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Effects of Cement Stabilization on Geotechnical Properties of Lateritic Soil of Ihube-Okigwe, Southeastern Nigeria

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Abstract The effects of cement stabilization on the Geotechnical properties of lateritic soil in Ihube Okigwe was undertaken to improve its strength and durability on construction. Laboratory tests carried out included Particle size distribution, Atterberg limits, specific gravity, linear shrinkage, Compaction and California Bearing ratio (CBR) and their behavior in terms of changes in engineering properties on treatment with various percentages (5, 10, 15, 20) of cement. Results of the study show that the soil is well graded (7% silt and clay, 85% sand 8% gravel and would therefore be described as well graded sand Unified Soil Classification Symbol SP). There were marked reductions on atterberg limits at 2% cement applications (26.3% to 23%, 18.2% to 8% on liquid limit and plastic limit with a reduction percentage of 13% and 26% respectively. At 15% cement application, the optimum moisture content reduced from 11.5% to 8.7%, MDD increased from 2.00 mg/m^3 to 2.06 mg/m^3, the CBR of the unsoaked soil increased from 64% to 100%. The CBR of soaked lateritic soil improved from 8% to38% with addition of 20% cement content. The cement stabilization on Geotechnical properties of the Ihube lateritic soil is expected to cushion problems of roads and pavement construction occasioned by cycles of wetting and drying.

Keywords Lateritic soil, cement improvement, California Bearing ratio

1. Introduction

Lateritic soil is a major construction material in Ihube and other parts of Nigeria owing to its natural abundance and affordability which has created conditions that make the use of such soils with low load carrying capacity imperative.

With growing concern on infrastructural development, road construction and housing deficit, and the quest to cussion these setbacks, this soil has played major roles to meet different construction needs. However, it often lacks the engineering properties needed for sufficient structural integrity [1]. A more issue of concern is that, these soils are not properly investigated to ascertain their suitability as good construction materials based on applicable industrial standards and regulations, the effect has led to several damages to civil engineering structures thus encouraging setbacks on development with its attendant effects on the economy.

In view of the above, there is therefore a need to carry out a thorough geotechnical assessment of lateritic soil in the study area to ascertain their strength and durability as construction materials, and to expose their failure characteristics.

Lateritic soils are highly weathered tropical or sub-tropical residual soils with varying proportions of particle sizes ranging from clay size to gravel, usually coated with sesquioxide rich concretions. They form under conditions of high temperature and high rainfall where the decomposition process results in a soil leached of (SiO_2) and calcium carbonate but retaining high concentrations of iron and aluminum sesquioxides (Fe_2O_3,Al_2O_3) [2]. The relative concentration of the geochemically less mobile elements-Al, Si, and Fe-simultaneous with the removal of relatively mobile, easily leached alkalis-Na, K, Ca are conditions that precede

Laterization [3]. Most tropical soils are in varying stages of laterization, which is to say that at various stages of accumulating insoluble compounds, the soluble elements are leached out [4]. We can deduce that lateritic soils derive their strength from the presence of high concentrations of sesquioxides especially the iron oxide (Fe_2O_3) and also good representation of grain size fractions. The higher their iron oxide content, the better their performance in pavements [5]. A major view held by Bell, 2017 [6] and various researchers revealed that Lateritic soils generally occur below a hardened ferruginous crust or hardpan, where hardening is as a result of exposure to air or may be due to a change in the hydration of iron and aluminium oxides.

Geographically, lateritic soils occur in most of the sedimentary basins in Nigeria, and are mainly used as sug-grade, sub-base construction materials in road construction and foundation fills.

Lateritic soils behave in a unique way with some changing volume when exposed to humidity variations while others are not affected. Hence, some components are referred to as stable when it has all soil fractions represented i.e. gravel, sand, silt and clay and referred to as unstable when preoccupied by a ratio of silt and clay more than gravel and sand. Stability in this sense is based on their ability to withstand variations in terms of moisture without a significant change in its properties, which is of course fundamental in materials for building construction. Their geotechnical behaviour is controlled by mineralogical composition, micro-fabric and environmental conditions.

Until recently, problem soils were excavated from building sites and replaced with better ones. This method increased prohibitive costs (haulage from problem site and transportation to dumping site) which forced builders to neglect the consequences of using such soils on civil engineering works.

Therefore, mechanical or chemical stabilization of superior materials is needed to improve such properties. These materials are more affordable and do not require long procedures to apply. Cementitious binders, such as cement, fly ash, or lime, are frequently used to fulfill this need. The benefits derived from Cementitious stabilization according to [7] are significant improvements on strength, stiffness, durability, permeability, and stability of host materials which allows them to support the load from the structure above them compared to untreated soils. Such stabilized materials can be used in many engineering practices, such as dams, buildings, airports, parking lots, and pavements.

