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Engineering Evaluation of Laterite Derived from Sedimentary Rock for Use as Subgrade and Sub-Base Materials

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Abstract: Geotechnical assessment of lateritic soils obtained from along the Ojota and Shagamu ends of the Lagos–Ibadan expressway was conducted to evaluate their suitability for use as sub-grade and sub-base materials. Laboratory tests, including moisture content, specific gravity, particle size distribution, fabric/plasticity, compaction, and California Bearing Ratio (CBR), were performed on eight (8) soil samples following British Standards (BS) 1377 methods for soil testing. The lateritic soils were classified as clayey sand, silty clay, and silty to clayey sand. They exhibited moderate plasticity and semi-pervious characteristics, suggesting suitability for use as sub-grade materials. Samples 3, 5, 7, and 8 were identified as more suitable for road construction materials, while Samples 1, 2, 4, and 6 showed susceptibility to seasonal volume changes due to high clay content. These samples would require minor soil stabilization to mitigate the effects of their active clay contents. Adequate drainage systems were recommended to prevent water accumulation, soil volume changes, loss of load-bearing capacity, and potential material failure beneath road pavements. The geotechnical properties of the lateritic soils from the tropical area of Ojota–Shagamu differed significantly from those of other lateritic soils found in southwestern Nigeria.

Keywords: Geotechnical properties, clay activity, soil permeability, road construction, Sedimentary rock, Lagos State

INTRODUCTION

Background

Soil in the engineering geology profession refers to the natural products of weathering of rocks that form part of the Earth's crust (Das, 2010). This includes all unconsolidated materials from the Earth's surface down to the bedrock. Soil is a fundamental component of engineering construction, as many structures are built on, in, or from soil. A wide range of soils, such as gravel, sand, clay, and laterite, are used in engineering constructions. Therefore, soils require investigation to determine their suitability based on their properties. Soil materials have a wide range of properties influenced by climate and time variations, geology, and geomorphology.

Construction engineers are particularly interested in soil properties that affect the support provided for structures, slope stability, lateral pressure exerted against structures, suitability as construction materials, compaction characteristics, and water retention ability (Nebeokike et al., 2020; Evurani et al., 2020). Natural soils encountered at construction sites often have variable geotechnical properties and may differ from the conditions anticipated by the engineer.

Due to the varied geotechnical properties of soils, it is essential to continually accumulate data on soil geotechnical properties to aid in understanding and predicting soil behavior, and in the effective design and construction of structures. Geotechnical data on soil can help predict likely site conditions. When natural geotechnical properties do not meet the required standards, engineers have the option to abandon the site, redesign the structure to suit the new soil conditions, or modify the location by removing unsuitable materials, importing suitable soils, or improving the quality of local soils.

Nigerian soils are often derived in place from the underlying rocks, which are equally divided between crystalline and sedimentary rocks (Adeola & Tubonemi, 2017; Oyawale et al., 2020). These soils can be gravel, sand, silt, clay, or laterite, depending on the rock type, rock chemistry, environmental conditions, and degree of weathering. There is currently a huge demand for sand and aggregates due to population growth and the resulting rapid expansion of infrastructure. Sand and aggregates are among the most commonly used raw materials for constructing buildings and roads. However, the current demand rate for sand and aggregates exceeds the natural formation rate, causing sustainability issues for society (Oyelami & Van Rooy, 2016; Oyelami & Van Rooy, 2018).

Locally, most soils encountered, especially in the tropical region, are residual and are broadly termed laterites (Adeola & Tubonemi, 2017). Although laterites display a variety of colors, textures, and petrographic features, they exhibit homogeneous mineralogical and chemical compositions that may not be specific to the parent rock from which they were derived (Oyelami & Van Rooy, 2018). The mineral composition of laterite from southwestern Nigeria includes kaolinite, quartz, muscovite, microcline, goethite, hematite, montmorillonite, anatase, talc, and rutile. The use of laterite for construction purposes significantly enhances social and ecological values.

The geotechnical characteristics and field performance of most lateritic soils are significantly influenced by the nature of the parent rock, degree of weathering, morphological characteristics, chemical and mineral composition, and environmental conditions (Oyelami & Van Rooy, 2018). Lateritic soil formed from feldspar-rich parent rock is rich in clay material, exhibiting clay properties such as expansion and low drainage characteristics. In lateritic soil formed from partially weathered rock materials, the parent rock material forms aggregates within the lateritic soil, which can pose problems of material contrast when used for construction (Oyelami & Van Rooy, 2016).

The morphological characteristics of lateritic soil, such as texture, grain distribution, and layer thickness, affect the behavior of the soil material. Lateritic soils formed from parent material rich in silicate minerals such as quartz tend to have higher shear strength and load-bearing capacity than those formed from parent rock rich in mafic minerals. In environments with high rainfall, such as the tropical areas of southern Nigeria, lateritic soils are prone to swelling, erosional activities, and loss of strength (Oloruntola et al., 2005).

