INVESTIGATION OF THE PROPERTIES OF FAILED SECTIONS ALONG ABAKALIKI-OBUBRA ROAD SOUTHEASTERN, NIGERIA

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ABSTRACT

Geoelectrical, mineralogical and geotechnical investigations was conducted to determine factors responsible for pavement failure in Abakaliki-Obubra road in Ebonyi State, Southeastern Nigeria. Six Vertical electrical sounding (VES) investigation of deeper section of the study area show that the area is underlain by four layers; top soil, sandy-clay, silty shale and clay with resistivity range of 32.0-201.6Ωm, 22.6-450.6Ωm, 15.9-95.1Ωm and 19.0-78.9Ωm respectively with KH, Q, HK, KK, H curve types respectively. The Optimum Moisture Content (OMC) of the sub-grade ranged from 13% to 21%. While those of the sub-base ranged from 8.8% to15%. The strength are far less than the minimum required value. The Maximum dry density (MDD) values for subgrade and subbase ranged from 1.53g/cm^3 to 1.81g/cm^3 and 1.59g/cm^3 to1.89g/cm^3 respectively. The amount of materials passing 0.075mm sieve for subgrade varied from 20% to 94% and 20% to 56% for the subgrade materials. The Plasticity Index (PI) of the sub-grade generally ranged from 8% to 30% and 6% to 35% for the subbase. The Liquid limit (LL) for subgrade and subbase ranged from 22% to 62% and 30% to 62% respectively. The X-ray diffraction results revealed that the study area was composed of a significant clay mineral montmorillonite. It was concluded that low MDD, the class of subsoils namely A-7-5, A-7-6(clayey soils), Poor drainage and the presence of montmorillonite maybe responsible for the cause of failure experienced in the study area. The soils are unsuitable for the road construction, requiring the necessity for stabilization during the road's reconstruction and rehabilitation.

Key words: Optimum Moisture Content, Maximum dry density, Vertical electrical sounding, X-ray diffraction

INTRODUCTION

The rate of pavement failures in Abakakili-Obubra road of Ebonyi State, Southeastern Nigeria is appalling. This condition poses challenges to both the government and the entire road users. Most roads within the area suffer severe deformation shortly after construction contrary to their designed lifetime. The pavement deformation includes fatigue, depression, rutting, corrugation, and potholes. The high frequencies of pavement failures are of concern to both road users and road engineers in Ebonyi State. Several internal roads within the study area are characterized by pavement failure. The problem had necessitated intensive researches to find out remote causes and means of improving pavement strength in the area under investigation. In their assessment of road failures in Abakaliki area. Aghamelu and Okogbue (2011) ascribed the ongoing failures to the low sub-grade quality and lack of suitable lateritic soil for subbase and base course layers, as well as the usage of lateritic soils for sub-base and base course layers. In addition, they claimed that shale material with poor geotechnical quality was frequently used as sub-base and subgraded for road construction, which contributed to road failure. Similarly, Ekeocha and Akpokodje (2012) used CBR for the assessment of sub-grade of lateritic soil from the part of Lower Benue Trough and concluded that geotechnical properties were of poor quality, thus they suggested soil stabilisation for soil improvement. This study aims at assessing the impact of geophysical, mineralogical and geotechnical properties of latenritic soils on sub-graded and sub-base contribution to road failure in Abakaliki-Obubra road. Taking into consideration the recurring pavement failure of the Abakaliki-Obubra road, there's need to assess the integrity of the underlying sub-grade and sub-base materials before rehabilitation. Road pavement failure is expected where there is relatively low resistivity and low CBR values along the section of the road.

Most road pavement failures have been attributed to problems associated with the subgrade and subbase. The subgrade and subbase are the receiving platform for the weight of the wheel load exerted on the road pavement. This study intends to evaluate the influence of lateritic soils' geotechnical and mineralogical characteristics on the sub-base and sub-grade contributions to road failure on the Abakaliki-Obubra road. Before repair, it is necessary to evaluate the integrity of the underlying subgrade and subbase materials in light of the Abakaliki-Obubra road's persistent pavement collapse. Where the resistivity and CBR values along the road are quite low, pavement failure is to be expected Ademila, O. (2021).

