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EVALUATION AND TREATMENT OF SWELLING BEHAVIOUR OF EXPANSIVE SOILS IN PARTS OF OHAFIA SOUTHEASTERN NIGERIA

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Abstract: Expansive soils are soils that swell when they are wet and shrink when they are dry. This characteristic nature of swelling and shrinking can cause engineering structures to fail. They can exist anywhere in the world, especially in tropical climates. The swelling of these soils can be attributed to the presence of swelling minerals such as montmorillonite and illite. The study area, Ohafia, lies within the Anambra Basin, Southeastern Nigeria, and is underlain by four different geologic formations (Nkporo, Mamu, Nsukka and Imo Shale) that are known to be shaly, with varying degree of expansion. The engineering structures in the study area show varying degrees of failures expressed as cracks as a result of these expansive soil units. The studied soils derived from different locations in the study area, covering the different swelling geologic formations have liquid limits ranging from 42% - 84%, plasticity indices range from 19.4% - 40%, linear shrinkage values range from 12.1% - 22.1%, free swell value range from 42.9% - 77.1% and have more than 80% passing sieve 75µm. The soils plot as CH and CL soils on the Casagrande plasticity chart and are regarded as inorganic fat and lean clays respectively. X-ray analysis of the soils shows presence of Montmorillonite, Kaolinite, Illite, Chlorite and Halloysite. On treating the soils with cement and lime, a reduction of the swelling characteristics of the soils were observed. The effect of the treatment of the soils with cement showed a reduction of the plasticity indices from 25.6% - 9.3% (Ndiorieke soil, Nkporo), 34.8% - 9.7% (Akanu soil, Mamu), 30.9% - 11.4% (OzuAbam soil, Nsukka), and 40.4% - 12.8 (Amaogbu soil, Imo Shale). On treating with lime, a reduction of plasticity indices from 25.6% - 8.2% (Ndiorieke soil, Nkporo), 34.8% - 10.8% (Akanu soil, Mamu), 30.9% - 7.4% (OzuAbam soil, Nsukka), and 40.4% - 14.7% (Amaogbu soil, Imo Shale) were also observed.

Keywords: expansive soil, swelling minerals, plasticity indices, treatment, additives, Ohafia.

1. Introduction

World over swelling soils exist, these soils are soils that change in volume as a result of water, swelling and drying of these soils is moisture dependent. They increase in volume when water is absorbed and shrink when dried; forming desiccation cracks wherever they exist.

These swelling soils are usually formed as weathering products of fine grained extrusive igneous rocks and montmorillonite rich mudrocks (Gromko,1974). Other clay minerals present in most swelling soils are kaolinite, illite, chlorite and halloysite etc. The behavior of this soils are usually attributed to the presence of these clay minerals (especially montmorillonite), parent rock and weathering conditions of the area they are found.

Fig. 1: Mud cracks or desiccation cracks of dried swelling soil.

Poorly constructed engineering structures on these soils fail as a result of heaving and settlement of soils as weather conditions change. Visible in areas underlain by these swelling soil Formations are cracks on the walls of buildings, road failures (polygonal and longitudinal), abandonment of structures (buildings and roads), impassable slippery untarred roads during rainy seasons and perishing agricultural farm produce are common sights.

Many researchers in many parts of the world have worked on swelling expansive soils, Holtz and Gibbs 1956 documented the presence of these soils in USA, Skempton 1954 in England, Ola 1981 and Okogbue 1990 in Nigeria. Relationship between swelling and montmorillonite clay mineral were indicated by Kassif and Baker 1971, Popescu 1980, Ola 1981 and Uduji et al 1994. Ola 1981 and Okeke 2010 observed that cracks and incessant failures of highways can be attributed to these swelling soils.

Treatment or stabilization of swelling expansive soils are various methods used for improving the geotechnical properties or reduction of the swelling behaviors for engineering purposes. Stabilization of swelling soils dates back to about 5000years ago, McDowell (1959), reported that stabilized earth roads were used in Mesopotamia and Egypt and that the Greeks and Romans used soil-lime mixtures. Vosteen (1998) reported the use of cement or lime for stabilization of pavement bases was investigated and developed into practical construction procedures.

A variety of methods are used to stabilize swellings of expansive soil by treating in situ. These methods include increasing density (such as compaction or preloading), pre-water pressure reduction technique (such as dewatering or electro-osmosis), the bonding of soil (such as ground freezing, grouting and chemical stabilization) and use of reinforcements (such as geo-textile and stone columns) (Powrie, 1997).

Soil stabilization includes both physical stabilization (such dynamic loading) and chemical stabilization (such as mixing with different additives such as cement, fly ash, rice husk ash, lime and lime by-products etc) (Materials and Test Division, Geotechnical section, Indiana, 2002).

Fig.2: Cracks on walls of buildings

Fig.3: Breakdown of trucks caused by swelling soil.

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This paper discusses the swelling behavior of soils and the clay minerals present and the effects of these soils on engineering buildings in Ohafia area, it also discusses the ways by which expansive soils can be stabilized using additives of cement and lime.

2. Geology of the study area

The study area lies within the Anambra basin, the post Santonian tectonism caused the downwarping of Anambra basin and Afikpo syncline. Anambra basin of which the study area lies forms part of the regionally extensive northeast-southwest trending Benue trough (Ibeneme et al, 2013, Mode, 2004 and Nwajide 2005). Deposition of sediments started immediately after the Santonian tectonism. Sediments that were deposited in the basin include Campanian Nkporo and Enugu Shale, Owelli and Afikpo Sandstone. The parallic Maastrician Mamu Formation Overlies the Nkporo group, it consist of sandstone, Shales, Mudstone and Coal seams. The Maastrician continental Ajali Formation overlies the Mamu Formation, it consist of thick friable, poorly sorted, medium to coarse sand. While the Danian Nsukka Formation comfirmably overlies the Ajali Formation consisting of Sandstone, Shales and limestone. The marine deposited Imo-Shale of Paleocene age overlies the Nsukka Formation, it consist of Shales, Sandstone and limestone members. The Eocene-Oligocene Ameke Formation overlies the Imo-Shale consisting of medium to coarse grained white sandstone and mottled clays (Reyment, 1965; Hoque, 1977; Kogbe, 1988; Ibe, 1998).

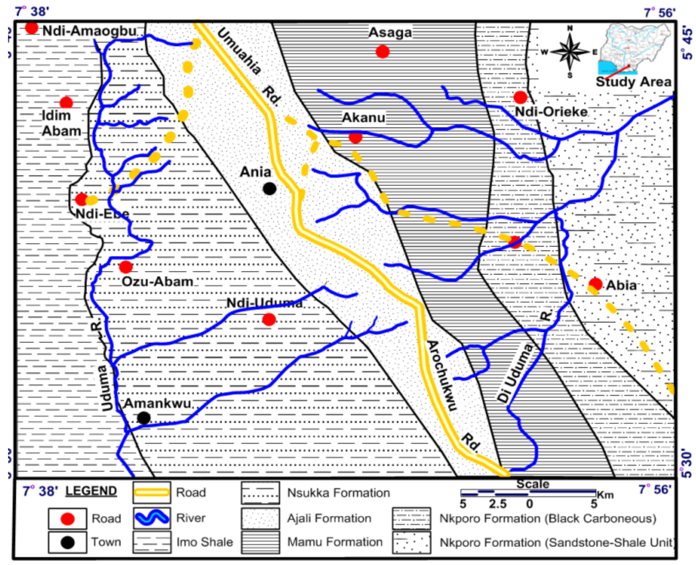

Fig. 4: Geologic map of the study area (modified from Mode, 2004).

