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Geotechnical Properties of Lateritic Soils from Northern Zone of Anambra State, Nigeria

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Abstract: - This investigation was carried out to determine the geotechnical properties of lateritic soils used for road construction in Obosi, Umunya, Awkuzu, and Igbariam towns, all in Northern Zone of Anambra state of Nigeria. Tests were carried out on the soil samples which include the Atterberg limit tests, particle size distribution analysis, specific gravity, compaction test using the British Standard Light (BSL), Compactive effort and California Bearing Ratio (CBR) test as specified by the West African Standard (WAS). The liquid limits, plastic limits and plasticity indices guided in the classification of the soil samples as A-2-4 soil of American Association of State Highways and Transportation Officials (AASHTO) classification and SC group of Unified Soil Classification System (USCS). The compaction characteristics of the soil were found to be **1931KN/m^3**, **2003.8KN/m^3**, **1965KN/m^3** and **1923KN/m^3** for maximum dry density and **10.8%, 9.4%**, **10.4%** and **12.20%** for optimum moisture content for samples 1, 2, 3 and 4 respectively. The California bearing ratio (CBR) results for the samples for 24 hours soaking are **48%**, **58%**, **45%**, and **52%** for sample 1, 2, 3, and 4 respectively. It was concluded that the four lateritic soil samples were suitable for sub-grade and sub-base but should not be used in road construction as a base material.

Keywords:- California Bearing Ratio, Compaction, Geotechnical properties, Lateritic soil

I. INTRODUCTION

Lateritic soils are generally found in warm, humid, tropical areas of the world. The geotechnical properties of these soils are quite different from those soils developed in temperate or cold regions of the world. The properties of lateritic soils are influenced by climate, geology and the degree of weathering or laterization. It has been found that the geotechnical properties of these soils in different tropical countries are also different. Lateritic soils formed on the same parent rock in the same tropical country, but under different climatic conditions have different geotechnical properties.

In this tropical part of the world, lateritic soils are used as a road making material and they form the sub-grade of most tropical road. They are used as sub base and bases for low cost roads and these carry low to medium traffic.

Since the discovery of lateritic soils by Francis Buchanan-Hamilton, (1807) in Malabar, India laterite has been defined and described by a number of researchers in several different ways. Ola, (1978) used local terminology in defining lateritic soils as all products of tropical weathering with reddish, brown colour, with or without nodules or concretion, but not exclusively found below hardened ferruginous crust of hardpan. Osula, (1984) defined laterite as a highly weathered tropical soil rich in secondary oxides of combination of iron, aluminium and manganese. Laterite (also known as “red soils”) is used to cover all tropically weathered soils that have been involved in the accumulation of oxides of iron, aluminium or silica. In other words, a red soil is a highly weathered material rich in secondary oxides of iron, aluminium, or both. Alexander and Candy, (1962) explained that laterites are nearly devoid of bases and primary silicate, but may contain large amount of quartz and kaolite. It is either hard or capable of hardening on exposure to wetting and drying. With the progress in chemical analysis, more and more samples were analysed and this showed the typical increase of iron and frequently of aluminium and decrease of silica in relation to the underlying parent rock. Therefore attempts were made to define laterites by the ratio Si: (Al + Fe) but a definite limit was not applicable for laterites on different parent rocks (Gidigasu, 1976). Laterites vary significantly according to their location, climate and depth. The main host minerals for nickel and cobalt can be iron oxides, clay minerals or manganese oxides. Iron oxides are derived from mafic igneous rocks and other iron-rich rocks; bauxites are derived from granitic igneous rock and other iron-poor rocks. Nickel laterites occur in zones of the earth which experienced prolonged tropical weathering of ultramafic rocks containing the ferro-magnesian minerals olivine, pyroxene, and amphibole (Alao, 1983). Many existing laterites are clearly relics of geologic antiquity. Van der Voort, (1950) expresses the opinion that true lateritic soils only occur on old geological formations and were probably formed under paleo-climatic conditions. Lacroix, (1913) in his studies on laterites from West Africa recognized hydrargillite (considered to be identical with gibbsite), limonite, kaolinite, halloysite and hydrated titanic acid as some important minerals in laterites.