MATERIALS AND METHODS

Location of study

The study area Abakaliki-Obubra road in South-eastern Nigeria lies within latitudes 06°02'30" - 06°18'03" N and longitudes 08°10'12" - 08°16'23" E. (Fig 1).

The study area is underlain by the Asu-River Group in southeastern Nigeria (Reyment 1965). stated that Eze-Aku Group overlies the Asu River Group, The group is a product of first marine transgression in the Benue Trough. The Asu-River Group which composed of over 200 m thick shale and sandy shale, siltstones, mudstones, lenses of sandstone and limestone and subordinate pyroclastics and intrusive unconformably underlies the Eze-Aku Group. Igwe and Okoro, (2016).

The study area is located in the South East of Nigeria, it links Abakaliki to Obubra. The road carriage way is 7.03m wide flexible pavement. The carriage way in most places consist of 60-100mm asphaltic concrete layer underlain by 100 -170mm stone base on subbase and subgrade of laterite.

The road is characterised by gentle slope with the highest point of elevation on the Abakaliki end.

During the fieldwork, visual inspection and reconnaissance surveys were conducted to assess and get access to the pavement's physical conditions. Forty-Five (45) samples of disturbed soil were taken with the aid of a shovel from the sub-grade, sub-base. To preserve its natural wetness, the samples were kept secure and sealed inside an airtight sack bag. The samples were labeled with information about the soils, sampling depths, and sampling dates.

The vertical electrical sounding (VES) subhead was used to conduct an electrical resistivity survey, which resulted in the acquisition of the geophysical data. Schlumberger's array was used to acquire the Vertical Electrical Sounding, which is an electrical resistivity study method. Across the study region, six (6) stations in total were examined geophysically. The resistivity meter t ABEM SAS 1000, was utilized to collect the field data as the electrode spacing was adjusted between 1 and 30m. The apparent resistivity was plotted against AB/2, or half the spread length, to create field curves, which represented the resistivity data (bi-logarithmic paper). Visually examining the field curves allowed for a qualitative interpretation of the data, and partial curve matching allowed for a quantitative interpretation as well and computer iteration method using WinResist Version 1.0 to obtain initial estimates of resistivity and thickness of the various geoelectric layers at each VES location.

Five (5) randomly chosen soil samples were taken to Kaduna's National Steel Raw Materials Exploration Agency for mineralogical examination. The tests were conducted using the X-ray diffraction (XRD) technique using RIGAKU Miniflex.

A minimum of 16kg of materials for each sample from the sub-base and sub-grade layers were carefully collected and placed in airtight bags and labeled laboratory. Forty-Five (45) samples were collected from sub-base layer at the depth between 400 and 500mm, while a total of Forty-Five (45) sample for subgrade samples were collected within the depth of 600 and 800mm. Before being subjected to geotechnical test, the samples were spread out on various mats to facilitate air drying and all of the clods and lumps were broken down and reduced to tiny particles. The geotechnical tests were performed in compliance with ASTM D6913-04, 2009 for Sieve analysis, ASTM D4318-10, 2015 for Atterberg Limit tests, ASTM D854-10, 2015; ASTM D854-14, 2015 for Compaction, and BS 1337 for California Bearing Ratio (CBR) tests. The strength tests included the California Bearing Ratio (CBR), which was designed to assess load bearing strength, and compaction to establish the ideal moisture content and maximum dry density.

