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Assessment of the Geotechnical Properties of Lateritic Soils in Minna, North Central Nigeria for Road design and Construction

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Abstract Laterite is a highly weathered material, rich in secondary oxides of iron, aluminum, or both. Geotechnical investigation is one of the effective means of detecting and solving pre, syn and post constructional problems. The geotechnical properties of lateritic soils and their suitability for road construction have been evaluated for selected sites in Minna, North-central Nigeria. All analyses were carried out in accordance with the British Standard Institution. The liquid limit ranged from 22.5% to 49.6% with an average value of 34.9%, plastic limits varied from 13.8% to 28% with a mean value of 21.38% while plastic index is of the order of 8.7% to 21.6% with an average value of 13.5%. The maximum dry density ranged from 1.78 g/cm^3 to 2.33 g/cm^3 with a mean value of 1.858 g/cm^3 while the optimum moisture content varied from 6.30% to 14.3% with an average value of 9.74%. The evaluation reveals that the lateritic soils have higher plastic limits, Maximum Dry Densities (MDD) and California Bearing Ratios (CBR) while their liquid limits, plasticity indices and Optimum Moisture Contents (OMC) are lower. The lateritic soils were classified as A-3, A-2-4 and A-2-6 and are adjudged suitable for sub-grade, good fill and sub-base and base materials. This geotechnical information obtained will serve as base-line information for future road foundation design and construction in the study area.

Keywords: *Geotechnical Assessment, Lateritic soil, road construction, Sauka-kahuta, Minna, North-central Nigeria*

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1. Introduction

The understanding of soil behavior in solving engineering and environmental issues as swelling soil especially expansive lateritic soils that can cause significant damage to road construction and other engineering application is the sole aim of geotechnical engineering (Abubakar, 2006; Oke and Amadi, 2008).One of the major causes of road accident is bad road which is usually caused by wrong application of constructional materials especially laterite as base and sub-base material by construction companies (Oke *et al.*, 2009a; Nwankwoala *et al.*, 2014). For a material to be used as either a base course or sub-base course depends on its strength in transmitting the axle-load to the sub-soil and or sub-grade (the mechanical interlock). The characteristics and durability of any constructional material is a function of its efficiency in response to the load applied on it (Oke *et al.*, 2009b; Nwankwoala and Amadi, 2013). The mineralogical composition of the lateritic soil has an influence on the geotechnical parameters such as specific gravity, shear strength, swelling potential, Atterberg limits, bearing capacity and petrograpic properties (Amadi *et al.*, 2012). The rate at which newly constructed roads in Minna and environs developed cracks and later damage is worrisome. Hence this study will ensure that the right lateritic soils with the right criteria are used as a base or sub-base material for road construction in Minna and environs, North-Central Nigeria, thereby ensuring their durability.

2. Location and Physiography of the study Area

The study area is Sauka-Kahuta industrial layout, behind the Minna building material market. It lies within longitude 06°28'11"E to 06°32'13"E of the Greenwich Meridian and between latitude 09°35'22"N to 09°30'36"N of the Equator (Figure 1). The study area has an undulating topography drained by river chanchaga and its tributaries. The area is within the Guinea Savannah with an annual rainfall of about 1100 mm in the northern part and 1600 mm in the southern part. The rainy season spans between the month of April- October and an optimum temperature of 41°C in dry season and minimum of 22°C during the rainy season (Sheriff, 2012).The study area is assessed through Talba farm road, Mandella road, other minor untarred road.