Pedologically, soil is the result of geochemical cyclic processes operating at the crust of the belt of weathering modified by the combined effect of climate, biosphere, parent material, topography and time. The genesis of laterite, since not completely understood even today has given rise to various theories and postulates. Lake, (1890) summarized the earliest ideas on laterite formation and suggested three different hypotheses as follows; (1)Laterite is a residual alteration product, (2)Laterite is a detrital and sedimentary product, (3) Laterite is of volcanic origin. D'hoore (1954) grouped these theories into two: (1) Concentration of sesquioxides by removal of silica and bases i.e. relative accumulation and (2) Concentration of sesquoxides by accumulation either across the profile or between profiles i.e. absolute accumulation. There is no specific basis for assuming that laterisation can occur due to a single process, although certain fundamental conditions are pre-requisite to the chemical and mineralogical alterations that occur, these may be satisfied by a variety of local conditions of weathering reactions, water relationships and other factors.

Before 1920, attention was focused largely on the pavement surface, and little notice was given to the sub-grade and base materials or to the manner in which they were placed or compacted. Later, increased vehicle speeds brought demands for higher design that resulted in deeper cuts and higher fills (Oglesby and Hicks, 1992). In many instances, subsidence or even total failure of the roadway resulted. Study of these failures indicated that faults lay in the sub-grade and not the pavement. This led to investigation of the properties of sub-grade materials, not leaving the sub-base and base course materials aside. The samples for this study were picked from popular borrow sites within the Anambra North senatorial zone and the findings are supposed to serve as guides to construction industries who source their lateritic materials from those areas.

II. MATERIALS AND METHODS

Four lateritic soil samples designated as Sample-1, Sample-2, Sample -3, and Sample-4, respectively were obtained from borrow pits in Obosi, Awkuzu, Igbariam, and Umunya, respectively, all located at Anambra North Zone of Anambra State, Nigeria as indicated in the Map shown in Appendix A. These soils belong to the group of ferriginous tropical soils derived from acid igneous and metamorphic rocks (Osinubi, 1998). The reddish-brown coloured lateritic soils used in this study are low-plasticity clays according to the Unified Soil Classification System, USCS (ASTM D 2487).

The natural moisture content was determined by the oven drying method. Specific gravity of soils, particle size distribution, plasticity characteristics were determined in accordance with procedures outlined in BS 1377 (1990). Hydrometer method was used to obtain values of the clay-size (% < 0.002mm) fraction of the soil particles. The British Standard Light Compaction (BSL) method was used. The BSL compaction procedure is described in clause 3.3 of Part 4, BS 1377 (1990). The BSL is equivalent to the reduced Proctor effort in Benson and Trast (1995). Figure 1; shows the different compaction test equipment. The California Bearing Ratios (CBR) tests for the samples were carried out after 24 hours of soaking.

