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Assessment of geotechnical characteristics of subgrade and use of lateritic soil as sub-base material in road construction (A case study of Abule-Egba to Owode, Lagos Abeokuta Expressway)

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ABSTRACT

The rapid rate of deterioration of major roads in Nigeria accounts for the rising cases of road accidents in the country. Therefore, an adequate study of the suitability of construction materials for these roads is part of the reasons for rapid pavement failure. This research aims to conduct geotechnical studies on the subgrade and borrowed pit laterite used as a subbase material for Lagos-Abeokuta Expressway construction. The subgrade soil samples were obtained at Abule-Egba, Sango-Joju Junction, and Owode Bus Stop along Lagos Abeokuta Expressway (termed samples A, B, and C, respectively). Laterite samples were collected for testing from three locations at Oteyi borrowed pit (termed L1, L2, and L3, respectively). The engineering properties of the subgrade soil and the borrowed-pit laterite, including their particle size distribution, Atterberg limits, maximum dry density (MDD), optimal moisture content (OMC), and California Bearing ratio (soaked and unsoaked CBR), were analyzed in a laboratory using British standards. The natural subgrade has moisture content ranging from 5.48-9.48%, while the liquid limit and plasticity index ranges from 19.75% to 35% and 5.9% to 6.11%, respectively. The OMC ranges from 11.05% to 18.14% while MDD ranges from 1.68g/cm3 to 1.95 g/cm3. The unsoaked CBR and soaked CBR range from 34.15 to 36.02 and 19.60-22.40, respectively. L1, L2 and L3 have moisture contents of 11.2%, 12.29%, and 13.6% while the liquid limit are 35%, 39.2% and 39% and plasticity index of 12%, 15%, and 15% respectively. The OMC of L1, L2, and L3 are 12.9%, 15.4% and 14.1% while the MDD are 1.86 g/cm3, 1.72 g/cm3 and 1.87 g/cm3. The unsoaked CBR are 60%, 46% and 44% while the soaked CBR are 40%, 28.5% and 27%. The natural subgrade meets the required standard for pavement design, while location 1 stockpile is most suitable as filling for construction according to subbase material specification. Standard construction materials and drainage will help increase road lifespan and prevent rapid pavement failure.

Keywords: Subgrade; Subbase; Borrowed-pit Laterite; pavement design; Bearing capacity; Geotechnical properties.

1. INTRODUCTION

In many countries of Africa and Asia, lateritic soils are the traditional material for road and airfield construction. Inadequate geotechnical investigations on subgrade and other pavement materials (subbase and base courses) before the commencement of road projects account for the increasing pavement failure in Nigeria (Abam et al., 2005).

Lateritic soils are commonly found in tropical and subtropical regions and used as surface deposits. They are rich in iron and aluminum and formed due to extensive and long-term weathering of the underlying parent rock. (Gidigasu, 1987). Laterite is used as subbase material in poorly drained roads, leading to soaking of the material, therefore, reduction in the strength of the material and failure of the road sections (Omowumi, 2017). Stabilization of Laterite with pulverized porcelain tiles (Apata et al., 2022) and pulverized cow bone (Apata et al., 2022) increases the geotechnical properties of laterite for road construction.

The Lagos-Abeokuta Expressway is a major road that links Abeokuta, the capital of Ogun State, and Ikeja, the capital of Lagos. The existing road is a double carriageway flexible pavement with an average median width ranging from 3.2 m to 10.0 m. Heavy trucks and buses conveying passengers and goods plying daily subject the road to rapid deterioration.

This research work aims to evaluate the strength characteristics of the natural subgrade and borrowed pit laterite for the subbase construction of the Lagos - Ota - Abeokuta Expressway. The following are the objectives to achieve these aims:

1. Characterize the soil samples (natural subgrade soil and laterite).
2. Determine the engineering properties of the subgrade and laterite for the sub-base.
3. Determine the performance of the laterite in the construction of the sub-base of the express road.
4. Analyse the results and make appropriate recommendations for optimal use.

Plate 1: Showing the failed pavement sections of the Lagos-Abeokuta Expressway

1.1. Scope of Study

The road in this study has a total length of about 81km; it was contracted to Julius Berger Plc in 2018 for reconstruction. The mid-way point between Lagos and Abeokuta is situated at the latitude of 6°38'42.8"N and the longitude of 3°18'21.1"E (Figure 1).

The pavement structure of the road consists of a 400 mm subbase course (laterite), 150 mm stone base course, 40 mm asphaltic concrete wearing course, and 60 mm binder course. For laterite compacted in layers, filing thickness is 300 mm, while the thickness after compaction is 250 ± 20 mm.

