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Geotechnical Properties of Lateritic Overburden Materials on the Charnockite and Gneiss Complexes in Ipele-Owo Area, Southwestern Nigeria

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ABSTRACT: *The lateritic soils that overburden Charnockite and Gneiss Complexes in Ipele-Owo area of Ondo State, Nigeria are in great use for local construction. However, little is known of their engineering properties and suitability as sub-grade and sub-base materials for large-scale building and road construction. This work utilized standard geotechnical analytical techniques to examine and characterize these laterites. The results show that the soil is characteristically of a moderate strength based on the average California Bearing Ratio (CBR) test result of 52.5%. The average particle size distribution indicates 11% fine grained sand, 2% medium grains, 12.4% coarse grains, 2% fine gravel and 74.6% clay-sized particles. The respective values of the linear shrinkage, liquid and plastic limits are 10.5%, 52.7% and 23.45%. The maximum dry density of the laterites is 1778.5 kg/m3 while the moisture content is 17.65%. It is therefore suggested that the Ipele-Owo laterites are suitable for use as sub-grade and sub-base construction materials since the geotechnical properties are fairly within the regulatory standards in Nigeria.*

Keywords: *Geotechnical properties, laterites, sub-grade, sub-base materials, Ipele-Owo.*

I. INTRODUCTION

Lateritic soils have wide applications in the Nigerian construction industry especially in road-building projects where they are utilized as fill materials and flexible pavement foundations. Their usage as sub-base and base construction materials is mainly because they are easy to manipulate on the road surface and have natural stable grading with a suitable proportion to act as binders. The degree of success in each case depends on the genetic characteristic of the soils and the specific purpose for which they have been used. The performance of lateritic soils as foundations for structure is varied and appears to depend upon the nature of the soil, the degree of the weathering, topography, the drainage condition and more importantly on the type of foundation and the amount of load imposed. In lateritic deposits, it may be possible to build ordinary structure on suitable design footings located a few feet below the ground surface. However, heavier structures may have to be based on firm layers which are determined by sub-soil investigations. The actual design bearing values will depend on the degree of weathering of the lateritic soil and the geotechnical characteristics of the soil layers of a particular site.

Lateritic soils develop from many rock types under different climatic and geochemical conditions. Hence in many instances, the properties of the parent materials are not lost on the resulting products of lateritisation. The process of lateritisation involves the breaking down of silicate materials such as illite and kaolinite leading to the formation of hydrous oxides of iron and aluminum. The dominance of iron oxides gives laterites the characteristic reddish brown or dark brown colour [1] with a unique set of physical, chemical and engineering properties. In the Ipele-Owo area, laterites provide the cover on the basement rocks dominated by charnockites and gneisses. It is therefore reasonable to think that the properties of the basement rocks will be inherent in the laterites, already noted as the weathering products of parent rocks. This relationship will distinguish Ipele-Owo laterites from other laterites that are not derived from similar parent rocks, and therefore give it a unique engineering property.

The results obtained from the assessment of the geotechnical properties of the soil samples will be used to determine the usefulness of the soils in road construction by comparing it to the Federal Government of Nigeria specification for road construction [2]. This information will guide construction engineers on the choice of suitable sub-grade and sub-base materials in order to deliver sustainable and cost-effective projects.

II. GEOLOGICAL SETTING

The area of study lies within the Basement Complex rocks of Southwestern Nigeria (Figure 1) which is part of the Pan African mobile belt lying to the east of the West African craton. The Precambrian Basement Complex covers about 50% of Nigeria and extends into the neighbouring countries of Benin and Cameroon. [3] recognized the Basement Complex to be dominated by the ancient metasediment; gneisses, migmatites and older granite; and the newer metasediments. These were later modified in [4] as the Migmatite-Gneiss-Quartzite Complex, Schist, Charnockitic-Gabbroic-Dioritic rocks, Older Granites, metamorphosed to unmetamorphosedcalc-alkaline volcanic and hypabyssal rocks; and the unmetamorphosed dolerites, basic and syenite dykes.

