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Geotechnical Properties of Azara Soil as Base and Subbase Materials for Road Construction

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Abstract

Road transport is one of the most important means of transportation and is pertinent to national growth and development. The materials used for road construction can determine whether it will last or not. This study investigated the geotechnical properties of Azara lateritic soils from Northcentral Nigeria for their potential use as base and subbase material in road construction. Six (6) samples were taken at about 2.5 m intervals each along an exposed cliff and subjected to laboratory analyses. All analyses were carried out following the British Standard. The required parameters for soils to be considered as base and subbase materials in road construction such as grain size distribution, Atterberg consistency limits, and maximum dry density were determined using the BS 1377 1990 standard. Results obtained show that the grain size analysis of the soil samples is silty clayey sand and clayey sand. The results of the Atterberg limit show that the samples can be grouped as low clay soils and medium clay soils. Compaction test analysis shows that sample SC has the highest optimum moisture content (OMC) value of 10.25%. Sample SB has the highest maximum dry density (MDD) value of 1.95 g/cm^3 while samples SC has the least MDD value of 1.52 g/cm^3 for the modified compaction test. Owing to the lateritic composition and compliance with Nigerian regulatory norms for geotechnical qualities, the lateritic soils found across the research region must be stabilized before they can be used as either base or subbase materials.

Keywords: Geotechnical, Atterberg, Grain-size, Compaction, Nigeria

1.0 Introduction

The actual physical movement of persons and things between two locations is known as transportation (Ahukannah et al, 2003). It is a crucial component of human action. All socioeconomic interactions are built on their foundation. The actual physical movement of persons and things between two locations is known as transportation (Ahukannah et al, 2003). Economic development is frequently hampered in many developing nations by a lack of transportation infrastructure. In order to enable economic growth and development, a good transportation system is necessary. The developing world is frequently characterized by poor roads, inadequate car and train fleets, crammed aircraft, and clogged ports. Physical issues include undertrained planners and managers of transportation, capital restructuring, and inefficient traffic laws. In Nigeria, road travel is the most popular and widely used mode of transportation. It entails transporting people, commodities, and services from one place to another where they are required to use vehicles such as bicycles, motorbikes, carts, cars, buses, lorries, trailers, tankers, etc. (Anyanwu, 1997).

Given the level of substandard roads across the length and breadth of the nation, the condition of Federal and State highways is terrible. One of the reasons for the rising number of kidnappings and highway robberies around the nation is bad roads (Oyinloye et. al, 2022). People in the nation have endured tremendous misery as a result of the country's terrible road system. The poor condition of many of the country's roads is one of the main reasons for unrest and fatal accidents on Nigerian highways. Besides auto accidents, the poor condition of Nigeria's roads makes it challenging for vehicles to drive quickly and safely, which delays travel times and makes it extremely expensive and risky. The condition of the road infrastructure has generally been abhorrent. Nigerian roads have been in poor condition for a long time. Some areas of the nation are practically cut off from the rest because of how bad the situation is. Numerous rural communities remain isolated, and numerous further communities have been cut off from the rest of the nation. Furthermore, there are insufficient connections between the various types of transportation.

Road collapse issues can be reduced if a thorough preliminary geological assessment is conducted that includes the evaluation of the subgrade and subbase's geotechnical characteristics as well as the estimation of the anticipated traffic volume. The primary goal of a preliminary study is to gather factual and reasonable data that will be useful when designing the route. For the purpose of suggesting a useful drainage system, the area's hydrological characteristics should be assessed (Afolayan et al., 2017). Current pavement conditions in Nigeria are marked by the distress of various types, such as potholes, cracks, depressions, ruts, etc., whose causes range from poor building methods to improper designs (Adams, 2014).

The purpose of this study is to determine if lateritic soils are suitable for use as base and subbase materials in the construction of roads. This will stop future road failures from occurring, which could be linked to the use of subbase materials during road construction.

2.0 Methods and Procedures

2.1 Location of the study area

Azara is located in the Awe Local Government Area of Nasarawa State. It shares boundaries with Plateau, Taraba, and Benue State of Nigeria with a latitude of 8° 22' 0 N and a longitude of 9° 15' 0 E. It is located in the Middle Benue trough and has an average elevation of 205 meters above the sea Figure 1.

