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Effects of Cement and Lime Stabilization on Geotechnical Properties of Expansive Soils in Awka and Environs, Southeastern Nigeria

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Abstract
Failures of engineering structures, superficially expressed as cracks on roads and buildings in Awka and environs, are believed to be caused by expansive soils on which the engineering structures were erected in the area. This study investigated the use of cement and lime as additives in the modification of the geotechnical properties of expansive soils in the study area (Awka and Environs) so as to reduce their swelling potentials. Two expansive soil samples were collected from different locations in the study area to represent soils derived from different geologic formations (Nibo, representing soils derived from Ameki Formation and Akpugoeze, representing soils derived from Imo Shale). The geotechnical properties of the soils including Atterberg limits (liquid limit and plasticity index), linear shrinkage, Maximum Dry Density (MDD) and California Bearing Ratio (CBR) were determined in the laboratory. The soil samples were later stabilized with various percentages of cement and lime (2, 4, 6, 8 and 10). The geotechnical tests earlier performed on the soils were repeated (after stabilization) to evaluate the effects of cement and lime stabilization on the geotechnical properties of the soils. Results of the study indicate that lime and cement stabilization of expansive soils in Awka and the environs have the general effects of reducing the swelling indicators (liquid limits, plasticity index and linear shrinkage) thereby reducing the swelling potential of the soil or tendency of the soil to swell in the presence of water. Stabilization with cement and lime also have the effect of increasing the strength characteristics (MDD and CBR) of the soils. Cement stabilization increases the MDD and CBR while lime stabilization increases the CBR but reduces the MDD. Optimum stabilization, that is, minimum values of swelling indicators were achieved with 6% lime stabilization and 8% cement stabilization. On the basis of actual values achieved from stabilization of the two soils derived from different geologic formations (Ameki Formation and Imo Shale), lime stabilization of expansive soils is more effective than cement stabilization in terms of reduction of swelling indicators. The two materials (cement and lime) are generally good, though, and any of them may be used in field operations depending on availability.

Keywords: *Expansive soils, Atterberg limit, swelling potential, cement, lime and stabilization.*

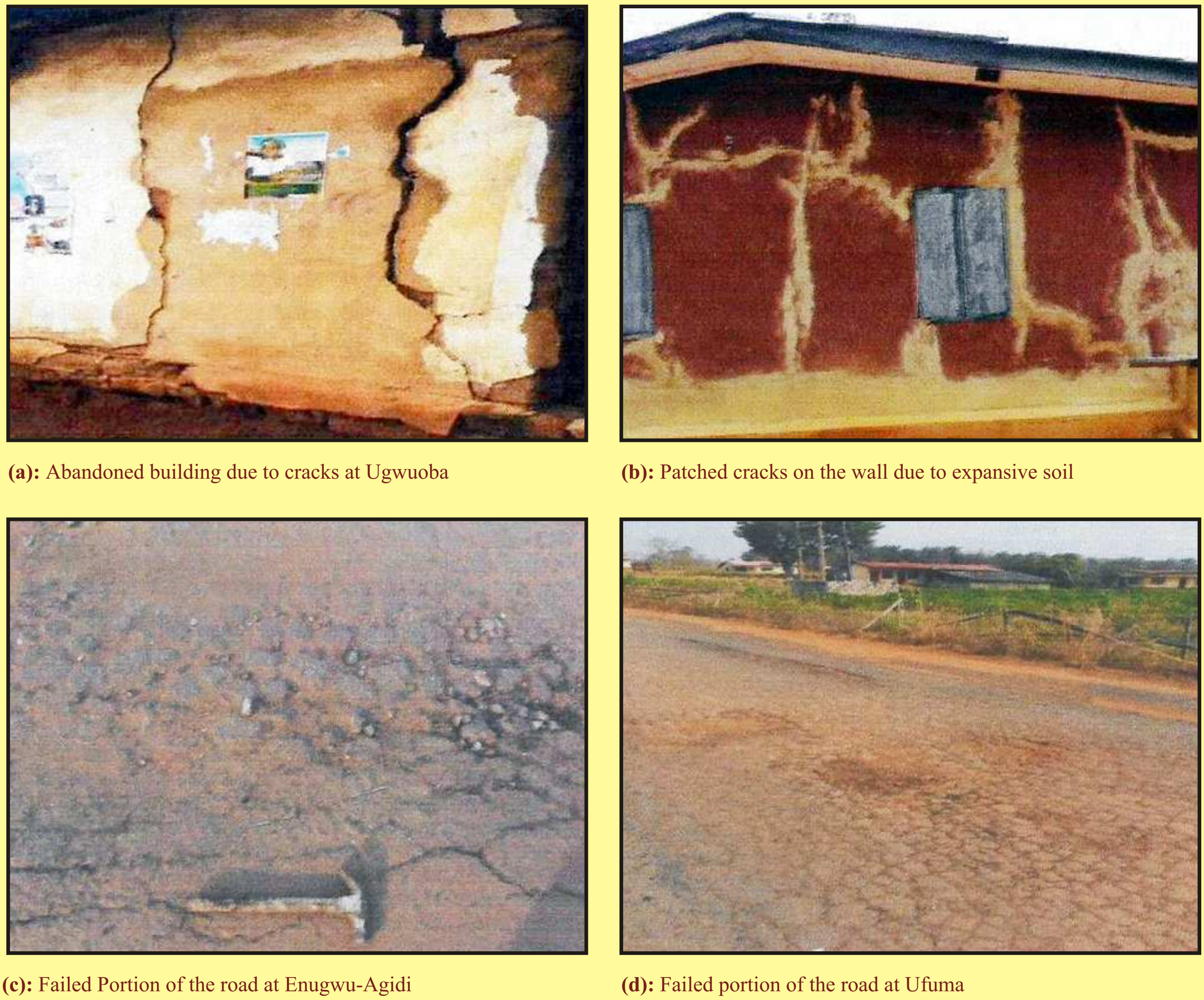
Introduction

Soil to a Geologist represent the result of ancient surface processes while to a Pedologist, it represent presently occurring physical and chemical processes but to an Engineer, it is a material that can be built on (foundation, bridges), built in (tunnels, culverts, basements), built with (road, runaways, embankments dams) and can even serve as a support in retaining walls and quays. The main important property of a soil to an engineer is the mechanical properties of the soil such as the strength, stiffness and permeability. The geotechnical engineers and geologists face a lot of challenges when engineering structures are founded on a problematic soil. Expansive soils are those soils containing clay minerals especially the montmorillonite which have the tendency to absorb moisture causing an increase in the soil volume (swell), but when they lose the moisture, they decrease in volume (shrink). Expansive soils occupy about 20% of the world surface area (Okogbue, 1990), but in Nigeria, these soils cover an area of about 10.4×10^4 km^2 in the northeastern part of the country (Ola, 1983). Krohn and Slossen (1980), estimated 9 billion US dollars damages due to expansive soil in the USA. The effects of expansive soils (swelling and shrinking) as they interface with moisture poses a serious threat to man and the environment (Jones and Holtz, 1973; Krohn and Slossen, 1980; Freeman et al. 1991; Braja, 1996). Damages caused on engineering structures due to the occurrence of expansive soils in some areas is not necessarily the lack of inadequate engineering solutions but due to the failure to identify the existence and extent of the expansion of the soils in the earlier stage of a project planning.