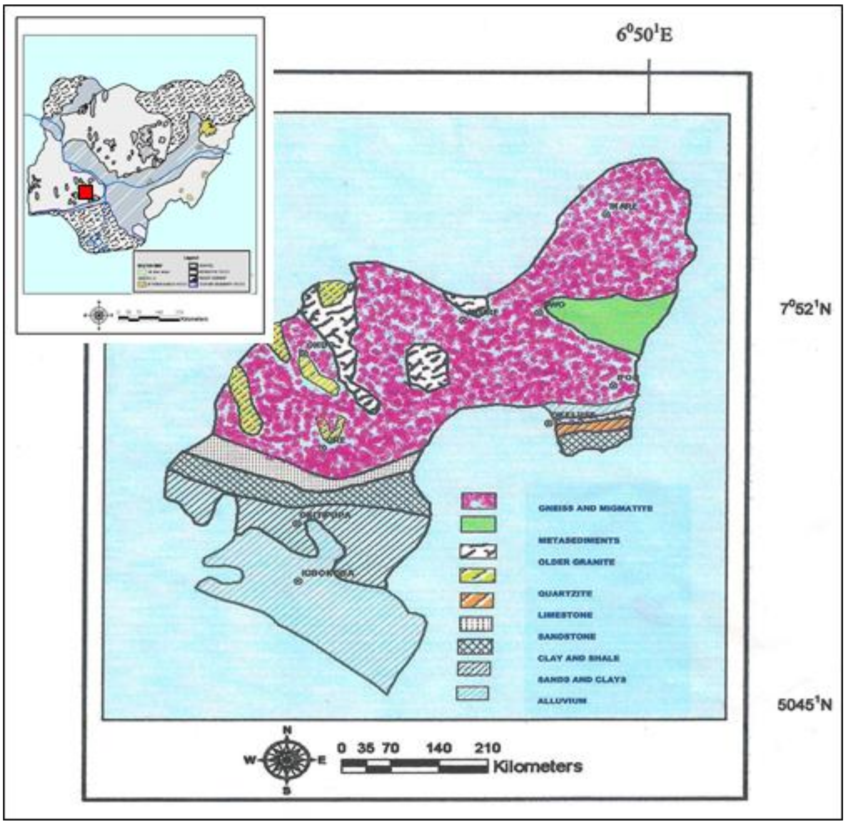

Figure 1: Geological Map of Ondo showing the study area. Inset is the map of Nigeria (modified from [5]).

The study area is dominated by the migmatite gneiss (MGC) which are regarded as the most widespread of the main rock units in the Basement Complex of Nigeria. It is a heterogeneous assemblage of migmatites, orthogneisses, paragneisses and a series of basic and ultrabasic metamorphosed rocks [4]. The principal lithologies as observed in Ipele-Owo area are the granite gneiss, migmatite and grey gneiss. The granite gneisses are the most widely distributed rock type within the study area, occurring mostly as hills and flat lying exposures with colour varying from dark grey to light grey. The texture is granoblastic in the leucocratic quartz-and-feldspar-rich bands while the melanocratic bands are biotite-rich. Some traces of coarse garnet (notably along the river courses) are also common.

The migmatites in the area are made up of granite gneisses, quartzofeldspathic gneisses, granites and basic rocks with quartzitic or pegmatitic intrusion cutting across and along the rock in different directions [6]. The grey gneiss is a grey foliated biotite-rich rock consisting of quartz with albite and /or hornblende gneiss of granodioritic to tonalitic composition. It is usually medium-to coarse-grained in texture with both linear and planar fabric. They commonly occur as hills, series of bouldery exposures and flat-lying exposure. In all the studied outcrops, it is mostly intruded by quartz veins. The paleosome includes the pegmatite and granite and they consist of light coloured minerals.

