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Investigation and Characterization of the Geotechnical Engineering Properties of Soil as Subgrade and Sub-Base Material for Sustainable Road Constructions in Akwa Ibom State, Nigeria

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Abstract**—** *This study evaluates the geotechnical properties of lateritic soils from two borrow pits in Akwa Ibom State, Nigeria; Ikot Ibritam (Oruk Anam LGA) and Ikot Akpan Afaha (Ukanafun LGA); to assess their suitability as subgrade and sub-base materials for road construction. Comprehensive field and laboratory investigations adhered to the Federal Ministry of Works and Housing (FMWH) General Specification (Roads and Bridges), 2016. Tests included particle size distribution, Atterberg limits, moisture-density relationships, and California Bearing Ratio (CBR). Results for Ikot Ibritam soil showed 15.96% passing the No. 200 sieve (75 µm), liquid limit (LL) of 28%, plastic limit (PL) of 18%, plasticity index (PI) of 10%, maximum dry density (MDD) of 1.97 g/cm³, optimum moisture content (OMC) of 10.20%, CBR (24-hour soak, sub-base) of 65.4%, and CBR (48-hour soak, subgrade) of 40.6%. For Ikot Akpan Afaha, results indicated 22.24% passing the No. 200 sieve, LL of 35%, PL of 25%, PI of 10%, MDD of 1.96 g/cm³, OMC of 9.85%, CBR (24-hour soak, sub-base) of 59.8%, and CBR (48-hour soak, subgrade) of 31.8%. Both soils classify as well-graded sand (SW) under the Unified Soil Classification System (USCS) and A-2-4 under the AASHTO system, meeting or exceeding FMWH standards for subgrade and sub-base applications. These findings confirm the soils' suitability for durable road infrastructure. Recommendations include mandatory geotechnical testing of borrow materials and exploration of stabilization techniques for marginal soils in flood-prone areas to enhance long-term road performance.*

Keywords**—** *Lateritic soil, Geotechnical properties, Sub-grade, Sub-base, Road construction, Akwa Ibom State.*

I. Introduction

1.1 Backgrounds

Robust road infrastructure is critical for economic and social development in Akwa Ibom State, Nigeria, a region pivotal to the Niger Delta's economic framework. As highlighted by [13], efficient road networks underpin regional connectivity and economic growth. However, road failures in Nigeria are frequently attributed to inadequate geotechnical characterization during the planning and design phases, resulting in premature structural deterioration [1 & 15].

Lateritic soils, prevalent in tropical regions like the Niger Delta, are widely used as subgrade and sub-base materials due to their abundance and favorable engineering properties [3 & 9]. These soils, formed through intense weathering, are rich in iron, aluminum, and manganese oxides, with engineering behavior influenced by mineral composition, weathering extent, and morphology [2 & 11]. In Akwa Ibom State, the region's weak bearing soils, compounded by frequent flooding and low bearing capacity, pose significant challenges to road durability [14].

This study investigates the geotechnical properties of lateritic soils from borrow pits in Ikot Ibritam (Oruk Anam LGA) and Ikot Akpan Afaha (Ukanafun LGA) to determine their suitability for sustainable road construction. The objectives are to: collect and analyze soil samples from selected borrow pits, conduct standardized laboratory tests to determine key geotechnical properties, classify the soils using USCS and AASHTO systems, and evaluate compliance with FMWH specifications for subgrade and sub-base applications.

II. Materials and Methods

2.1. Sampling

Soil samples were collected from two borrow pits in Akwa Ibom State: Ikot Ibritam (Oruk Anam LGA) and Ikot Akpan Afaha (Ukanafun LGA), key material sources for local road projects. Sampling followed the guidelines of the Federal Ministry of Works and Housing (2016) to ensure representativeness, with in-situ collection methods adapted from ASTM standards (ASTM D420).

2.2. Laboratory Tests

All tests complied with ASTM standards (ASTM D422, D4318, D698, D1883) and FMWH (2016) specifications.

2.2.1 Particle Size Analysis

Sieve analysis was conducted to determine gradation. A 500 g oven-dried sample was washed over a No. 200 sieve (75 µm) to separate fines, followed by dry sieving using a mechanical shaker (British Standard sieves). Percentages retained and passing were calculated to plot gradation curves.

2.2.2 Atterberg Limits

Consistency was assessed using the Casagrande apparatus. Soil passing the No. 40 sieve (425 µm) was mixed with water to form a paste. The liquid limit (LL) was determined by plotting the number of blows against moisture content, and the plastic limit (PL) was measured as the moisture content at

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which a 3 mm thread could be rolled without breaking. The plasticity index (PI) was calculated as LL - PL.

