ABSTRACT

The subgrades of three different rural roads alignment were investigated with the aim to determine their geotechnical properties. The three roads are on two different geologic terrains. Two of the roads, the 18 km Yahe-Waniye-Wanakom road and the 6 km Okpoma-Okuku road are on Cretaceous sediments terrain, while the 8 km Ugboro-Imaje-Okuku road is on the Basement Complex terrain. Based on American Association of Highways and Transportation Officials (AASHTO) most of the soils classify as A-2-4, A-2-6 on the first two roads with A-7-5, A-7-6 soils interspersed between the A-2-4 soils. The A-2-4, A-2-6 soils were also encountered on the only alignment on the basement complex, but the A-7 group of soils were not encountered on this alignment. Based on The Transport Research Laboratory Road Note 31, subgrade quality on all the three alignments is classed into ‘S4 to S6’ subgrade class. In this classification scheme ‘S6’ is the subgrade of the highest quality.

*Corresponding author: Email: bidemillini@gmail.com, abidemiiilor@uniuyo.edu.ng;
Keywords: Geotechnical characterization; highway; subgrade quality; geology; influence.

1. INTRODUCTION

The underlying soil and rock at a particular site will generally influence any engineering structure at that site. In road construction, the natural soil at such sites often serves as the subgrade material. However, if the materials at site do not meet requirements for its intended purpose (s), then it must be improved upon to meet acceptable engineering requirements as stipulated by regulatory agencies. Such agencies include the Nigerian Federal Ministry of Works, American Association of State Highways and Transportation Officials (AASHTO), American Society of Testing and Material (ASTM) and British Standard Institute (BSI).

Therefore, a proper geotechnical identification and classification of the underlying soil will enable the engineer to carry out adequate and economical design and eventual construction of such a highway pavement.

Within the country of study, it is a general notion that roads in the Northern part of the country last longer than roads in the Southern part especially the South-East, South-South, South-West and the Midwest. While the dominant geology in the Northern part of the country is basement complex same in the South-West except Lagos and Ondo and Ogun riverine, the South-East and South-South are characterized by sedimentary geology. In a study of Calabar-Ilu and Calabar-Akamkpa highway, Edet and Akpan [1] had indicated that, pavement constructed on the basement complex area (Calabar-Akamkpa) have less failure rate compared to Calabar-Ilu highway constructed on sedimentary area. Though the two pavements were constructed about the same period and are exposed to the same climatic conditions. Therefore, it has become imperative to look at the influence of geology on the performance highway pavement in a tropical setting with high rainfall and temperature.

Against this background, some roads in parts of northern Cross River State were selected for study bearing in mind the typical geologic setting of each right of way. These include the following:

i. The 17 km Yahe – Waniye – Wanokom road (Yala Local Government Area).
ii. The 6 km Okpoma-Okuku road (Yala Local Government Area).
iii. The 8 km Ugboro-Imaje-Okuku road (Bekwarra Local Government Area).

1.1 Objectives and Scope of the Study

The general objective of the study is to assess the influences of geology on road pavement. The study aims to investigate whether underlying geology of the terrain the roads being studied will have significance bearing on the geotechnical properties of the subgrade and whether such properties will influence the stability and durability of the road favourably or otherwise. To achieve this, the study intends to do the following along each alignment right of way:

i. Determine the dominant geology in each of the alignment.
ii. Identify the soil types along each route alignment.
iii. Carry out geotechnical characterization of the different soil types.
iv. Determine the suitability or otherwise of the identified soil types as pavement materials.
v. Suggest improvement to the soil if they do not meet required criteria.

2. DESCRIPTION OF STUDY LOCATIONS AND GEOLOGY

The study area is located is located in the extreme North Western part of Cross River State, Nigeria (Fig. 1). The area has the following geographical coordinates; it is bounded by latitudes 6°20’ N in the South and 6°55’ N in the North, and longitude 8°15’ E in the West and 9°00’ E in the East.