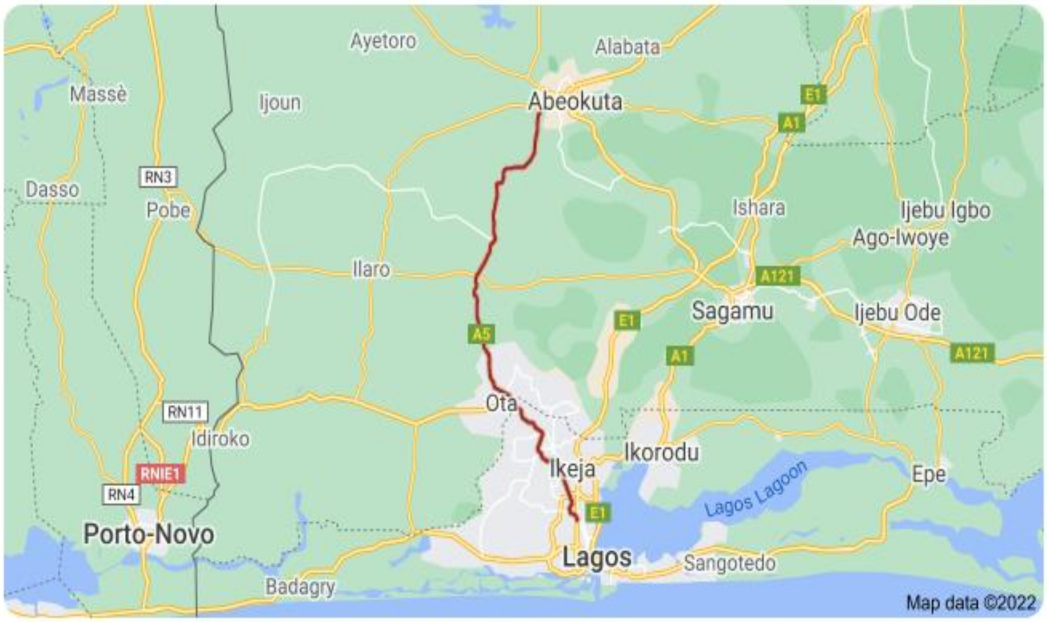

Figure 1: Route Location Map (Ikeja – Abeokuta on Lagos – Abeokuta Expressway) (Source: Google map)

Amadi et al. (2015) assessed the Geotechnical Properties of Lateritic Soils for Road design and Construction. The lateritic soils were classified as A-3, A-2-4, and A-2-6 and are suitable for sub-grade, good fill, and subbase and base materials.

The increase in natural moisture content along the failed sections of the Lagos Ibadan Expressway, according to Odunfa et al. (2018), could be due to a rise in the water table of the failed sections. Some of the materials at failed locations had linear shrinkage greater than 8%, which suggests high susceptibility to shrinkage and swelling, which results in differential settlement and contributes to pavement failure along these sections of the road.

(Fatoba et al., 2015) The Ago-Iwoye-Ilisan road connects Abeokuta, the state capital of Ogun -state, to Ijebu towns. Pavement failure has always occurred on the road in the form of cracks and potholes. The soaked CBR values of the subgrade materials range between 67% and 75%, compared to the minimum of 30% specified by FMWH in 1997.

Abam (2015) stated that low subgrade CBR values indicate that the soils that have weak bearing strength are more susceptible to erosion and pavement deformation. Factors such as construction materials, traffic volume, hydrological regime, and climate should be considered to obtain optimum benefits from lateritic soils for use as sub-grade and sub-base (Enaworu, 2017).

The significant factors that influence the engineering properties and field performance of lateritic soils are:

1. Soil forming factors (e.g., parent rock, vegetational climatic conditions, topography, and drainage conditions).
2. Degree of weathering (degree of laterization) and texture of soils, genetic soil type, the predominant clay mineral type, and depth of the sample.
3. Pretest treatments and laboratory test procedures as well as interpretation of test results.

1.2. Composition of Laterite

Laterites are two-component mixtures of the original host or parent material and the authigenic cementing, replacing, or relatively accumulated minerals (mostly sesquioxides but also certain clay minerals). As the laterite develops, so the authigenic mineral content increases until it may constitute almost the whole material. As a result, hardpan laterite is expected to contain more sesquioxides (Al_2O_3 + Fe_2O_3) than nodular laterite. The primary chemical composition of laterites is shown in Table 1. The citrate-carbonate-dithionite (CBD)-extractable iron content (a measure of the total free iron oxide and hydroxide minerals present) of hardpans laterites ranges between 43 and 77 % (Fitzpatrick, 1978; Fitzpatrick and Schwertmann, 1982). In the case of lateritic soils and gravels, the content of Fe_2O_3 increases, and that of Al_2O_3 decreases with particle size, while SiO_2 is highest in intermediate fractions (LNEC et al., 1969).

