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ENGINEERING BEHAVIOUR OF CEMENT-STABILIZED LATERITIC SOILS DERIVED FROM VARIOUS GEOLOGIC FORMATIONS IN AWKA AREA, SOUTHEASTERN NIGERIA.

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Abstract
The need for adequate assessment of lateritic soils used as construction material will help to avoid or prevent failure of civil engineering structures like roads, high rise buildings, bridges, railways etc. The engineering behaviour of cement-stabilized lateritic soil derived from various geologic formations in Awka area was undertaken to improve its strength and durability on construction work. Laboratory tests carried out include: particle size distribution, atterberg limits, California bearing ratio, compaction test, specific gravity and moisture content tests and their behaviour in terms of changes in geotechnical properties for control test (without cement) and on treatment with various percentages of cement (5%, 10%, 15%, 20%, 25%). Result of the study shows that liquid limit and plasticity index values of the treated soils were reduced while the maximum dry density and California bearing ratio (CBR) values were increased. The results of the study on particle size distribution shows the soil as fine to coarse grained, and the result on the specific gravity of the laterites grades the soil as organic. There were marked reductions on atterberg limits for example, at 15% cement applications using Laterites from Amansea location 1; 37.05% to 33.95%, 13.67% to 11.90% on liquid limit and plasticity index with a reduction percentage of 8% and 13% respectively. At the same 15%, using Laterites from Amansea location 2, maximum dry density (MDD) increased from 1.67Mg/m^3 to 1.84Mg/m^3 and California bearing ratio (CBR), increased from 7.15% to 53.62%. These values for strength characteristics (CBR and MDD) and swearing potentials (plasticity index and liquid limit) fall within the limits of FMWH, 1997 specifications for soils used as sub grade and base materials for civil engineering works. It is therefore important to say that cement-stabilization is very effective in improving strength properties and swearing potentials to reach the expected values from the analysis of the lateritic soils in Awka area, and therefore helps to cushion the problems or effects of cracks on roads, buildings and other construction works and its subsequent failures occasioned by changes that may occur during rainy (wetting) and dry (drying) seasons, while also increasing the bearing capacity respectively. We can therefore conclude that, geotechnical properties of lateritic soils be tested before being used for various civil engineering works to ascertain their engineering behaviours.

Key Words: Engineering behaviour, lateritic soils, geotechnical properties, cement-stabilization, Awka area.

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1.0 Introduction

The important nature of soils in their natural states requires that its engineering properties meet construction standards. Braja (2011) defined soil as "the strong material on the Earth which results from weathering and organic action on the parent material." Lateritic soil can also be defined as weathered tropical or sub-tropical soil, generally composed of sesquioxide rich solidifications [Hematite (Fe_20_3), Corundum (Al_20_3), and Manganese Oxide (Mn_20_3)] (Oyelami and Van Rooy, 2016). In the same manner, Luis and Mercedes (2011) reported that soil is characterized with high temperature and moisture content leading to intense chemical weathering that forms well graded residual soils. Soil is used as a construction material in various building and civil engineering projects to provide structural supports to foundation. Lateritic soil is a major construction material in Awka Area and other parts of Nigeria owing to its abundance and affordability. It is note-worthy to state that not all soils are suitable for construction in their natural states. The properties that make soils unsuitable for construction of engineering structures in their natural state are generally referred to as problematic soil (Ola, 1978). Problematic soils could either be expansive soil or collapsible soil which in return causes low bearing capacity in building foundation, breaking and cracking of road structures (Ameta, Purohit and Wayal, 2007).

Bello and Adegoke (2010) defined laterite as a product of weathering which is rich in oxides of iron and aluminum. Raheem, Olugbenro and Kehinde (2012) opined that laterite is a red tropically weathered soil containing iron oxide derived from leaching conditions. Patrick, Uphie, Elie and Arlin (2011) was of the view that laterites are formed in tropical regions of the world through weathering processes that favours the production of aluminum, iron, manganese and titanium oxides. Furthermore, Amu, Ogunniyi and Oladeji (2011) added that laterites were mostly formed in leached soils of humid tropics rich in iron and aluminium. Finally, Aguwa (2013) described laterite as a soil containing cementitous materials called sesquioxide. Sesquioxides are oxides with three atoms of oxygen and two atoms of another element. Examples of sesquioxides of laterite include hematite (Fe_2O_3), corundum (Al_2O_3), and manganese oxide (Mn_2O_3). The definition of laterite which has had wide acceptance among authors state that "laterite is a highly weathered material, rich in secondary oxides of iron and aluminum (Amadi, ezetoha, Okeke, Nwachukwu and Ibezim (2020). It is void or nearly void of basic primary silicates, but it may contain large amounts of quartz and kaolinite" (Alexandra and Cady, 1962).

Lateritic soil has less than 30% silt content, between 25-63 % liquid limit and 5-42 % plasticity index (Badmus, 2010; Quadri, Adeyemi and Olafusi, 2012; Eluozo and Nwaobakata, 2013). On this basis, it is understandable that the geotechnical properties of lateritic soil could be improved before its usage for engineering purposes. Otherwise they are bound to cause damages when used in their natural states. Different researchers have reported that the engineering properties (permeability, density and porosity) of lateritic soil could be improved through sterilization just like expansive soil (Osula, 1996; Dauda, Akinmusuru, Dauda, Durotoye, Ogundipe and Oyesomi, 2018). This improvement is usually done by stabilization. Soil stabilization enhances the strength, control soil dust and ensure soil water proofing (Amu and Adetuberu, 2010). Soil stabilization is the process of elimination of swelling properties of soils to enhance its shear strength and improve its load bearing capacity (Amadi et al., 2020).

Oyediran and Kalejaiye (2011) define soil stabilization as process of chemical, mechanical, and biological means of improving soil properties and therefore making the properties of soil

more suitable for engineering purposes. Soil stabilization also connote the alteration of the soil properties, this means that the three phases present in the soil are modified i.e. the solid phase which is the mineral particles, the liquid phase which denotes the moisture content of the soil and the gaseous phases, which is the void or air present in the soil are all modified in the process of soil stabilization to obtain desirable lasting properties, which are compatible with a particular application. Stabilization method could either be by water through bonding the soil particles together, water proofing the particles or combine the two methods (Sherwood, 1993).

Cement has been meaningfully used for soil stabilization and improvement (Eze-Uzomaka and Agbo, 2010, Joel and Agbede, Joel and Agbede, 2010 and 2011). Improvement in properties of soil treated with cement is attributed to the hydration reaction of cement. The use of cement for soil stabilization is very effective when the plasticity index is less than 10%.According to (Garba and Hoel, 2010, Yoder and Witczak, 1975) where plasticity index value is greater than 10 % more cement will be required for effective stabilization.