The area falls under the Savanna zones of soil of Northern Nigeria. Annual rainfall ranges from 1200 mm to 2000 mm, evaporation is at annual mean of 46.7 mm and temperature at a annual mean of 33.6°C [2].

2.1 General Geology

The study area straddles two geologic terrains. The first is the Precambrian Obudu Plateau (Basement area, BA). The major rock types here include gneisses, schist, metaperidotites, amphibolites, quartzite, charnockites and granites, dolerite and pegmatite intrusives. These rocks belong to the three major lithologic divisions of
the Nigerian basement, namely: the migmatite gneiss complex, the metavolcano-sedimentary series and Pan African Older Granites [3,4]. Overlying the plateau are sedimentary rocks (Sedimentary area, SA) of the Benue Trough. The major rock types are sandstone, shale, mudstone and limestone belonging to the Asu River Group and Eze Aku Formation. The thickness of sediments here has been estimated to range from 2000 to 6000 m [5]. Two major tectonic events affected the area during the pre-Turonian and post Santonian periods. This gave rise to numerous faults and folds with characteristics NW-SE and N-S fracture systems.

2.2 The Road Alignments

The road alignments are described below, while Table 1 presents a summary of the alignment and underlying geology of each of the proposed alignment.

2.2.1 Yahe-Waniye-Wanokom-Okpoma-Okuku road

Yahe and Okpoma road project was proposed for construction to provide efficient rural access road to better the movement of people and agricultural farms produce to major towns of Ogoja and Obudu. Yahe and Okpoma are border communities located near the boundary of the adjoining Benue State in the Northern part of Cross River State. The area lies on a flat to gently undulating slopes of about 0 - 6° and occupies a low-lying area which is derived by positive influence of water lock basin.

The data area is a wetland characterized by swamps, marshes and bogs from engineering point of view, the major engineering problems were excess surface ground water, poor drainage, among others. The length of the Yahe-Waniye-Wanokom road is approximately 18 km traversing from Yahe junction to Benue state border. The route cut across four major villages namely; Ebo, Waniye, Wanikande and Wanokom. The length of Okpoma-Okuku road alignment is 6 km.

2.2.2 Ugboro-Imaje-Okuku road

The study area lies within the Utugwang relief areas, the Bekwarra area is part of the paleoproterozoic geological unit that is bounded by the metamorphic of sedimentary basin of Utugwang with rolling topographical terrain. According to Onyeagocha and Ekwueme [6] the rock type and composition consist of amphibolites bodies invaded by pegmatic veins. Most predominant mineral are the quartz schist biotite and hornblende structural forms of the parent rock ate feature of foliation trends and dip subjected to faulting and folding. The road alignment is 8 km.

3. MATERIALS AND METHODS

Disturbed soil samples were collected from trial pits dug between 1.0 to 2.0 m depths at intervals of 1.0 km, along each road alignment. The sample collection was carried out in February and March, which is period within the dry season. The samples collected were subjected to a range of tests that includes natural moisture content, sieve analysis, Atterberg limits test, shrinkage limit test, modified Proctor compaction test and 24 hours soaked California Bearing ratio test. All the tests were carried out in accordance with relevant American Society of Testing and Materials (ASTM) standards.

4. RESULTS AND DISCUSSION

4.1 Geotechnical Parameters of Yahe-Wanayi-Wanakom Road

Fig. 2 is the plot of the soil domains from all the three alignments on the Casagrande plasticity chart, while Fig. 3 presents grain size distribution for soils from some test location along each of the three road alignments. On Yahe-Wanayi-Wanakom road alignment, the grain sizes for the soils here are uniformly graded. Table 2 presents laboratory analyses results for the soil samples collected along this road alignment.

4.1.1 Soil indices and soil types

Based on American Association of State Highway Officials (AASHTO) classification, more than 75% of the soil sampled classify as granular soil into the A-2 group, with two subdivision of the group dominant; which are A-2-4 and A-2-6, occurring at various locations. The A-2-7 soil subdivision group occurs consecutively at only two locations. The A-2 granular soil is interspersed by fine grained silty and clayey soil, A-7-5 and A-7-6 soils. The A-6 occurs only at a location along this alignment.