The occurrence of expansive soils has led to cracking and eventually collapse of engineering structures such as buildings and drainage structures, and damages on roads in the study area, and the durability of these engineering structures are threatened or reduced due to cracks on the walls of buildings. Figure 1 shows effects of expansive soils on engineering structures in the study area (Ogbuchukwu et al, 2019). Bell (1993 and 2007) and Craig (1992), suggested that the treatment of such soil can be done by preventing the ingress of groundwater flow or replacing the soil with non-expansive soils, but due to the high cost of the soil replacement method, several authors proposed an alternative means of improving the geotechnical properties of the soil. They believed that soil treatment with cementing agents (chemical method) such as lime, cement, calcium or sodium chloride and industrial byproducts like fly ash, rice husk ash, slags, lime kiln dust, cement kiln dust, quarry dust; mechanical method by application of mechanical energy (compaction or preloading); pore water pressure reduction techniques (dewatering or electro-osmosis); the bonding of soil particles (ground freezing, grouting, and chemical stabilization); and use of elements such as geotextiles and stone columns can improve the geotechnical properties.

Powrie (1997) and Okeke et al. (2015) noted that the sole aim of soil stabilization with additives like cement or lime is to reduce the affinity of the soil to swell when in contact with water. They concluded that engineering properties such as liquid limit, plasticity index and linear shrinkage which are normally responsible for swelling behavior of the soils are generally reduced when appropriate percentage of addictive is added to the soil.

Petry and Armstrong (2001) stated that the most widely used chemical additives for stabilization of expansive soils are cement, lime and fly ash. Though Roads and Streets (1959), Thompson (1968) and Greaves (1996) explained that lime and cement are widely used in soil stabilization of highway pavement subgrades. They concluded that soil stabilization with lime is mostly recommended especially in soils with high plasticity and high clay fraction because it improves the workability of the clay and achieves higher and faster rate of reduction of the engineering properties within a short time, while treatment of subgrade soils with cement is recommended in soils with less clay fraction, low plastic characteristic and where early strength is desired (Moh, 1962; Peck, et al., 1974; US Army, 1983 and 1984; Mowfy et al., 1985; Bell, 1993; Raj, 2008; Jha and Sinha, 2009).



(a): Abandoned building due to cracks at Ugwuoba

(b): Patched cracks on the wall due to expansive soil

(c): Failed Portion of the road at Enugwu-Agidi

(d): Failed portion of the road at Ufuma

Fig. 1: Effects of expansive soils on engineering structures in the study area (Ogbuchukwu et al, 2019)

Generally, soil stabilization which is the process of modifying expansive soils to enhance its physical properties an effective way for improving the geotechnical properties of expansive soils by controlling the shrinkage and swelling properties of the soil, thereby improving the load bearing capacity, strength and durability of subgrade to support pavement and foundation and the work of the stabilizing agent in treatment process of expansive soils is to reinforce the bounds between the grains/particles or filling the pore spaces. Soil stabilization using chemical methods can result in the alteration and improving of geotechnical properties of the soil for better workability and constructability. Occurrence of expansive soils in southeastern Nigeria has been reported by Uduji et al. (1994), Okeke and Okogbue (2010a) and Ogbuchukwu et al. (2019). Okeke and Okogbue (2010b) described the effects of lime stabilization on geotechnical properties of expansive soils derived from Ezeaku Formation in Akaeze, Southeastern Nigeria. Okoro et al. (2019) described the effects of lime/cement stabilization on geotechnical properties of expansive soils derived from various geologic formations in parts of Ohafia, Southeastern Nigeria.

In this paper, expansive soils derived from Ameki Formation (Nibo) and Imo Shale (Akpugoeze) in Awka area, Southeastern Nigeria, were stabilized with cement and lime and the effect stabilization on their geotechnical properties evaluated.

Study Area Description

Location and Climate of the Study Area

The study area is within Awka and environs which 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 5° 56'N to 6° 16'N and longitude 6° 59'E to 7° 17'E and elevation of 93 to 134m above sea level (Figure 1). The study areas Nibo and Akpugoeze are accessible through; Awka-Onitsha road and Awka-Enugu express road. The major topographic feature in the study area is the cuestas and it falls within the rainforest vegetation with two seasonal climatic conditions (Rainy and Harmattan seasons). 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 (Nigerian Metrological Agency, 2007). The mean temperature of the study area is 27°C with daily minimum and maximum temperature ranges of about 22°C and 34°C respectively. It has a relative humidity of 80% at dawn (Source: Hydrometeorological department, Awka). 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. The towns, coordinates, elevation above mean sea level, geological Formations and soil type shown are below (Table1.1).

Geology of the Study Area

The study area is highly dominated by the Imo Shale and Ameki Formations. The Imo Shale Formation was deposited during Paleocene - late Eocene (Reyment, 1965) and it's of shallow marine environment (Nwajide, 1990). The Formation outcrops on the plane of the Mamu river which consists of thick clayey shales, fine textured, occasional clay ironstones sandstone beds in which carbonized plants remains may occur (Nwajide and Reijers, 1996; Kogbe, 1989). It has Ebenebe sandstone as its sand member in the study area while Ameki Formation and its lateral equivalent Nanka Sands (Okeke and Igboanua, 2003; Ezeigwe, 2005; Nwajide, 1992) were laid down in the early-middle Eocene (Reyment, 1965; Berggren, 1960; 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 2 and Figure 2).

Table 1: Towns/Locations, Geologic Formations and soil types of expansive soils used in the study.