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Table 1: Chemical composition of lateritic material (Netterberg, 1985)

Component	% By Mass	Main form of occurrence
SiO_2	5 - 70	Quartz, feldspar, clay minerals
Al_2O_3	5 - 35	Feldspar, clay minerals, gibbsite
Fe_2O_3 [2]	5 - 70	Goethite, hematite
TiO_2	0 - 5	Anatase, rutile
MnO	0–5?	?
P_2O_5	0-1	
H_2O +	5 - 20	Clay minerals, goethite, gibbsite
Loss on Ignition	5 - 30	Clay minerals, goethite, gibbsite, organic matter
Organic matter	0,2 - 2	Organic matter

Notes:

[1] Bauxites are excluded.
[2] Total iron as Fe_2O_3.

The minerals usually found in laterites are summarized in Table 2 (Netterberg, 2013)

Table 2: Sesquioxide minerals typically found in lateritic material

Major Element	Mineral [1]	Composition [2]	Colour [2]
Fe	limonite [3]	$Fe{\cdot}OH{\cdot}nH_2O$	yellow to brown
	goethite	α – FeO(OH)	yellow to brown to black
	lepidocrocite	γ– FeO(OH)	orange
	haematite	α – Fe_2O_3	red, reddish brown to black
	maghemite	γ - Fe_2O_3	reddish brown
	magnetite	Fe_3O_4	Iron black
	ferrihydrite	$Fe_5HO_8{\cdot}H_2O$ [4]	reddish brown
Al	gibbsite	γ– $Al(OH_3)$	white, greyish, greenish or reddish white
	boehmite	γ – AlO(OH)	white, grey, pale lavender, yellow-green
	diaspore	α –-AlO(OH)	white grey, pale lavender, yellow-green
Mn	pyrolusite?	MnO_2	iron black
	manganite?	MnOOH	grey to black
Ti	anatase	TiO_2	red, reddish brown to black
	rutile	TiO_2	red, reddish brown to black
	ilmenite	$FeTiO_3$	Iron black

2. METHODOLOGY

The research data was gathered by visiting the site and collecting samples of natural subgrade soil and borrowed pit laterite. Laboratory tests were performed to determine the engineering properties of the soils being studied. The tests were carried out under BS 1377-2, 1990. First, the moisture content, particle size distribution, plasticity index, and liquid limit were determined, followed by compaction and CBR tests.

2.1. Sample collection

The materials used for this investigation are subgrade and laterite. For the laboratory tests, three soil samples were collected each. The subgrade soil samples were obtained at Abule-Egba, Sango-Joju Junction, and Owode along the Lagos Abeokuta expressway, while the laterite samples were obtained from Oteyi borrowed pit at depths between 1.5m to 2m. The materials obtained were stored in polythene to prevent the loss of moisture in the atmosphere. Analysis was carried out in order to ascertain the physical and engineering properties of the samples.

3. RESULTS AND DISCUSSION

The test results are in Tables 3 -6 below.

Table 3 Results summary for soil classification (Natural Subgrade)

Soil Properties	Sample A	Sample B	Sample C
% passing No. 200 sieve	31.57	38.86	41.09
Moisture Content (%)	5.48	9.48	5.83
Liquid Limit (%)	19.75	27.45	35.00
Plastic Limit (%)	13.85	21.01	28.89
Plasticity Index (%)	5.90	6.44	6.11
AASHTO	A-2-4	A-4	A-4

Table 4 Results summary for soil classification (Oteyi Borrowed Pit Laterite)

Soil Properties	Location 1	Location 2	Location 3
% passing No. 200 sieve	30	50.86	44
Moisture Content (%)	11.2	12.49	13.6
Liquid Limit (%)	35	39.2	39
Plastic Limit (%)	23	24.2	24
Plasticity Index (%)	12	15	15
AASHTO	A-2-6	A-6	A-6

Table 5 Results summary for geotechnical properties (Natural Subgrade)

Parameters	Sample A	Sample B	Sample C
OMC (%)	11.05	13.93	18.14
MDD (g/cm^3)	1.95	1.81	1.68
Unsoaked CBR (%)	35.3	34.15	36.02
Soaked CBR 96hrs (%)	19.95	22.40	19.60

