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The geochemistry and geotechnical (compaction) analysis of lateritic soils: A case study of Okpanam area

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Abstract

The major elements of geochemistry and compaction characteristics of lateritic soils in Okpanam area, located in the Anambra Basin were investigated. This was with a view to determine the silica sesquioxide ratio and assess the suitability of the lateritic soils as a highway sub-base and sub-grade materials. Bulk samples of soil were collected from two separate horizons – A and B at depths of 1.38m and 3.39m in a burrow pit. The major elements geochemical analysis was carried out by means of Atomic Absorption Spectrometry (AAS). The geotechnical analysis – compaction, was executed by following the modified AASHTO test (T-180). The amount of total irons in terms of iron III oxide ranged from 6.07% - 7.22%. Silica – sesquioxide of iron and aluminium molar ratios were between 1.9 and 1.96. Compaction characteristics values for this area varied with sampling depth, with an average Optimum Moisture Content (OMC) range of 11.10% to 9.30% and an average Maximum Dry Density (MDD) range of 2.00g/cm^3 to 2.06g/cm^3. With these values, the soils can be compacted at specific optimum moisture contents in order to ensure close packing of the soil particles under compaction energy, thus ensuring their subsequent use as sub-base and sub-grade highway construction materials.

Key words: *Optimum moisture content, Compaction, Lateritic soils, Silica-sesquioxide ratio, Maximum dry density.*

INTRODUCTION

The settlement of un-compacted fills did not result in any serious inconveniences until the beginning of the 20th century, when the rapid development of the automobile created an increasing demand for hard surface roads. It soon became apparent that concrete roads on un-compacted fills were likely to break up and that the surface of other types of high-grade pavement had a tendency to become very uneven. The necessity for avoiding such undesirable conditions fostered the development of methods of soil compaction that would satisfy the requirement of both economy and efficiency. Simultaneous increase of activity in the field of earth-dam construction provided an additional incentive for the development of compaction methods. The investigation that was made has led to the conclusion that no one method of compaction is equally suitable for all types of soil. Furthermore, the extent to which a given soil is compacted as a result of a particular procedure mainly depends on the water content of the soil. The greatest degree of compaction is obtained when the water content has a certain value known as the optimum moisture content.

The soil name 'laterite' was coined by Buchanan (1807), in India, from a Latin word 'later' meaning brick. It was used by Buchanan to refer to some red, porous ferruginous earth materials in the present day India, which could be cut with a trowel or a large knife and because hardened when exposed to air. Although confusion has risen in the use of the term 'laterites', as many material possess various compositions similar to laterites, workers mostly prefer to use the following terms based on hardening: Iron-rich – ferric, silica-rich – silcrete, carbonate-rich – calcrete and bauxite or 'alcrete' for aluminum-rich (Fookes, 1997). Based on the ratios of sesquioxides ($Fe_2O_3 + Al_2O_3$) to silica (SiO_2) other definitions for laterites have been given. Ratio less than 1.33 depict laterites, between 1.33 – 2.0 indicate lateritic soils while those greater than 2.0 indicate non-lateritic soils (Bell, 1993).

Lateritic soils are soils that have undergone a serious weathering process, enriched with oxides of both aluminum and iron. They usually contain high quantities of kaolinite and quartz and usually lack the primary silicates and their bases. Attempts have been made by various investigators to produce a method identifying and evaluating lateritic soils for engineering purposes (Gidigasu, 1976); (Townsend, 1985).

Lateritic soils located in Nigeria have been used extensively in the construction industry. They are mainly used as subgrade and sub-base materials for road construction. They usually form on various types of rocks in different drainage and sub-climate environments. Lateritic soils found everywhere shows unique physical, chemical and engineering properties. Therefore, it is necessary that a comprehensive evaluation be carried out on any lateritic soil in order to determine if it meets the requirements of lateritic soils, prior to its utilization for any engineering purpose.