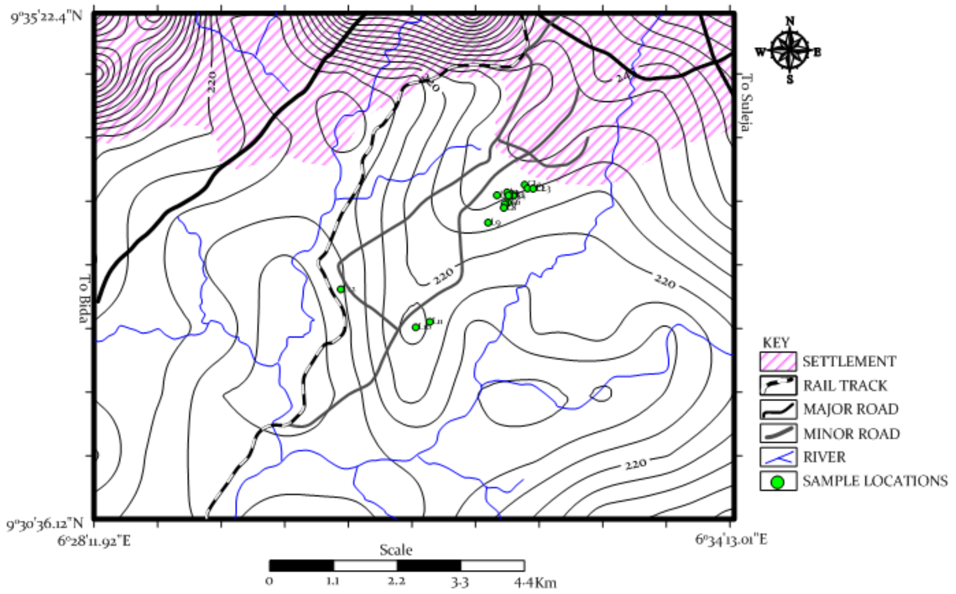

Figure 1. Topographical map of the Study Area

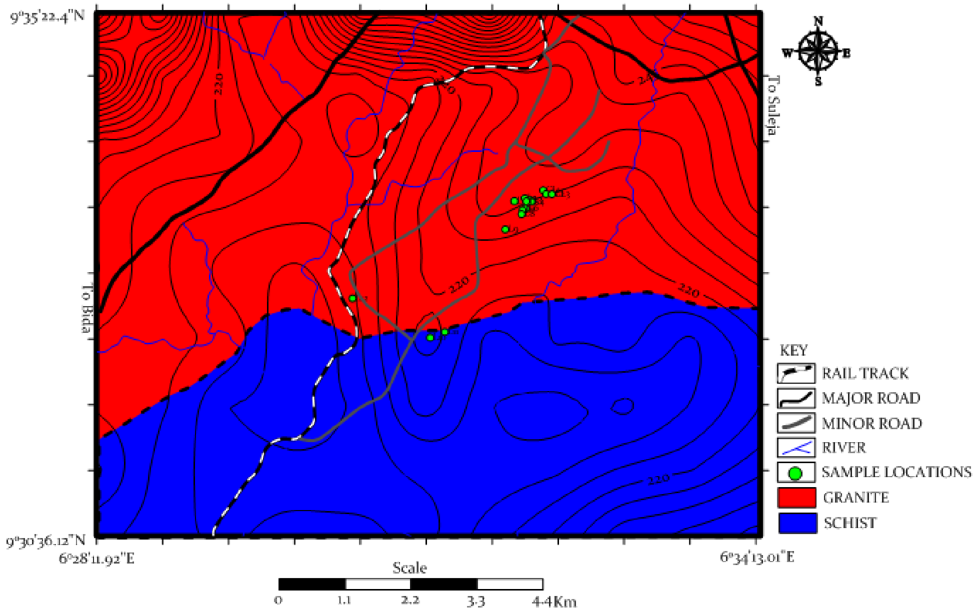

Figure 2. Geological map of the Study Area

3. Geological Mapping

The mapping exercise was carried out to identify and examine the rock type in the study area. The rock type in the area comprises of granite and schist (Figure 2).

4. Methodology of Investigation

The sub-soil conditions was investigated by excavating five trial pits from existing ground level to a maximum of 4.5 m according to British standard code of practice for site investigation (1981), depending on topography and overburden. Disturbed samples soil samples were collected from the trial pits and analyzed at civil engineering laboratory, Federal University of Technology, Minna, Nigeria for relevant geotechnical analysis.

