



Assessment of Geotechnical Properties of Lateritic Soil at Dorawar 'Yan Nana Wudil, Kano State

Mujittafa Sariyyu¹, Umar Faruk Lawan², Naziru Ado Musa², Muhammad Tukur Muhammad¹, Sadiq Ahmad Bello¹

¹Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano, Nigeria

²Department of Water Resources & Environmental Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano, Nigeria

ABSTRACT

Generally speaking, lateritic soils are found in tropical, warm climates. Different soils used in civil engineering construction failed when subjected to environmental conditions such as; Road deformation, erosion, settlement, and slope stability. The index properties of lateritic soil at Dorawar 'Yan Nana, Wudil were determined. Also, the suitability of the lateritic soil of Dorawar 'Yan Nana for pavement construction was determined. All the analyses were carried out by British standards. The sieve analyses were performed to determine the proportion of fine material present. The Atterberg limits test conducted includes the plastic limit, the liquid limit, and the plasticity index. The compaction of a soil mass results in an increase in dry density. CBR test was conducted to check the suitability of the soil. The moisture content average value was 18.37%, the liquid limit had an average value of 39.96%, the average value of the plastic limit was 27%, and the plasticity index was 11%. The specific gravity average value is 2.60, and the CBR average value of 14.62%. The CBR result indicated that Lateritic soil is not suitable for supporting heavy loads for supporting heavy loads in pavement construction.

ARTICLE INFO

Article History

Received: September, 2023

Received in revised form: December, 2023

Accepted: February, 2024

Published online: June, 2024

KEYWORDS

Lateritic Soil, Pavement, Atterberg limit, Compaction, Specific gravity, CBR test.

INTRODUCTION

Soil is the loose top layer of the Earth's surface, consisting of rock and mineral particles mixed with decayed organic matter (humus), and capable of retaining water, providing nutrients for plants, and supporting a wide range of biotic communities. Soil is formed by a combination of depositional, chemical, and biological processes and plays an important role in the carbon, nitrogen, and hydrologic cycles (Pas, 2017).

(Zame et al., 2017) investigated that Lateritic soils are generally found in warm, humid, tropical areas of the world. The geotechnical properties of these soils are quite different from those soils developed in temperate or cold regions of the world. The properties of lateritic soils are influenced by climate, geology,

and the degree of weathering (Nwa-david, 2023).

In the general sense of engineering, the soil is defined as the cemented aggregate of mineral grains and decayed organic matter along with liquid and gas that occupy the empty spaces between the solid particles. Laterite is usually reddish brown with a relative density of 2.5 – 3.6. The Nitrogen content generally varies from 0.03 – 0.06%. Laterite has a PH ranging from 4.8 to 5.5 and the base-exchange capacity is low (Amadi & Akande, 2017).

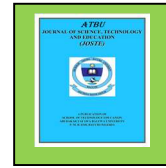
(ASTM, 2004) narrated that, Lateritic soils are formed in hot, wet, tropical regions or latitudes with annual rainfall between 750mm to 2000mm (usually in areas with a significant dry season) on a variety of different types of rocks, with high iron content or quantity. The location on

Corresponding author: Mujittafa Sariyyu

✉ mujittafasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.



the earth that characterizes these conditions falls between latitude 35° south and 35° north. Three major processes or stages have been identified in laterite formation (Ige et al., 2020).

(Amadi et al., 2015) defined Laterite (also known as “red soils”) is used to cover all tropically weathered soils that have been involved in the accumulation of oxides of iron, aluminum, or silica. In other words, red soil is a highly weathered material rich in secondary oxides of iron, aluminum, or both. Also, (Mustapha, 2012), explained that laterites are nearly devoid of bases and primary silicate, but may contain large amounts of quartz and kaolite. It is either hard or capable of hardening on exposure to wetting and drying. The mineralogical composition of the lateritic soil influences the geotechnical parameters such as specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity, and petrographic properties (Adunoye¹ et al., 2018).

(Science, 2021) listed the following geotechnical properties of laterites in Burkina Faso: maximum dry density (MDD) of 21.7 KN/m³ at an optimum moisture content (OMC) of 6.6% with 43% CBR at 95% of MDD. They went further to describe the stress-strain curves of the soils, which show a ductile type of rupture mechanism with a well-defined plastic phase.

