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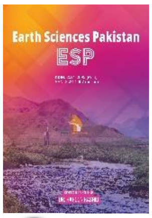

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RESEARCH ARTICLE

GEOTECHNICAL ASSESSMENT OF LATERITIC SOILS IN OWO SOUTHWESTERN NIGERIA AS MATERIALS FOR ROAD SUBBASE

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ABSTRACT

Road construction is a critical infrastructure vital for human civilization and infrastructure. However, Nigeria is currently experiencing significant road failures across all levels of government, from federal to municipal. Among the various factors contributing to road failure are corruption and poor maintenance or supervision, but the primary reason for road failure is the quality of materials used in road construction. This research presents a laboratory study of four soil samples as material used as base and subbase in road construction. All analyses were conducted following British Standards. The liquid limit of the samples ranged from 27.1% to 29.3%, while the plastic limit ranged from 19% to 19.7%, and the plasticity index ranged from 8% to 9.65%. Linear shrinkage values were between 13.0% and 13.4%, and moisture content ranged from 10.2% to 11.2%. Maximum dry densities (MDD) varied from 2101 kg/m^3 to 2144 kg/m^3, with optimum moisture contents (OMC) ranging from 10.9% to 12.4%. The California Bearing Ratio (CBR) for unsoaked samples ranged from 35% to 70%, while soaked samples ranged from 27% to 56%. Due to their lateritic composition and compliance with Nigerian regulatory standards for geotechnical properties, the soils in the study area are deemed suitable as subbase materials. However, soil improvement is necessary to make them suitable for base course applications.

KEYWORDS

Geotechnical, Grain size, Nigeria, Pavement, Plastic index, Road failure.

1. INTRODUCTION

Road infrastructure is an essential precondition for any nation's social and economic development. The availability of economic resources to society and how well they are used are two essential aspects that define an economy's capacity to experience economic growth (Janský et al., 2011). Every civilization and nation recognizes the critical role of road transportation. It controls how quickly a nation's socioeconomic development proceeds. Where there is no excellent road, no economy in that area can prosper. Road has a great influence on the growth of any country's gross domestic product (GDP). The quality of a nation's road network and its economic development are positively correlated. A nation's road system should be planned and built in a methodical way to maximize the intended social, cultural, and economic benefits (Ighodalo, 2008). The benefit of the road transport network to Nigeria cannot be overemphasized because an adequate road transport system acts as an agent of national development. The dilapidating condition of road transport infrastructure in Nigeria today raises many concerns in Nigerians' minds, considering the number of deaths recorded in Nigeria's road accidents. The number of people that lose their lives on the Nigerian highway daily shows how dilapidated our roads are, and efforts to maintain those parts by the government prove abortive. It is unfortunate to note that injuries as a result of accidents on Nigerian roads have overwhelmed Nigerian hospitals and the health system at large. The major cause of this accident is road failure, largely attributed to the materials used for the road construction. Pavement failure is usually attributed to low relative density (Mohammed, 2022). Within a short time, most of the constructed roads in Nigeria become cracked, depressed, and full of potholes, which end up draining the economy (Abiola et al., 2010). Base materials that show changes in volume need to be improved and stabilized to reduce the effect of the active clay content, which showed susceptibility to seasonal volume changes due to high clay content. (Owolabi, 2024).

The base and subbase of flexible pavement are usually made up of lateritic material, which is common in tropical and subtropical regions of the world. It is rich in iron and aluminum under intensive and very prolonged weathering of the underlying parent rock. In Nigeria, laterites serve as the perfect soil materials to solve construction problems such as the construction of earth dams, highways, embankments, airfields, and foundation materials to support structures without considering its classification as the problem and non-problem types and the actual field geotechnical performance of the soils (Amadi, 2015; Adunoye, 2013). Also, when soils are modified they could be utilized for road construction as sub-base materials (Osinubi et al, 2022). Some road construction projects in Nigeria have failed as a result of inadequate knowledge of soils and their qualities. This research was carried out to investigate the geotechnical properties of lateritic soils in Owo, Ondo State, Nigeria and their suitability as subbase materials in road construction.

