# ANALYSIS OF THE ENGINEERING PROPERTIES OF LATERITIC SOILS IN SONG AREA, ADAMAWA STATE, NIGERIA

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**ABSTRACT:**
*In the course of this research, four lateritic soil samples ($SO_1$, $SO_2$, $SO_3$ and $SO_4$) were tested to ascertain their suitability as construction materials in civil engineering projects. The samples were collected from borrow pits at Song area, Adamawa State, Nigeria at depths of 2.0m each. The area is a prc-cambrian basement complex terrain; underlain by migmatites, gneisses, older granites and basalts. The results of natural moisture content test range from 13.55% to 25.83%. The particle size analysis showed ranges of values of the amount of fines and amount of coarse fraction of 5% to 41% and 59% to 95% respectively. The effective size ($D_{10}$), the coefficient of uniformity ($C_u$) and the coefficient of curvature ($C_c$) range from 0.5 to 1.0; 1.6 to 3.0; and 1.2 to 1.3 respectively. The results of atterberg limits tests indicated ranges of values of 2.79% to 25.54% for plasticity index; 35.3% to 45.5% for liquid limit; and 13.46% to 32.51% for plastic limit. Specific gravity values of the soil samples range between 2.54 and 2.65. The results of compaction test showed ranges of values of maximum dry density and optimum moisture contents of 1.50 g/cm$^3$ to 1.80 g/cm$^3$ and 12.38% to 14.90% respectively. The unconfined compressive strength results range from 27.00KPa to 42.00KPa. Based on these, it can be deuced that; lateritic soil samples $SO_1$ and $SO_2$ are likely to be suitable for use as fills and embankments, while the rest would be poor to fair; only sample $SO_1$ is likely to be suitable for use in sub-base courses; the rest are all poor and hence unsuitable; all lateritic soil samples are very likely to be poor and unsuitable for use in base courses; with the exception of sample $SO_1$ that may be marginal.*

***Keyword:*** *Construction materials, Lateritic soils, Particle size analyses, Atterberg limits, Natural moisture contents, Unconfined compressive strength, Compaction.*

## INTRODUCTION
## BACKGROUND INFORMATION

The frequencies of roads and dams failures are increasing at an alarming rate; hence the need for quick action and lasting solution. Engineering Geologists and Civil Engineers have great roles to play in providing this solution. It is very important that the geotechnical properties of soils used in construction of roads, dams and