Soil stabilization is a collective term for any physical, chemical, or biological method, or any combination of such methods, that is employed to improve certain properties of a natural soil to make it adequate to serve an intended engineering purpose over the service life of an engineering facility (Fang, 2013; Arabani and Haghsheno, 2020). Chemical methods are widely used for soil stabilization (Ingles and Metcalf, 1972). Chemical stabilization by cementing agents, especially Portland cement, is usually adopted to improve the mechanical characteristics of soils. This technique is commonly applied to current geotechnical problems. Cement stabilization serves based on the cementation bonds between the calcium silicate and aluminate hydration products of cement and the soil particle (Bergado, Anderson, Miura and Balasubramaniam, 1996; Schaefer, Abramson, Drumheller and Sharp, 1997; Arabani and Haghsheno, 2020).

Cement is a binder, a chemical substance used for construction that sets, hardens and adheres to other materials to bind them together. The main reaction in a soil/cement mixture comes from the hydration of two anhydrous calcium silicates; tricalcium silicate (3CaO.SiO2) and dicalcium silicate (2CaO.SiO2), the major constituents of cement, which form two new compounds; calcium hydroxide and calcium silicate hydrate (CSH), which are the main binder of concrete (Tremblay, 1998 and Billong, Mello and Ndikontar, 2008). Hydration is the process by which Portland cement becomes firm, hardened mass after the addition of water. The hydrated cement is relatively insoluble in water.

$$\textbf{Cement} + H_2O \rightarrow \textbf{CSH} + \textbf{Ca}(OH)_2 \text{……..(1)}$$

The mineralogical composition and the granulometry of cement treated soils have little influence on the reaction since the cement powder contains in itself everything it needs to react and form cementitious products (Patrick et al, 2011). Cement will create physical links between the particles of soil, thus increasing the soil strength (Tremblay, 1998 and Kerali, 2001).

In civil engineering structures, various kinds of soils are used; however, some soil deposits in their natural form are suitable for construction purposes, whereas others are unsuitable without treatment, such as the problematic soils (Ikeagwuani and Nwonu, 2019). These soils need to be excavated and then replaced, or their properties should be modified before they can sustain the applied loads by the upper structures. Typical of problematic soils are the expansive soils, which are frequently observed due to their existence worldwide, except the

arctic regions (Steinberg, 2000). This kind of soil has caused a significant amount of damage in the United States (Jones and Holtz, 1973), due to its high susceptibility to volume change, sensitive to moisture content. The inherent volume change characteristics of expansive soils are mainly resulting from their fine-grained clay mineral content. Due to cost implication, geotechnical engineers often prefer modifying the properties of fine-grained soils in situ via stabilization in comparison with the soil replacement in practice (Buhler and Cerato, 2007;Hussey, Cerato, Grasmick, Holderby, Miller and Tabet, 2010).

2.0 Study Area Description

2.1 Location of the Study Area

The study area, Awka is predominantly a low lying region on the western plain of the Mamu River with all parts at 333meters above sea-level. It lies between latitude 6^0 4'0" N to 6^0 16'0"N and longitude 7^0 4'0"E to 7^0 12'0"E and elevation of 53 to 170m above sea level (Figure 1). It is accessible through; Awka-Onitsha road, Awka-Enugu express road, Ekwulobia-Umunze road.

2.2 Climate and Vegetation

The study area is part of the rainforest vegetation with two seasonal climatic conditions (Rainy and Harmattan seasons) (Oguntoyinbo, 1978; Ezeigwe, 2015; Ben-Owope et al., 2019). The hot season (Harmattan) is between February to May, while the wet season (rainy) is between June and September. It is also characterized by the annual double maxima of rainfall with a slight drop in either July or August known as dry spell or August break. The annual total rainfall in the area is about 1,450mm concentrated mainly in eight months of the year with few months of relative drought (Nigeria Meteorological Agency, 2007). The mean temperature of the study area is 27^0C with daily minimum and maximum temperature ranges of about 22^0C and 34^0C respectively. It has a relative humidity of 80% at dawn (Source: Nigeria Meteorological Agency, 2007). The vegetation in the study area comprises different species of tall forest trees, shrubs, with thick undergrowth as well as numerous climbers and grasses. The typical trees are deciduous in nature, such trees are palm trees, raffia palm, iroko trees, oil bear trees and gravelina trees. Oil palm trees and raffia palm are the most common and they are not deciduous in nature.

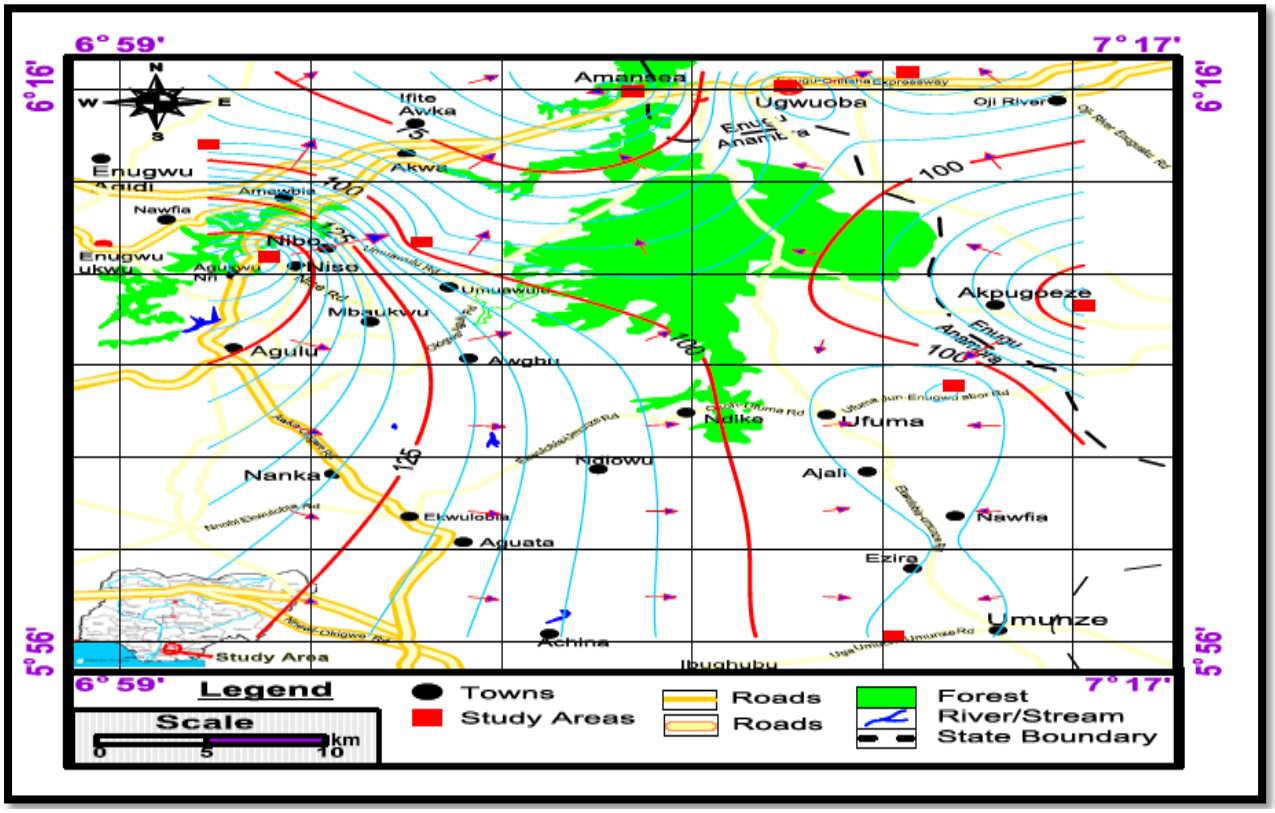


Figure 1: Topographic Map of Awka and Environs (Adapted from Digitized Google-earth Imagery, 2017; Ogbuchukwu et al., 2019)