Fig.1: sample been washed under a running pipe

Fig.2: Set British Standard sieves on shaker

2.2.3 Compaction Test

Standard Proctor compaction (ASTM D698) was used to evaluate moisture-density relationships. A 6 kg sample was divided into portions, each mixed with increasing water volumes (100–300 ml increments). Samples were compacted in a mold using a 4.5 kg rammer (27 blows per layer, five layers). Maximum dry density (MDD) and optimum moisture content (OMC) were derived from the compaction curve using the following equations:

$$\% \text{ Moisture} = \frac{\text{Weight of moisture}}{\text{Weight of dry sample}} \times 100$$

$$\text{Dry Density} = \frac{\text{Wet Density x } 100}{\% \text{ Moisture Content} + 100}$$

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

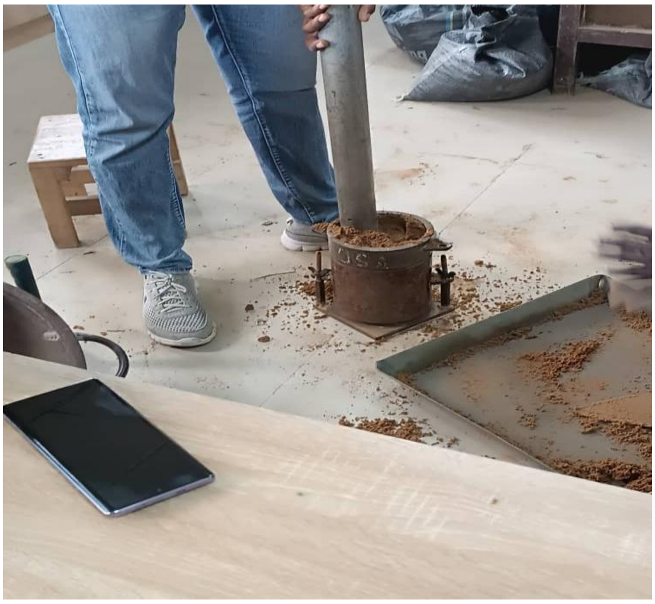

Fig. 4: Compaction test apparatus showing moisture density relationship determination.

2.2.4 California Bearing Ratio (CBR)

CBR tests (ASTM D1883) assessed load-bearing capacity. Compacted samples were subjected to 24-hour half-soaked conditions (sub-base) and 48-hour fully soaked conditions (subgrade). Penetration resistance was measured under a plunger at 2.5 mm and 5.0 mm, with CBR calculated as the higher value.

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Fig. 5: CBR test machine used in CBR test determination.

III. Results and Discussion

Table 1 summarizes the geotechnical properties of the soils from both sites.

3.1 Particle Size Analysis

Gradation curves indicate well-graded sands with fines below 35%, meeting FMWH Clause 6201 for drainage and stability. The Ikot Ibritam sample has lower fines (15.96%) than Ikot Akpan Afaha (22.24%), suggesting better drainage potential.

3.2 Atterberg Limits

Both soils exhibit low plasticity (PI = 10%), indicating minimal swelling or shrinkage potential, compliant with FMWH Clauses 6201 and 6252 (LL ≤ 35%, PI ≤ 12%). The higher LL of Ikot Akpan Afaha (35%) suggests slightly greater water retention compared to Ikot Ibritam (28%).

3.3 Compaction

Compaction tests yielded MDD values of 1.97 g/cm³ (Ikot Ibritam) and 1.96 g/cm³ (Ikot Akpan Afaha), with OMC values of 10.20% and 9.85%, respectively. These results indicate high compatibility, suitable for achieving stable road bases with moderate moisture content.

3.4 California Bearing Ratio

CBR values significantly exceed FMWH minimums (Clauses 6102, 6122, 6201), with Ikot Ibritam outperforming Ikot Akpan Afaha for both sub-base (65.4% vs. 59.8%) and subgrade (40.6% vs. 31.8%) applications. These values confirm excellent load-bearing capacity.

TABLE 1: Summary of Geotechnical Test Results

Parameter Tested	Specification Limits	Test Result – Sub Base/Subgrade IKOT IBRITAM	Test Result-Sub Base/Subgrade IKOT AKPAN AFAHA	Remarks
Percentage Passing Sieve 200u	Not Greater than 35%	15.96%	22.24%	Satisfactory
Liquid Limit	Not Greater than 35%	28%	35%	Satisfactory
Plastic Limit	Not Greater than 35%	18%	25%	Satisfactory
Plasticity index	Not Greater than 12%	10%	10%	Satisfactory
Maximum Dry Density		1.97g/cm³	1.96	Satisfactory
Optimum Moisture Content		10.20%	9.85%	Satisfactory
CBR after 24 hours for sub base	Not Less than 30%	65.4%	59.8%	Satisfactory
CBR after 48 hours for sub grade	Not Less than 10%	40.6%	31.8%	Satisfactory
AASHTO Soil Classification System		A-2-4	A-2-4	
USCS Soil Classification System		Well-graded sand (SW)	Well-graded sand (SW)	

