Geotechnical properties of lateritic soil from Nimo and Nteje areas of Anambra State, Southeastern Nigeria

F U Ogbuagu* and C A U Okeke

1Department of Civil Engineering Technology, Federal Polytechnic, Oko, Anambra State, Nigeria.
2Department of Civil Engineering, Covenant University, Ota, Ogun State, Nigeria.
*Corresponding Author: fredrick.uche@yahoo.com, 08136966947

Abstract: The strength and durability of materials used as subbase and subgrade for pavement design and construction are the main factors determining the performance and service life of highway pavements and airfields. This study investigates the geotechnical properties of lateritic soils from Nimo and Nteje areas of Anambra State, Southeastern Nigeria. The soil samples obtained from the two study areas are hereinafter referred to as LAT-1 and LAT-2 for Nimo and Nteje areas, respectively. The samples were collected at depths ranging from 1 to 1.5 m, and were analyzed at the Anambra State Materials Testing Laboratory, Awka. Geotechnical tests such as Atterberg limits, Standard Proctor Compaction, California Bearing Ratio (CBR), Tri-axial tests and Particle size Distribution analysis were conducted on the soils. All the geotechnical tests were done in accordance with the ASTM and British standards. The soil samples were classified as A-2-7, while the unsoaked CBR values of the soils were 0.89 and 1.43 % for LAT-1 and LAT-2, respectively. The Plasticity Index and Maximum Dry Density of the soils were 21 and 17 %, and 1.93 and 2.19 Mg/m$^3$ for LAT-1 and LAT-2, respectively. Similarly, the effective friction angle and effective cohesion of LAT-1 and LAT-2 were determined as 13.54° and 22.09°, and 38.72 and 10.43kPa, respectively. It was found that the lateritic soil from Nteje (LAT-2) showed higher strength and compaction properties than the soil from Nimo (LAT-1). However, the general trend of the results indicates that the lateritic soils are not suitable for use as subbase and subgrade in pavement construction.

Keywords: Lateritic soil, California bearing ratio (CBR), Pavement construction, Subgrade, Southeastern Nigeria.

1. Introduction
The behavior of laterite and lateritic soil in an undisturbed as well as in laboratory conditions is essential since they are often used as foundation or base layers for road construction [1], [2], [3]. Lateritic soils have the advantage of good porous properties [4]. Obviously, the safety, stability, durability and suitability of roads and airfields greatly depend upon a proper understanding of the geotechnical properties of this soil.

While undertaking a study of the cause of cracking of civil engineering structures especially the roads in most parts of Anambra State, it was observed that the strength and stability of the sub-grade, sub base...
and base course are the main factors in determining the required thickness and good performance of roads. This load bearing strength or engineering behavior is expressed in terms of their CBR value, the magnitude of shear strength from the tri-axial shear laboratory test (the cohesion and shear angle), the nature of compaction curve and the plasticity index (PI) value. The Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index of soils are used extensively, either individually or together with other soil properties to discern engineering behaviors such as compressibility, hydraulic conductivity (permeability compatibility, shrink -swell and shear strength. The LL and PL of a soil and its moisture content can also be used to express relative consistency and liquidity index.

This study is in line with the importance attributed to lateritic soils for road construction in the humid tropical countries where they often develop [5]. Foundation layers are commonly compacted in the course of road construction and are sometimes stabilized by the addition of asphalt, lime Portland cement or other modifiers.

2. Geological setting
Anambra state is located in Southern Nigeria (figure 1) in a humid tropical rainforest region underlain by the sediments of Anambra Basin. The study area is within the Anambra Basin and situates on a N-S trending highland known as Awka Orlu Cuesta. The Awka-Orlu upland has a maximum elevation of about 1500m in Isuofia area. The topography flattens out towards the Northwest into the alluvial sediments of the River Niger and into the Plains of the Cross River toward the Southeast [6].

