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# Investigation of the Geotechnical Engineering Properties of Laterite as a Subgrade and Base Material for Road Constructions in Nigeria

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**Abstract**

This project is an in-depth investigation of the geotechnical engineering properties of subgrade and base soils used in the construction of Omolayo Road in Akobo Area of Lagelu local government, Oyo State, Nigeria. Subgrade samples were collected at chainages 0+000, 1+000, 2+000, 3+000 and 4+000 respectively at depths ranging 0.5m to 1.0m, while the base sample was collected from one of the heaps of laterite brought from the borrow-pit at Oluwo area along New Ife Express Road, Oyo State, Nigeria. The samples were subjected to the following laboratory tests; Particle (grain) size analysis, Atterberg limit test, Compaction test, California bearing ratio (CBR) test and Specific gravity test. The particle size analysis results showed that all samples, both subgrade and base were well graded since their Uniformity Coefficients were greater than 15. It further revealed that base sample were more plastic compared to subgrade samples since it has highest percentage of clay passing sieve no. 200 (75μm) i.e. 27.60%. This indicates that samples with high silt clay content are susceptible to volume changes when wet. The liquid limit and plastic index range from 24% to 48% and 2.7% to 25% respectively with base sample having the highest in both cases. This shows that base sample has high clay content and its load bearing capacity could be reduced when wet. The maximum dry densities ranged from 1.90mg/m$^3$ to 2.19mg/m$^3$ and Optimum moisture contents range from 5.4% to 14.2% respectively. The California bearing ratio is from 78% to 132% (unsoaked). The Specific gravity results ranged from 2.65 to 2.68. The samples were classified using AASHTO classification. The AASHTO system classified the subgrade samples as A-1-b and A-2-4 constituting 50% and 33.3% respectively, and base sample classified as A-2-7 constituting 16.6%. This shows the subgrade samples are excellent to good while base sample is fair to poor.

**Keywords:** Laterite, subgrade, base, particle size analysis, atterberg limit, compaction test, California bearing ratio, Specific gravity

## 1. Introduction

The construction of foundations of most engineering structure requires that adequate information about the engineering properties of the soil and sub-soil condition of the area are known. This is necessary for the engineering planning, design and construction of such foundations to be based on sound geotechnical parameters.

This is more important especially in the design and construction of highways, where there is need for a good and sound knowledge of the geotechnical and engineering properties of the subgrade and, more importantly, the construction materials' properties for sound engineering decisions to be taken. Such geotechnical parameters include the strength, the maximum dry density (MDD), the amount of fines (clay and silts) as well as the compaction performance of the proposed highway construction materials.

In Nigeria, the non-availability of generalized relevant data in this area, particularly for initial preliminary engineering planning and designs, has been the bane and cause of failure of most of our highway construction projects, such that, failure occurs almost immediately after the project is commissioned or even before. The construction material which is used for engineering highway projects is therefore as important, as other engineering design factors. Thus in road pavement design, the soil (sub-base and base course) materials used in the pavement construction transmit the axle-load to the sub-soil or subgrade. Hence, the durability of a highway pavement is a function of the ease and rigidity of the pavement soil to transmit the stress induced in it to the sub-soil such that unnecessary deformation is avoided.

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. Furthermore, in rural areas of Nigeria they are used as building material for molding of blocks and plastering.

Since its discovery by Buchanan, 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 laterite soils as all product of tropical weathering with reddish, brown color 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, aluminum and manganese. Laterite (also known as "red soils") is used to cover all tropically weathered soil that has been involved in the accumulation of oxides of iron, aluminum or silica (Malomo, 1977). In other words, red soil is a highly weathered material rich in secondary oxides of iron, aluminum, or both. According to Alexander and Candy (1962) it is nearly devoid of bases and primary silicate, but it may contain large amount of quartz and kaolite. It is either hard or capable of hardening on exposure to wetting and drying (Agbede, 1992).

