Geotechnical Properties of Lateritic Soils Derived from Various Geologic Formations in Ohafia Area, Southeastern Nigeria

***Odinkemere, J.C., Okeke, O.C., Ikoro, D.O., Amadi C.C. Akiang F.B. and Okonkwo S.I.**
Department of Geology, Federal University of technology, Owerri, Nigeria
* Corresponding authors' Email:
writetojoe24@yahoo.com, ositachris12@gmail.com
sender: ositachris12@gmail.com
DOI: 10.56201/ijgem.v10.no10.2024.pg84.100

Abstract
Some lateritic soils collected and used for road construction in Ohafia Area, Southeastern Nigeria are not suitable. The purpose of this paper was to evaluate the quality of lateritic soils derived from various geologic formations in Ohafia, Area, as road construction materials using their geotechnical properties (Atterberg limits, grain-size distribution and CBR). Eight representative samples derived from various geologic formations in the study area (including 2 from Mamu Formation (Asaga and Akanu); 3 from Nsukka Formation (Ebem, Ozu Abam and Ndi Uduma); 1 from Nkporo Formations (Ndiorioko); 1 from Ajali Formations (Ndi Uduma Ukwu); and 1 from Imo Shale (Amagbu), was used in the study. Results of the laboratory tests indicate that the liquid limits range from 26.0 to 33.0%, while the plasticity indices range from 2.8 to 10.0%. The % fines range from 18.6 to 64.9%. The CBR (Soaked) range from 17.0 to 39.0%, while CBR (unsoaked) range from 35 to 79%. On the basis of Federal Ministry of Works Specifications for highway pavement materials, only soils derived Ajali Formations, Nsukka Formation and Nkporo Formation are fairly suitable materials. They satisfy the specification in all areas LL<36%, P1 < 12% and % fines < 30%), though they have low CBR values (soaked and unsoaked). Soils derived from Mamu Formations and Imo Shale are not good because of their particularly very high % fines. Treatment of any of or all the soils with either cement or lime will improve the poor quality aspect (low CBR and high % fines) and hence make the soils suitable to be used as road construction materials.

Keywords: *Lateritic soils, Grain-size, CBR, Atterberg limits, Ohafia Area*

1.0 Introduction

Geotechnique is vital areas of study in the field of geosciences. By definition, lateritic soils are formed from the weathering of rocks and practically remain at the location of origin with little or no movement of individual soil particles. Lateritic means that it formed in place or in-situ. Soils that form directly over in situ bedrock are called residual soils. Alternatively, soils may develop from non-residual (i.e., transported) unconsolidated material, such as alluvial (water-laid), aeolian (wind-laid), or glacial deposits. Furthermore, lateritic soil is defined as a soil material which is derived from pre-existing rocks and had not undergone transportation, usually found in tropical climates with relatively high temperatures and rainfall (Ehujuo et al., 2017; Okeke et al., 2011; Ogbuchukwu et al., 2019).

Soil mechanics entails soil behavior developed from the study of sedimentary or lateritic soils. In fact, most of the early concepts emanate from the study of remoulded sedimentary soils and involved investigating the influence of stress history on their behavior, in the belief that this was simulating the influence of stresses which soils may be subject to during their formation processes. Large areas of the earth (including large areas in the Ohafia regions and environs, Soil mechanics entails soil behavior developed from the study of sedimentary or lateritic soils.

2.0 Location and Geology of the study Area

The study area Ohafia is located in Anambra Basin Southeastern Nigeria. The region is bounded between latitude 5^{o} 15N and longitude 7^{o} 13E to 7 81E. In order to comprehend the geology of the area, the physiography of the region which includes the drainage pattern, vegetation, topography, and climate were investigated. The study area falls on the nose of the lower Benue trough and the Anambra basin Southeastern Nigeria. Sediment deposition in the Southeastern Nigeria began in the Campanian with a brief marine transgression followed by a regression. The Nkporo shale and its lateral equivalents, the Enugu shale and Owelli Sandstone (Nkporo Group), comprised the basal beds of the Campanian period. The broad shallow sea gradually became shallower because of gradual subsidence, causing regressive phase during the Maastrichtian that deposited Deltaic fore-sets and flood plain sediments of the Mamu Formation (Lower Coal Measures). The Mamu Formation is overburdened by the continental beds of Ajali Sandstone (False bedded Sandstone), followed by a return to partially paralic conditions and the deposition of the Nsukka Formation. Fig1. Show the Regional Geologic map of Southeastern Nigeria (Eldosouky et al., 2022).

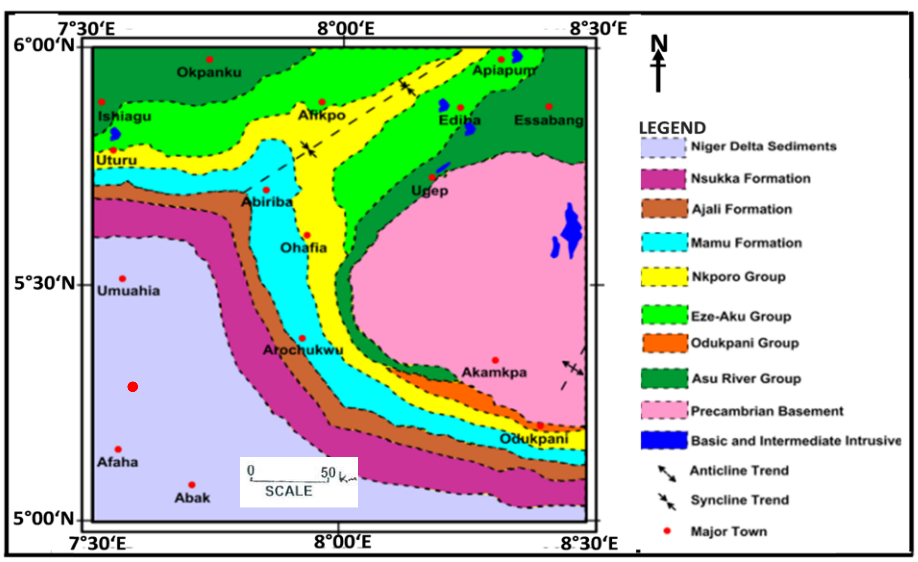

Fig. 1. Geologic Map of Southeastern Nigeria (Modified from Eldosouky et al., 2022)