![Figure 1: Map of Anambra State showing the study areas.](image)

The Paleogene strata within the Anambra Basin that evolved during the Santonian Orogeny consists of sedimentary succession of over 7000m thick. They were deposited under variable environmental conditions. The lithofacies include the Campanian- Maestrichtian Nkporo Shale, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale, Ameki Group (Nanka Sand) Ogwashi-Asaba Formation and Benin Formation) [7], [8], [9], [10], [11], [12], [13].
However, only Nanka Sand and Imo Shale are exposed in the study areas (Nimo and Nteje) (Figure 1). The former forms the resistant highlands that are presently being ravaged by erosion. Approximately, the uppermost 10m has been oxidized to reddish lateritic sandstone [14]. The soil in the areas is mostly bound by laterization.

3. Materials and Method
After the samples were collected from the mining sites (borrow-pits), they were taken to the Anambra State Materials Testing Laboratory, Awka. The samples were air dried for 24 hours at room temperature. Afterwards they were then divided into different parts regarding the tests that were carried out. The tests were carried out according to British Standard (BS) 1377 part 2 and 4, 1990.

4. Results and Discussion

4.1. Compaction
Compaction of LAT-1 was done with moisture content ranging from (11.04% to 19.42%) and the dry density ranging from (1.68mg/m$^3$ to 1.92 mg/m$^3$). The compaction curve (figure 2) shows the optimum moisture content (OMC) at 14.00% while the maximum Dry Density (MDD) at 1.93mg/m$^3$.

![Figure 2: Compaction curve for LAT-1](image)

The compaction of LAT-2 (Nteje) was done with moisture content ranging from (5.64% to 12.38%) and the dry density ranging from (2.09mg/m$^3$ to 2.19mg/m$^3$). The compaction curve (figure 3) shows the optimum moisture content (OMC) at 10.00% while the maximum dry density (MDD) at 2.19mg/m$^3$. 
These results are in agreement with the findings of [15], [16] and [17] for the purpose of fills in dams, buildings and foundation layers in road construction and liner in landfills. The maximum dry density increases with decrease in fines [18]. Low values of optimum maximum content show that the samples have low water absorption and can easily be washed off. Moreso, the low values of the maximum dry density show that the lateritic soils are generally loosely bound. The minimum maximum dry density recommended for base course material is 1.69 Mg/m³ [19].

4.2. Atterberg Consistency Test
The Atterberg limit moisture content result for LAT-1 gave 12%, 46% of liquid limit and 25% of plastic limit (Table1).

| Location | Moisture content (%) | Liquid limit (%) | Plastic limit (%) | Plasticity index (%) |
|----------|----------------------|------------------|-------------------|----------------------|
| NIMO     | 12                   | 46               | 25                | 21                   |
| NTEJE    | 3                    | 35               | 18                | 17                   |

The Plasticity Index is 21%. The Atterberg limit moisture content result for LAT-2 gave 3%, 35% of Liquid Limit and 18% of Plastic Limit indicating the probable absence of expandable clay materials. The value of Plasticity Index is 17%. The lesser the percentage of fines in a lateritic sample, the lesser the Liquid Limit, Plastic Limit and Plasticity Index. Consequently, absence of fines in a lateritic soil results to reduced plasticity and obviously increases the permeability of the soil [25], [26].

Generally, the two samples are of medium plasticity (Liquid limit is between 40% and 70%) [20], [21], [22]. Many past works placed the plasticity of lateritic soils at this same level of moderate plasticity[21], [22], [23],[23] recommended liquid limits not greater than 80% for subgrade and 50% maximum for subbase and base course materials.

In addition, the plasticity index should not be greater than 55% for subgrade and not greater than 12% for both subbase and base course. The studied soil samples fall within this specification, thus making them suitable for foundation layer materials for road constructions. The results also indicate that the soils are of moderate swelling potential [23].
4.3. *California Bearing Ratio (CBR) Test*

The CBR result for unsoaked test shows 0.89% and 1.43% for LAT-1 and LAT-2 respectively (Table 2).

| Location     | C.B.R (%) |
|--------------|-----------|
| Nimo (Lat-1) | 0.89      |
| Njete (Lat-2)| 1.43      |

Lateritic soils are exceptionally recommended as foundation layers when CBR values are greater than 80%.[20] Standard specification states that the subbase, type 2 material shall have a minimum CBR value of 20% and the subbase type 1 materials shall have a minimum CBR value of 30% [24].