The studied lateritic soils are at latitude 06^{o} 14^{I} 10 ^{II} N and longitude $006^{o}37^{I}$ 78^{II} E, along the Asaba-Benin expressway way in Okpanam areas in Southern Nigeria. The soils were actually obtained from two different layers in a burrow pit. The geochemistry and geotechnical properties of the lateritic soils were also studied with a view of classifying the soil into lateritic and non-lateritic soils, and assessing the suitability or otherwise of the soil as a sub grade and sub base materials. The study area falls under the tropics, in the rain forest of Nigeria, and has a high humidity with lowest rainfall of about 30mm recorded in January & the highest rainfall of about 406mm recorded in September. This work was carried out towards the end of the rainy season-characterized by surface run offs. The study area has an undulating to predominantly flat topography, thickly forested vegetation with tall elephant grasses and shrubs. Type of soils found here are reddish lateritic soils and clayey sands. Temperature ranges from 24^{o}C – 27^{o}C.

Okpanam is an area dominated mainly by lateritic soils of the Quaternary sediments of the Ogwashi-Asaba formation in the Anambra Basin. Surface exposures of these areas were mainly of humus (top soil) which extends downwards to a depth of 0.04m. This top soil further extends downward to a lateritic soil profile. The burrow-pit profile observed at the location was approximately 4.24m deep with a predominantly flat to undulating topography. There was also a general change in colour and lithological characteristics down the profiles. These changes were probably due to the leaching away of mobile elements from the top of the profile to the bottom.

The Anambra basin is a sedimentary Basin in South central part of Nigeria that covers an area of 40,000km^2 (Udo, 1970). The southern boundary of the Anambra Basin coincides with the northern section of the Niger Delta, with the Basin as main precursor and the Basin extends north wards beyond the Benue River (Udo, 1970). The Anambra Basin is linked with the splitting of the Gondwana supercontinent (Reijers, 1996). The Santonian tectonic pulse which dated back to 84my occurred before the formation of the Anambra Basin proper. The sedimentary deposits of the Anambra Basin according to Murat (1970), belong to the Cretaceous – Tertiary age and lie uncomfortably on the crystalline basement complex rocks (Rayment, 1965). The formation on which the studied soils is located is called the Ogwahsi-Asaba Formation, it conformably overlies the Ameki formation and consists of alternation of seams of lignite displayed sandstone and occasional limestone horizons. An upper Oligocene to Micoene has been assigned to it with a thickness of about 3,000m (Rayment, 1965).

Over the years, considerable works on lateritic soils had been carried out in many different countries and parts of Nigeria and already presented are explicit reviews of available literature. (Alexander and Candy, 1962) ascertained that a lateritic soil contains kaolinite and quartz in large amounts, lacks bases of primary silicates rich in aluminum and iron oxides, and highly weathered. Gidigasu (1976), identified three major stages in the process of laterization. Ola (1978), calculated the silica sesquioxide molar ratio of lateritic soils, and also evaluated the geotechnical properties and behavior of some lateritic soils in Nigeria. Townsend (1985), evaluated lateritic soils for the purpose of engineering and stated that the iron oxide present in these soils is considered to play a key role in concentration and aggregate formation, which affects their engineering behavior significantly. Akpokodje (1986), studied the geotechnical properties of non-lateritic and lateritic soils in the South-eastern part of Nigeria and their evaluations for construction of roads. The chemistry, mineralogy and basic geotechnical properties of some lateritic soils from southwestern Nigeria were also studied by Ogunsanwo (1988). Rao et al. (1988), presented a paper which attempts to understand the role of iron oxide and the mechanisms by which the sesquioxides influence the index and compressibility characteristics of a kaolinite rich red soil and a montmorillonite dominant black soil, based on results obtained with remolded saturated specimens tested in the untreated and iron oxide removed (decemented) conditions.

Field Manual (FM 5- 410) on Military Soils Engineering, (1992) listed the compaction specifications and characteristics of various soils, the moisture density relationship for two different soils, sub grade and base compaction requirements; as well as the corrective actions to be taken when the density and/or moisture of a soil at different environmental conditions has something missing in order to bring out the mechanism that control the compaction characteristics of lateritic soils subjected to some environmental changes.