The Nsukka Formation marks the onset of the Sokoto transgression Murat, (1972) and documents a return to paludal conditions. Sedimentation was mainly fluvial origin. The Imo shales reflect shallow-marine shelf conditions in which foreshore and shoreface sands are occasionally preserved Petters et al., (1981). The Imo formation consists of blue-grey clays and shales and black shales with bands of calcareous sandstone, marl, and limestone (Reyment, 1965).

It is quite possible that the basal beds of the Ogwashi-Asaga Formation are partly Oligocene in age, Kogbe, (1985). During the Miocene, the Niger Delta continued to build up and prograde seawards. There was a lowering of sea level during the Pleistocene. The River Niger cut wide valleys through its own delta. These troughs are being filled today as the sea level gradually rises.

The tectonic evolution of the Anambra Basin may be traced back to the late Jurrassic when convention currents in the asthenosphere caused the break-up of the Gondwana Supercontinent. The separation of the African and South American plates left the Benue Trough as an aulacogen, a failed arm of an RRR Triple Junction, Burke, (1972); Olade, (1975). The Benue Trough is itself a part of the very expansive west and central African rift system in which it opened as an extensive sinistral wrench complex Emery et al., (1975); White (1982); Genik, (1993). A reconstruction by Murat (1972) shows the southern part of the Benue Trough as longitudinally faulted, with its Eastern half subsiding preferentially to become the Abakaliki depression. During the filling of the Abakiliki-Benue sector of the Benue Trough in the Albian-Santonian times, the proto-Anambra Basin was a platform that became only thinly sediment-drapeds, Nwajide and Reijers, (1997). Basin subsidence in the Southern Benue Trough was spasmodic. It was at a high rate in pre Albian time, low in lower Cenomanian, and very high in Turonian; the latter was an important phase of platform subsidence, Ojoh, (1990). This is thought to be the actual time of initiation of the Anambra Basin; a process that gained momentum in the Coniacian and climaxed during the Santonian thermotectonic events (Nwajide, 2005).

The geology of Ohafia area falls within the Deltaic marine sediment of cretaceous to recent age. Anambra basin of which the study area lies forms part of the regional extensive northeast-southwest trending Benue trough, Ibeneme et al, (2013), Mode, (2004), and Nwajide, (2005). The marine deposited Imo shale of Paleocene age overlies the Nsukka Formation, it comprises of shale, Sandstone, and limestone members. The Eocene-Oligocene Ameke Formation Overlies the Imo Shale consisting of medium to coarse grained white sandstone and mottled clay, Reyment, (1965), Hogue, (1977); Kogbe, (1988), Ibe, (1998).

Fig 2 shows the local geology map of Ohafia area (Mode 2004; Okoro et al., 2019)

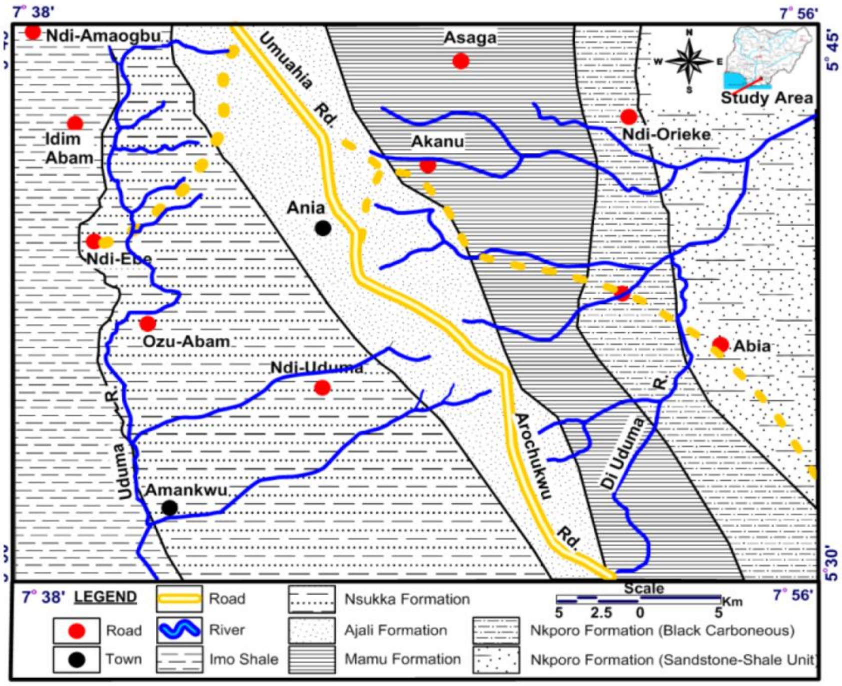

Fig 2: Geology map of Ohafia area (Mode 2004; Okoro et al., 2019)

Table 1: Generalized regional stratigraphy of Southeastern Nigeria (Modified from Reyment, 1965 and Offodile, 1975)