A literature review has revealed that the geo-technical characteristics and engineering behavior of red soils depend mainly on the genesis and degree of weathering (i.e. decomposition, laterisation, desiccation and hardening). Morphological characteristics as well as the type and content of secondary minerals are other genetic characteristic (Agbede, 1992).

Good understandings of the basement soil on which highways and other transportation facilities are constructed are very important. Salter (1988) said the performance of a highway pavement is influenced to a very considerable extent by the subgrade material.

Furthermore, Oglesby and Hicks (1992) said that before 1920, attention was focused largely on the pavement surface, and little notice was given to the subgrade 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. In many instances, subsidence or even total failure of the roadway resulted. Study of these failures indicated that faults lay in the subgrade and not the pavement. This led to investigation of the properties of subgrade materials.

## 2. Materials and Methods

### *2.1 Sampling*

Samples of subgrade were collected in-situ from the construction works of Omolayo Road in Akobo Area of Lagelu local government, Oyo State, Nigeria at chainages 0+000, 1+000, 2+000, 3+000, 4+000 at depths ranging between 0.5m – 1.0m, while base sample was collected from one of the heaps of sand deposited on the road, since all base materials supplied to the site were brought from same borrow pit.

### *2.2 Laboratory Tests*

I. Particle Size Analysis

This was done to analyze the soil particles according to their aggregate. Soil sample was poured into the Reffle box with the intention of getting an appreciable sample that would contain all particles present in the soil (a small sample that would contain different sizes of particles present in the soil. A handful of sample was collected into the crucible and kept in the oven at a temperature of 105$^{o}$C for 24 hours so as to remove moisture content in the soil sample. The sample was weighed with the aid of weighing balance (weight of sample before sieving).

Consequently, wet sieving was carried out on the sample. The sample was poured/soaked in a tray filled with water and was stirred, washed, sieved with sieve No.200 (75μm) under tap until water became clean as shown on Plate 1. This was done to remove clay/silt particles finer than sieve No.200. The particles retained in the sieve were collected into the crucible and oven dried for 24 hours to expel moisture content in preparatory for dry sieving. Dry sieving was accomplished by passing/pouring the particles through assemblage of sieves of various sizes. These sieves were shaken for some time so that each sieve could retain particles not finer than the sieve and weight of particles retained in each determined, from where percentage retained and percentage passing were deduced.

II. Atterberg Limit Test

This was done to determine the liquid limit, plastic limit, Plastic Index and Shrinkage limit of soil.

An appreciable sample of laterite soil was poured in a mortal and was ground with a rubber-headed pestle and also sieved using sieve N0.36 (425μm) to separate the pebbles from the fines (pulverization process). Water was added to the fines on a wide glass, mixed thoroughly with the aid of spatula to obtain a paste that was subsequently wrapped with/in polythene nylon, and kept in a crucible for 24 hours so as to allow the paste to swell to its maximum capacity.

 

Consequent upon this, water was added to the paste and mixed thoroughly with spatula. The paste was now placed in a brass cup on the Liquid limit device and leveled to a maximum depth. A long narrow cut (groove) was made along symmetrical axis on the cup. The cup was made to fall on a hard rubber base by turning the handle on the device. The number of blows that closed the groove was first noted between the ranges of 40 – 50 blows. At this point, a small sample or paste was collected along the symmetrical axis on the cup and kept in a can from where weights of wet sample and dry sample were determined to the moisture content. More water was added and the number of blows that closed the groove was noted at ranges of 30 – 40 blows, 25 – 30 blows, 15 – 25 blows and 10 – 15 blows respectively, and samples were collected to determine their moisture contents. The more the volume of water added, the lesser the number of blows that would close the groove. The sample for shrinkage limit was collected when 18 – 22 blows closed the groove. The sample was used to fill shrinkage limit mold of 12.7cm long and kept in the oven for 24 hours so as to determine linear shrinkage in percentage.

$$\text{Linear shrinkage} = \frac{(P - P')\,100}{P'}$$

Where P = Original length of mold

P' = New length after oven drying

A thread of about 3mm was made from the paste after being left for a while and kept in a can so as to determine moisture content (Plastic limit of the sample).