A good knowledge of the geotechnical characteristics of laterites enables engineers to use these soils appropriately by predicting their performance under field conditions with a fair degree of accuracy. Although there is often a wide variability in properties and conditions of laterite encountered on site, the behavior of a particular soil type can sometimes be accurately predicted based on the characteristics of other soils of similar classification. For instance, clayey soils generally have low permeability, while sandy soils generally have high permeability. The use of inappropriate laterite or other soil materials in engineering construction can lead to structural failure, resulting in the loss of lives and property (Olofinyo et al., 2019; Evurani et al., 2020). Studies into the fundamental failures of engineering structures built on laterite soils have shown that an adequate understanding of the geotechnical characteristics of the soil is invaluable.

In Nigeria, the great depths of unsaturated sediments of the coastal plain sands develop into laterite mounds on earth fills and are used for road pavement, foundations, and land reclamation (Adeyemi et al., 2015). This is due to the low cost and high availability of laterite. Most laterites in Nigeria, in their natural state, are best suited for the construction of sub-bases, but not as standard base construction materials. However, a high percentage of road failures in the tropics have been attributed to poor-quality laterite (Oloruntola et al., 2005). Edeh et al. (2012) showed that the strength and binding properties of lateritic soils can be enhanced using additives such as cement and asphalt, reducing failures in engineering structures.

To reduce the incidence of road failures attributed to the use of poor-quality laterites in the tropics, it is essential to establish the geotechnical properties of laterites used for road construction in tropical environments. This study seeks to evaluate the geotechnical properties of laterites in the tropical area of Lagos, assessing their suitability as road construction material to enable proper performance prediction and minimize the loss of lives and property. This will be achieved by determining the geotechnical properties of the lateritic soils, the clay activity of the soils, and the degree of permeability of the soils. The results obtained will be compared to similar studies on lateritic soils around southwestern Nigeria. The results of this study will enhance the suitability of recommendations for lateritic soil improvement for optimal performance.

Geological Settings

The study area is the Ojota–Shagamu stretch of the Lagos-Ibadan expressway, located within the Dahomey Sedimentary Basin in southwestern Nigeria (see Fig. 1). This area lies entirely within the Dahomey Sedimentary Basin, which forms the left extension of the Nigerian sedimentary basin. The Ojota–Shagamu stretch of the Lagos-Ibadan expressway is situated within the alluvial littoral and lagoonal deposits, and the Ewekoro and Abeokuta Formations of the sedimentary basin. This road serves as a major link between Lagos, a suburb in southwestern Nigeria, and the northern and eastern states of Nigeria.

The area lies in the tropical forest zone, characterized by thick vegetation and luxuriant trees. The average annual rainfall is 1200 mm, with extreme temperatures ranging between 22°C and 34°C (Boboye & Akinmosin, 2018). The area is fairly well drained, with streams exhibiting a dendritic drainage pattern that empties into the River Owuru, which in turn empties into the Atlantic Ocean (see Fig. 1). The topography of the area is relatively flat, with occasional weathered rocky hills. There are several lateritic mounds or profiles around the study area. The general succession of deposits above the crystalline Basement Complex includes the southern Cretaceous, Tertiary, and Quaternary sedimentary deposits, referred to as the Abeokuta Formation, Ewekoro and Ilaro Formations, and Coastal Plain Sands and Alluvium, respectively.