The table 1 below shows the stratigraphic sequence of soils derived in Ohafia (Anambra Basin) area and their lateral equivalence.

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

Age	Basin	Stratigraphic Units						
Oligocene-Recent	Niger Delta	Ogwashi-Asaba Fm						
Eocene		Ameki/Nanka Fm/Nsugbe Sandstone (Ameki Group)						
Thanetian		Imo Formation						
Danian	Anambra Basin		Nsukka Formation					
Maastrichtian			Ajali Formation					
			Mamu Formation					
Campanian		Nkporo Fm	Nkporo Shale	Enugu Fm	Owelli Ss	Afikpo Ss	Otobi Ss	Lafia Ss

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3. Materials and methods

3.1 Sample collection

Ten (10) soil samples were collected at depths of 0.5m and 1m with hang auger for this paper cutting across Nkporo, Mamu, Nsukka and Imo Shale Formations following spangler and Hardy (1973) technique for sample collection. Samples were packed in ziplock nylon bags to preserve their moisture and sent to the lab.

3.2 Laboratory analysis.

The test necessary for determination of swelling behavior of the soils include, Natural Moisture Content(NMC), atterberg, linear shrinkage test, free swell, Particle-size analysis, specific gravity, Bulk and dry density test and x-ray diffraction. Also treatment was carried out using additives of cement and lime by weight percent of the soil samples.The test were performed in accordance with the British Standard Institute, BS 1377(1990) and American Standard for Testing and Materials (ASTM), at the Quality and Control Department, Arab contractors Owerri, Imo- state, Nigeria.

4. Results and discussion

The results of the coordinates were samples were collected, the parent rock type and the soil color are shown in the table 2 below.

Table 2: Towns/locations coordinate, geologic Formations, soil type/color.

S/N	Town/Location	Sample ID	Latitude	Longitude	Parent rock Formation	Soil Type/color
1	Ndiorieke	ND	N5^{0}33'58.9''	E7^{0}53'13.6''	Nkporo Shale	Brownish clay
2	Abia-Ukwa road	AU	N5^{0}32'9.8''	E7^{0}53'43.5''	Nkporo Shale	Dark grey clay
3	Abia-Akanu road	AA	N5^{0}33'20.9''	E7^{0}52'7.8''	Nkporo Shale	Dark grey clay
4	Akanu	AK	N5^{0}33'24.3''	E7^{0}51'28.8''	Mamu Formation	Reddish brown clay
5	Asaga	AN	N5^{0}35'57''	E7^{0}52'8.0''	Mamu Formation	Reddish brown clay
6	OzuAbam	OZ	N5^{0}37'10.0''	E7^{0}47'58.0''	Nsukka Formation	Grayish brown clay
7	Ndi Uduma	NU	N5^{0}31'27.1''	E7^{0}49'7.2''	Nsukka Formation	Brown clay
8	Ndiebe Abam	NA	N5^{0}36'19.0''	E7^{0}42'45.0''	Nsukka Formation	Grayish brown clay
9	Amaogbu junction	AO	N5^{0}35'38.4''	E7^{0}41'48.6''	Imo Shale	Brown clay
10	Idima Abam	IA	N5^{0}35'38.0''	E7^{0}41'22.1''	Imo Shale	Brown clay

4.1 Natural moisture content

The results of the natural moisture content are shown in table 3,soils derived from Abia – Ukwa road, Nkporo Formation has the lowest water content of about 24.4% while that of soils derived from Amaogbu (Abam) Imo-Shale has the highest moisture content value of 51.4%. This high moisture content shows that the soils have high affinity for water and low transitivity. This high retentiveness is usually associated with smectite (montmorillonite) rich soils. Welthman and Head (1983) classified soils with 5 to 15% as moisture content favorable for engineering construction. These high moisture content values show that the soils are not suitable for engineering purposes.

4.2 Atterberg and linear shrinkage

The results of the atterberg test presented in table 3 below shows that the derived soils has moderate to high liquid limit values (>42%). The results of the plasticity index of the soils,showed moderate to high plasticity (>19.4%). While the linear shrinkage values shows critical values of more than 8%. All the soils analyzed are swelling soils as all showed liquid limits greater than 42%, with the highest degree of 84% for Imo – Shale at Amaogbu, while the value of 42% was determined for both soil samples derived from Abia – Ukwa and Abia – Akanu road Nkporo Formation.

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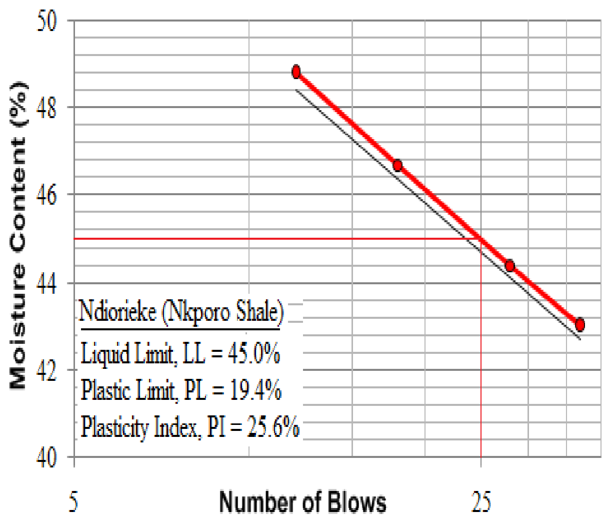

