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Engineering assessment of Lateritic soils of Obiaruku highway sections in South-southern, Nigeria

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ABSTRACT

In order to determine the suitability of lateritic soils for the paving structures of highways, an engineering examination of some numbers of unsuccessful routes and highways in Obiaruku, southern Nigeria, was conducted. Thirty-two (32) lateritic bulk soil samples were taken for road construction-related index and strength testing from three stable and five failing sections. Compared to soils from the failed parts of A-7-6, which indicate poor-quality sub-grade materials, the soils from the stable sections have a greater specific gravity (2.49–2.85) and a lower percentage of clay (23.90%), indicating A-2-6 on the AASHTO classification system. Pores water pressure developed as a result of the high water absorption capacity, high proportion of fine particles (> 40%), and high values of linear shrinkage (> 8%) of the majority of soils from failed sections, leading to a loss in soil index strength. The degree of instability observed is caused by the predominance of fines in lateritic soils, low California bearing ratio (16–39% un-soaked), intermediate and high OMC above recommendation for most soil samples (12.6–19.1), maximum dry density (MDD) (<2000 kg/m^3), and liquid limit (35.1–53.0). The lateritic soils of failed sections have poor geotechnical qualities, which suggest that they are not appropriate for use as sub-grade materials in other engineering constructions or even in the construction of new roads. For an accurate assessment of the sub-grade soils for highways, the significance of lateritic soils in detail sampling is emphasized. The findings of this study will be helpful in the rehabilitation and reconstruction of the road's failing parts, and it is advised that this investigation be well documented for future use.

Keywords:
Engineering evaluation,
Lateritic soil,
Obiaruku highway,
Strength properties,
Road construction

INTRODUCTION

Every engineering structure is built on either rock or soil, and the properties of the soil affect how well the structure works. Engineering buildings are built with the intention that they would endure over time anywhere in the world. Unfortunately, a thorough understanding of soils' geotechnical characteristics is lacking, which is a requirement for using them in civil engineering building projects. A country's road network is essential to its socioeconomic development. Nigeria ranks among the nations with the highest rates of traffic accidents, with fatalities and property damage resulting from poor road conditions on a regular basis (Ademila, 2016).

In Nigeria, decisions are made on road design and construction without considering the underlying soils' geotechnical behavior and geology. These have caused problems with highways and roads. In any country that wants to grow, the connection between highway pavements and foundation soils cannot be overstated. Every locality's geological past has a significant impact on the resulting engineering soils in every situation (Meshida, 2006; Esi and Akpoyibo, 2023). Pavement damage appears soon after repairs, despite ongoing rehabilitation and also reconstruction of the failing parts along Obiaruku-Umutu road.

The most prevalent surface deposits in Nigeria's southern regions are lateritic soils, which are rich in iron and aluminum and result from extensive, protracted weathering of the parent rock beneath them for sand variability (Gidigasu and Kuma, 1987; Esi et al., 2023). Only in Nigeria can laterites be used as the ideal soil material to solve any construction-related issue, including building airfields, roads, embankments, earth dams, and foundation materials for supporting structures without taking into account the soil's actual field geotechnical performance or its classification as a problem or non-problem type. Laterites with qualities that make them challenging for building road are known as issue laterite.

When utilized as sub-base materials, these soil types cause pavement to swell, sink, and migrate laterally in the presence of water even with mild wheel loads. These soil types are easily identified in aviation and highway pavement. Their low natural densities, friable structure, large natural water contents and liquid limits (Gidigasu and Kuma, 1987).

Laterites without these characteristics are therefore non-problem kinds. Building roads is done with lateritic soil in tropical regions of the world, such as Nigeria. It serves as the base course, sub-base, and sub-grade for most tropical roads as well as the sub-grade for low-cost routes that typically see minimal to moderate traffic. They are also utilized as building materials for plastering and brick moulding. The majority of the time, inadequate geotechnical qualities of the underlying soils that make up the entire road surface are the cause of failures on Nigerian highways. Akpoyibo et al. (2022) have provided a study of the elements impacting pavement performance. These factors include a variety of road failure types, such as ruts, cracks, potholes, and road-cutting that results in differential heave of the pavement.