III. MATERIALS AND METHODS

The conventional tests for evaluation of soil suitability for engineering purposes were carried out on selected samples picked from the study area. The investigation progressed through field studies and laboratory analysis. Field studies involved basic geological mapping of the parent rocks during which the soil profile along the road was also examined especially where there are road cuts, ditches and borrow-pits. Geological features of engineering significance such as drainage patterns and topography were investigated from regional maps and outcrop visits. Ten representative samples were collected from different depths of the weathered profile along the road. Sampling was done at horizontal interval of 1.5 m and was limited to a depth of 1.0 m. The materials used in the collection of the samples were sample bags, hand-held Garmin geographic positioning system, masking tape for labeling, marker for field indentation and digging tools. Laboratory procedures were followed in the determination of natural moisture content of the samples. Thereafter, several of the required geotechnical analyses were carried out. These include particle size analysis, liquid limit, plastic limit, plasticity index, linear shrinkage, specific gravity, standard compaction test and the California Bearing Ratio (CBR) test. The work flow described in [7] for each of the tests was adopted.

IV. RESULTS AND DISCUSSION

The results of the analysis of geotechnical parameters of the soil samples are presented and subsequently discussed. For ease of discussion, the results are presented as graphical plots, and where necessary also as tables.

i. Moisture Content

The moisture content of the soil ranges from 12% to 21.35%. The variation of the moisture content did not follow a consistent and predictable pattern along the soil profile (Figure 2). From the recorded values, it can be inferred that the moisture content is high. The implication of a high moisture content is that the soil might exhibit a reduced strength [8].

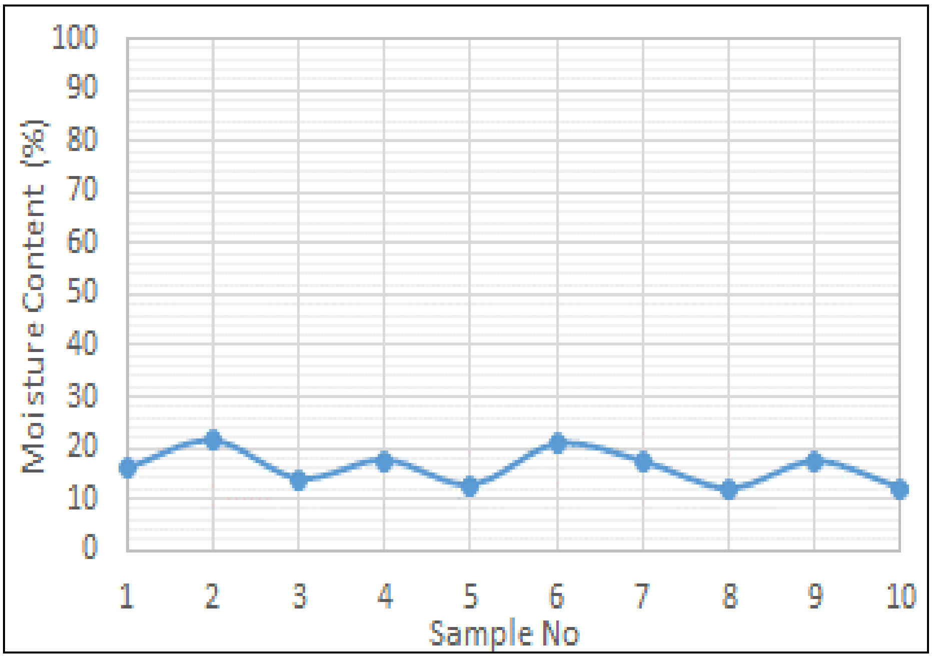

Figure 2: Plot of the average moisture content for each of the soil samples shows variation between 12 % and 21.3 %.

ii. Particle Size Analysis

The grain size distribution shows that the samples contain an appreciable proportion of sands and gravel. By plotting the percentage finer of the samples against their particle sizes (Figure 3), the distribution shows that on the average, the samples comprise 2% fine-grained gravel, 12.4 % coarse-grained sand, 2% medium-grained sand, 11% fine sand and 74.6% clay-sized particles.