It is generally assumed by most authors and researchers that clays almost always negatively influence the geotechnical properties of soils (Nwaiwu and Chidera, 2020). This invariably means that the lower the clay content, the better the soil for engineering uses. This assumption should be evaluated in context as the engineering properties of soil not only depend on the shear strength characteristics but also index properties (Bello and Adegoke, 2010). The geotechnical properties of soils used in construction can therefore be improved significantly by stabilization. The chemical mineralogical composition of lateritic soil is primarily kaolinite and often mixed with quartz, Montmorillonite, and Illite. Non-clay minerals are manganese, Na₂O, MgO, silica, Fe₂O₃, Al₂O₃, and titanium (Ige et al., 2020).

Different soils are used in civil engineering construction but fail when subjected to environmental conditions such as; Road deformation, erosion, settlement, dam seepage, slope stability, and leachate permeability through hydraulic barriers. Due to the failure of some pavements (roads) within Wudil local government, it is important to check the engineering properties of lateritic soil and to make it stable. The use of cement, lime, and bitumen as stabilizers to enhance the stability of lateritic soils. The significance of this study is to investigate the geotechnical properties of lateritic soil located at Dorawar ‘Yan Nana and determine its properties by using sieve analysis, moisture content, Atterberg limits, specific gravity, compaction & California bearing ratio (CBR). This research evaluated the effect of some environmental conditions such as repeated rise and fall in water table, unfavorable settlement & weathering as it affects the foundation of structures such as sub-base and base-course of road.

In Warri, Delta state, Nigeria, lateritic soils were classified and their compaction properties were examined by (Oghenero et al., 2014). The Lateritic soils demonstrated A6, A3, and predominantly A-2-4 type features according to the American Association of State Highway and Transport Officials (AASHTO, 1986), Classification Scheme, as determined by classification tests (sieve analysis and consistency tests).

The study aims to evaluate the geotechnical properties of lateritic soil at Dorawar ‘Yan-Nana Wudil, Kano State. The objectives of this research are to determine the index properties of lateritic soil at Dorawar ‘Yan Nana, Wudil, and the suitability of the lateritic soil of Dorawar ‘Yan Nana for pavement construction.

In this research, we consider 5 samples from the study area (borrow-pit), from sample A to Sample E at an interval of 0.5m as shown in Figure 1. Usually, the Wudil community used the available laterite from the study area for different purposes. They used manual equipment but sometimes used pieces of machinery such as excavators.

Corresponding author: Mujittafa Sariyyu

✉ mujittafasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.



Source: Survey field data, 2021
Plate 1: photo of lateritic soil at Dorawar 'Yan Nana, Wudil

MATERIALS AND METHODS

The natural soil properties were determined according to (ASTM, 2004). The disturbed soil samples were collected from Dorawar 'Yan-nana, Wudil Local Government area. Laboratory tests conducted on the samples are natural moisture content, sieve analysis, Liquid limits, Plastic limit, Compaction test, Specific gravity & California Bearing Ratio (CBR) test.

The sieve analyses performed were following (BS 1377:2 (1990)), to determine the proportion of fine material present. A 1000gram of the air-dried sample was weighed and soaked in a can for 24 hours, the sample was sieved with 75µm sieve sizes and washed with water. The particles passing through the mentioned sieve size were used for hydrometer analysis without the dispersant. Particles retained on the sieve for the soil were placed in the oven and dried at 105°C before dry sieving was done to obtain the

particle size distribution. The residual soil samples were oven-dried for 24 hours and allowed to cool, the weight was noted and recorded. The result from the Sieve analysis was plotted in Figure 2 and determined the particle size distribution.

The weight of the sieves and pan which had earlier been weighed was subtracted from the combined weight of the soil sample and the sieves. This gave the actual soil sample retained in each of the sieves as calculated using Equation 1. The sum of each of the retained weights was checked against the original soil.

$$\text{Percentage retained} = \frac{\text{weight of sample retained}}{\text{total weight of the sample}} \times 100\% \quad (1)$$

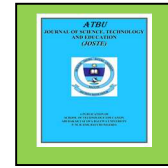
$$\text{Percentage passing} = 100 - \text{cumulative percentage retained} \quad (2)$$

Corresponding author: Mujittafa Sariyyu

✉ mujitaffasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.



The Atterberg limits are the water contents at which soil consistency changes from one state to another. These are the plastic limit, the liquid limit, and the plasticity index.

