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COMPARATIVE ANALYSES OF THE ENGINEERING PROPERTIES OF LATERITES DERIVED FROM DIFFERENT ROCK TYPES ALONG YOLA-MUBI FEDERAL HIGHWAY

WILBERFORCE ISHAYA KATAGUI; MUHAMMAD SANI ABDULLAHI; SULEIMAN UMAR MAGAJI; HAMAJODA JIBIRILLA; ABANA MOHAMMED; & AHMED BUBA SELI

Department of Civil Engineering Technology, Adamawa State Polytechnic, Yola, Nigeria
Corresponding Author: babasayyida78@gmail.com
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Abstract

This research investigated the qualities of laterites in localities along Yola-Mubi Federal Highway; to evaluate their suitability as civil engineering construction materials. The study area has tropical climate and the existing rocks are sandstones, basalts, older granites, gneisses and migmatites. Ten laterite samples from five different localities (**VG_1, VG_2, GS_1, GS_2, MG_1, MG_2, MH_1, MH_2, $BM_1$and BM_2**) were subjected to geotechnical investigations in accordance to BS1377 (1990). The particle size distribution ranged; **gravel** (0% - 18 %), **sand** (39% - 94 %,) and **fines** (5% - 61%). The highest **LL** of 43.15% was recorded on **GS_2** and **VG_2** has the highest **PL** of 25.15%. **GS_1** yielded highest **PI** of 36.46%. The highest **NMC** of 30.01% was recorded on **GS_1** while the lowest **NMC** of 8.75% was recorded on **VG_2**. The mean **SG** (2.685) of the basaltic samples and the **SG** (2.57) on the sandstone samples differ significantly. The highest **MDD** of 1.84 mg/m^3 was recorded on **VG_2** while **MG_1** yielded the lowest **MDD** of 1.50 mg/m^3. The highest **OMC** of 18.75 % was recorded on

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VG_2 and **MG_1** has the lowest **OMC** of 12.38 %. **T**he highest **UCS** of 42 kPa was recorded on **MG_1** while **BM_2** recorded the lowest **UCS** of 27 kPa. The unsoaked **CBR** ranges from 55% to 86%; they are directly proportional to **SG** and **MDD;** and inversely proportional to the **NMC**, **OMC** and **LL.** Samples **VG_1, VG_2, MG_1, MG_2, MH_1 and MH_2** satisfied the requirements (**OMC**, **LL**, **PI** and **fines content**) and are likely to be good as general fills, sub-base and embankment materials. All samples except **VG_1 and VG_2** are poor as base course materials; their **UCS** and **CBR** fall outside specifications. Sandstone derived laterites (**VG_1 and VG_2**) are the most suitable for civil engineering construction purposes.

Introduction

Highly weathered residual soils; rich in secondary oxides of iron, aluminum, or both; contain large amount of quartz and kaolinite; void of bases and primary rock-forming minerals (silicates) are termed laterites. This soil group is used extensively as construction materials for various civil engineering projects (Mobasser, et. al., 2019). They are formed by the in-situ weathering of rocks in the tropical and sub-tropical regions with hot, humid climatic conditions (Mobasser, et. al., 2019). The engineering properties of these soils are influenced by nature of parent rocks, geochemical, mineralogical and climatic factors; and their particulates constituents are determined by rock horizons and weathering conditions (Yunusa, et. al., 2024).

Inadequate application of constructional materials especially laterites usually cause road failures (Ogunribido, et al., 2019). The suitability of a material to be used as either a base course or sub-base course depends on its strength in transmitting the axle-load to the sub-soil and or sub-grade; since the characteristics and durability of any constructional material is a function of its efficiency in response to the load applied on it (Ogunribido, et al., 2019). The composition of minerals in a laterite affects its geotechnical parameters such as specific gravity, shear strength, swelling potential, plasticity and bearing capacity (Yunusa, et al., 2024).

Yola-Mubi federal highway traversed seven Local Government Areas (Yola-North, Girei, Song, Gombi, Hong, Mubi-South and Mubi-North) and all the rock types (Igneous, Metamorphic and Sedimentary) are found in these places. Various civil engineering construction projects which make use of laterites as materials (roads, embankments, dams, foundations, base course or sub-base courses) are carried out in towns and villages located in these LGA's. This study is an attempt to investigate the engineering properties of laterites in the study area to know which one meets the criteria and is suitable to be

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used as fills, bases or sub-bases material for civil engineering construction; thereby ensuring their standard and durability.