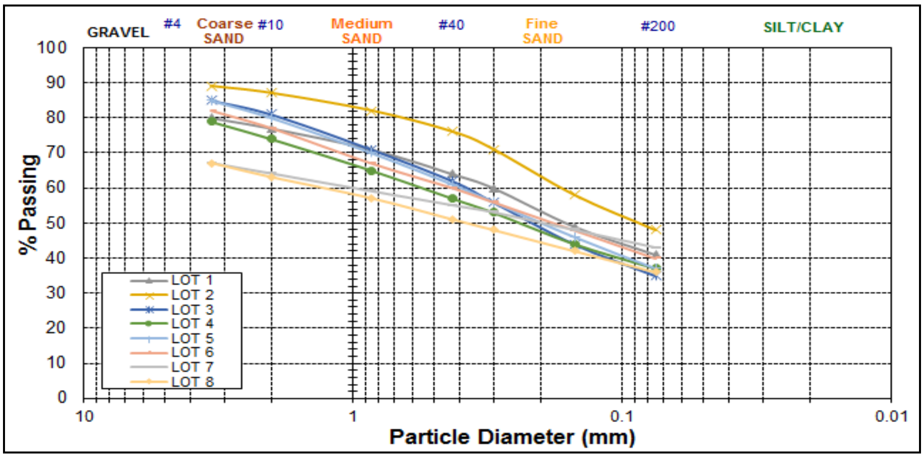

Figure 3: Particle size distribution obtained for the soil samples. The distribution is dominated by clay-sized particles.

The Nigerian government standard specification of sub-grade soils for roads and bridges [2] recommends that soil to be used in road construction must not contain less than 12% fines. The grain size analysis result of the samples collected has shown that the soil is fairly compliant with the national standard. It is also obvious from the analysis that the soil contains high percentage of clay. However, this high percentage of clay in the soil may be responsible for the high percentage of fines.

iii. Shrinkage Limit

Linear shrinkage of the soil samples ranges from 7.1% to 13.9% (Table 1) and is plotted in Figure 4. [9] had noted that the linear shrinkage of soils used in road construction in Nigeria, by regulatory specifications must not be greater than 10%. Going by this baseline, except for the samples in the location 1, 4 and 5, all the samples are compliant with regulatory requirements.

Table 1: Table of values for the linear shrinkage test.

Parameter	1	2	3	4	5	6	7	8	9	10
Original Length (mm)	140	140	140	140	140	140	140	140	140	140
Final length (mm)	125	130	130	120.5	120.5	128.7	128.4	128.8	128.7	128.7
Linear Shrinkage (%)	10.7	7.1	7.1	13.9	13.9	8.1	8.3	8.0	8.1	8.1
FMW (1970) standard ≤ 10%	*F	*P	*P	*F	*F	*P	*P	*P	*P	*P

*F = Fail; *P = Pass

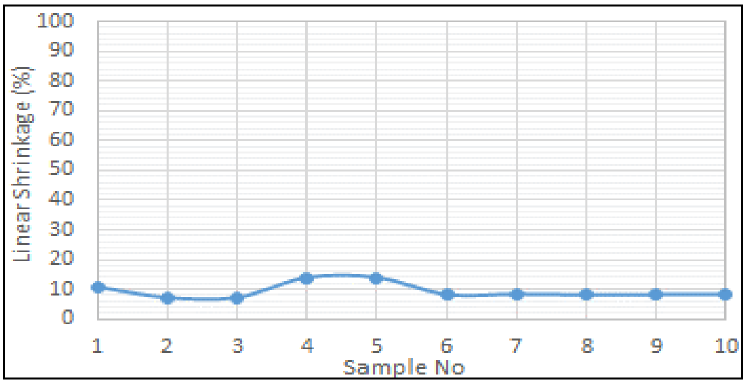

Figure 4: Percentage linear shrinkage determined for the soil samples. All the samples (except 1, 4 and 5) are below the maximum recommended limit of 10% for sub-grade and sub-base soils.

iv. Liquid Limits, Plastic Limits and Plasticity Indices

The analyses show that liquid limits of the soil samples range from 40.3% to 65.1% while the plastic limits are between 19.5% and 27.4%. This suggests that locations 1 to 3 have moderate liquid limit as required by regulatory standards for sub-grade materials in construction while locations 4 to 8 have very high liquid limits that are above approved limits. Considering that plastic limits of construction materials must not be in excess of 33%, the soil samples are considered to be within the regulatory standards.