(Udoeye and Abubakar, 2001) designed an experimental programme and studied the influence of compaction delay on some characteristics of laterites stabilized with cement kiln dust-an industrial waste from cement manufacturing company. Adeyemi (2002), evaluated and studied the geotechnical, clay mineralogy, and geochemical properties of lateritic soils in the Ishara area with a view to assessing the suitability or otherwise of the soil as highway sub-grade and fill material. Ogunsanwo (2002), studied and investigated some soils from South-western Nigeria in order to ascertain their geotechnical behaviour in the compacted state under the direct shear and consolidation tests in the laboratory. In order to stimulate a condition of inundation, he further examined the behavior of the soils in the remoulded state similar tests.

METHODOLOGY

The methodology of this research work consisted of both field and laboratory (experimental) procedures.

Field Procedure

The field work basically involved the observation of the study areas and subsequent collection of fresh samples at various depths for geotechnical (compaction) and geochemical analysis. The sites where these samples were collected were about 4.24m in thickness. Fresh samples were collected with the aid of a spade and stored in polythene bags after delineating the different soil horizons according to their textural and color variations. The thickness of the soil profile was measured with the aid of a measuring tape. This is the first time geotechnical (compaction) and geochemical analyses has ever been carried out in this location.

During the course of the field work, various instruments were utilized such as: location map for access to the exact location and a Global Positioning System (GPS) device for obtaining the exact co-ordinates of the study area.

Geochemical Analysis

The method used for the sample analysis was the Atomic Absorption Spectrometry (A.A.S) technique.

Sample preparation

The soil samples were prepared individually by sun drying and grinding them in a mortar into a fine powder. About 1.5g of each sample were used for the analysis.

Sample Digestion

Reagents (specific reagents for specific elements), concentrated HF 3mls, Aqua regia 2ml HCL + HNO3.

About 1.5g was weighed into a plastic container; 3ml of concentrated hydrogen fluoride (HF) was added into the sample and stirred for 10 minutes then 2mls of aqua regia was added into the mixture and shaken for 15minutes. The samples under digestion were kept for 24 hours. The samples were made up to the mark with distilled water and 150cl volumetric flask was used. The samples were made ready for atomic absorption spectrophotometric analysis. The 200AA flame bulk model was used.

Compaction Laboratory procedures

The compaction laboratory procedure employed during the course of this study on the soil samples was the Modified AASHTO Test (T- 180). A sample of the soil was dried in the oven for 24 hours at a constant temperature of 105^0C. 6000g of the soil sample was pulverized in a tray and a quantity of water (4% of the mass of soil sample) was added and thoroughly mixed to produce a damp aggregate. The damp soil aggregate was then packed, in five equal layers, into cylindrical mould). Each layer was compacted by 56 blows of a standard 4.5k weight rammer that fell from a height 0.46m. Then the cylindrical mould was filled and leveled by series of scrapping operations with straight edge, beginning at the central axis and working towards the edge of the mould. The soil was de-moulded and samples for water content determination were collected in small metal containers of known weight and oven dried for 24 hours.

The soil was further pulverized by hand and 2% of the original mass of soil for quantity of water was added and mixed thoroughly by hand. The compaction process was repeated until there was a drop in the combined weight of the mould and wet soil. The bulk density (wet density) and dry density were then determined from equations 1 and 2 and a curve was plotted showing the relationship between dry density and moisture content.

Let W = Weight of mould
W_1 = weight of wet soil + mould
W_2 = weight of wet soil
$W_2 = W_1 - 1$
V = Volume of mould
m = Moisture content

$$\text{Dry Density } (\ell d) = \frac{W_1 - W}{V} \quad \text{.........................(1)}$$

$$\text{Wet (bulk)density } (\ell) = \frac{\ell}{1+m} \quad \text{.........................(2)}$$

Moisture Content Laboratory Procedure

To ensure a proper determination of the moisture contents of the soil samples the following laboratory procedures were employed:

1. The small containers were cleaned, dried and their weights obtained.
2. Wet soils samples were collected in the small containers and weighed in order to determine the weight of containers and wet soil samples.
3. Containers with their wet soil sample contents were placed in the oven, for about 24 hours for them to get dried, at a maintained required temperature of 105^0c.
4. The containers with their respective contents were removed from the oven after 24 hours and opened by moving the lids in order to allow the soil samples cold down.
5. When fully cooled, the container lids were replaced and weighed in order to determine the weight of the dry soil and container.
6. The moisture content in percentage was then calculated as shown below.