2.3. Geology of the Study Area

The prevalent sedimentary rocks in the study area are the Imo Shale and Ameki Formation (Figure 2.1). The Imo Shale is of Paleocene-Lower Eocene in age (Reyment, 1965) and it outcrops on the plane of the Mamu River and the formation is of shallow marine environment (Nwajide, 1990). It consists of thick clayey shales, fine textured, occasional clay ironstones sandstone beds in which carbonized plants remains may occur (Kogbe, 1989; Nwajide and Reijers, 1996). Wilson (1925) observes that carbonized plant remains may be locally common and the Formation becomes sandier towards the top where it may consist of alternating bands of sandstone and shale. It has Ebenebe sandstone as its member in the study area while Ameki Formation and its lateral equivalent Nanka Sands (Okeke and Igboanua, 2003; Ezeigwe, 2015) were laid down in the early-middle Eocene (Berggren, 1960; Reyment, 1965; Adegoke, 1969). Its rock types are mainly sandstone, calcareous shale with thin limestone bands (Reyment, 1965; Arua, 1986). Outcrops of the sandstone occur at Abagana and Nsugbe, where they are being quarried in commercial quantity. Nanka sands outcrop mainly at Nanka, Ekwuluobia and Agulu towns in the study area. The regional stratigraphic sequence and Geologic map of the study area is shown below (Table 1).

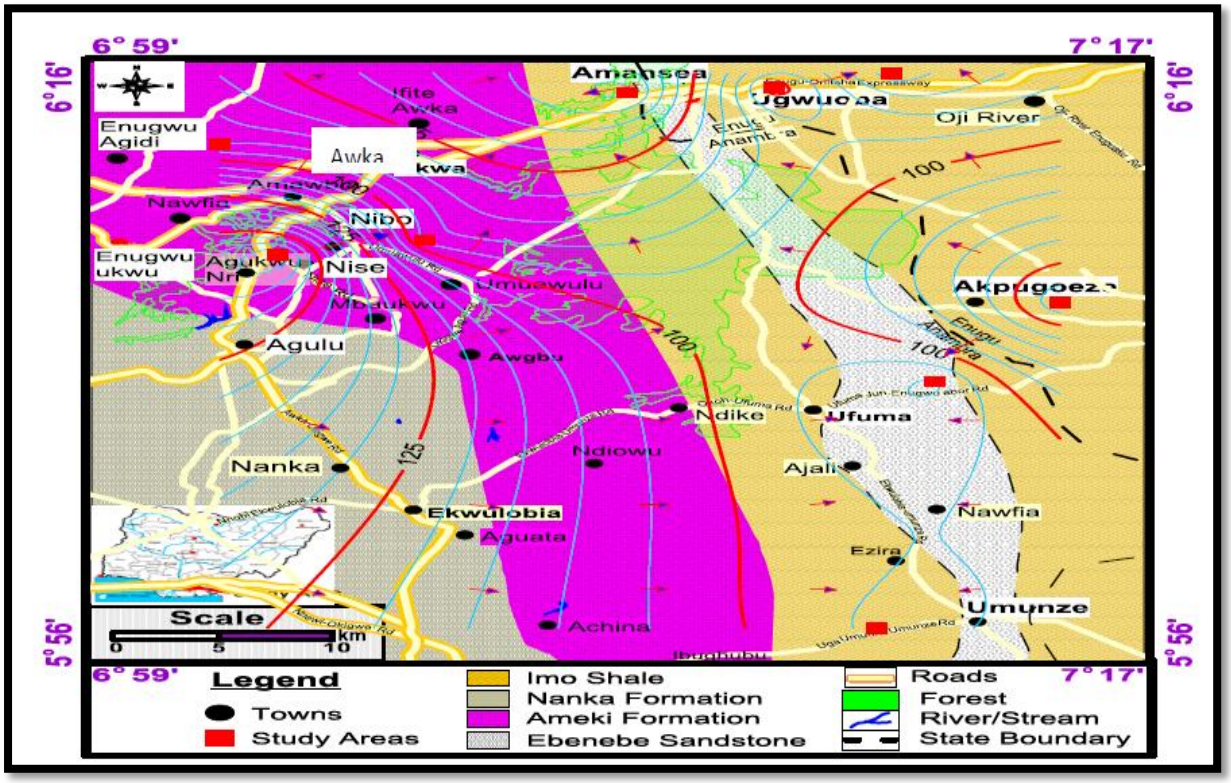


Figure 2: Geologic Map of the Study Area (Modified from Okeke and Igboanua, 2003; Ogbuchukwu, Okeke, Ahiarakwem and Ozotta, O.O., 2019).

Table 1: General Regional Stratigraphy of Southeastern Nigeria (Modified from Reyment, 1965, Offodile, 1975 and Mode 2004)

	Age	Formation	Lithology
	Recent	Recent sediments	Alluvium/Deltaic Plains
Tertiary	Miocene Recent (5-23 m.y.)	Benin Formation	Unconsolidated sandstone with lenses of clay
Tertiary	Oligocene Miocene (23-34 m.y.)	Ogwashi-Asaba Formation	Unconsolidated sandstone, mudstone, clays and lignite seams
Tertiary	Eocene (34-38 m.y.)	Ameki Formation	Grey to green argillaceous sandstone, shale and limestone unit
Upper cretaceous	Paleocene (56-66 m.y.)	Imo Shale	Blue to dark grey shales and subordinate sandstone members (Umunna and Ebenebe)
Upper cretaceous	Maastrichtian (65-72 m.y.)	Nsukka Formation	Alternating sequence of shale, sandstone and coal seams
Upper cretaceous		Ajali Formation	Friable sandstones with iron stains
Upper cretaceous		Mamu Formation	Sandstones, shale, siltstone with coal seams

3.0. Materials and Methods

3.1. Field work and sample collection

The materials used for the purpose of the study are Portland cement and lateritic soils derived from Awka area, Southeastern Nigeria. The equipment used for sample collection in the field includes:

i. The **location map** of the study area for accessibility within and around the outcrop exposures.
ii. The **Geologic map** was used for identifying geologic features in the study area.
iii. A **geologic hammer** was used for collecting samples from hard formations.
iv. A **hand lens** was used for megascopic field study (estimation of grain size).
v. A **compass clinometer was used** for measuring the bearing of the different locations, dips, strike and its directions.
vi. A **measuring tape** was used to determine the extent of gully.
vii. **Sample bags** labeled were used for collection and easy identification of different location samples.
viii. **Field note book** and other writing materials served for writing down anything observed in the field.
ix. **Global positioning system (GPS) was used for** locating the geographical areas under study.
x. **And others like camera, masking tape, shovel, cutlass etc.**