III. Compaction Test

This was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Weights of cylindrical molds were determined using weighing balance. The sample of laterite was divided into four different portions of about 6kg each. 100ml of water was added to the first portion and mixed thoroughly. Some parts of it were kept in two separate cans to determine weight of wet sample and weight of dry sample after spending 24 hours in the oven in order to know its moisture content. The first layer of a 5- layer cylindrical mold was filled with the sample and rammed 27 times with the aid of 4.5kg rammer. The same was done on the rest layers and rammed 27 times each. The weight of compacted wet sample was determined using weighing balance and wet density calculated thereof as shown in Plate 2 below. The same procedures were followed for remaining three portions but with increment of 100ml of water on each portion from the first 100ml. That is, 200ml, 300ml, 400ml of water respectively.

$$\%\,Moisture = \frac{Weight\ of\ moisture}{Weight\ of\ dry\ sample} \times 100$$

$$Dry\ density = \frac{Wet\ density \times 100}{\%\,Moisture\ content + 100}$$

IV. Specific Gravity Test

This was carried out to determine the fineness of the sample i.e. to have an idea of the quality of fine particle contained in the sample. The weight of an empty bottle was determined using a weighing balance as shown in plate 3 below. The bottle was filled with water to the brim and its weight determined. One third of empty bottle was filled with the subgrade sample and its weight determined appropriately. Water was added to the latter to the brim and mixed thoroughly for few minutes before determining its weight.

Therefore, Specific gravity was calculated through the following steps;

Weight of bottle + water (full) W4

Weight of bottle + soil + water W3

Weight of bottle + soil W2

Weight of bottle W1

Weight of water (to fill bottle) (W4 – W1)

Weight of water added to the soil (W3 – W2)

Weight of soil (W2 – W1)

 

Weight of water displaced by soil (W4 – W1) – (W3 – W2) = W

Specific gravity of soil particles (W2 – W1)/ W

V. California Bearing Ratio (CBR)

This was carried out to estimate the bearing capacity of the soil to use in sub-grade and base course using the California Bearing Ratio (CBR) Machine. The compacted wet soil was placed on the California Bearing Ratio (CBR) machine. The proofing ring gauge and plunger penetration gauge were set at zero. Immediately the plunger penetration made a contact with the soil, the gauges started working simultaneously and, the readings were taken on the proofing ring gauge at every 25 division on the plunger penetration gauge. The first 10 readings were referred to as first pointer and the $10^{th}$ reading being the correct reading was adopted and multiplied with a multiplication factor of 0.18 while the last 10 readings were referred to as second pointer, and so also, the $20^{th}$ reading was adopted and multiplied with a multiplication factor of 0.12. The test was done on both top and bottom of the compacted wet soil. The higher of the two values was chosen as actual CBR. The average of the top and bottom was however the final actual CBR. The same was done for the remaining three compacted wet samples as shown in Plate 4 below.

## 3. **Results and Discussion**

### *3.1 Particle Size Analysis*

The particle size distribution analysis shows not only the range of particle sizes present in a soil but also the type of distribution of various size particles.

According to clause 6201 of Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement, for a sample to be used as both subgrade/fill and base, the percentage by weight passing the No.200 sieve (75µm) shall be less than but not greater than 35%. And if the percentage passing sieve No. 200 for a Lateritic base course is greater than 35%, no need for further tests and material rejected.

Sequel to the above, the samples under review (subgrade samples and base) were good samples because percentages by weight passing sieve No. 200 for both soil do not exceed 35% requirement.

### *3.2 Atterberg Limit Test*

It is obvious from the results that base sample absorbs more water and swells on drying which is evident in the result of Linear Shrinkage and Plastic index. It can be said to be more clayey/plastic than subgrade samples.

According to Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement in clauses 6201 and 6252, material passing the 425µm sieve shall have a liquid limit of not more than 35% and a Plastic Index (P.I) of not more than 12% as determined by American Society for Testing Materials Method.