Earlier works on the use of cement to stabilize the geotechnical properties of problem soils include those of [8-11]. Mixing Portland cement with problem soils have widely been used, and has resulted in a product which effectively serves as a sub-base, base or even surface course construction material [12].

This study summarizes the effects of cement stabilization on geotechnical properties of lateritic soil of Ihube, okigwe, south eastern Nigeria. It evaluates the Geotechnical characterization and the effects of cement on stabilization of lateritic soil with a view to improving its strength characteristics. There is the expectation that the results from this research will lend understanding to possible causes of failed engineering structures and proffer advise to avoid failure of structures, and to avert imminent loss to life and properties.

2. Description of the Study Area

2.1. Location, Climate and Physiography

The study area is Ihube, Okigwe. It is located in Imo State, Southeastern Nigeria, and located on latitudes 5°53'46"N and longitudes $7^0$23'44" E (Fig.1) and with an altitude of about 298m high above mean sea level and a low of about 30m above mean sea level.

The study area lies within the tropical rainforest of Nigeria. Rainfall distribution is bimodal with a mean annual rain fall of between 1875mm to over 2560mm. Temperature ranges from 28 ^{o}C to 32 ^{o}C with an average speed of 10km/h. These seasonal changes in temperature, humidity, rainfall and pore pressure are the most favourable conditions for laterization. The drainage pattern is dentritic and the streams are perennial.