S/N	Towns	Location Description	Location Coordinates		Elevation (m)	Geologic Formation	Soil Type
			Latitude	Longitude			
1	Nibo	Nibo-Umuawulu Road	6° 10'	7°04'	93	Ameki	Greyish green argillaceous clay
2	Akpugoeze	Amagu-Akpugoeze	6° 7'	7° 15'	134	Imo Shale	Greyish brown clay

Table 2: General Regional Stratigraphy of Southeastern Nigeria (Modified from Reyment, 1965; Offodile, 1975; Mode 2004)

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

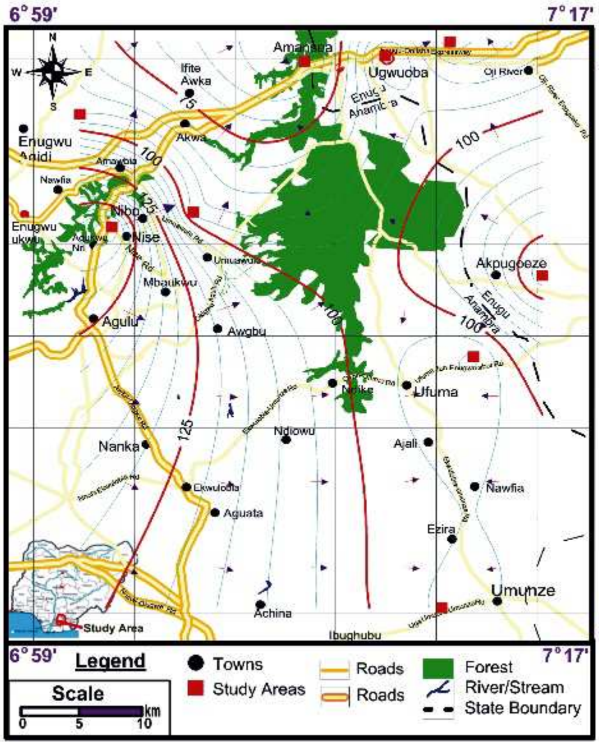


Fig. 2: Topographic/location Map of the Study Area (Digitized Google-earth Imagery, 2017)

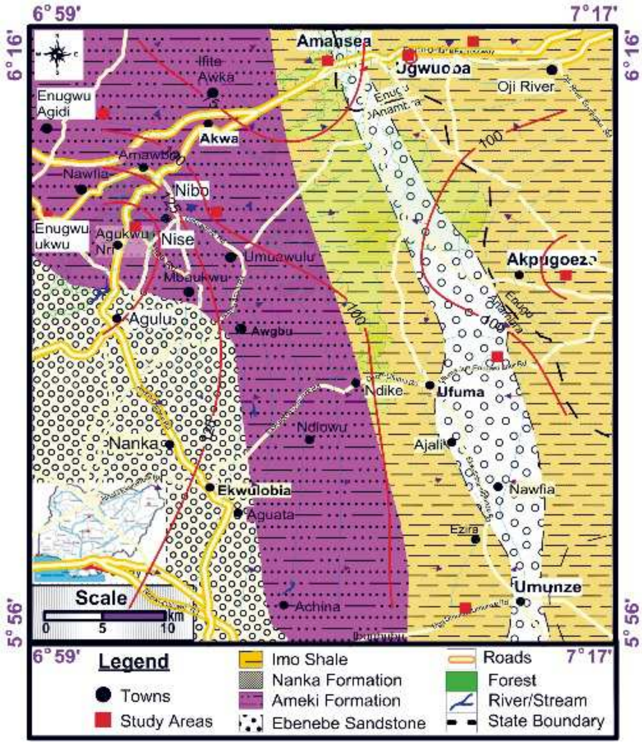


Fig. 3: Geologic Map of Awka and Environs (modified from Okeke and Igboanua, 2003)

Materials and Methods

The materials used for the purpose of this study are Portland cement, hydrated lime and expansive soils derived from Awka and environs, Southeastern Nigeria. The field studies were performed to identify the presence of expansive soils and their destructive effects on engineering structures like buildings, roads and drainage facilities in the study area. A total of two (2) expansive soil samples were collected from different locations of the study area with the aid of a geologic map, global positioning system (GPS), calibrated hand auger, polythene bag masking tape and ink maker. The sampling strictly followed standard procedure specified in British Standard Institution (BSI) 1377 (1990), US Bureau of Reclamation (USBR) (1963) and Spangler and Handy (1973). The samples were sent to the laboratory within 24 hours of collection for further analysis and the sampling was done between July, 2017 and January, 2018. The laboratory tests were conducted at the Arab Contractor Nigeria Ltd and FUTO Institute of Erosion Studies soil laboratory. The tests were performed in accordance to the specifications of Akroyd (1957) and BS 1377 (1990).

In both methods of cement and lime stabilization, different percentages of the additive (Cement and lime); 2, 4, 6, 8 and 10 were mixed with dry weight of the soil and cured for 7 days before applying some tests to evaluate the effectiveness of the stabilization.

The tests which include Atterberg limits, linear shrinkage, compaction and California Bearing Ratio(CBR) were performed on the natural soil as well on the soil mixed with the various percentages of cement and lime in accordance to the method described in Ingles and Metcalf (1972).

Results and Discussion

Results

The results of the index property parameters, strength characteristics and stabilization treatment of the expansive soils derived from Akpugoeze and Nibo are presented in tables below (Table 3-8) and their plot when stabilized with different proportion of cement and lime are also represented in figures below (Figure 3-16). The evaluation of effectiveness of treatment with cement and lime on the index properties and strength characteristics of the expansive soils derived from Akpugoeze and Nibo are shown below (Table 9-16).

Table 3: Result of the Geotechnical index properties of Expansive Soils derived from Nibo (Ameki Formation) and Akpugoeze (Imo Shale) in Awka and environs, Southeastern Nigeria

Parameter	Geologic Formations		
	Nibo (Ameki Formation)	Akpugoeze (Imo Shale)	
Liquid limit (%)	65.00	76.40	< or =35%
Plastic limit (%)	30.95	29.95	-
Plasticity index (%)	34.05	46.45	< or =12%
Linear Shrinkage (%)	20.00	17.90	< or =8
Natural moisture content (%)	30.60	28.80	-
Specific Gravity	2.62	2.71	0.94
Clay fraction (%)	32.42	24.29	
Activity of clay	0.98	1.55	-
Bulk Density (Mg/m^3)	1.14	1.05	-
Dry Density (Mg/m^3)	0.84	0.82	-
Free Swell (%)	58.00	63.00	<50%
% passing sieve 200	84.90	94.80	<or=35%
Gravel (%)	0.30	0.78	-
Sand (%)	41.70	39.30	-
Silt (%)	25.58	35.71	-
Clay (%)	32.42	24.29	-
USCS classification	CH soil	CH soil	-

Table 4: Result showing the strength characteristics of expansive soils derived from Ameki Formation (Nibo) and Imo Shale (Akpugoeze) in Awka and environs, Southeastern Nigeria.