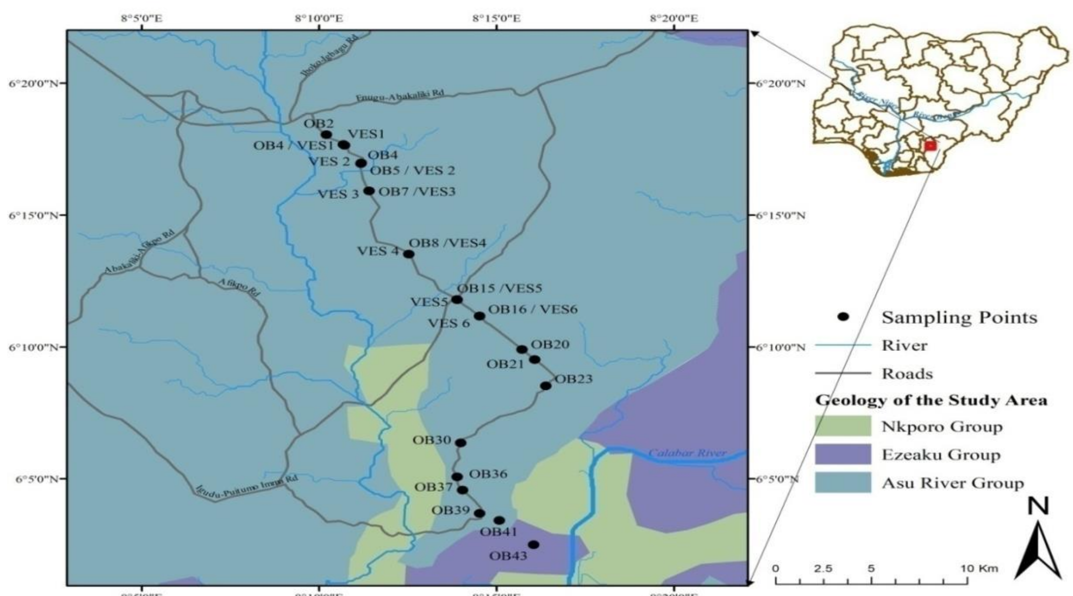


Fig 1. Location and Geology of the Study Area

RESULTS AND DISCUSSION

Electrical Resistivity Method

The results of the vertical electrical soundings carried out at stations 1-6 (Fig. 3-8) are summarized as a table of geo-electric parameters (Table 1) and geo electric section (Fig 2).