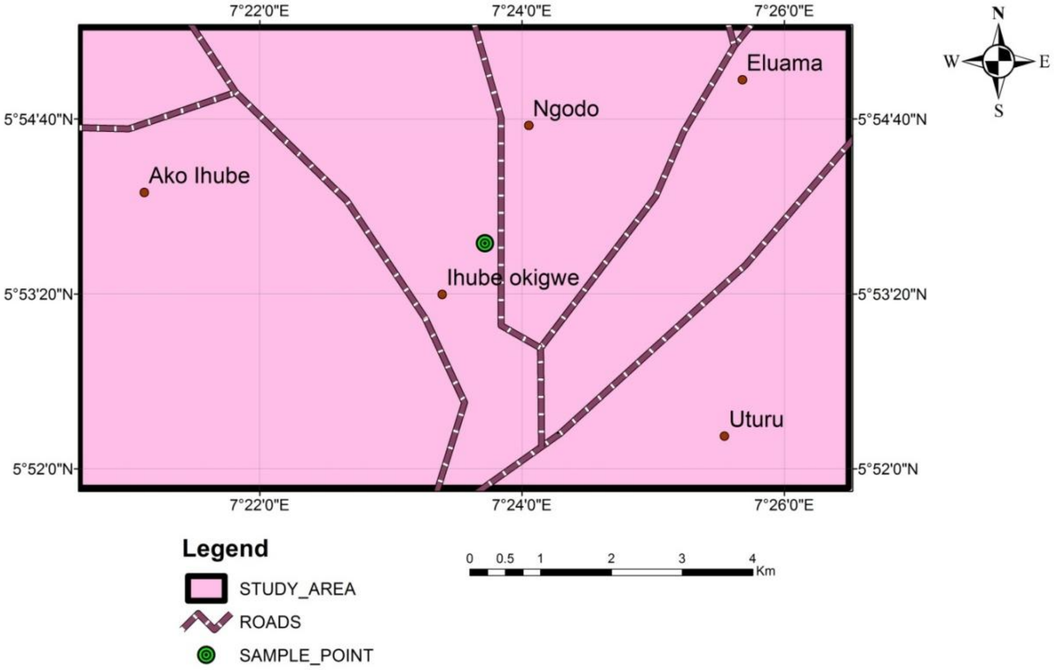

Figure 1: Location map of the study area

2.2. Geology of the Study Area

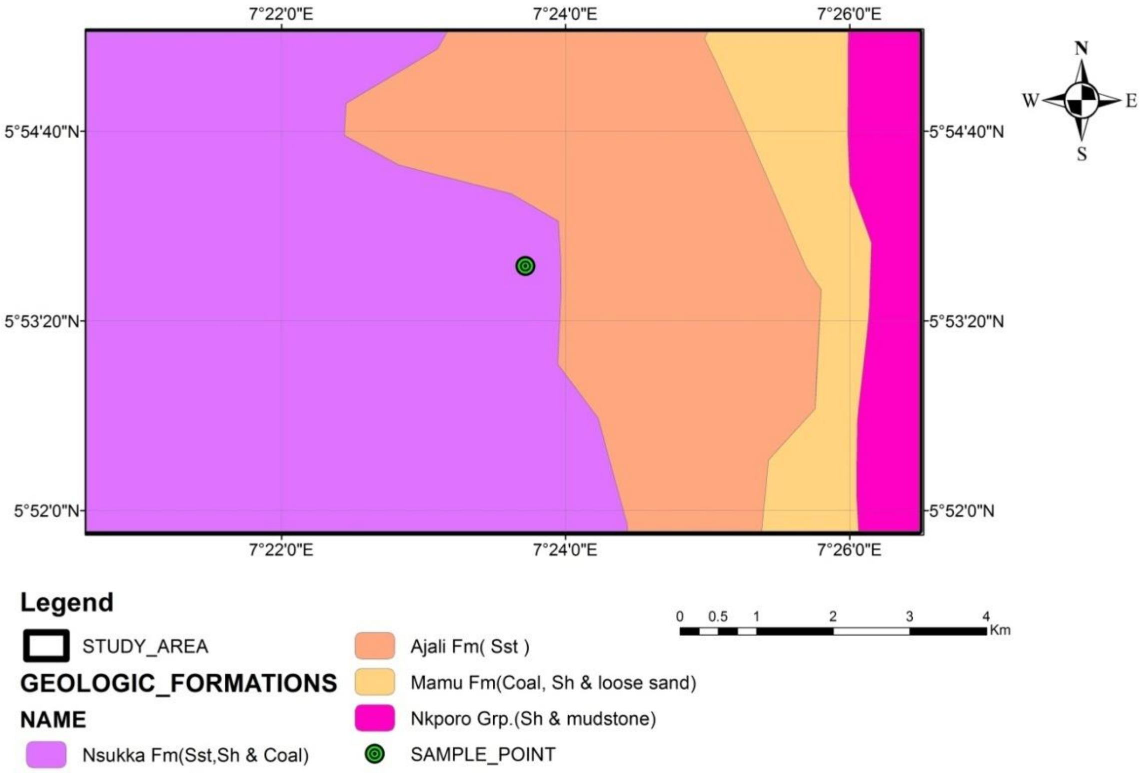

Figure 2: Geological map of the study area adapted from Babatunde, 2010

The study area is part of the Anambra basin and is one of the major sedimentary basins in Nigeria. The Anambra basin is located in the southeastern part of Nigeria and is bounded to the North by Bida basin, to the east by Benue trough, to the west by West African massif, and to the south by Niger delta. The Anambra basin is generally characterized by two sedimentary facies according to [13]. The first cycle occurred in the Cretaceous (Campanian-Maastrichtian) and the second cycle occurred in the younger ages (Paleocene –Late Miocene). The regressive phase saw the deposition of the oldest sediment in the basin called the Nkpro group [5]. It was deposited in the late Campanian, comprising Nkporo Shale, Owelli Sandstone and Enugu Shale [13]. Its lithofacies form low-lying topographic forms, and are of shallow water origin with thin sandstones, shales and impersistent coals.

The Ajali Sandstone overlies the Nsukka Formation (Fig. 2.) and consists of cross-bedded sandstone, poorly cemented; with lenses of mudstone and siltstone in some places which are about 400 m thick. The coal bearing Mamu Formation and the Ajali Sandstone accumulated during this epoch of overall regression of the Nkporo cycle The Ajali sandstone is overlain by the diachronous Nsukka Formation(Maastrichtian-Danian) which is also known as the Upper Coal Measure [14].

The dominant sandstone unit is the Ajali from where laterites were collected. They are residual fragments from pre-existing rocks like basalt and are mined in large quantity and used for construction in the study area.

3. Materials and Methods

3.1. Field work and Sampling Procedure

Detailed site investigation and mapping was carried out at Ihube, along Okigwe-Enugu road to access ground conditions and the general geology of the study area prior to sampling. Fresh disturbed representative soil samples were collected from an exposure within the study area with a hand held auger at a depth of 0.3 to 1m; it was air-tightly bagged to retain the natural moisture content of the soil. Samples were labeled and taken to the laboratory to analyze the geotechnical and engineering properties to ensure safe use of the material

3.2. Laboratory Analysis

3.2.1 Geotechnical Analysis.

Geotechnical analyses were carried out on lateritic soil samples such as Particle size distribution, Atterberg limits, linear shrinkage, dry density, moisture content, specific gravity, and Strength Tests such as Compaction and CBR (soaked and unsoaked). The samples were analysed at Arab Contractor's Soil Laboratory, Alakwo, Owerri, Imo State

Particle size distribution tests were performed on soil samples in line with procedures outlined for coarse grained soils. 200g of soil sample was dried in an oven to avoid lumps of particles and also to expel moisture content, clumps were broken to loosen soil grains to prevent clogging. The sample was passed through a stack of sieves of progressively mesh size (opening) of between (0.075-4.76mm) corresponding to sieve no 200- 4 by shaking.

Larger particles were caught on the upper sieves, while the smaller particles filtered through to be caught on one of the smaller underlying sieves. The weight of the material retained on each sieve would be converted to a percentage of the total sample.