3.1 Field Work: The field work were carried out to identify the presence of lateritic soils and their behaviour on engineering structures like buildings, roads, bridges and drainage facilities in the study area. A total of eight (8) soil samples were collected from four different locations (two samples from each): Nanka/Awka – Nanka Sands, Nise/Nibo – Ameki Formation, Amansea- Imo Shale and Ugwuoba- Ebenebe Sandstone. The soil sampling strictly followed standard procedure specified in British Standard Institution (BSI) 1377 (1990), US Bureau of Reclamation (USBR) (1963), Spangler & Handy (1973). The lateritic soils were collected with the aid of a shovel 10feet below, two samples from each formation 50m apart in the study area and geo-referenced using the GPS and carefully sealed in a clean polythene bag in order to prevent loss of moisture and carefully labeled using the masking tape and ink maker. Later, the samples were sent to the laboratory within 24 hours of collection for further analysis. The sampling was done between June, 2022 and December, 2022.

The description of the study areas as identified in the field includes:

1. Amansea (Location 1 by Holy Trinity Church)
It is moist in condition with colour between brown and grey. It is fine in size and has presence of root. It has coordinates of $N06^0$ 15.826^1 and E 007^0 07.373^1 with elevation of 144feet. It is a member of the Imo group.

2. Amansea (Location 2, Okukwa)
It is a reddish brown lateritic soil, little moist and a fine clayey soil. It has coordinates of $N06^0$ 15.281^1 and $E007^0$ 08.264^1 with elevation of 148feet.

3. Ugwuoba (Location 3 near Ugwuoba Mast)
It is reddish fine grained in nature and in moist condition. It has coordinates of $N06^0$ 15.498^1 and $E007^0$ 09.931^1 with elevation of 331feet.

4. Ugwuoba (Location 4, Agungwu Village)
It is a dark reddish fine grained lateritic soil with little roots. It has coordinates of $N06^{0}$ 15.154^{1} and $E007^{0}$ 09.285^{1} with elevation of 214feet.

5. Ameki Formation (Location 5, Quarry site)
It has coordinates of $N06^{0}12.528^{1}$ and $E007^{0}05.260^{1}$ with elevation of 438feet. It can be described as follows;

i. It is made up of visible contrition's
ii. It is an active quarry site
iii. Moderate vegetation within the area

6. Ameki Formation (Location 6, Borrow peat off Mbaukwu Nibo road)
It is reddish fine grain lateritic soil with moist condition. It has coordinates of $N06^{0}$ 09.135^{1} and $E007^{0}$ 04.142^{1} with elevation of 415feet.



Figure 3: Excavation of laterites at the borrow peat

7. Nanka Sands (Location 7)
It is a cohesive lateritic soil, moist and reddish brown in colour. It is made up of contrition's. It has coordinates of $N06^{0}$ 06.883^{1} and $E007^{0}$ 02.429^{1} with elevation of 631feet. It is a member of Ameki formation.

8. Nanka Sands (Location 8)
It is moist and reddish brown in colour. Location 8 has the presence of massive gully erosion bigger than a stadium. It has coordinates of $N06^{0}$ 02.642^{1} and $E007^{0}$ 04.821^{1} with elevation of 892feet.

Table 2: Location of sampling points for Lateritic Soils Used in the Study

Sample/Location	COORDINATES Latitude	Longitude	Elevation	Location Description	Geologic Formation
Amansea 1	$6^0$15.826^{1}N	$7^0$07.373^{1}E	144FT	Amansea by Holy Trinity Church	Imo Shale
Amansea 2	$6^0$15.281^{1}N	$7^0$08.264^{1}E	148FT	Okukwa	Imo Shale
Ugwuoba 3	$6^0$15.498^{1}N	$7^0$09.931^{1}E	331FT	Ugwuoba Mast	Ebenebe Sandstone
Ugwuoba 4	$6^0$15.154^{1}N	$7^0$09.285^{1}E	214FT	Agungwu Village	Ebenebe Sandstone
Nise/Nibo 5	$6^0$12.528^{1}N	$7^0$05.260^{1}E	438FT	Quarry Site	Ameki Formation
Nise/Nibo 6	$6^0$09.135^{1}N	$7^0$04.142^{1}E	415FT	Borrow peat by Mbaukwu Nibo road	Ameki Formation
Nanka 7	$6^0$06.883^{1}N	$7^0$02.429^{1}E	631FT	Depression by the four junction	Nanka Sands
Nanka 8	$6^0$02.642^{1}N	$7^0$04.821^{1}E	892FT	The massive gully site behind the filling station.	Nanka Sands

3.2 Laboratory Test (Geotechnical Tests): The laboratory tests of the studied soils were performed in accordance with the Federal Ministry of works and Housing (1997), General Specifications for Roads and Bridges (Revised Edition), 2, 137-275.

The following Geotechnical Analysis was carried out on the laterites and later tested using cement-stabilization**;**

i. **Particle Size Distribution Analysis:** This was done with the aim of finding the distribution of grain sizes within the soil samples that were collected.
ii. **Atterberg Limit Test:** Atterberg limit test was used in determining the following parameters: liquid limit, plastic limit, plasticity index, liquidity index and relative consistency.
iii. **Determination of California Bearing Ratio (CBR):** California bearing ratio is the ratio of force per unit area required to penetrate into a soil mass with a circular plunger of 50mm diameter at the rate of 1.25mm min.
iv. **Specific Gravity Test:** The specific gravity of soil particles is the ratio of the mass density of solids to that of water.
v. **Compaction Test:** Compaction is the process of densification of soil by reducing air voids. The degree of compaction of a given soil is measured in terms of its dry density. The dry density is maximum at the optimum water content.
vi. **Moisture Content Test:** The water content or moisture content (w) of a soil sample is the mass of water which can be removed from a soil, usually by heating between 105^0 C to 110^0C and it is equal to the mass of water divided by the mass of solids.

4.0. Results and Discussion

4.1. Results

Tables 3, 4 and 5 shows effects of treatment with cement on the geotechnical properties of lateritic soils derived from various formations in Awka area. Note that the results of untreated soils (that is, zero cement percentage) represent average value of two measurements from two sampling points in one formation. These effects or behaviours are illustrated in the graphs below.

4.1.1 Results for Atterberg or Consistency Limit Test

During the analysis of the eight samples in the laboratory, it was observed that locations 1, 3, 4 and 6 were non plastic and as a result could not be used for atterberg limit test. The figure below depicts the engineering behaviour of laterites before stabilization and after cement-stabilization for liquid limit, plastic limit and plasticity index.