On the Casagrande[10] Plasticity Chart (Figure 5), all the soil samples plot between medium and high plasticity with plasticity index generally above 12%. When soils of similar liquid limit are compared, the toughness and dry strength increase with increasing plasticity index. The U-line is the maximum liquid limit versus plasticity index for soils. The A-line segregates coarse-grained and silty soils from fines and clayey soils. The coarse-grained and silty soils plot below the A-line while fines and clayey soils plot above the line. Thus, it is further interpreted based on Figure 5 that the samples are mainly fines and clayey soil. This is consistent with the results of the particle size analysis.

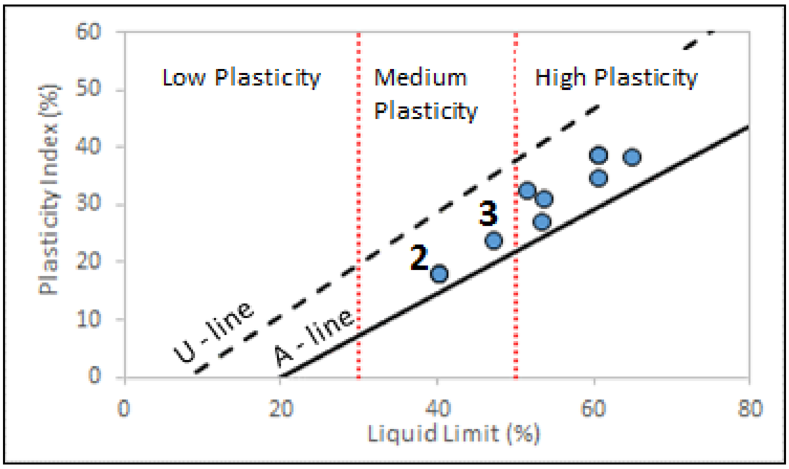

Figure 5: Plot of Atterberg Limits tests results on the Casagrande Plasticity Chart. Samples grade from medium plasticity (samples 2 and 3) to high plasticity.

v. Specific Gravity

The specific gravity for the studied soil samples ranges from 2.654 to 2.804 (Figure 6) and is considered to be acceptably high. This is because it is required that soils to be used for construction should have specific gravity that is not less than 2.25. The high values of specific gravity are expected because other test results (particle size analysis and Atterberg limits) have indicated that the soils are fine grained. The mineral composition of the crystalline rock might have contributed to the relatively high specific gravity values [8]

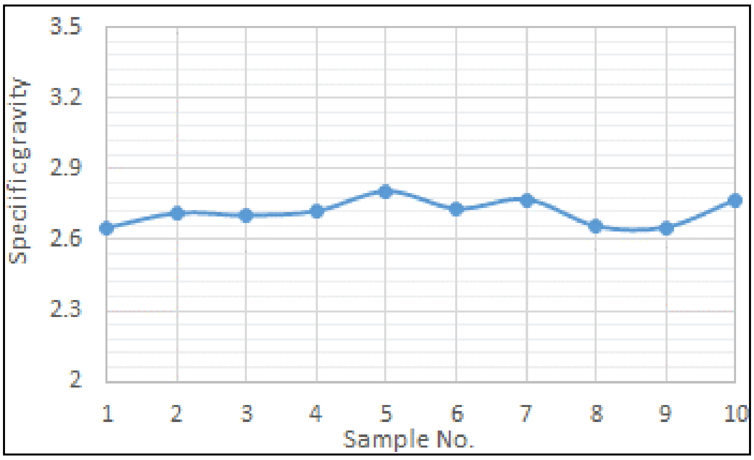

Figure 6: Plot of specific gravity of the tested soil samples. This is broadly within the range of known specific gravity for soils.

vi. Standard Compaction Test

This test is used to establish a dry density/ moisture content relationship of a soil under controlled condition which can form a standard for comparison with field specifications. By plotting the dry density values of the soil samples against the moisture content (Figure 7), the maximum dry density is obtained.