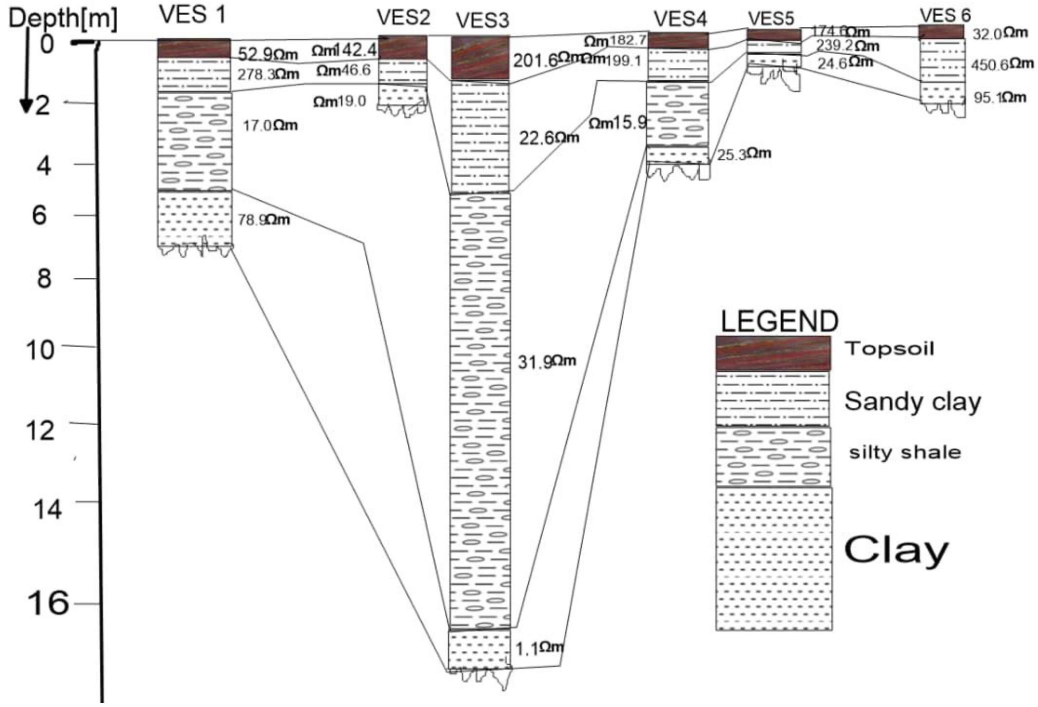


Fig 2. Geo-electric section along the studied section of Abakaliki-Obubra road

The geo-electric section presents the variation of the subsurface lithologic unit along Abakaliki-Obubra road. VES results show four (4) observable lithologic units successions along Abakaliki-Obubra road, the first, second third and fourth layers which are top soil, silty shale, sandy-clay and clay respectively (Fig 3-8). The resistivity of the various lithologic units ranged from: 32.0-201.6Ωm for top soils, 22.6-450.6Ωm for sandy clay, 15.9-95.1Ωm for silty clay soil and 19.0-78.9Ωm for clay.

The stability of road pavement can be inferred from the resistivity of the subbase and subgrade and the overburden lithologic units. Increase in moisture and clay content lowers the resistivity values of the overburden (tends to be less than 100 Ωm), with the presence of clay and moisture suggestive of weak zones that are capable of determining the stability of overlying road pavement. It was observed that stability of road pavement along the Abakaliki-Obubra road decreases with lower average overburden resistivity, as the lower resistivity (< 100 – 200 Ωm) is indicative of abundance of clay presence. The various curve types in the study area are; KH, Q, HK, KK and H.