Table 3: Atterberg limit for locations 2, 5, 7, 8 showing LL, PL and PI for control and cement-stabilized conditions.

FORMATION/ LOCATION	**ATTERBERG LIMIT TESTS**	0%	5%	10%	15%	20%	25%	FMWH STANDARD, 1997.
IMO SHALE 2	LL	37.05	36.86	36.62	33.95	31.27	29.03	<35%
	PL	23.38	23.26	23.22	22.05	21.45	20.36	-
	PI	13.67	13.60	13.40	11.90	9.82	8.67	<12%
AMEKI FM 5	LL	33.50	32.07	31.70	29.67	29.00	28.06	<35%
	PL	19.56	18.26	17.80	17.69	17.43	17.21	-
	PI	13.94	13.81	13.70	11.98	11.57	10.85	<12%
NANKA 7	LL	38.04	35.68	35.44	34.91	33.53	32.2	<35%
	PL	27.70	26.51	26.48	26.08	25.04	24.07	-
	PI	10.34	9.17	8.99	8.83	8.49	8.13	<12%
NANKA 8	LL	39.49	37.93	37.30	34.95	34.88	34.72	<35%
	PL	27.86	27.58	27.53	25.35	25.33	25.21	-
	PI	11.63	10.35	9.76	9.60	9.55	9.51	<12%

WHERE; PI= PLASTIC LIMIT, LL= LIQUID LIMIT, PI= PLASTICITY INDEX.

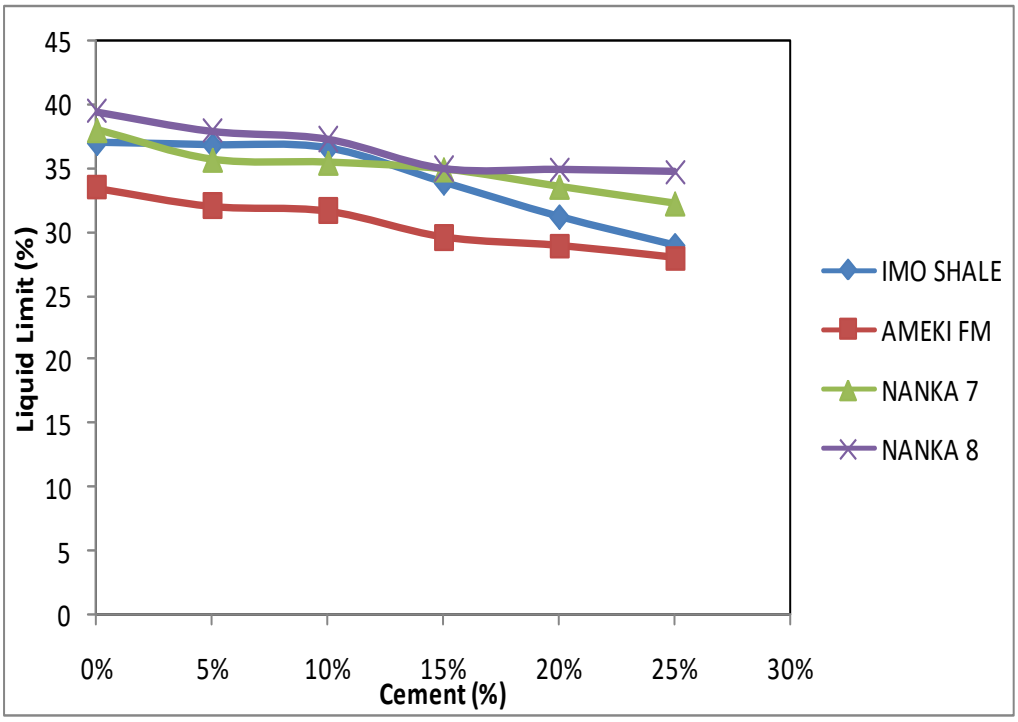


Figure 4: Plot of Liquid Limit against Cement for Locations 2, 5, 7 and 8.

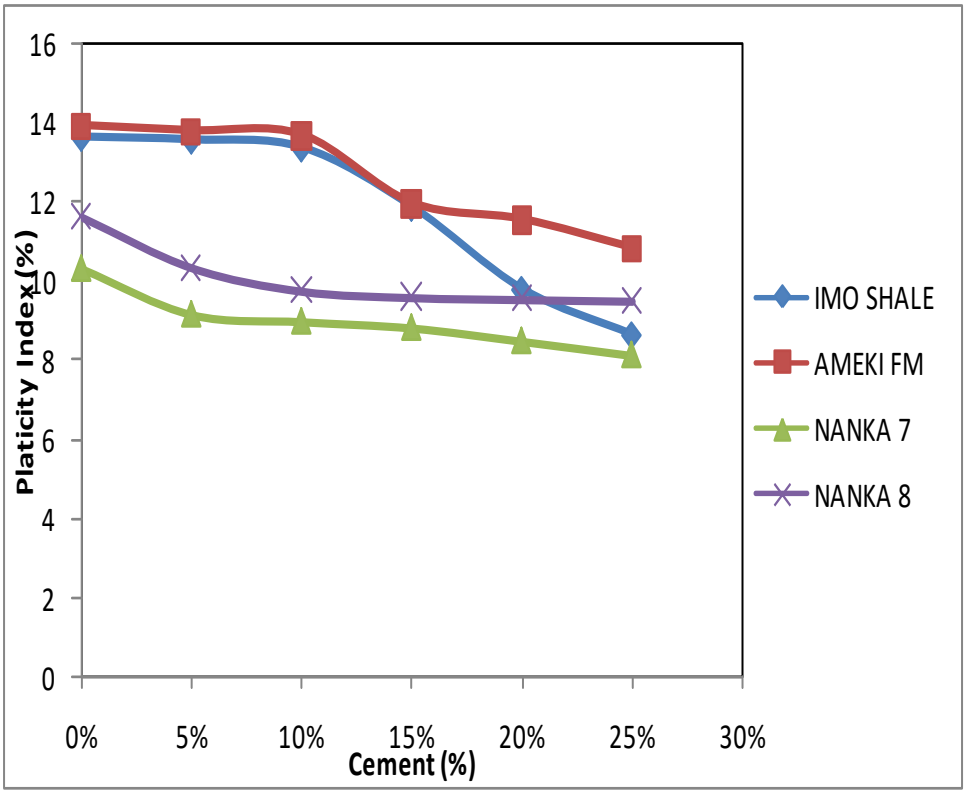


Figure 5: Plot of Plasticity Index against Cement for Locations 2, 5, 7 and 8.