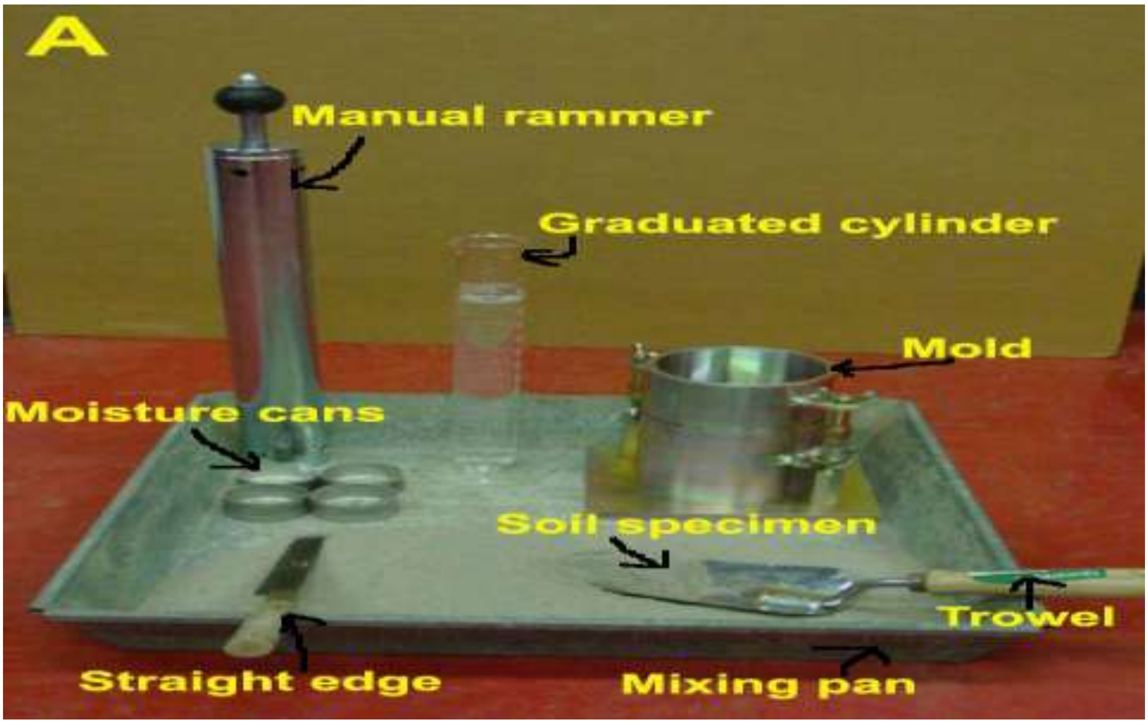

Figure 1: - Compaction test equipment.

III. RESULTS AND DISCUSSION

3.1. Properties of the Lateritic Soils

Table 1: - Index Properties of the Lateritic soils

Property	**Sample Designation**			
	Sample 1	Sample 2	Sample 3	Sample 4
Specific gravity	2.65	2.6	2.62	2.7
% gravel (>4.76mm)	0	0	0	0
% sand (<4.76mm to 0.075mm)	97.91	97.98	98.45	99.07
% fines (<0.075mm)	2.09	2.02	1.55	0.93
Cu	2	2.72	2.38	3
Cc	1.02	1.47	1.10	1.12
Liquid limit (%)	42	40.41	33.42	28.93
Plastic limit, %	23.7	23.39	25.46	21.79
Plasticity Index, %	18.30	17.02	7.96	7.14
Colour	Reddish brown	Reddish brown	Reddish brown	Reddish brown
AASHTO Classification	A-2-4	A-2-4	A-2-4	A-2-4
USCS Classification	SC	SC	SC	SC

Table 1 above displays the index properties of the four soil samples tested. The table shows that the lateritic soils have similar index properties, with samples 1 and 2 being more closely identical. The graphs of the particle size distribution, which was carried out in accordance to BS1377 (Part2; 1990), as can be seen from figure 2 is a clear picture of the similarity in the grading of the soils. This also brought about their similar classification as A-2-4 and SC in the AASHTO and USCS classifications, respectively.