Parameter	Geologic Formation		Federal Ministry of Works Standard (1997) (subgrades)
	Nibo (Ameki FM)	Akpugoeze (Imo Shale FM)	
MDD (Mg/m^3)	1.49	1.40	>1.76
OMC (%)	27.00	23.20	-
UnSoaked CBR (%)	17.30	10.20	>40
Soaked CBR (%)	2.40	3.30	>15

Discussion

When the soil sample derived from Akpugoeze and Nibo was treated with 8% cement, there were reductions in liquid limit (76.40-40.20%) plasticity index (46.45-9.20%), linear shrinkage (17.90-7.30%) and optimum moisture content (23.20-11.84%) while plastic limit (29.95-31.00%), maximum dry density (1.40-1.73Mg/m^3), unsoaked CBR (10.20-47.00%) and soaked CBR (3.30-31.00%) increased. Also when the same soil was treated with about 6% of lime, liquid limit (76.40-38.90%) plasticity index (46.45-7.65%), linear shrinkage (17.90-5.40%), maximum dry density (1.40-0.98Mg/m^3) and optimum moisture content (23.20-17.90%) while plastic limit (29.95-31.25%), unsoaked CBR (10.20-49.00%) and soaked CBR (3.30-38.10%) increased. Similarly, when the soil from Nibo was treated with 8% of cement, the liquid limit (65.00-41.30%) plasticity index (34.05-9.55%), linear shrinkage (12.00-7.20%) and optimum moisture content (27.05-10.85%) was reduced while plastic limit (30.95-32.25%), maximum dry density (1.49-1.72Mg/m^3), unsoaked CBR (17.04-32.10) and soaked CBR (2.41-27.11) increased. Also when the same soil was treated with about 6% of lime, liquid limit the liquid limit (65.00-39.80%) plasticity index (34.05-7.80%), linear shrinkage (12.00-5.60), optimum moisture content 27.05-18.23%) and maximum dry density (1.49-1.06Mg/m^3) was reduced while plastic limit (30.95-32.00%), unsoaked CBR (17.04-45.00%) and soaked CBR (2.41-27.11%) increased.

Clayey soils are mostly stiff when dry and give up the stiffness when saturated. Soil stabilization causes reduction in swelling potentials and degree of expansion of the soil material thereby improving the soil stiffness, permeability, strength and durability. The chemical reaction involved in soil stabilization with cement is hydration process. When the soil is mixed with cement and water, the calcium silicate and calcium aluminate

Table 5: Effects of cement stabilization on geotechnical properties of expansive soils derived from Imo Shale (Akpugoeze) in Awka and environs, Southeastern Nigeria

S/N	% Cement Added	Atterberg Limit			LS (%)	Compaction Tests		CBR Tests (%)	
		LL (%)	PL (%)	PI (%)		MDD (Mg/m^3)	OMC (%)	Unsoaked	Soaked
1	0	76.40	29.95	46.45	17.90	1.40	23.20	10.20	3.30
2	2	71.10	30.00	41.10	16.10	1.52	22.10	19.00	16.10
3	4	63.80	30.45	33.35	14.90	1.59	18.20	26.10	21.30
4	6	51.65	30.80	20.85	10.30	1.65	15.00	33.00	26.00
5	8	40.20	31.00	9.20	7.30	1.73	11.84	47.00	31.00
6	10	49.50	30.85	18.65	6.80	1.68	11.44	40.00	27.80

Table 6: Effects of lime stabilization on geotechnical properties of expansive soils derived from Imo Shale (Akpugoeze) in Awka and environs, Southeastern Nigeria.

S/N	% Lime Added	Atterberg Limit			LS (%)	Compaction Tests		CBR Tests (%)	
		LL (%)	PL (%)	PI (%)		MDD (Mg/m^3)	OMC (%)	Unsoaked	Soaked
1	0	76.40	29.95	46.45	17.90	1.40	23.20	10.20	3.30
2	2	67.10	30.10	37.00	13.70	1.30	22.80	19.90	18.00
3	4	54.70	30.90	23.80	9.50	1.10	20.10	36.30	26.40
4	6	38.90	31.25	7.65	5.40	0.98	17.90	49.00	38.10
5	8	46.10	30.60	15.50	4.10	1.08	16.35	46.30	34.20
6	10	53.90	30.15	23.75	3.80	1.20	16.00	45.65	29.78

Table 7: Effects of cement stabilization on geotechnical properties of expansive soils derived from Ameki Formation (Nibo) in Awka and environs, Southeastern Nigeria.

S/N	% Cement Added	Atterberg Limit			LS (%)	Compaction Test		CBR Test (%)	
		LL (%)	PL (%)	PI (%)		MDD (Mg/m^3)	OMC (%)	Unsoaked	Soaked
1	0	65.00	30.95	34.05	12.00	1.49	27.05	17.04	2.41
2	2	61.50	31.10	30.40	11.30	1.57	23.03	21.00	7.60
3	4	57.10	31.65	25.45	10.50	1.60	17.90	25.12	12.72
4	6	50.60	32.00	18.60	9.10	1.68	13.30	29.00	15.81
5	8	41.30	32.25	9.55	7.20	1.72	10.85	32.10	21.25
6	10	48.70	31.55	17.15	6.90	1.55	10.10	27.05	16.33

Table 8: Effects of lime stabilization on geotechnical properties of expansive soils derived from Ameki Formation (Nibo) in Awka and environs, Southeastern Nigeria.

S/N	% Lime Added	Atterberg Limit			LS (%)	Compaction Test		CBR Test (%)	
		LL (%)	PL (%)	PI (%)		MDD (Mg/m^3)	OMC (%)	Unsoaked	Soaked
1	0	65.00	30.95	34.05	12.00	1.49	27.05	17.04	2.41
2	2	59.80	31.40	28.40	10.30	1.35	25.51	23.00	17.00
3	4	48.30	31.75	16.55	6.90	1.25	21.80	31.03	24.34
4	6	39.80	32.00	7.80	5.60	1.06	18.23	45.00	27.11
5	8	43.70	31.70	11.40	4.50	1.15	17.80	41.23	22.80
6	10	50.80	31.10	19.70	3.95	1.30	16.00	37.08	19.00

Table 9: Evaluation of effectiveness of treatment with cement on geotechnical properties of expansive soils derived from Imo Shale (Akpugoeze) in Awka and environs, Southeastern Nigeria