According to Adeyemi and Wahab (2008), there may be a large variation in the geotechnical characteristics of the soils across relatively short distances. The geological foundation for some of the western Niger Delta's, Nigeria's failures was investigated by Ugbe (2011). He came to the conclusion that additional stabilizations were necessary since the soils beneath the failing parts are not mechanically stable. The stability, strength, and integrity of lateritic soil cannot be guaranteed under strain when water is present if there is a significant concentration of clay elements present.

The way soil behaves under loads is determined by its geotechnical characteristics, which include its specific gravity, grain size distribution, plasticity, compressibility, soil compaction, California bearing ratio, and so forth (Ofomola et al., 2018; Anomohanran et al., 2023). The appropriate laboratory can assess these attributes. The need for a thorough geotechnical assessment of lateritic soil before using it for road building has been highlighted by the failure of lateritic roads in Nigeria and other developing nations. This is necessary to select the right soil materials for the pavement structure. This research project aims to discover the factors causing the continuous failure of Obiaruku-Umutu road quickly after rebuilding and rehabilitation, which includes removal and replacement of the unstable soil materials responsible for the never stopping failure.

MATERIALS AND METHODS

Location and study area geology

The Ukwuani investigated area is located in the southwestern end of Nigeria called the Niger-Delta basin.It lies within Latitudes 5° 51' N and 5° 521 N and Longitudes 6° 121 E and 6° 18'E and is bounded in the North, East and by West as shown in Figure 1. The detailed description of the geology of Niger-Delta has been extensively given by Short and Stauble (1967), Kogbe (1981), Okolie and Akpoyibo, (2012) and Ofomola et al., 2017.