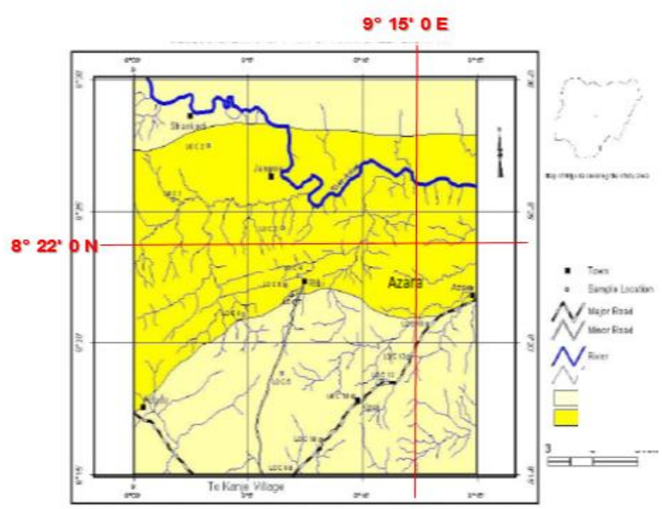

Figure 1: Road Map of the study area (Adapted from Chaanda, et al., 2008).

2.2 Field Sampling

GPS coordinates at the top of the cliff were recorded to determine the height of the cliff. The highest point on the cliff with a coordinate of N 080 18 97 and E 090 14 86 has an elevation of 498 ft (151.8 m) while the lowest point (N 080 12 00, E 090 48 74) has an elevation of 547 ft (166.7 m). Six samples were collected from the cliff at intervals of 2.5 m each. The samples are grouped into silty sand, silty clayey sand, and clayey sand which is predominant among the samples (Figure 2).

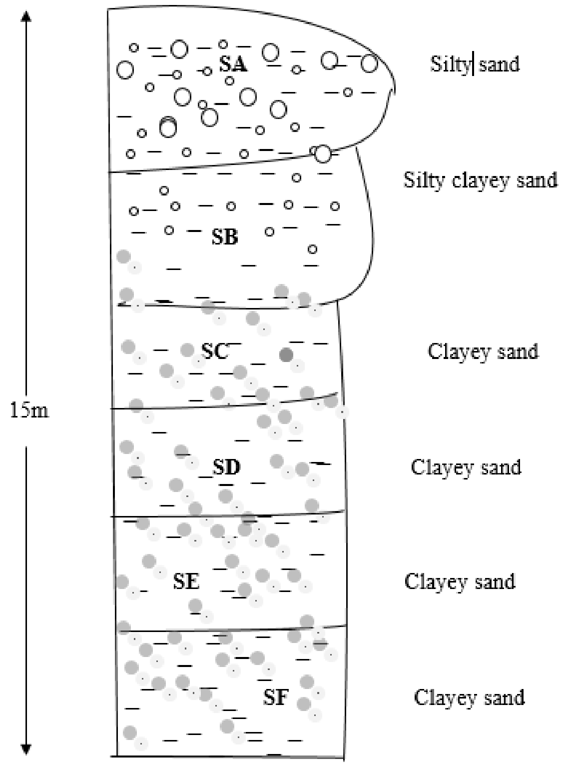

Figure 2: Geological – Lithological Log at the Sampling Site.

2.3 Sample Preparation and Testing Procedure

Samples and specimens were prepared in accordance with BS1377 (1990). Before preparing the tests, the materials were air-dried and carefully crushed into smaller fragments. The tests carried out on the samples are; classification tests, compaction, California bearing ratio, shear strength, and specific gravity. The procedures of these tests are as follows:

2.3.1.0 Particle Size Distribution

This test was carried out using the methods of wet sieving and hydrometer method. The sample was washed using the BS 200 sieve and the fraction passing was used for the hydrometer test. The fraction retained on the sieve was air-dried and used for the sieve analysis.

2.3.1.1 Grain-Size Analysis

Sieve analysis was performed to determine the soil particle size distribution. A representative sample of approximately 500 g was used for the test after washing and oven-dried. The samples were 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 the mechanical method using automatic shakers and a set of sieves.

2.3.2 Liquid Limit Determination

Soil sample passing through a 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. Also, moisture contents were determined.

2.3.3 Plastic Limit Determination

A 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 into a ball. The ball of soil was rolled on a glass plate until the thread cracked at approximately 3 mm in diameter. The 3 mm diameter sample was placed in the oven at 105^oC to determine the plastic limit.

2.3.4 California Bearing Ratio (CBR) Test

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 a 2.5 kg hammer at a drop of 450 mm (standard proctor test). The compacted soil and the mold were weighed and placed under the CBR machine and a seating load of approximately 4.5 kg was applied. The load was recorded at the penetration of 0.625, 1.9, 2.25, 6.25, 7.5, 10, and 12.5 mm.