Objectives

- Carry out geotechnical analyses of laterite samples obtained from different locations with different parent rocks.
- Determine the differences if any between the laterites generated from different rock types based on their geotechnical properties.
- Compare and contrast the engineering properties of the different laterites from different source rocks.
- Recommend the most suitable laterite in the study area based of the parent material.

Materials and Methods

Location and Geomorphology

The study area is located in Adamawa State, northeastern Nigerian (between latitudes 9°22'N - 10°16'N and longitudes 12033'E - 13°19'E) and runs from Jimeta Bridge to Mubi town; a linear distance of about 200 km; traversing Girei, Song, Gombi, Hong, Mubi-South and Mubi-North LGA's. It is within the northeastern Nigerian basement complex with the exception of Girei and southern part of Song LGA's which lie in the Yola arm of the Upper Benue sedimentary basin. Characteristic landforms are hills with structural ridges and inselbergs which resulted from various past geological and geomorphological processes.

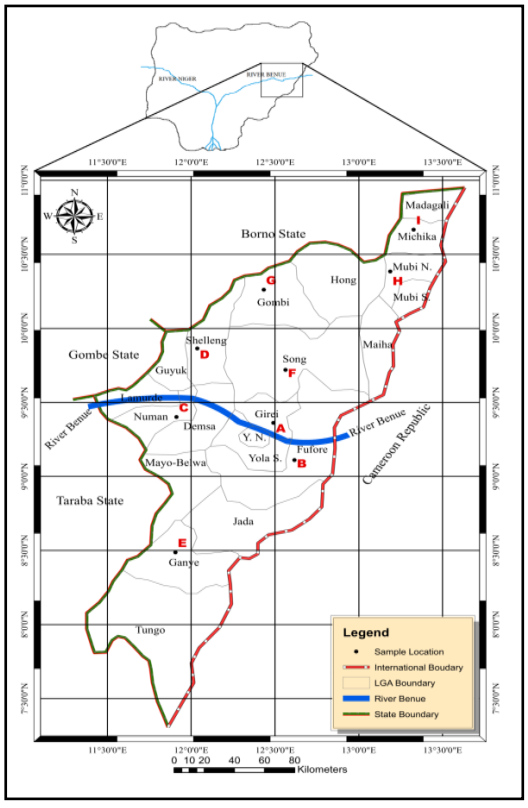

Fig.1. Map of Adamawa State, Nigeria showing the Study Area

Climate

The study area experience both wet and dry seasons characteristics of the tropics. Dry season lasts from November to March, while the wet season starts in April and ends in October. The mean annual rainfall ranges from 800 mm to 900 mm. The driest months are March and April while the wettest months are August and September (Adebayo, et. al., 2020).

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Temperatures are high from March to June, and also in October and November; when the daily maximum temperatures may reach 42°C. During the months of December and January, temperatures drops to as low as 20-26°C. Relative humidity varies from season to season; rising up to 90% in the rainy season due to the influence of the tropical maritime air mass which covers sun rays during this time.

Geology of the Study Area

The study area is composed of all the three major rocks types; igneous, metamorphic and sedimentary. The northern part; covering Mubi-North, Mubi-South, Hong, Gombi and most of Song LGA's is a basement complex terrain which have undergone both pre-pan African and pan-African orogenies and resulted into consequent metamorphism, migmatization and granitization of some of the pre-existing rocks. Parts of the rocks have been weathered with few outcrops of the basement rocks still preserved as hills. The rock types found are migmatites, gneisses, older granites and basalts. The migmatite-gneisses are coarse-grained high-grade metamorphic rocks formed at high pressures and temperatures, in which light and dark mineral constituents are segregated into visible bands. The biotite gneisses are fine-grained with strong foliation caused by the parallel arrangement of alternating dark and light minerals. The banded gneisses show alternating light-coloured and dark bands and exhibit intricate folding of their bands (Ekwok, et. al., 2021). The older granites are coarse-grained; made up of feldspar, mica, quartz and biotites; which occur as large circular masses within the migmatite-gneiss complexes. Ekwok, et. al., (2021) opined that these rocks evolved from geodynamic disturbances and magmatic activities generated deep within the Earth's crust during the Pan-African orogeny (about 1500 Ma). The basalts are volcanic rocks which occur as post metamorphic extrusives formed during the Pan-African Orogeny and composed of calcic plagioclases and ferromagnesian minerals; characterized by small grain sizes (Ekwok, et. al., 2021). They developed a characteristic columnar jointing, where by the rocks split into polygonal columns oriented perpendicular to the cooling surfaces; and sometimes also occur as pumices and bombs visibly as low ridges. The sedimentary rocks are Bima Sandstones of the Yola arm of the Upper-Benue sedimentary basin; which overlie the Basement Complex (upper Albian in age and continental). Their thickness ranges from 300 m to 3,000 m. They are light brown in colour, made up of quartz and feldspars, medium to coarse-grained, often grade bedded, laminated and cross bedded (Kamaunji, et. al., 2022).