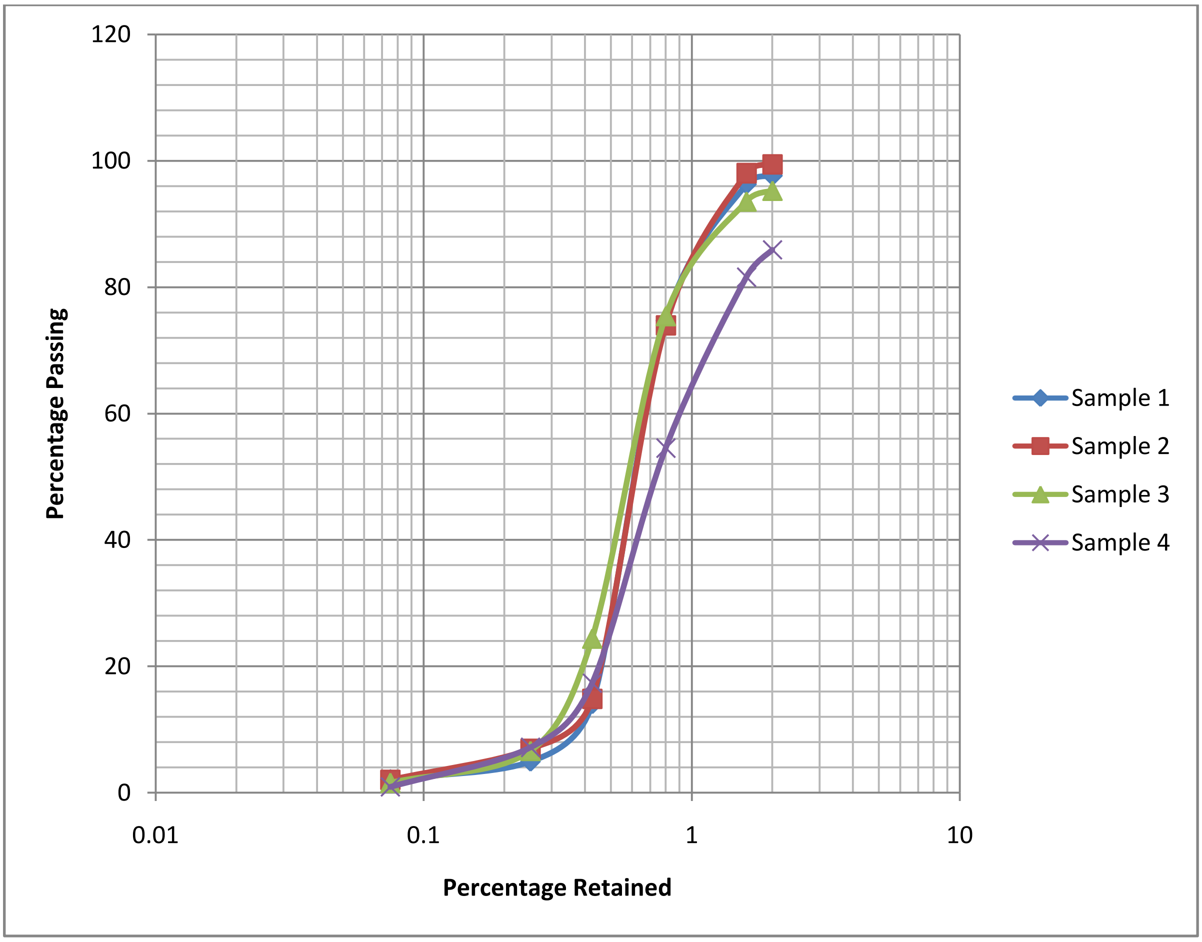

Figure 2:- Particle Size Distribution of the Different Lateritic Soils

3.2. Effect of Grading on Plasticity

It was observed from the outcome of the particle size distribution and the Atterberg's limits that a relationship exists between the grading of the lateritic soils and their consistency limits. A critical look at the table 1 shows that sample 1 has the lowest quantity of sand and consequently, the highest quantity of fines. The quantities of fines observed are 2.09%, 2.02%, 1.55%, and 0.93% for the samples 1, 2, 3, and 4 respectively. This suggests that the sample 1 is the finest while sample 4 seems to be the coarsest. The table 1 also shows that the liquid limit decreased in like manner from 42% to 28.93%. This shows that the higher the quantity of fine in a lateritic sample, the greater the liquid limit. Sample 1, also has the highest plasticity index. The plasticity indices of the four samples obviously decreased with decrease in the quantity of fines. In other words, the more the presence of fines in a lateritic soil, the higher the plasticity of the soil and obviously the less the permeability of the soil. This agrees with the findings of Siswosoebrotho et al, (2005) and Augusta (2000). Yoder and Witczak (1975) also support this fact, adding that as the permeability decreases, the density also increases. This can be pictured in the graphs of figure 3.