% Cement Added	LL (%)	% Reduction	PI (%)	% Reduction	LS (%)	% Reduction
0	76.40	-	46.45	-	17.90	-
2	71.10	6.96	41.10	11.52	16.10	10.06
4	63.80	16.49	33.35	28.20	14.90	16.76
6	51.65	32.40	20.85	55.11	10.30	42.46
8	40.20	47.38	9.20	80.19	7.30	59.22
10	49.50	35.21	18.65	59.85	5.80	67.60

present in portland will react with the compounds in the soil cement (hydration processes) to form a cementious compound of calcium-silicate-hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) similar to that of lime releasing enough calcium hydroxides (CaOH) (Prusinski and Bhattacharja,1999; Rajasekaran, 2005). This hydration process causes a decrease in swelling tendency and increase the strength of the material. The chemical reaction involved in soil stabilization with lime is cation exchange reaction and it involved two main stages; flocculation/agglomeration and pozzolanic reaction. The flocculation/agglomeration stage starts immediately when the lime is added to the soil with sufficient water and the process results in

Table 10: Evaluation of effectiveness of treatment with lime on geotechnical properties of expansive soils derived from Imo Shale (Akpugoeze) in Awka and environs, Southeastern Nigeria

% Lime Added	LL (%)	% Reduction	PI (%)	% Reduction	LS (%)	% Reduction
0	76.40	-	46.45	-	17.90	-
2	67.10	12.17	37.00	20.34	13.70	23.46
4	54.70	28.40	23.80	48.76	9.50	46.93
6	38.90	49.08	7.65	83.53	5.40	69.83
8	46.10	39.66	15.50	66.63	4.10	77.09
10	53.90	29.45	23.75	48.87	3.80	78.77

Table 11: Evaluation of effectiveness of treatment with cement on CBR and MDD of expansive soils derived from Imo Shale (Akpugoeze) in Awka and environs, Southeastern Nigeria

% Cement Added	CBR (%)				Compaction Tests	
	Soaked		Unsoaked			
	CBR (%)	% Increase	CBR (%)	% Increase	MDD (Mg/m^3)	% Increase
0	3.30	-	10.20	-	1.40	-
2	16.10	387.88	19.00	86.27	1.52	8.57
4	21.30	545.46	26.10	155.88	1.59	13.57
6	26.00	687.89	33.00	223.53	1.65	17.87
8	31.00	839.39	47.00	360.78	1.73	23.57
10	27.80	742.42	40.00	292.16	1.68	20.00

Table 12: Evaluation of effectiveness of treatment with lime on CBR and MDD of expansive soils derived from Imo Shale (Akpugoeze) in Awka and environs, Southeastern Nigeria

% Lime Added	CBR test				Compaction Test	
	Soaked		Unsoaked			
	CBR (%)	% Increase	CBR (%)	% Increase	MDD (Mg/m^3)	% Reduction
0	3.30	-	10.20	-	1.40	-
2	18.00	445.45	19.90	95.10	1.30	7.14
4	26.40	700.00	36.30	255.88	1.10	2.42
6	38.10	1054.54	49.00	380.39	0.98	30.00
8	34.20	936.36	46.30	353.92	1.08	22.86
10	29.78	802.42	45.65	347.55	1.20	14.29

Table 13: Evaluation of effectiveness of treatment with cement on geotechnical properties of expansive soils derived from Ameki Formation (Nibo) in Awka and environs, Southeastern Nigeria

% Cement Added	LL (%)	% Reduction	PI (%)	% Reduction	LS (%)	% Reduction
0	65.00	-	34.05	-	12.00	-
2	61.50	5.38	30.40	10.72	11.30	5.83
4	57.10	12.15	25.45	25.26	10.50	12.50
6	50.60	22.15	18.60	45.37	9.10	24.17
8	41.30	35.69	9.55	71.95	7.20	40.00
10	48.70	25.08	17.15	49.63	4.10	65.83

Table 14: Evaluation of effectiveness of treatment with lime on geotechnical properties of expansive soils derived from Ameki Formation (Nibo) in Awka and environs, Southeastern Nigeria

% Lime Added	LL (%)	% Reduction	PI (%)	% Reduction	LS (%)	% Reduction
0	65.00	-	34.05	-	12.00	-
2	59.80	8.00	28.40	16.59	10.30	14.17
4	48.30	25.69	16.55	51.39	6.90	42.50
6	39.80	38.77	7.80	77.09	5.60	53.33
8	43.70	33.69	11.40	66.52	3.50	70.83
10	50.80	30.30	19.70	42.14	2.30	80.83

Table 15: Evaluation of effectiveness of treatment with cement on CBR and MDD of expansive soils derived from Ameki Formation (Nibo) in Awka and environs, Southeastern Nigeria

% Cement Added	CBR test (%)				Compaction test	
	Soaked		Unsoaked			
	CBR (%)	% Increase	CBR (%)	% Increase	MDD (Mg/m^3)	% Increase
0	2.41	-	17.04	-	1.49	-
2	7.60	215.35	21.00	23.24	1.35	9.40
4	12.72	427.80	25.12	45.31	1.25	16.11
6	15.81	556.02	29.00	70.19	1.06	28.86
8	21.25	781.74	32.10	88.38	1.15	22.82
10	16.33	577.59	27.05	58.74	1.30	12.75

Table 16: Evaluation of effectiveness of treatment with lime on CBR and MDD of expansive soils derived from Ameki Formation (Nibo) in Awka and environs, Southeastern Nigeria

% Lime Added	CBR test (%)				Compaction test	
	Soaked		Unsoaked			
	CBR (%)	% Increase	CBR (%)	% Increase	MDD (Mg/m^3)	% Reduction
0	2.41	-	17.04	-	1.49	-
2	17.00	605.39	23.00	34.98	1.35	9.40
4	24.34	909.99	31.03	82.10	1.25	16.11
6	27.11	1024.90	48.00	181.69	1.06	28.86
8	22.80	846.06	41.23	141.96	1.15	22.82
10	19.00	688.38	37.08	117.61	1.30	9.40

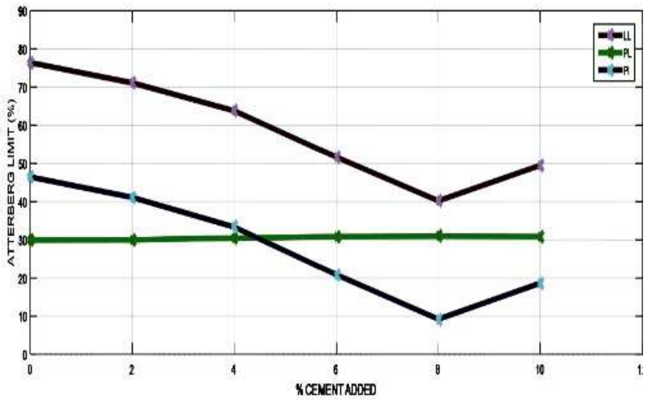


Fig. 4: variation of liquid limit (LL), plastic limit (PL) and plasticity index (PI) of expansive soils derived from Imo Shale with different percentages of cement

