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Assessment of Geotechnical Attributes of Laterites as Sub-base and Sub-Grade Materials in Parts of Northern Anambra Basin Nigeria: Implications for Road Pavement Construction.

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Abstract: *The suitability of quality sub-base and sub-grade material is crucial for the durability of roads, which in turn drives economic development. Therefore, in this study, we investigates the causes of road pavement failures in the Anyigba region, Nigeria, focusing on the geotechnical and geomorphological characteristics of laterite. The research area, located between 07°21'0" to 07°37'30"N and 07°20'0" to 07°33'0"E, is characterized by fluctuating climatic conditions and varying geomorphological features. Geotechnical sampling and rigorous laboratory analysis were conducted on laterite samples from various locations along the Ajaokuta–Anyigba and Akpa–Anyigba–Dekina roads. Key tests included moisture content, grain size distribution, Atterberg limits, compaction, and California Bearing Ratio (CBR).Results indicated that the laterite samples had moisture contents ranging from 11.4% to 15.9%, and grain size analysis showed sand content between 91.3% and 99.7%, with fines ranging from 0.3% to 8.7%. The Atterberg limits revealed liquid limits between 21.2% and 39.6%, plastic limits between 16.4% and 32.6%, and plasticity indices between 2.5% and 7.9%. Compaction tests showed Maximum Dry Density (MDD) values between 1964 kg/m³ and 2101 kg/m³, and Optimum Moisture Content (OMC) values between 10.7% and 12.4%. CBR tests indicated values from 26% to 66% for unsoaked materials and 13% to 61% for soaked materials. These findings suggest that the laterite in the study area possesses low moisture content and favorable grain size distribution for road construction, with low plasticity and moderate shrinkage resistance. The high MDD and suitable OMC values confirm the material's suitability for sub-base and subgrade applications. CBR values support the adequacy of laterite as a subgrade and sub-base material. This comprehensive analysis highlights the importance of pre-engineering investigations to prevent road failures and contributes to sustainable infrastructure development in the region*

Keywords:Northern *Anabra basin, Geotechnical attributes, laterites, sub-grade materials, Atterberg limit.*

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1.0 Introduction

Any nation's ability to transfer people and goods between areas is facilitated by a well-functioning road system, which is necessary for economic success. In developing nations, rail, water, and air transportation systems are typically underdeveloped. (Akudo *et al.*, 2024; Aderemi and Adeola, 2021). Any nation's roads are vital and significant national assets (Aghamelu, 2022). Although roads are essential for trade, economic growth, and transportation, Nigerian investment in high-quality roads is inadequate, which has shortened the roads' lifespan and increased the risk of failure, traffic accidents, and fatalities (Oluyinka and Olubunmi, 2018; Akudo et *al.*, 2023). Many reasons have been put forward for the cause of the road failures such as the nature of the subsurface geology, geomorphology, geotechnical, construction method and design (Babadiya and Igwe, 2021; Adiat *et al.*, 2017; Ojo *et al*., 2016; Akudo *et al*., 2022). Depth to the water table, presence of swelling clay, and presence of weak zones (Abija, 2023; Abija et *al.*, 2019; Akpah *et al*, 2009). Lack of subsurface information, no proper site investigation, corruption and lack of experienced contractors and engineers have led to road failures in Nigeria (Tijani and Abija, 2022; Akudo *et al.* 2024). According to Ehujuo *et al.* (2017), the underlying geologic formation and the laterite's unsuitability as a sub-base and sub-grade materials for filling are the reasons behind road failures in Okigwe, South Eastern Nigeria. In contrast, Babadiya and Igwe (2021) attribute the reasons behind road pavement failure in Abakaliki, southeast Nigeria, to incorrect laterite compaction. Laterite serves as a material that is both sub-base and sub-grade. In Southwestern Nigeria, the main reasons for road pavement collapse are the clayey nature of the pavement, the subgrade, and the poor geotechnical characteristics of the soils (Oyelami and Alimi, 2015; Oyeyemi *et al.*, 2020; Olayanju *et al.*, 2017). Pre-engineering investigations need to be carried out for sustainable infrastructure (Oyeyemi *et al.*, 2020). Due to the significance of sub-grade (Vaibhav Mittal *et al.*, 2023; Tsado *et al.*, 2018; Kowalczyk *et al.*, 2017; Souley *et al.*, 2022), If the subgrade feature is unknown before road building, it will constitute a danger. In Nigeria's northern region, Akudo *et al.* (2023) attribute the cause of road failure in the Lokoja part of north-central Nigeria to an underlying deep fracture of the basement rock. The Ajaokuta-Anyigba road collapse is believed by Obasaju *et al.* (2022) to be caused by the state of the underlying basement rock. They obtain this information through seismic refraction and geotechnical analysis, areas underly by mica-schist failed because the schist is more susceptible to weathering than areas overly by granitic gneiss. Onimisi (2014) uses a geophysical method to estimate the thickness of the laterite in Anyigba part of the study area to be 1.022M, Given the frequent failure of road pavement in Anyigba and its environs, Examining the reasons for road failure in the research area is vital and important. The goals will be to combine statistical and geotechnical analysis to evaluate the laterite's properties and identify the reason behind the study area's road pavement failure.