Fig. 5: Atterberg test result for Nkporo Shale

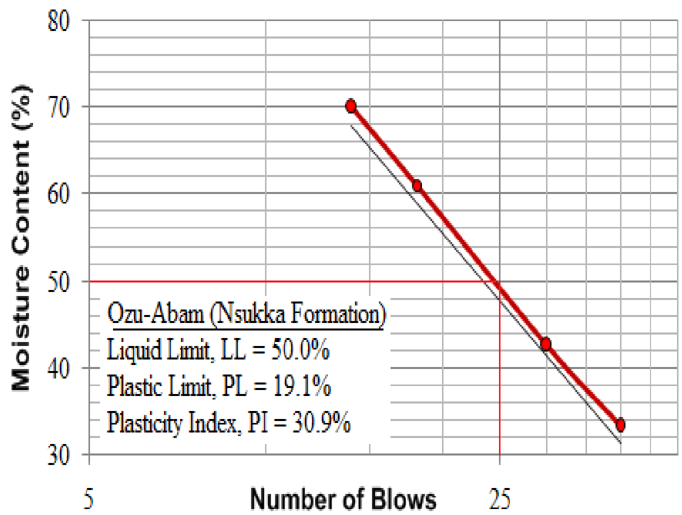

Fig. 7: Atterberg test result for Nsukka Formation

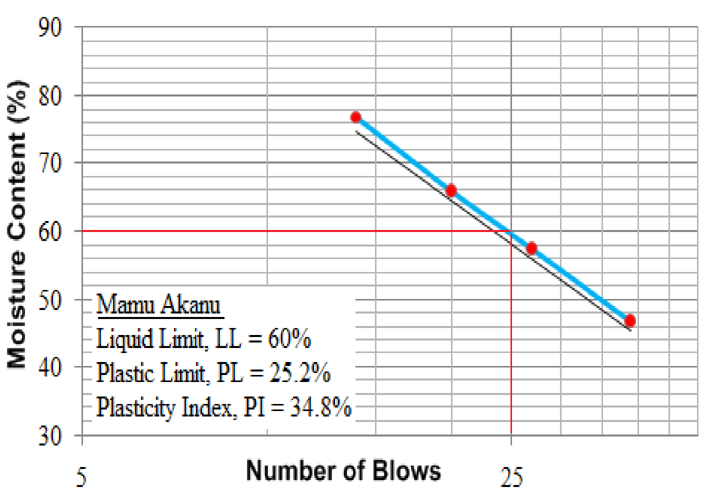

Fig. 6 Atterberg test results for Mamu Formation

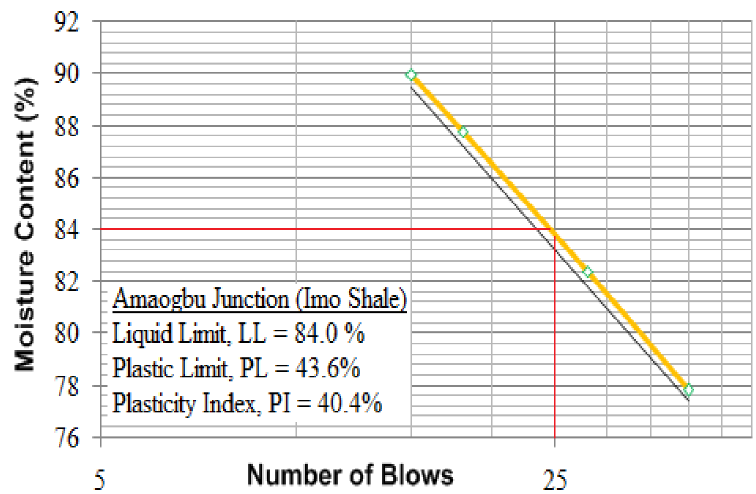

Fig. 8: Atterberg test result for Imo Shale

These values are indicative that the soil are swelling soils and possesses varying liquid limit degrees of expansion from medium to very high as indicated in Holtz and Gibbs (1956) classification. These high values of atterberg results are usually attributed to the presence of montmorillonite clay minerals.

The use of atterberg limit as a tool for recognizing problem soils in estimating the degree of swell and shrinkage is widely acknowledged (Au &Chae 1980). Baracos and Bozozuk (1957) observed that high atterberg limit values and high montmorillonite content should be enough indicators of swelling clays.

The possibility of recognizing expansive soil with linear shrinkage was proposed by Kantey and Brink (1952), they noted that linear shrinkage greater than 8% indicates expansiveness. Attimeyer (1956) also established linear shrinkage boundaries corresponding to volume changes ratings, these ratings were also adopted by Ola (1981).

Table 3 Moisture content, atterberg and linear shrinkage test of sampled soils

Location	Parent rock	Natural moisture content (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Linear shrinkage (%)
Ndiorieke	Nkporo	40.8	45.0	19.4	25.6	12.1
Abia-Ukwa	Nkporo	25	42.0	21.4	20.6	12.9
Abia-Akanu	Nkporo	24.4	42.0	21.1	19.4	12.5
Akanu-Ania	Mamu	39.5	60.0	25.2	34.8	21.8
Asaga	Mamu	27.6	57.5	26.2	31.3	20.7
OzuAbam	Nsukka	29.6	50.0	19.1	30.9	20.0
Ndi-Uduma	Nsukka	31.6	45.0	20.1	24.9	17.1
NdiEbe	Nsukka	28.2	48.0	21.3	26.7	18.6
Amaogbu	Imo shale	51.5	84.0	43.6	40.4	22.1
IdimaAbam	Imo shale	48.3	80.0	45.3	34.7	20.7

Relationship between liquid limit, plasticity and degree of expansion by Ola (1981), and Holtz and Gibbs (1956) is presented in Table 4.

Table 4: Relationship between liquid limit, plasticity and swelling potential

Liquid Limit (%) LL Holtz and Gibbs (1956)	Plasticity Index PI Ola (1981)	Swelling Potentials
< 35	0-15	Low
35- 50	15-25	Medium
50-70	25-35	High
>70	>35	Very high

Using Ola (1981) degree of plasticity index, the soil at Amaogbu (Imo Shale) has the highest degree of swelling potential with value of 40.4, followed by the values for Mamu Formation at Akanu road with value of 34.8. These values are indicative that they have very high degree of expansion as this can also be the reason why the sample at Amaogbu has the highest degree of natural moisture content of 51.5%. The soil sample at Abia-Akanu and Abia-Ukwa road (Nkporo Formation) has the lowest degree of plasticity index of 19.4 and 20.6 respectively. This can also be adjudged to the reason why they (Nkporo Formation) have the lowest degree of natural moisture content of 24.4% and 25.0% respectively.

Table 5: Plasticity index classification of the studied soils

Plasticity index (PI) (Ola, 1981)	Swelling potential	Sampled location/Formations
0-15	Low	-
15-25	Medium	Abia-Ukwa road (Nkporo) Abia-Akanu road (Nkporo) Ndi-Uduma (Nsukka)

25-35	High	Akanu(Mamu) Asaga (Mamu) OzuAbam (Nsukka) Ndiebe (Nsukka) Ndiorieke village (Nkporo)
>35	Very high	Amaogbu (Imo shale) IdimaAbam (Imo shale)

Table 6: Below shows the relationship between the degree of expansion and linear shrinkage (Attimeyer 1956).

Table 6: Relationship between linear shrinkage and degree of expansion

Linear shrinkage (%) (Attimeyer 1956)	Degree of expansion
0-5	Non critical
5-8	Marginal
>8	Critical

The Federal government of Nigeria specifies that values of plasticity index of soil should be less than 20% and liquid limit should be less than 30% for the soil to be used as building foundations.

Table 7: Federal Government of Nigeria Standard Specification for Roads and Bridges 1997.

Geotechnical properties	Values for both sub base and base course materials
Liquid limit (%)	Not more than 30%
Plasticity index	Not greater than 12
Linear shrinkage (%)	Not greater than 8%

4.3 Activity (A)

Activity of soil is a measure of the contribution or influence of clay minerals present in a soil to the swelling behavior of the soil (Attewel and Farmer, 1976). The amount of retained water or state (quantity) of water in soil mass depends upon the available clay minerals in soil.

According to Skempton (1954), when activity of soil is below 0.75, the soil behaves inactive (dominant clay minerals being kaolinite); when activity of soil is between 0.75 – 1.25 the soil is regarded as being normal (dominant clay minerals being illite and montmorillonite); above 1.25 soil is regarded as being active (predominantly Ca – montmorillonite) and as such exhibits larger volume change when wet and higher shrinkage when dry.

The activity of soil is related to the structural complexity of the minerals in soil ranging from quartz through kaolinite and up to montmorillonite and thus affects its behavior and engineering properties.

The studied soils of Nkporo Shale and Nsukka Formation have activity values of 1.04 and 1.17 respectively, which categorize them as normal clay. While soils from Mamu Formation and Imo Shale have values of 1.38 and 1.50 respectively, which categorize them as active clay, this can also be attributed to the varying degree of presence of water (natural moisture content) as a result of smectite clay minerals in them, high liquid, plasticity indexes and free swell.

4.4 Soil classification

Using atterberg, soils can be classified with respect to the type of clay present and how compressible they are. The system is known as the Unified soil classification system (USCS) proposed by Casagrande in the early 1940's.