Figures 4 and 5 show the CBR test result of the two lateritic soil samples at different Loads (KN) and Penetrations (mm). Picking the penetration at 5mm for each curve gives the CBR values in table 2. When the CBR of sample is low, it indicates low strength of the soil but if it is high, it indicates high strength of the soil. These indicate that the studied lateritic soils cannot be used in road construction particularly as foundation layers [20] [21] [22] [28].

![Figure 4: C.B.R test curve for LAT-1](image-url)
4.4. Sieve analysis/Particle size distribution test.

In the sieve analysis clay is absent. Table 3 shows the result of the sieve analysis.

Table 3: Sieve analysis result for the study areas

| LOCATION       | GRAVEL (%) | SAND (%) | SILT (%) | CLAY (%) |
|----------------|------------|----------|----------|----------|
| NIMO (LAT-1)   | 10         | 55       | 35       | -        |
| NJETE (LAT-2)  | 46         | 43       | 11       | -        |

Grain size analysis enabled the establishment of grain size curves (figures 6 and 7). The overall trend of results indicates that the two particles maintained same behaviours as shown by the curves. The absence of clay indicates low plasticity index and linear shrinkage values. Generally, the lower the linear shrinkage, the lesser the tendency for the soil to shrink when dried [18] [19].
From the table above, LAT-1 can be classified as sandy, silty, gravelly, lateritic soil and LAT-2 gravelly, sandy, silty lateritic soil using the American Association of State High Way and Transportations Officials (AASHTO) system. Following the Unified Soil Classification System (USCS), the samples were classified as good in terms of their suitability as construction materials.

4.5. Triaxial Shear Test
Table 4 shows the result of triaxial test performed on the samples

| Location    | Shear angle ($\Phi$) | Cohesion ($C$) |
|-------------|----------------------|----------------|
| Nimo (Lat-1)| 13.54                | 38.72          |
| Njete (Lat-2)| 22.09                | 10.43          |

Table 4 shows the results of tri-axial test performed on the samples. The results obtained from Mohr circles for LAT-1 reveals the shear angle ($\Phi$) of 13.54° and cohesion ($C$) of 38.72 kPa. The stress state for the two lateritic samples is represented by Mohr circles (figures 8 and 9), the higher the values, the higher the shear strength.
The shear angle (\(\phi\)) for LAT-2 is 22.09° and cohesion (c) is 10.43 Kpa. The two samples have high shear strength as depicted in the high values of the two components of shear strength, the apparent cohesion and shear angle (friction). If soil expands its volume, the density of particles will decrease and the strength will decrease. Consequently, the peak strength would be followed by a reduction of shear stress.

The stress state is represented by Mohr circles (figures 8 and 9), the higher the values, the higher the shear strength. A summary of the laboratory test results for the study areas is given in table 5.
Table 5: Summary of laboratory test results for the study areas

| Location   | Triaxial test | Compaction | C.B.R | Atterberg limit% | Sieve analysis | Classification |
|------------|---------------|------------|-------|------------------|----------------|----------------|
|            | SHEAR ANGLE (°) | COHESION (C) | M.D.D (mg/m³) | O.M.C % | LL | P.L | P.I | M.C | GRAVEL % | SAND % | SILT % | CLAY |
| NIMO       | 13.54 | 38.72 | 1.93 | 14 | 0.89 | 46 | 25 | 21 | 12 | 10 | 55 | 35 | A-2-7 |
| SAMPLE     | 22.09 | 10.43 | 2.19 | 10 | 1.43 | 35 | 18 | 17 | 3.0 | 46 | 43 | 11 | A-2-6 |

5. Conclusion and Recommendation

The results show that the values do not conform completely to the quality requirements of AASHTO and Federal Ministry of Works and Housing (Table 5). Consequently, these samples cannot provide quality materials for better road construction. Several authors [5], [1], [27], [2], [28] & [21] had earlier agreed on the use of lateritic soils for construction. The results also show a general trend in characteristics indicating uniformity in the climatic factors and weathering processes that affected the two areas where the samples were obtained. The uniformity in the topographic conditions further supports the similarity in the values. Stabilization of the soil samples is recommended.

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