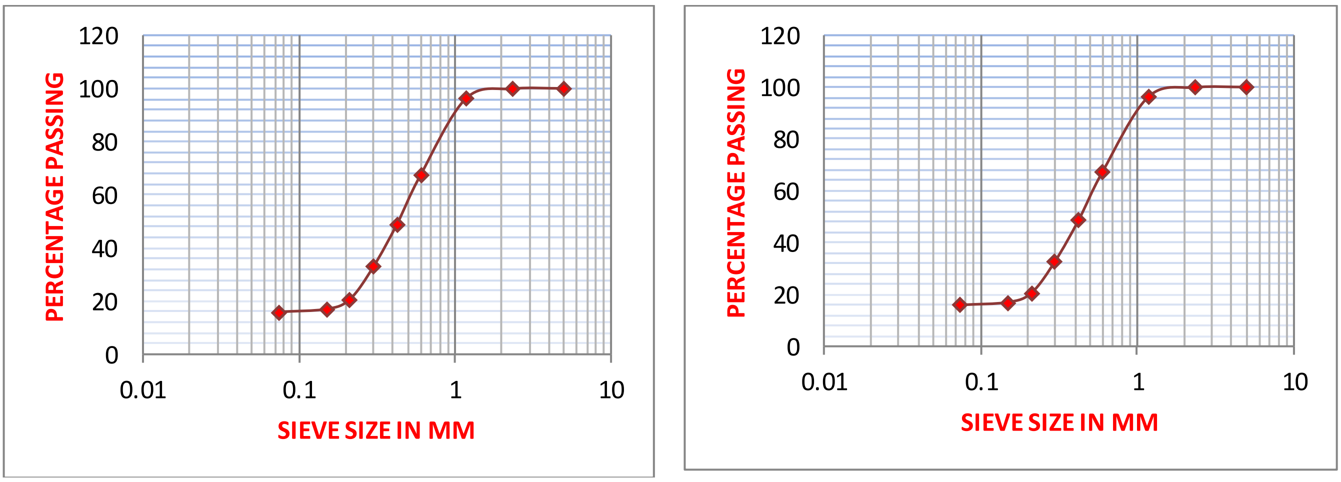

Fig. 6: Particle size distribution curves for both sites.

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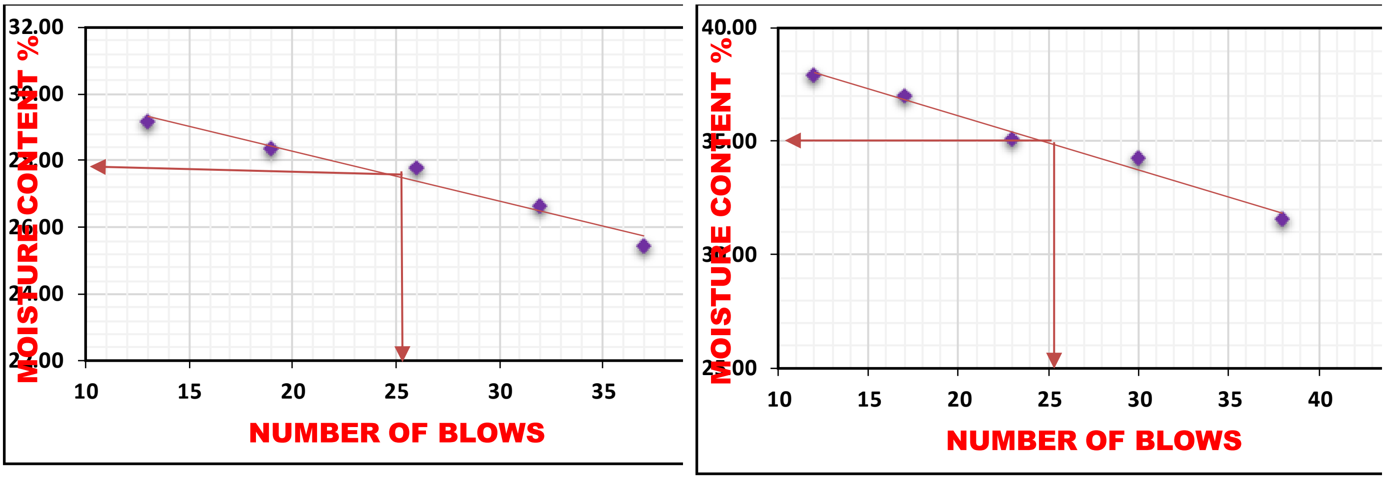

Fig. 7: Atterberg limits plots for both sites.