4.1.2 Results for California Bearing Ratio (CBR) Test

Table 4: Soaked CBR results for Locations 1 to 8 with 0%, 5%, 10%, 15%, 20%, and 25% cement

	PERCENTAGE OF CEMENT-STABILIZATION					
FORMATION/ LOCATION	0%	5%	10%	15%	20%	25%
IMO SHALE 1	40.13	122.51	355.19	-	-	-
IMO SHALE 2	7.15	19.92	35.20	53.62	81.24	113.57
EBENEBE 3	28.71	58.06	96.84	145.42	211.06	286.78
EBENEBE 4	21.12	41.27	66.46	103.50	152.41	206.35
AMEKI FM 5	3.36	11.48	24.48	41.05	63.53	91.31
AMEKI FM 6	28.60	53.51	87.20	136.16	197.74	271.02
NANKA 7	9.42	45.71	81.02	116.01	161.67	211.06
NANKA 8	10.72	44.84	80.81	116.88	160.04	211.88

Federal Ministry of works and Housing (1997) specified that materials for subgrade, subbase, and base soils should attain minimum CBR values of 10%, 30%, and 80%, respectively.

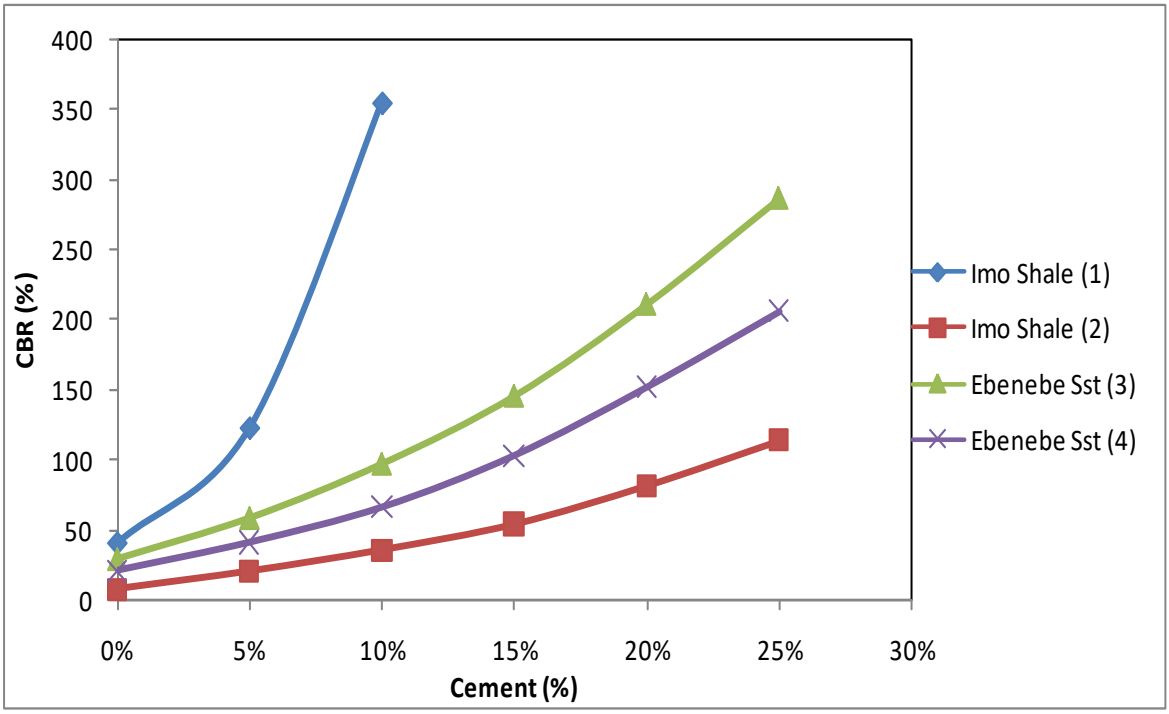


Figure 6: Plot of CBR (soaked) against Cement (%) for Location 1 to 4

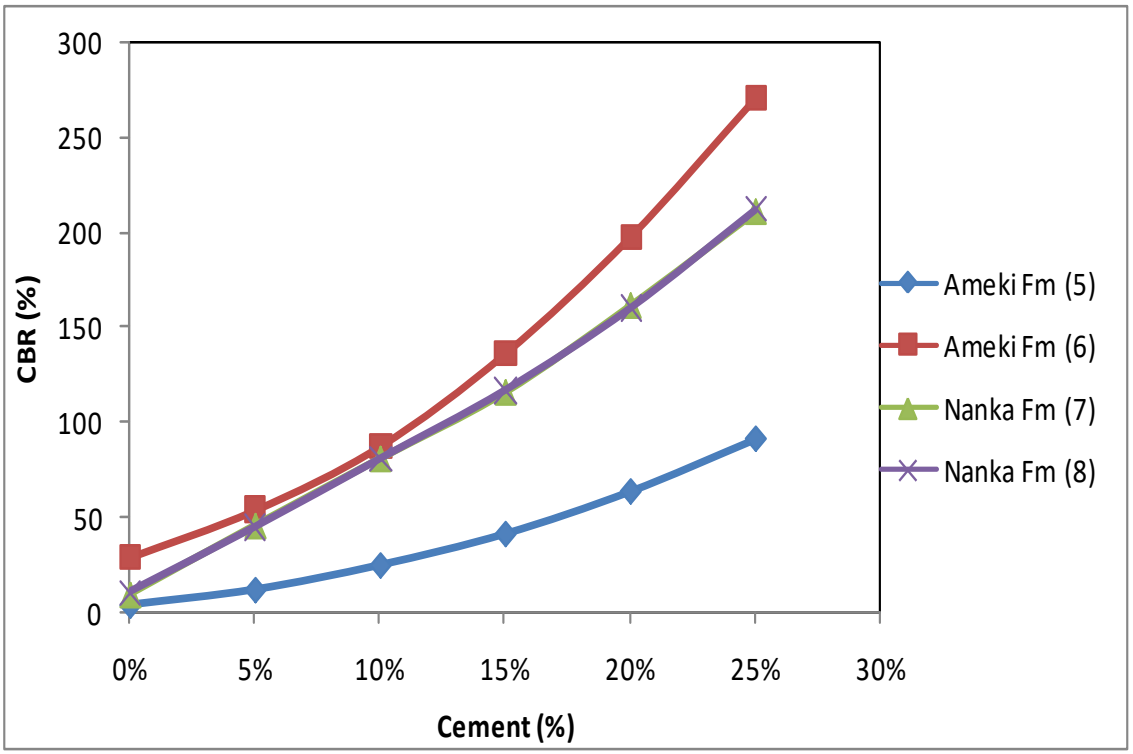


Figure 7: Plot of CBR (soaked) against Cement (%) for Location 5 to 8.

4.1.3 Results for Compaction Characteristics

Table 5: Compaction test results showing MDD for Location 1 to 8 with 0%, 5%, 10%, 15%, 20%, and 25% Cement-Stabilization.