5. Laboratory Analysis

The laboratory analysis was performed according British standard methods of test for soil for civil engineering purposes (BS 1377: Part 1-9, 1990). The laboratory test carried out to determine the suitability of the lateritic soils for use as base and sub-base material using the AASHTO standard method in relation to the generation specification for roads and bridges.

6. Sieve Analysis

Sieve analysis was performed in order to determine the soil particle size distribution. Representative sample of approximately 500 g was used for the test after washing and oven-dried. The sample was washed using the BS 200 sieve and the fraction retained on the sieve was air dried and used for the sieve analysis. The sieving was done by mechanical method using an automatic shakers and a set of sieves.

7. Atterberg Limits (Liquid Limit and Plastic Limit)

This test determines the clay content in terms of liquid limit, plastic limit, plasticity index and shrinkage potential in order to estimate plasticity, strength and settlement characteristics of the soil sample. For the determination of liguid limit, the soil sample passing through 425 µm sieve, weighing 200 g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casangrade's apparatus cup with a grove created and the number of blows to close it was recorded. Similarly, for plastic limit determination, the soil sample weighing 200 g was taken from the material passing the 425 µm test sieve and then mixed with water till it became homogenous and plastic to be shaped to ball. The ball of soil was rolled on a glass plate until the thread cracks at approximately 3 mm diameter. The 3 mm diameter sample was placed in the oven at 105°C to determine the plastic limit.

8. Moisture content

Moisture content is defined as the ratio of the weight of the water in a soil specimen to the dry weight of the specimen. The moisture content of lateritic soil can be influenced by the mineralogy and formation environment.

9. Compaction Test

The densification of soil with mechanical equipment thereby rearranging the soil particles which makes them more closely packed resulting in an increase of the ratio horizontal effective size to the vertical effective stress. The degree of compaction is measured in term of its dry weight and it increasing the bearing capacity of road foundation, stability slopes, controls undesirable volume changes and curb undesirable settlement of structures. The mould is filled and compacted with soil in five layer via 25 blows of a 4.5 rammer.

10. California Bearing Ratio

The California bearing ratio (CBR) test is a penetration test carried out to evaluate the mechanical strength of a sub-base or base course material. It measures the shearing resistance, controlled density and moisture content. Both the soaked and unsoaked method of CBR was conducted to characterize the lateritic soil for use as a base or sub-base material. A portion of air-dried soil sample was mixed with about 5% of its weight of water. This was put in CBR mould in 3 layers with each layer compacted with 55 blows using 2.5 kg hammer at drop of 450 mm (standard proctor test). The compacted soil and the mould was weighed and placed under CBR machine and a seating load of approximately 4.5 kg was applied. Load was recorded at penetration of 0.625, 1.9, 2.25, 6.25, 7.5, 10 and 12.5 mm.

11. Triaxial Test

In this test, horizontal load was applied as soon as vertical load has been imposed and shearing continued at the rate of 0.25 mm/min until the shear force goes beyond its maximum value and becomes constant or decreases, representing failure condition. Normal stresses of 188.0 kPa, 324.3 kPa, 460.5 kPa and 596.8 kPa were employed in all the direct shear tests. The results of the direct shear tests for the lateritic soils are presented in the form of stress-strain curves and plots of shear stress versus normal stress. From these, the shear strength parameters (angle of cohesion (c) and angle of internal friction (Φ)) were obtained.

12. Results and Discussion

The result of the laboratory analyses are summarized in Table 1 while the revised AASHTO system of soil classification is contained in Table 2. The description of the lateritic soils is shown in Table 3 and Figure 3 while the physical properties of soil samples are presented in Table 4. Federal Ministry of Works and Housing general specification for roads and bridges is shown in Table 5. According to Federal Ministry of Works and Housing (1997) specification, the lateritic soil samples are suitable for subgrade, subbase, and base materials as the percentage by weight finer than No. 200 BS test sieve is less than 35% except locations 8 and 10 (Table 1). The liquid limits value, ranged from 15.8% to 49.6%, the plastic limits varied from 12.0% and 28.0% while the plastic index is of the order of 3.8 to 19.4 (Table 1). Federal Ministry of Works and Housing (1997) for road works recommend liquid limits of 50% maximum for subbase and base materials. All the studies soil samples fall within this specification, thus making them suitable for subgrade, subbase and base materials. The plot of plasticity index versus liquid limit is shown in Figure 4. The unsoaked California bearing ratio value for the lateritic soil sample range from 0.0% to 83.8%. Federal Ministry of Works and Housing recommendation for soils for use as: subgrade, subbase and base materials are: ≤ 10%, ≤ 30% and ≤ 80% respectively for unsoaked soil. This implies that locations [2,8,9] with values less than 10% are excellent subgrade materials, locations [1,2,3,8,9,10] having values less than 30% are good materials for subbase.