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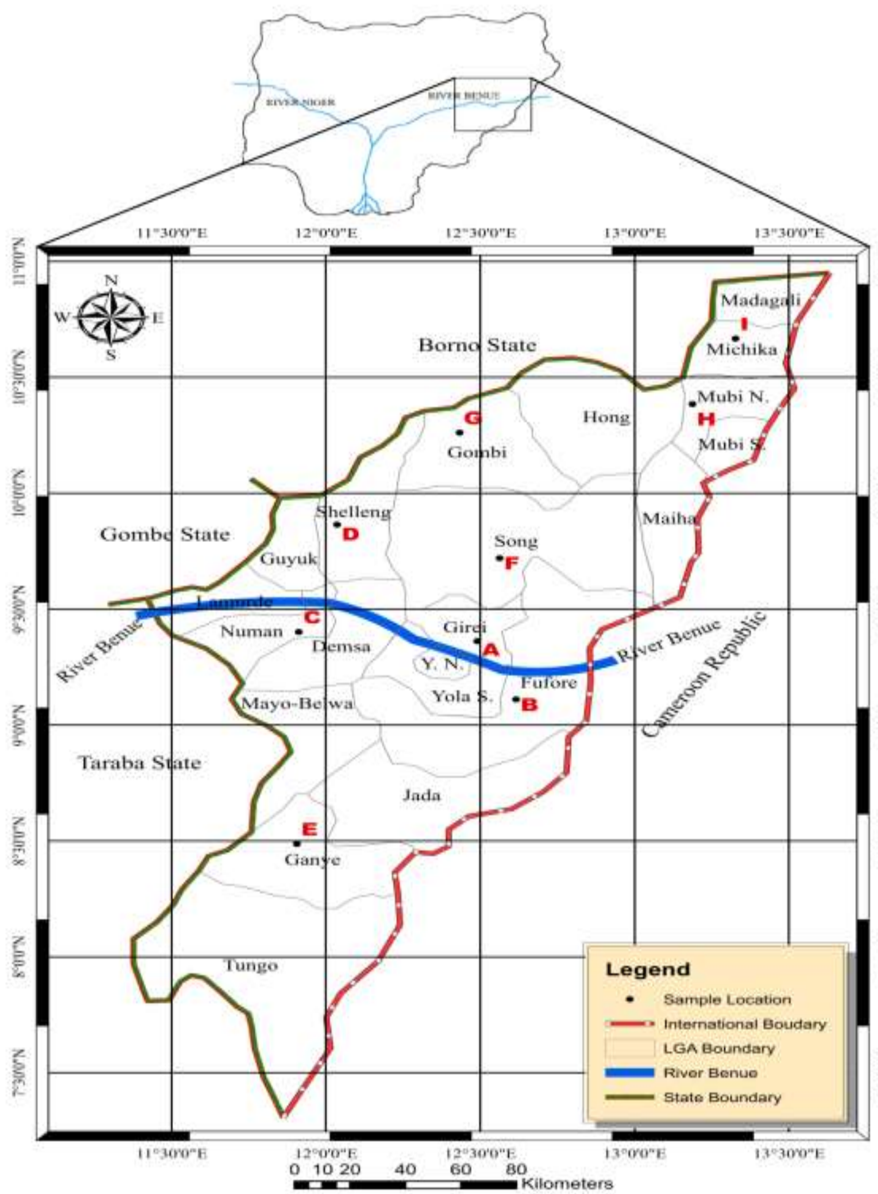
embankments be well understood in order to avoid failures. Due to their heterogeneous nature, the geotechnical characteristics of lateritic soils need to be studied so as to know their suitability as construction materials.

This paper investigates the lateritic soils obtained from borrow pits in Song and environs, Adamawa state, North-Eastern Nigeria. The area is situated between longitudes $12^0$36'E and $12^0$40'E and latitudes $9^0$48'N and $9^0$52'N (Fig.1)




(Source: Field survey, 2019)

Fig. 1. Map of Adamawa State showing the study area

The index and geotechnical properties of lateritic soils are influenced by parent rocks, geochemical and mineralogical factors (Little, 1971), as well as temperature variation, rainfall and transpiration (Correla, 1969).

Lateritic soils are highly weathered materials, rich in secondary oxides of iron, aluminium, or both and are void or nearly void of primary silicates, but may contain large amounts of quartz and kaolinite (Alexandra and Cady, 1962). They are products of tropical weathering with red, reddish brown, or dark brown colours, with or without nodules or concreting and generally (but not exclusively) found below hardened ferruginous crust or hard pan (Ola, 1983). Based on the ratios of silica ($SiO_2$) to sesquioxide ($Fe_2O_3$, $Al_2O_3$) present, lateritic soils are categorized into laterites, lateritic soils, and non-lateritic soils. Ratios less than 1.33 are indicative of laterites; those between 1.33 and 2.00 indicate lateritic soils and those greater than 2.00 are indicative of non-lateritic soil types (Bell, 2006).

Lateritic soils are formed in hot, wet tropical regions of the world on a variety of types of rocks with high iron content. They are used extensively as construction materials for roads, embankments and dams, and to support the foundations of buildings, bridges and load-bearing pavements (Blight and Leong, 2012). In this paper we examined the geotechnical properties of lateritic soils as well as their usefulness in engineering works in the area under investigation.

## OBJECTIVES OF THE STUDY

i. To determine the differences if any between the lateritic soils generated from the parent rocks in the study area based on their geotechnical properties;
ii. To distinguish inferior lateritic soils from the superior ones if so identified;
iii. To evaluate the suitability of the lateritic soils as construction materials.