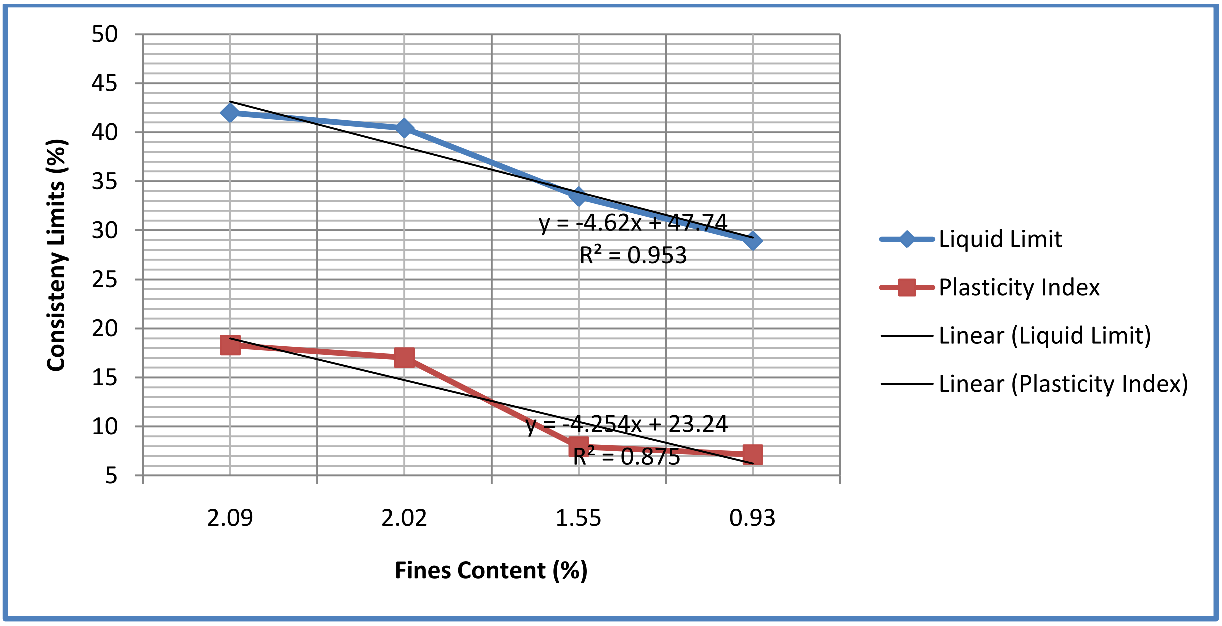

Figure 3- Decrease in Liquid Limits and Plasticity Indices with Increase in Fines Content.

3.3. Compaction of the Soils

The maximum dry densities of the soil samples at their optimum moisture contents were determined using the British Standard Light compaction method. Figure 4 shows the compaction curves for the soil samples tested. From the curves, it was observed that the maximum dry densities of the samples 1, 2, 3, and 4 are 1931KN/m^3, 2003.8 KN/m^3, 1965 KN/m^3, and 1923 KN/m^3 respectively. Their optimum moisture contents are 10.8%, 9.4%, 10.4%, and 12.2% respectively. From the result shown, sample 2 has the best compaction quality being that it achieved the highest maximum dry unit weight at the same compaction effort. The least, of course is sample 4. From the curves, it was observed, as well, that the optimum moisture contents decreased with increase in dry densities. This agrees with Proctor (1933), Venkatramaiah (2006), Rowe (2000) and other concluded research works. It is actually an already existing fact.

3.4. California Bearing Ratio (CBR)

The California bearing ratio (CBR) test results for the samples after 24 hours soaking are 48%, 58%, 45%, and 52% for sample 1, 2, 3, and 4 respectively. Since the four samples have CBR less than 80%, they are not suitable for use as road base materials. Besides, all the samples have CBR values above 30%, and have, consequently, been judged to be suitable as sub-grade and sub-base materials.