In view of the above, subgrade samples are fit to be used in road construction since both their Liquid limits and Plastic Index values do not exceed the stipulated values of 35% and 12% respectively. The base sample is not suitable for the purpose for which it was used, since it shows Liquid Limit and Plastic Index of 48% and 25% which do not fall within the stipulated values of 35% and 12% for Liquid Limit and Plastic Index respectively.

### *3.3 Compaction Test*

From the results obtained from the Compaction test, subgrade samples at chainages 0+000, 1+000, 2+000, 3+000, have higher MDDs which are (2.19, 2.18, 2.16, 2.19) mg/$m^3$ while base sample has lower MDD which is 1.92mg/$m^3$.Only subgrade sample at chainage 4+000 shows MDD lower than that of base, which is 1.90mg/$m^3$. For Optimum Moisture Content (OMC), base sample has higher OMC which is 14.3% while subgrade samples at chainages 0+000, 1+000, 2+000, 3+000, 4+000 have OMCs of 6.2%, 6.2%,5.4%, 6.5%, 14.2% respectively. Because of the disparities in Optimum Moisture Contents of the samples, subgrade samples are the better of the samples because they exhibit lower OMCs of 6.2%, 6.2%, 5.4%, 6.5%, 14.2% compared to 14.3% OMC for base sample. The base sample has affinity to absorb more water and swell on drying which is not healthy for Civil Engineering works.

### 3.4 Specific Gravity Test

The specific gravity of the soil depends on the amount of sand and also depends on their mineral constituents and mode of formation of the soil. According to specification, a good lateritic material should have specific gravity ranging from 2.5 to 2.75. Based on this fact, samples of subgrade at chainages 0+000, 1+000, 2+000, 3+000, 4+000 and base are good lateritic materials since they exhibit specific gravities of 2.68, 2.67, 2.65, 2.68, 2.65 and 2.65 respectively.

### 3.5 California Bearing Ratio (CBR)

The results of California bearing ratio test revealed that subgrade samples at chainages 0+000, 1+000, 2+000, 3+000, 4+000 have CBR values of 108%, 120%, 81%, 132%, 78% while base sample has a CBR value of 78%.

According to clause 6201 of Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement, the minimum strength of base course material shall not be less than 80% C.B.R (unsoaked) while minimum strength for subgrade/fill shall not be less than 10% after at least 48 hours soaking.

In light of the above, base sample is not fit to be used since it exhibits CBR of 78% (unsoaked) which is less than the stipulated 80%. The subgrade samples are good because they exhibit CBR (unsoaked) values (108%, 120%, 81%, 132%, and 78%) that are even higher than what is stipulated in the specification. Based on this, subgrade samples are better than the base sample used for the construction of the road which is evident in their CBR values.

### 3.6 Description of samples according to Uniformity Coefficient, $C_u$

This is done to determine whether material is uniformly graded or well graded.

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{D_{30}^{\ 2}}{D_{10} \times D_{60}}$$

Cc is Coefficient of Curvature while Cu is Coefficient of Uniformity.

$D_{10}$, $D_{30}$, $D_{60}$ are diameters at 10%, 30% and 60% finer on gradation curve.

Therefore, Cu, subgrade (CH 0+000) =17.5

$C_u$, subgrade (CH 1+OOO) =19.16

$C_u$, subgrade (CH 2+OOO) =17.5

$C_u$, subgrade (CH 3+OOO) = 28.88

$C_u$, subgrade (CH 4+OOO) =32.5

$C_u$ (base) =86.25

Table 3 shows Hazen's soil grading according Uniformity Coefficient, Cu

It could be deduced from table 3 that, samples of both subgrade and base are well graded soils since their Uniformity Coefficients are greater than 15.