The liquid limit values for the A-2 group of soils range from 28.7% to 46.1% while their plasticity index values are from 3% to 18.6%. The A-7
group of soils liquid limits is from 42.5% to 55.1%, while plasticity index for the group is from 19.3% to 21.9%. These two indices are higher in the A-7 soil group than in A-2 group. The shrinkage limits are also higher in the A-7 group at 9.6% to 11.0%, than in the A-2 group which is from 4.4% to 9.4%, exception being 9.9% at kilometer 13 along the alignment. Based on table of soil classification according to shrinkage limits presented by Murthy [7], the soils along this alignment are rated ‘Good’ to Medium good’. The A-7 groups of soils are shale soils.

The A-2 group of soils plots above the A-line on the plasticity chart (Fig. 2), indicating silty sands (SM), and clayey sands (SC). One plots in the clay and silt (CL-ML) band; indicating a dual symbol soil; SC-SM. Three soil samples with the highest liquid limit values of 45.6%, 46.1% and 55.1% plots below the A-line indicating organic based soils with low and high plasticity index respectively.

Liquidity index values of all the soils are less than +1 and more than -1, indicating there is no sensitive clay soil among the soil types [8].

### 4.1.2 Subgrade quality

The 24 hours soaked CBR values for the A-2 group ranged from 9.1% to 29.9%, while that of the A-7 and A-6 soil group ranged from 10.3% to 26%. [9] places these subgrade soils in the S4 and S5 strength classification. In this classification subgrade S6 is the highest. The ‘S’ classification for subgrade is adopted by FRN [10].

AASHTO soil classification scheme rated the A-2 soil group as ‘good’ subgrade material, while the A-7 and A-6 group soil are rated as ‘poor’ subgrade material.

The maximum density values for the subgrade soils ranged from 16.72 kN/m³ to 18.82 kN/m³, while the optimum moisture content is from 9.5% to 12.0%. These moisture content values are all less than the natural moisture contents of the in situ soils. This will create a compaction problem for the subgrade soil. To overcome this problem, the subgrade will need to be scarified deeply to expose the underlying wet soils to the atmosphere to dry to the level the moisture can be controlled when compacted. The scarifying will take place when the grade or formation level of the alignment has been constructed.

### 4.2 Geotechnical Parameters of Ugboro - Imaje - Okuku Road

Table 3 presents laboratory analyses results for the soil samples collected along this road alignment, while from Fig. 3, the soil is uniformly or poorly graded in grain sizes. However the shape of its grain size has a pronounced upward concave.

#### 4.2.1 Soil indices and soil types

The A-2 group of soils dominates this alignment with A-6 occurring at one location. The liquid limits values for the soils on this alignment is between 23.1% to 28.0%, while plasticity index values ranged from 6.2% to 11.9% indicating soil with low expansive potential. On the plasticity chart (Fig. 2), all the subgrade soils on this alignment plots above the A-line and close to the CL-ML band region. Three of the soils plot within the band, indicating dual nature SC- SM soils. The A-7 shale soil group was not encountered along this alignment.

#### 4.2.2 Subgrade quality

The 24 hour soaked CBR for the soils ranged from 9.1% to 29.8%. Based on these, the subgrade soils classify as S4 and S5 using Road Note 31. AASHTO subgrade rating for the soils is ‘good’.

Two of the soils with lowest CBR of 9.1% and 9.7% have the highest natural moisture content values of 26% and 21.6%. The other natural moisture content values are far less than these at 6.3% to 12.4%. Shrinkage limit values are from 3.5% to 6.4%. This indicates ‘good’ quality soil [7].