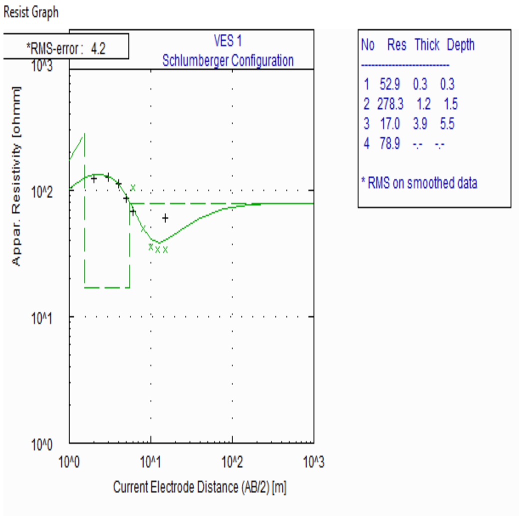


Fig 3. VES inversion curve for VES station

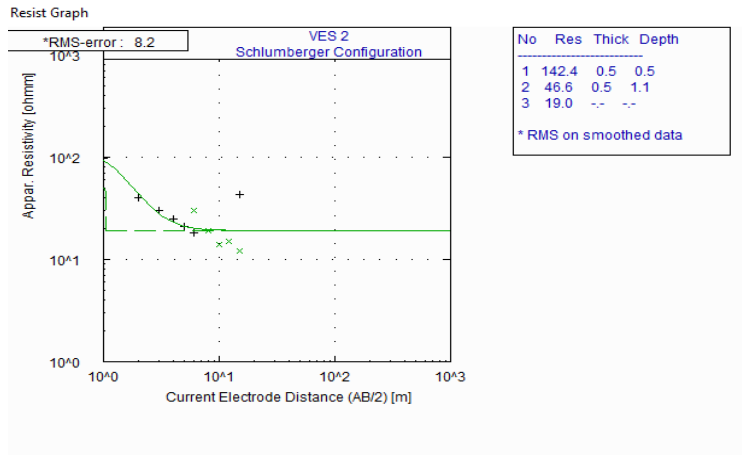


Fig 4. VES inversion curve for VES station 2

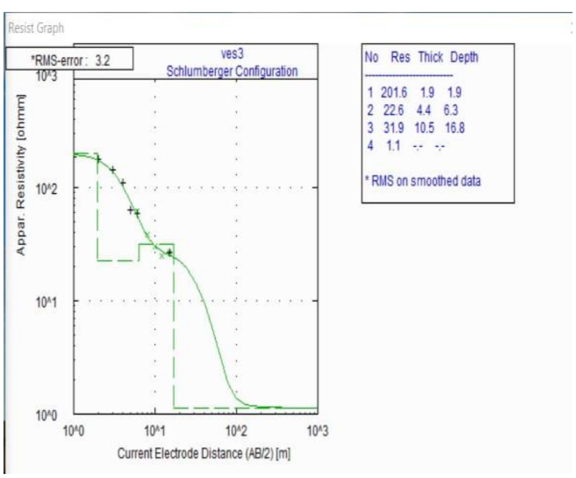


Fig 5. VES inversion curve for VES station 3

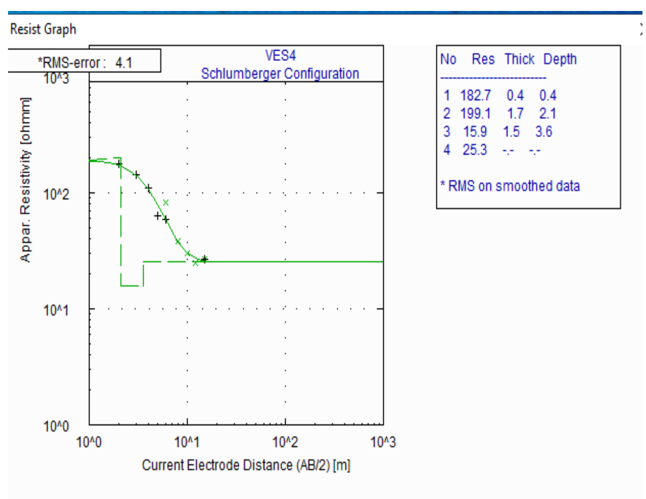


Fig 6. VES inversion curve for VES station 4

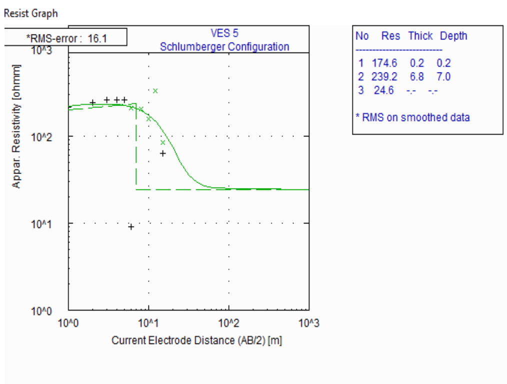


Fig 7. VES inversion curve for VES station 5

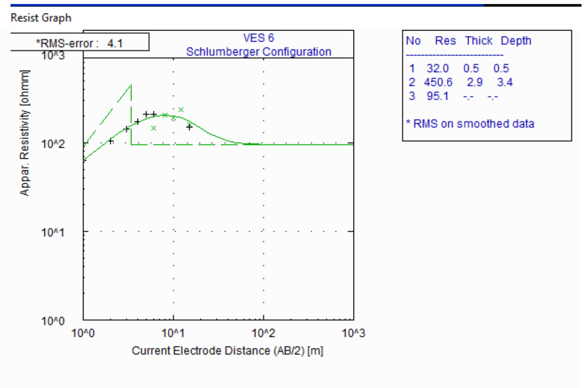


Fig 8. VES inversion curve for VES station 6

Table 1. VES results

VES No	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve type	Lithology
1	1	52.9	0.3	0.3	KH	Topsoil
	2	278.3	1.2	1.5		Sandy Clay
	3	17.0	3.9	5.5		Silty Shale
	4	78.9	---	---		Clay