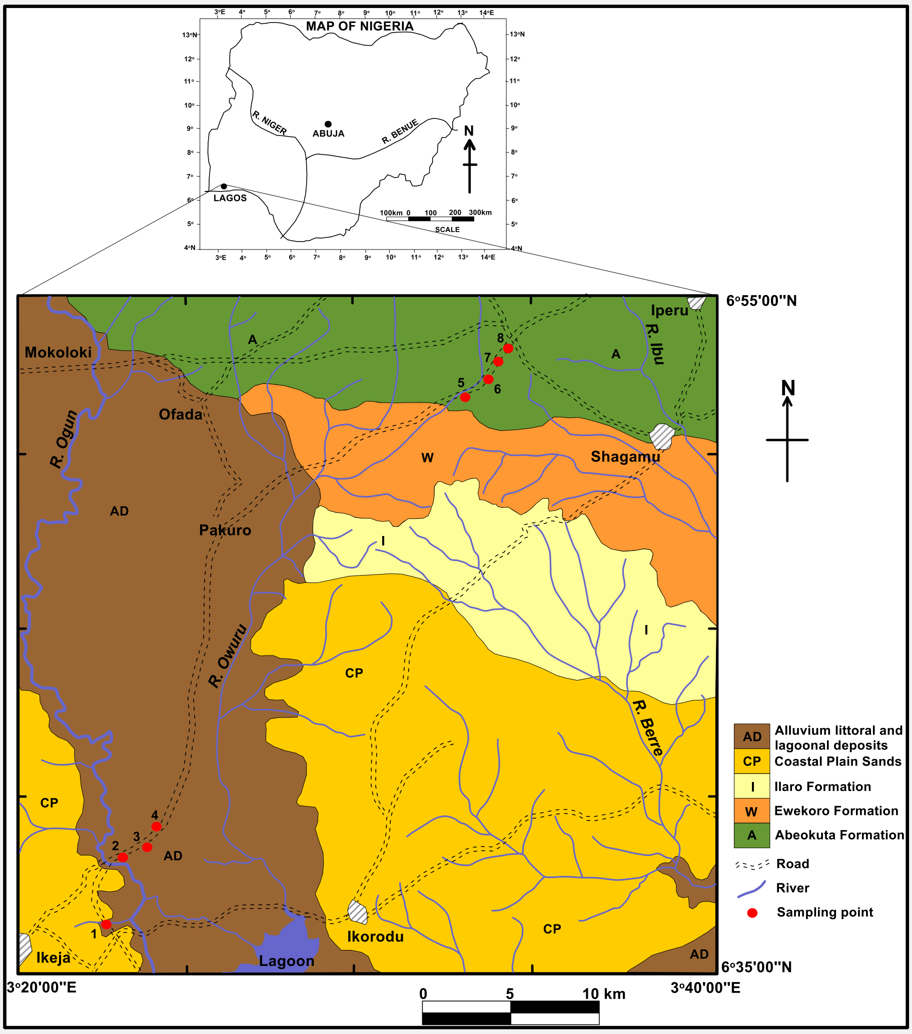

Figure 1. Map of Part of Southwestern Nigeria Showing Study Area.

Weathering and Laterization

The sedimentary formations characterizing the southern Cretaceous, Tertiary, and Quaternary deposits are largely sandstone, containing primary minerals such as iron and aluminum (Emmanuel et al., 2021). When these sedimentary formations are exposed at or near the Earth's surface, they undergo weathering due to variations in physical and chemical conditions, as well as an increase in the degree of consolidation with age (Jones & Hockey, 1964).

In tropical regions like Lagos State, Nigeria, weathering produces a wide range of tropical and subtropical soils with colors varying from light grey to yellow to dark red. These materials were first used to make bricks, hence the term "laterite" derived from the Latin word "Later," meaning brick. Laterite is a weathering product of various crystalline igneous rocks, sediments, detrital deposits, and volcanic ash, identified morphologically as surface or near-surface materials.

The process of weathering and decomposition of rock materials into kaolinite, ferric oxides, alumina-silica sesquioxide, goethite, and hematite, while retaining more resistant quartz and mica particles, and the subsequent loss of cementation due to leaching and groundwater action is called laterization (Mesida, 1981). Lateritic soils are products of tropical weathering with red, reddish-brown, or dark brown colors, with or without nodules or concretions, and are generally (but not exclusively) found below hardened ferruginous crust or hardpan (Ola, 1978; Adeola & Tubonemi, 2017).

While it is important to recognize the differences between lateritic and non-lateritic soils and further distinguish between various types of laterites, the primary consideration for identifying and evaluating lateritic soils for engineering purposes is not their nomenclature but their significant geotechnical characteristics and engineering behavior.

METHODS

Eight different lateritic soil samples were collected randomly from designated borrow pits for the road construction project using a hand auger. The samples were collected at a depth range of 15 cm to 50 cm from the surface to ensure representative sampling. The soil samples were placed in plastic bags, properly labeled, and sealed to prevent the loss of natural moisture content. The collection sites were existing borrow pits located at Ojota, Lagos State, and Shagamu ends of the Lagos-Ibadan expressway in southwestern Nigeria.

The geotechnical assessment of the eight lateritic soil samples was conducted in the Soil Mechanics Laboratory of the Department of Civil Engineering at the University of Lagos, Nigeria, in accordance with BS 1377 specifications. Laboratory tests were performed on the soil samples to determine their composition and geotechnical properties, including moisture content, specific gravity, particle size distribution, fabric/plasticity, compaction, and California Bearing Ratio (CBR).

Approximately 200 g of each soil sample was crumbled and weighed to the nearest 0.1 g in a container. The samples were then oven-dried for 24 hours, and the dry weight was recorded. The moisture content was calculated as a percentage of the dry soil mass.

For the specific gravity determination, about 50 g of each soil sample was transferred directly from the desiccator into a 50 ml density bottle and weighed. The weights of equal volumes of distilled and clean water were determined and used to compute the specific gravity of the soil samples.

The particle size distribution (grain size analysis) was determined using both wet and dry sieving methods. The sieves were nested together from the largest aperture sieve at the top to the pan beneath the smallest aperture sieve at the bottom. The soil samples were passed through the sieves, and the percentage retained on each sieve was determined.