Table 1. Geochemical Analysis Result For Lateritic Soils

	Horizon A	Horizon B
Sampling depth	1.38m	3.39m
Elemental oxides (%)		
SiO_2	46.70	47.12
$A1_2O_3$	36.81	36.31
Fe_2O_3	6.07	7.22
Na_2O	1.98	1.73
MgO	1.83	1.60
K_2O	1.90	1.93
TiO_2	0.93	0.94
Total	96.22	96.85
Silica/Sesquioxide molar ratio	1.95	1.96

Percentage moisture = $\frac{\text{weight of water}}{\text{Weight of dry soil}}$ x 100%

Let W = weight of container
W_1 = weight of wet soil + container
W_2 = weight of dry soil + container

Weight of dry soil (W_d) = $W_2 – W$

Weight of water (W_w) = $W_1 – W_2$

% moisture content = $\frac{W1 - W2}{W2 - W}$ x 100%

Moisture content = $\frac{W1 - W2}{W2 - W}$

The value of percentage moisture content for each individual content specimen was calculated to the nearest 0.1%.

Geochemical Analysis Results

The geochemical analysis results of lateritic soils from the study area showing the major elements are shown below in (Table 1).

$$\text{Silica/Sesquioxide Molar Ratio} = \frac{\frac{\%\,SiO_2}{\text{Mol.Wt.of } SiO_2}}{\frac{\%\,Al_2O_3}{\text{Mol.Wt.of } Al_2O_3}+\frac{\%\,Fe_2O_3}{\text{Mol.Wt.of } Fe_2O_3}} \quad \ldots\ldots(3)$$

Molar mass of Si = 28.0g
Molar mass of O = 16.0g
Molar mass of Al = 27.0g
Molar mass of Fe = 56.0g
Molar weight of SiO_2 = 60.0g
Molar weight of Al_2O_3 = 102.0g
Molar weight of Fe_2O_3 = 160.0g

Winterkorn et al. (1952), as cited in Adeyemi (2002), have suggested the use of the silica/sesquioxide of iron and aluminum molar ratio for the classification of soils. While soils with ratio less than 1.33 were classified as true laterites, those with ratio between 1.33 and 2.00 were classified as lateritic soils and soils whose ratio is in excess of 2.00 were decided to be non-lateritic tropical soils. With a silica/ sesquioxide molar ratio between 1.64 and 1.77 the soils from the study area can thus be described as lateritic soils.

Discussion of Geochemical results

From (Table 1), there is a general increase in Iron III oxide down the soil horizons. This is evidenced by an increase in the amount of iron III oxide from 6.07% at a depth of 1.30m to 7.22% at a depth of 3.39m.

It was observed by (Chandrakaran and Nambiar, 1997) that in the top soil, iron III oxide exist as an inert material whereas in the bottom layers, it exists as a cementing material. Also, according to Rao et al. (1988), iron oxide present in soils binds individual soil particles into coarser aggregates and contributes to the development of random soil structure. Therefore, down the soil horizon, there is more cementing of the soil particles, forming coarser aggregates.

Compaction Analysis Results

From the geotechnical analysis, (Table 2 and 3) compaction results were obtained.

Discussion of Compaction Analysis Results

From the average compaction laboratory test result for the study area (Table 4), there is an increase in average Maximum Dry Density (MDD) values and a decrease in average Optimum Moisture Content values down the soil profile from horizon A to horizon B. This could be due to the filling of available voids

Table 2. Compaction Analysis Results for Horizon A

SOIL HORIZON A sampling point 1 sampling depth (1.00m)					
DESCRIPTION	**Determination numbers**				
	1	2	3	4	5
Wet density (g/cm^3)	1.86	2.09	2.20	2.13	2.06
Dry density (g/cm^3)	1.73	1.91	1.97	1.87	1.78
Moisture content %	7.7	9.4	11.4	13.3	15.0
Sampling point 2					
Sampling depth 1.38m					
Description	**Determination number**				
	1	2	3	4	5
Wet density (g/cm^3)	1.90	2.13	2.24	2.17	2.10
Dry density (g/cm^3)	1.77	1.95	2.02	1.93	1.84
Moisture content%	7.1	8.8	10.8	12.7	14.4