	Age	Formation	Lithology
Tertiary	Recent	Recent Sediments	Alluvium/Deltaic Plains
Tertiary	Miocene-Recent	Benin Formation	Unconsolidated sandstone with lenses of clay
Tertiary	Oligocene-Miocene	Ogwashi-Asaba Formation	Unconsoliddated sandstones, mudstone, clay and lignite seams.
Tertiary	Eocene	Ameki Formation	Grey to green argillaceous sandstone, shale and limestone units
Upper Cretaceous	Paleocene	Imo Formation	Blue to dark grey shales and subordinate sandstone members (Umuna and Ebenebe)
Upper Cretaceous	Maastritchian	Nsukka Formation	Alternating sequence of shale, sandstone and coal seams
		Ajali Formation	Friable sandstone with iron stains
		Mamu Formation	Sandstone, shale, siltstone with coal seams
Upper Cretaceous	Campanian	Nkporo Formation/Enugu Shale	Mudstone and shale with thin beds of sandstone
Upper Cretaceous	Santonian Coniacian	Awgu Formation (Awgu Shale)	Shale with intercalations of sandstones and shaly limestones
Upper Cretaceous	Turonian	Ezeaku Formation (Ezeaku Shale)	Siltstone and shale with sandstone lenses
Upper Cretaceous	Cenomanian	Odukpani Formation	Alternating sequence of sandstone, shale and limestone
Lower Cretaceous	Albian	Asu River Group, Abakaliki Shale and Awi Formation	Sandy shales, sandstone and sandy limestone lenses
	Precambrian	Basement Complex	Older granites and gneisses

Table 2 shows the stratigraphic sequence in Southeastern Nigeria in relation to Niger Delta Basin and Anambra Basin (Nwajide, 2005).

Table1. Stratigraphic Sequence of Niger Delta and Anambra Basin (Modified from Nwajide, 2005).

<table>
<tr><th>Age</th><th>Basin</th><th colspan="7">Stratigraphic Units</th></tr>
<tr><td>Oligocene-Recent</td><td rowspan="3">Niger Delta</td><td colspan="7">Ogwashi-Asaba Fm</td></tr>
<tr><td>Eocene</td><td colspan="7">Ameki/Nanka Fm/Nsugbe Sandstone (Ameki Group)</td></tr>
<tr><td>Thanetian</td><td colspan="7">Imo Formation</td></tr>
<tr><td>Danian</td><td rowspan="4">Anambra Basin</td><td rowspan="3"></td><td colspan="6">Nsukka Formation</td></tr>
<tr><td rowspan="2">Maastrichtian</td><td colspan="6">Ajali Formation</td></tr>
<tr><td colspan="6">Mamu Formation</td></tr>
<tr><td>Campanian</td><td>Nkporo Fm</td><td>Nkporo Shale</td><td>Enugu Fm</td><td>Owelli Ss</td><td>Afikpo Ss</td><td>Otobi Ss</td><td>Lafia Ss</td></tr>
</table>

The Mamu Formation is the coal bearing stratigraphic unit of the Anambra Basin. The Formation comprises a heterolithic succession of wave ripple laminated and fine grained sandstone, alternating with thin beds of shale, mud laminated sandstone, mudstone and coal beds. The Maastrichtian Mamu Formation is an intracratonic Formation within the Anambra Basin and is one of the three upper cretaceous coal measures.

In the distal basinal area of awgu, the Mamu Formation occurs as M-scale cycles of carbonaceous Fissile shale-oncolitic mudstones-oolitic sandstone deposited in shallow shelf to shoreface environment, Obi, (2000); Obi and Okogbue, (2004). Succeeding the mamu Formation is the Ajali sandstone of Maastrichtian age Ladipo, (1986); Obi, (2000). The Nsukka Formation which is Late Maastrichtian to early paleogene in age consists of carbonaceous mudstones and sandstone, similar to those of Mamu Formation Reyment, (1965); Obi and Okogbue, 2004). Nwajide(2005) suggests that the Anambra Basin fill terminated with Nsukka Formation.

Imo shale (Paleocene) overlies Nsukka Formation, Nwajide, (1990). It consist clayey shale with occasional iron stone and thin sandstone in which carbonized plants remains may occur Kogbe, (1989).

The Eocene stage was characterized by regressive phase that led to deposition of Ameki Group Obi, (2000). The Imo shale Formation consists of blue-grey clays and black shales with bands of calcareous sandstone, Marl, and limestone Reyment (1965). Ostracods and foraminifera boistratigraphy (Reyment, 1965), microfauna recovered from the basal limestone unit Adegoke et al; Arua, (1986); indicate a Paleocene age for the formation. The Imo Formation is the outcrop lithosfacies equivalent of the Akata formation in the subsurface Niger Delta, Short and Stauble, (1967), Avborbo, (1978).

Laterization processes

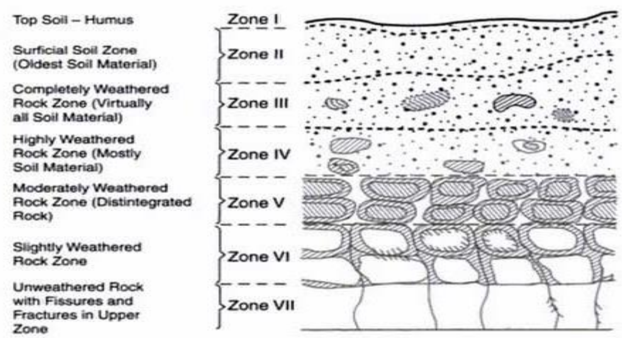

Figure 3 Stages of formation of lateritic soils adapted from McCarthy, (1982)

Laterization is a prolonged process of chemical weathering of rocks leading to the formation of soils. Lateritic soils are formed directly from the physical and chemical weathering of the parent material, normally rock of some sort. Various attempts have been made to group or classify lateritic soils, but none are particularly useful. Some, such as that of the British Geological Society (1990) make use of soil science classifications and are not very useful for engineering purposes. Terms such as vertisols, andosols, etc are not normally meaningful to engineers, and the discrepancies in properties within these groups is likely to be so large as to make the grouping of little relevance. Focusing on the two factors discussed above, namely geochemical and geotechnical properties or structure provides a basis for dividing lateritic soils into groups that can be expected to have fairly similar engineering properties. Red clays may be referred to as lateritic soils or as latosols.