Soil Sampling and Geotechnical Analyses

Ten laterite samples were obtained from five different localities within the study area namely; Vunoklang (Girei), Gulungo (Song), Muchala (Gombi), Makera (Hong) and Barama

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(Mubi). The soil samples were collected from depths of 2.00m and subjected to natural moisture content, grain size distribution, atterberg limits, specific gravity, compaction and unconfined compressive strength tests. BS1377 (2021) and Sahadat Hossain, et. al., (2021) were used as standards of samples preparation. The materials were air-dried and broken into smaller fragments; care was taken not to reduce the sizes of the individual particles.

The specific gravity and natural moisture content tests were carried out following BS 1377 (2021) standard. The laterite sample was washed and oven-dried. Approximately 500g of representative sample was used for the test. These were sieved by mechanical methods using automatic shakers and a set of sieves, and then weighed. Laterite soil samples passing through 425µm sieve, weighing 200g were mixed with water until they formed thick homogeneous paste. Cone penetrometer method was used for the liquid limit test. The penetration of a standard cone into a soil sample paste was measured at a variety of moisture contents. The moisture content corresponding to a penetration of 20 mm was taken as **LL**. Laterite soil sample passing through 425µm sieve, weighing 200g was taken and mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3mm diameter and the moisture contents were determined as the **PL**. The Plasticity index (**PI**) was calculated by subtracting plastic limit from liquid limit.

The compaction characteristics of the soils were determined by proctor's test (Sivakugan, 2021). The degree of compaction was measured in terms of its dry density. The dry density is highest at the optimum moisture content. A graph of values of moisture content against values of dry density gives a curve; the maximum dry density and the optimum moisture content. The unconfined compressive strength **UCS** is the load per unit area at which the cylindrical specimen of a cohesive soil falls in compression. California Bearing Ratio, **CBR** is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50mm diameter at a the rate of 1.25mm/minute to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 and 5 minutes and forms part of site investigation used to determine the thickness of materials needed for proposed road construction project.

Results and Discussion

Tables 1 and 2 contain summaries of geotechnical analyses results and description of the studied laterites. From field observations; the sandstones, gneisses, migmatite-gneisses and older granites derived laterites are coarse grained; while the basalts derived ones are relatively fine grained. The following section explains their index and engineering properties.

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Natural Moisture Content (NMC)

The results of **NMC** tests range from 8.75% to 30.01% (Table 1). Values of natural moisture content are functions of the void ratios (Sivakugan, 2021); thus **GS_1** which is a basalt derived laterite probably had the largest void ratio and most porous; and **VG_2**; a sandstone laterite had the smallest void ratio and least porous. This implies that laterites with appreciable moisture content are largely affected by the climatic conditions and the degree of weathering (Das, 2023).

Specific Gravity (SG)

The values of **SG** analysis range between 2.58 and 2.72 (Table 1). Specific gravity is a measure of the degree of maturity, i.e. laterization (Das, 2023). Lower specific gravity values indicate a coarse soil, while higher values indicate a fine grained soil (BS1377, 2021).