The consistency test was carried out to determine the liquid, plastic, and shrinkage limits of the soil samples. The liquid limit test was conducted using the standard liquid limit apparatus designed by Casagrande. About 200 g of the dried soil samples passing through a 0.425 mm BS sieve was used for the plastic limit test. This involved rolling a portion of the samples, which contained sufficient water, on a glass plate using the palm of the hand until a thread of uniform diameter was formed. The threading and remolding process continued until the thread, at 3 mm diameter, began to crumble. The water content at which the crumbling took place was recorded as the plastic limit.

The soil compaction test was performed using the modified American Association of State Highway and Transportation Officials (AASHTO, 2008) compaction test (African Standard). 6.0 kg of air-dried soil, broken into individual particles, was mixed with 6% by weight of water. The mixture was divided into five parts and successively compacted in a mold using 25 evenly distributed blows of a 4.5 kg rammer. The compacted soil was then divided into two halves using a mallet and chisel. The first half was used for moisture content determination, while the second half was used to calculate the bulk density in mg/m^3.

The compaction process and calculation of moisture content and bulk density were repeated, with 2% by weight of water added incrementally to the soil samples until a drop was observed in the subsequent weight of the mold and soil. The dry density obtained in the series of determinations was plotted against the corresponding moisture content, and the resulting curve was used to determine the maximum dry density (MDD) and the optimum moisture content (OMC).

The California Bearing Ratio (CBR) values of the soil samples were obtained by measuring the relationship between force and penetration when a cylindrical plunger with a cross-sectional area of 1935 mm^2 was made to penetrate under a force of 250 N at a uniform rate of 1 mm/min. The force readings were taken at intervals of penetration of 0.25 mm up to a total penetration not exceeding 7.5 mm. The CBR values at 2.5 mm and 5.0 mm were calculated from the plot of force on the plunger against penetration, and the higher value was taken as the CBR value of the soil (Evurani et al., 2020).

RESULTS & DISCUSSION

The results of the geotechnical assessment of the eight (8) lateritic soil samples are presented in Table 1. The moisture content of the soil samples ranged between 4.00% and 14.46%, and the specific gravity ranged between 2.54 and 2.66. Particle size distribution (grain size analysis) was determined using wet and dry sieving methods. The analysis revealed that the soil samples exhibited varying particle sizes, with the percentage passing the 0.075 sieve ranging between 13.30% and 59.15%.

Consistency tests were conducted to determine the liquid and plastic limits of the soil samples. The results indicated that the liquid limit ranged from 27.00% to 47.00%, and the plastic limit ranged from 6.90% to 34.51%. Soil compaction tests were performed using the modified AASHTO compaction test method. The maximum dry density (MDD) of the soils ranged from 1.66 to 1.96 g/cm³.

The California Bearing Ratio (CBR) values for the soaked soil samples ranged from 18.73% to 55.59%, while the unsoaked CBR values ranged from 22.96% to 74.90%.

Grain Size Analysis

The results of the mechanical sieve analysis are presented in Table 1 and were used for soil classification (see Table 1). The fines content in the soil samples ranged from 13.30% to 59.15%. Soils with a high content of fines, primarily clay and silt materials, are known to be susceptible to expansion (Evurani et al., 2020). According to AASHTO (2008), soils with more than 35% fines passing the 75 μm sieve are considered to have high clay and silt content. High clay and silt contents in soils suggest that moisture presence could induce volume changes, leading to reduced load-bearing capacity. Volume changes are anticipated, particularly in soils with high percentages of fines, such as Samples 1, 4, 6, and 7, with fines percentages of 57.80%, 39.20%, 59.15%, and 35.50%, respectively (Table 1).

Table 1. Soil Geotechnical Properties

Sample No	1	2	3	4	5	6	7	8
Coordinate	6°36'25.4N 3°22'30.7E	6°38'28.9N 3°23'01.1E	6°38'40.4N 3°23'45.9E	6°39'35.4N 3°24'05.6E	6°52'08.4N 3°33'16.1E	6°52'30.4N 3°34'00.9E	6°53'10.1N 3°34'15.2E	6°53'50.5N 3°34'35.0E
Specific gravity	2.57	2.54	2.60	2.58	2.66	2.56	2.54	2.58
%Passing 0.075	57.80	23.10	30.35	39.20	34.40	59.15	35.50	13.30
Liquid Limit (%)	47.0	30.0	39.0	46.0	35.0	41.0	27.0	35.0
Plastic Limit (%)	12.14	6.90	34.51	20.63	25.90	18.50	13.74	29.34
Plastic Index (%)	34.86	23.10	4.49	25.37	9.10	22.57	13.26	5.66
MDD (mg/m³)	1.66	1.96	1.88	1.85	1.91	1.81	1.95	1.91
Moisture content (%)	14.46	3.55	6.31	6.35	6.05	4.00	5.00	7.00
OMC (%)	21.89	11.28	13.66	14.69	9.47	14.22	10.54	9.15
CBR (Soaked %)	55.59	41.09	18.73	28.40	24.17	21.15	24.17	35.65
CBR (Unsoaked %)	74.90	83.99	22.96	36.86	40.48	30.21	37.46	73.72
AASHTO Classification	A-7-6	A-2-6	A-2-4	A-7-6	A-2-4	A-7-6	A-6	A-2-4
USCS	CL	SC	SC-SM	SC	SC	CL	SC	SC-SM
Linear Shrinkage (%)	12.06	9.45	8.27	9.85	7.40	9.85	8.27	5.12