He classified soils with 50% passing sieve 75µm, liquid limit of more than 50% and PI plots above the "A" line as inorganic fat clays CH soils, and soils with less than 50% liquid limit, PI greater than 7% and plots on or above "A" line as inorganic (fine grained) lean clay CL soils.

A plot of the soils on the Casagrande Plasticity chart shows that the soils plot between the "A" line and the "U" line and are indicative that they are expansive soils (Jennings, 1953; Holtz &kovacs, 1981). Soils with more than 50% passing sieve 75µm, liquid limit of more than 50% and PI plots above the "A" line are classified as inorganic fat clays CH soils, and soils with less than 50% liquid limit, PI greater than 7% and plots on or above "A" line as inorganic (fine grained) lean clay CL soils.

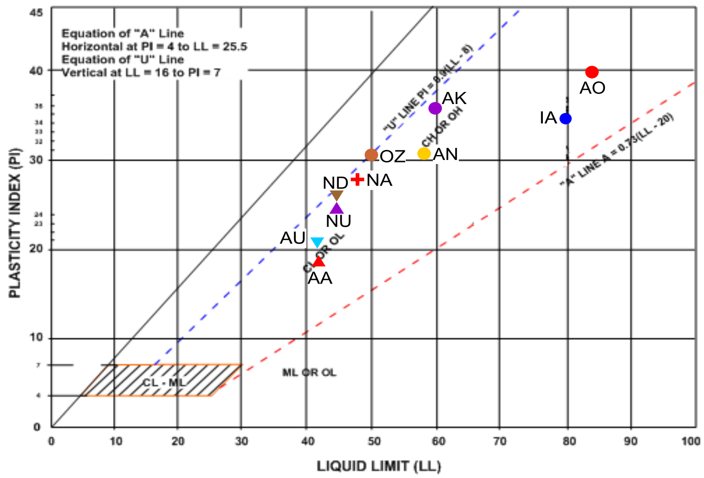

Fig. 9: Casagrande plasticity chart

4.5 Free swell

The studied soil has free swell values ranging from 42.9 to 77.1% (table 8), these values shows that the soils have high affinity for water and can swell easily without external constraints; this swelling ability can be attributed to the smectite clay mineral present. Dawson 1956, classified soils with less than 50% free swell as low while more than 50% as high.

Table 8: Specific gravity, Free swell, Bulk and Dry density and percentage fine of soils

Location	Parent rock Formation	Specific Gravity	Free Swell (%)	Bulk Density (Mg/m^3)	Dry Density (Mg/m^3)	Percentage Fine (%)
Ndiorieke	Nkporo	2.71	42.9	1.91	1.55	80.98
Abia-Ukwa	Nkporo	2.53	44.7	1.41	1.21	98.4
Abia-Akanu	Nkporo	2.46	46.0	1.43	1.24	97.5
Akanu	Mamu	2.79	77.1	1.69	1.25	92.7
Asaga	Mamu	2.68	68.6	1.71	1.26	90.0
Ozu Abam	Nsukka	2.76	62.0	1.69	1.24	96.5
Ndi Uduma	Nsukka	2.68	56.4	1.73	1.24	95.2
Ndiebe Abam	Nsukka	2.69	60.7	1.69	1.25	94.4
Amaogbu Abam	Imo–Shale	2.72	75.0	1.42	0.99	92.3
Idima Abam	Imo–Shale	2.70	72.7	1.43	0.95	93.1

4.6 Dry and Bulk density

Dry density of most soils varies between 1.1-1.6g/m^3 in clayey soils and aggregated the loam; it can be as low as 1.1g/m^3 (Hillel; 1980). Dry density of soils depends on soil structure (compaction or looseness) and on the soil matrix swelling and shrinking characteristics.

Typical values of dry density of various studied soil samples fall within the ranges specified by Linsley *et al*., (1982) and Poffijn (1988), the lowest values of 0.94 and 0.96g/cm^3 for Imo shale at Amaogbu and Idima Abam respectively are also indicative that they are highly swelling clays. While the highest values of 1.35g/cm^3 which was derived for soil sample at Ndiorieke can be attributed to the presence of sandstone in that unit.

4.7 Particle size distribution

The results of the particle size distribution presented in Fig. 10 and 11, Shows that none of the soils have particles coarser than 2.36mm. The graph shows that the soils are poorly grade with deficiency of coarse sand. The results also shows that the soils have more than 80% passing sieve 200 (75microns) and as such are classified as fine grained soil.

Unified Soil Classification system, classified soil with more than 50% passing sieve 200 as fine grained soils (A 2487 – 06).

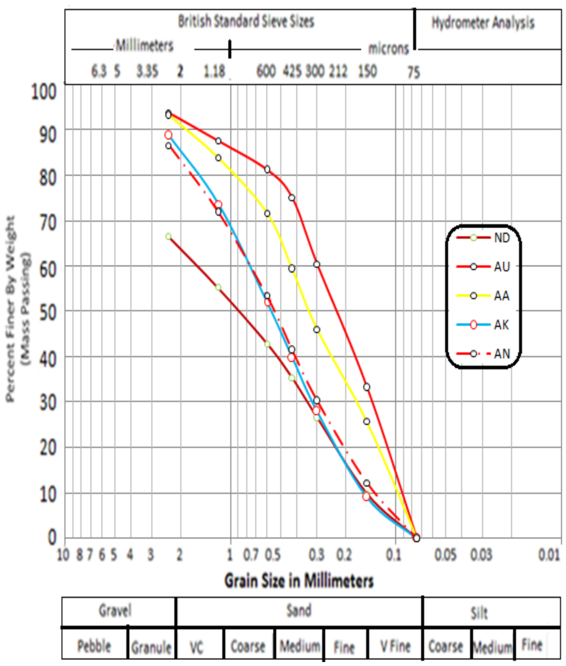

Fig. 10

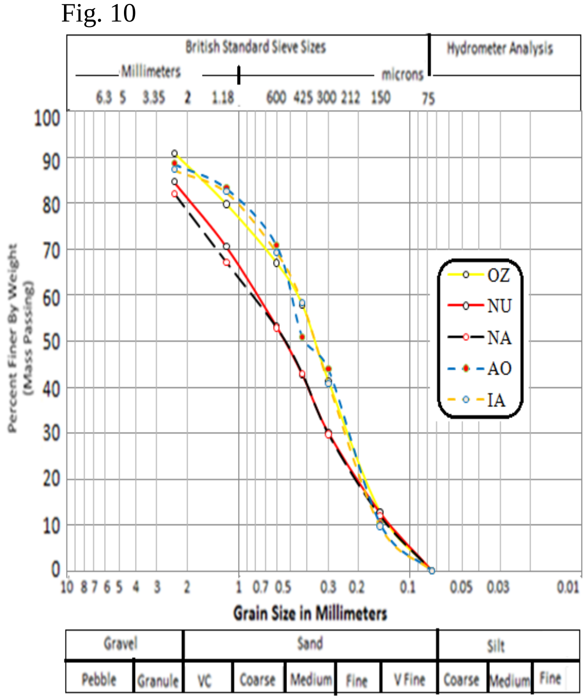

Fig. 11

Fig. 10 and 11 Showing grain size distribution test of sampled soils

4.8 X-ray diffraction

The result of the x-ray diffraction shown in the diagram below confirmed the presence of clay minerals in the soil**,** the clay minerals present include chlorite , halloysite, kaolinite, montmorillonite, and illite. Quartz which is shown in the diagram is the major constituent of every soil. Montmorillonite having the highest peak count can be seen in the diagram and as such controls the behavior of the studied soils, this behavior of high water affinity can also be shown in the results obtained for other analysis carried out (especially atterberg, free swell and natural moisture content of soil). Quantitative analyses of the samples were not carried out in this research paper.