1.1 Geomorphology and Climate of the Are

The research area lies between 07^{0}21’0” to 07^{0}37’30”N and longitude 07^{0}20’0” to 07^{0}33’0”E which is in Dekina topographic sheet 248 SW and Ejule 268 NW (Fig:1). The area is generally a highland with flat land, with elevation not less than 200m, The terrain is made up of valleys, steep slopes, and undulating hills. Trellis is the drainage pattern. The area of study experiences a fluctuating climatic condition. The climate is divided into two primary seasons: the wet season and the dry season. From March through October is the rainy season, with a break in August in between. The highest rainfall falls in late June and early July. With freezing weather in December and January, November through March is when the dry season occurs. Tall grasses and evergreen trees, both short and tall, define the vegetation. The Research area is underlain by the Anambra Basin's Maastrichtian Ajali Sandstone

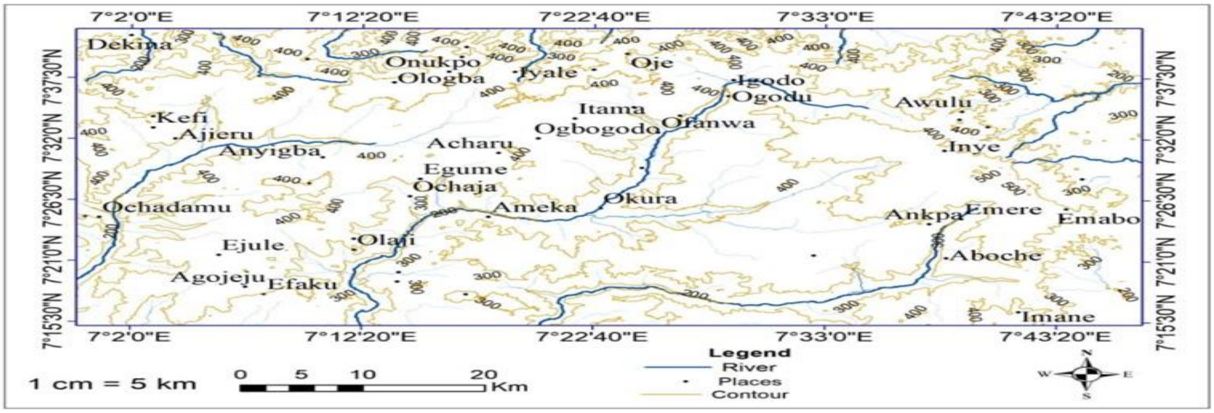

Fig. 1: Topographic map of the study area showing drainage pattern

2.0 Materia1s and Method

2.1 Location and Sampling

The area of study is accessible through the Ajaokuta-Anyigba Road and Akpa-Anyigba-Dekina Road respectively, Anyigba house the Prince Audu Abubakar University. Eleven carefully selected samples were taken from each exposure along the road cut and open pit (Fig. 2). Before being sent to the lab for examination, the samples were preserved in their original moisture content by being sealed in a polythene bag. Geotechnical qualities are studied for five samples. The British norm is followed in every detail regarding the sampling and preservation. BSI 1377 (1990).