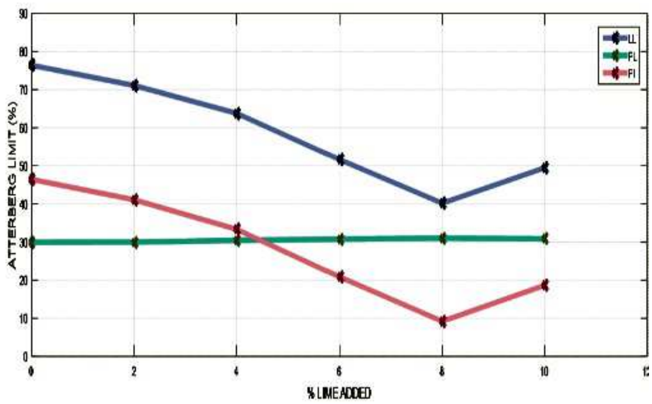


Fig. 4: variation of liquid limit (LL), plastic limit (PL) and plasticity index (PI) of expansive soils derived from Imo Shale with different percentages of cement

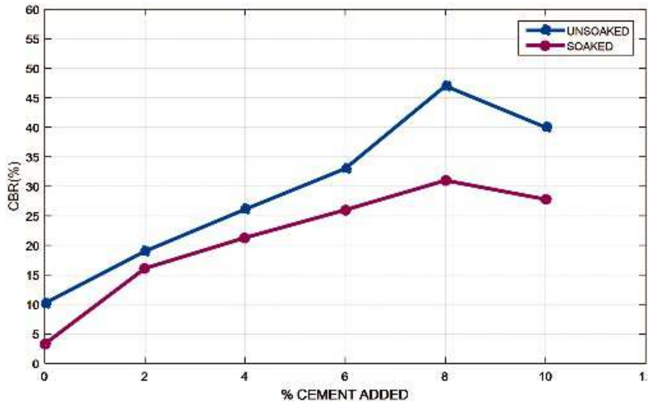


Fig. 6: Variation of soaked and unsoaked CBR test of expansive soil derived from Imo Shale with different percentages of cement

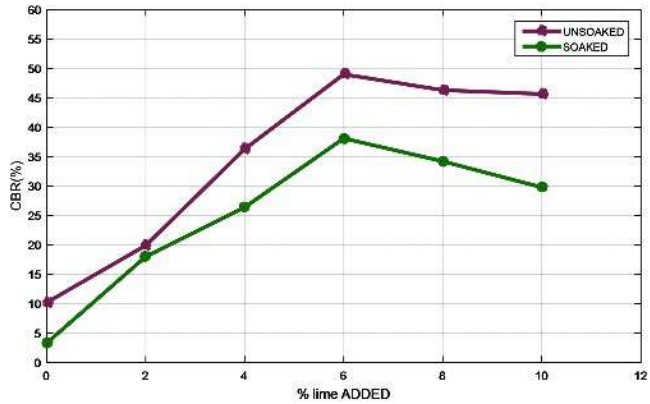


Fig. 7: Variation of soaked and unsoaked CBR test of expansive soil derived from Imo Shale with different percentages of lime

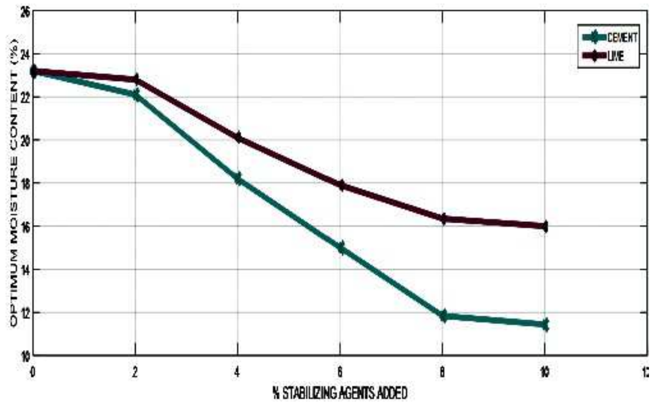


Fig. 8: Variation of optimum moisture content (OMC) of expansive soil derived from Imo Shale with different percentages of cement and lime

cation exchange which increase the plastic limit and reduction in liquid limit and plasticity index. When lime dissolved in water, the calcium ion present in the soil exchange with sodium and other cations (clay mineral) in the soil to increases the ionic concentration of the pore water thereby forming aggregates which result in the increase of the grained size of the soil. The pozzolanic process in lime stabilization sets in after flocculation/agglomeration process when there is sufficient lime and water content. When lime reacts with

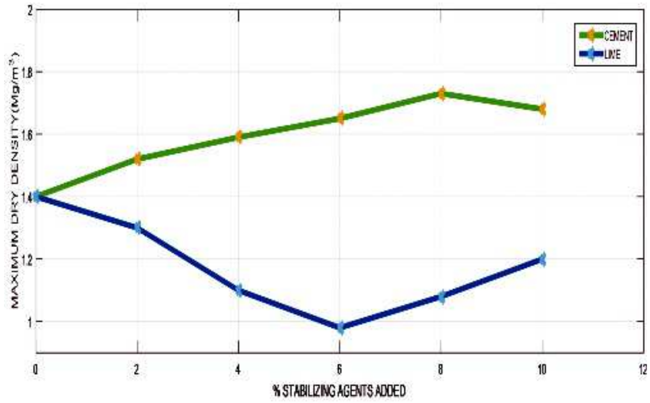


Fig. 9: Variation of maximum dry density (MDD) of expansive soil derived from Imo Shale with different percentages of cement and limeVariation of maximum dry density (MDD) of expansive soil derived from Imo Shale with different percentages of cement and lime.

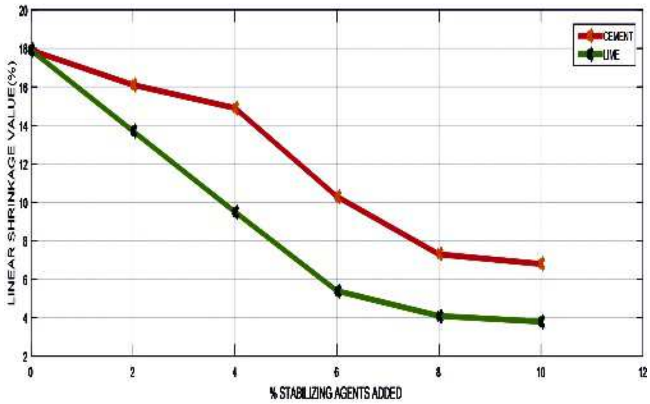


Fig. 10: Variation of linear shrinkage (LS) of expansive soil derived from Imo Shale with different percentages of cement and lime.