## GEOLOGY OF THE STUDY AREA

The study area is underlain by Precambrian basement complex rocks. These rocks have undergone both pre-pan African and pan-African orogenies resulting into metamorphism, migmatization and granitization of the pre-existing rocks. The upper parts of the underlying geology have been weathered to superficial deposits. However, outcrops of the basement rocks are still preserved in the hilly regions. The rocks consist of gneisses, older granites and tertiary volcanics. The gneisses are coarse-grained high-grade metamorphic rocks formed at high pressures and temperatures, in which light and dark mineral constituents are segregated into visible bands (Mohr, 1993). They are comprised of two main types: the biotite gneiss and the banded gneiss (Ekwueme,

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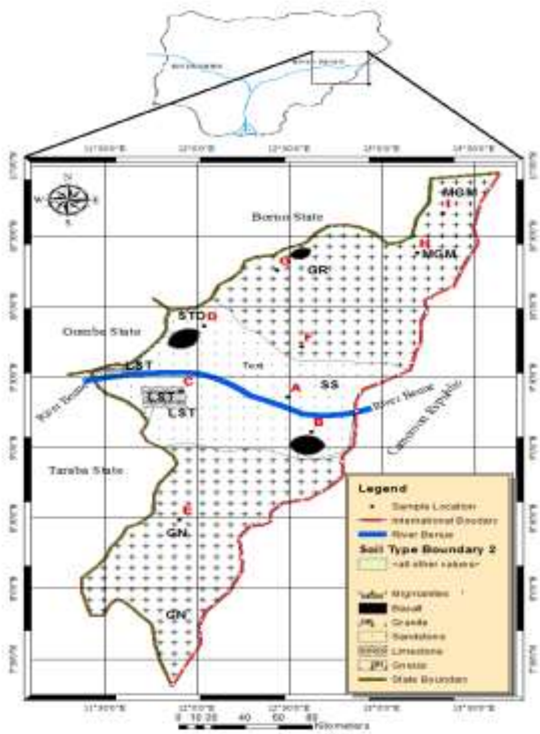
1994). In some cases, the veins are filled with remobilized minerals such as quartz and feldspars called the quartzo-feldspathic veins.

The older granites which cover about 70% of the area is a coarse-grained igneous rocks made up of feldspar, mica, quartz, biotites, and occasionally microcline. They occur as large circular masses within the older gneiss complexes (Kennedy, 1964).

Volcanic rocks of Cambrian age occur as pockets in the study area both as interbedded lavas among the basement complex and as post metamorphic extrusives. These are composed largely of calcic plagioclases and ferromagnesian minerals. Basalts, the most prominent volcanic rocks in the study area and are characterized by small grain sizes (less than 5mm) and approximately equal proportion of calcium-rich plagioclase, feldspar and calcium rich pyroxenes (Ekwueme, 1994).




(Source: Field survey, 2019)

Fig.2. Geologic Map of Adamawa State Showing the Different Rock Types Found in the Study Area

## MATERIALS AND METHODS

Four lateritic soil samples were collected from depths of 2.00m, from borrow pits in Song area, Adamawa state, North-Eastern Nigeria. The area is located between longitudes12$^{0}$36’E and 12$^{0}$40’E and latitudes 9$^{0}$48’N and 9$^{0}$52’N (Fig.1). The samples were tested for natural moisture content, particle size distribution test, atterberg limits test, specific gravity tests, compaction tests and unconfined compressive strength.

**Preparation of Sample Specimens**

The samples and specimens were prepared in accordance with BS1377 of 1990 and Head (1992). Prior to preparing the test specimens, the materials were air-dried and broken into smaller fragments.

**Natural moisture content and specific gravity**

The determination of specific gravity and natural moisture content tests followed the standard as outlined in BS 1377 of 1990.

**Particle Size Distribution Analyses**

500g of the sample was used for the test after being washed and oven-dried. The samples were sieved by mechanical methods using automatic shakers and a set of sieves.