Table 3. Compaction Analysis Results for Horizon B

SOIL HORIZON B Sampling point 1 Sampling depth 1.29m					
Description	**Determination numbers**				
	1	2	3	4	5
Wet density (g/cm^3)	1.92	2.11	2.23	2.21	2.10
Dry density (g/cm^3)	1.81	1.95	2.03	1.98	1.91
Moisture content %	5.6	8.0	9.8	11.3	13.6
Sampling point 2 Sampling depth 1.68m					
Description	**Determination number**				
	1	2	3	4	5
Wet density (g/cm^3)	1.96	2.15	2.27	2.25	2.14
Dry density (g/cm^3)	1.85	2.01	2.09	2.04	1.95
Moisture content%	4.4	6.8	8.7	10.1	12.4

in the soil with silica grains down the horizons (Udeoyo and Abubakar, 2001).

Generally, there is a variation in compaction properties along the profile. Samples taken from horizon A exhibit lower Maximum Dry Density (MDD) values and higher Optimum Moisture Content (OMC) values than those taken from horizons B. This is probably due to an increase in hard concretionary particles and quartz down the horizons (Bwalya, 2003). Usually, the higher the MDD, the more well graded, coarse and granular the soils and this enhances their subsequent performance as sub-base and sub-grade construction materials. Lateritic soils from Okpanam will then be effective for use as sub-grade and sub-base materials. Thus, down the soil horizons, their MDD will not be affected by moisture contents. This downward increase in MDD is also in agreement with the findings of Adeyemi (2002), who investigated some lateritic soils developed over quartz schist in Ishara area, Southwestern Nigeria.

From field manual 5 – 410 of Military Soils Engineering, 1992; soils with an optimum moisture content variation from 12%-25% have been classified as fine grained soils while variation from 7% -12% have been classified as well graded granular soils. From the mean OMC values of 9.3% - 11.1%, the lateritic soils in this area can thus be classified as well graded soils. The mean Maximum Dry Density value for the study area also shows a general increase from 2.00g/cm^3 – 2.06g/cm^3. This characteristic compaction property further enhances their suitability for use as sub-grade and sub-base road construction materials.The geochemical analysis result (Table 1) shows an increase in iron oxide content values down

Table 4. Average Compaction Analysis Results

SOIL HORIZON A					
Description	**Determination numbers**				
	1	2	3	4	5
Wet density (g/cm^3)	1.88	2.11	2.22	2.15	2.08
Dry density (g/cm^3)	1.75	1.93	2.00	1.90	1.81
Moisture content %	7.4	9.1	11.1	13.0	14.7
Average maximum dry density (M.D.D) = 2.00g/cm^3 Average optimum moisture content (O.M.C) = 11.1%					
SOIL HORIZON B					
Description	**Determination number**				
	1	2	3	4	5
wet density (g/cm^3)	1.94	2.13	2.25	2.23	2.12
dry density (g/cm^3)	1.85	1.98	2.06	2.01	1.93
moisture content%	5.00	7.4	9.2	10.7	13.0
Average maximum dry density (M.D.D) = 2.06g/cm^3 Average optimum moisture content (O.M.C) = 9.30%					