Plastic Limit (PL): This is defined as the minimum water content at which the soil can be deformed plastically. About 300g of the soil sample passed through a sieve 425µm prepared in liquid limit. A small sample of the soil-like ball was then rolled between the hand and the glass plate. The portion of the crumbled soil was gathered and placed in a moisture can for moisture content determination.

For the Liquid limit (Cone penetration method) test, about 500g of air-dried soil passing through the 425µm sieve was mixed with distilled water to a putty-like consistency in a cup and leveled with a spatula. The height of the penetrometer cone was adjusted to a 0.00mm reading and placed under the cone. The knob is pressed which releases the penetrometer to penetrate the soil sample. The penetrometer reading was taken and noted. The weight of the can and the wet sample was recorded.

$$\begin{aligned} \text{Plasticity Index (PI)} \\ &= \text{Liquid limit} \\ &- \text{Plastic limit} \end{aligned} \quad (3)$$

The specific gravity test was conducted for the natural soil following (BS 1377:2 (1990)). About 10g of the soil sample passed the 2 mm BS sieve size and was oven-dried at 105- 110°C. The sample was allowed to cool in a desiccator and then placed in a 50ml density bottle with the stopper attached. Specific gravity depends significantly on the factors which are the size of samples, the position of samples in soil profiles, grading characteristics, and mineralogical composition.

The specific gravity (S.G) can be computed mathematically as:

$$S.G = \frac{W_2 - W_1}{[(W_4 - W_1) - (W_3 - W_2)]}$$

Where:

W_1 = Weight of bottle,

W_2 = Weight of bottle + dry soil

W_3 = Weight of bottle + soil + water, W_4 = Weight of bottle + water

These parameters can be obtained from the laboratory practical as follows:

1. We weighed the empty and clean volumetric flask (W_1).
2. We cleaned and dried the inside and the outer part of the flask and weighed it (W_2).
3. We emptied and dried the Flask and weighed around 500 grams of soil material.
4. We placed the soil into the flask and weighed it (W_3).
5. We filled around 2/3 of the flask with distilled water.
6. We weighed the flask (W_4).

Compaction is the process in which rapid reduction in volume takes place due to the sudden application of loads caused by ramming, tamping rolling, and vibration. The compaction of a soil mass results in an increase in dry density. 3000g of dried soil sample passed through a 4.75mm sieve was taken in the tray. The mold is filled and compacted with soil in five layers via 25 blows of a standard rammer (4.5), at the quantity of 4%, 6%, 8%, 10%, and 12% of water added for the whole trial. The mass of mold with base plate [M_1] was found. The collar was removed and the excess soil projection above the top of the mold was trimmed off the mass of the mold + base plate + compacted soil [M_2] was determined. By knowing the mass of compacted soil [$M_2 - M_1$], the bulk density was calculated.

$$\rho = \frac{M_2 - M_1}{V} \quad (5)$$

$$\begin{aligned} \rho_d \\ &= \frac{[100]}{[100 + W]} \end{aligned} \quad (6)$$

Where,

ρ = Bulk density (Mg/m^3)

M_1 = mass of empty mold (g)

M_2 = mass of mould + wet soil (g)

W = moisture content (%)

ρ_d = dry density (Mg/m^3)

Corresponding author: Mujittafa Sariyyu

✉ mujittafasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.

The process of mechanically densifying soil results in a more closely packed soil particle arrangement, which raises the ratio of the horizontal effective size to the vertical effective stress. Compaction level is expressed in terms of dry weight and improves road foundation carrying capacity stabilizes slopes, prevents unintended volume changes, and reduces unintended settlement of structures. The results of the compaction test are shown in Table 3.

The natural moisture content also known as the natural water content is the ratio of the weight of wet soil (water) to the weight of the dry soil (solids) in a given mass of soil and is usually expressed as a percentage.

1. The container was first cleaned and weighed as the weight of an empty can (W_1),
2. A little sample was taken from the soil sample in the container and weighed as "weight of empty can + wet soil" (W_2),
3. We recorded the final constant weight as "weight of can + dry soil" (W_3) of the container with dried soil sample,
4. We determined the weight of wet soil as ($W_2 - W_3$),
5. We determined the weight of dry soil as ($W_3 - W_1$).
- 6.