2.3.5 Compaction

The soil was compacted with two different Proctor energies (modified and standard) which represent the commonly used energy of compaction on the field as recommended by Daniel and Benson (1990) and Daniel and Wu (1993).

3.0 Results and Discussion

3.1 Grain-Size Analysis

The result of grain analysis is presented in Table 1 and a typical example of a grain size distribution curve is shown in Figure 3. Based on this analysis, the soils are grouped as follows; sample SA silty sand, sample SB silty clayey sand, sample SC, SD, SE, and SF are clayey sand.

Table 1: Grain Size Distribution

Sample	Grain Size Distribution					Soil Type (Unified Standard)
	Gravel(%)	Sand (%)	Silt (%)	Clay(%)	Fines (%)	
SA	12	53	20	15	35	Silty Sand
SB	7	53	20	20	40	Silty clayey Sand
SC	6	54	17	23	40	Clayey Sand
SD	5	60	15	20	35	clayey Sand
SE	6	44	20	30	50	clayey Sand
SF	6	39	20	35	55	Clayey Sand

Table 2: Nigeria Standard of soil classification for road and bridges, (Federal Ministry of Works and Housing, 1997).

Sample	SA	SB	SC	SD	SE	SF
LL (≤35%)	37 Fail	40 Fail	36 Fail	35 Pass	41 Fail	47 Fail
P.I (≤12%)	17.2 Fail	19.3 Fail	14.6 Fail	13.0 Fail	23.2 Fail	28.9 Fail
C.B.R. Soaked for subbase (≥30)	1 Fail	5 Fail	1 Fail	1 Fail	1 Fail	1 Fail
C.B.R. unsoaked for base course (≥80)	2 Fail	7 Fail	2 Fail	4 Fail	2 Fail	4 Fail
Overall Rating	poor	Poor	Poor	Poor	Poor	poor

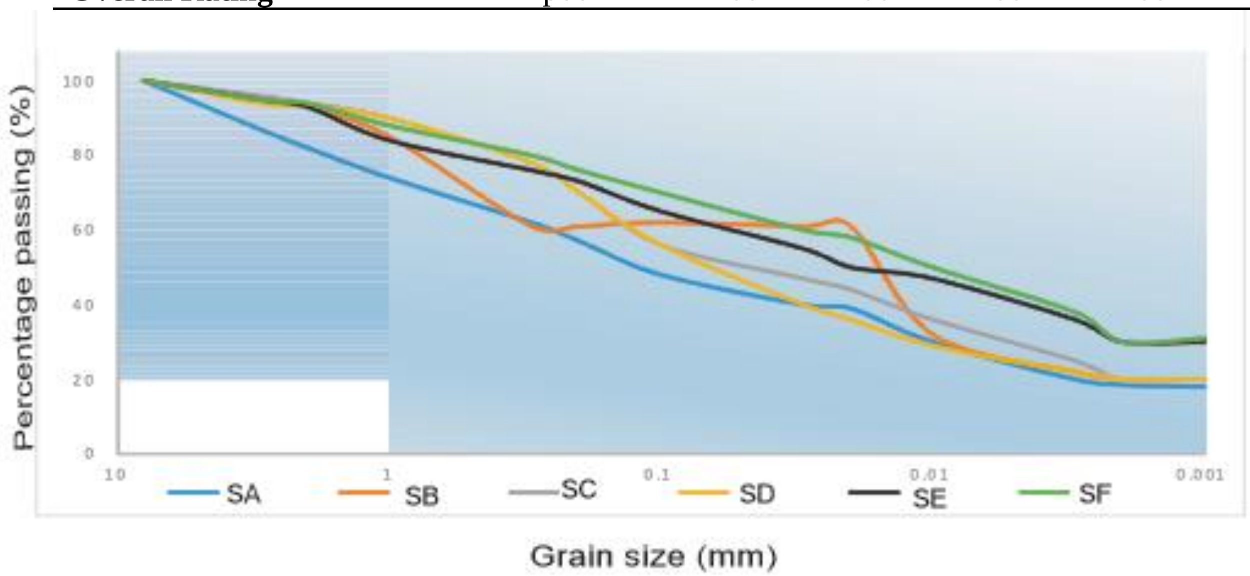

Figure 3: Grain size distribution curve.