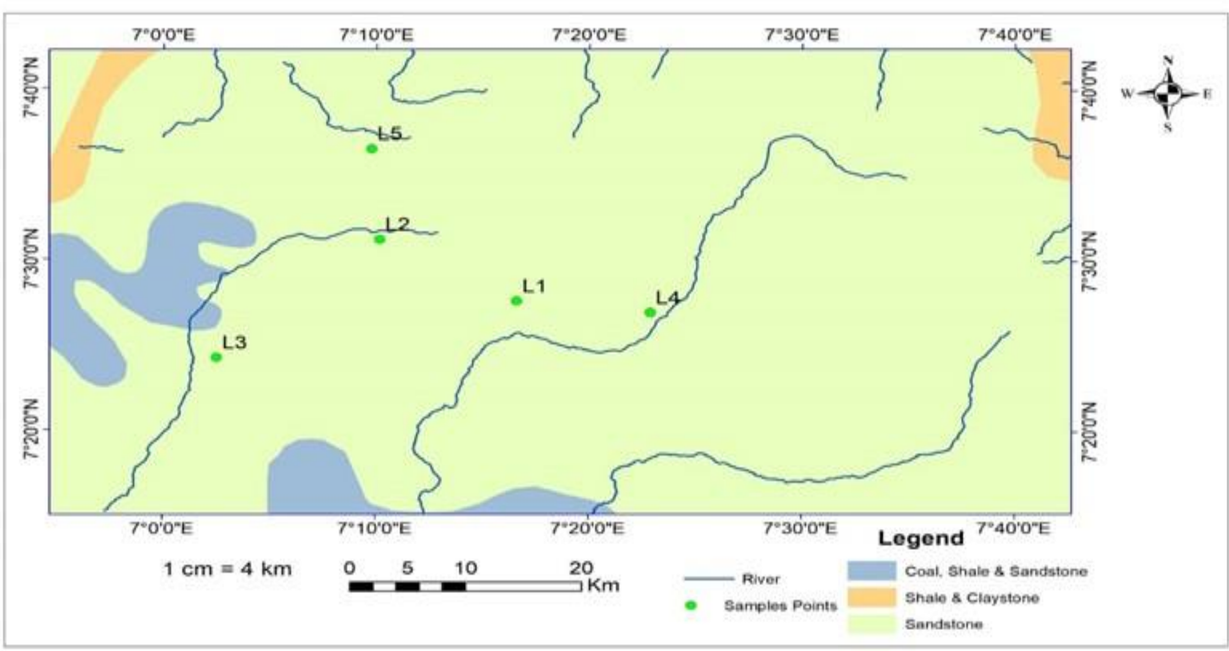

Fig: 2. Geologic map of the study area showing point of sample collection

2.0 Materials and Methods

The soil categorization test, which includes the following tests: moisture content, Atterberg limit, and linear shrinkage, grain size analysis, was one of two types of testing performed on the sample in the lab. In compliance with British standard BSI 1377 (1990), the laterite sample is then put through a soil strength test that includes the compaction and California bearing ratio (CBR) tests. A known mass of laterite was placed on a can and oven-dried for eighteen hours at a temperature between 1050 and 1100 degrees Celsius. The oven-dry sample was weighed, and the variations in percentage between the oven-dry and wet sample represented the moisture content found within the sample (Maduka et *al*., 2017), (BSI, 1990, 1377).

The sample's grain size was assessed by placing 100g of the disintegrated material onto the highest sieve, which was arranged so that the largest-diameter sieve was on top of the British standard sieve. Next, the sample was vibrated with a sieve shaker for ten minutes, and the sieve was opened after the soil had had five minutes to settle. Weigh the sieve and soil retention mass and note it.

Obtain mass retained (g) = (Mass of sieve and soil – Sieve mass)

Obtain cumulative mass retained

Obtain mass passing (g) = (TMR - CMR)

Obtain % passing == (Mass Passing / TMR x 100)

A homogeneous paste was formed by combining 150g of sample laterite with water after it had been filtered using 0.425mm BS sieves for the linear shrinkage analysis. Two hours were spent letting the paste air dry after it was put in the linear shrinkage apparatus. The gadget was then put in the oven after the initial length (L_0) was measured and noted. Following a 24-hour oven drying period, the soil's final length (L_F) was measured. Equation $S_L = ((L_0 - L_F)\ 100)/L_O$ was used to express the length difference as a percentage of the original length. where L_F is the final length, L_0 is the initial length, and S_L is linear shrinkage.