Specific Gravity

The specific gravity of soil depends significantly on sand content, mineral constituents, and soil formation processes (Oyediran & Durojaiye, 2011). The specific gravity values obtained for the eight (8) soil samples ranged from 2.54 to 2.66, with a mean of 2.58. These values fall within the acceptable range of 2.50 to 2.75 for good lateritic materials (Oluyinka & Olubunmi, 2018), indicating that the specific gravity of the lateritic soil samples in this study is considered acceptable.

However, Roy & Dass (2014) noted that an increase in specific gravity enhances shear strength parameters (cohesion and angle of shearing resistance) and California Bearing Ratio (CBR), which are crucial for sub-grade material strength. Thus, although the specific gravity values of the soil samples in this study are acceptable, their shear strength is relatively low, suggesting less stability in supporting structures compared to soils with specific gravity values closer to the upper limit recommendation.

Comparison of the specific gravity of the lateritic soil obtained in this study with that of other lateritic soils in southwestern Nigeria (see Table 2) reveals that the specific gravity of the study area's lateritic soil is lower. This lower specific gravity indicates reduced shear strength parameters, including cohesion and angle of shearing resistance, translating to weaker sub-grade material strength.

Table 2. Comparison of Soil Geotechnical Properties with Previous Studies

Property	Study	Osun	Ogun	Ekiti	Kwara
Specific gravity	2.50 – 2.58	2.55 – 2.80	2.51 – 2.89	2.52 – 2.72	
MDD (kg/m³)	1.66 – 1.96	1.11 – 1.85	1.40 – 1.81	1.7 – 1.86	1.84 -1.85
OMC (%)	9.15 – 29.89	13.5 – 24.6	18.20 – 28.30	15.0 – 15.2	14.0 – 15.0
LL (%)	27.0 – 47.0	35.8 – 46.2	12.80 – 40.10	32.4 – 37.0	40 – 46
PL	6.90 – 34.51	23.33 – 35.4	10.00 – 22.00	15.60 – 17.7	18.2 – 23.5
PI	4.49 – 34.86	3.6 – 16.1	2.80 – 20.40	16.8 – 19.6	21.8 – 22.5
Clay activity	0.41 – 2.11	ND	ND	ND	0.63 – 0. 95
CBR % (soaked)	18.73 – 55.59	17.0 – 21.0	ND	2.0	1 - 4
CBR % (unsoaked)	22.96 – 74.90	ND	12.52 – 55.84	2.0 – 3.0	3 - 4

ND – Not determined
Source: Ayodele et al. (2021), Oluyinka & Olubunmi, (2018), Obaro & Obaro (2021), Omotoso et al. (2012)

Soil Classification

According to the AASHTO soil classification chart, Samples 2, 3, 5, and 8 contain less than 35% fines and are classified as A-2 (Table 3). These samples consist of silty or clayey gravel and sand, making them suitable for excellent to good sub-grade material. Samples 1, 4, 6, and 7 contain more than 35% fines and are classified as A-6 or A-7 (Table 1). These soil samples are predominantly clayey and are considered fair to poor sub-grade material.

Using the Unified Soil Classification System (USCS), Samples 1 and 6 are classified as silty clay (CL). Samples 2, 4, 5, and 7 are classified as clayey sand (SC), while Samples 3 and 8 are categorized as silty to clayey sand with gravel (SC-SM).

The effective grain size (D_{10}) ranged from 0.00003 to 0.03000 mm (Table 3). The uniformity coefficient (Cu) for the soil samples varied significantly, ranging from a low value of 28.33 to an extremely large value of 10000.00 (Table 3). Extremely large Cu values are associated with well-graded soils exhibiting flat grain size distribution curves (Ajayi et al., 2021).

The coefficient of curvature (Cc) ranged from 0.15 to 63.38 across the soil samples (Table 3). Soils with smooth curves typically have Cc values between 1 and 3, whereas irregular curves have Cc values less than 1 or greater than 3. The Cc values obtained from the soil samples indicate that all samples exhibit smooth curves, except for Samples 2, 3, and 8.