In the liquid limit test, the specimen (200g of soil) was thoroughly dried in an oven at a temperature of about 70 ^{o}C, clumps were loosened to prevent clogging on sieve, care was exercised to ensure that the natural size of the individual grains did not reduce. The sample was passed through a sieve size 425-µm (No.40) U.S size [15] to remove any material retained on it. A portion of the specimen was spread in a brass cup, divided into two by a grooving tool, and then allowed to flow together from the shocks, caused by repeatedly dropping the cup in a standard mechanical device. The test was carried out four times at blows numbers 13, 19, 28 and 39 over a range of moisture contents.

In the Plastic limit test, specimen that passed a U.S. sieve 425 µm (No.40) was used. The plastic limit was determined by alternately pressing together and rolling into a 3mm (1/8-in) diameter thread of the specimen until its water content was reduced to a point at which the thread crumbled and could no longer be pressed together and re-rolled. The water content of the soil at this point was recorded as the plastic limit.

The Plasticity index is the numerical difference between the liquid limit and the plastic limit (PI= LL-PL).

For linear shrinkage, a sample of 200g of the material passing the No 40 U.S. sieve (425µm) was prepared according to the Liquid limit procedure for disturbed soil samples. Sample was placed in the mixing bowl and thoroughly mixed with deionised water using the spatula, until the mass became a thick homogeneous paste. Sufficient water was added to bring it to a consistency equal to or slightly wetter than the liquid limit. The wet soil was placed in a greased clean shrinkage mould; care was taken to thoroughly remove all air bubbles from each layer by lightly tapping the base of the mould. The mould was slightly overfilled and then the excess material was leveled off with the spatula. Soil that adhered to the rim of the mould was removed and specimen allowed to dry at room temperature for about 24 hours until a distinct change in colour was noticed. Specimen was transferred into an oven and dried at between 105 °C and 110 °C for 1 hour. The result was presented as a percentage of its original length. Mathematically;

LS = Length of oven dried specimen/Length of initial specimen x 100 %(i.e. LF/L Ix1000)

The oven drying method is used to determine the Moisture content of the sample. A clean container with the lid (if fitted) is taken and the mass in grams is recorded (m_1) together with container number. The container plus lid or bottle plus stopper should have the same number and be used together. The sample of wet soil is crumbled and placed in the container. The container with the lid on is weighed in grams (m_2). The lid was removed and both lid and container are placed in the oven. The sample was then dried in a thermostatically controlled drying oven which is maintained at a temperature of 105±5 0C. A period of 16 to 24 hours is was sufficient, The soil is considered dry when the differences in successive weighings of the cooled soil at 4 hour intervals do not exceed 0.1% of the original mass.) The container is removed from the oven. For fine-grained soils, the container and lid, or bottle and stopper if used, should preferably be placed in a dessicator and allowed to cool. After cooling, the lids or stoppers should be replaced and the container plus dry soil weighed in grams (m_3).

Moisture content, w = mass of moisture mass of dry soil x 100% = (mass of container + wet soil) - (mass of container + dry soil)/ (mass of container + dry soil) - (mass of container) x 100%

i.e $W=m_2-m_3/m_3.m_1x100$

Compaction test was carried out according to the standard procedure provided by [16] for proctor compaction. The soil was air dried, passed through a sieve size of 425µm and then compacted in a mould of volume 944cm^3 with a diameter of 101.6mm. The mould was attached to a base plate at the bottom and to an extension at the top. The soil was compacted with energy of 600KN in three equal layers by a 2.5 kg hammer of falling height or drop of 30.5mm, which delivered 25 blows to each layer. . Before placing each new layer, the surface of the previous layers is scratched in order to ensure a uniform distribution of the compaction effects. A smooth curve is plotted for the dry unit weight (or density) as a function of the water content. From this curve, the optimum water content (OMC) to reach the maximum dry density (MDD) could be

California Bearing Ratio

CBR test may be conducted in remoulded or undisturbed sample. Test consists of causing a cylindrical plunger of 50mm diameter to penetrate a pavement component material at 1.25mm/minute. The loads for 2.5mm and 5mm are recorded. This load is expressed as a percentage of standard load value at a respective deformation level to obtain CBR value [17].

4. Results and Discussion

4.1. Geotechnical Results

Geotechnical results communicate site specific conditions and properties of soils which assist in classification and description for construction purposes, and to avert human and material losses.

A summary of the geotechnical properties of Ihube lateritic soil is presented on Table 1. A graphical representation of geotechnical tests is also shown in Figure 1.

The particle size distribution curve is shown in fig. 1 and shows that the lateritic soil has 7% silt and clay,85% sand 8% gravel and would therefore be described as well graded sand (Unified Soil Classification Symbol SP). The high amount of coarse soils is expected to increase its strength [6] especially with a modifier like Portland cement when used as sub grade material in road and pavement construction. Therefore the Ihube laterite falls within the Statutory Regulatory limits for subgrade materials (<35% passing sieve No 200(75µm) for pavement and highway construction).