However, engineering construction such as highways, airports, and residential buildings has necessitated for evaluation of good soil conditions for proper safety of the structures; Madurwar et al., (2013). Hence, the agenda of this study is to ascertain the, geotechnical properties of lateritic soil, its economic impacts and possible remedial measures for engineering construction.

3.0 Materials and Methods

Eight lateritic soil samples were collected from road outcrops in the study area from the various geologic formations. The soil samples were kept in safe bags and were properly identified. The location of the various samples derived included: Asaga, Ndiudma Ukwu, Akanu, Ebem, Ndiorioeke, Ozu Abam, Ndi Uduma and Amaogbu. Their geotechnical investigations were carried out to ascertain their engineering index properties. The California Bearing Ratio (CBR) test soaked and unsoaked was conducted to evaluate the strength of soils used ie, airport runways and taxiways, parking lots, and other pavements (Ogbuchukwu et al.,) 2019. CBR is the **ratio expressed in percentage of force per unit area required to penetrate a soil mass with** a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 and 5 mm. The california bearing ratio test is penetration test meant **for the evaluation of**

subbase strength of and pavements. The results obtained by these tests were used with the empirical curves to determine the thickness of pavement and its component layers. In tandem with the specification for design by the state Departments of Transportation, the Federal Highway Administration (FHWA), and Federal Aviation Administration (FAA). Approximately 200g of the samples were crushed and weighed to the nearest 0.1g in a vessel. The samples were dried in an oven for 24 hours and the dried weight was recorded. Their Atterberg limits which include plastic and liquid limits and specific gravity were tested.

Table 3: Sampling points and their coordinates

S/n	Location Name	Parent rock / Formation	Coordinators	
			Latitudes	Longitudes
1	Asaga	Mamu Formation	N5^0 351	E7^0 52’
2	Ndiuduma Ukwu	Ajali Formation	N5^0 35’	E7^0 55’
3	Akanu	Mamu Formation	N5^0 35’	E7^0 51’
4	Ebem	Nsukka Formation	N 5^0 36’	E7^0 42’
5	Ndiorioko	Nkporo Formation	5^0 33’	E7^0 53’
6	Ozu Abam	Nsukka Formation	N5^0 37’	E7^0 47’
7	Ndi Uduma	Nsukka Formation	N5^0 31’	E7^0 49’
8	Amaogbu	Imo Shale	N5^0 35’	E7^0 41’

4.0 Results and Discussion

4.1 Results

The results of the geotechnical tests carried out on the soil samples were summarized in Table 2, and 3; which are important parameters in soil engineering calculation.

Table 4: Geotechnical properties of lateritic soils in Ohafia Area

Sample Location site	**LL(%) (Liquid Limit),**	**PL(%) (Plasticity Limit),**	**PI(%) (Plasticity Index)**	**Specific gravity (Gs)**	**(%) Fine**	**CBR (Soaked)**	**CBR (Un Soaked)**	**Maximum Dry Density (Mg/m^3)**
Asaga(Mamu)	**26**	**30.8**	**4.50**	**2.87**	**62.7**	**22.0**	**43**	**1.65**
Ndi Uduma-Ukwu (Ajali)	**33.0**	**22.0**	**10.0**	**2.76**	**19.8**	**25**	**75.0**	**2.04**

Akanu(Mamu)	**27**	**31.9**	**3.00**	**2.09**	**19.8**	**27.0**	**42**	**1.71**
Ebem(Nsukka)	**26**	**32.3**	**6.30**	**2.57**	**21.9**	**39.0**	**51**	**2.30**
Ndiorioeke(Nkporo Sandtone)	**27**	**31.3**	**4.3**	**2.43**	**29.3**	**25.0**	**41**	**1.90**
Ozu Abam (Nsukka Fam)	**26.8**	**29.0**	**2.20**	**2.61**	**18.6**	**24.0**	**39**	**2.03**
Ndi Uduma (Nsukka sandstone)	**26.0**	**30.9**	**4.9**	**2.64**	**27.8**	**17.0**	**34**	**1.80**
Amaogbu Junction(Imo Shale)	**26.0**	**33.6**	**7.6**	**2.72**	**64.8**	**18.0**	**35**	**1.72**
Idima Abam(Nkporo Sandstone)	**27**	**34.0**	**33.1**	**2.64**	**1.35**	**24.0**	**37**	**1.71**
FMW Standard (1997)	**<36**	**-**	**<12**	**-**	**<30**	**>30**	**>80**	**>1.76**

4.2 Discussion

4.2.1 Grain Size Distribution and Atterberg's Limits

The results of grain size distribution analysis are given in Table 2. The statistical summary of obtained results are presented in Table 2 and represented graphically in Figure 2. The percentage of fines (% passing sieve 80 µm) has significant effect on the performance of the base sub-base materials (Garg 2009). Too much fines will result in the reduction in the possible maximum density and strength and increase the susceptibility to weakening from water infiltration or seepage (Garg 2009). The results show that the amount of fines in the weathering profile of soil samples is quite similar (greater than 60%). Figure 3 show that the soil samples are well graded gravel and sandy soils. The "well graded" curve soil samples represents a non-uniform soil with a wide range of particle sizes that are evenly distributed (Figure 2). Densification of a well-graded soil causes the smaller particles to move into the voids between the larger particles (Naresh and Nowatzki 2006). As the voids in the soil are reduced in the soil samples, the density and strength of the soil may increase. In contrast, poorly graded or uniform soils (vertical section of the soil samples) are composed of a narrow range of particle sizes (Figure 3). During compaction of these soils, inadequate distribution of particle sizes prevents reduction of volume of voids with infilling by smaller particles. Thus, uniform soils are expected to have low mechanical properties. As clearly shown in Figure 3, only samples from Ndiorioke area meet the limit of not more than 35% of fines recommended by the **CEBTP** for sub-base materials (Table 2). None of the tested samples meet the **CEBTP** specification of not more than 20% of fines for base materials. The Atterberg consistency limit tests show that the UCL and MCL samples have in average a LL of 61% and 63%, PL of 31% and 33%, plasticity index (PI) of 29% and 30% while INL samples has in average a LL of 56%, PL of 31% and PI of 27% (Table 3). The results of Atterberg's limit tests together with the grain size distribution results allowed the classification of UCL and MCL soil samples in the A-7-5 group of American Association of State Highway and Transportation Officials **(AASHTO)** classification scheme.