According to ASTM D4318 (2020), the Liquid Limit analysis is carried out by air-drying 100g of the sample, sieving it through ASTM Sieve No. 40 (0.425mm), and then adding distilled water to the dry soil and completely mixing it to form a homogenous paste. Draw the grooved instrument through the sample on the cup's symmetry axis after smoothing the paste section's surface down to a maximum depth of 1 cm in the liquid limit device cup. A measurement was made of the number of blows needed to seal the groove in the soil across a distance of 10mm by rotating the tool perpendicular to the cup at the point of contact at a rate of about two rotations per second. The earth filled the groove and sealed it; to find the soil's moisture content, remove around 10g of soil from the edge of the soil. The sample should be mixed once more in the cup, and the preceding steps should be repeated until the water content of the soil is altered and the number of blows required to close the groove does not differ by more than one. Between 10 and 40 blows, four measurements of the water content were gathered. The soil's liquid limit is reached at the water content that, on the curve, equates to 25 blows. Plot the water content vs the total number of blows. The plastic limit can be determined by taking a portion of the same sample from the liquid limit, mashing it into a paste with 20g of distilled water, and then shaping some of the dirt into a ball. Using a glass plate, roll the ball into a tread and continue rolling until the diameter of the tread crumbles. Measure the amount of moisture in the crumbled soil by placing it in a can. To find the average moisture content value or the soil's plastic limit, repeat the previous stages. The term "plasticity index" refers to the variation between the limit values of plastic and liquid to (IP = Plasticity index - Plastic limit - Liquid limit)) The ASTM D4318 for 2020. For compaction testing, the standard proctor method (BSI, 1377, 1990) is employed. A produced laterite sample was layered three times in a mould and compressed with 25 blows in each layer to obtain the proper moisture content and compactness to achieve the highest possible dry density (Cabalar *et al.*, 2017). To find the sample's maximum dry density, one plots the dry density against the mean moisture content, forming a graph.

The California Bearing Ratio (CBR) test quantifies the discrepancy between the bearing load that pierces a material to a specific depth and the load that pierces crushed stone to an identical depth. Utilizing a typical plunger with a 50 mm diameter and a 1.25 mm/min rate of insertion, the penetration is achieved. The actual load that produces the 2.5 mm or 5.0 mm penetrations for standard loads on crushed stone is represented by the CBR as a proportion of that load. The penetration of lead is shaped like a curve. The load values of standard crushed stone are 13.44 kN for 2.5 mm penetrations and 20.15 kN for 5.0 mm penetrations, respectively.

3.0 Result and Discussion

3.1 Moisture Content

The moisture content of the laterite sample in the study area ranges from 11.4% to 15.9% (Table 1). The low moisture content suggests the presence of sand and is in line with the findings of the particle size analysis, which show that small fine sand makes up the laterite. Because sand does not retain water, it has strong strength qualities, making low moisture content soil an excellent sub-grade material. (Akudo *et al.*, 2024). Because fine-grain soil retains water and causes it to swell, weakening its strength, it is mechanically unstable and connected to clay. FMWH (1997) states that for soil to be an appropriate sub-grade material for engineering construction, its moisture content must be less than 50%. Table 1 indicates that the laterite in the research region has a low moisture content and therefore serves as a good sub-grade material.

3.2 Grain Size Analysis

The laterite is weakly graded, indicating that the grains are found within a single size range spanning from coarse to fine, according to the particle size distribution curve. Table 1 and Fig. 3, respectively, present the results of the grain size analysis. The graph's right-aligning particle size distribution curve, which represents all of the samples in the research area, is for sand. The sample's percentage of sand and fine value fall between the ranges of 99.7 - 91.3% and 0.3% – 8.7%, respectively (Fig 4 and Table 1).

Table 1: The moisture content of the laterite sample in the study area

Geotechnical Test	*Parameters*	*L1*	*L2*	*L3*	*L4*	*L5*	*MEAN*
Grain size analysis	*Sand %*	*96.2*	*96.5*	*93.8*	*91.3*	*99.7*	*89*
	Fines %	*3.8*	*3.5*	*6.2*	*8.7*	*0.3*	*11*
Atterberg Limit Analysis	*LL%*	*21.2*	*35.6*	*25.5*	*21.7*	*39.6*	*28.7*
	PL%	*18.7*	*21.3*	*17.6*	*16.4*	*32.6*	*21.3*
	PI%	*2.5*	*14.3*	*7.9*	*5.3*	*7*	*7.4*
	LS	*2.9*	*5.7*	*3.6*	*5.0*	*5.7*	*4.6*
Moisture Content (%)		*11.5*	*11.4*	*12.5*	*13.3*	*15.9*	*12.9*
Compaction	*OMC (%)*	*10.7*	*12.4*	*11.9*	*12.1*	*12.4*	*11.9*
	MDD (kg/m^3)	*1989*	*2088*	*1972*	*1964*	*2101*	*1822.8*
CBR	*Unsoaked (%)*	*26*	*37*	*26*	*27*	*66*	*36.4*
	Soaked (%)	*14*	*32*	*13*	*13*	*61*	*26.6*

Note: LL= liquid limit, PL= Plastic limit, PI= Plasticity index, Ls= Linear shrinkage, Mc= moisture content, Omc= optimum moisture content, Mdd= maximum dry density, CBR= California bearing ration, L1= Egume town, L2= Anyigba town, L3= Ochidamu, L4= Okura, L5= Odu, Source: created from author own result/research

Table 1 shows percentage passing sieve no 200 is <35% which indicate the laterite is sandy. According to the American Association of State Highway and Transportation officials (AASHTO, 1986) and the Federal Ministry of Works and Housing of Nigeria (FMWH, 1997), the percentage of a soil sample that passes sieve number No. 200 or 0.075mm must be less than or equal to thirty-five percent (35%), though, for the sample to be appropriate for use as base and sub-base material for road construction. Because every sample value was less than 35% , the samples can be used as base and subgrade aggregate when building new roads.