For the three soil tested to determine maximum dry density and optimum moisture content, the maximum dry density values takes on 18.80 kN/m³ to 20.25 kN/m³, while optimum moisture is mostly nine percent plus, that is 9.1% to 9.9%. The optimum moisture content is not too widely different from the natural moisture content of the subgrade soil along this alignment therefore compaction will not pose any problem, exception to this are at two locations with 21.6% and 26% moisture content. At these location the subgrade soils will have to be exposed to air for drying for the soil to be effectively compacted.
4.3 Geotechnical Parameters of Okpoma - Okuku Road

The soil indices parameters are presented in Table 4. Liquid limits values are from 35.1% to 43.2% while plasticity index is from 13.9% to 21.7%. Most of the soil class into A-2-6, A-2-7 group, while soil sampled at two locations along the alignment classify into A-7-6 group. The highest liquid limits and plasticity index values occur in the A-7-6 soils. These values are 43.2% and 47.3% for the former and 21.7% and 20.3% for the latter. The A-7-6 soils are also shale soil.

The liquid limits and plasticity index values are higher in the soils along this alignment than in the Yahe - Wanayi – Wanakom alignment, and Ugboro - Imaje – Okuku road alignment.

4.3.1 Subgrade quality

The 24 hours soaked CBR for all the soils are higher than 30% except at one location which has a CBR of 13.2%. These values places the subgrade strength in the ‘S6’ class based on Road note 31. The stretch with CBR of 13.2% is in the ‘S4’ strength class.

The optimum moisture content of soils on which compaction tests were carried out is from 8.2% to 14.8%. These values are less than the natural soil moisture content of the subgrade soil. This will create compaction problem of the native soil like in case of the initial two road alignments.

4.4 Soil Expansive Potential

Plasticity index value is a parameter that is commonly used to evaluate the potential for expansion of a given soil. Different classification exists by which the plasticity index values are used to classify a given soil into different degree of expansiveness. Two of such schemes by [11,12,13] are presented in Table 5. Table 6 presents the classification of expansive potentials of the soils along the three alignments using these two schemes. Most soils fall into medium expansive potential using both classifications, although Ugboro - Imaje - Okuku Road has a low expansive potential. These degrees of expansiveness will not be detrimental to any pavement construction on all the alignments.

4.5 Design Moisture Content for the Subgrade

Western Australia Engineering Road [14] gives guide on pavement moisture for strength assessment classifies pavement structure into four units, based on the following attributes;

- Position of water table
- External drainage
- Climate moisture (deficit or Surplus)
- The presence or otherwise of permeability inversion.

It also gives the following formula to determine the design moisture content for granular base and subbase materials as;

\[ MC = 0.70(OMC) + 0.29(AR – PE) + 0.58(P_{0.425}/P_{0.075}) - 0.02(P_{0.236}) \]  

Where

- \( MC \) = Predicted pavement moisture content in outer wheel path (%)
- \( OMC \) = Optimum Moisture Content (%)
- \( P_{0.236} \) = % finer than 3.26 mm
- \( P_{0.425} \) = % finer than 0.425 mm
- \( P_{0.075} \) = % finer than 0.075 mm
- \( AR \) = Annual rainfall (m)
- \( PE \) = Potential evaporation (m)

\[ DMC = MCx[1+1.04(CV)] \]

Where

- \( CV \) = The coefficient of Variation which is taken as 0.15
- \( DMC \) = Design Moisture Content.

Igboro – Imaje - Okuku Road can be assigned the following attributes;

- Moisture surplus climate
- Deep water table
- Good external drainage
- No permeability inversion

Applying equation (1) above to Igboro – Imaje - Okuku Road, in which most of the soil along the subgrade is granular. Design Moisture Content (DMC) calculated for soils samples obtained at kilometer zero and at Kilometer 2 along the alignment gives values of 7.01% and 7.72%. For this computation Annual rainfall (AR) was taken to be 1.2 m, and Potential Evaporation as 0.043 m [2].

For the other two roads, Yahe – Waniye – Wanakom and Okuku – Okpoma roads, the first of three attributes are applicable to them but due to high natural water content, the high...