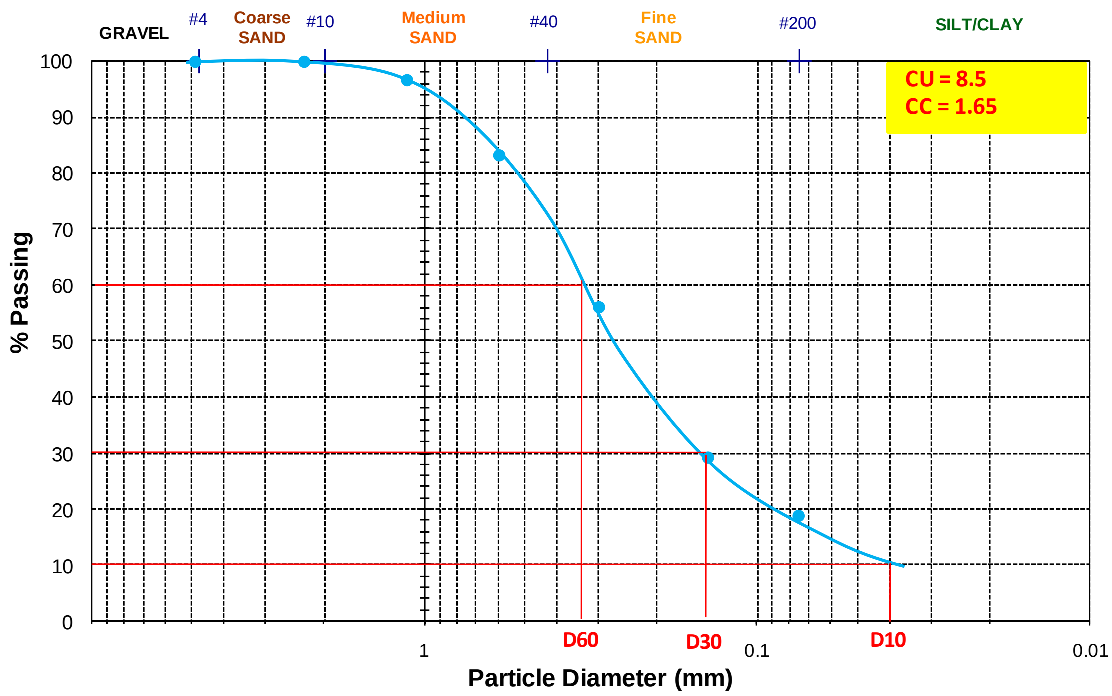

Figure 1: Particle size distribution curve

Table 1: Summary of results of geotechnical properties of lateritic soil samples under investigation

S/N	Parameter tested	Test result	Specification required limit for subgrade material [18]	Specification required limit for sub-base material [18]
1	Sieve analysis (% passing 200)	19.8%	< or = 35%	≤35%
2	Liquid limit %	26.3%	< or = 50%	≤35%
	Plastic limit %	18.2%	< or = 50%	-------------
	Plasticity index %	8.1%	< or 30%	< or 12%
3	Optimum water content (OMC) %	11.50%	------------	-------------
	Maximum Dry Density (MDD) mg/m^3	2.00 mg/m^3	------------	-------------
4	California Bearing Ratio (CBR)	7.8%	15%	> 80%
5	Linear Shrinkage %	6.4%	<8%	< 6%
6	Specific gravity	2.255 g/cm^3	------------	------------
7	Coefficient of Uniformity	8.5		
8	Coeeficient of Curvature	1.65	1-3 for gravel and sand	1-3 for gravel and sand

The value of Coefficient of Uniformity CU is 8.5 while Coefficient of Curvature CC is 1.65. According to [20], a well-graded soil has a uniformity coefficient greater than about 4 for gravels and 6 for sands, and a Coefficient of Curvature between 1 and 3 for gravels and sands. Therefore, the results from the calculation shows that the soil is well graded.

Results from Specific gravity (2.255 g/cm^3) and Atterberg limits (PL 18.2%, LL 26.3%, PI 8.1% and Linear shrinkage of 6.4) are satisfactory and meet the requirements for subgrade material and sub-base materials used in construction, this is because of the low amount of fines (clay and silt) contained in the soil; an indication of low swelling potential and presence of low expansive clay. However, the linear shrinkage does not meet the

Statutory Requirement for sub-base material and hence the need for modification. Linear shrinkage can manifests as cracks on soil especially when moisture is lost.