The moisture content ($M.C$)

$$= \frac{W_2 - W_3}{W_3 - W_1} \quad (7)$$

The California bearing ratio [CBR] is a penetration test for the evaluation of the

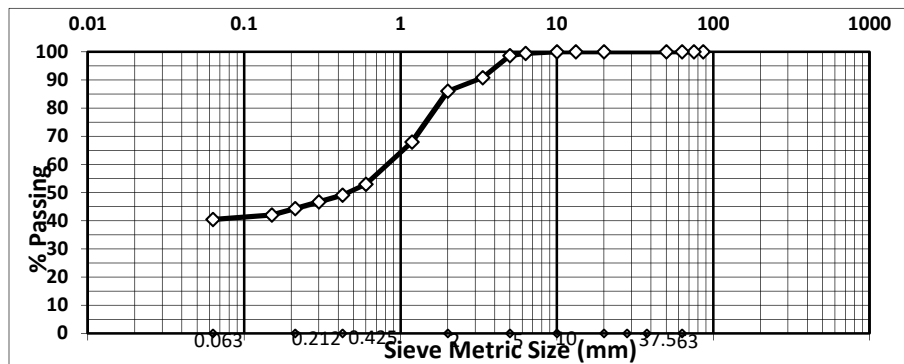


Figure 2: Particle Size Distribution Chart

mechanical strength of road subgrade and base-course. It gauges the moisture content, controlled density, and shearing resistance. To characterize the lateritic soil for usage as a base or subbase material, CBR was applied both drenched and unsoaked. About 5% of the weight of the air-dried soil sample was combined with water. This was placed in a CBR mold in three layers, and each layer was compacted using a 2.5 kg hammer for 55 blows at a 450 mm drop (standard proctor test). After weighing the compacted earth and the mold, the CBR machine was used to provide a seating load of about 4.5 kg. The specified effort for compaction corresponds to 2.5kg rammer. The CBR results are shown in Figure 3. The penetration reading was recorded at intervals of 0.5mm for both the top and bottom.

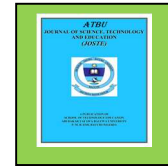
The required readings for evaluating the CBR are those of 2.5mm and 5.0mm penetration.

$$CBR = \frac{\text{test load} \times \text{ring factor}}{\text{standard load}} \times 100 \quad (8)$$

Where, Proving ring factor = 0.0268
 Standard load = 13.24 at 2.5mm penetration and 19.96 at 5.0mm penetration.

RESULTS AND DISCUSSION

Particle size distribution is the process of grading a sample of aggregate into fractions of the same particle size.



The moisture contents of soil at the point where it passes from one state to another are known as consistency limits. The soil

samples show that it has a state of liquid, plastic, and semi-solid values, indicating the consistency of the soil as shown in Table 1.

Table 1: Atterberg limits test

LIQUID LIMIT		Natural M.C. (%)			
Specimen number	1	2	3	4	
Can number	A	B	C	D	
Mass of empty can (g)	4.8	6	6.2	6.3	
Mass of can & moist soil (g)	24.7	26.3	27.3	28.3	
Mass of can & dry soil (g)	19.6	20.5	21.1	21.6	
Mass of dry soil (g)	14.8	14.5	14.9	15.3	
Moisture loss (g)	5.1	5.8	6.2	6.7	
Water content, w%	34.46	40	41.61	43.79	
Penetration (mm)	15	19.5	26.8	30.9	
SHRINKAGE LIMIT					
Specimen number	1		2		
Initial Length of Specimen (mm)	140		140		
Final Length of Specimen (mm)	125		124.5		
Linear Shrinkage (%)	10.7		11.07		

All the sample has high plasticity because the liquid limit value was greater than 35% and the liquidity index confirms that the sample has more moisture than required to reach the liquid limit. The plasticity index of the sample shows that the plastic limit state range is classified as silt soils and may exhibit some plastic behavior when it contains a moderate amount of mixture. By comparing our results with

the findings of (Ige et al., 2020), plastic index, liquid limit, and plastic limit range from 2.8 to 20.4%, 10.0 to 22.0%, and 12.0 to 40.1%, respectively. This suggests that the lateritic soil found is appropriate for use as basis and sub-base materials because its geotechnical characteristics are largely within Nigeria's regulatory parameters.