2	1	142.4	0.5	0.5	Q	Topsoil
	2	46.6	0.5	1.1		Silty Shale
	3	19.0	---	---		Clay
3	1	201.6	1.9	1.9	HK	Topsoil
	2	22.6	4.4	6.3		Sandy Clay
	3	31.9	10.5	16.8		Silty Shale
	4	1.1	---	---		Clay
4	1	182.7	0.4	0.4	KK	Topsoil
	2	199.1	1.7	2.1		Sandy Clay
	3	15.9	1.5	3.6		Silty Shale
	4	25.3	---	---		Clay
5	1	174.6	0.2	0.2	H	Topsoil
	2	239.2	6.8	7.0		Silty Shale
	3	24.6	---	---		Clay

6	1	32.0	0.5	0.5	H	Topsoil
	2	450.6	2.9	2.9		Silty Shale
	3	95.1	---	---		Clay

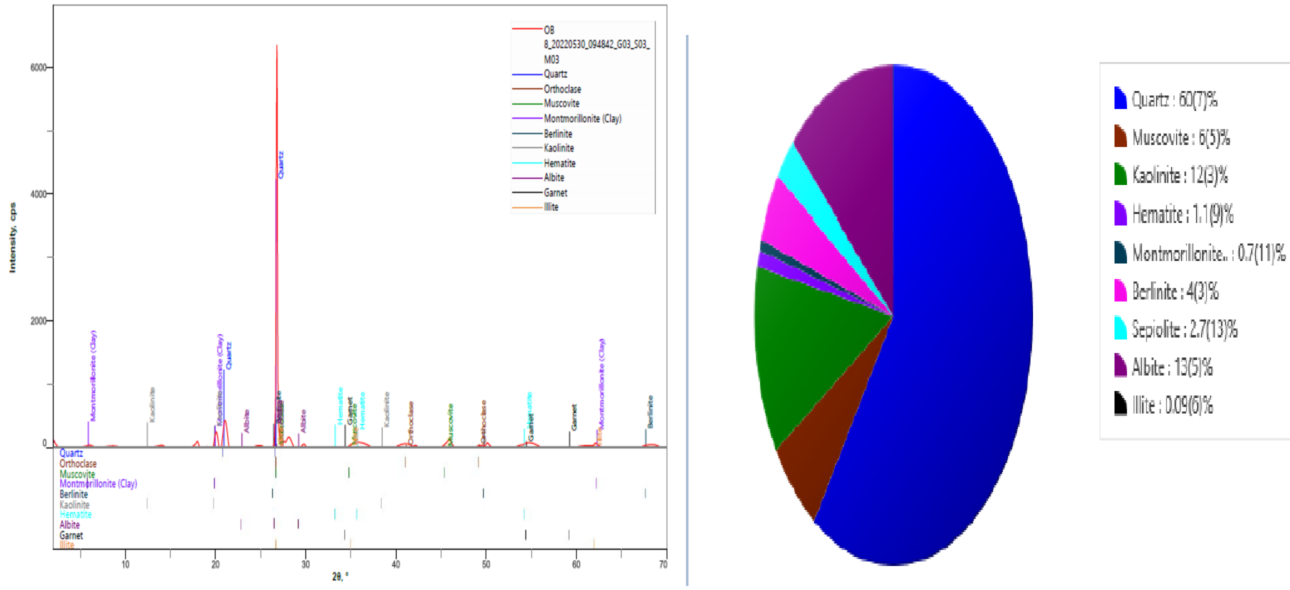
Mineralogical Properties of Some Selected Soil Samples

The mineralogical characteristics of the five chosen samples are displayed in Table 3. Quartz, hematite, muscovite, illite, kaolinite, and montmorillonite are the dominant mineral kinds.