Atterberg Consistency Limits

The results of Atterberg limits tests gave ranges of **LL** (28.64% - 43.15), **PL** (4.74% - 32.51%) and **PI** (3.49% - 36.46%). Laterites with **LL** less than 35% indicate low plasticity, between 35% and 50% indicates intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity and greater than 90% extremely high plasticity, (Das, 2023). Hence, **VG_1** and **VG_2** have low plasticity while the rest indicate intermediate plasticity. The **LL** values from all the samples suggested that they have very little potential to swell or shrink (Olofinyo, et. al., 2019). All the laterite samples (except **VG_1** and **VG_2**) comparatively recorded lower plasticity (low values of **LL** and **PI**). This implies low clay content resulting from low amount of convertible feldspathic minerals. Presence of ferromagnesium may point to the appreciable **LL** and **PI** recorded in **VG_1** and **VG_2** (Das, B.M. 2023 and Ajayi, et. al., 2024).

Table 1: Results of Geotechnical Analyses on Studied Laterites

S/N	Sample	Location	Coordinates	Rock Type	Laterite Type	NMC (%)	SG	LL	PL	PI	USCS Classification
1.	VG_1	Vunoklang (Girei)	9°22'16"N, 12°33'24"E	Sandstones	Coarse grained	9.65	2.58	29.20	24.59	4.61	SW
2.	VG_2	Vunoklang (Girei)	9°22'19"N, 12°35'24"E	Sandstones	Coarse grained	8.75	2.56	28.64	25.15	3.49	SW
3.	GS_1	Gulungo (Song)	9°49'28"N, 12°37'30"E	Basalts	Fine grained	30.01	2.72	41.20	4.74	36.46	CL
4.	GS_2	Gulungo (Song)	9°49'31"N, 12°33'30"E	Basalts	Fine grained	28.76	2.65	43.15	6.87	36.28	CL
5.	MG_1	Muchala (Gombi)	10°9'44"N, 12°44'24"E	Gneisses	Coarse grained	13.55	2.54	35.30	32.51	2.79	SW
6.	MG_2	Muchala (Gombi)	10°9'46"N, 12°41'24"E	Gneisses	Coarse grained	15.75	2.61	36.25	31.64	4.61	SW

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S/N	Sample	Location	Coordinates	Rock Type	Laterite Type	NMC (%)	SG	LL	PL	PI	USCS Classification
7.	MH_1	Makera (Hong)	10°13'54"N, 12°55'49"E	Older Granites	Coarse grained	22.06	2.64	38.50	19.83	18.67	**SP**
8.	MH_2	Makera (Hong)	10°13'57"N, 12°55'51"E	Older Granites	Coarse grained	24.32	2.62	39.65	20.11	19.54	**SP**
9.	BM_1	Barama Mubi	10°16'43"N, 13°16'32"E	Migmatites	Coarse grained	26.78	2.63	40.15	15.47	24.68	**SP**
10.	BM_2	Barama Mubi	10°16'45"N, 13°19'32"E	Migmatites	Coarse grained	27.10	2.67	41.23	14.76	26.47	**SP**

Particle Size Distribution

The results of particle size distribution analysis (Table 2) indicated that the amount of fines range between 5% and 61% and the amount of coarse fraction range from 39% to 95%. Hence all the laterites can be generally rated as fair to good sub-grade foundation material (FMWH, 2022); having good workability as construction materials for roads and earth dams (Ajayi, et. al., 2024).

The effective sizes (D_{10}) values range from 0.2 to 1; the coefficient of uniformity (C_u) values range from 1.6 to 15 and the coefficient of curvature (C_c) values range between 1.2 and 6.7. The larger the numerical value of C_u, the more the range of particles. Soils with a value of C_u less than 2 are uniform soils and those with values of C_u of 4 or more are well graded (Sivakugan, 2021). For a well graded soil, the value of C_C lies between 1 and 3. This showed that the soil samples are generally well-graded sandy-silt-clays. The sandstone, granite, gneiss and migmatite derived laterites show closeness in their gradation results. This may be due similarity in their mineralogy; quartz richness. The basalt derived laterites however differ greatly from the rest; indicating that mineralogical composition of parent rocks affects the products of laterization (CIRIA, 2020).