3.2 Atterberg Limit Consistency

The Atterberg limits are the basic measure of the water contents of fine-grained soil: its shrinkage limit, plastic limit, and liquid limit. Depending on the result of its water content, the soil may appear in one of four states: solid, semi-solid, plastic, or liquid. The results of the Atterberg limits test are presented in Table 2 and Figure 4. The plastic index of the samples falls within the range of 13% - 28.9 %. The soil plasticity index of ≤12% is suitable as subbase materials for the road as specified by FMWH 1990; none of the samples can be used as subbase materials for road construction. The samples fall within the recommended linear shrinkage value of the Federal Ministry of Work and Housing (1997) of a maximum shrinkage limit of 8% for highway soils.

Table 3: Atterberg and Shrinkage Limits of the Studied Samples.

Sample	Liquid Limit (LL %)	Plastic Limit (PL %)	Plasticity Index (IP %)	Shrinkage Limit (SL %)
SA	37.0	19.8	17.2	3
SB	40.0	20.7	19.3	3
SC	36.0	21.4	14.6	4
SD	35.0	22.0	13.0	4
SE	41.0	17.8	23.2	5
SF	47.0	18.1	28.9	7

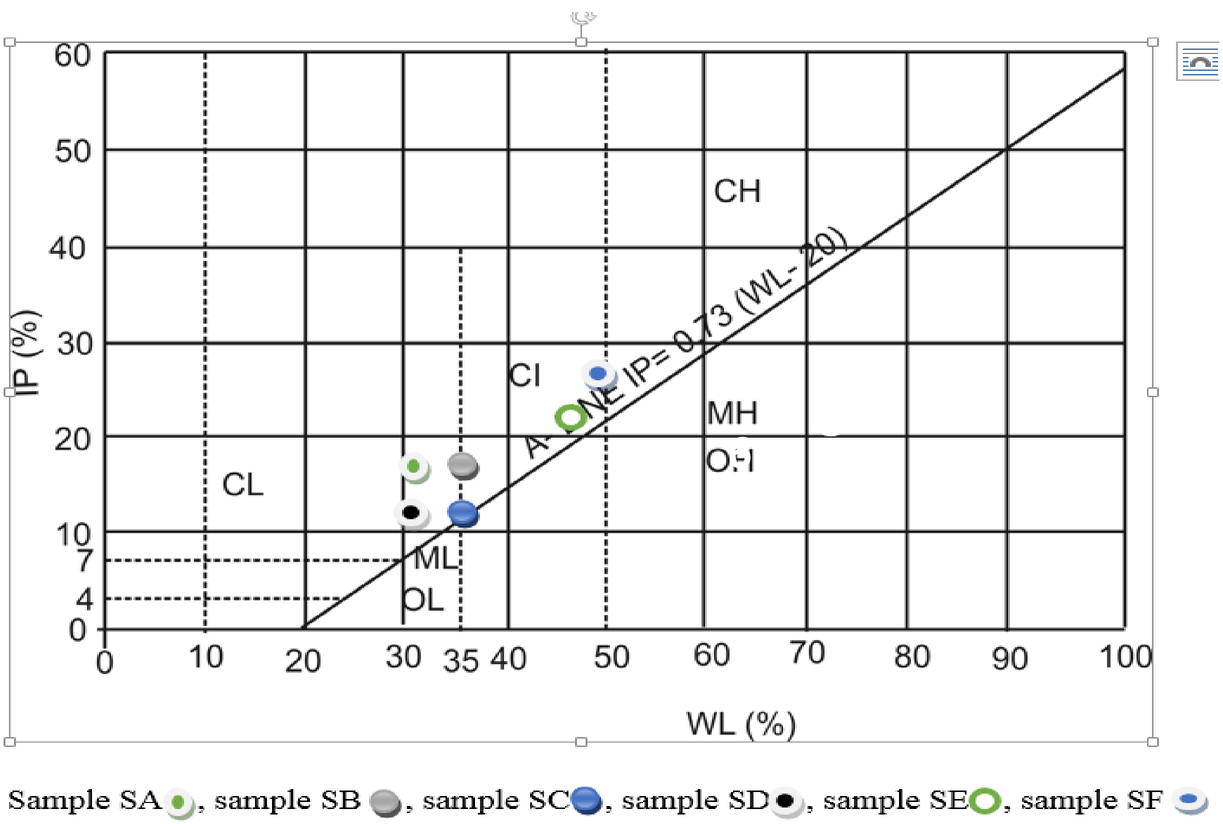

Figure 4: Casagrade Soil Chart.