**Atterberg Limits**

**Liquid Limit Determination**

200g of soil samples passing through 425µm sieve were mixed with water to form a think homogeneous paste. Liquid limit was determined using the Cone penetrometer method (Vickers, 1978). The penetration of a standard cone into a soil sample paste was measured at a variety of moisture contents and the moisture content corresponding to a penetration of 20 mm was taken as the liquid limit.

**Plastic Limit Determination**

200g of soil sample was taken from the material passing the 425µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3mm diameter. Therefore, the moisture contents were determined.

**Determination of Plasticity Index**

Plasticity index was calculated by subtracting plastic limit from liquid limit.

**Compaction Test**

Compaction test was carried by proctor's test (Arora, 2009). This is the process of densification of soil by reducing air voids and it is measured in terms of its dry density.

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The dry density is maximum at the optimum moisture content. A curve of moisture content against dry density gives the maximum dry density and the optimum moisture content.

**Unconfined Compressive Strength Test**

The unconfined compressive strength ($q_u$) is the load per unit area at which the cylindrical specimen of a cohesive soil falls in compression.

$(q_u) = P/A$ ………………………………………………………………….. (2)

Where P= axial load at failure, A= corrected area = $A_0 / (1 - \varepsilon)$, where $A_0$ is the initial area of the specimen, ε = axial strain = change in length/original length.

## RESULTS AND DISCUSSION

**Natural Moisture Content Test**

The natural moisture content test results (Table 1) are 13.55%, 16.42%, 25.83% and 22.06% for samples $SO_1$, $SO_2$, $SO_3$ and $SO_4$ respectively. The values of natural moisture content are functions of the void ratios and the specific gravities of the lateritic soil samples. Thus Sample $SO_3$ probably had the largest void ratio and $SO_1$ had the smallest void ratio. Lateritic soil samples with high moisture are largely affected by the climatic conditions and the degree of weathering (Das, 2010).

**Particle Size Distribution Analysis**

The particle size analysis for samples $SO_1$, $SO_2$, $SO_3$ and $SO_4$ (Table 1) shows that the amount of fines are 5%, 41%, 5% and 6% and the amount of coarse fraction are 95%, 59%, 95% and 94% respectively. The effective sizes ($D_{10}$) values are 1 and 0.5; the coefficient of uniformity ($C_u$) values is 3 and 1.6 and the coefficient of curvature ($C_c$) values is 1.3 and 1.2 for $SO_1$ and $SO_4$ respectively.

From the results of particle size analysis, lateritic soil samples $SO_1$, $SO_3$ and $SO_4$ have percentage fines of less than 35%; hence, can be rated as fair to good sub-grade foundation material and may have good workability as construction materials for roads and earth dams (FMW&H, 1972).

The gradation coefficients give the description of the lateritic soil samples (Arora, 2009). From the results, the lateritic soil samples are uniform, reddish-brown, sandy-silt-clay soils.

**Atterberg Limits**

The results of Atterberg consistency limits tests carried out on lateritic soil samples $SO_1$, $SO_2$, $SO_3$ and $SO_4$ (Table 1) gave plasticity indices of 2.79%, 25.54%, 20.60% and 23.67%; liquid limit of 35.3%, 39.0%, 45.5% and 45.5% and plastic limit of

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32.51%, 13.46%, 24.90% and 21.83% for plastic limit; respectively. Whitlow (1995) presented that lateritic soils with liquid limit less than 35% indicates low plasticity, between 35% and 50% indicates intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity and greater than 90% extremely high plasticity.

Before Lateritic soils are used as fills, bases or sub-bases, they must conform to Nigerian specifications complemented by Road Note No. 29&31. Generally, lateritic soils having high values of liquid and plastic limits are considered as poor foundation materials. The following are in line with the Federal Ministry of Works and Housing (FMW&H; 1972, 1997 and 2003) specifications.

**1. Fill materials: LL (**0 – 45%); **PI** (0 – 20%)
**2. Sub- Base materials: LL (**0 – 35%); **PL** (0 – 12%)
**3. Base materials: LL (**0 - 30%); **PL** (0 – 12 %)

The values of Atterberg test results showed that the lateritic soil samples have intermediate plasticity, may have potential to swell or shrink and are therefore expected to stand the risk of failing when used as construction materials (Das, 2006).