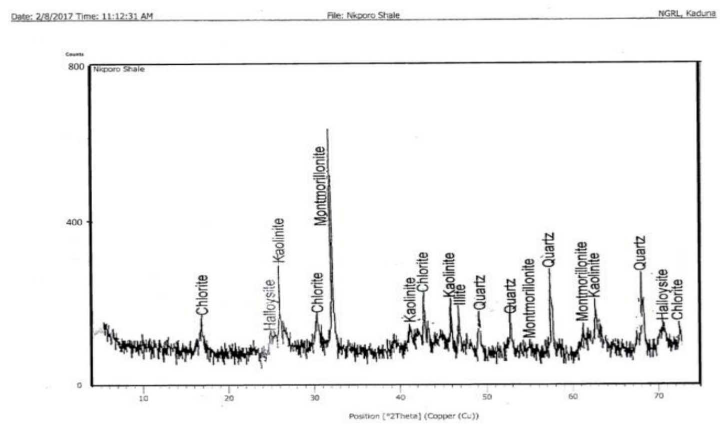

Fig. 12: X-ray diffractogram of Nkporo Shale

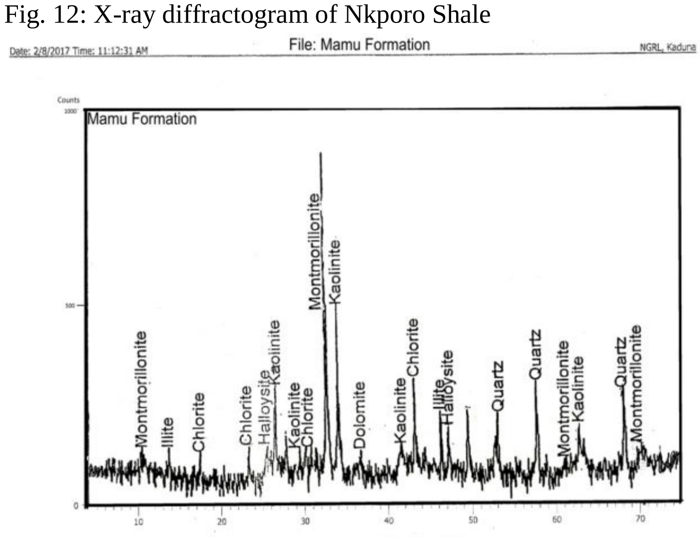

Fig. 13: X-ray diffractogram of Mamu Formation

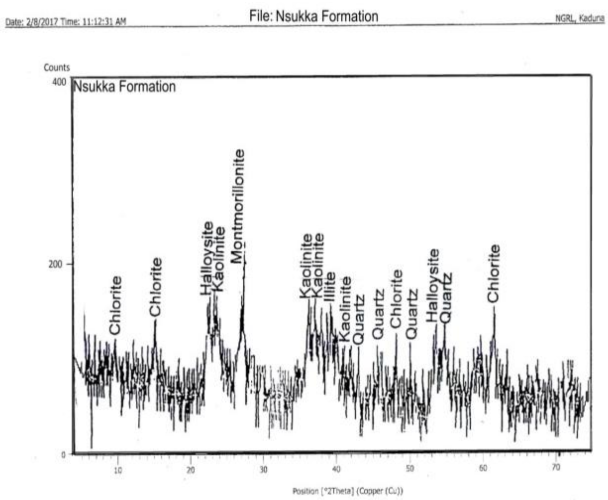

Fig. 14: X-ray diffractogram of Nsukka Formation

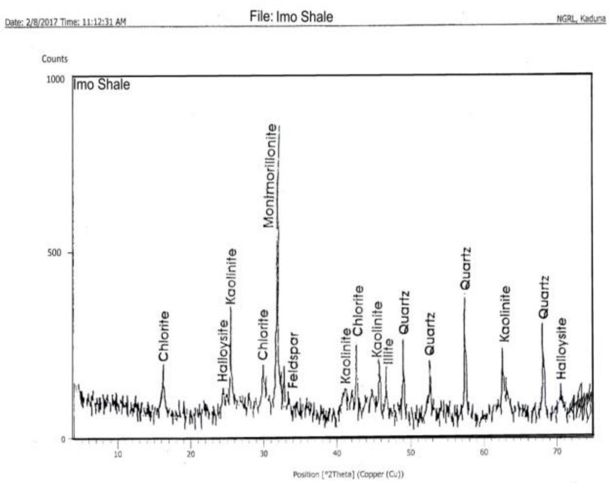

Fig. 15: X-ray diffractogram of Imo Shale

Treatment test

The engineering behavior of lime/cement treated expansive soil refers to the improvement or stability in the engineering properties of the soil when treated with various percentages of lime and cement.

LIME

Lime is the most widely used additive to treat soil, thereby improving the quality of the soil for construction and durability. Lime treatment includes the use of burned lime products, quicklime and hydrated lime (Oxides and hydroxide respectively) or lime by-products. The amount of lime additive depends on soil to be modified. Lime is usually suitable for soils with Plasticity indices ≥ 20% and percentage passing sieve No. 200 >35%. Lime treatment is applied in road construction, rail road's, airports construction and for improvement of soil beneath building foundations (Anon, 1985 & 1990).

Lime stabilization takes place through two basic chemical reactions as follows

i) Short term reactions which include cation exchange and flocculation, lime being a strong alkaline base that reacts chemically with clays causing Cation Exchange.

ii) Long term reaction are pozzolanic reactions, where calcium from the lime reacts with the soluble alumina and silica from the clay in the presence of water to produce stable Calcium Silicate Hydrate (CSH), Calcium Aluminate Hydrate (CAH) and Calcium Alumino-silicate Hydrate (CASH) which generates the long term strength gain and improves geotechnical properties of the soil. These hydrates were observed by many researchers (Diamond *et al.*, 1964, Sloane, 1965, Ormsby&Kinter, 1973 and Choquette*et al.*, 1987).

These pozzolanic reactions can be clarified using the following chemical equations

$Ca(OH)_2 + SiO_2 \rightarrow CaO\text{-}SiO_2\text{-}H_2O$…………………………(1)

Calcium Silicate Hydrate (C-S-H)

$Ca(OH)_2 + Al_2O_3 \rightarrow CaO\text{-}Al_2O_3\text{-} H_2O$……………………….(2)

Calcium Aluminate Hydrate (C-A-H)

$Ca(OH)_2 + Al_2O_3 + SiO_2 \rightarrow CaO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O$……………(3)

Calcium Alumino Silicate Hydrate (C-A-S-H)

Pozzolanic reactions are time dependent and require long period of time (years) because such reactions are a function of temperature, calcium quantity, PH value and percentage of Silica and Alumina in soil mineral (Eades& Grim, 1960; Kassim*et al.*, 2005).

The use of lime for soil stabilization is either in the form of quicklime (CaO) or hydrated lime [$Ca(OH)_2$]. In this present study dry powdered hydrated lime was used. It is a product of quicklime reacting with sufficient amount of water to form a white powder. This is referred to as slaking.

High calcium quicklime + water → hydrated lime + heat

$CaO + H_2O \rightarrow Ca(OH)_2$ + heat………………(4)

CEMENT

Cement is the second widely preferred chemical additive after lime. Cement is suitable for soil with Plasticity Indices of < 20% and percentage passing sieve No. 200 < 35%.