4.2.2 Californian Bearing Ratio (Cbr)

The overall soaked and unsoaked CBR results presented in Table 2 show both lateral and vertical variation with the values range between 16 and 43%. The soil samples collected at the **Asaga and ebem area shows CBR values higher than those collected at the Abia Ukwu and Ndi Uduma** environs at unsoaked (Table 2). Along the vertical transect, the CBR values are generally higher (with average of 35 ± 22% unsoaked, and soaked) in the weathering profile of the samples and lower (average of 17 ± 27%) in profile samples (Table 1). However, the study of the vertical profile of lateritic soils indicates that samples with higher proportions of fines (>80 μm) have lower values of MDD and CBR and vice versa. Thus, it can be deduced that the higher the fine components, PI and OMC, the lower the MDD and CBR values. This suggests that soil samples may be useful as sub-base materials whereas the engineering properties of the soil samples are of standard quality which allows their use as raw materials in road pavement. However, due to its relative high PI, LL and swelling potential (Figure 3 and Tables 2), these soils require mechanical, physical and/or chemical improvements with hydraulic binders such as quicklime, bitumen and or cement prior to their uses as base materials for engineering construction..

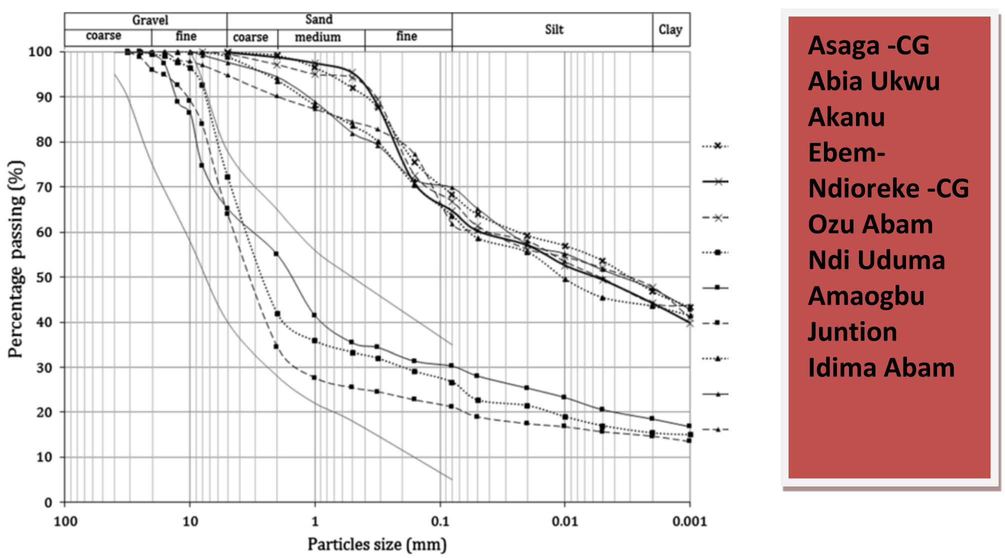

Figure 4: Sieve curves of soils samples from different layers of the weathering profiles in the studied area; UCL: upper clayey layer, INL: intermediate nodular layer, MCL: bottom mottled clayey layer. The continue gray curves represent the upper and lower bounds of typical lateritic soils intended to be used in road construction according to the road pavement standards for tropical countries (CEBTP, 1984)

Further, the plot in the Casagrande diagram (Figure 3) shows that all the samples are located alongthe A-line on the limit of high plasticity clays and silts domains; according to Day (2000).

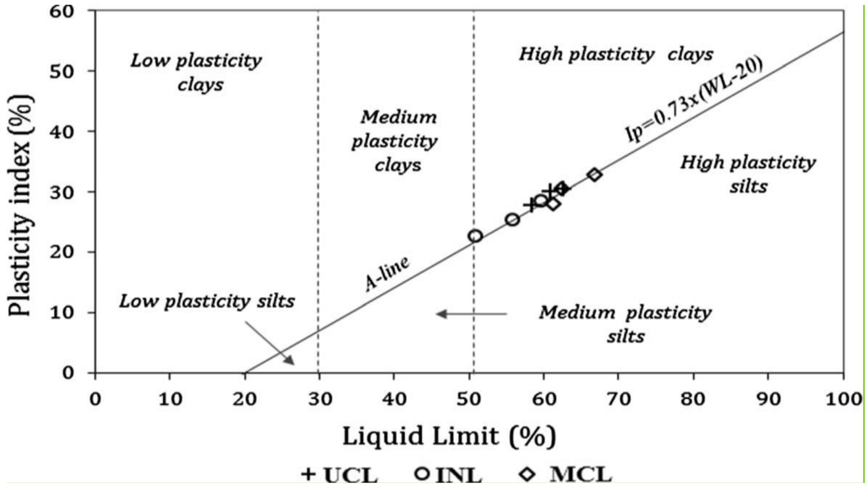

Figure 5: Casagrande chart classification of lateritic soils in the study area

According to Djedid et al. (2001) and references therein, the lateritic soils that contain clay fraction between 8 and 65% are considered as low, moderate and high swelling soils of εs value range between 0–1.5, 1.5-5, and 5–25, respectively. This indicates that the UCL and MCL samples could be more susceptible to considerable change in volume in a changing clime.