Table 3. Summary of Grain Size Analysis and Coefficient of Permeability

Sample No	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	$C_u = \frac{D_{60}}{D_{10}}$	$C_c = \frac{D_{60}}{D_{10}D_{60}}$	K ($\times 10^{-3}$cm.s^{-1})	% Clay (2µm)	A = PI/%Clay
1	0.00070	0.00350	0.12000	171.43	0.15	0.049	20	1.74
2	0.00100	0.19500	0.60000	600.00	63.38	0.100	13	1.78
3	0.00150	0.08500	0.45000	300.00	10.70	0.225	11	0.41
4	0.00040	0.00600	0.35000	875.00	0.26	0.016	12	2.11
5	0.00150	0.02500	0.23000	153.33	1.81	0.225	11	0.83
6	0.00003	0.00350	0.30000	10000.00	1.36	0.900	12	1.88
7	0.00050	0.02000	0.30000	600.00	2.67	0.025	12	1.11
8	0.03000	0.40000	0.85000	28.33	6.27	90.000	5	1.13

The coefficient of permeability of the soil samples was determined using the Hazen's formula, which is most suitable for sandy materials with D_{10} between 0.1 and 3.0 mm and a coefficient of uniformity less than 5.0 (Fetter, 2001; Odong, 2007). The coefficient of permeability values ranged from 9.0 x 10^-2 to 4.9 x 10^-5 cm/s (Table 3).

Based on these values, all soil samples exhibit semi-pervious characteristics (Bear, 1972), which is advantageous for soils used in road construction. However, these soils have high clay content and will retain water upon contact, potentially leading to reduced strength and eventual material failure.

Consistency (Atterberg) Limit

The results of the consistency tests, including liquid limit, plastic limit, plasticity index, and shrinkage limit, were used to assess the strength and settlement characteristics of the soil material. The liquid limits of the soil samples ranged from 27.0% to 47.0%, plastic limits ranged from 6.90% to 34.51%, and the plasticity index ranged from 4.49 to 34.86 (Table 1).

According to guidelines, sub-base materials should have a liquid limit of ≤ 30% and a plasticity index of ≤ 12%, while materials for use as sub-grade should have a liquid limit < 50% and a plasticity index < 30% (FMWH, 1997; Ige, 2009; Evurani et al., 2020). A liquid limit of less than 30% indicates low plasticity, whereas a liquid limit of 50% and above indicates high plasticity (Whitlow, 1995).

All soil samples in this study are capable of significant deformation under load due to their plastic nature. However, the soil samples generally exhibit medium plasticity, with liquid limits ranging between 30% and 50%, except for Sample 7, which showed low plasticity with a liquid limit of 27.0% (see Fig. 2).

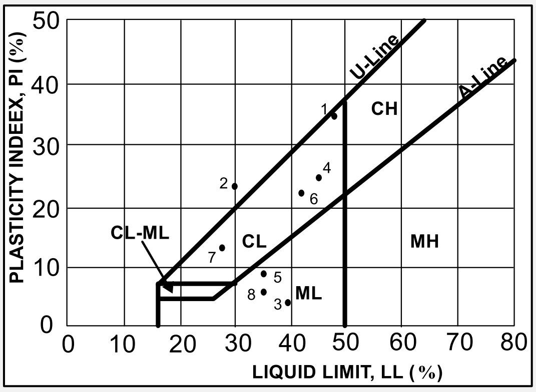

Figure 2. Casagrande's Plasticity Chart.

The soil samples exhibited a range of plasticity indices from 4.49% to 34.86% (Table 1), indicating they are fairly plastic. Samples 3 and 8 had the lowest plasticity indices at 4.49% and 5.66%, respectively. Lower plasticity indices suggest better performance as sub-base or sub-grade materials, as they are less prone to significant changes in plasticity with varying moisture content. All soil samples except Sample 1, which had a high plasticity index of 34.86%, are suitable for use as sub-grade materials based on their plasticity indices. Samples 3 and 8, with their low plasticity indices, are particularly ideal for sub-grade applications. Sample 7 met the requirement for sub-base material due to its low liquid limit (27.0%) and plasticity index (13.26) (Table 1).

In Casagrande's plasticity chart (Fig. 2), Samples 1, 4, 6, and 7 fell within the low plasticity clay (CL) region with medium compressibility (liquid limit between 30% and 50%), except for Sample 7, which exhibits low compressibility (liquid limit < 30%). Sample 2 is classified as medium plasticity sandy clay with medium compressibility, plotting above the U-line. Samples 3, 5, and 8 fell below the A-line and were classified as low plasticity silt (ML) with medium compressibility.

The linear shrinkage test results indicate that soil samples exhibit linear shrinkage ranging from 5.12% to 12.06% (Table 1). Four samples (1, 2, 4, and 6) exceed the maximum recommended value of 8% for sub-grade materials (Olofinyo et al., 2019). These samples are susceptible to swelling in the wet season and shrinkage in the dry season, typical of tropical environments like the study area. Samples 3, 5, 7, and 8 are suitable for use as sub-grade materials based on their linear shrinkage characteristics. Samples 1, 2, 4, and 6, which exceeded the recommended limit, may benefit from soil stabilization processes to enhance their suitability for road construction.

