI in failed sections), these soils' lower PI suggests better stability under Akwa Ibom State's wet climate.

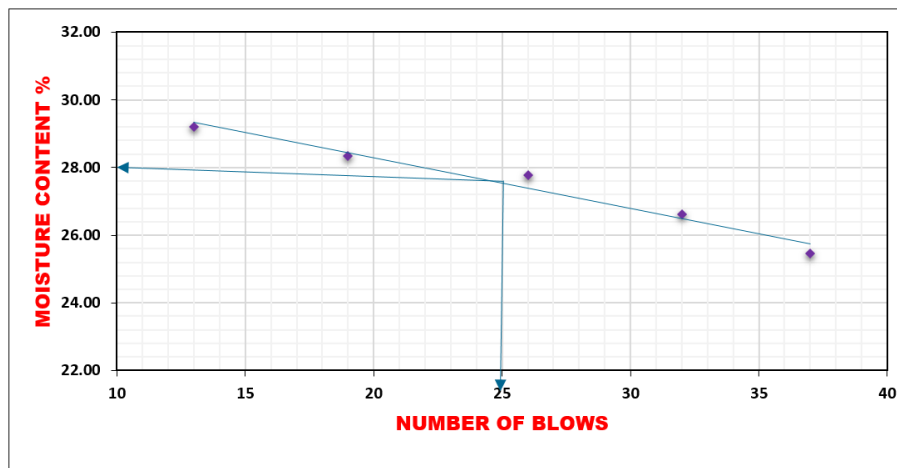


Figure 7. Liquid limit curve for soil sample L1.

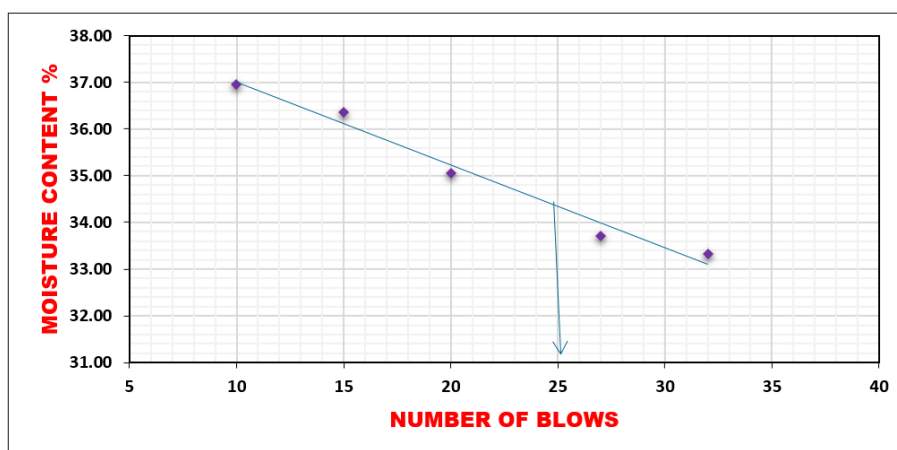


Figure 8. Liquid limit curve for soil sample L2.

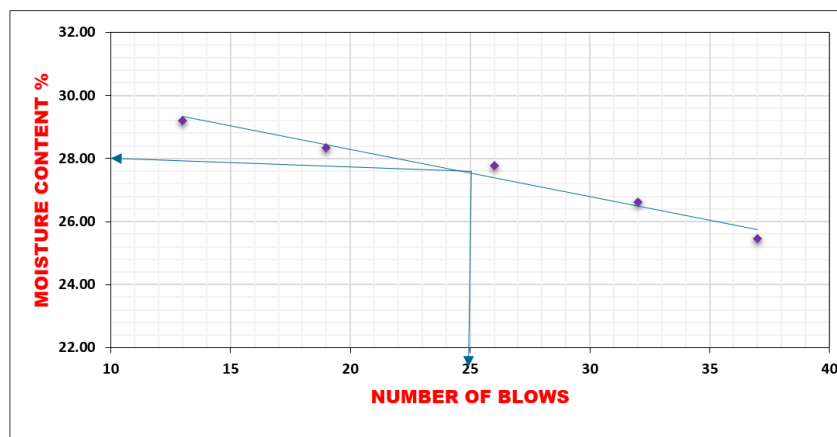


Figure 9. Liquid limit curve for soil sample L3.

3.3. Compaction Test Results and Analysis

Compaction increases dry unit weight, enhancing shear strength and reducing permeability/settlement. MDD values were 2.00 g/cm^3 (L1), 2.02 g/cm^3 (L2), and 1.97 g/cm^3 (L3); OMC were 8.11%, 9.89%, and 10.02% (Figures 10-12). L2 shows superior compaction. These align with [15] on

Nigerian laterites (MDD 1.8-2.1 g/cm^3), but higher MDD here indicates denser packing suitable for heavy traffic. In comparison to [4] on southwestern soils, the OMC is lower, reflecting less water sensitivity in Akwa Ibom's humid environment.