5.0 Conclusion and Recommendation

5.1 Conclusion

Lateritic soils derived from Ohafia area, found in the Anambra Basin, South eastern Nigeria were investigated for their, as well as their index and engineering property tests. Investigations on the engineering properties of lateritic soils, have helped in deducing the following conclusions:

i. The results of geotechnical tests reveal that samples from upper clay layer (UCL) and bottom mottled clay layer (MCL) are poorly graded soils with engineering properties (fines of 61 and 63%, plasticity index of 30 and 31%, CBR at unsoaked and soaked of 35 and 22%) which do not allow their use as raw materials in road construction. INL samples are gravel and sand soils well graded having engineering properties (fines of 26%, plasticity index of 26% and CBR of 35%) that meet specifications require for sub-base materials for light traffic roads. However, Atterberg's consistency limit tests indicate that the samples are moderate to high plastic soils with moderate swelling potential. Hence, their use as base and sub-base construction materials for heavy traffic roads require pre-treatment with non-plastic soils, bitumen, cement and or lime. The direct shear test results show that the soils have high bearing capacity (cohesion of 62 kPa and 27.2° of angle of internal friction) making them to be useful in slope stability and in shallow foundation design.

ii. The comparison of the studied soils with some lateritic soils in South Eastern, Nigeria; indicates that provenance and climatic conditions are potentials factors that influence the engineering properties of lateritic soils. More so, the comparison also indicates that soils developed in semi-arid conditions exhibits the best engineering characteristics.

5.2 Recommendation

Based on findings from the study, the following recommendations were hereby made:

i. The soil samples investigated cannot be used as raw materials in road construction due to their geotechnical results which reveal that samples from upper clay layer **(UCL)** and bottom mottled clay layer **(MCL)** are poorly graded soils with engineering properties of fines of 61 and 63%, plasticity index of 30 and 31%, CBR at soaked and unsoaked of 22 and 35%) which made them unsuitable for road construction.

ii. **Intermediate nodular layer (INL)** samples are gravel and sand soils well graded having engineering properties (fines of 26%, plasticity index of 26% and CBR of 35%) that meet specifications require for sub-base materials for the construction of light traffic roads.

iii. However, Atterberg's consistency limit tests indicate that the samples are moderate to high plastic soils with moderate swelling potential. Hence, their use as base and sub-base construction materials for heavy traffic roads require pre-treatment with non-plastic soils, bitumen, cement and or lime.

iv. The natural moisture content of the analyzed soil samples from the study area indicates a high water adsorption capability of the soil material. Hence, good drainage systems should be provided in the area in order to prevent pore water pressures to develop below pavement structures, which could result in significant loss of strength.

References

Adeoye, G.O; Ogunsanwo, O and Ige, O.O. (2013) Geotechnical Evaluation of some soils from part of southwester Nigeria Usable as Liners in Waste Disposal Landfills. Journal of Civil and Environment Science. 3(7), 107-114.

Adeoye, G.O; Ogunsanwo, O and Ige, O.O. (2013) Geotechnical Evaluation of some soils from part of southwester Nigeria Usable as Liners in Waste Disposal Landfills. Journal of Civil and Environment Science. 3(7), 107-114.

Adeoye, G.O; Ogunsanwo, O and Ige, O.O. (2013) Geotechnical Evaluation of some soils from part of southwester Nigeria Usable as Liners in Waste Disposal Landfills. Journal of Civil and Environment Science. 3(7), 107-114.

A. O. 1998: Geology, Geochemistry and Origin of the Banded and Granite Gneisses in the Basement Complex of the Ilesha Area, Southwestern Nigeria. Journal of Earth Sciences. 26 (4): 633-641.

Aginam CH, Chidolue CA, Nwakaire C. (2014) Geotechnical Properties of Lateritic Soils From Northern Zone of Anambra State, Nigeria, *Int J of Eng Research & Dev.* Vol , Issue 12 (2014), pp.23-29

Aginam CH, Chidolue CA, Nwakaire C. (2014) Geotechnical Properties of Lateritic Soils From Northern Zone of Anambra State, Nigeria, *Int J of Eng Research & Dev.* Vol , Issue 12 (2014), pp.23-29

Alayaki F. M., Water Absorption Properties of Laterite Soil in Road Pavement: A Case Study Ife-Ilesha Highway, South Western Nigeria.

Amadi A. (2010). Evaluation of Changes in Index Properties of Lateritic Soil Stabilized with Fly Ash. Leonardo Electronic Journal of Practices and Technologies, Issue 17, pp. 69-78.

Amadi A. (2010). Evaluation of Changes in Index Properties of Lateritic Soil Stabilized with Fly Ash. Leonardo Electronic Journal of Practices and Technologies, Issue 17, pp. 69-78.

ASTM, 1996, „Special procedure for testing soil and rock for engineering purpose‟. ASTM International, Washington DC, USA

British Standards Institution 1990: British Standard Methods of test for Soils for Civil Engineering Purposes: BS 1377. British Standards Institution, London.

British Standards Institution 1990: British Standard Methods of test for Soils for Civil Engineering Purposes: BS 1377. British Standards Institution, London.

Daramola SO, Malomo S, Asiwaju-Bello YA (2015) Engineering geology of failed sections of Isua–Idoani road Southwestern Nigeria. J Enviro Ear Sci 5(19):38–45

Day, R. W. (2000). Geotechnical Engineer's Portable Handbook. New York: McGraw-Hill.

Ehujuo, N.N., Okeke, O.C. and Akaolisa, C.C.Z (2017)., Geotechnical Properties of latetritic soils derived from various Geologic Formations in Okigwe Area, Southeastern Nigeria. FUTO Journal Series, 3(2), 178-189.