Classification

Particle size distribution and plasticity are used in soil classification (Sivakugan, 2021 and Das, 2023). Based on **USCS Classification** system, laterite samples **VG_1, VG_2, MG_1** and **MG_2** fall under group **SW;** samples **GS_1** and **GS_2** are classified as **CL;** and samples **MH_1, MH_2, BM_1** and **BM_2** fall under **SP.**

Compaction Characteristics

Compaction test results showed that the laterite samples have **MDD** values ranging from 1.50 g/cm^3 to 1.84 g/cm^3; while their **OMC** values range between12.38% and 18.75%. These values show that, the laterite samples respond gradually to compaction (Ampadu, et. al., 2022). High values of **MDD** indicate improved soil property and low **OMC** implies workability of lateritic soil (Olofinyo, et. al., 2019). From Table 2, the **MDD** values of all the laterite samples (except **MG_1, MG_2** and **BM_1**) are more than 1.700g/cm^3; indicating their

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suitability in general filling, sub-grade and sub-base courses of roads (FMWH, 2022). The **OMC** and **LL** increase with the increase in percentage of fines; showing that plasticity strongly influenced the **MDD** and **OMC** of soils in study area (Fatoyinbo, et. al., 2024).

Unconfined Compressive Strength (UCS)

From Table 2, the values of **UCS** for the laterite soil samples range from 27 KPa to 42 KPa; indicating inorganic clays with fair workability as construction materials, medium compressibility and fair shearing strength (Ajayi, et. al., 2024). The common binding agent in laterites is Fe oxide. In their highly developed laterization stages, laterites record Fe and Al oxides concretions that formed from high degree of Fe cementation (Kumar, et. al., 2022). Thus, the samples with high **UCS** are those that have undergone high degree of ferruginization. High clay content, from conversion of ferromagnesium and feldspathic minerals, in the basaltic laterites may have negatively influenced their **UCS** results (Kumar, et. al., 2022).

California Bearing Ratio CBR

CBR test is performed to evaluate the strength of soil subgrade and base course materials; it is a measure of the strength of the subgrade of a road or other paved area and of the materials used in construction. The **CBR** results of the laterite samples (Table 2) revealed ranges of values for the unsoaked **CBR** ranges from 55% to 86%. These values are directly proportional to specific gravity and **MDD**; and inversely proportional to the **NMC**, **OMC** and **LL**. Hence, as **CBR** increases strength of subgrade also increases. Alzara, et. al., (2024). opined that the harder the surfaces have higher the **CBR** value (clay - 2%, sand - 10% and high quality subbase 80 - 100%).

Table 2: Results of Geotechnical Analyses on Studied Laterites

S/N	Sample	Location	Fines (%)	Sand (%)	Gravel (%)	D_{10}	D_{30}	D_{60}	C_u	C_c	MDD (g/cm³)	OMC (%)	UCS (kPa)	Unsoaked CBR (%)
1.	VG_1	Vunoklang (Girei)	6	81	13	0.2	2	3	15	6.7	1.82	13.75	41	82
2.	VG_2	Vunoklang (Girei)	5	83	12	0.2	2	3	15	6.7	1.84	13.93	40	86
3.	GS_1	Gulungo (Song)	59	41	0	-	-	-	-	-	1.77	18.57	36	55
4.	GS_2	Gulungo (Song)	61	39	0	-	-	-	-	-	1.73	18.75	38	58
5.	MG_1	Muchala (Gombi)	5	77	18	1	2	3	3	1.3	1.50	12.38	42	78
6.	MG_2	Muchala (Gombi)	7	76	17	1	2	3	3	1.3	1.52	13.65	41	75
7.	MH_1	Makera (Hong)	6	94	0	0.5	0.7	0.8	1.6	1.2	1.80	16.86	29	69

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S/N	Sample	Location	Fines (%)	Sand (%)	Gravel (%)	D_{10}	D_{30}	D_{60}	C_u	C_c	MDD (g/cm³)	OMC (%)	UCS (kPa)	Unsoaked CBR (%)
8.	MH_2	Makera (Hong)	8	88	0	0.5	0.6	0.7	1.5	1.2	1.78	17.24	30	66
9.	BM_1	Barama Mubi	6	92	2	1	3	3	4	1.4	1.65	13.14	29	63
10.	BM_2	Barama Mubi	7	89	4	1	2	3	3	1.3	1.71	12.83	27	61

MDD= Maximum Dry Density, OMC= Optimum Moisture Content, UCS= Unconfined Compressive Strength, CBR = California Bearing Ratio, D_{10}= Effective diameter, D_{30}= Diameter of particles 30 percent weight passing, D_{60}= Diameter of particles 60 percent weight passing, C_u= coefficient of uniformity, C_c= coefficient of curvature, - not determined due to nature of results

Suitability of the studied laterites as construction materials

The quality of the studied laterite samples as construction materials is evaluated by comparing their engineering properties with the specifications given by the Nigerian Ministry of Works and Housing (FMWH, 2022). The results of the comparative analysis are presented in Table 3.