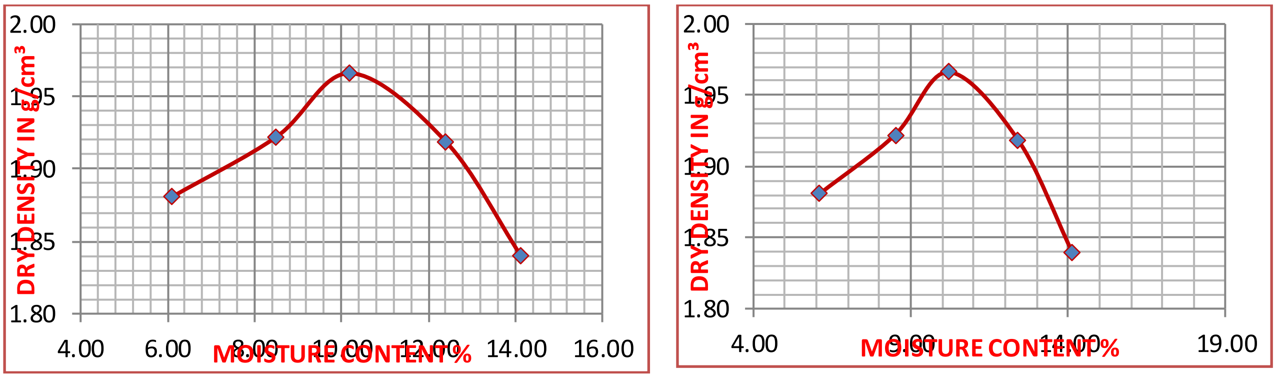

Fig. 8: Compaction curves for both sites.

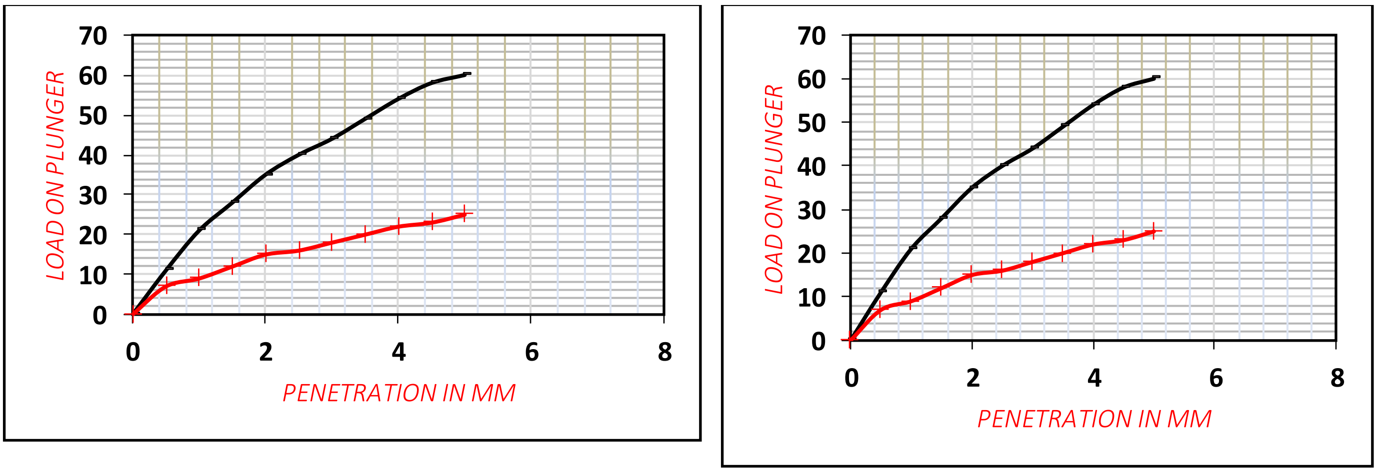

Fig. 9: CBR penetration curves for both sites.

Both soils classify as SW (USCS) and A-2-4 (AASHTO), rated good-excellent for road bases (AASHTO, 1982).

IV. Conclusion

The lateritic soils from Ikot Ibritam and Ikot Akpan Afaha demonstrate geotechnical properties that fully comply with FMWH standards for subgrade and sub-base materials. Their well-graded nature, low plasticity, high density, and superior CBR values ensure suitability for sustainable road construction in Akwa Ibom State. These properties mitigate risks of premature road failure, reducing long-term maintenance costs and enhancing infrastructure durability.

V. Recommendations

The following suggestions are made in light of the study's findings: to conduct mandatory geotechnical testing on all borrow materials prior to use to ensure compliance with specifications, adhere to engineering ethics and best practices during construction to optimize performance, explore

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stabilization techniques (e.g., cement or lime) for marginal soils in flood-prone areas to enhance durability.

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