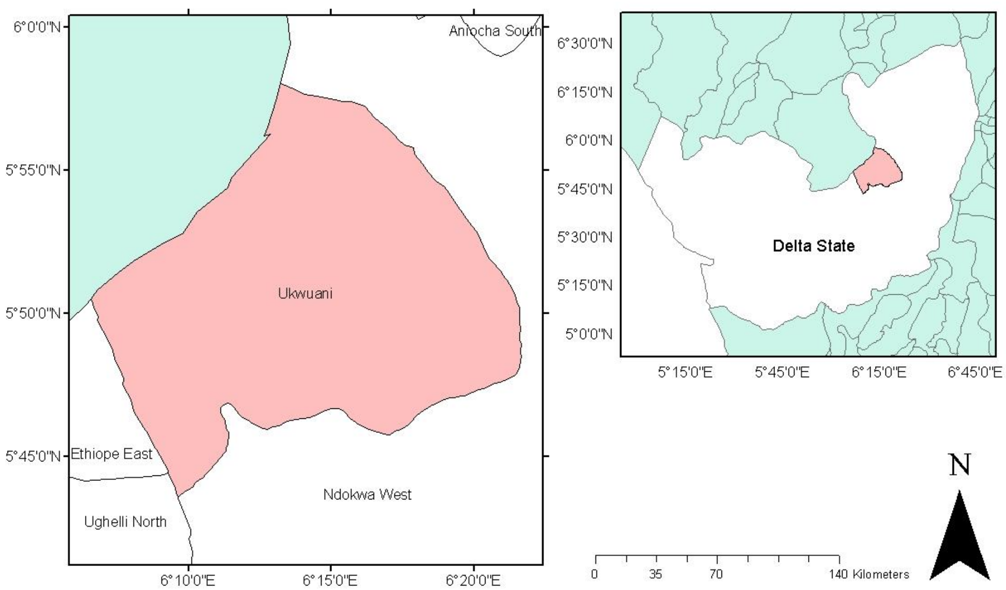

Figure 1: Map of Delta State showing Ukwuani where Obiaruku is located

Comprehensive geological field mapping is part of this research project, which aims to determine the local geology of the area and identify stable and failing areas of the route under study. The rock and soil exposures on the field were noted and documented. Eight trial pits yielded thirty-two bulk samples of the soils. At sampling depths of 0.3 m to 2 m, twenty samples from five failed sections and twelve samples from three stable portions of the road acting as a control were collected. This allowed for the acquisition of real representative samples of the fillings, materials that are subgrade and subbase. Before being transported to the lab in sealed polythene bags to avoid contamination and moisture loss, each soil sample was meticulously labeled in sample bags. In the lab, the natural moisture content was ascertained right away. Prior to further investigation, soil samples were allowed to air dry for two weeks in order to partially remove natural water. Following drying, the samples' lumps were carefully ground under light pressure so as not to decrease the size of the individual particles. The materials were subjected to natural moisture content (amount), specific gravity, atterberg (consistency) limits, linear shrinkage, compaction, grain size distribution, and the ratio of California bearings tests in the laboratory. The British Standard Methods of Testing Soils for the use of civil engineering (BS, 1990) and (ASTM, 2009) were followed in the execution of these laboratory investigations. Grain size analysis samples were immersed in a mild calgon solution to aid in the disintegration process during wet sifting.

RESULTS AND DISCUSSION

Low compressibility and sufficient strength from a solid foundation are key components of satisfactory pavement performance. In order to transfer loads evenly and effectively, pavement constructions rely on the physical and technical characteristics of the base and subgrade layers beneath them.

Table 1: Soil index properties of the studied area

Road condition	Pit No.	Depth (m)	Natural moisture content (NMC)	Specific density(GS) range	Size distribution		AASHTO Classification
					Clay grain (%)	Fines (%)	
Failed	F1	0.3-2.0	12.6-17.6	2.54-2.62	36.8	42.8	A-7-6
Failed	F2	0.3-2.0	11.6-18.1	2.16-2.69	41.5	50.4	A-7-6
Failed	F3	0.3-2.0	13.6-19.2	1.69-2.72	36.2	57.4	A-7-6
Failed	F4	0.3-2.0	12.9-22.5	2.04-2.56	37.8	50.7	A-7-6
Failed	F5	0.3-2.0	14.2-23.7	1.56-2.49	46.5	41.6	A-7-6
Stable	S1	0.3-2.0	10.6-23.7	2.64-2.82	23.9	39.0	A-2-6
Stable	S2	0.3-2.0	9.82-12.6	2.49-2.68	15.6	30.5	A-2-6
Stable	S3	0.3-2.0	8.96-11.9	2.74-2.85	17.4	32.9	A-2-6

Table 2: Atterberg limits of the investigated soils

Pit Count (Number)	Liquid limit range (%)	Plasticity index range (%)	Linear shrinkage
F1	35.1-42.2	13.1-20.0	10.1-14.2
F2	40.1-45.5	15.2-22.4	11.4-13.6
F3	37.2-53.0	17.5-21.5	9.2-15.6
F4	39.0-49.2	9.6-18.5	10.2-16.0
F5	33.5-52.8	14.2-25.6	5.0-15.3
S1	28.9-34.8	10.5-15.2	5.3-10.6
S2	19.8-40.5	8.0-122	4.9-9.5
S3	27.2-30.4	9.2-12.6	7.6-11.3

Index Characteristics

Table 1 summarizes the findings of the index tests performed on the soil samples, which are crucial variables in the computation of soil engineering.

Natural moisture content

The studied soil samples from the failing sections of the highway ranged in natural moisture content from 11.58 to 23.7% (Table 1), whereas the samples from the stable sections varied between 8.96 and 13.7%. The fact that these values exceed the FMWH, 2000 average range of 5–15% for engineering construction indicates that the soils from the failed portions has a high natural moisture content. This suggests that the soil material has a high capacity to absorb water. However, the topography, hydrology, and the area's climate where the road is to be built may all have an impact on lateritic soil's performance (Ademila, 2017). The natural moisture content among the soils within the research areas varies, and these variations are caused by several causes. Because a rise in moisture content causes a decrease in material shear strength, natural moisture content is employed as a gauge for soil shear strength.