**Table 1. PROPERTIES OF LATERITIC SOILS IN SONG AREA**

| Properties of the lateritic soil | $SO_1$ | $SO_2$ | $SO_3$ | $SO_4$ |
|---|---|---|---|---|
| Depth of Sampling | 2.0m | 2.0m | 2.0m | 2.0m |
| Natural moisture content (%) | 13.55 | 16.42 | 25.83 | 22.06 |
| Fines (%) | **5** | 41 | 5 | 6 |
| Sand (%) | **77** | 59 | 95 | 94 |
| Gravel (%) | 18 | 0 | 0 | 0 |
| Effective Size ($D_{10}$) | 1 | - | - | 0.5 |
| Coefficient of Uniformity ($C_u$) | 3 | - | - | 1.6 |
| Coefficient of Curvature ($C_c$) | 1.3 | - | - | 1.2 |
| Liquid Limit (%) | 35.3 | 39.0 | 45.5 | 45.5 |
| Plastic Limit (%) | 32,51 | 13.46 | 24,90 | 21.83 |
| Plasticity Index (%) | 2.79 | 25.54 | 20.60 | 23,67 |
| Maximum Dry Density ($g/cm^3$) | 1.50 | 1.72 | 1.69 | 1.80 |
| Optimum Moisture Content (%) | 12.38 | 15.00 | 18.00 | 16.86 |

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| | | | | |
|---|---|---|---|---|
| **Unconfined Compressive Strength (KPa)** | 42.00 | 38.00 | 27.00 | 29.00 |
| **Specific Gravity** | 2.54 | 2.61 | 2.65 | 2.64 |
| **Colour** | Reddish Brown | Reddish Brown | Reddish Brown | Reddish Brown |

**Specific Gravity**

The results of the specific gravity analysis of soil samples $SO_1$, $SO_2$, $SO_3$ and $SO_4$ (Table 1) are 2.54, 2.61, 2.65 and 2.64; respectively. Specific gravity is a measure of the degree of laterization (Lyon, 1971). Lower specific gravity values indicate a coarse soil, while higher values indicate a fine grained soil (BS1377, 1990).

**Compaction Test**

Compaction test results (Table 1) showed that the soil samples $SO_1$, $SO_2$, $SO_3$ and $SO_4$ have maximum dry density (MDD) values of 1.50g/cm$^3$, 1.72g/cm$^3$, 1.69g/cm$^3$ and 1.80g/cm$^3$; while their optimum moisture content (OMC) values are 12.38%, 15.00%, 18.00% and 16.86% respectively.

Having MDD values greater than 1.7g/cm$^3$, samples $SO_2$ and $SO_4$ became suitable for general filling and construction of sub grade and sub base courses of roads.

**Unconfined Compressive Strength Test**

The results of Unconfined Compressive Strength tests obtained (Table 1) are 42.00KPa, 38.00KPa, 27.00KPa and 29.00KPa for samples $SO_1$, $SO_2$, $SO_3$ and $SO_4$ respectively.

According to the engineering use chart, all the lateritic soil samples are inorganic clays which can thus be used as erosion resistance in canal construction. They can also be used as a homogenous embankment in rolled earth dams because of their good to fair workability as construction materials, medium compressibility when compacted and saturated and their fair shearing strength when compacted and saturated (Wagner, 1957).

## COMPARISON OF THE PROPERTIES OF LATERITIC SOILS WITH THE NIGERIAN SPECIFICATION FOR CONSTRUCTION PROJECTS

**General fills and embankments**

For a lateritic soil to qualify to be used in fills and embankment, it must have Maximum Dry Density > 0.04 g/cm$^3$, Optimum Moisture Content < 18 %, Liquid Limit < 40%, Plasticity Index < 20% and percentage fines of $\leq$ 35%. Therefore, lateritic soil samples $SO_1$ and $SO_2$ are likely to be good and suitable (Table 2).