All the locations except location 5 have their unsoaked CBR value less than 80% which is the maximum value recommended for soils to be used as base materials (Federal Ministry of Works and Housing, 1997). By interpretation the lateritic soils from other locations except location 5 are suitable materials for subgrade, subbase and base materials. Location 5 failed the geotechnical characteristics for use as subgrade, subbase or base material. The maximum dry density for the soil samples varied between 1.81 mg/m^3 and 2.35 mg/m^3 while that of optimum moisture content ranged between 7.81% and 14.4%. According to O"Flaherty (1988) the range of values that may be anticipated when using the standard proctor test methods are: for clay, maximum dry density (MDD) may fall before 1.44 mg/m^3 and 1.685 mg/m^3 and optimum moisture content (OMC) may fall between 20-30%. For silty clay MDD is usually between 1.6 mg/m^3 and 1.845 mg/m^3 and OMC ranged between 15-25%. For sandy clay, MDD usually ranged between 1.76 mg/m^3 and 2.165 mg/m^3 and OMC between 8 and 15%. Thus, looking at the results of the soil samples, it could be noticed that they are sandyclay. The cohesion (c) of the quick undrainedtriaxial compression test (Figure 5) ranged from 130 KN/m^2 to 165 KN/m^2 and the angle of internal friction (Ø) was found to be 8° and this implies low plasticity, high permeability, shear strength and bearing capacity.

The moisture content from the compaction test in ranged from 6.30% to 14.4% with an average value of 10.39 (Table 1 and Table 3) indicating that the soil is generally poorly graded and sandyclay with plastic fines (material passing sieve No. 200) and this finding is in agreement with other determined geotechnical parameters. Federal Ministry of Works and Housing (1972) for road works recommend liquid limits of 50% maximum for subbase and base materials. All the studies soil samples fall within this specification, thus making them suitable for subbase and base materials.

Table 1. Summary of Laboratory Results

		Sieve Analysis	Compaction	Test	Atterberg Limit			California Bearing Ratio	
Trial Pit No	Depth of Sampling	% passing	MDD(g/cm^3)	OMC (%)	LL	PL	PI	Soaked	Unsoaked
L1	2.0	1.41	2.05	12.10	34.5	21.0	13.5	11.0	28.0
L2	2.0	31.9	2.06	13.20	36.6	24.5	12.1	40.0	3.0
L3	2.0	0.8	2.18	7.81	33.5	22.0	11.5	18.0	30.0
L4	2.5	2.1	2.33	6.30	23.5	14.3	9.2	64.9	77.5
L5	3.5	2.5	2.35	6.50	22.5	13.8	8.7	72.7	83.8
L6	3.0	0.0	2.11	9.05	35.50	23.0	12.5	36.0	48.0
L7	2.5	34.4	2.08	10.80	37.5	24.2	13.3	54.0	0.0
L8	2.0	56.8	1.79	14.30	49.6	28.0	21.6	5.1	1.0
L9	2.5	2.2	2.19	9.50	15.8	12.0	3.8	9.0	40.0
L10	2.0	55.9	1.81	14.40	41.4	22.0	19.4	7.7	0.0