1.1 Location of the Study Area

Owo Town is a local government area in Ondo State, Southwest Nigeria. Owo can be accessed by 3 major federal roads that cross the town. Owo is located in South-Western Nigeria, on the south of the Yoruba hills and it is on the federal road that passes through Kabba, Benin City from Akure. It is bounded by longitude 9° 11' 56.04"N and latitude 5° 35' 35.52"E (Figure 1). The study area has an elevation of 305 meters above sea level. Owo is relatively flat, as the terrain ranges from 940ft to 1100ft.

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Though the study area has a rugged topography, it is highly accessible as there's a good road network and footpaths which help in locating the lateritic burrow pit deposit within the study area.

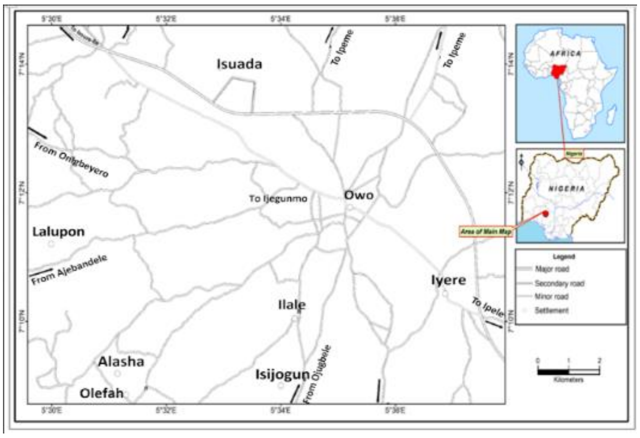


Figure 1: Location Map of Owo

1.2 Topography and Drainage of the Study Area

The topography of the study area is high (about 1200m above sea level), which causes the ridges noted while participating in the fieldwork (figure 2). The study area is typically controlled geomorphologically due to its dendritic drainage pattern (Iloeje, 1981). The major rivers in the region are the Aisewen, Iporo, and Ubeze. These rivers run throughout the year and their streams are mainly seasonal, reaching the peak of dryness at the climax of the dry season. The majority of these large rivers have a perennial character, whereas their tributaries are primarily seasonal, reaching their greatest dryness during the climax of the dry season. The research location is situated in Nigeria's tropical savannah zone. The wet season, which is between March and September, and the dry season, which is between October and February, are its two main climates. The research area has a temperature range of 12.8 to 42.7 °C. The research area experiences between 900 and 1800 mm of precipitation annually (Falowo, 2014).