Table 1. Summary characteristics of the pavement under study

<table>
<thead>
<tr>
<th>S/N</th>
<th>Right of way</th>
<th>Distance (km)</th>
<th>Local government area</th>
<th>Approximate geographical coordinates</th>
<th>Geologic formation</th>
<th>Area</th>
<th>Lithology</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Yahe-Waniye-Wanokom- Road</td>
<td>17</td>
<td>Yala</td>
<td>6° 35' E 8° 35'</td>
<td>Eze Aku</td>
<td>Cretaceous Sedimentary</td>
<td>Shale with basic intrusives</td>
</tr>
<tr>
<td>2</td>
<td>Ugboro-Imaje-Okuku Road</td>
<td>8</td>
<td>Bekwara</td>
<td>6° 40' E 8° 45'</td>
<td>Obudu Plateau</td>
<td>Precambrian Basement Complex</td>
<td>Schist, Gneiss, Amphibolite, Shale</td>
</tr>
<tr>
<td>3</td>
<td>Okpoma-Okuku Road</td>
<td>6</td>
<td>Yala</td>
<td>6° 45' E 8° 30'</td>
<td>Eze Aku</td>
<td>Cretaceous Sedimentary</td>
<td>Shale with basic intrusives</td>
</tr>
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</table>

Table 2. Yahe - Wanayi – Wanakom road in Yala local government area (18 km)

<table>
<thead>
<tr>
<th>S/N</th>
<th>Sampling locations</th>
<th>Distance along alignment (km)</th>
<th>Natural moisture content (%)</th>
<th>Liquid limit (%)</th>
<th>Plastic index (%)</th>
<th>Plasticity index</th>
<th>Liquidity index</th>
<th>Maximum Dry Density, kN/m³ (MDD)</th>
<th>Optimum Moisture Content, % (OMC)</th>
<th>Shrinkage limit (%)</th>
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<th>14</th>
<th>25</th>
<th>36</th>
<th>52</th>
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<th>Soaked CBR (%)</th>
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AASHTO classification
Unified Soil Classification System (USCS)
Lithology

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<th>Plastic limit (%)</th>
<th>Plasticity index (%)</th>
<th>Liquidity index</th>
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<th>Optimum Moisture Content, % (OMC)</th>
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Fig. 1. Geological map of study area, showing the three road alignments
(Source: Inventory of National Site conditions, Cross River Basin Development Authority, 1996)
Fig. 2. Plot of soil domains along the three alignments on the plasticity chart
Fig. 3. Samples of grain size plot of soils from the three road alignments
Table 5. Classification of soil swelling potential

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Table 6. Swelling potentials of soil domains along the three alignments

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<td>Medium</td>
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<tr>
<td>Ugboro - Imaje - Okuku Road</td>
<td>6.2% - 11.9%</td>
<td>Low</td>
<td>Low</td>
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<tr>
<td>Okpoma - Okuku Road</td>
<td>14.7% - 21.7%</td>
<td>Medium</td>
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</table>

percentages of soils passing sieve No 200 on both alignments, the subgrade here is likely to have permeability inversion. The procedure advanced by Western Australia Engineering Road [14] to compute the Design Moisture Content for this situation requires a lot of hydraulic parameters including rainfall intensity, time of concentration, depth of rain water with time, and matrix suction from grain sizes. Computation of these parameters cannot be made because of the type of soil tests carried out in this study which is as a result of limitations of the laboratory facilities available.

4.6 Influence of Geology

4.6.1 Natural moisture content

The natural moisture content of the road alignment on cretaceous sediments with shale and basic intrusive are higher than the road alignment on Precambrian Basement Complex.

The two roads, Yahe-Waniye-Wanokom road and Okpoma-Okuku road are on cretaceous sediments. For the former, the highest moisture content value is 30.7% while lowest value is 12.5%, and an average of 19.3%; while the latter have an highest value of 42% and lowest of 8.2%, with a mean value of 16.4%.

The natural moisture content of the soil on Imaje-Okuku road has a highest value of 26.0% with a lowest value of 7.4 % and average of 12.3%. This road is on the Basement Complex.