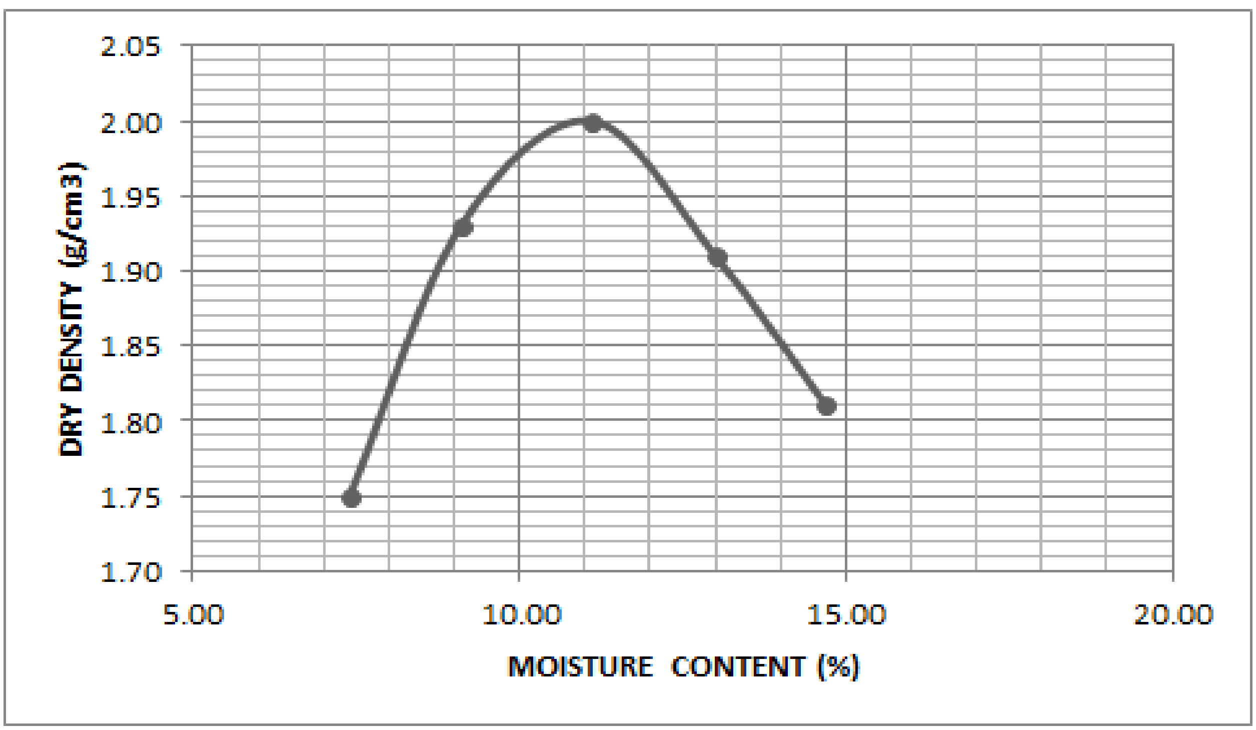

Figure 1: Moisture Density Relationship Graph for Horizon A

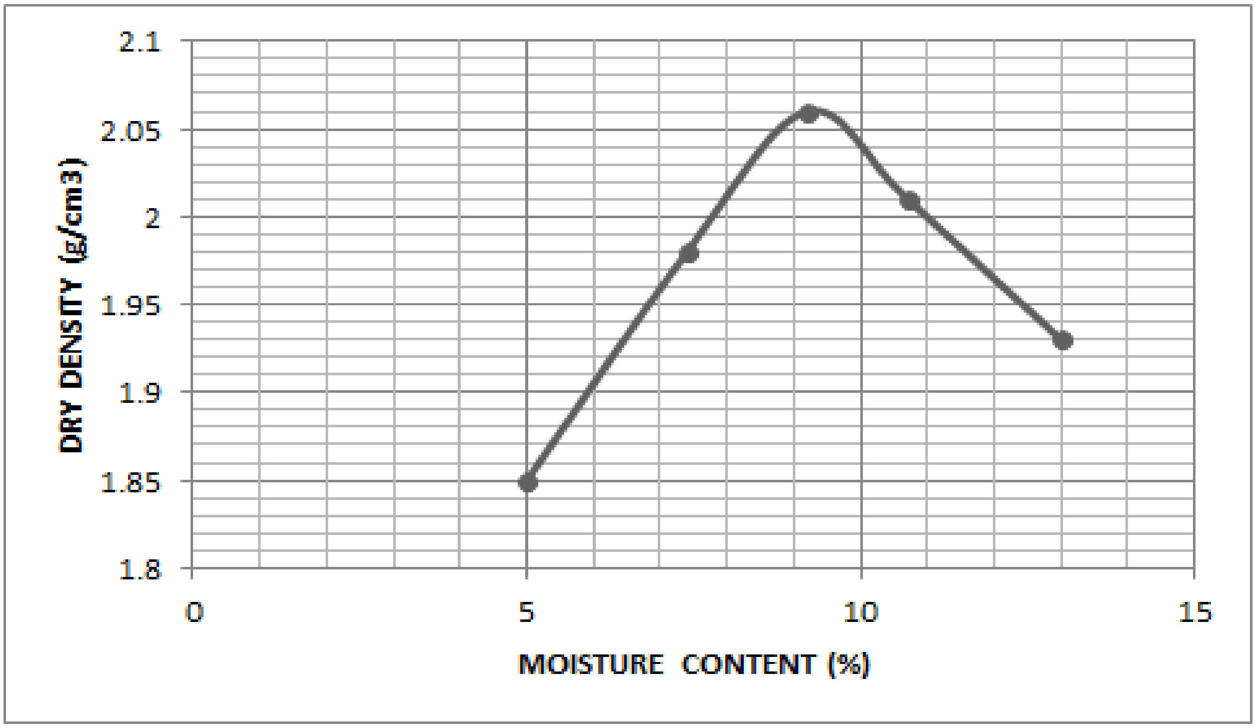

Figure 2: Moisture Density Relationship Graph for Horizon B

the horizons, since there is more effective laterization (sequioxide coating) down the horizons, (Adeyemi, 2002). This increase in iron oxide results in an increase in the cementing and hardening of the concretionary particles and subsequent decrease in OMC and increase in Maximum Dry Densities down the horizons for the study area.

The moisture–density relationship graphs (Figures 1 and 2) for both horizons shows an initial increase in dry density at low moisture content is increased, for a given compactive effort. The possible explanation for this is that at low moisture contents, the soil tends to be dry and lumpy, and with little water to aid the breaking up process a significant proportion of the comparative energy is absorbed in simply crushing the lumps before any compaction of the soil particle can take place.

But at higher water contents, sufficient water becomes available to penetrate and help break up the lumps while allowing absorbed water layers to develop more fully around the mineral particles in the fines. This has the effect of reducing inter-particle bounding, permitting a greater orientation of the clay particle and developing a more dispersed microstructure. Thus, a reduction in void ratio and concomitant higher densities are obtained.

Beyond the optimum value, however, increase in water content are progressively less effective in reducing the new quite small air void content. Much of the compaction energy is absorbed by the pure-water as a result of excess pure water pressure, the soil particles are displaced rather than compacted and so increases the void space which results in lower densities. The OMC at which dry density is gotten is the moisture content at which the soil becomes easily workable under a given effort of compaction, thus ensuring that most of the air is expelled from the voids due to the compacted and parked nature of the soil particles. This is thus not a unique value but rather is a function of soil types, the compactive effort and soil treatment.