Comparison of the consistency limits of the lateritic soil in this study with those of other lateritic soils in southwestern Nigeria (Table 2) reveals larger ranges in liquid limit, plastic limit, and plasticity index for the soil in this study. This variability suggests that the soils studied here exhibit a wide range of water contents, influencing their shear strength, plastic behavior, and shrinkage characteristics.

Clay Activity

Clay activity of the soil samples was determined by combining Atterberg limits and clay content into a single parameter (Skempton, 1953). This parameter reflects the mineralogy and geological history of the clays present in the soils, as the properties of clay soils are influenced by the physicochemical characteristics and proportions of constituent minerals (Olofinyo et al., 2019). The plasticity index of each soil sample was divided by the percentage of clay-sized fraction to obtain the activity, which measures the likelihood of exhibiting colloidal behavior. Activity values less than 1 indicate kaolinite, values between 1 and 2 indicate illite, and values above 2 indicate montmorillonite. Values below 0.75 indicate inactive minerals, while values between 0.75 and 1.25 are considered normal, and values above 1.25 indicate active minerals (Skempton, 1953).

In this study, clay activity ranged from 0.41 to 2.11 (Table 3). Samples 3 and 5 exhibited activity values less than 1, indicating the presence of kaolinite. The kaolinite in Sample 3 is inactive (activity < 0.75), whereas the kaolinite in Sample 5 is active (activity > 0.75). Samples 1, 2, 6, 7, and 8 had activity values between 1 and 2, indicating the presence of active illite. Sample 4 had an activity value of 2.11, indicating the presence of active montmorillonite. These results correlate with the consistency test and linear shrinkage findings, where Samples 3, 5, 7, and 8, recommended as suitable for road construction, exhibited lower clay activity compared to Samples 1, 2, 4, and 6. Samples 5, 7, and 8 may require minor soil stabilization to mitigate the effects of their active clay content.

Comparison with other lateritic soils in southwestern Nigeria (Table 2) revealed that the lateritic soil from this study generally exhibited higher clay activity. This higher clay activity in the Ojota–Shagamu area's lateritic soil could be attributed to the concentration of active clay minerals resulting from weathering of the parent rock material.

Compaction

The results of the compaction test were plotted as a graph of dry density versus moisture content (Fig. 3). The plot shows that higher densities are achieved with increased moisture content up to an optimal moisture content (OMC), beyond which further increases in moisture content lead to lower densities. This curve shape indicates that adding a small amount of water to cohesive soil improves compactibility by enhancing cohesion between particles and increasing dry density. However, excessive water beyond the OMC reduces compactibility as water acts as a lubricant, causing soil particles to slide past each other and decreasing dry density (Fig. 3).

Compaction testing is crucial in geotechnical assessments as it reveals soil compressibility and compactibility. The results showed that Samples 2 and 7 achieved the highest Maximum Dry Density (MDD) of 1.96 kg/m³ and 1.94 kg/m³, respectively, at OMCs of 11.28% and 10.54%, respectively. Sample 1 exhibited the lowest MDD of 1.66 kg/m³ at an OMC of 21.89%. Samples 2 and 7, achieving MDD at relatively low OMCs, are deemed the most suitable for use as sub-base or sub-grade materials based on their compactibility. In contrast, Samples 1, 3, 4, and 6 (excluding Samples 5 and 8) achieved MDD at higher OMCs (>13%) due to their higher fines content and therefore more pronounced plasticity, particularly evident in Sample 1.

The primary objective of soil compaction is to increase soil density and shear strength while reducing compressibility and permeability. Optimal results are achieved when compaction reaches 100% of MDD at OMC, ensuring desired soil properties such as consolidation and reduced permeability (Ogundipe, 2012).

Comparison with other lateritic soils in southwestern Nigeria (Table 2) revealed that the lateritic soils from the Ojota–Shagamu area generally exhibited higher compaction abilities at low OMCs compared to other lateritic soils in the region. However, Sample 1 from the Ojota–Shagamu area exhibited low compaction ability, likely due to its high percentage of fines.

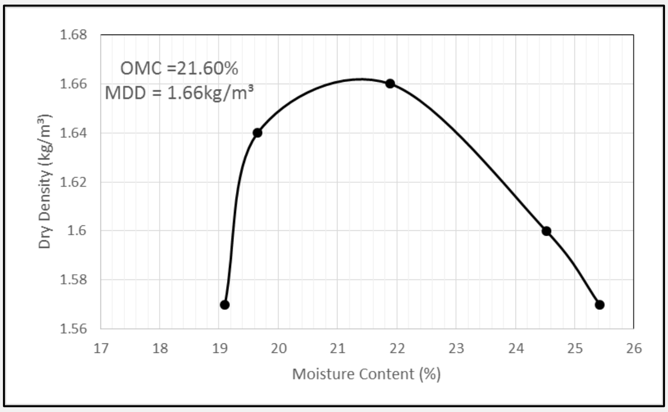

Figure 3. Typical Compaction Curve for Sample 1.