Eldosouky, M.A., Ekwok, E.S, Akpan, E.A., Ogiji-Idaga, M.A. Pham, T.L. Abdelrahman, K., Gomez – Ortiz, D. and Alarifi, S.S. (2022) Deliniation of the structural liniaments of Southeast Nigeria, using high resolution aeromagnetic data. Open Geosciences, 14, 331-340.

Elueze, A. A. 1982: Mineralogy and Chemical Nature of Meta-ultramafite in Nigeria schist Belts. Nigerian Journal of Mining and Geology, Vol. 19. pp. 21-29.

Federal Ministry of Works and Housing 1997: General Specification- Roads and Bridges. Vol. 2, 280 pp.

Federal Ministry of Works and Housing, 1997. Nigerian General Specification for Roads and Bridges (Revised Edition), 137-275.

Fookes G. (1997).Tropical Residual Soils: A Geology Society Engineering Group Working Party Revised Report. Geology Society: Tulsa, OK.

Garber JN, Hoel LA (1999) Traffic and highway engineering. Brooks/Cole publishing

Garg, S. K. (2009). Soil Mechanics and Foundation. Engineering (7th ed., pp. 673–683). New Delhi: Khana publishers.

Genik, G.J., 1993. Petroleum Geology of Cretaceous–Tertiary Basins in Niger, Chad and Central African Republic. *AAPG Bull*., 77: 1405-1434.

Gidigasu M.D. (1976). Laterite Soil Engineering: Pedogenesis and Engineering Principle. Development in Geotechnical Engineering. 9:554p.

Gidigasu MD (1973) Review of identification of problem laterite soils in highway engineering. Transport Res Board 497:96–11

Gidigasu MD (1976) Geotechnical evaluation of residual gravels in pavement construction. Eng Geo 15:173–794

Gidigasu, M. D. (1983). Development of acceptance specifications for tropical gravel paving materials. Eng Geo, 19, 213–240.

Gidigasu, M. D. 1971: The Importance of Soil Genesis in the Engineering Classification of Ghana Soils. Eng. Geol. 5: pp. 117-161.

Gillot J.E. (1969). Clay in Engineering Geology. Elsevier Publishing: Amsterdam, the Netherlands.

Ige O.Omoniyi, Ogunsanwo. O; Aweda K. A; Geotechnical and Mineralogical Evaluation of Some Lateritic Soils from Southwestern Nigeria; vol 19(2014).

Ige, O. A., Durotoye, B., & Oluyemi, A. E. (2005). Mineralogy and geochemistry of lateritic weathering profile on ultramafic rock bodies around Mokuro, Ile-Ife area, Southwestern Nigeria. *Journal of Mining and Geololgy, 41*(1), 11-18.

Ige, O.O., and Ogunsanwo, O.O. (2009). Assessment of Granite-derived residual soil as mineral seal in sanitary landfills. Researcher, 1 (6), p 84-90.

Ighodalo CA (2009) Transport Infrastructure and Economic Growth in Nigeria. Revised Paper Submitted for Presentation at the First International Conference on Transport Infrastructure (ICTI 2008), Beijing, China. April 24-26, 2008.

Jegede G (1997) Highway pavement failure induced by soil properties along the F209 highway at Omuoke, southwestern Nigeria. Nig J Sci.

Jegede G (1998) Effects of some engineering and geological factors on highway failures in parts of Southwestern Nigeria. Unpublished Ph.D. thesis. Federal University of Technology, Akure, p 251

Jegede OG (2004) Highway pavement failure induced by poor geotechnical properties at a section along the F209 Okitipupa-Igbokoda highway, Southwest Nigeria. Ife J Sci 6(1):41–44

Jegede OG, Olaleye BM (2013) Evaluation of engineering geologic and geotechnical properties of subgrade soils along re-alligned Igbara-Ikogosi Highway, South-west Nigeria. Inter J Eng &Sci 2(5):18–21.

Kabir, M. H., & Taha, M. R. (2004). Assessment of physical properties of a granite residual soil as an isolation barrier. Electron J Geotech Eng, 92, 13.

Kogbe, C. A. 1985. Paleogeographic history of Nigeria from Albiam time. In Geology of Nigeria (ed C.A Kogbe), P. 237. Lagos (Nigeria): Elizabethan Pub. Co.

Madedor, A. C. 1983: Pavement Design Guidelines and Practice for Different Geological Areas in Nigeria. In: Ola, S. A. (ed) Tropical Soils of Nigeria in Engineering Practices. AA Balkema, Rotterdam, pp. 291 – 297.

McCarthy, D. F. 2007: Essential of Soil Mechanics and Foundations. Basic Geotechnics. Pearson Prentice Hall. New Jersey.

Meshida, E. A. 1986: Some Geotechnical Properties of Residual Mica Schist Derived Subgrade and Fill Materials in the Ilesha Area, Nigeria. Bull. I.A.E.G. 33.

Meshida, E. A. 1987: Genetic Influence on the Compaction and CBR Characteristics of Three Lateritic Soils in Ile-Ife Area, S.W. Nigeria. 9th Reg. Conf. For Afr. On Soil Mech. And Found. Eng. Lagos, pp.461-465.

Meshida, E. A. 2006: Highway failure over Talc- Tremolite- Schist Terrain: a case study of the Ife-Osu-Ilesha Highway, Southwestern Nigeria. Bulletin of Engineering

Mitchell J.K 1993, Fundamental Soil Behavior, Wiley, New York.

Mode, A.W. (2004). Shallow marine transgressive sedimentation in the Nsukka Formation, Southeastern Anambra Basin, Nigeria. NAPE Bull., 17(1), 28-paleogeography of West Africa. J. Geol., 8, 311-322

Mode, A.W. (2024). Shallow marine transgressive sedimentation in the Nsukka Formation Southeastern Anambra Basin, Nigeria. NAPE Bull., 17(1), 28-41.