FORMATION/LOCATION		0%	5%	10%	15%	20%	25%	FEDERAL MINISTRY OF WORKS AND HOUSING STANDARD (FMWH), 1997.
IMO SHALE 1	MDD(Mg/m^3)	1.71	1.80	1.97	1.99	2.04	2.08	>1.70
IMO SHALE 2	MDD(Mg/m^3)	1.67	1.68	1.68	1.84	1.88	1.90	>1.70
EBENEBE SST 3	MDD(Mg/m^3)	1.72	1.78	1.85	1.89	1.89	1.99	>1.70
EBENEBE SST 4	MDD(Mg/m^3)	1.78	1.79	1.91	1.93	1.97	1.98	>1.70
AMEKI FM 5	MDD(Mg/m^3)	1.64	1.67	1.70	1.70	1.73	1.90	>1.70
AMEKI FM 6	MDD(Mg/m^3)	1.80	1.81	1.87	1.90	1.92	1.93	>1.70
NANKA SANDS 7	MDD(Mg/m^3)	1.72	1.77	1.83	1.85	1.91	1.92	>1.70
NANKA SANDS 8	MDD(Mg/m^3)	1.71	1.75	1.77	1.80	1.81	1.97	>1.70

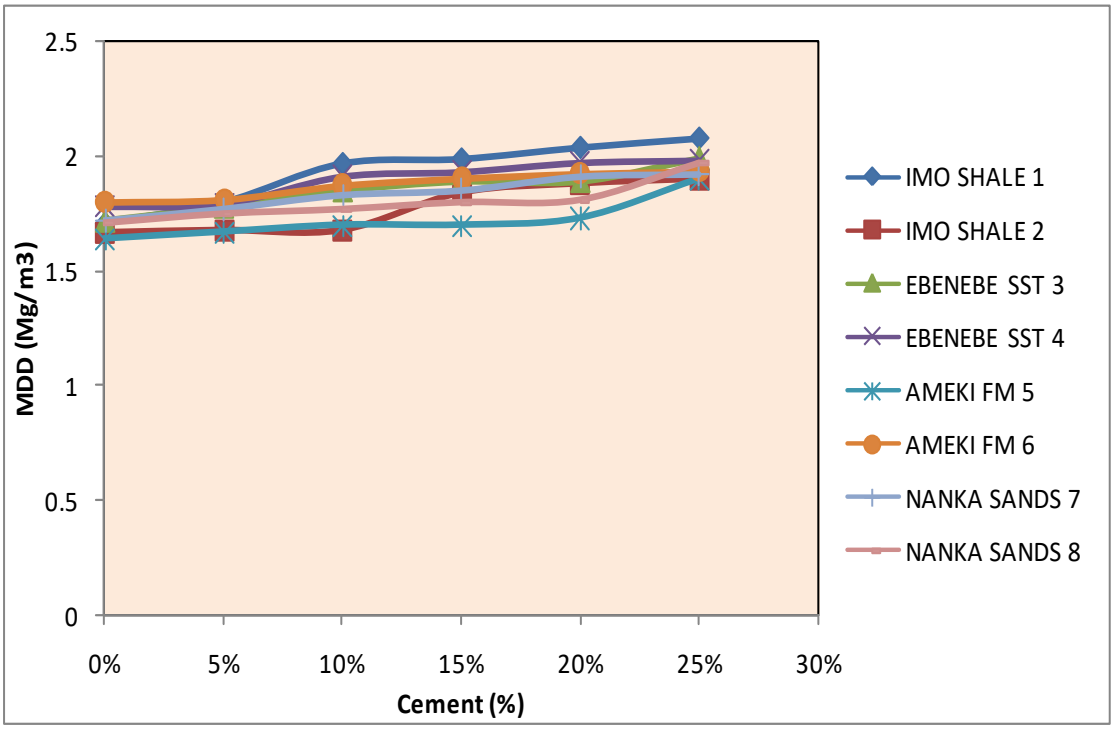


Figure 8: Plot of MDD versus Cement additive for location 1 to 8

4.2 Discussion

A study of the engineering behaviour of cement-stabilized lateritic soils derived from various geologic formations in Awka Area, Southeastern Nigeria was carried out by taking eight samples which were analyzed and the results were given above. During the analysis in the laboratory, a control test was carried out for these geotechnical parameters; Compaction test, Atterbeg limits, specific gravity, grain size distribution and California bearing ratio. After observing the control test results, cement-stabilization was now carried out on the samples using the same geotechnical parameters. The cement stabilization was carried out for 5%, 10%, 15%, 20% and 25% respectively.

4.2.1. Discussion of Results for Atterberg or Consistency Limit

The consistency of a fine-grained soil is largely influenced by the water content of the soil. A gradual decrease in water content of a fine-grained soil slurry causes the soil to pass from the liquid state to a plastic state, from the plastic state to a semi-solid state, and finally to the solid state. The water contents at these changes of state are different for different soils. The water contents that correspond to these changes of state are called the Atterberg limits. The water contents corresponding to transition from one state to the next are known as the liquid limit and plastic limit (Kaniraj, 1988).

The liquid limit of a soil is the water content, expressed as percentage of the weight of the oven dried soil, at the boundary between the liquid and plastic states of consistency of the soil (IS: 2720 – Part 5, 1970). The soil has negligibly small shear strength (Kaniraj, 1988). The plastic limit of a soil is the water content, expressed as a percentage of the weight of oven dried soil, at the boundary between the plastic and semi-solid states of consistency of the soil (IS: 2720 – Part 5, 1970). Sand has no plastic stage, but very fine sand exhibits slight plasticity. The plastic limit is an important soil property. Earth roads are easily usable at this water content. Excavation work and agricultural cultivation can be carried out with the least

effort with soils at the plastic limit. Soil is said to be in the plastic range when it possesses water content in between liquid limit and plastic limit. The range of the plastic state is given by the difference between liquid limit and plastic limit and is defined as the plasticity index. The plasticity index is used in soil classification and in various correlations with other soil properties as a basic soil characteristic (Raj, 2012). Based on the plasticity index, the soils were classified by Atterberg, shows the correlations between the plasticity index, soil type, degree of plasticity and degree of cohesiveness (Table 6) (Prakash and Jain, 2002).

Table 6: Types of soils based on plasticity index (Prakash and Jain, 2002)

Plasticity index (%)	Soil type	Degree of plasticity	Degree of cohesiveness
0	Sand	Non-plastic	Non-cohesive
<7	Silt	Low plastic	Partly cohesive
7-17	Silt clay	Medium plastic	Cohesive
>17	Clay	High plastic	cohesive

Based on the studies carried out, the Atterbeg limits of the studied soils derived from the geologic formations under the control test include; liquid limits for sample 2 was 37.05%, sample 5 was 33.50%, sample 7 was 38.04% and sample 8 was 39.49%; Plastic limits for sample 2 was 23.38%, sample 5 was 19.56%, sample 7 was 27.70% and sample 8 was 27.86%; Plasticity indexes for sample 2 was 13.67%, sample 5 was 13.94%, sample 7 was 10.34% and sample 8 was 11.63%.

After stabilization of the various samples (5% to 25%), the following figures were derived; for sample 2 under Imo group, the liquid limit decreased from 37.05% to 29.03%, sample 5 decreased from 33.50% to 28.06% respectively; Plastic limits for sample 2 decreased from 23.38% to 20.36%, sample 5 decreased from 19.56% to 17.21% respectively; Plasticity indexes for sample 2 decreased from 13.67% to 8.67%, sample 5 decreased from 13.94% to 10.85% respectively. After stabilization of the various samples, it was observed that the atterberg limit values decreased and fall within acceptable standards. According to Federal Ministry of Works and Housing, 1997, the liquid limit range is <35%, while plasticity index range is <12%.