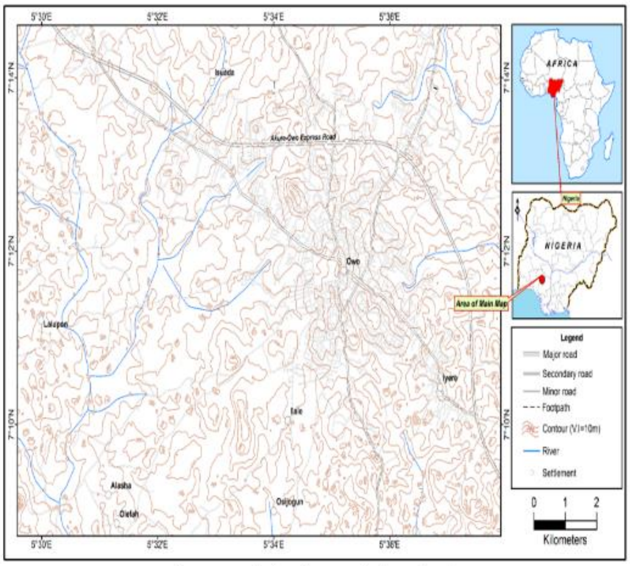


Figure 2: Topographical map of Owo

1.3 Geology of the Study Area

The study area is located within the Pan-African mobile belt between the West African and Congo cratons (Oyinloye, 2011). The most common component unit in the Nigerian basement is the gnesis migmatite quartzite complex, which is often referred to as the basement complex sensustricto (Dada et al., 2006). The Geology of Nigeria is dominated by crystalline and sedimentary rocks, both occurring approximately in equal proportions. The Precambrian basement rocks in Nigeria consist of the migmatite gneissic–quartzite complex dated Archean to Early Proterozoic (2700–2000 Ma) (Oyinloye, 2011). Other units include the NE–SW trending schist belts mostly developed in the western half of the country and the granitoid plutons of the older granite suite dated Late Proterozoic-to-Early Phanerozoic (750–450 Ma) (Oyinloye, 2011). The main lithologies in the southwestern part of Nigeria include amphibolite, migmatite gneisses, granites, and pegmatites. Other important rock units are the schists, made up of biotite schist, quartzite schist, talc-tremolite schist, and muscovite schists. The crystalline rocks intruded into these schistose rocks (Oyinloye, 2011). The southwestern Nigeria basement complex had undergone four major orogeneses, which are the Liberian (Archaean) 2500–2750 ± 25 Ma, the Eburnean orogeny (Early Proterozoic), 2000–2500 Ma, the Kibaran orogeny (MidProterozoic), 1100–2000 Ma, and the Pan-African Orogeny, 450–750 Ma. Within the basement complex, tectonic deformation has completely obliterated primary structures. The major faulting in the area is not evident and most of those recognized have been traced from aerial photographs and satellite imagery. The study mapped out lineaments in the Okemesi area using photogeological methods (Anifowose and Borode, 2007). The study showed that the Itawure fault is the major lineament in the region that passes through Itawure and Efon-Alaye. It trends from E–W and it is a transcurrent fault which displaces the fold nose resulting in the double plunging of the fold axis. Field observation according to shows that fractures in the area are predominantly trending in the E–W direction, while a few of them are in the ENE– WSW direction (Anifowose and Borode, 2007). The basic rocks in the study area are migmatite, granite, schists, and quartzite. The quartzite trends mainly from ENE–WSW. The schist and quartzite are predominantly found in Owo and Ipele, while Ogbese, Uso-Owo, Oba-Akoko, and Emure-Owo are located on migmatite (Figure 3). The study area is underlain by crystalline Basement Complex rocks of Precambrian age. Migmatite gneissic, quartzite, granite, and granite gneisses were observed in the area. Around 60% of the total area is covered with migmatite gneiss followed by quartzite. Groundwater is expected to be low in granite and higher in quartzite. Most of the wells in the study area are found within the moderately high–moderate groundwater potential areas. Thirty percent of the wells studied were found within areas with low groundwater potential. It was also observed that most of the wells studied are found close to or on a fracture zone. Geomorphological features recognized in the area are hills, pediments, and valley flats. The field observations reveal recently formed outcrops with rough surfaces that don't appear to be deteriorating much. There are small intrusions of quartz, aplite, and pegmatite veins on the outcrops. Quartz, plagioclase, alkali feldspar, orthopyroxene, clinopyroxene, hornblende, biotite, and fayalite are typically found in them. Zircon, apatite, and iron ores are frequently used as accessory minerals.

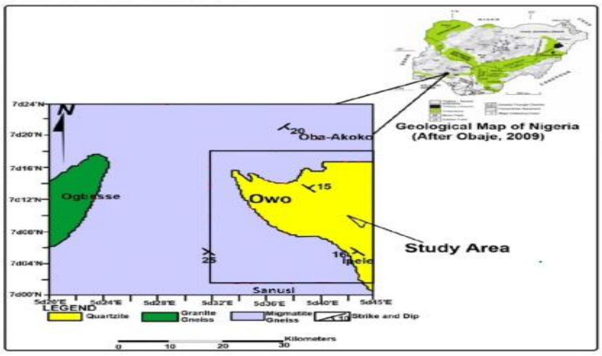


Figure 3: Geological Map of Study Area (After Obaje, 2009)

2. Field Sampling

The lateritic soil samples were collected from a burrow pit laterite deposit (1.60m deep) along Adekunle Ajasin road, Federal Medical Center area of Owo, Ondo State, and Southwestern Nigeria. (Precisely longitude 7°13' 0.84" N and 7°13'12.36"N, latitude 5°35'52.08"E and 5°35'58.2"E). The preservation of the samples was enhanced with the aid of polythene bags, which minimizes loss of moisture content.