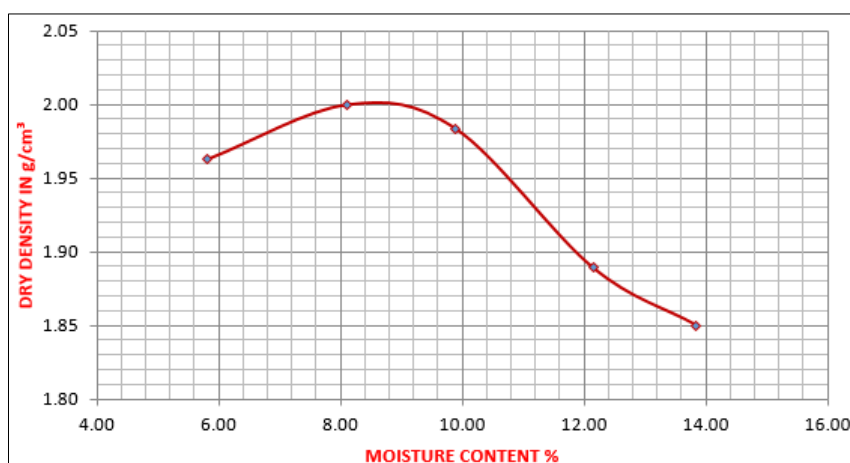


Figure 10. Compaction curve for soil sample L1, showing MDD and OMC.

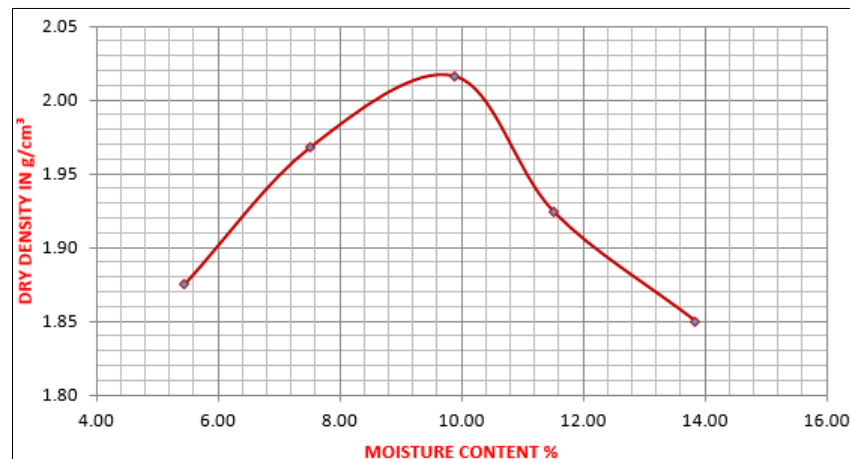


Figure 11. Compaction curve for soil sample L2, showing MDD and OMC.

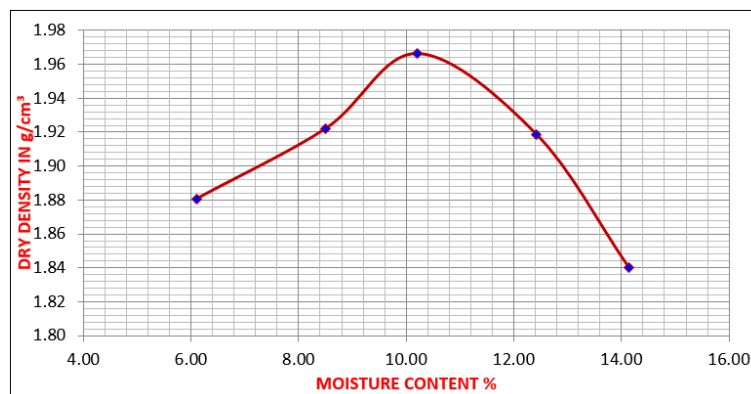


Figure 12. Compaction curve for soil sample L3, showing MDD and OMC.

3.4. California Bearing Ratio (CBR) Test Results and Analysis

CBR is effective for evaluating tropical lateritic soils in highway applications. Half-soaked CBR: 38.50% (L1), 33.30% (L2), 65.40% (L3); fully soaked: 21.60%, 15.00%, 40.60%. All exceed Federal Ministry standards ($\geq 30\%$ sub-base, $\geq 10\%$ subgrade). High values confirm load-bearing capacity

(Figures 13-15). Compared to [17] on Nigerian borrow pits (CBR 20-50%), L3's high CBR suits high-traffic highways, while L2's lower soaked value suggests low-traffic roads or stabilization. In Niger Delta contexts, [5] reported similar drops in soaked CBR due to moisture, linking to seepage failures; thus, these soils are ideal for sub-base in drained pavements but may require geotextiles for subgrades in flood-prone areas.