California Bearing Ratio (CBR)

The CBR test results obtained in this study ranged from 18.73% to 55.59% for soaked tests, and from 22.96% to 74.90% for unsoaked tests (Table 1). Figure 4 illustrates a typical CBR curve for Sample 1. FMWH (1992) recommends a minimum CBR of 30% (soaked) and 10% (unsoaked) for materials used as sub-base and sub-grade, respectively. Samples 1, 2, and 8 exhibited CBR values exceeding 30%, indicating suitability for use as sub-base materials. Additionally, all soil samples showed CBR values above 10% (soaked), indicating suitability for use as sub-grade materials based on CBR criteria.

Furthermore, the CBR test results demonstrated that soaked CBR values were considerably lower compared to unsoaked CBR values. This reduction signifies that water absorption into the compacted soil diminishes its strength. Therefore, when utilizing such soils as sub-base or sub-grade materials, adequate drainage is crucial, particularly in regions with high precipitation such as the study area.

Comparison of the CBR (soaked and unsoaked) values of the lateritic soil from this study with those of other lateritic soils in southwestern Nigeria (Table 2) revealed a wide range of CBR values. This suggests that the lateritic soil in the study area exhibits higher CBR values but lower shear strength parameters of cohesion and angle of shearing resistance, resulting in reduced strength when used as sub-grade material.

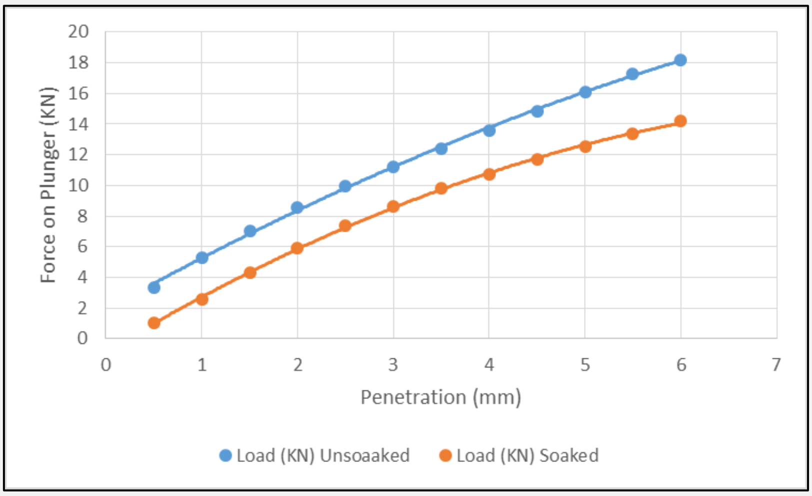

Figure 4. Typical CBR for Soil Sample 1 (Adesanya, 1997).

CONCLUSION

Laterite soils collected along the Ojota and Shagamu ends of the Lagos–Ibadan expressway were assessed for their suitability as sub-base and sub-grade materials. Various tests including moisture content, specific gravity, particle size distribution, consistency, compaction, and CBR were conducted on the soil samples to determine their suitability.

The geotechnical assessment revealed that 50% of the soils were classified as clayey sand, 25% as silty clay, and the remaining 25% as silty to clayey sand. Overall, all soil samples exhibited moderate plasticity and semi-pervious characteristics, indicating suitability for use as sub-grade materials, except for Sample 1 which had a high plasticity index of 34.86. Approximately 50% of the lateritic soils (Samples 3, 5, 7, and 8) were identified as suitable for road construction materials, while the remaining samples (Samples 1, 2, 4, and 6) would require minor soil stabilization due to their active clay content.

Samples 1, 2, and 8 exhibited CBR values exceeding 30%, indicating suitability for use as sub-base materials. Furthermore, all soil samples exhibited CBR values above 10% (soaked), confirming their suitability as sub-grade materials. However, soils with high clay and silt content, such as Samples 1, 4, 6, and 7, may experience volume changes due to water retention, potentially leading to reduced load-bearing capacity and material failure.

The lateritic soils from the Ojota–Shagamu area exhibited lower shear strength, higher clay activity, relatively higher compaction ability at low OMC, and a wide range of CBR values (soaked and unsoaked), distinguishing them from lateritic soils in other parts of southwestern Nigeria. To mitigate potential issues, it is recommended to implement adequate drainage systems to prevent water accumulation around road pavements. Further research on soil stabilization techniques specific to Ojota–Shagamu lateritic soils would enhance their applicability and usefulness for construction purposes.

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