2.1 Sample Preparation and Testing Procedure

British Standard (BS) 1990 was used to prepare the sample and the specimen. The sample soils were carefully air-dried and crushed with little energy to reduce sizes. The tests carried out on the samples are: classification tests, compaction, California bearing ratio, shear strength, and specific gravity. The processes of these tests are listed below:

2.1.1 Particle Size Distribution

This test was conducted using the hydrometer and the wet sieve method because of the fine-grain soil particles in the soil. The sample was cleaned using the BS 200 sieve, and the portion that made it through the sieve was used for the hydrometer test. The grains that were left in the sieve were allowed to air-dry before being used for the sieve analysis.

2.1.2 Liquid Limit Determination

When a 200g sample of soil is passed through a 425µm sieve, a thick homogeneous paste is formed by mixing it with water; this paste is then collected inside the Casangrade apparatus cup, which has a groove made in it, and the number of blows required to close it is recorded. This helps determine the moisture content.

2.1.3 Plastic limit determination

To determine the plastic limit, a sample of soil with a diameter of 3 mm is placed on a glass plate and rolled into a thread-like shape. A 200g sample of the soil, which was taken from the material passing the 425µm test sieve, is weighed out and then mixed with water until it becomes homogenous and plastic to be shaped into a ball.

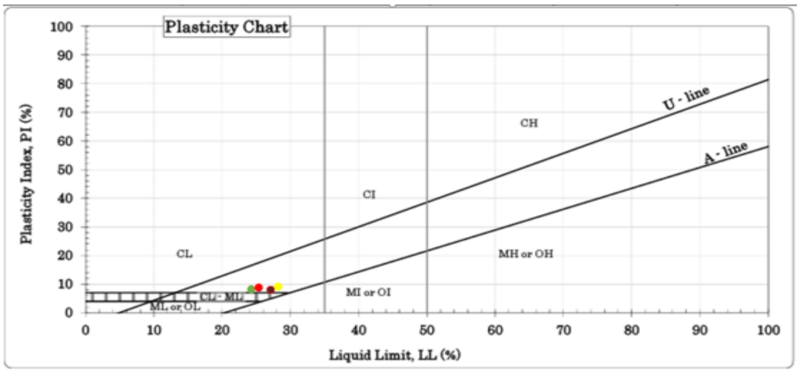
2.1.4 California Bearing Ratio (CBR) Test

The soil that was air dried is diluted with 5% of water. It was compacted with 55 blows with the aid of 2.5kg hammer from the height of 450mm (Standard proctor test) after putting in the mold of 3 layers. Force of 4.5kg was applied after the compacted soil and the mold were weighed under the CBR machine. The load was recorded at the penetration of 0.625, 1.9, 2.25, 6.25, 7.5, 10, and 12.5mm.

3. Result Presentation

3.1 The Atterberg Limit

The results of Atterberg consistency limits carried out on samples T1, T2, T3, and T4 gave a liquid limit of 28.4%, 27.2%, 28.2%, and 29.3% respectively; plasticity limits of 19.4, 19.1% 19.0%,19.7% respectively; Linear shrinkage limit of 13.0%, 13.4%, 13.4%, 13.0% respectively; moisture content 10.3%, 10.2%, 10.7%, 11.3% respectively; plasticity index of 9.00%, 8.00%, 9.20%, and 9.65% respectively (Figure 4). Comparing the values of moisture content and shrinkage limit of the soil samples, it can be concluded that they have a very slight capacity to swell or shrink. They are liable to show little shrinkage when dry. The soil cannot exhibit failure when used as sub-base material in pavement construction. The Federal Ministry of Works (1994) gave requirements of 80% for liquid limit for sub-grade and sub-base and base course should not be greater than 35% for roads and bridges. Also, the plasticity index is not greater than 55% for subgrade and not greater than 12% for both sub-base and base. From the soils that were studied, the samples T1, T2, T3, and T4 fall within this requirement, which makes them appropriate for subgrade, sub-base, and base pavement material.