From the results of the study, stabilization of the lateritic soils to be used as sub grade or sub base material was necessary for civil engineering work in Awka Area, South Eastern Nigeria. However, these properties of the soils play an essential role in many engineering projects, such as the construction of roads, bridges, high rise buildings etc.

4.2.2. Discussion of Results for California Bearing Ratio (CBR) Test

The CBR test quantitatively evaluates the inherent strength of a sub grade for a road pavement to be designed for a particular strength of sub grade. The higher the CBR value of soils, the more recommendable the soils to be used as sub grade and sub-base materials. CBR is therefore a measure of strength of sub grade soils (foundation soils) for construction of the pavements (Saklecha, Kedar and Saklecha, 2013).

The California Bearing Ratio (CBR) test of the studied soils indicates that the soaked CBR value of lateritic soil samples derived from Imo group for the control test (samples 1 to 4) varied from 7.15% to 40.13% with an average of 24.28%, while that of the Ameki formation (samples 5 to 8) varied from 3.36% to 28.60% with an average of 13.01%. After stabilization with cement(5% to 25%) the following values were derived; for Imo group (sample 1 to sample 4), sample 1 increased from 40.13% to 355.19% with an average of 197.66%, sample 2 increased from 7.15% to 113.57% with an average of 60.36%, sample 3 increased from 28.71% to 286.78% with an average of 157.75%, sample 4 increased from 21.12% to 206.35% with an average of 113.74%; for Ameki formation (sample 5 to sanple 8), sample 5 increased from 3.36% to 91.31% with an average of 47.34%, sample 6 increased from 28.60% to 271.02% with an average of 149.81%, sample 7 increased from 9.42% to 211.06% with an average of 110.24% and sample 8 increased from 10.72% to 211.88% with an average of 111.30%.FMWH (1997) recommend soaked CBR value of minimum of 15% for highway sub grade. In general, the studied soils yield high CBR values which are likely to provide a stable compacted sub-grade and sub-base materials.

The studied soils after stabilization with cement for both Imo Group and Ameki formation, there was an increase in strength and stability with increased stabilization which is therefore suitable to be used as sub grade and foundation materials in civil engineering construction works.

4.2.3. Discussion of the Results for Compaction Characteristics

Soil compaction is a vital part of the construction process. It is used for support of structural entities such as building foundations, roadways, walkways, and earth retaining structures to name a few. For a given soil type certain properties may deem it more or less desirable to perform adequately for a particular circumstance.

In general, the preselected soil should have adequate strength, be relatively incompressible so that future settlement is not significant, be stable against volume change as water content or other factors vary, be durable and safe against deterioration, and possess proper permeability (McCarthy and David,2007).

The compaction test of the studied soils indicates that maximum dry density (MDD) of the lateritic soils derived from Imo shale location 1 for the control test is 1.71 Mg/m^3, Imo shale location 2 is 1.67 Mg/m^3, Ebenebe SST location 3 is 1.72 Mg/m^3, Ameki Location 5 is 1.64 Mg/m^3 etc. After stabilization with cement (5% to 25%), the Maximum dry density (MDD) derived from Imo shale location 1 increased from 1.71 Mg/m^3 to 2.08 Mg/m^3, Imo shale location 2 increased from 1.67 Mg/m^3 to 1.90 Mg/m^3, Ebenebe Sandstone location 3 increased from 1.72 Mg/m^3 to 1.99 Mg/m^3, while Ameki location 5 increased from 1.64 Mg/m^3 to 1.90 Mg/m^3 respectively.

Bello et al., (2007) and Madedor (1983) characterized soil samples with high maximum dry density (MDD) as suitable for sub-grade and sub-base materials while Federal Ministry of Works and Housing (1997), also characterized such soils as suitable for both sub-grade and sub-base materials. Thus, the soil samples derived from both Imo group and Ameki Formation are suitable to be used as sub-grade or sub-base materials because they have good MDD value. The results are useful in the stability of civil engineering works in the constructions of roads, buildings, bridges etc.

5.0 Conclusion

Work done by researchers on lateritic soils found that different geotechnical properties of soils have different behaviour on the structures. The higher the specific gravity, the higher the load carrying capacity of soils (Oyediran and Durojaiye, 2011). Consistency or Atterbeg limits indicate the properties of fine grained soils; accordingly, fine grained soils can be used for the construction of low permeable layer for disposal of solid wastes and core in earth dams. Particle size shows the gradation of soils, which helps in construction of roads, dams, embankments, high rise buildings, etc. (Bowels, 2012). Compaction improves the bearing capacity of soils used as sub grade and base course. The interactions among different geotechnical properties of soils can help the researchers while designing the foundations for different types of civil engineering structures.

Cement-Stabilization of lateritic soil from Awka Area improved both the Index properties (liquid and plastic limits) and the strength properties (CBR and MDD) of the soil as could be observed in the tables and graphs above.

We could therefore say that, cement- stabilization of lateritic soils helps to improve the strength of materials and swearing potentials of lateritic soils used as sub grade and base course. Hence, this will enhance stability of civil engineering construction works like roads, dams, bridges and high rise buildings particularly in the area under study. This study will therefore enable Civil Engineers in making better material choices especially during highway construction within Awka Area, South Eastern Nigeria.

In conclusion therefore, the following can be referred to for future research:

i. From the graphs and tables for the results of geotechnical properties above, it was observed that after cement-stabilization of the lateritic soil particularly at 15%, its values improved to acceptable values as stipulated by FMWH, 1997 for strength characteristics (CBR and MDD). It is therefore imperative to monitor the improvement in the behaviour of the soil at each percentage cement-stabilization.
ii. Atterberg values decreased to expected values particularly at 15% thereby reducing the effects of expansive and problematic soils like cracking of roads and buildings by improving the bearing capacity of the soil.
iii. Nanka area that has a massive gully erosion site and is prone to erosion effects should be tested for their geotechnical properties before use as a subgrade or base material for civil engineering works.
iv. We can therefore state that cement-stabilization improved the engineering behaviour of lateritic soils in the area under study irrespective of the parent rock (Ameki Formation and Imo Group) where the lateritic soils were derived.
v. Samples 4 and 6 on analysis were observed before cement-stabilization to be suitable as base materials for civil engineering works based on FMWH, 1997 specification.
vi. Sample 1 is non plastic and could not be used for atterberg limit test unlike sample 2 even though both are from Amansea (Imo Shale). Also, Sample 6 was also non plastic and could not also be used for atterberg limit test unlike sample 5 even though both are from Nise/Nibo area.
vii. It is therefore not a guarantee that soils from the same formation will have the same engineering behaviour as observed from the findings in the study. So proper analysis of soils should be carried out before being used for construction works.

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