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**Sub-base courses**

For sub-base courses, lateritic soils are required to have Liquid Limit of < 35% and Plasticity Index of < 16%. Hence only sample $SO_1$ is likely to be good, while the rest would be poor (Table 2).

**Base courses**

Lateritic soils to be used for base courses must have Liquid Limit of ≤ 30%, Plasticity Index of ≤ 13%, Percentage gravel (%) of 5 – 15 and Unconfined Compressive Strength of > 103 kPa. Therefore, all samples are poor, except sample $SO_1$ that may be marginal (Table 2).

**Table 2. Comparison of the properties of lateritic Soil samples from Song Area with the Nigerian specification for construction projects (FMW&H 1972, 1997, 2003)**

| PROPERTY | NIGERIAN SPECIFICATIONS | TESTED LATERITE SAMPLES | | | | REMARKS |
|---|---|---|---|---|---|---|
| | | $SO_1$ | $SO_2$ | $SO_3$ | $SO_4$ | |
| **General fill and embankment** | | | | | | |
| **MDD (g/cm³)** | > 0.04 | 1.50 | 1.72 | 1.69 | 1.80 | ***Samples $SO_1$ and $SO_2$ are likely to be good, while the rest would be poor to fair*** |
| **OMC (%)** | < 18 | 12.38 | 15.00 | 18.00 | 16.86 | |
| **LL** | < 40 | 35.3 | 39.0 | 45.5 | 45.5 | |
| **PI** | < 20 | 2.79 | 25.54 | 20.60 | 23.67 | |
| **Percentage fines (%)** | ≤ 35 | 5 | 41 | 5 | 6 | |
| ***Quality*** | | ***Good*** | ***Good*** | ***Poor*** | ***Poor*** | |
| **Sub-base course** | | | | | | |
| **LL** | < 35 | 35.3 | 39.0 | 45.5 | 45.5 | ***Only sample $SO_1$ is likely to be good, while the rest would be poor*** |
| **PI** | < 16 | 2.79 | 25.54 | 20.60 | 23.67 | |
| ***Quality*** | | ***Good*** | ***Poor*** | ***Poor*** | ***Poor*** | |
| **Base course** | | | | | | |
| **LL** | ≤ 30 | 35.3 | 39.0 | 45.5 | 45.5 | ***All samples are very likely to be poor, except*** |
| **PI** | ≤ 13 | 2.79 | 25.54 | 20.60 | 23.67 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Percentage gravel (%)** | 5 – 15 | 18 | 0 | 0 | 0 | ***sample*** **$SO_1$** ***that may be marginal*** |
| **UCS (kPa)** | > 103 | 42 | 38 | 27 | 29 | |
| ***Quality*** | | ***Poor*** | ***Poor*** | ***Poor*** | ***Poor*** | |

## CONCLUSION

From the investigation of the geotechnical properties of four lateritic soil samples ($SO_1$, $SO_2$, $SO_3$ and $SO_4$) collected from the study area, the following conclusions were drawn:

**a.** The natural moisture content ranges between 13.55% ($SO_1$) and 25.83% ($SO_3$).

**b.** The particle size analyses showed that the amount of fines ranges from 5% ($SO_1$ and $SO_3$) to 41% ($SO_2$) and the amount of coarse fraction range between 59% ($SO_2$) and 95% ($SO_1$ and $SO_3$). The effective size ($D_{10}$) ranges from 0.5 ($SO_4$) to 1.0 ($SO_1$); the coefficient of uniformity ($C_u$) ranges from 1.6 ($SO_4$) to 3.0 ($SO_1$) and the coefficient of curvature ($C_c$) ranges from 1.2 ($SO_4$) to 1.3 ($SO_1$).

**c.** Atterberg tests of the lateritic soil samples indicated that the liquid limit ranges from 35.3% ($SO_1$) to 45.5% ($SO_3$ and $SO_4$); the plastic limit ranges from 13.46% ($SO_2$) to 32.51% ($SO_1$) and the plasticity index ranges from 2.7% ($SO_1$) to 25.54% ($SO_2$). These values of showed that the lateritic soil samples have intermediate plasticity and therefore likely to be poor construction materials.