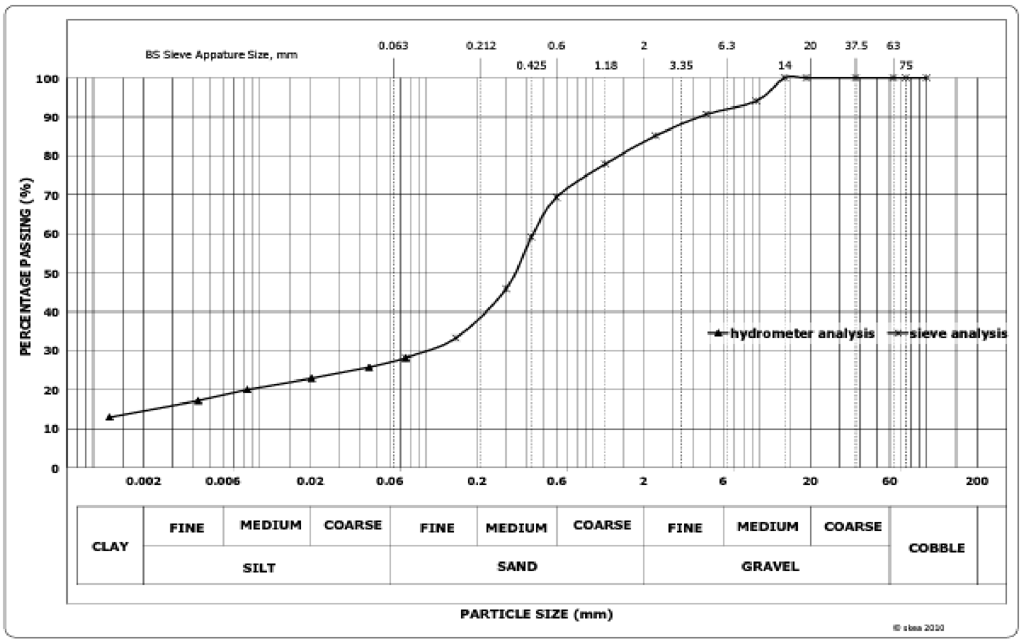


Sample T1 Sample T2 Sample T3 Sample T4

Figure 4: Casagrade Soil Chart

3.2 Grain size analysis

The grain size analysis chart of sample T1 indicated the percentage of gravel, sand, and silt, to be greater than clay, but sand outweighs with the percentage of 51.9%, clay of 10.4%, the silt of 14.9%, and gravel has a total percentage of 22.7% each and thus the soil is gravel-silty sand, while sample T2 is silty-sand, being made up of 63% sand, 12.3% clay, 12.9% silt, and 11.8% gravel. Sample T3 is also silty sand, comprised of 14.8% gravel, 57.1% sand, 15.1% silt, and 13.00% clay (Figure 5a and b). The fourth sample, T4 is also silty sand comprised of 8.1% gravel, 62.9% sand, 16.5% silt, and 12.5% clay. This indicates that each sample has the highest percentage. Interestingly, these values are in contrast with Olayemi et al., 2015, with clayey soil greater than 35% which enhanced the swelling potential of the soil. A high percentage of clay contributes greatly to the shrinkage and swelling properties of soil and makes it not suitable for construction works, especially road pavement. Sand has the highest percentage, with a considerable volume of clay making it appropriate for the description. The percentage of material passing through the No. 200 BS sieve ranges between 25.1% - 29.0%. According to the Federal Ministry of Works requirements for roads and bridges (2015), samples T1, T2, T3, and T4 can be considered suitable for sub-grade, subbase, and base materials as the percentage by weight finer that pass through sieve NO 200BS is less than 35%.