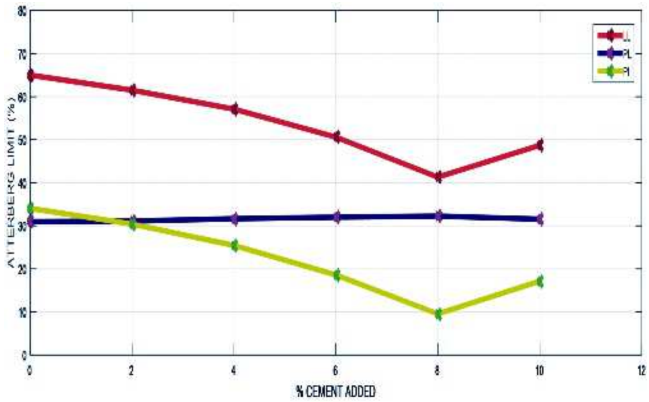


Fig. 11: Variation of liquid limit (LL), plastic limit (PL) and plasticity index (PI) of expansive soil derived from Ameki Formation with different percentages of cement

the wet clay mineral in the soil, it increases the pH of the soil due to the increased concentration of the hydroxyl ions which favours solubility of the siliceous and aluminous compounds in the soil. These compounds will then react with the calcium in the lime to form calcium silicate hydrate(C-S-H) which gels the clay particles together to strengthen the soil.

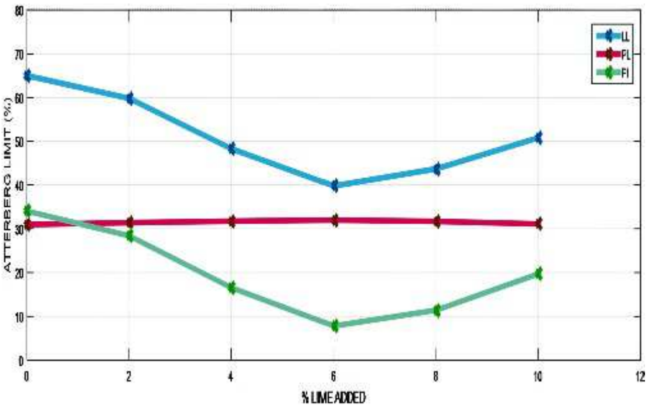


Fig. 12: Variation of liquid limit (LL), plastic limit (PL) and plasticity index (PI) of expansive soil derived from Ameki Formation with different percentages of lime.

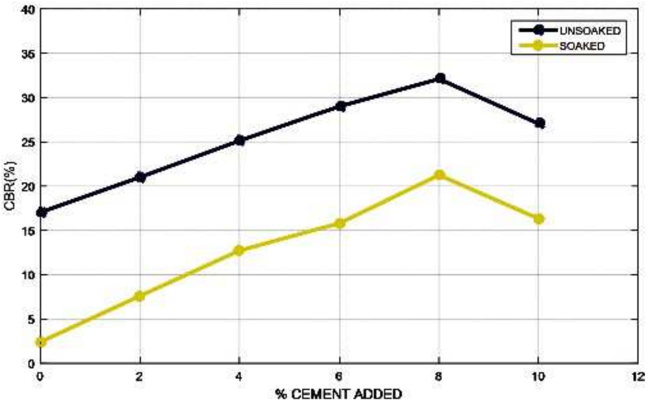


Fig. 13: Variation of soaked and unsoaked CBR test of expansive soil derived from Ameki Formation with different percentages of cement.

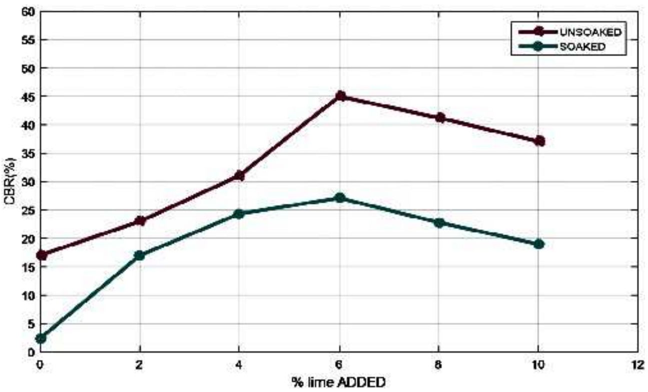


Fig. 14: Variation of soaked and unsoaked CBR test of expansive soil derived from Nibo (Ameki Formation) with different percentages of lime.

The equations below illustrate the reactions (Sowers, 1979);

Reactions involving lime ($Ca(OH)_2$) and soil (Base exchange and pozzolanic reactions) (Lee, 1996).

$$\underset{\text{Lime}}{Ca(OH)_2} + \underset{\text{Silica}}{SiO_2} \rightarrow \underset{\text{Calcium silicate (gel)}}{CaSiO_3} + \underset{\text{water}}{H_2O} \text{ .... (1)}$$

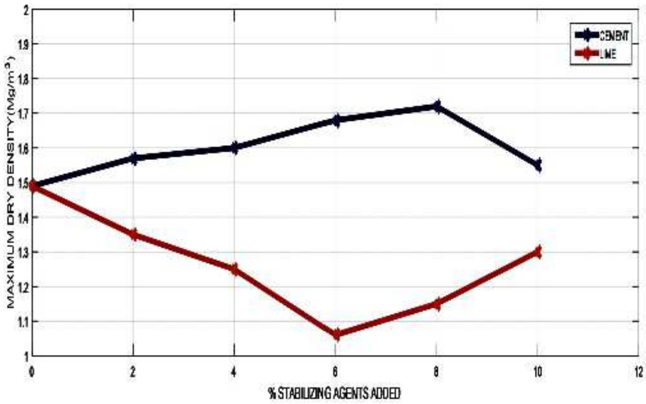


Fig. 15: Variation of maximum dry density (MDD) of expansive soil derived from Nibo (Ameki Formation) with different percentages of cement and lime.