**d.** Specific gravity values of the lateritic soil samples ranges from 2.54 ($SO_1$) to 2.65 ($SO_3$). This indicated that the lateritic soils are fine to medium grained.

**e.** The compaction test results showed that the values of maximum dry density (MDD) range from 1.50 g/cm$^3$ ($SO_1$) to 1.80 g/cm$^3$ ($SO_4$); while the values of optimum moisture contents (OMC) range between 12.38% ($SO_1$) and 18.00% ($SO_3$). This shows that the lateritic soils have medium to high percentage of fines and are unlikely suitable for general filling and construction of sub grade and sub base courses of roads.

**f.** The unconfined compressive strength (UCS) test results shows the values of UCS ranges from 27.00KPa ($SO_3$) to 42.00KPa ($SO_1$). This shows that the soils have low shear strength and are unsuitable for construction of roads and earth dams.

## RECOMMENDATIONS

Lateritic soil samples $SO_1$ and $SO_2$ are likely to be suitable for use as fills and embankments, while the rest would be poor to fair. Only sample $SO_1$ is likely to be suitable for use in sub-base courses; the rest are all poor and hence unsuitable. All

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lateritic soil samples are very likely to be poor and unsuitable for use in base courses, except sample $SO_1$ that may be marginal.

## REFERENCES

Alexander, L.T. and Cady, F.G. (1962). Genesis and hardening of Laterite in Soils. Technical Bulletin 1282, US Department of Agriculture, Washington, D.C.

Arora, K.R. (2009). Soil Mechanics and Foundation Engineering, (7th ed), Delhi: Lomus.

Correla, F.G. (1969). Engineering geology and geotechnics, (2nd ed), MacMillan,pp115.

Bell, F.G. (2006). Engineering Geology, London UK: Blackwell Scientific Publication.

Blight, G.E. and Leong, E.C. (2012). Mechanics of Residual Soils, (Second Edition), Taylor & Francis.

British Standard Institution. (1990). Methods of Test for Soils for Civil Engineering Properties (BS 1377), London UK, British Standard Institution.

Das, B. M. (2006). Principles of geotechnical engineering, Stamford, CT: Thomson Learning College.

Das, B.M. (2010). Principles of geotechnical engineering, (6th ed), Stamford, CT: Thomson Learning College, 6th edition, pp 418.

Ekwueme, B.N., (1994). Structural Features of Southern Obudu Plateau, Bamenda Massif.

Federal Ministry of Works and Housing, Lagos, Nigeria, (1972). "Nigerian Highway Design Manual Part I (Design) and Part II (Maintenance)".

Federal Ministry of Works and Housing, Lagos, Nigeria (2003). "General Specifications for Roads and Bridges", Volumes 1 and 2.

Federal Ministry of Works and Housing, Abuja, Nigeria. (1997). "General Specifications for Roads and Bridges", Volume II.145-284.

Kennedy,W.Q., (1964). The Structural Differentiation of Pan African Tectonic Episodes. Research Institute of African Geology, University of Leeds. 8th Ann. Dept. 48

Head, K.H. (1992). "Manual of Soil Laboratory Testing", Soil specification and Compaction Tests, (2nd edition), Vol. 1. Pentech Press: London, UK.

Mohr, DW, (1993). Gneisses. Mc Grawhill Encyclopedia of Science and Technology. Vol. 8.

Ola, S.A. (1983). "Geotechnical Properties of an Attapulgite Clay Shale in Northwestern Nigeria", Engineering Geology.19:1-13.

Vickers, B., (1978). Laboratory work in civil engineering soil mechanics. Granada.

Wagner, A.A. (1957). The use of the Unified soil classification system by the Bureau of Reclamation. Proceedings, 4th International conference on soil mechanics and foundation engineering (London), 1, p.125.

Whitlow, R., (1995). Basic Soil Mechanics, (3rd Ed), Edinburgh: Addison Wesley Longman.

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