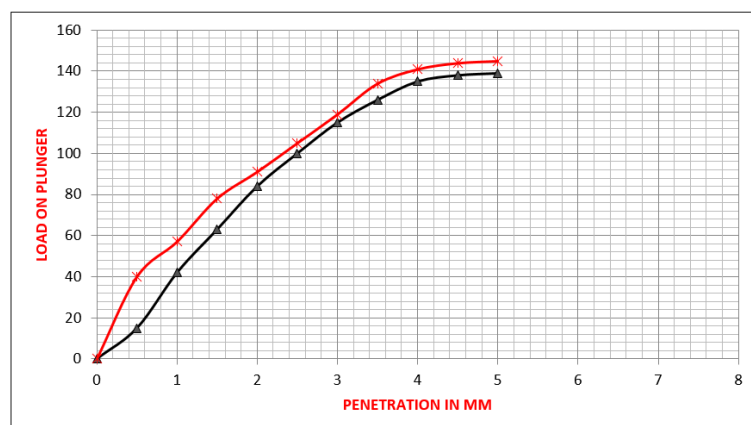
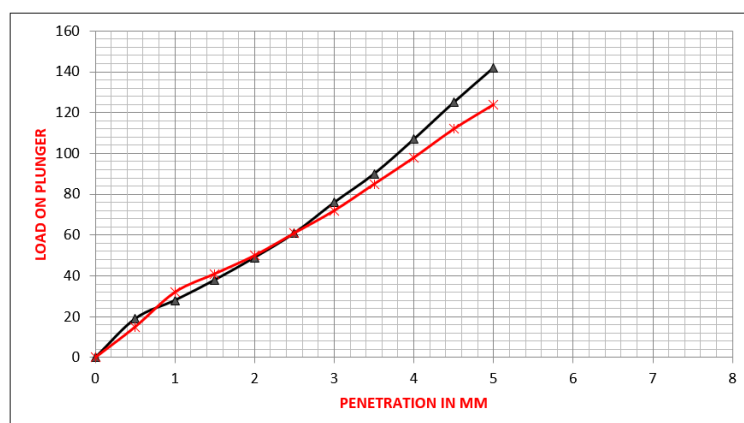
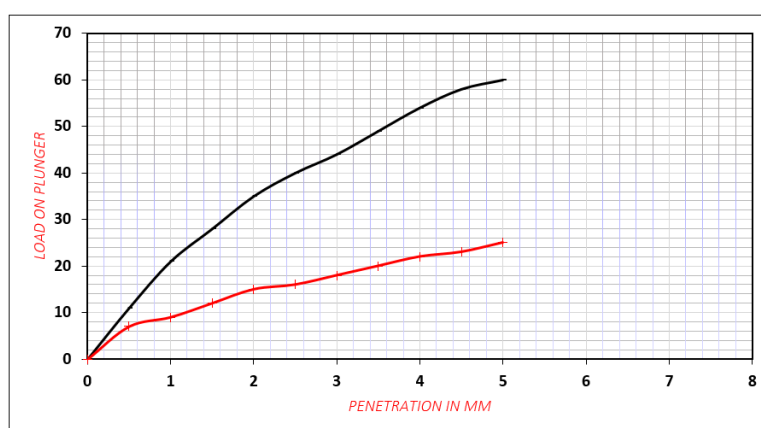


Figure 13. CBR penetration curve for sub-base soil sample L1 (half-soaked and fully soaked).**Figure 14.** CBR penetration curve for sub-base soil sample L2 (half-soaked and fully soaked).**Figure 15.** CBR penetration curve for sub-base soil sample L3 (half-soaked and fully soaked).

4. Conclusion

Geotechnical tests on three lateritic soil samples from Akwa Ibom State borrow pits provided valuable classification data. Particle size distribution showed 90% sand, classifying as SC (USCS) [17] and A-2-6 (AASHTO) [1], suitable for sub-base in low-traffic roads but not base courses. Atterberg limits (LL 28-34%, PI 11-13%) indicate moderate plasticity. MDD ranged 1.97-2.02 g/cm³, OMC 8.11-10.02%, with CBR exceeding standards (half-soaked 33.30-65.40%, fully soaked 15.00-40.60%). These confirm suitability for sub-base and subgrade per Federal Ministry of Works and Housing (2016) [7].

Expanding on these, practical recommendations for infrastructure planning in Akwa Ibom State include incorporating proper drainage systems to counter high rainfall and seepage, using stabilization additives (e.g., cement) for lower CBR soils in high-traffic areas, and conducting site-specific tests for all borrow pits to account for spatial

variability. Policymakers should mandate regular geotechnical audits and promote documentation of borrow pit data for statewide databases, facilitating sustainable development amid climate challenges. Further research on stabilization techniques and long-term performance monitoring is advised to enhance road longevity and economic growth.

Abbreviations

BSL	British Standard Light
BSH	British Standard Heavy
CBR	California Bearing Ratio
USCS	Unified Soil Classification System
AASHTO	American Association of State Highway and Transportation Officials
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
MDD	Maximum Dry Density

OMC Optimum Moisture Content

Author Contributions

Imoh Godwin Nwa is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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