Table 6 Results summary for geotechnical properties (Oteyi Borrowed Pit Laterite)

Parameters	Location 1	Location 2	Location 3
OMC (%)	12.9	15.4	14.1
MDD (g/cm^3)	1.86	1.72	1.87
Unsoaked CBR (%)	60	46	44
Soaked CBR 48hrs (%)	40	28.5	27

Particle Size Distribution

The particle size distribution analysis shows the range of particle sizes present in the soil. According to the Federal Ministry of Works and Housing (1997), a road construction sample finer than No. 200 sieves shall be less than or equal to 35% of the percentage weight.

Figure 3 represents the combined particle size distribution for the natural subgrade, while Figure 4 represents the combined particle size distribution for the borrowed pit soil.

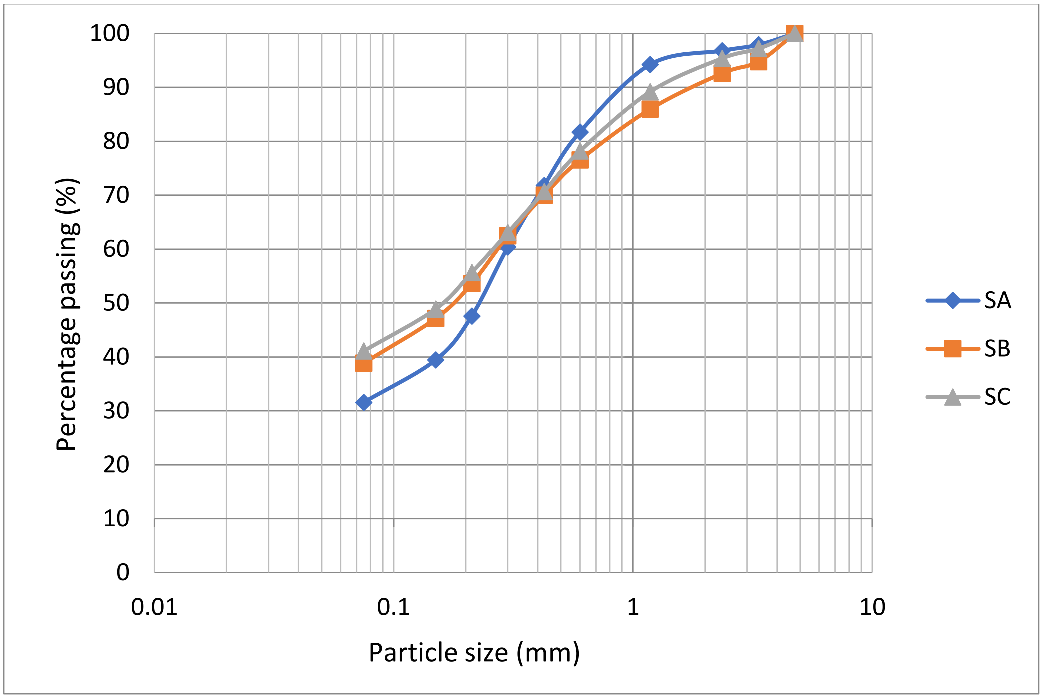

Figure 3: Particle size distribution of the natural subgrade soil

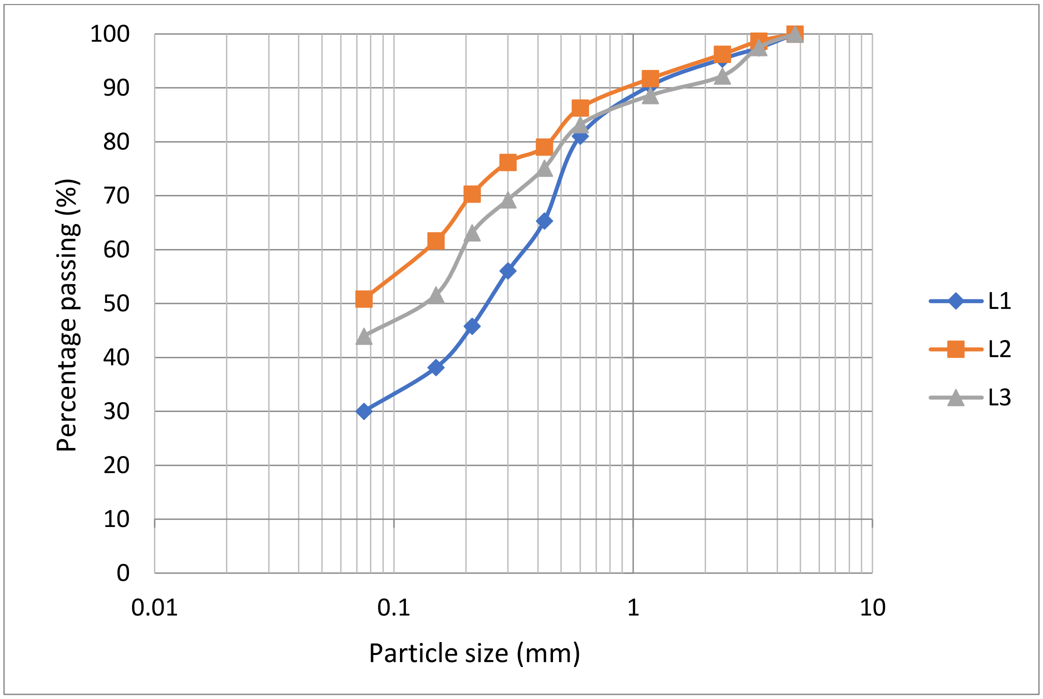

Figure 4: Particle size distribution of the borrowed pit laterite

Discussion

AASHTO classifies the natural subgrade soil samples as A-2-4, A-4, and A-4 for samples A, B, and C, respectively, while UCS for sample A is sand, and that of samples B and C is silt soil. AASHTO classifies the borrowed pit laterites as A-2-6, A-6, and A-6 for samples obtained from location 1 (L1), location 2 (L2), and location 3 (L3), respectively. UCS for samples L1, L2, and L3 are sand, clay, and clay, respectively.

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Moisture Content

The average moisture content of the soil samples in their natural state is a function of the availability of moisture in the environment, which is trapped in the soil structure. This moisture content governs their mechanical behavior of them in their natural state. The natural moisture content of the subgrade soil ranges from 5.48% to 9.83%, while the moisture content of the borrowed pit laterite ranges from 11.2% to 13.6%.

Atterberg Limit Test

The Atterberg Limit test was performed on the soil samples. The summary of results for the plastic limit and liquid limit of the subgrade and laterite is shown in Tables 3 and 4. The results show that the natural subgrade soil has liquid limit 19.75%, 27.5% and 35%, plastic limit 13.85%, 21.01% and 28.89%, plasticity index 5.9%, 6.44% and 6.11%. The borrowed pit laterite has a liquid limit of 35%, 39.2%, and 39%, plastic limit of 23%, 24.2%, and 24%. The plasticity index of the borrowed pit laterite is 12%, 15%, and 15% for the three observed locations. This implies that the natural subgrade soil has low to medium plasticity and the borrowed pit laterite also has intermediate plasticity.