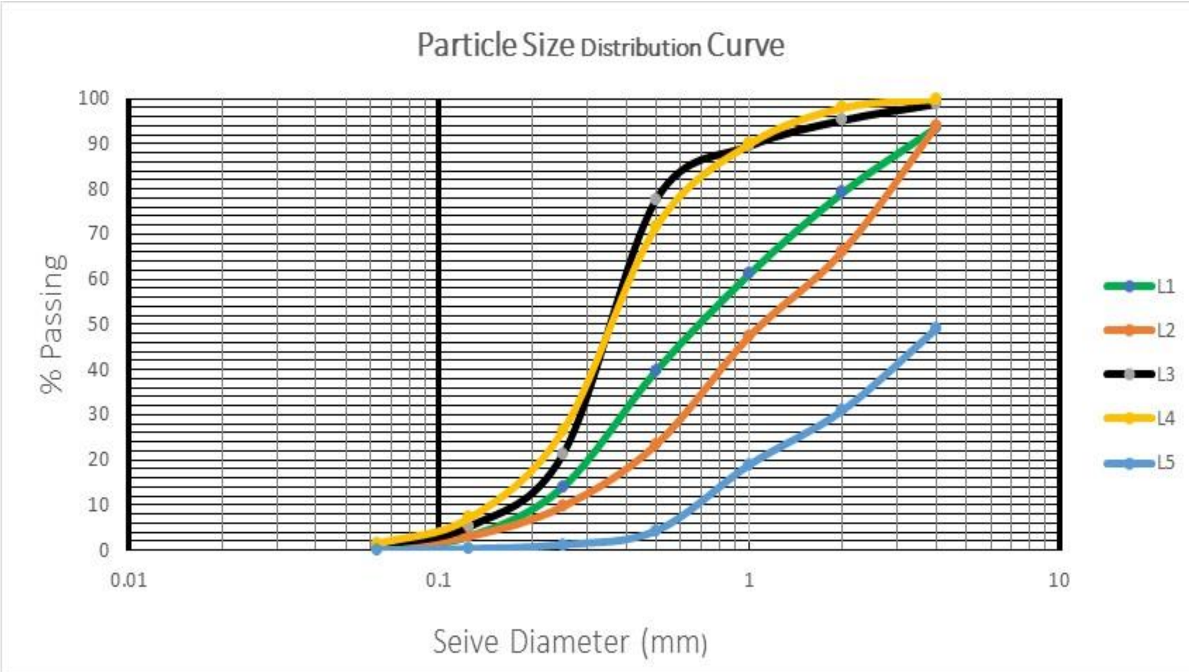

Fig: 3: Particle size distribution curve for samples L1, L2, L3, L4 and L5

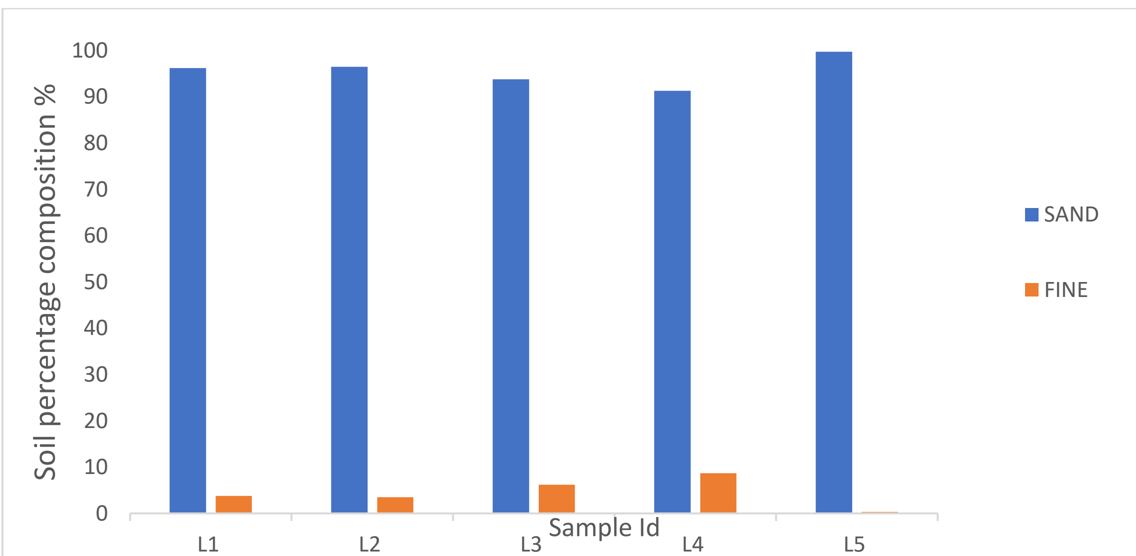

Fig: 4: Percentage soil composition of the samples

3.3 Atterberg Limit

The strength, weakness, and failure of soil are estimated by the Atterberg limit when it is exposed to load and water (Akintola *et al.*, 2014; Sowers and Sowers 1970, and Adeyemi (1995). Table 1 shows the values for the liquid limit, plastic limit, and plasticity index, which are, respectively, 21.2% – 39.6%, 16.4% – 32.6%, and 2.5% – 7.9%. According to the Federal Ministry of Housing and Works, soil with a plasticity index of >20% and a liquid limit of not more than 35% should not be used as subgrade material because these materials tend to deform engineering structures (Omotoso, 2010; Adiat *et al.*, 2017; Olabode *et al.*, 2019; Akudo *et al.*, 2023); and Omotoso, 2010). However, according to studies by Olayanju *et al.* (2017) and Akpah *et al.* (2009), soil that is characterised by swelling and clay content shouldn't have linear shrinkage of more than 8%. However, 0% to 7% is classified by Folowo (2020) as having good to medium resistance to shrinkage. Table 1 and Fig. 3 present the results of the analysis of grain size, respectively. The AASHTO soil classification system (1993) places sample L1, L3, L4, and L5 in the A-2-4 group and sample L2 in the A-2-6 group, all of which are suitable subgrades for building roads. According to Akudo *et al.* (2022), a plasticity index chart (Fig. 5) classifies soil as silty if the point is below the U-line and as clay if it is above the U-line. The analysis of every soil sample revealed that the soil is inherently silty and has low to moderate flexibility. According to Table 1, the laterite exhibits good to medium resistance to shrinkage, following Folowo's (2020) classification.