Subsequently, in this area, horizon A has a higher peak than horizon B and this is probably because the added water contributing to the lubrication of particle contact points is higher in horizon A than B, and this leads to effective workability.

CONCLUSION

The lateritic soils at Okpanam possess basic compaction properties, which make them suitable for use as a sub-base and sub-grade material for road construction works. The maximum dry densities and optimum moisture contents together with the geochemistry of these lateritic soils have been determined. Soils compacted at the drier side of the optimum moisture content are more suitable for road construction due to the fact that there will be lower permeability, high shear strength, reduced rate of settling and less volume change; unlike when compacted at the wetter side of the optimum moisture content.

The increase in maximum dry densities and decrease in optimum moisture content down the horizon signifies that down the horizon, the soil becomes more suitable for use as a sub-grade and sub-base material for road construction works, because the higher the maximum dry density the more well graded, coarse and granular the soil will be. Down the soil profile, the soils generally coarsen and as such, the maximum dry densities will not be affected by moisture content over a broad range of moisture contents. The presence of SiO_2 and the sesquioxide (Fe_2O_3 + $A1_2O_3$) has a significant influence on the geochemistry and compaction characteristics of the lateritic soils. The increase in the sesquioxides down the profile signifies that the soil becomes more lateritic and thus results in an increase in the thickness of free iron oxide coating of soil particles, leading to their cementing and aggregate formation. As such, horizon B is more suitable for excavation for use as a sub-base and sub-grade material for construction works.