Murat, R.C., 1972. Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In Dessauvagie, T.T.J., and white man, A.J. (Eds), African Geology, University of Ibadan Press, Nigeria, pp: 251-266.

Nwajide, C.S. (2005). A guide to Geological Field Trips to Anambra and related Basins in Southeastern Nigeria. Great Ap Express Publishers, Ltd Enugu.

Nwankwoala HO, Amadi AN (2013) Geotechnical investigation of sub-soil and rock characteristics in parts of Shiroro–Muya–Chanchaga Area of Niger State, Nigeria. Inter J Ear Sci& Eng 6(1):8–17

Nwankwoala HO, Amadi AN, Ushie FA, Warmate T (2014) Determination of subsurface geotechnical properties for foundation design and construction in Akenfa Community, Bayelsa, Nigeria. Amer J Civ Eng Arch 2(4):130–135

Ogbuchukwu, P.O., Okeke, O.C., Ahiarakwem, C.A. and Ozotta, O.O. (2019). Geotechnical properties of expansive soils in Awka and environs, Southeastern Nigeria, in relation to Engineering problems. International Journal of Applied Science and Research (IJASR), 2(4), 79-93.

Ogunsanwo O (1988) Basic geotechnical properties, chemistry and mineralogy of some laterite soils from southwestern Nigeria. Bul Inter Ass Eng Geo 37:131–135

Ojoh, K.A., 1990. Cretaceous Geodynamic Evolution of the southern part of the Benue Trough (Nigeria) in the equatorial Domain of the south Atlantic Stratigraphy Basin Analysis and Paleogeography. Bull. Centres Rech. Explor-Prod, Elf-Aquaintine, 14: 419-442.

Oke SA, Amadi AN, Abalaka AE, Nwosu JE, Jibade SA (2009) Index and compaction properties of laterite deposits for road construction in Minna Area, Nigeria. Nig J Cons Tech Man 10(1–2):28–35

Okeke, O.C. Ezeoke, E.I. and Onuoha, B.O. (2011). Geotechnical Evaluation of lateritic soil deposits in parts of Anambra Basin, Southeastern Nigeria, for road construction. International Journal of Environmental Sciences, 7, 108 – 114.

Okogbue CO (1988) The physical and mechanical properties of laterite gravels from south eastern Nigeria relative to their engineering performance. J Afr Earth Sci 5(6):659–664

Okonkwo, C. T. (2005). Geochemistry of quartzites and quartz-mica schist in Jebba area, Nigeria. *Journal of Mining and Geololgy, 28*, 203-209. http://dx.doi.org/10.4314/jmg.v40i2.18814

Okoro, L.O., Okeke, O.C. and Opara, A.I. (2019). Evaluation and Treatment of swelling behaviour of expansive soils from Ohafia and Environs, Southeaster Nigeria. Academic Journal of Current Research, 6(4), 1-20.

Ola SA (1983) In: Ola SA, Balkama AA (eds) Tropical soils of Nigeria in engineering practice, Netherlands, pp 61–24

Ola, S.A. 1981. Mineralogical properties of some Nigerian residual soils in relation with building problems. Engineering Geology, 15: 1-13

Olade, M. A. and Elueze, A. A. 1979: Petrochemistry of the Ilesha Amphibolites and Precambrian Crustal Evolution in the Pan African Domain of Southwestern Nigeria. Precambrian Research. 8, pp 303-318.

Olade, M.A., 1975. Evolution of the Nigerian Benue Trough (Aulocogen): A Tectonic Model. *Geol*. *Mag*., 12: 575-583.

Omowumi, Ademila. Engineering Evaluation of Lateritic Soils of Failed Highway Sections in Southwestern Nigeria, July, 2017.

Oyinloye, A. O. 1998: Geology, Geochemistry and Origin of the Banded and Granite Gneisses in the Basement Complex of the Ilesha Area, Southwestern Nigeria. Journal of Earth Sciences. 26 (4): 633-641. Oyinloye,

Oyinloye, A. O. 2001: Geochemical Characteristics of some Granite Gneisses in Ilesha Area, Southwestern Nigeria: Implication the Evolution of Ilesha Schist Belt. Journal of Pure and Applied Sciences 7 (1): 85-90.

Peters, S. W. and Ekweozor, C. M. 1981. Origin of Cretaceous black shales in the Benue trough, Nigeria. Palaeogeography Palaeoclimatology Palaeoecology, 40, pp. 311-319

Rahaman, M. A. (1988). Recent advances in the study of the Basement Complex of Nigeria. *Publication of Geological Survey of Nigeria*, 1-44.

Reyment, R.A, 1965. Aspects of the Geology of Nigeria. Ibadan Univ. Press. 133p, 19pl.

Road Research Laboratory 1952: Soil Mechanics for Road Engineers. H. M. Stationery Office, London, 541pp

Rossiter, D.G., 2004. Digital soil resource inventories: status and prospects. Soil Use & Magemt 20(3)296–301

Rotterdam, Holland: 7emeCongres International de l'AIGI.USCS (1986)

Skempton, A.W. 1953: Soil mechanics in relation to geology. Proc. Yorksshire Geol. Soc., 29, Part 1(3), 33-62.

Tardy, Y. (1992). Pétrologie des latérites et sols tropicaux. Masson (ed) (p. 459). Tockol, I., Massiera, M., Chiasson, P. A., & Maiga, M. S. (1994). *Les graveleux latéritiques dans les pays du sahel: Cas des routes non revêtues* (pp. 3423–3431).

Unified Soil Classification System for Foundation Analysis.Waziri BS, Lawan ZA, Mustapha, Mala M. 2013 Properties of Compressed Stabilized Earth Blocks (CSEB) For Low Cost Housing Construction: A Preliminary Investigation. *Int J of Sust Constr Eng & Technol.* (ISSN: 2180-3242)