Specific gravity

Table 1 show that the soils' specific gravities varied from 1.56 to 2.85. The American Association of State Highways and Transport Officials (AASHTO) have classified subgrade material as good to fair (group A-2-6). It is evident that soils from stable portions have a greater specific gravity (Gs = 2.49 – 2.85) and less clay (23.9%). The investigated soils can be categorized as inorganic clayey soils based on this specific gravity (Ramamurthy and Sitharam, 2005). The weight of that specific soil divided by the weight of an equivalent volume of water is known as specific gravity. It is a sign of the dry, saturated surface state. It also depends on how many spaces and quartz-like particles there are in the soil. According to Ademila (2017), the specific gravities of the majority of clay minerals are within a broad range (1.6 - 2.9). The degree of soil laterization increases with increasing specific gravity. This suggests that the laterization of soils from stable portions is higher than that of soils from failed sections. The findings indicate that the stable sections' soils primarily contain quartz material whereas the failed sections' soils are montmorillonitic in nature.

Particle size distribution

Table 1 provides an overview of the findings from the analysis of the distribution of the grain size. A sample grading curve is shown in Figure 2. The soil percentage from failed portions that pass No. 200 (0.075 mm) ranges from 42% to 58% while the stable sections' percentages range from 31% to 39%. The grading curves allow the soils to be categorized as well-graded soils. The large fines proportion (>50%) in the failed soils sections (F2, F3, and F4) can be observed. This suggests that the earth's soil surfaces have the tendency to repeatedly shrink and enlarge throughout the alternate seasons, both rainy and dry, in the humid tropics climate of southwest Nigeria, causing noticeable distress on the road. It is thought that forces created by the expanding soils are what lead to the failures seen in the study region. Additionally, the soils from the collapsed sections' high clay content indicate that they have a significant propensity for swelling, rendering them inappropriate for subgrade material. According to Ademila (2017), the sections of the stable soils designated S2 and S3 have percentages passing 0.075 mm of less than 35% with an average of 32% value, while the tested soils of the stable sections S1 have percentages passing 0.075 mm of 39% with an average of 34.8%. These soils are generally rated the subgrade roadway material as fair to good. The AASHTO categorization group A-7-6 for the failing's soils sections indicates substandard material with a range of fines from 42 to 57% (Table 1). The level (extent) of instability observed can be attributed to the prevalence of fines.

Atterberg limits

Table 2 provides an overview of the water (liquid) limit, index of plasticity, and linear shrinkage test findings. The failed portions soils had liquid limits, plasticity indices, and linear shrinkages ranging from 34 to 49%, 10 to 25%, and 5 to 16%, respectively, while stable soils parts had values ranging from 20 to 40%, 9 to 15%, and 5 to 11%, respectively. Liquid limit values between 35% and 50% imply intermediate plasticity, high plasticity if between 50% and 70% and very high plasticity if it is 70% to 90% (Whitlow 1995; Ademila, 2016).All soils exhibits notable deformation under load since they are classified as moderately plastic. The findings demonstrated that the poor geotechnical qualities of the soils from the unsuccessful sections make them unsuitable as base material and subgrade for pavement structure foundations. The subgrade soils' activity is often greatly influenced by the plasticity index. The failed soil portion had linear shrinkage ranging from 5.0% to 16.0%. Because the value is higher than the maximum 8% advised by Madedor, 1983, the soil in southwest Nigeria's humid tropical climate is unsuitable for use for both highway and foundation because it is prone to swelling and shrinking during the region's seasons. The engineers need to consider this when designing the pavement structure's base. For some subsurface material, the stable sections linear shrinkage soils values ranged significantly over the required value. The fine soil mixtures of the failed sections contained clay with greater plasticity index and linear shrinkage values in contrast to the soil combinations found in the places that are stable. According to Jegede (1999) and Ademila (2017), there is generally less trend for soil to shrink after drying due to lower linear shrinkage. Consequently, this study demonstrates that stabilization is still an option for changing the soils to meet the required parameters.