Recommendations

Based on the data obtained on the proceeding study, the following recommendations are made:

To derive maximum benefits from lateritic soils for use as sub-base and sub-grade, the climate and hydrological regime in which the road is constructed, the quality of the lateritic-materials, traffic volume and the strength of sub-grade should be taken into consideration. Adequate drainage should be provided to obstruct the increase of moisture on the soil to adverse proportion; the soil should not be over compacted to levels where fines are increased.

Further analysis could be done on other engineering properties atterberg limits, california bearing ratio, particle size distribution and clay mineralogy, of the lateritic soils in order to determine the load bearing capacity, plasticity index, mineralogy and classification of the lateritic soils. This will aid in further determination of the suitability of the soils for use as sub-base and sub-grade construction materials.

Conflict of interest

Authors have none to declare

REFERENCES

Adeyemi GO (2002). Geotechnical properties of lateritic soil developed over Quartz schist in Ishara Area, Southwestern Nigeria. *Journal of Min. and Geol*. **38**, 65-69.

Akpokodje EG (1986). The Geotechnical properties of Lateritic and Non- lateritic soils of Southeastern Nigeria and their evaluation for road construction. *Bull. Int. Assoc. Engr. Geol*. **33**, 115-121.

Alexander LT and Cady JG (1962). Genesis and hardening of laterite in soils. U.S. Dept. Agric. *Tech. Bull.*, **1282**, 90.

Bell FG (1993). Engineering Geology, pp. 104. Blackwell Scientific Publications Oxford, London, Edinburgh, Boston, Melbourne, Paris, Berlin, Viena.

Buchanan F (1807). A journey from Madras through the Countries of Mysore, Canara and Malabar, pp. 436-560, **2,** East India Co., London.

Chandrakaran S and Nambiar MRM (1997). Influence of some environmental factors on the engineering behavior of compacted lateritic soils. *Publ. Indian highways,* 29-35.

Field Manual 5-410. (1992). Military Soils Engineering Head Quarters. Dept. of the Army, Washington, DC, **8,** 1-13.

Fookes G (1997). Tropical Residual Soils. A Geotechnical society Engineering Group Working party revised report, pp. 21-33. Publ. Geol. Soc. London, Tulsa, New South Australia, Delhi, Tokyo.

Gidigasu MD (1976). Lateritic Soil Engineering, Development in Geotechnical Engineering, pp. 554. Elsevier Sci. Publ. Com., Amsterdam.

Jackson N and Dhir RK (1988). Civil Engineering Materials, pp. 347. 4th Edition, Macmillan publ., hound mills, Basingstoke, Hampshire.

Murat RC (1970). Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In: T.F.J Dessauvagre and A.J. Whitema (Eds.), Afric. Geol. Univ. Ibadan press, pp, 251-268 Nigeria.

Ogunsanwo O (1988). Basic geotechnical properties, chemistry and mineralogy of some lateritic soils from Southwestern Nigerian. *Bull. Int. Assoc. Engr. Geol., Paris*. **37,** 131-135.

Ogunsanwo O (2002). Effect of Inundation on the geotechnical properties of some soils from parts of Southwestern Nigeria. *Jour. Min. Geol*. **38,** 57-63.

Ola SA (1978). Geotechnical properties and behaviours of some stabilized Nigerian lateritic soils., *Quarterly Journal Engineering Geology, London*, **2,** 145-160.

Rao SM, Sridharan A and Chandrakaran S (1978). The role of iron oxide in tropical soil properties. *Proceedings 2nd Nat. Conf. on geo-mechanics in Tropical soils. Singapore*, **1**, 43-49.

Reijers TJA (1996). Selected chapters on Geology. Shell Pet. Dev. Co. Nig. Reprographic services, Warri. 143.

Reyment RA (1965). Aspects of the geology of Nigeria. Ibadan University press. 133.

Townsend FC (1985). Geotechnical Characteristics of residual soils. *Geotechnical Engr. Proc. Am. Soc. Engrs*. **111**, 77- 93.

Udo RK (1970). Geographical regions of Nigeria. pp. 212. Heinemann Educational Books Ltd. London.

Udoeyo FF and Abubakar MA (2001). Influence of Compaction delay on some characteristics of lateritic soil stabilized with cement kilm dust. *Glo. Jour. Pure. Appl. Sci.*, **7**, 727-731.