4.2. Stabilization Results

Generally, Lateritic soils can successfully serve when protected from percolating or migrating water and the effects of heavy repetitive loadings. In this research, soil-cement stabilization was employed with a view to altering one or more properties of the lateritic soil so as to improve its engineering performance and/or to reduce its sensitivity to moisture changes. A ratio of 2-8% by weight of Portland cement was used to improve the limits of the soil as shown on figure 2. The maximum reduction was obtained at 2% which signifies a reduction from 26.3% of liquid limit to 23% and 18.2% of plastic limit to 8% as seen in figure 3, a reduction percentage of 13% and 56% respectively. This is in perfect agreement with Murthy [21] that cement requirement for soil improvement is controlled by the gradation of the earth materials under study. He stated that a well graded lateritic soil will require 5% or less cement by weight to achieve best results, again, well graded soil with plasticity index of less than 20% are most suitable for this method of stabilization [22]. With improvement on the atterberg limits of the lateritic soil, the cement hydrates, the mixture becomes a hard, durable structural material which does not soften when exposed to wetting and drying, or freezing and thawing cycles.

The optimum moisture content relationship with cement is shown on figure 5, the results show that between 0 to 15% cement application, the Optimum moisture content reduced from 11.5% to 8.7%.This reduction to the sensitivity of soil moisture by cement may be attributed to the chemical reactions of cement (cementing action) with the coarse fraction in the presence of water.

The relationship between the maximum dry density (MDD) and cement contents is shown in figure 5.MDD increased from 2.00 mg/m^3 to 2.06 mg/m^3. The increase in MDD was minimal, this may be because of the coarse soil type, which does not require much additive to gain cohesion. Unlike finer soils, well-graded soils with less than 50% of particles finer than 75µm are most suitable for the soil-cement method of stabilization and perform better with the normal range of cement content of 5 to 15% by weight of the dry soil.

Table 2: Summary of soil atterberg limits improvement with 2%, 4%, 6%, 8% cement

Percentage of cement added	Atterberg limits		
	Liquid limit	**Plastic limit**	**Plasticity Index**
0%	26.3	18.2	8.1
2%	23.3	17.3	6.5
4%	21.8	15.8	5.9
6%	18.0	15.4	2.6
8%	24.2	18.2	6.0

Table 3: Summary of MDD and OMC before and after stabilization

Cement (%)	OMC%	MDD mg/m^3
0	11.5	2
5	10.9	2.04
10	10.2	2.05
15	8.7	2.06
20	9.6	2.01

Table 4: Summary of CBR before and after stabilization

Percentage (Cement) %	CBR	
	Soaked	**Unsoaked**
0	8	64
5	18	77
10	28	92
15	38	101
20	38	95

The relationship between California Bearing Ratio and cement content is shown in figure 6. The result shows that between 0% to 15% cement addition, the CBR of unsoaked lateritic soil increased from 64% to 100% and reduced to 94% with subsequent increase in cement content to 20%. The increase may be as a result of the chemical reactions of cement with the silicious soil in the presence of water which is responsible for the cementing action. Also, good mixing of cement with soil and adequate compaction may have improved the stress-strain properties. On the other hand the /reduction may be as a result of the resistance of the soil to penetration under controlled density and moisture conditions by the cement reaction.

The result for soaked lateritic soil showed an increase in CBR of soaked lateritic soil from 8% to38% with addition of 0% to 20% cement content. The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. Under wet conditions, there may be a reduction in internal friction and cohesion if the soil is not stabilized. The value of 8% to 38% is close to the borderline value of > than 5 to > 30 for subgrade and subbase materials requirements. The Ihube lateritic soil may not perform well under cycles of wetting and drying and thus will require adequate stabilization to deal with roads and pavements during the rains.