LL: liquid limit; PL: plastic limit; PI: plastic index

MDD: maximum dry density; OMC: optimum moisture content

Table 2. Revised AASHTO system of soil classification

General Classification	General Materials (35% or less passing 0.075 mm)							Silt-clay materials (more than 35% passing 0.075 mm)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis % passing											
2.00 mm (No10)	50max										
0.425 mm (No40)	30max	50max	51min								
0.725 mm (No200)	15max	25max	10max	35max	35max	35max	35max	36min	36min	36min	36min
Characteristics of fraction passing	6max										
Liquid limit			N.P	40max	41min	40max	41min	40max	41min	40max	40min
Plastic Index				10max	10max	11min	11min	10max	10max	11min	11min
Usual types of significant Constituent material	Stone fragment Gravel and sand		Fine Sand	Silty or clayey Gravel and sand				Silty soils		Clayey soils	
General rating	Excellent to Good							Fair to poor			

Table 3. Description of lateritic soils

Sample No	M.D.D(g/CM3)	O.M.C(%)	Group symbol	Description
L1	2.05	12.11	SM-SC	Sandysilt clay mix with slightly plastic fines
L2	2.059	13.2	SM-SC	Sandysilt clay mix with slightly plastic fines
L3	2.18	7.81	SC	Siltyclay mix with slightly plastic fines
L4	2.33	6.30	SC	Siltyclay mix with slightly plastic fines
L5	2.35	6.50	SC	Siltyclay mix with slightly plastic fines
L6	2.11	9.05	SC	Siltyclay mix with slightly plastic fines
L7	2.076	10.8	SM-SC	Sandysilt clay mix with slightly plastic fines
L8	1.785	14.3	SM	Silty soils, poorly graded sandysilt mix
L9	2.19	9.5	SM-SC	Sandysilt clay mix with slightly plastic fines
L10	1.805	14.4	SM	Silty soils, poorly graded sandysilt mix

Table 4. Correlation of the Atterberg limit versus plasticity of the lateritic soils

Location	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
Sample Nos	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Liquid limit	34.5	36.6	33.5	23.5	22.5	35.5	37.5	49.6	15.8	41.4
Plastic limit	21.0	24.5	22.0	14.3	13.8	23.0	24.2	28.0	12.0	22.0
Plasticity	LP	IP	LP	LP	LP	IP	IP	IP	LP	IP
Description	Silty	Intermediate	Silty	Silty	Silty	Intermediate	Intermediate	Intermediate	Silty	Intermediate

LP: low plasticity; IP: intermediate plasticity

Table 5. Nigerian Standard of soil classification for roads and bridges

Location	1	2	3	4	5	6	7	8	9	10
Sample	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
L.L (≤35%)	34.5 Pass	36.6 Fail	33.5 Pass	23.5 Pass	22.5 Pass	35.5 Fail	34.5 Pass	49.6 Fail	34.5 Pass	41.4 Fail
P.I(≤12%) comment	13.5 Fail	12.1 Pass	11.5 Pass	9.5 Pass	8.7 Pass	12.5 Fail	11.3 Pass	21.6 Fail	13.5 Fail	19.43 Fail
C.B.R soaked for subbase (≥30%)	11.0 Fail	40.0 Pass	18.0 Fail	64.90 Pass	72.70 Pass	36.0 Pass	54 Pass	5.1 Fail	9.0 Fail	**7.7** Fail
C.B.R unsoaked Base course (≥80%)	32.0 Fail	ND	30.0 Fail	77.5 Pass	83.8 Pass	48.0 Fail	ND	ND	40.0 Fail	ND
Overall Rating	Sub-base	Sub-base	Sub-base	Base	Base	Sub-base	Sub-base	Poor	Poor	Poor