Table 2: Specific Gravity Test Result

Sample	A	B	C
Weight of bottle (W1) g	866	866	866
Weight of bottle + dry soil (W2) g	1366	1367	1365
Weight of bottle + water + soil (W3) g	2246	2247	2245
Weight bottle + water (W4) g	1938	1939	1937
Specific gravity	2.60	2.59	2.61
Average	2.60		

The soil samples in this investigation had specific gravities ranging from 2.59 to 2.61 (Table 2), which is why they were categorized as inorganic soils. These findings concur with

Ademila's earlier research (2017). According to the soil's specific gravity, the substance is 2.60 times denser than the same volume of water.

Corresponding author: Mujittafa Sariyyu

✉ mujitaffasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.

Table 3: Compaction Result

Compaction parameters	Sample A At 0.5m	Sample B At 1.0m	Sample C At 1.5m	Sample D At 2.0m	Sample E At 2.5m
Maximum dry density (Mg/m ³)	0.87	0.87	1.05	1.06	1.04
Optimum moisture content %	2.77	7.89	8.82	10.34	13.52

The maximum dry density for the soil samples varied between 0.87 mg/m³ and 1.04

mg/m³ while that of optimum moisture content ranged between 2.77% and 13.52%.

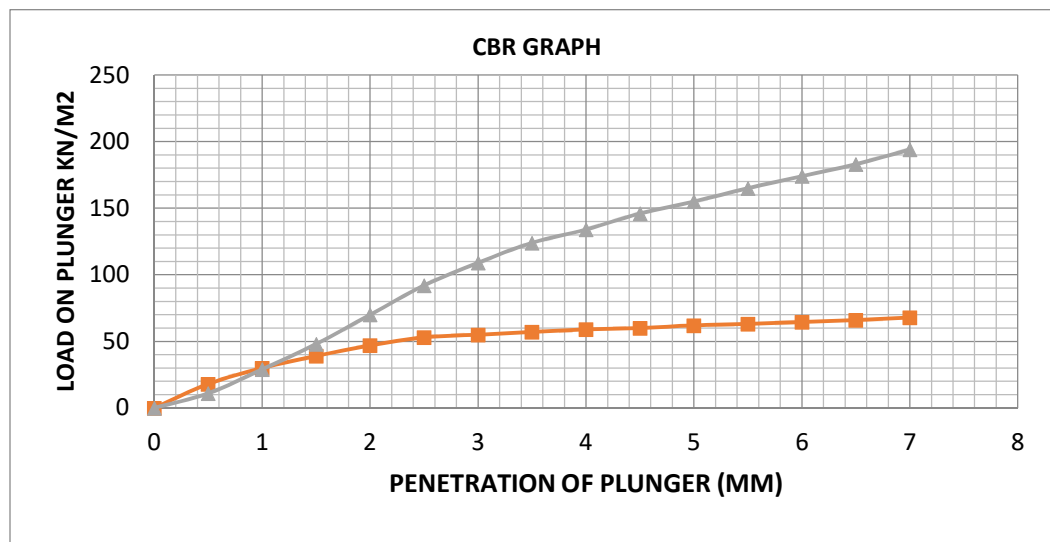


Figure 3: California bearing ratio

The graph shows that, at 2.5 penetration, the test loads are 53 and 92KN at the top and bottom respectively, and the average CBR value is 14.67%, and at 5.0 penetration, the test load was 62 and 155 KN at the top and bottom respectively, with average CBR value of 14.57%. This result indicated that the study soil is not particularly suitable for supporting heavy loads in pavement construction and may experience a deformation or rutting under traffic loads. Average CBR value =14.62%, Maximum Dry Density (MDD) = 1.06 mg/m³, and Optimum Moisture Content (OMC) = 10.34%.

CONCLUSION

The geotechnical properties of lateritic soil in Dorawar ‘Yan-Nana Wudil LGA, Kano

state, have been carried out in compliance with regulatory standards (BS 1377:2, 1990). The result showed that the studied soil samples are classified as silt soil which is moderate in compressibility when saturated with water it exhibits significant volume changes, including swelling when wet and shrinkage when dry making it susceptible to settling and instability.

The study soil is not particularly suitable for supporting heavy loads in pavement construction and may experience a deformation or rutting under traffic loads.

RECOMMENDATION

1. From the experiment carried out on the lateritic soil at Dorawar ‘Yan Nana Wudil, the material was not suitable for pavement

Corresponding author: Mujittafa Sariyyu

✉ mujitaffasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.