### 3.7 Description of samples according to AASHTO Classification

This system was originally proposed in the year 1928 by the U.S Bureau of Public Roads for the use of highway engineers. A committee of highway engineers for the Highway Research Board, U.S.A met in 1945 and made an extensive revision of (the PRA system. This system in USA is known as AASHTO (American Association of State Highway and Transport

 

Officials) System. The revised system comprises seven groups of inorganic soils, A-1 to A-7 with 12 subgroups in all as shown in table 2. The system is based on the following three soil properties:

i. Particle size distribution

ii. Liquid Limit

iii. Plasticity Index

Group Index (GI) = (F – 35) [0.2 + 0.005 (LL – 40)] + 0.01 (F – 15) (PI – 10)

F = % Passing No. 200 (Murthy, 2007)

## 4. Conclusion

A comprehensive investigation into geotechnical engineering properties of laterites used in the construction of Omolayo Road, Akobo, Ibadan, has been carried out. Based on the investigations of the study, the following conclusions can be drawn;

a. The subgrade samples and base sample are well graded soils following the results of sieve analyses.

b. The base sample is more clayey than the subgrade samples, which are sandy in nature. Due to the high plastic nature of base sample, it has affinity to swell when wet which is not healthy for construction purposes.

c. The subgrade samples fall within categories A-1-b and A-2-4 as according to AASHTO system classification. This classification reveals the rating of the subgrade as excellent to good except for base sample which belongs to A-2-7 that is fair to poor as a subgrade material.

d. The subgrade samples are suitable as highway construction materials since their percentages passing Sieve No. 200, Liquid limits, Plasticity index values are not greater than 35%, 50%, and 30% respectively as stated in Federal Ministry of Works and Housing (FMW & H) Specification requirements.

e. Finally, the base material used for the construction of the road ought not to have been used for the purpose for which it was used, since most of its properties fall short of the requirements for lateritic base material as stipulated in the Federal Ministry of Works and Housing (FMW & H) Specification requirement. Apart from its percentage passing Sieve No. 200 that is greater than stipulated value of 35%, its Liquid limit, Plasticity index value are greater than stipulated values of 35% and 12% respectively. Its California Bearing Ratio (CBR) value of 78% is also not greater than 80% as required in specification.

## 5. Recommendation

Based on the investigations of the study, the following recommendations are proffered;

a. It is recommended that laboratory tests be carried out on borrow pit materials to be used for construction of roads so as to know their suitability for the intending purposes which would or could reduce cost of maintaining such roads in the long run if proper materials are selected or used, that could make roads stand a test of time.

b. Resident engineers and contractors should always work in strict adherence to code of ethics of engineering profession so as to achieve or maintain best practices.

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**Plate 1** Sieve Analysis Experiment (Wet sieving)

**Plate 2** Compaction Experiment (Determination of weight of compacted soil plus the mold)

**Plate 3** Specific Gravity Experiment

**Plate 4** California Bearing Ratio Experiment

**Table 1** Sieve Analysis

| **Sample** | **%Passing Sieve No. 200 (75µm)** |
|---|---|
| Subgrade @ CH 0+000 | 16.37 |
| Subgrade @ CH 1+000 | 17 |
| Subgrade @ CH 2+000 | 19.96 |
| Subgrade @ CH 3+000 | 15.06 |
| Subgrade @ CH 4+000 | 10.10 |
| Base | 27 |

Table 2 Atterberg Limit Test Values

| **Sample** | **LL (%)** | **PL (%)** | **PI (%)** | **SL (%)** |
|---|---|---|---|---|
| Subgrade @ CH 0+000 | 28 | 20.63 | 7.35 | 3.5 |
| Subgrade @ CH 1+000 | 29 | 24 | 5 | 1 |
| Subgrade @ CH 2+000 | 24 | 21.30 | 2.7 | 1 |
| Subgrade @ CH 3+000 | 25 | 19.08 | 5.94 | 2.9 |
| Subgrade @ CH 4+000 | 26 | 19.35 | 6.65 | 3.6 |
| Base | 48 | 23 | 25 | 11 |

**Table 3** Soil grade according to uniformity Coefficient $C_u$

| $C_U$ | **Type of Soil** |
|---|---|
| <5 | Uniform size particles |
| 5 – 15 | Medium graded soil |
| >15 | Well graded soil |