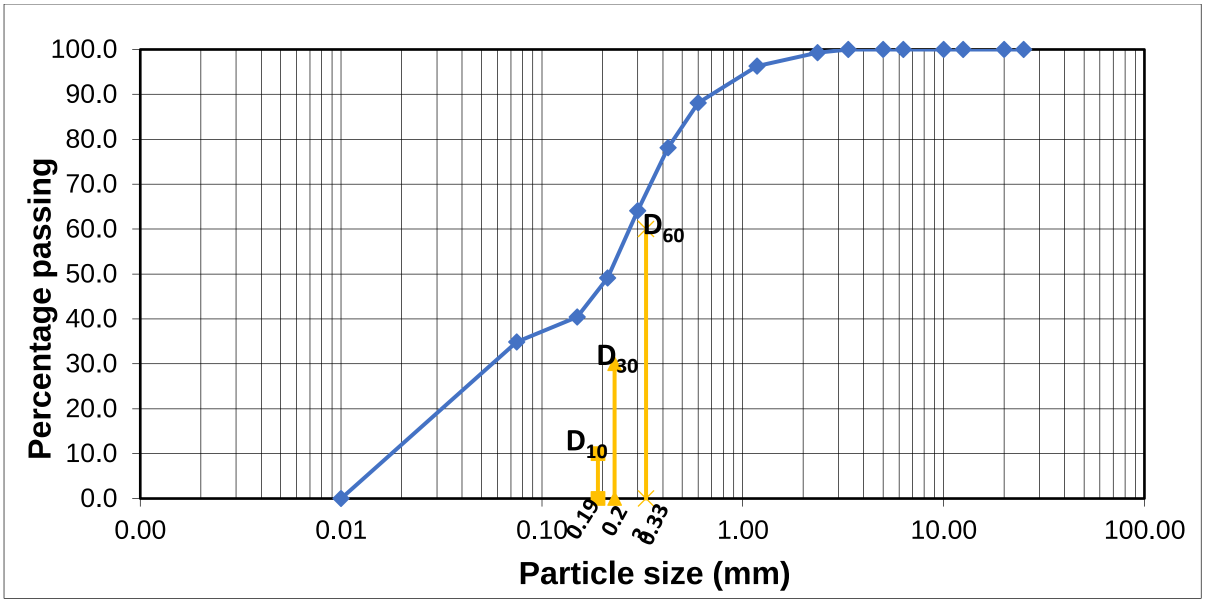

Figure 2: Particle size distribution sketch for soil sample acquired from Failed section 4 (F4).

Compaction features

Reaching a high density during construction is necessary for compacting soils for roads to prevent damaging consolidation happening under the weight of traffic or an embankment. Compaction also lessens the negative impacts of water. The maximum (peak) dry density (MDD) and optimal moisture content (OMC) of soils that are lateritic at the West African level of compaction are reported in Table 3 and Figure 3 displays typical compaction curve. The soils from the failed roadway portions had MDD ranging from 1706 to 2026 kg/m^3 at OMC of 10.5 to 19.1%, while the soils from the stable sections had MDD ranging from 2010 to 2204 kg/m^3 at 8.0 to 13.0% (OMC) (Table 3). The soils react to compaction gradually, as these values demonstrate. On the other hand, high MDD soil at low OMC is the ideal soil for foundation (Ugbe 2011). Improving the desired load bearing capacity of pavement constructions is the main goal of compaction. The constant saturation of underlying soils with water leads to rise in the breakdown of structures designed by civil engineers and road pavements. The findings indicate that in order to achieve maximum strength, stop water infiltration, and evenly distribute wheel loads throughout the pavement structures, those constructions' foundations must always be compacted above the MDD (> 2000 Kg/m^3) and OMC ($\leq$ 8) to produce maximum strength, stop water from entering the pavement, and evenly distribute wheel stresses across the pavement structures.