General fill and embankment

As shown in Table 3, samples **VG_1, VG_2, MG_1, MG_2, MH_1** and **MH_2** are likely to be good as general fill and embankment materials, having satisfied requirements such as **MDD**, **OMC**, **LL**, **PI, CBR** and **fines content**. Samples **GS_1, GS_2, BM_1** and **BM_2** failed to meet most requirements, especially **LL** and **PI** and may be poor to fair as subgrade (FMWH, 2022).

Sub-base course

Table 3 reveals that only six samples **VG_1, VG_2, MG_1, MG_2, MH_1** and **MH_2** satisfied **LL** and **PI** requirements as sub-base materials. The remaining samples failed and are likely to be poor to marginal. Their quality in service can be improved by adequate stabilization (Fatoyinbo, et. al., 2024).

Base course

All the tested laterites, except **VG_1** and **VG_2**, failed to meet almost all the standard limits (Table 3), and are therefore very likely to be poor as base course materials. Their **UCS** and **CBR** significantly fall outside specifications seriously and this undermines their acceptability on the basis of marginal **LL** results (FMWH, 2022). Samples **VG_1** and **VG_2** showed a good consistency in quality for use in most engineering projects.

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Table 3: Properties of studied laterite samples versus Nigerian specifications

Property	Nigerian specification*	Tested laterite samples										Remarks
		VG 1	VG 2	GS 1	GS 2	MG 1	MG 2	MH 1	MH 2	BM 1	BM 2	
General fill and embankment												
MDD (g/cm^3)	> 0.04	1.82	1.84	1.77	1.73	1.50	1.52	1.80	1.78	1.65	1.71	**Samples VG_1, VG_2, MG_1, MG_2, MH_1 and MH_2 are likely to be good, while samples GS_1, GS_2, BM_1 and BM_2 would be fair to poor.**
OMC (%)	< 18	13.75	13.93	18.57	18.75	12.38	13.65	16.86	17.24	13.14	12.83	
LL	< 40	29.20	28.64	41.20	43.15	35.30	36.25	38.50	39.65	40.15	41.23	
PI	< 20	4.61	3.49	36.46	36.28	2.79	4.61	18.67	19.54	24.68	26.47	
Fines (%)	≤ 35	6	5	59	61	5	7	6	8	6	7	
Unsoaked CBR (%)	≥ 80	82	86	55	58	78	75	69	66	63	61	
Quality		**Good**	**Good**	**Poor**	**Poor**	**Good**	**Good**	**Good**	**Good**	**Poor**	**Poor**	
Sub-base course												
LL	< 35	29.20	28.64	41.20	43.15	35.30	36.25	38.50	39.65	40.15	41.23	**Only samples VG_1, VG_2, MG_1, MG_2, MH_1 and MH_2 are likely to be good, while the rest would be poor**
PI	< 16	4.61	3.49	36.46	36.28	2.79	4.61	18.67	19.54	24.68	26.47	
Unsoaked CBR (%)	≥ 80	82	86	55	58	78	75	69	66	63	61	
Quality		**Good**	**Good**	**Poor**	**Poor**	**Good**	**Good**	**Good**	**Good**	**Poor**	**Poor**	
Base course												
LL	≤ 30	29.20	28.64	41.20	43.15	35.30	36.25	38.50	39.65	40.15	41.23	**All samples are very likely to be poor, except samples VG_1 and VG_2 that may be marginal**
PI	≤ 13	4.61	3.49	36.46	36.28	2.79	4.61	18.67	19.54	24.68	26.47	
Fines (%)	5 – 15	6	5	59	61	5	7	6	8	6	7	
UCS (kPa)	> 103	41	40	36	38	42	41	29	30	29	27	
Unsoaked CBR (%)	≥ 80	82	86	55	58	78	75	69	66	63	61	
Quality		**Fair**	**Fair**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	

*From FMWH (2022)

Summary and Conclusions

1. Ten laterite samples formed from different rock types were collected and subjected to basic geotechnical tests determine their engineering quality in construction projects.
2. Particles sizes range as follows; gravel sized from 0% to 18 %, sand sized from 39% to 94 %, and fines 5% to 61 %. Basaltic laterites recorded the highest amount of fines, while

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an older granite laterite has the highest amount of sand sized particles. This trend indicated the influence of mineralogy, degree of laterization and depth of sampling.