- construction but can be used for other filling, therefore, further engineering research should be carried out on the material.
2. It's necessary to consider soil improvement techniques or alternative pavement design to compensate for its low strength this could involve adding stabilizing agents, increasing the thickness layers, or choosing different types of pavement structure.

REFERENCES

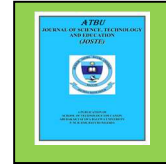
- AASHTO. (1986). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*. American Association of State Highway and Transportation Officials, (14th Editi).
- Adunoye¹, G. O., Kolapo¹, S. A., Olamuju¹, T. O., & O.T. Akanbi. (2018). Investigation Of Geotechnical Properties Of Lateritic Soils In Parts Of Ife Central Local Government Area, Osun State, Southwestern Nigeria. *African Journal of Environment and Natural Science Research*, 1(2), 31–41.
- Amadi, A. N., & Akande, W. G. (2017). *Assessment of the Geotechnical Properties of Lateritic Soils in Minna, North Central Nigeria for Road Design and Construction*. May 2015. <https://doi.org/10.12691/ajmm-3-1-3>
- Amadi, A. N., Akande, W. G., Okunlola, I. A., Jimoh, M. O., & G, F. D. (2015). Assessment of the Geotechnical Properties of Lateritic Soils in Minna, North Central Nigeria for Road Design and Construction. *American Journal of Mining and Metallurgy*, 3(1), 15–20. <https://doi.org/10.12691/ajmm-3-1-3>
- ASTM. (2004). *ASTM Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*. (04:08).
- Bello, A. A., & Adegoke, C. W. (2010). Evaluation of Geotechnical Properties of Ilesha East Southwestern Nigeria s Lateritic Soil. *The Pacific Journal of Science and Technology*, 11(2), 617–624.
- BS 1377:2. (1990). *Methods of Tests for Soils for Civil Engineering Purposes*, BSI
- Publications. Federal Ministry of Works and Housing (FMWH) (1997). Nigerian General Specification for Roads and Bridges, Vol. 2.*
- Ige, J. A., Ibitoye, B. A., Kazeem, M. B., Federal, T., & Offa, P. (2020). Geotechnical Properties of Offa Lateritic Soils and its Suitability as Subbase and Base Materials. *International Journal of Civil and Structural Engineering Research*, 8(5), 645–652.
- Mustapha, A. M. (2012). Geotechnical Properties of Lateritic Weathering Profile Derived from Granite Basement. *EJGE*, 17, 1505–1514.
- Nwa-David, C. D. (2023). Variability Analysis of the Behaviors of a Lateritic Soil Profile as a Structural Material. *Engineering and Technology Journal*, 41(April), 666–672.
- Nwaiwu, C. M. O., & Chidera, and I. S. (2020). Suitability Assessment of Selected Lateritic Soils for Highway Construction in Anambra State, Nigeria. *Journal of Engineering and Technology (FUOYEJET)*, 5(2), 208–212.
- Oghenero, A.E., Okey, A.T., Brume, O., Okunuwadje S.E., and J. O. (2014). Classification and Compaction Characteristics of Lateritic Soils of Warri, Delta state, Nigeria. *Advances in Applied Science Research*, (3)(5), 451–457.
- Pas, N. A. (2017). Assessment of Geotechnical Parameters of Lateritic Soil of Jos and Environs, for Civil Engineering Constructions North Central part of Nigeria. *International Journal of Geosciences*, 8, 222–239.
- Science, E. (2021). *Determination of Types and Characteristics of Laterite Soil as Basic Land for Building Construction*. *Determination of Types and Characteristics of Laterite Soil as Basic Land for Building Construction*. <https://doi.org/10.1088/1755-1315/930/1/012041>
- Zame, P. Z., Assomo, P. S., & Onwualu, J. N.

Corresponding author: Mujittafa Sariyyu

✉ mujittafasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alkoro Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.



(2017). Assessment of Geotechnical Properties of Lateritic Gravels from South-Cameroon Road Network.

International Journal of Geosciences, 08(08), 949–964.
<https://doi.org/10.4236/ijg.2017.88054>

Corresponding author: Mujittafa Sariyyu

✉ mujitaffasariyyu@gmail.com

Department of Civil Engineering, Faculty of Engineering, Alko Dangote University of Science and Technology, Wudil, Kano State.

© 2024. Faculty of Technology Education, ATBU Bauchi. All rights reserved.