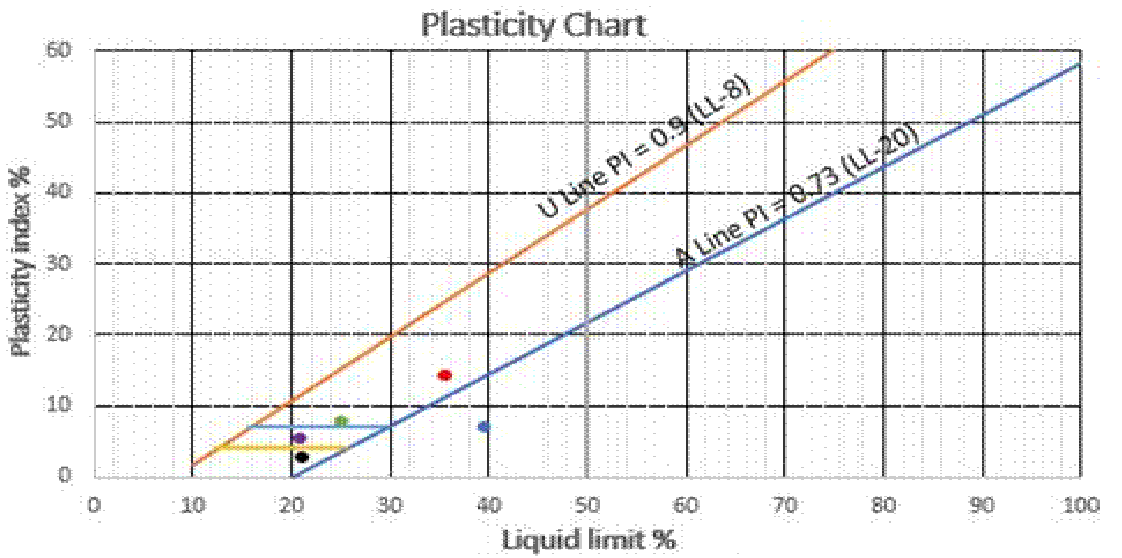

Fig: 5: Plasticity chart of sample L1, L2, L3, L4 and L5

3.4. *Compaction Analysis*

Assessing the standard and suitability of the soil is the goal of compaction. The Maximum Dry Density (MDD) and optimum Moisture Content (OMC) limits listed in Table 1 are 1964 kg/m^3 – 2101 kg/m^3 and 10.7% – 12.4%, respectively. In Fig. 6, the maximum dry density versus the moisture content compaction curve is shown. As material to be utilised as subgrade, Emesiobi (2000) classifies soil with an MDD of > 2100 kg/m3 as excellent, 1900 – 2100 kg/m3 as good, 1700 – 1900 kg/m3 as fair, 1600 kg/m^3 – 1700 kg/m3 as poor, and 1100 – 1600 kg/m^3 as extremely poor. The Nigerian Federal Ministry of Housing and Works in 1997 recommended OMC and MDD values of 18% kg/m3 and 1700 kg/m3 for pavement material, according to Oyelami and Alimi (2015). The samples from Table 1 and Fig. 6 are excellent and outstanding materials that can be utilised for sub-base and sub-grade in the construction of roads. Nonetheless, samples L1, L2, and L5's maximum dry density falls under the class A-2 categorization, per the American