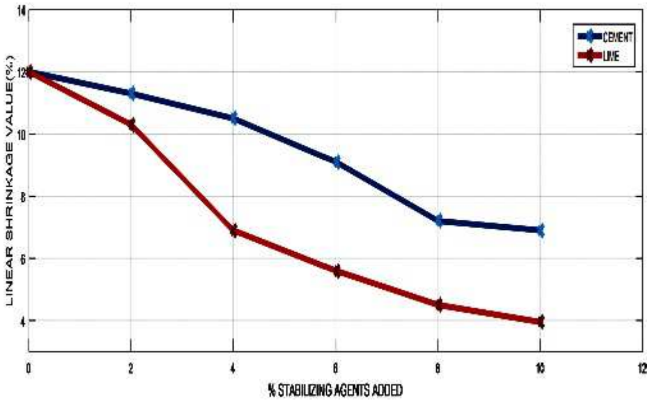


Fig. 16: Variation of linear shrinkage (LS) of expansive soil derived from Ameki Formation with different percentages of cement and lime.

$$\underset{\text{Lime}}{2Ca(OH)_2} + \underset{\text{alumina}}{Al_2O_3} + \underset{\text{water}}{3H_2O} \rightarrow \underset{\text{Calcium aluminate (insoluble)}}{2CaAl(OH)_5} \text{ …............(2)}$$

$$\underset{\text{Lime}}{CaAl(OH)_5} + \underset{\text{water}}{H_2O} \rightarrow \underset{\text{aluminum hydroxide (insoluble)}}{Al(OH)_3} + \underset{\text{lime}}{Ca(OH)_2} \text{ ....(3)}$$

Reactions involving cement (Tricalcium silicate, C_3S and Dicalcium silicate, C_2S; active ingredients in cement and soil (Hydration) (Gupta and Gupta, 2004).

C_3S and Dicalcium Silica C_2S, acting ingredients in J, cement and soil (Hydracous) (Gupta and Gupta, 2004).

$$2C_3S + 6H^{-1} \rightarrow \underset{\text{Tricalcium silicate (gel)}}{C_3S_2H_3} + \underset{\text{lime}}{3Ca(OH)_2} \text{ ....(4)}$$

$$2C_2S + 4H- \rightarrow \underset{\text{Tricalcium silicate (gel)}}{C_3S_2H_3} + \underset{\text{lime}}{Ca\,(OH)_2} \text{ ....(5)}$$

Note that lime ($Ca(OH)_2$) is released in both reactions and the final product is $C_3S_2H_3$ release of lime also ensures associated weak base exchange reaction.

Hydration of cement/concrete may be defined as the reaction taking place in water and cement paste by virtue of which the Portland cement becomes a bonding agent (precipitation products of hydration).

The use of lime and cement in soil stabilization has been considered an effective way of improving the workability, load-bearing characteristics, stability and impermeability of the soil. But application of cement in soil stabilization had been proven more economical and effective in both granular and fine grained soils and aggregates than soils with high plastic materials due to the cementitious materials and calcium hydroxide(lime) formed during the stabilization process (Little et al., 2016). Extensively, expansive soils stabilized with cement tend to gain more strength in faster pace than those stabilized with lime due to the hydration process involved while lime stabilization is most suitable in clays, silty clay, and clayey gravels because lime reacts faster to the swelling potentials of a soil than cement.

Compaction test was performed on the studied soils to evaluate the compaction characteristics of the soils with change in moisture content. The compaction of soil is the optimal moisture content at which a given soil becomes most dense and achieves its maximum dry density in other to reduce the air voids. When mechanical energy induced to the soil mass during compaction test, the air voids between the soil particles tends to decrease due to the applies force which increase the density and frictional force of the soil particles. Once the optimum moisture content is achieved, any further addition of water(moisture) will cause reduction in the dry unit weight because the pore water pressure will be pushing the soil particles apart, decreasing the friction between the particles. California bearing ratio test (penetration test) was performed to the studied soils to evaluate the strength of the soils to be used as a subgrade in roads and pavement construction. This test measures the resistance of the material to penetration of a standard plunger under controlled density and moisture conditions. This test is mostly used to determine the thickness of pavement and component layers usually used in flexible pavement designs.

Generally, the result of the studied proved that when the soils were treated with up to 8% cement and 6% lime, it drastically reduces the swelling potential, degree of expansion and increases the strength characteristics of the soils. It was also observed that the maximum dry density (MDD) reduced and at a point increases when treating the soils with lime but cement stabilization increases the maximum dry density (MDD). Other geotechnical properties of the soils like optimum moisture content (OMC), liquid limit (LL), plasticity index (PI), linear shrinkage (LS) reduced when both additives (cement and lime) were used causing reduction in the swelling potential, degree of expansion and permeability of the soil, thus increases the strength and durability of the soils to be used as subgrade and foundation soils in engineering constructions. The liquid limit and plasticity index at 8% cement and 6% lime additives in Imo Shale and Ameki Formation shows that the soils have low swelling potential (Holtz and Gibbs, 1956; Ola, 1981) while the linear shrinkage of both geologic Formations at 8% of cement and 6% of lime additives indicates non-critical degree of expansion (Attimeyer, 1956) and this causes the strength characteristics of the studied soils (MDD and CBR values) to improved.

The maximum stabilization points were achieved at 8% and 6% cement lime additives respectively. Any further addition of the additives will not have effects on the geotechnical properties of the soil because the soils have reached its saturation point (fixation point).

The resilient factors in soil stabilization depend primarily on soil type, additives used, mode of mixing, temperature, soil mineralogy and curing time. The presence of organic matter and other compounds like sulphur (gypsum) in an expansive soil can affect the stabilization process. When expansive soils containing sulphur (gypsum) is stabilized with lime/cement, the calcium in the lime/cement will react with these compound which increases the soil volume (swell) thereby reducing the strength characteristics of the soil.

Conclusion

Expansive soils derived from different geologic formations in Awka area were investigated in terms of their stabilization with lime and cement. The result of the shows that when the studied expansive soil samples were stabilized with different percentages of cement or lime, there is a reduction in swelling potential (Atterberg limit), degree of expansion (linear shrinkage), optimum moisture content (OMC) and increase in the strength characteristics (MDD and CBR). The processes involved in the treatment include hydration, cation exchange, flocculation agglomeration of soil particles and pozzolanic reactions to form calcium silicate hydrate (C-S-H).

Factors affecting soil treatment include type of additive, curing time, temperature and soil mineralogy.

Advantages of soil treatment include soil strength gain, reduction in plasticity (increased workability), reduction in liquid limit and increase in soil durability. Carbonation, sulphate attack and environmental impact are some of the disadvantages associated with treating soil with a calcium based additive.

The use of hydrated lime alone is suitable to stabilize the swelling soil which has high liquid limit and high plasticity index while stabilization with cement is suitable for stabilizing fine grained swelling soils which contained low amount of clay particle and higher amount of silt.

The effects of lime and cement on the stabilization of the expansive soils in the area have been successfully compared. The result proved that lime stabilization perform better than cement stabilization in both Formations. Though, cement stabilization is more economical than lime stabilization because cement is generally cheaper than lime.

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Pictorial view of the new NMGS House under construction at Abuja.