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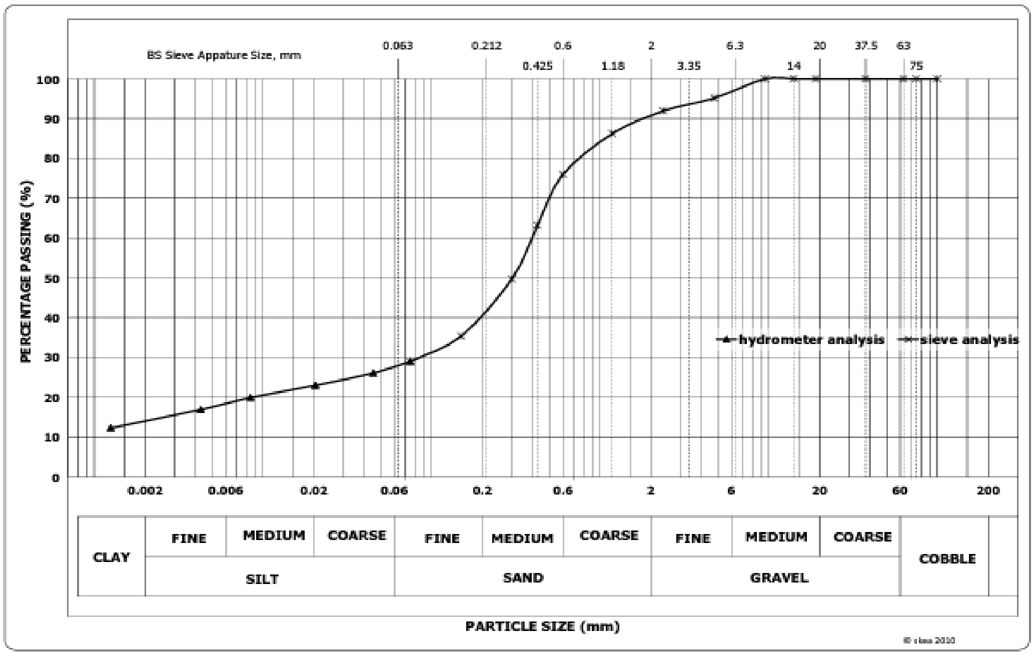

Figure 5a and 5b: Sample T3 and T4 Grain Size Distribution Curve

3.3 Moisture Content Analysis

The natural moisture content (NMC) for the soil samples ranges between 10.2% to 11.3% with a mean value of 10.6% as seen from the summary table 1. These results are consistent with research ranges specified by (Amadi, 2015; Bello, 2007).

3.4 Maximum Dry Unit Weight and Optimum Moisture Content Analysis.

The maximum dry density for the soil samples varies between 2101 kg/m3 and 2144kg/m³, while that of the optimum moisture content ranged between 10.9% to 12.4%. Comparisons of MDD and OMC (Table 1). The MDD determined for laterite soil from the Owo study area is quite close to the general range according to (FRNH, 1992).

Table 1: Tests and Laterite Properties Summary

Laboratory Test	T1 Results	T2 Results	T3 Results	T4 Results
Atterberg Limit Test: Liquid limit (%) Plastic limit (%) Plasticity index (%) Linear shrinkage (%) Moisture content (%)	28.4 19.4 9.0 13.0 10.3	27.1 19.1 8.0 13.4 10.2	28.2 19.0 9.2 13.4 10.7	29.3 19.7 9.65 13.0 11.3
Grain size analysis : Gravel (%) Sand (%) Fine (%)	22.7 51.9 25.4	11.8 63.0 25.1	14.8 57.1 28.1	8.1 62.9 29.0
Compaction Test : OMC (%) MDD (kg/m3)	10.9 2144	11.2 2136	11.9 2115	12.4 2101
Specific gravity Test	2.656	2.662	2.653	2.663
CBR Test : Unsoaked CBR (%) Soaked CBR (%)	35 27	47 33	63 52	70 56

3.5 Compaction Analysis

Compaction tests can be grouped into standard proctor and modified proctor; Sample 1 has an optimum moisture content (OMC) of 10.9%, sample T2 11.2, sample T3 11.9, and sample T4 12.4. Sample T1 has MDD of 2.144 g/cm3 sample T2 2.136 g/cm³ sample T3 2.115 g/cm³ sample T4 2.101 g/cm3 (Table 1). The Federal Ministry of Works and Housing (1997) required sub-base and subgrade materials to have an OMC of less than 18%.