The mean value of the natural moisture content of the soils from Imaje-Okuku road, which is on Basement complex at 12.3%, is smaller when compared to the mean values of 19.3% and 16.4% for the two road alignment on Cretaceous sediments.

4.6.2 Grain size distribution and shape

The shape of the grain size distribution curves for the soils from Yahe-Waniye-Wanokom road and Okpoma-Okuku road which shows uniformly or poorly graded soils are concave downward within the sand region, while that from Ugboro - Imaje – Okuku road alignment also within the sand region are concave upward, giving a separation and then a close shape. Soils from basement terrain always gives a pronounce upward concave shape in most part of the grain size distribution plot, that is tends towards the finer side; while soils from sediments gives a downward concave shape within the sand region grain size distribution plot that is the curve sags towards the coarse side. Olofinyo et al. [15] in a study of engineering properties of residual soils in part of Southwestern Nigeria had sieve analysis plot of 16 soil samples, which are residual soils from Basement complex geology. 14 of the curves plotted with upward concave shape that has slight kinks towards the fine region of the sieve graph. Only two plots with downward concave shape. Similar trend are noticeable in the sieve analysis presented by Jegede and Olaleye [16] and Daramola et al. [17] whose works were on road alignments underlain by Basement complexes. All lends support to the proposition that soils from basement complex geology plots on a sieve graph with a upward concave kink.

4.6.3 Soil indices

Liquid limits values are higher generally on Yahe-Waniye-Wanokom road, and Okpoma – Okuku road, which are alignment on Cretaceous sediments with values ranging from 28.7% to 55.1% and 35.3% to 43.2% respectively. While on Ugboro- Imaje – Okuku road, alignment on basement it is in range of 21.6% to 29%. Plasticity index values follows similar trend.
4.6.4 Groundwater and soil drainage

Waziri et al. [18], in a study of instability of the pavement between Shango and Paiko along Minna – Lambata Road, Central Nigeria, had indicated that topography, geology and rainfall determine the depth of groundwater in a given terrain. They posit that these factors together create a condition that makes the section of the pavement studied very unstable. The section is characterized by igneous rocks (Granite, Granodiorite, and Schist) which are highly weathered into clayey materials that are mostly impermeable to the flow of water, coupled with poor elevation of the section of the pavement leads to unfavorable or excessive moisture condition within the soil subgrade that makes the pavement unstable. Furthermore the clays from the weathered rocks here have high expansive potential with plasticity index as high as 44% with a lowest value of 19%. Abam et al. [19], in their study of influence of geology on pavement performance of the Shagamu – Benin highway also indicated that high groundwater table due to the presence of thin weathered soil lying on fresh basement rocks causes high water level and contributed to poor subgrade drainage thereby making pavement unstable. For the pavement under investigation, the soils on the lithologic types can be classified mostly as having low expansive potential, index as presented in Table 6.

With respect to groundwater level, no ground water table was encountered along all the two lithologic terrain during soil sample collection. Although; the subgrade moisture content for all the soils on Cretaceous sediments all have higher values than those from Basement lithology. The pavement alignment on the Basement lithology appears to be well drained. Also fresh rock or rock outcrops were not encountered in any of the sampling pits all along alignment on the Basement terrain. Therefore, the risk of pavement instability due to high ground water level trapped by fresh rock close to the surface is not likely to occur.

5. CONCLUSIONS

Geotechnical properties of the subgrade on three rural roads on two different geologic terrains were determined. The subgrade soil on all the alignments were classified into the ‘S4 to S6’ class based on [9].

The soils of the subgrade on the two roads on the Cretaceous sediments have clayey sands (SC), silty sands (SM), as the dominant soils but are interspersed with inorganic clays (CL) and inorganic silts (ML). These latter soils were not encountered along the subgrade soils on the Basement complex terrain.

Some inferences were made with respect to geologic influence on natural moisture content, grain size analysis plot shapes, soil indices and soil and drainage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES


14. Western Australia Engineering Road Note No. 5. Interim guide to prediction of pavement moisture for strength assessment of granular base course and subbase materials. Main Roads, Western Australia; 2003.