The strength of soil-cement mixture increases with increasing amount of cement. If too much organic matter is present, cement would not produce proper strength.

According to Jha and Sinha (2009) and Gupta and Gupta (2004), the major constituent of cement which have a distinct effect on strength aspect of cement mixture are

i) Dicalcium silicate ($2CaO.SiO_2$)
ii) Tricalcium silicate ($3CaO. SiO_2$)
iii) Free lime.

Tricalcium silicate sets fast and is responsible for immediate strength gain. Free lime in the cement may bring about cation exchange capacity and change of soil texture. Dicalcium is responsible for long term strength due to hydration.

For treatment of the swelling soil, one soil sample from each Formation would be used to determine the improvement/stability test. The soil characteristics that were evaluated for improvement when cement and lime was added include, (a) the liquid limit, (b) Plastic limit, (c) Plasticity index and, (d) Linear shrinkage.

The results are shown in the tables and figures below

Table 9: Lime treatment for Nkporo derived soil (Ndiorieke village)

Lime (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
0	45.0	19.4	25.6	12.1
2	40.0	20.2	19.8	11.4
4	36.0	20.7	15.3	10.0
6	29.5	21.3	8.2	8.6
8	32.5	21.4	11.1	7.6

Table 10: Lime treatment for Mamu derived soil (Akanu-Ania road)

Lime (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
0	60.0	25.2	34.8	21.8
2	52.0	25.9	26.1	18.5
4	46.5	26.2	20.3	12.1
6	37.5	26.7	10.8	11.5
8	43.5	27.6	15.9	10.7

Table 11: Lime treatment for Nsukka Formation derived soil (OzuAbam)

Lime (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
0	50.0	19.1	30.9	20.0
2	41.5	19.4	22.1	19.3
4	37.5	21.2	16.3	17.1

6	29.0	21.6	7.4	14.3
8	35.5	22.3	13.2	10.0

Table 12: Lime treatment for Imo Shale derived soil (Amaogbu Junction)

Lime (%)	**Liquid limit (%)**	**Plastic limit (%)**	**Plasticity index**	**Linear shrinkage (%)**
0	84.0	43.6	40.4	22.1
2	72.0	38.1	33.9	14.3
4	66.0	40.2	25.8	11.4
6	62.5	47.8	14.7	7.9
8	63.0	46.5	16.5	6.4

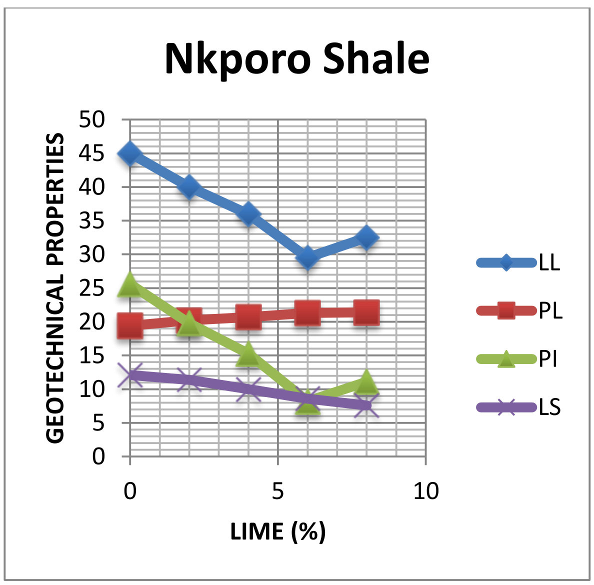

Fig.16 Lime treatment test plot for Nkporo Formation derived soil.

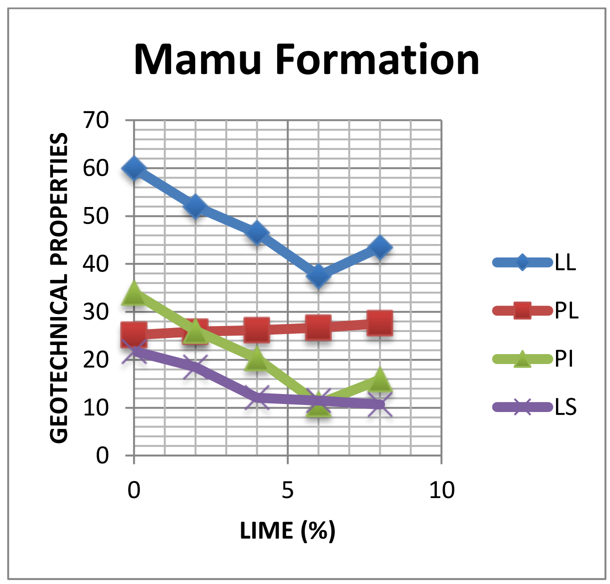

Fig. 17 Lime treatment test plot for Mamu Formation derived soil

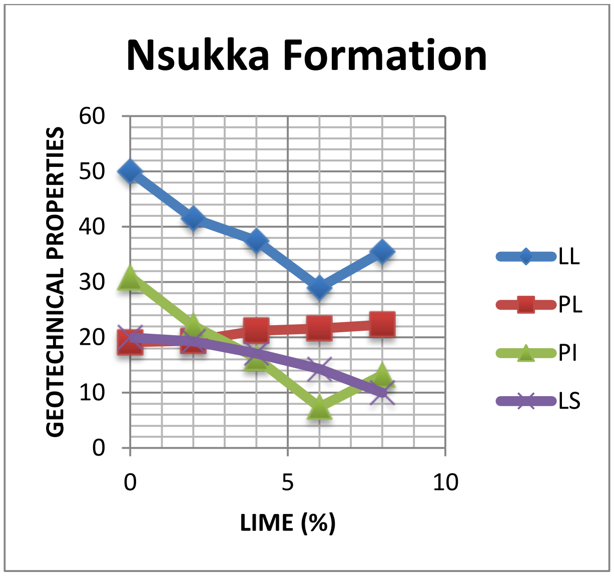

Fig.18 Lime treatment test plot for Nsukka Formation derived soil

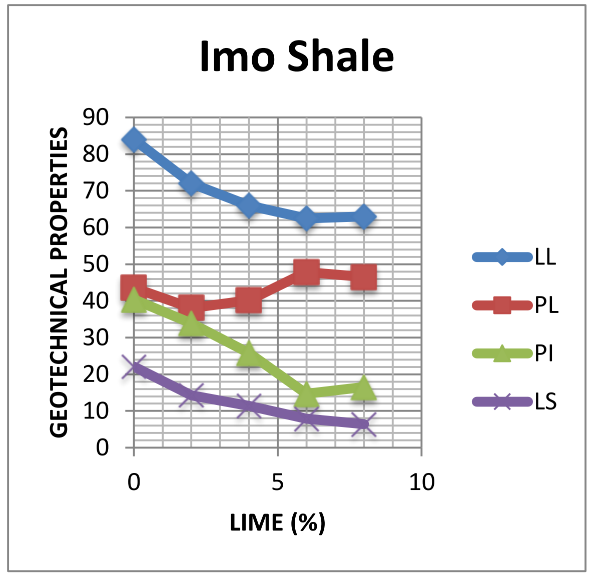

Fig.19 Lime treatment test plot for Imo Shale derived soil

Table 13: Cement treatment for Nkporo derived soil (Ndiorieke)