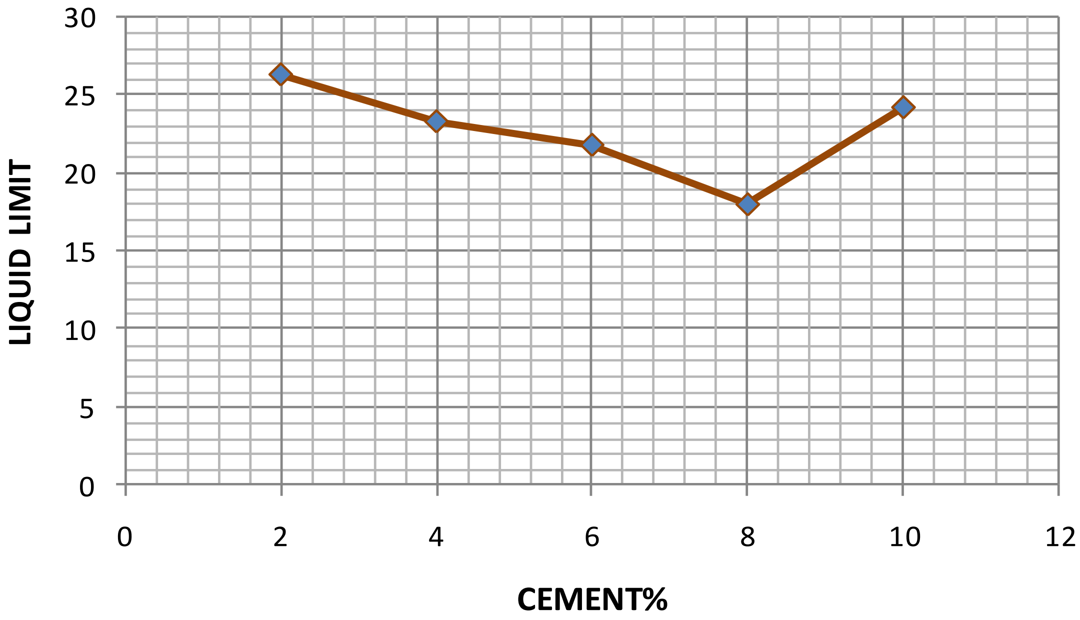

Figure 2: Plot of Liquid limit against cement

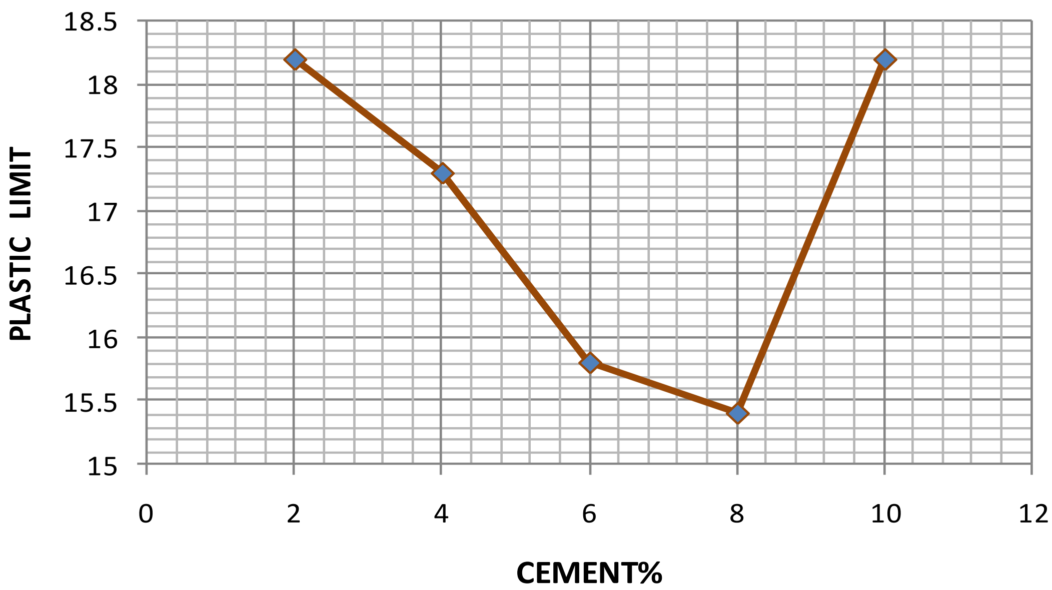

Figure 3: Plot of Plastic limit against cement

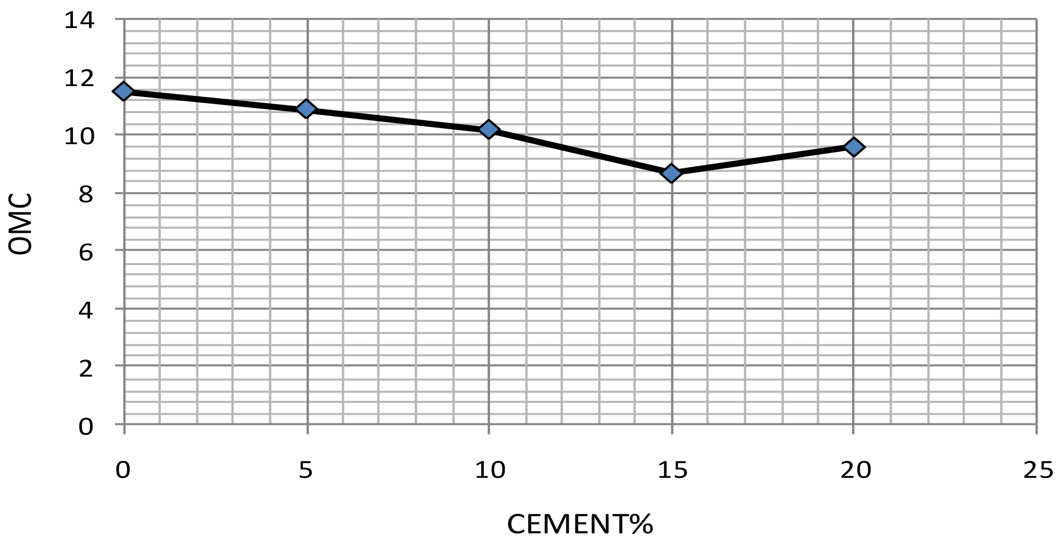

Figure 4: Plot of cement % on liquid and plastic limit

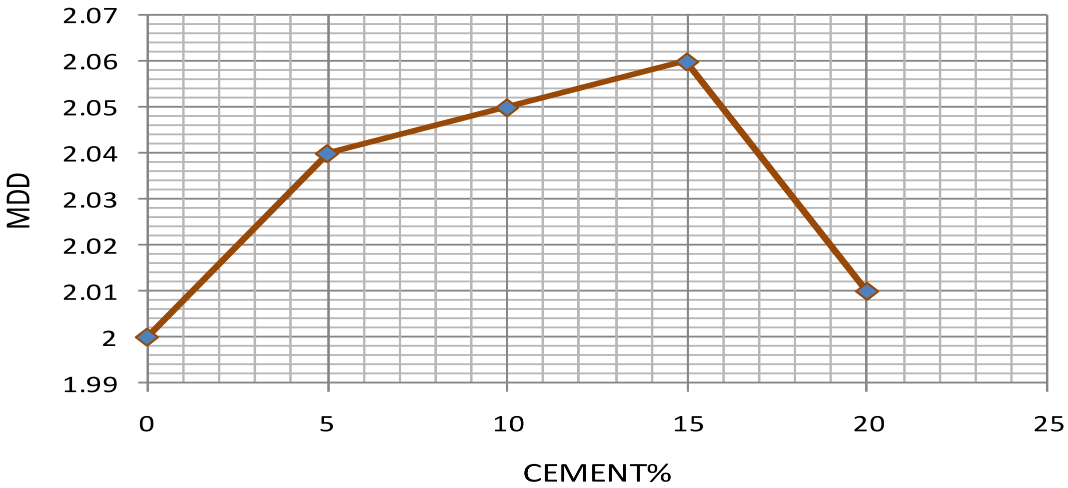

Figure 5: Plot of cement against OMC and MDD

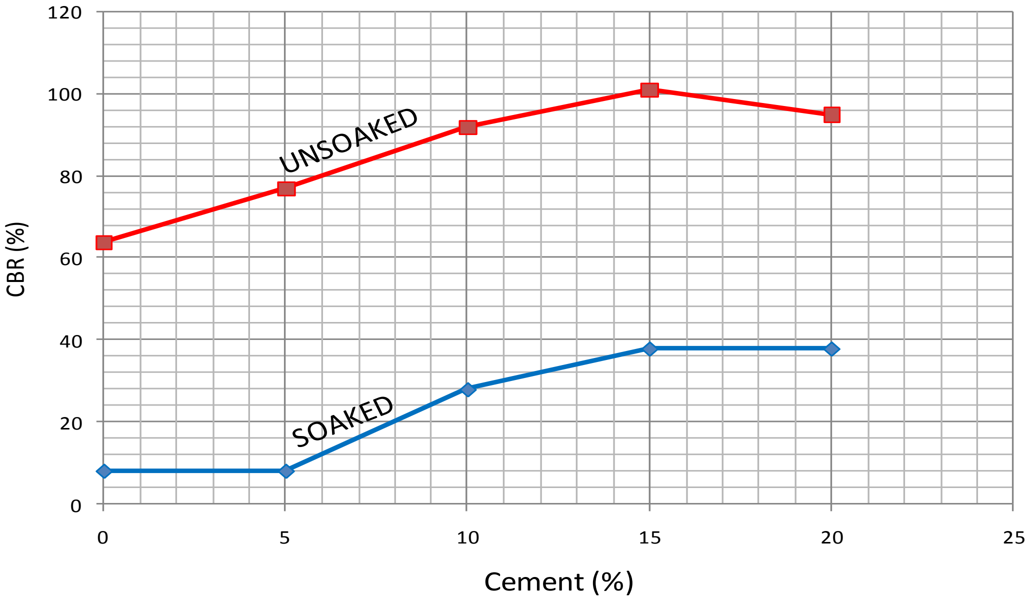

Figure 6: Plot of CBR against cement for soaked and unsoaked

5. Conclusions

The following conclusions can be made from the study:

1. Stabilization of lateritic soil from Ihube Okigwe reduced the Index properties (liquid and plastic limits) of the soil and increased the strength properties (CBR and MDD).
2. Cement stabilization Results of the study show that the soil is well graded (7% silt and clay,85% sand 8% gravel and would therefore be described as well graded sand Unified Soil Classification Symbol SP).
3. There were marked reductions on atterberg limits at 2% cement applications (26.3% to 23%, 18.2% to 8%) on liquid limit and plastic limit with a reduction percentage of 13% and 26% respectively.
4. At 15% cement application, the optimum moisture content reduced from 11.5% to 8.7% , MDD increased from 2.00 mg/m^3 to 2.06 mg/m^3, the CBR of the unsoaked soil increased from 64% to 100%.
5. The CBR of soaked lateritic soil improved from 8% to38% with addition of 20% cement content

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