Table 3: Strength behaviors of the research soils

Pit Count	OMC range (%)	MDD (Kg/m^3)	CBR
F1	11.6-18.9	1892-2014	18-36
F2	15.2-19.1	1706-2026	20-40
F3	12.6-14.5	1868-1940	15-32
F4	10.7-13.0	1906-2120	19-39
F5	13.6-15.6	1860-1980	16-28
S1	9.6-12.2	2059-2090	36-49
S2	8.2-11.4	2010-2159	38-52
S3	8.0-13.0	2118-2204	40-49

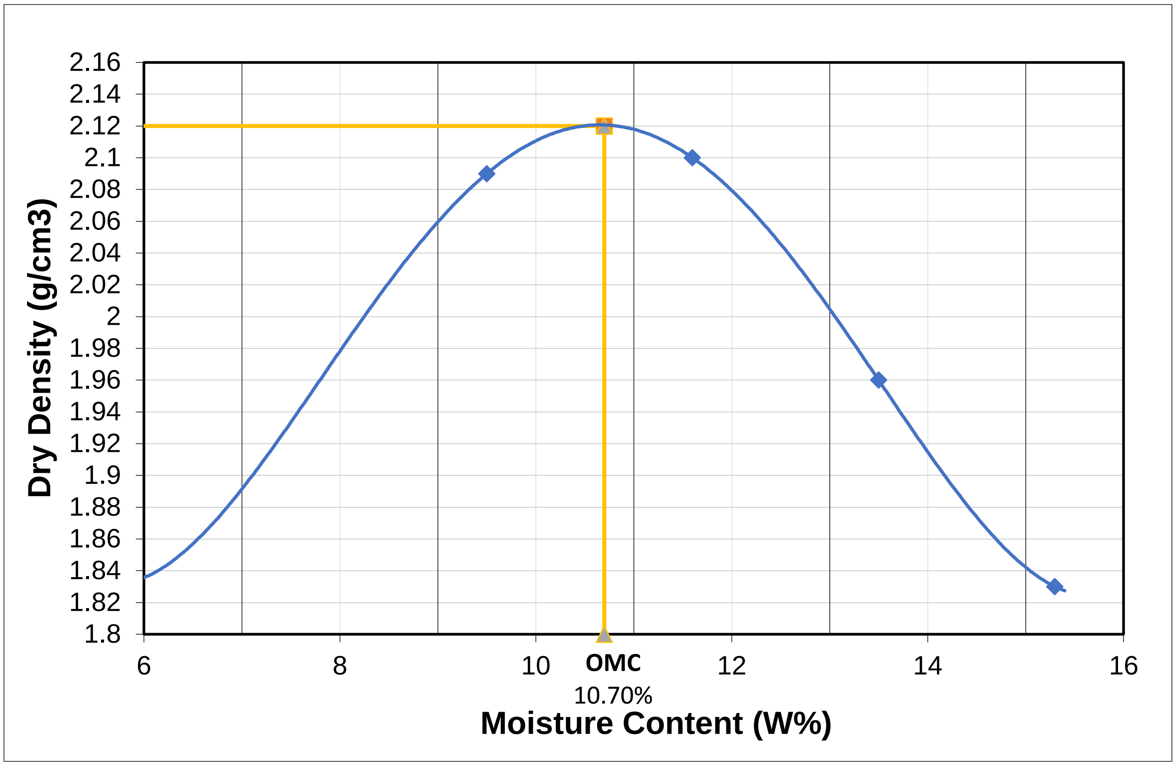

Figure 3: Compaction behavior soil sample curve obtained from Obiaruku failed section (F4)