Society for Testing and Materials (ASTM D698 and D1557), while samples L3 and L4 fall under the class A-3 classification. while the Optimum moisture content of samples L1 and L3 fall in the group I class, samples L2, L4 and L5 fall in the group II class. O'Flaherty, (1988) suggestion of soil classification, reveals that the soil is silty to sandy clay.

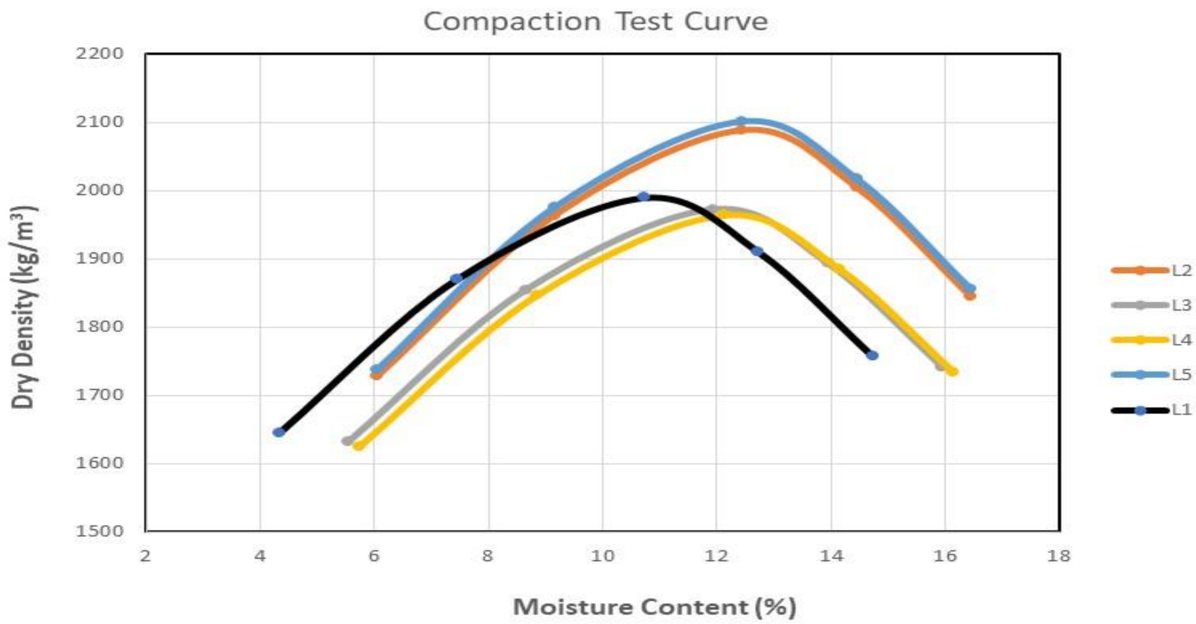

Fig: 6: Compaction test result showing dry density versus moisture content

3.5 California Bearing Ratio

To determine if soil can be utilized as a base material, subgrade, or sub-base, the California Bearing Ratio test is employed (Adeyemi 2013; Adeyemi 2002; Olabode *et al.*, 2019). For both soaked and unsoaked materials, the California Bearing Ratio (CBR) varies from 26 to 66%, and for soaked materials, it varies from 13 to 61% (Table 1 and Fig. 7). 2010 saw the Federal Ministry of Works and Housing Nigeria propose values for below-grade of at least 10%, sub-base of at least 30%, and base course of at least 80%. All the samples can serve as a good sub-grade material while samples L3 and L5 are good for both sub-base and sub-grade material.