Table 2: Nigeria Standard of Soil Classification for Road and Bridges, (Federal Ministry of Works and Housing, 1997).

Sample	T1	T2	T3	T4
LL (≤35%)	28.4% Pass	27.1% Pass	28.2% Pass	29.3% Pass
P.I (≤12%)	9% Pass	8 Pass	9.2 Pass	9.65 Pass

Table 2 (cont): Nigeria Standard of Soil Classification for Road and Bridges, (Federal Ministry of Works and Housing, 1997).				
C.B.R. Soaked for subbase (≥30)	56% Pass	63% Pass	47% Pass	35% Pass
C.B.R. soaked for base course (≥80)	56% Fail	63% Fail	47% Fail	35% Fail
Overall Rating for subbase	Pass	Pass	Pass	Pass

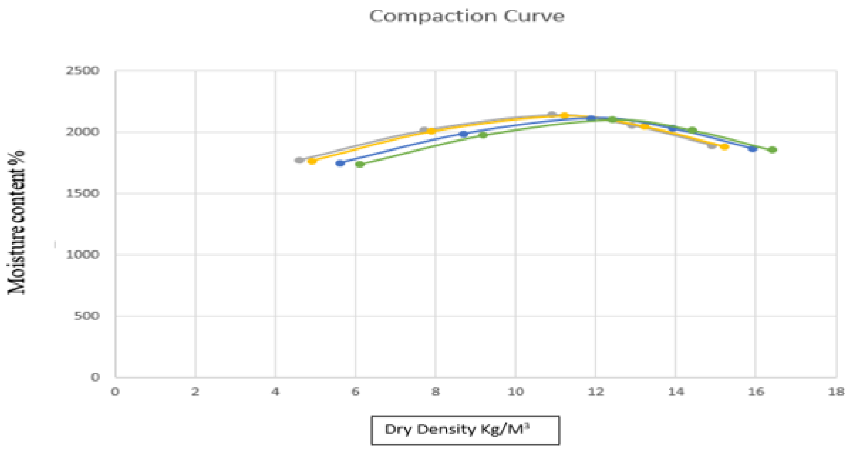

Figure 5: Compaction Curve

3.6 Specific Gravity

The values of Gs of the sampled soils in the study area are between 2.653 and 2.663 with an average of 2.658 (Table 1). The usual value for lateritic soil is around 2.75. Hence, the value obtained from the analyzed soils shows that they are typical examples of laterite. Soils with lower values of specific gravity indicate coarse soil while higher values indicate fine-grained soils.

3.7 California Bearing Ratio (CBR)

Lateritic soil samples yielded CBR values ranging from 26% to 56% when soaked, and between 35% to 70% when unsoaked. According to the Federal Ministry's 1992 recommendation, soaked CBR should be at least 5% and 30% for sub-grade and sub-base soils, respectively. A minimum of 80% for the base (unsoaked CBR) (Table 1). According to the results of the soil sample analysis, all of the soils are appropriate for sub-grade and sub-base courses. The image displays the CBR graphs, and the table displays a summary of the CBR data.

4. Conclusion

Investigations have been made into the lateritic soils' geotechnical suitability for use as subbase and base materials. The outcomes showed that the lateritic soils' standard range for specific gravity was met by the soil from the pits. The natural moisture content of samples T1 to T4 conforms to the specified limit for road construction. Soils of samples T1 - T4 are within the maximum specified limit for liquid limit and plastic limit, thereby making them appropriate as subbase and base materials. The California bearing ratio values show that the lateritic soils of samples T1-T4 are suitable for use as subbases according to the specifications of the Federal Ministry of Road and Housing. The California bearing ratio results demonstrate that the lateritic soils of samples T1-T4 are eligible for use as subbase. Also, the CBR values show that the samples are not appropriate as base course materials and there is a need for soil improvement to make them suitable. The findings of this study will help with road building in Owo and the surrounding area and will act as a reference for future road pavement design. The limitation of the study is that soil properties can change over time due to factors such as weathering, loading, and environmental changes. The research provides a snapshot of conditions at a specific time, and predictions may not account for future changes adequately.

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