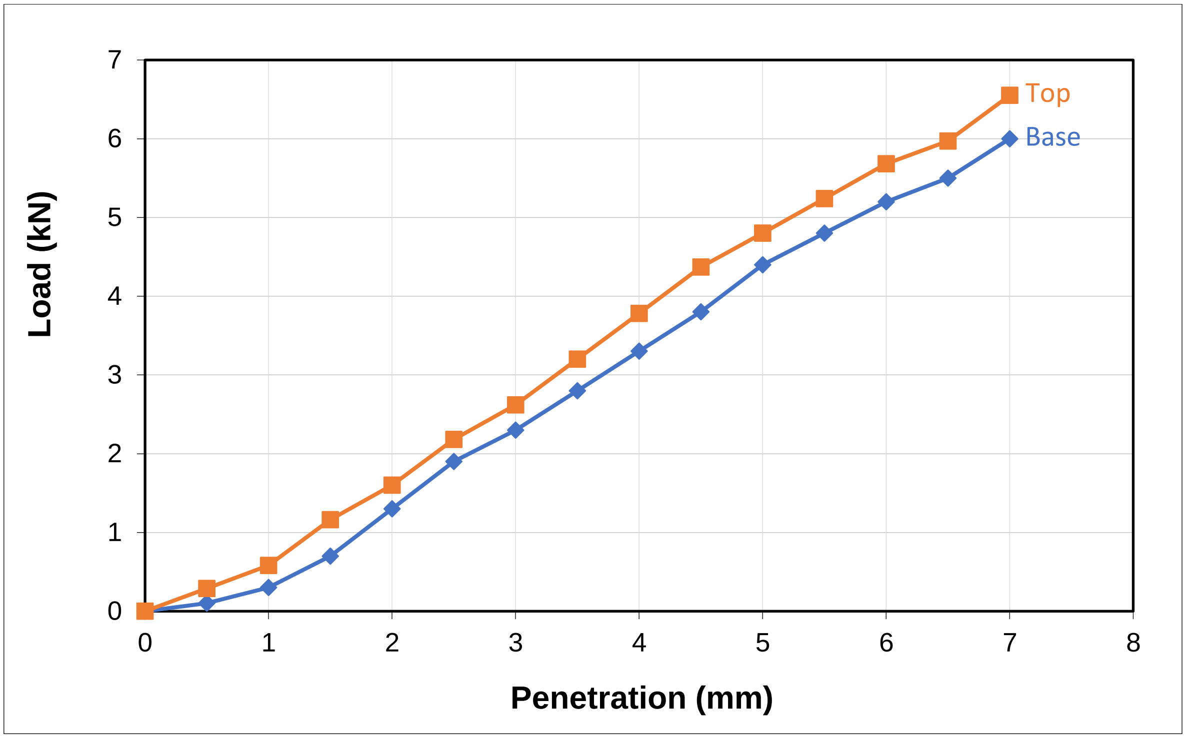

Figure 4: CBR curve of Obiaruku failed section 4

The CBR or California Bearing Ratio

A test called the California Bearing Ratio is used to calculate the soil strength when in filling, subgrading, subbasing, and base course materials are employed in the design of roads and airfields (landing fields). Table 3 shows that the unsoaked CBR values of the soils in the unsuccessful portions varied from 15% to 40%. According to the CBR, when subgrade soils in failed parts are exposed to too much moisture, their volume can alter. It was discovered that samples from stable sections had higher unsoaked CBR values than samples from failed sections. FMWH (2000) recommends an 80% lowest unsoaking CBR amount for highway sub-base and sub-grade soils, which is not present in any of the examined samples. Because the research area's CBR values are poor, soil improvement actions are necessary.

CONCLUSION

Lateritic soils generally encountered in the filling of south-southern Nigeria were explored by their engineering property testing. The samples show low, intermediate (medium), and high plasticity, which could be an indicator of strong compressibility, and they are often well graded. The analyzed soil samples' naturally occurring moisture content from the failed regions indicates that the soil composition has a significant capacity for adsorbing water. Therefore, it is vital to have adequate drainage systems in the region to avoid the development of pore water pressures beneath pavement constructions, which could cause a major loss of strength. In comparison to soils from stumbled (failed) sections, soils obtained from stable sections exhibit a higher degree of laterization, or stability, as shown by their higher specific gravity. The AASHTO classification system places the failed soils portions in group A-7-6, indicating sub-standard materials for the roadway subgrade. The amount that the subgrade and subbase soils have been weakened by water interaction is shown by the percentage of soil strength lost after soaking the compacted samples. The degree (level) of inconsistency and instability seen can be attributed to the low MDD and CBR values strength features, in addition to the dominance of clayey particles in lateritic soils. Stabilization, however, will increase the robustness of stable structures. The study's findings will be helpful in rebuilding the route's failed parts and could influence pavement design for new road construction.

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