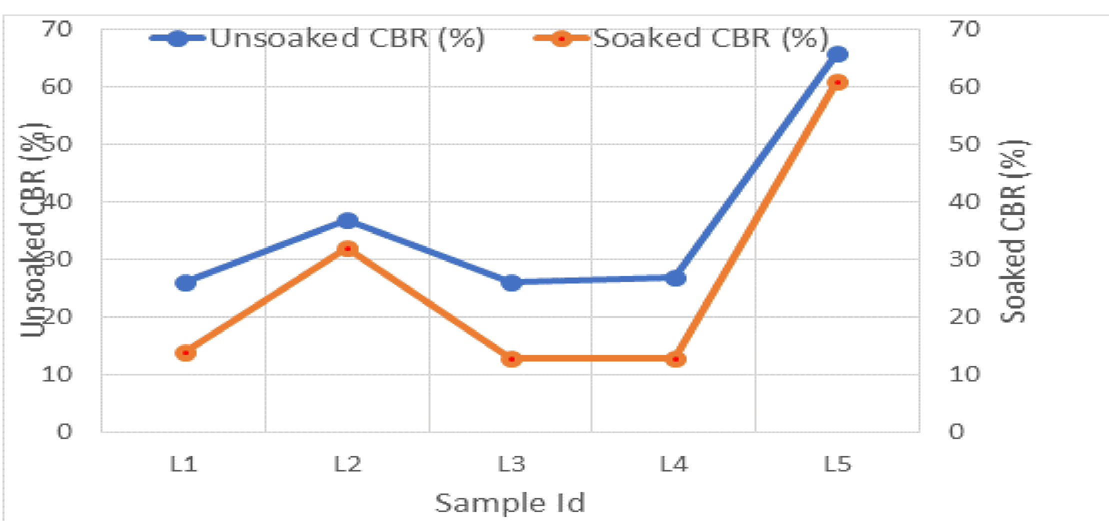

Fig: 7: Chart comparing soaked and unsoaked CBR result

4.0 Conclusion

The investigation into the geotechnical and geomorphological characteristics of laterite in the Anyigba region, Nigeria, has provided valuable insights into the causes of road pavement failures in the area. The study revealed that the laterite samples exhibit low moisture content, favo***u***rable grain size distribution, and appropriate Atterberg limits, indicating low plasticity and moderate shrinkage resistance. The compaction tests showed high Maximum Dry Density (MDD) and suitable Optimum Moisture Content (OMC), further confirming the material's suitability for road construction. Additionally, the California Bearing Ratio (CBR) values supported the adequacy of laterite as subgrade and sub-base material.

The findings suggest that the geotechnical properties of laterite in the Anyigba region are generally suitable for road construction, provided that proper engineering practices are followed. The frequent road failures in the region can be attributed to inadequate site investigations, improper construction methods, and the lack of experienced contractors and engineers.

Based on the results and associated findings from the present study, we present the following recommendation.

(i) The implementation of Pre-Engineering Investigations including detailed geotechnical and geomorphological surveys, to assess the suitability of laterite and other materials for road construction.

(ii) Implementation of stringent quality control measures during road construction to ensure that laterite compaction, moisture content, and other parameters are within the recommended limits.

(iii) Employment of experienced contractors and engineers who are knowledgeable about the local geological conditions and best construction practices to ensure the longevity of road infrastructure.

(iv) Provision of training and capacity-building programs for local engineers and contractors to improve their understanding of geotechnical principles and road construction techniques.

(v) Establishment of a routine maintenance schedule to monitor and address any emerging issues promptly, preventing minor problems from escalating into major road failures.

(vi) Implementation of anti-corruption measures to ensure that resources allocated for road construction and maintenance are used effectively and transparently.

(vii) There is a serious a need for further research into alternative materials and innovative construction techniques that could enhance the durability of roads in the region.

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Data availability

All data used in this study will be readily available to the public

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data Public.

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Authors' contributions

The design, conceptualization, field mapping writing and proof reading of the manuscript was carried out by Esharive Ogaga. The field mapping and review of the manuscript was done by Onimisi Martins and Abdulateef Onimisi Jimoh. Akudo Ernest Orji and Aigbadon Godwin Okumagbe was involved in the field mapping, compilation of the report and drafting of the manuscript. Achegbulu Ojonimi Emmanuel produce the maps of the study area.