Cement (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
0	45.0	19.4	25.6	12.1
2	41.0	20.7	20.3	11.8
4	37.5	20.7	16.8	10.7
6	35.0	22.7	12.3	9.2
8	32.5	23.2	9.3	7.9
10	37.0	24.1	12.9	6.4

Table 14: Cement treatment Mamu derived soil (Akanu)

Cement (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
0	60.0	25.2	34.8	21.8
2	56.0	26.2	29.8	18.5
4	51.0	27.7	23.3	17.6
6	48.0	29.1	18.9	15.3
8	39.0	29.3	9.7	11.4
10	45.0	30.3	14.7	10.0

Table 15: Cement treatment for Nsukka derived soil (Ozu Abam)

Cement (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
0	50.0	19.1	30.9	20.0
2	48.0	20.7	27.3	18.6
4	43.0	20.7	22.3	17.1
6	37.5	22.5	15.0	16.4
8	35.0	23.6	11.4	12.9
10	39.5	23.6	15.9	10.7

Table 16: Cement treatment for Imo Shale derived soil (Amaogbu Abam)

Cement (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Linear shrinkage (%)
0	84.0	43.6	40.4	22.1
2	75.0	44.4	30.6	15.0
4	67.5	46.4	21.1	13.6
6	65.0	46.4	18.6	12.1
8	60.0	47.2	12.8	9.2
10	68.0	47.2	20.8	7.6

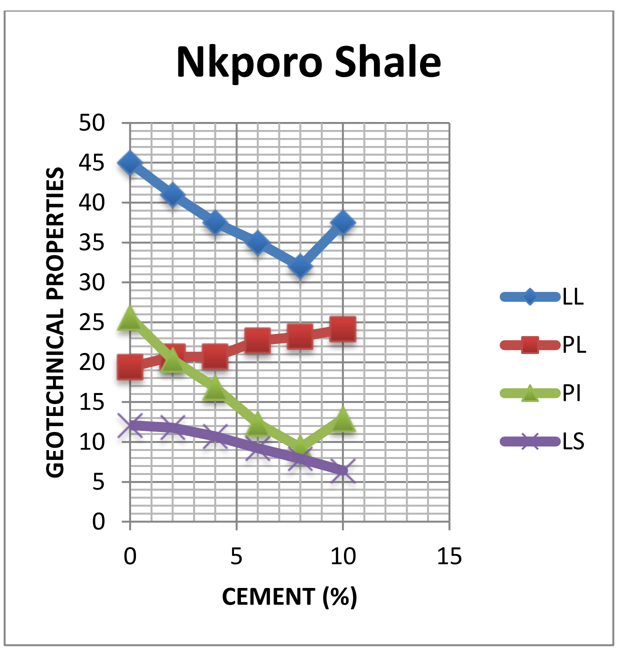

Fig. 20: Cement treatment test for Nkporo Formation derived soil.

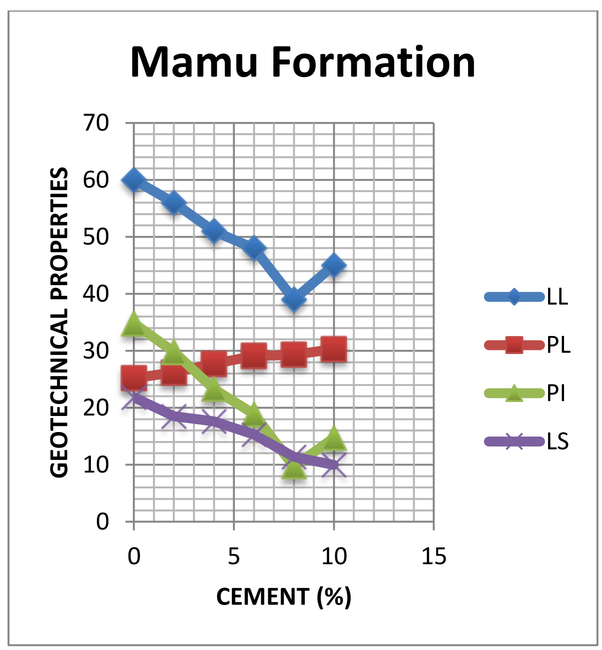

Fig. 21: Cement treatment test for Mamu Formation derived soil

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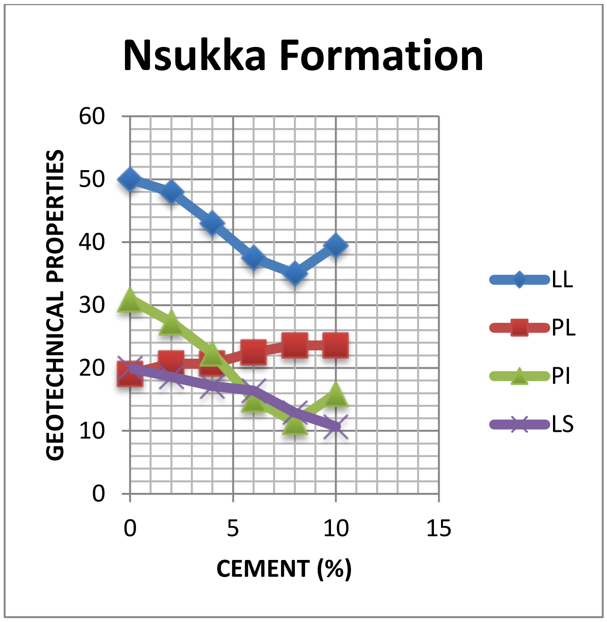

Fig. 22: Cement treatment test for Nsukka Formation derived soil.

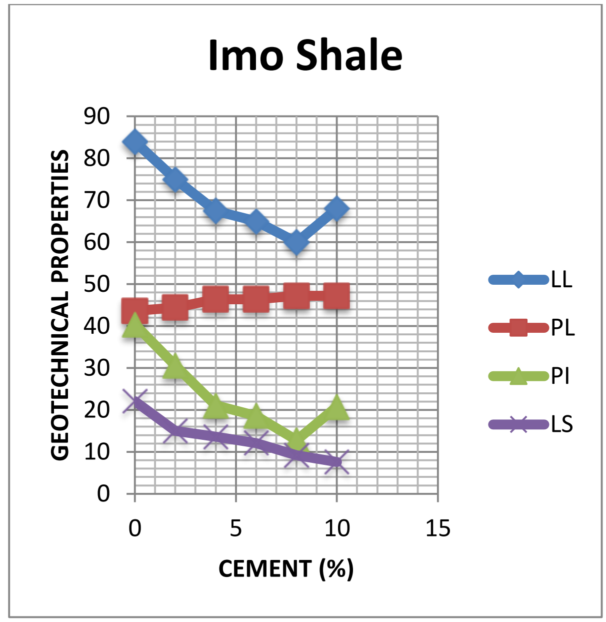

Fig. 23: Cement treatment test for Imo Shale derived soil

Stabilization/treatment

Stabilization or treatment of expansive soils with different additive such as cement and lime has the general effect of reducing the ability of the soil to swell (swelling potential) and increasing the strength characteristics (Okeke *et al*., 2015).

Table 9 – 16 and figures 16 – 23 shows the reduction of liquid limit, plasticity index and linear shrinkage for the four soils derived from different swelling Formations when treated with varying percentages of cement and lime. Optimal addition of 8% cement and 6% lime led to the maximum reduction after which a slight increase is noticed.