ND: not determined

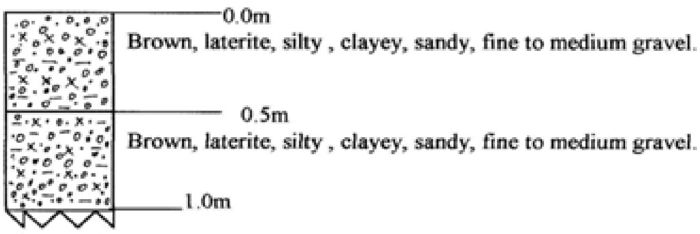

Figure 3. Soil profile of trial pit in the study area

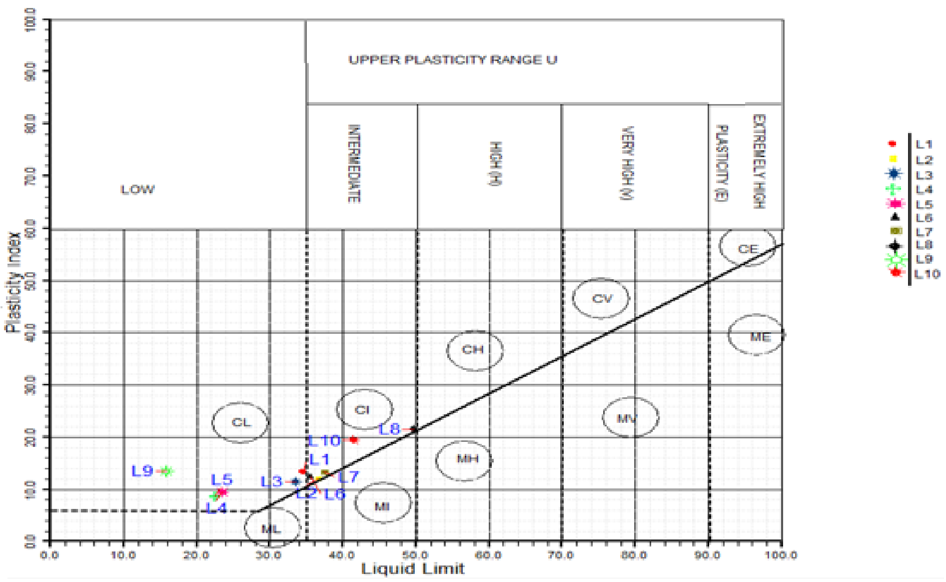

Figure 4. Plasticity chart of the Atterberglimits result

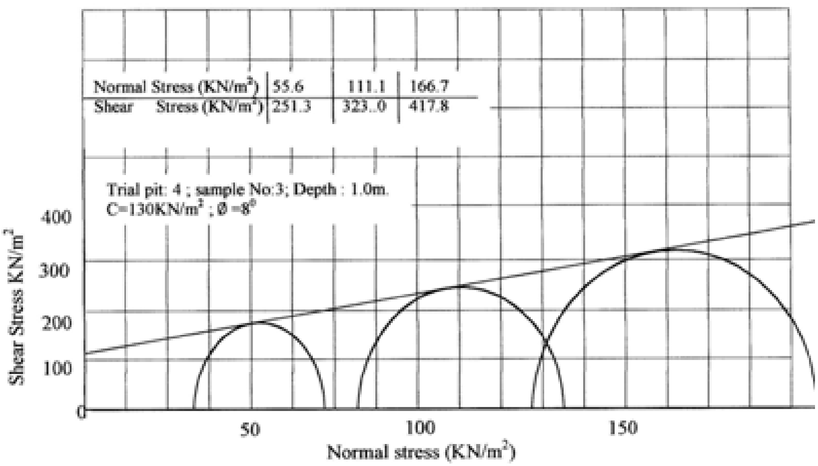

Figure 5. Quick undrainedtriaxial compression test indicating the stress Mohr's circles

13. Conclusion and Recommendation

The geotechnical properties of Minna, North-central Nigeria has been carried out in compliance with BS 1377 (1997) and head of (1990) methods of soil testing for Civil engineers. The result showed that the studied soil samples are classified as sandyclay, incompressible, easily compactable with good drainage. The soil samples tested from the study area indicate a general cohesive nature with low moisture content, high granular material which is suitable for road construction except location 5. These valuable data obtained from the geotechnical analysis can be useful for civil engineers in the design and construction of roads in Minna and environs for maximum durability and efficiency. It is recommended that engineering confirmatory test be carried out before embarking on any construction such as road. Location 5 which failed lateritic soil should be stabilized with either cement, sand; crushed stone (gravels) of ½ and 3/4 inch size in order to meet the sub-base or base course requirement.

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