3.3 Specific Gravity

The specific gravity (SG) is a very useful index in the identification and evaluation of laterite aggregates for pavement construction. An increase in specific gravity has been found to be associated with a decrease in a void ratio (Yzenas, 2006). According to Oyelami, (2017), the SG of lateritic soil falls within a range of 2.60 to 3.40 while Ramamurthy and Sitharam (2005) recommended a SG value range of 2.5 - 2.7. The specific gravity of the soil samples ranges between 2.5-2.7, sample SA has a specific gravity of 2.66, sample SB has 2.67, sample SC has 2.65, sample SD has 2.63, sample SE has 2.68, and sample SF has 2.68. Sample SD has the lowest specific gravity, while samples SE and SF have the highest specific gravity. This result is presented in Table 4. Based on the recommendation, the soils are good lateritic soil.

3.4 Natural Moisture Content

The bulk density of the tested sample ranges between 5.11 – 17.04 %. Sample SA has 5.11%, sample SB has 8.35%, sample SC has 7.64 %, sample SD has 9.34%, sample SE has 17.04%, and sample SF has 17.04%. The Natural moisture contents of samples SA, SB, SC, and SD are within the average range of 5 – 15% specified by FMWH (2000) for road construction. However, sample SE and SF does not conform to the specified range.

3.5 Compaction Test.

Compacting soils for roads and airfields requires attaining a high degree of density during construction to prevent detrimental consolidation from occurring under an embankment's weight or traffic (Ademila, 2017; Olofinyo et al., 2019). For sandy clay, MDD usually ranged between 1.76 mg/m3 and 2.165 mg/m3, and OMC between 8 % and 15 % (Bello and Adegoke, 2010; Adunoye and Agbede, 2013). Compaction tests can be grouped into standard proctor and modified proctor, for standard proctor sample SC has the highest Optimum moisture content (OMC) which is 18%, and sample SA has the lowest OMC of 10.25%, sample SB has the highest value of 1.95 g/cm^3 for MDD, and samples SD, SE, and SF have the lowest value of maximum dry density (MDD) which is 1.5 g/cm^3. The result of the compaction test is presented in Table 4 below.

According to Bello et al., (2007), samples characterized by a high value of maximum dry density and low optimum moisture content are best suitable as subbase and sub-grade materials. Also, the Federal Ministry of Works and Housing, (1997) specified OMC of less than 18% for both sub-base and subgrade materials. All the samples satisfied this criterion to be used as subbase and subgrade materials. Also, the compaction values of soils are considered good, if 100% of the MDD and OMC are attained during field compaction (Ogundipe, 2012).

Table 4: Compaction test

Sample	Standard Compaction		Modified Compaction	
	OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)
SA	10.25	1.42	9.00	1.65
SB	13.00	1.56	12.00	1.95
SC	18.00	1.42	15.5	1.52
SD	17.00	1.40	16.00	1.50
SE	17.00	1.48	16.00	1.54
SF	17.00	1.42	17.50	1.50

3.6 California Bearing Ratio (CBR)

The results of the CBR are presented in Table 5 below and summarized as follows; sample SA, SC, and SE have the lowest value of 2% for the unsoaked, and sample SA, SC, SD, SE, and SF lowest value of 1% for soaked CBR. According to the Federal Ministry of Works and Housing 1997, CBR. Soaked for the subbase should be (≥30), and CBR. unsoaked for the base course (≥80). Therefore, none of the sample fit to be used as a base or subbase material as they did not meet the CBR criteria to be used as a base or subbase material.

Table 5: Some Basic Geotechnical Properties of the Studied Soils

Sample	Specific Gravity	Dry Density (g/cm^3)	Moisture Content (%)	Bulk Density (g/cm^3)	Soaked CBR Results (%)	Unsoaked CBR Results (%)
SA	2.68	1.69	5.11	1.77	1	2
SB	2.70	1.22	8.35	1.36	5	7
SC	2.65	1.33	7.64	1.43	1	2
SD	2.69	1.40	9.34	1.53	1	4
SE	2.52	1.39	17.04	1.42	1	2
SF	2.50	1.22	17.04	1.42	1	4

4.0 Conclusion

The geotechnical appropriateness of lateritic soils for usage as subbase and base materials has been examined. The results demonstrated that only soil with a plasticity index of less than 12 percent is eligible for use as subbase materials for roads, as required by FMWH 1990. None of the samples tested met this requirement. Additionally, soil compaction values can be regarded as good, but they fail to meet Ogundipe's 2012 recommendation of 100% MDD and OMC. None of the samples are suitable for use as base or subbase material according to the CBR standards. Before they can be utilized as subgrade or subbase materials, there is a need for soil improvement, and the samples can only be used as fill materials.

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