On treating the soils with hydrated lime, the tables showed a reduction of 45 – 29.5% liquid limit, 25.6 – 8.2 plasticity index, and 12.1 – 7.6% linear shrinkage (Nkporo Formation). Mamu Formation derived soil at Akanu showed a reduction of 60 – 37.5% liquid limit, 34.8 – 10.8 plasticity index and 21.8% – 10.7%. Nsukka Formation derived soils at OzuAbam showed reduction of 50 – 29.0% liquid limit, 30.9 – 7.4% plasticity index and 20.0 – 10.0% linear shrinkage. Imo Shale derived soils reduced from 84.0 – 62.5% liquid limit, 40.4 – 14.7 plasticity index and 22.1 – 6.4% linear shrinkage.

While on treating the soils with cement a reduction of 45 – 32.5% liquid limit, 25.6 – 9.3 plasticity index and 12.1 – 6.4% linear shrinkage for Nkporo Formation derived soils was noticed. Mamu Formation derived soils showed a reduction of 60.0 – 39.5% liquid limit, 34.8 – 9.7 plasticity index and 21.8 – 10.0% linear shrinkage. Nsukka derived soils reduced from 50.0 – 35.0% liquid limit, 30.9 – 11.4 plasticity index and 20.0 – 10.7% linear shrinkage. A reduction of 84.0 – 60.0% liquid limit, 40.4 – 12.8 plasticity index and 22.1 – 7.6% linear shrinkage was noticed on treating Imo Shale derived soils with cement.

Table 17: Plasticity index classification of studied soils before and after treatment

Plasticity index (PI) (Ola, 1981)	**Swelling potential**	**Sampled soils 0(%) treatment**	**Sampled soils on treating with lime**	**Sampled soils on treating with cement**
0 – 15	Low	-	Ndiorieke (Nkporo), Akanu (Mamu) OzuAbam (Nsukka) AmaogbuAbam (Imo Shale)	Ndiorieke (Nkporo), Akanu (Mamu) OzuAbam (Nsukka) AmaogbuAbam (Imo Shale)
15 – 25	Medium	-		
25 – 35	High	Ndiorieke (Nkporo), Akanu (Mamu) OzuAbam (Nsukka)		
>35	Very high	AmaogbuAbam (Imo Shale)		

5. Conclusion

Natural soil of the four different expansive Formations underlying parts of Ohafia were studied extensively both in literature and in the field. Numerous field and laboratory studies were conducted to evaluate the degree of swelling behavior of the ten studied soil samples from the four swelling Formations in Ohafia area. Several types of test that determines the swelling behavior of soils in the area was conducted. The test carried out in this research ascertained that they are expansive which is typical of humid tropical soil of Nigeria.

Expansive soils that occur in parts of Ohafia area have moderate to high liquid limit, plasticity index and show presence of kaolinite, illite and montmorillonite clay mineral content. They also have high (critical) linear shrinkage, moderate to high free swell values based on their plots on the Casagarande plasticity chart; they classify as fat and lean clays, CH and CL soil with more than 42% liquid limit, and plots above the "A" line.

The results of the study indicate that the swelling behaviour of soils in Ohafia area are influenced by the parent rocks from which the expansive soils were derived. Thus the occurrence and distribution of expansive soils developed from the swelling potential values of the soils in the study area is shown in the map below which classifies the soils as follows;

i. Soils derived from Imo-Shale – (very high swelling potential, average PI, 37.5%)
ii. Soils derived from Nsukka Formation – (high swelling potential, average PI, 27.5%)
iii. Soils derived from Mamu Formation – (high swelling potential, average PI, 33.1%)
iv. Soils derived from Nkporo Shale – (medium swelling potential, average PI, 21.9%).

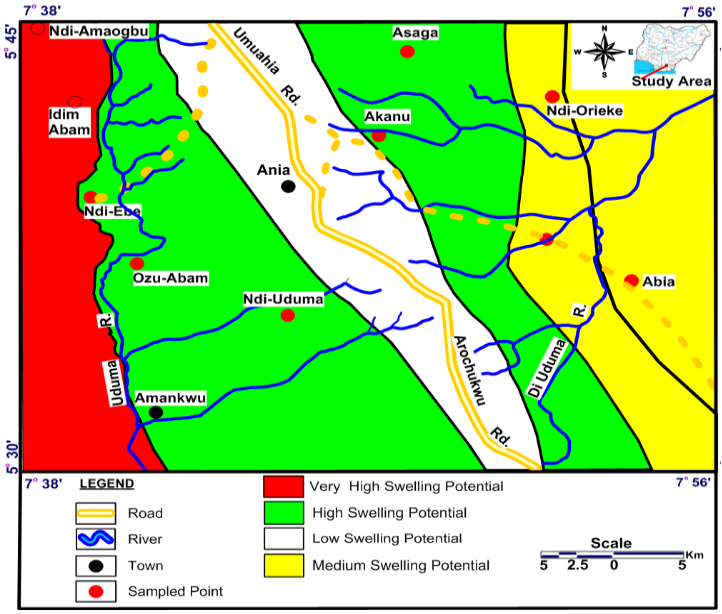

Fig. 24: Map showing the distribution of expansive soil in parts of Ohafia.

The test carried out in this research ascertained that they are expansive which is typical of humid tropical soil of Nigeria. The occurrence of expansive soil in Ohafia area can be traced to the weathering of pyroclastic rocks of Abakiliki area and are distributed in Nkporo, Mamu, Nsukka and Imo-Shale Formations.

The failures of many engineering structures can be traced to the pressures of these swelling soils on foundations of buildings and roads. Other areas where the adverse effects of expansive soils have been noticed in southeastern Nigeria include Amuro in Okigwe, Afikpo, Akaeze, Agwu and Mpu all in southeastern Nigeria.

Treatment/stabilization was performed to simply reduce the effect of swelling behavior of studied expansive soil in the area. Treatment was performed with additives of cement and lime at different percentages. The mechanism of treatment comprised of hydration, cation exchange, flocculation agglomeration of soil particles and pozzolanic reactions to form Calcium Silicate Hydrate (CSH), Calcium Aluminate Hydrate (CAH) and Calcium Alumino Silicate Hydrate (CASH).

The drying of wet soil and the increase in the soil workability is attributed to immediate treatment, whereas increase in strength, durability and compressibility of soil is associated with long term treatment (Locat *et al.*, 1990; Wild *et al.*, 1996; Mallela *et al.*, 2004;Geiman 2005).

In general all lime treated fine grained soil exhibit decreased plasticity, improved workability and reduced volume change characteristics. However, it is to be noted that not all lime-soil mixtures give rise to improvement; it is dependent on some other factors such as soil type, lime type, lime percentage and curing conditions, time, temperature and moisture, (U.S Army, Air force and Navy 2005).

5.2 Recommendations

i. The use of hydrated lime alone is suitable to stabilize the swelling soil which has high liquid limit and high plasticity index
ii. The use of cement is suitable for stabilizing fine grained swelling soils which contained low amount of clay particle and higher amount of silt.
iii. In the case of lime and cement treatment, addition of 6% and 8% respectively by total weight of soil sample does not result to further improvement of the geotechnical properties of soil, as this is the lime/cement optimum fixation point.
iv. Furthermore additional studies would be required to evaluate the use of lime and cement to treat and stabilize different types of soil and to establish a more reliable Nigerian guideline and standard specification for lime/cement stabilization process.
v. It is recommended that through the findings of this research, expansive soil should be treated or stabilized with lime or cement additives as it reduces the problems that are usually associated with swelling soils. The federal, state governments and individuals can key into results of this research work and previous research works to stabilize soil before construction to save long term cost of maintenance when swelling problems surfaces.

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