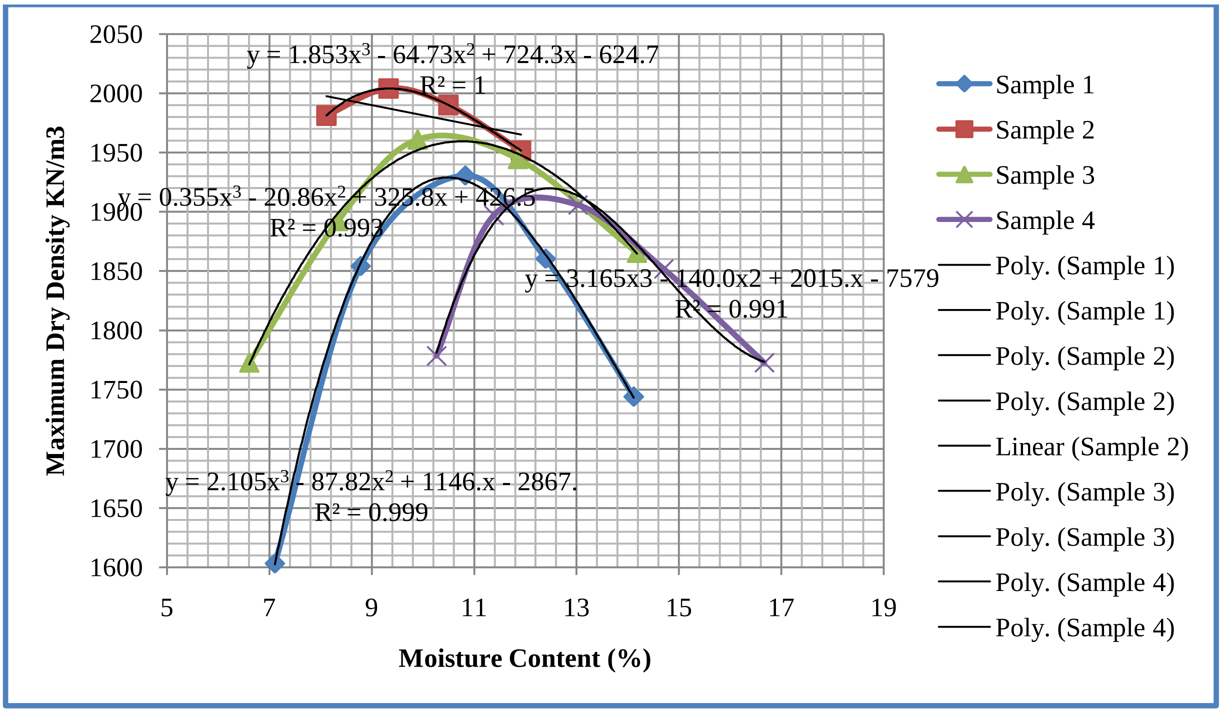

Figure 4: - Compaction Curves for the Soil Samples tested.

3.5. Compaction Characteristics and California Bearing Ratio

Table 2 is the summary of the maximum dry density, optimum moisture content, and California bearing ratio values for the four samples. Actually there is an observed inconsistency in the relationship between the compaction parameters and CBR of the lateritic soils. But a linear plot of CBR against MDD and OMC as shown in figures 5 and 6 shows that CBR increases with increase in MDD and decreases with OMC. This result agrees with Siswosoebrotho *et al*, (2005).

Table 2: - Relationship between Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and California Bearing Ratio (CBR)

Soil sample	MDD (KN/m^3)	OMC	CBR Values
Sample 1	1931.0	10.8%	48 %
Sample 2	2003.8	9.4%	58 %
Sample 3	1965	10.4%	45 %
Sample 4	1923	12.2%	52 %

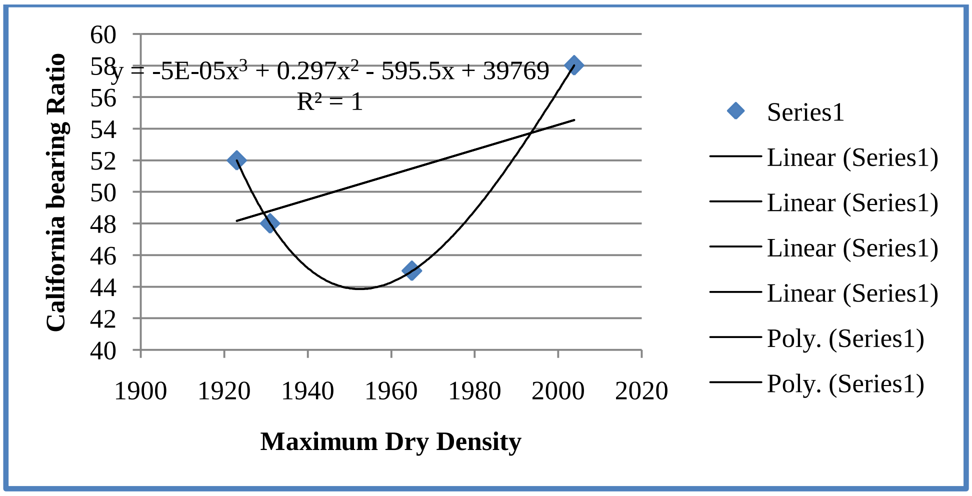

Figure 5: - California Bearing Ratio (CBR)/Maximum Dry Density (MDD) Relationship