Compaction Test

This test was performed on the natural subgrade soil samples and the borrowed pit laterite to specify suitable moisture content for field compaction. By plotting the dry density values of the soil samples against the moisture content, the maximum dry density is obtained. The optimum moisture content serves as a guide to knowing the amount of water to add during construction to achieve maximum dry density.

According to regulatory standards in Nigeria, the dry density of soils in road construction must not be greater than 1.8g/cm^3, and the optimum moisture content (OMC) must not exceed 50%. The samples are primarily complaints about the OMC specification. The samples in the subgrade and borrowed pit laterite with the lowest maximum dry densities have the highest percentages of fines, establishing that the maximum dry densities decrease with the increase in fines.

California Bearing Ratio

This test was performed on the samples to readily know the true behavior of the soil and the soil resistance to shear. The unsoaked CBR and soaked CBR for the natural subgrade range from 34.15 to 36.02 and 19.60 to 22.40, respectively. The borrowed pit laterite unsoaked CBR are 60%, 46% and 44%, while the soaked CBR are 40%, 28.5%, and 27%, respectively.

The Federal Ministry of Works and Housing (1997) recommended that the CBR values for soils to be used for subgrade, sub-base and base materials should be ≥ 10%, ≥ 30%, and ≥ 80%, respectively, for unsoaked soil. The subgrade and laterite samples meet the required CBR specification for construction materials.

4. CONCLUSIONS AND RECOMMENDATION

This project has shown the benefits of conducting a geotechnical study on pavement materials before using them for road construction. Further studies involving the investigation of causes of pavement failure on major roads should the done. From the results obtained, it is economical and safe to use laterite as a sub-base material for road construction. Proper supervision must be done on-site to ensure that the materials used for construction are the ones specified in the design.

Funding

This study has not received any external funding.

Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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