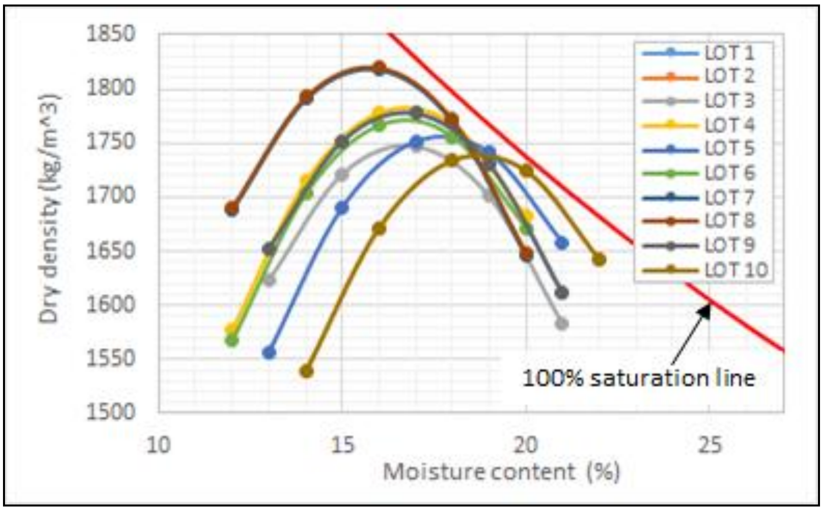

Figure 7: Compaction curves derived from the Standard Proctor test of the different soil samples. All curves are reasonably constrained by the 100% saturation line.

The maximum dry density ranges in value from 1737 kg/m^3 to 1820 kg/m^3 while the optimum moisture content is between 16.6% to 18.7%. Regulatory standards in Nigeria demand that the dry density of soils in road construction must not be greater than 1800 kg/m^3 while the optimum moisture content must not exceed 50%. The samples are therefore largely compliant with the specifications.

vii. California Bearing Ratio (CBR)

The CBR is a semi empirical test that is often employed in the estimation of the bearing capacity of sub-grade and sub-base materials [11] and [12]. It measures the resistance a material offers to the penetration of a plunger under specified density and moisture conditions. The more difficult it is to penetrate the material, the higher the CBR rating. The CBR values obtained from the analyses range from 47% to 58%. This is higher than the specified minimum of 30% for non-dry soil purposed for use as subbase material for construction purposes in Nigeria.

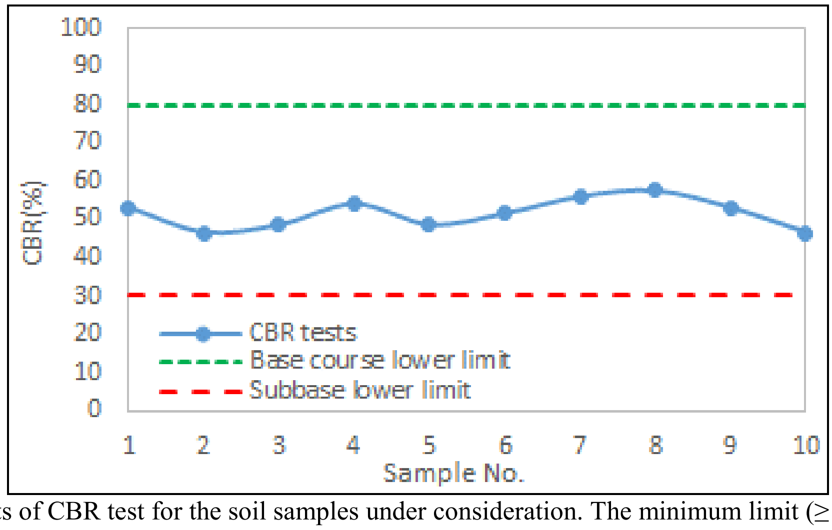

Figure 8: Results of CBR test for the soil samples under consideration. The minimum limit (≥ 30%) for soaked subbase is the dashed red line while the dashed green line is the minimum limit (≥ 80%) for dry base course.

V. CONCLUSION

The geotechnical properties of the lateritic soils that mostly cap the charnockites and gneisses in Ipele-Owo area of Ondo State have been investigated. The results of the various analyses conducted show that the geotechnical properties of the soils are fairly within the specifications required of sub-grade and sub-base materials for road construction. It is suggested that the soil should be effectively stabilized in order to optimize the physical and engineering properties of the soil.

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