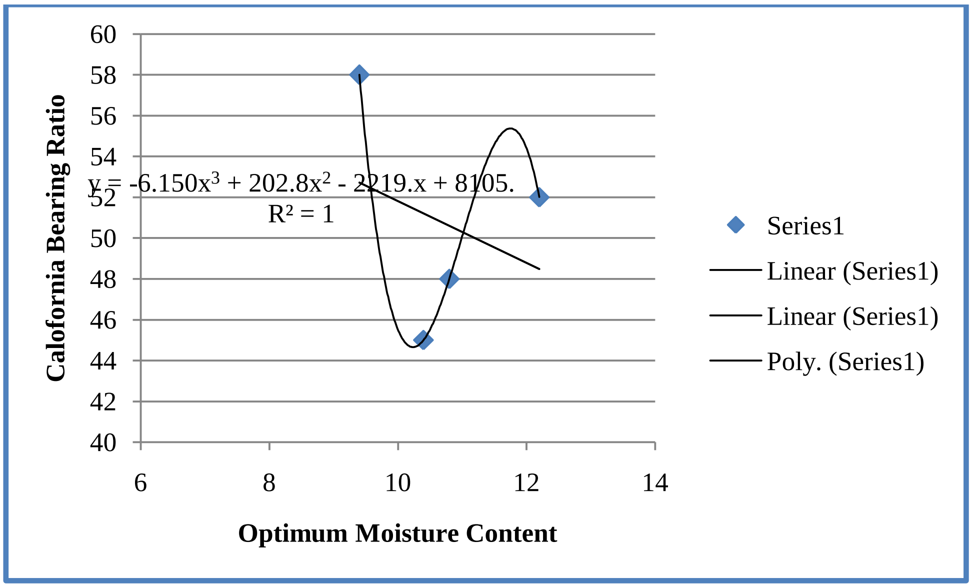

Figure 6: - California Bearing Ratio (CBR) / Optimum Moisture Content (OMC) Relationship.

V. CONCLUSIONS

In this research work, four lateritic soil samples were collected from four different locations within the Northern zone of Anambra state Nigeria. The Geotechnical properties of the soil samples that were investigated include the index properties, the compaction characteristics and the California Bearing Ratio (CBR). From the outcome of the investigations, the following conclusions were reached:

a. The four soils, according to AASHTO classification system, belong to A-2-4 subgroup of A-2 group consisting of granular material and group index of zero. The four soil samples can be classified as SC (Clayey sands) using the USCS classification.

b. The higher the quantity of fines in a particular soil sample, the higher the liquid limit and plasticity index; and consequently the lesser the permeability of the soil.

c. The compaction characteristics of the soil were found to be 1931KN/m^3, 2003.8KN/m^3, 1965KN/m^3 and 1923KN/m^3 for maximum dry density and 10.8%, 9.4%, 10.4% and 12.20% for optimum moisture content for samples 1, 2, 3 and 4 respectively. This shows that Maximum Dry Density (MDD) decreases with increase in Optimum Moisture Content (OMC).

d. The California bearing ratio (CBR) results 48%, 58%, 45%, and 52% for sample 1, 2, 3, and 4 respectively indicates that the soils are suitable as sub-grade and sub-base materials, but should not be used as base course materials since none achieved up to 80% California Bearing Ratio (CBR).

e. The California (CBR) of the samples increased with increase in Maximum Dry Density (MDD) and consequent decrease in Optimum Moisture Content (OMC).

f. There is high linear correlation between percentage (%) consistency limits and percentage (%) fine contents which is denoted by Linear regression models; Y= -4.62X+ 47.74 and; Y = -4.254X + 234 for liquid limit and plasticity index respectively. The coefficients of determination for the regression line are 0.952 and 0.875 for liquid limit and plasticity index respectively, which are high (see figure 3).