3. The highest **LL** value of 43.15% was recorded on a basaltic sample, while the highest **PL** of 25.15% was recorded on a sandstone sample. A basaltic laterite yielded the highest **PI** of 36.46%. High **LL** and **PI** recorded on lateritized basalts suggested the presence of expansive clays from conversion of rich feldspathic and ferromagnesium minerals in the rock.
4. The highest **NMC** of 30.01% was recorded on a basaltic laterite, while the lowest **NMC** of 8.75% was recorded on sandstone laterite. The **NMC** values appear to be generally high in basalt derived laterites, while the samples derived from quartz-rich rock types (that is, sandstone, gneiss and granite) comparatively have low **NMC**. The **NMC** and **PI** show fair consistency in their data trend; samples with low values of **PI** generally recorded low **NMC**, and vice versa. Mineralogy, void ratio, moisture condition and particle gradation are thought to be responsible.
5. The **SG** value on a basaltic sample is highest (2.72). Comparatively, the mean **SG** (2.685) of the basaltic samples and the **SG** (2.57) recorded on the sandstone laterite samples differ significantly; implying that the basaltic laterites have higher amount of sesquioxides, lower void ratio, or have undergone highest degree of ferruginization and laterization.
6. The highest **MDD** value of 1.84 mg/m^3 was recorded on a sandstone laterite, while the lowest **MDD** of 1.50 mg/m^3 was recorded on a gneissic laterite. The highest **OMC** value of 18.75 % was recorded on a basaltic laterite, while the lowest **OMC** of 12.38 % was recorded on a gneiss laterite. Most samples with high **MDD** recorded high **OMC**, and vice versa.
7. The highest **UCS** value of 42 kPa was recorded on gneiss laterite sample, while the lowest **UCS** value of 27 kPa was recorded on migmatitic sample. Laterite samples with high **UCS** recorded low **NMC**, and vice versa, implying that the moisture conditions may have had direct influence on their **UCS**.
8. The highest **CBR** value of 86% was recorded on a sandstone laterite sample, while the lowest **CBR** value of 55% was recorded on a basaltic sample. The **CBR** values are directly proportional to **SG** and **MDD**; and inversely proportional to the **NMC**, **OMC** and **LL**.
9. Only six (**VG_1, VG_2, MG_1, MG_2, MH_1 and MH_2**) out of the ten tested samples are likely to be good as general fills, base, sub-base and embankment materials, having satisfied most of the requirements, such as **MDD**, **CBR**, **OMC**, **LL**, **PI** and fines content. The rest of the samples could be considered marginal, poor or fair, owing to their failure to meet most requirements, especially **LL** and **PI**. Samples **VG1** and **VG_2** showed good

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quality in almost all the tested parameter and compared favourably with the Nigerian specification for most construction projects.

10. A classification based on **USCS** rated the studied samples variously as poorly graded sand **SW** (**VG_1, VG_2, MH_1** and **MH_2**), clay of low plasticity **CL** (**GS_1 and GS_2**) and poorly graded sand **SP** (**MH $_1$, MH_2, BM_1 and BM_2**).
11. All the tested samples, except **VG_1 and VG_2,** failed to meet almost all Nigerian standards, and are therefore very likely to be poor especially as base course materials. Their **UCS** and **CBR** significantly falling outside specifications seriously undermines their suitability for use as civil engineering construction materials for such purpose.
12. The sandstone derived laterites (**VG_1 and VG_2**) showed a good consistency in quality for use in most engineering projects. This may mean that sandstone terrain should be the prime target when laterites are desired for construction purpose in the study area. Laterites from other parent rock types, especially basalts; may however be considered but their use would require caution or adequate treatment.

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