g. The relationship of maximum dry density and percentage (%) Moisture content is of 3-order polynomial. The Polynomial regression models for the samples 1, 2, 3 and 4 in terms of relationship between maximum dry density and percentage moisture contents are respectively;
$Y = 1.853X^3 - 64.73X^2 + 724.3X - 624.7$, $Y = 0.355X^3 - 20.86X^2 + 325.8X + 426.5$,
$Y = 2.105X^3 - 87.82X^2 + 1146X - 2867$, $Y = 3.165X^3 - 140.0X^2 + 2015X - 7579$, with the respective coefficients of determination as 1, 0.993, 0.999, and 0.991(Y= maximum dry density; X = moisture contents- see figure 4).

h. The relationship between the California Bearing Ratio (CBR) and Maximum Dry Density (MDD) is modeled by 3-order polynomial regression as: $Y = 5.0 \times 10^{-5} X^3 + 0.297X^2 - 595.5X + 39769$ with coefficient of correlation as 1 (Y=CBR, X= MDD see figure 5), while the relationship of CBR and Optimum Moisture Content (OMC) model is; $Y = -6.150X^3 + 202.8X^2 - 2219X + 8105$ with R^2 as 1(Y=CBR, X= OMC, see figure 6).

REFERENCES

[1]. Alao, D.A. (1983). Geology and Engineering Properties of Laterites from Ilorin, Nigeria. *Journal of Engineering Geology.* **Vol. 19**: Pp.111-118.

[2]. Alexander, L.T. and Cady, F.G.(1962). Genesis and Hardening of Laterite in Soils. Technical Bulletin 1282. US Department of Agriculture, Washington, D.C, p.90.

[3]. ASTM (2004). Standard Test Method for Liquid limit, Plastic Limit, and Plasticity Index of Soils. D 4318 – 00. Annual Book of ASTM standards. Section 4, Construction. Soil and Rock (I); Baltimore, Md, U.S.A. **Volume 04**:**08**.

[4]. Augusta E. (2000), The Influence of Fines Content and Plasticity on the Strength and Permeability of Aggregate Base Class A, Thesis, Master Program on Highway and Development, Bandung Institute of Technology.

[5]. BS 1377 (1990). Methods of Test for Soil for Civil Engineering. British Standard Institution, London.

[6]. Gidigasu, M.D. (1976). Laterite Soil Engineering Pedogenesis and Engineering Principles; Elserier Scientific Publishing company, Amsterdam, New York.

[7]. Benson, C.H. and Trast, J.M. (1995), Hydraulic conductivity of thirteen compacted clays. Clays and Clays Minerals, 43 (6) 669-681

[8]. Buchanan, C.(1807). Laterite Bauxite. Elsevier, Amster-dam, Oxford, New York.

[9]. Ola, S.A.(1983) Geotechnical Properties of an Attapulgite Clay Shale in Northwestern Nigeria. Engineering Geology.19:1-13.

[10]. Osinubi, K.J. (1998) "Influence of Compactive Efforts and Compaction Delays on Lime-treated Soil". Journal of Transport Engineering, ASCE, 124(2), 149-155.

[11]. Proctor, R.R. (1933). Design and Construction of Rolled Earth Dams. English News Record, Aug.31, Sept. 7, Sept.21, and Sept.28, Pp 245-248, 286-289, 341-351, and 372-376, respectively.

[12]. Rowe, K. (2000). Geotechnical and Geoenvironmental Engineering Handbook; Kluver Academic Publishers.

[13]. Siswosoebrotho, B.I., Widodo, P., and Augusta, E. (2005). The Influence of Fines Content and Plasticity on the Strength and Permeability of Aggregates for Base Course Material. Proceedings of the Eastern Asia Society for Transport Studies, Vol. 5, pp. 845-856.

[14]. Venkatramaiah, C. (2006). Geotechnical Engineering Revised 3rd Edition, New Age International Publishers, New Delhi.

[15]. Yoder, E.J. and Witczak, M.W. (1975), Principles of Pavement Design, 2nd edition, John Wiley & Son, Inc, New York, USA.

Appendix A: -Map Showing the Study Areas (Obosi, Umunya, Awkuzu, Igbariam)