Onana et al(2017) speculate that the presence of muscovite in particular areas may cause a problem with field compaction. The X-ray diffractograms of the whole soil samples (Fig. 9-13) shows that the two main clay minerals present are montmorrilonite and kaolinite (Table 3). Sections of the road along Abakaliki-Obubra road which contain relatively montmorillonite in the soil structure exhibit severe form of pavement failure, This is expected because montmorillonite is an active clay mineral with high hydroaffinity which causes cyclic soil swelling and shrinking resulting in pavement distress and damages. The high clay mineral content correlates well with low values of resistivity and high natural moisture content. Sections of the road at Abakaliki-Obubra area where the soils contain mainly kaolinite as the clay mineral experienced less severe pavement failure since kaolinite is a relative more stable clay mineral than montmorillonite in terms of differential volume changes.

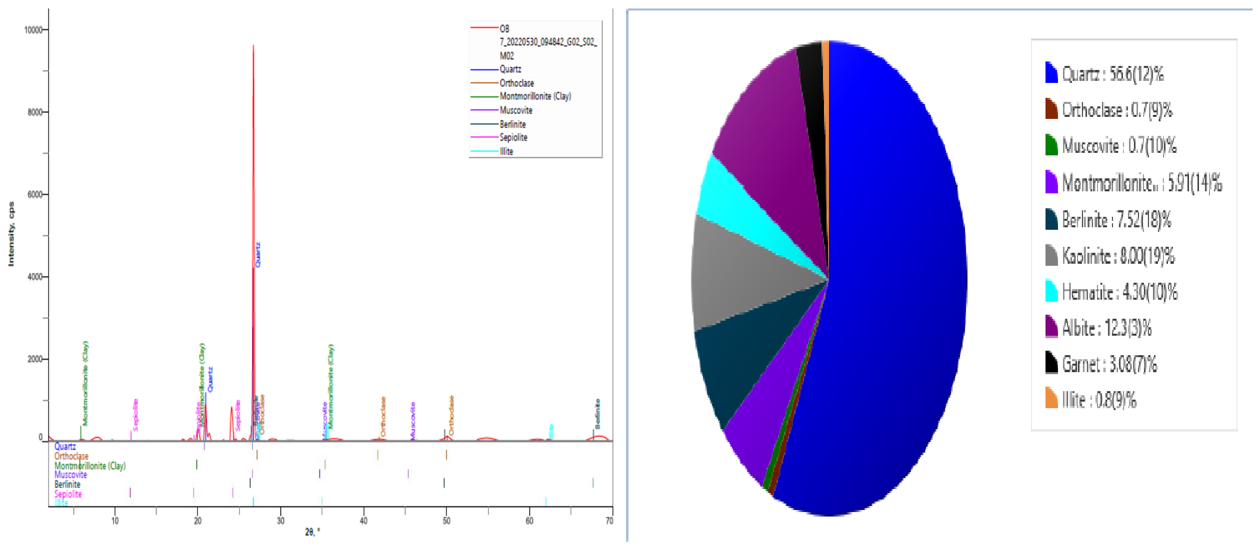
Table 2. Mineralogical properties

Sample Locations	OB4	OB14	OB8	OB16	OB7
Quartz (%)	52	60	56.6	58.6	65
Muscovite (%)	1	6	0.7	8.6	2
Kaolinite (%)	9.0	12	8	6.78	---
Hemetite (%)	0.6	1.1	4.30	3.53	---
Montmorillonite (%)	---	0.7	5.91	4.5	6.2
Sepiolite (%)	---	2.7	---	2.84	0.6
Albite (%)	1.6	13	12.3	3	---
Illite (%)	1.3	0.09	0.8	6.27	1.7
Berlinite (%)	8.1	4	7.52	6.42	14.3
Garnet (%)	3.3	---	3.08	---	---
Nacrite (%)	4.5	---	---	---	---
Orthoclase (%)	---	---	0.7	---	10.8



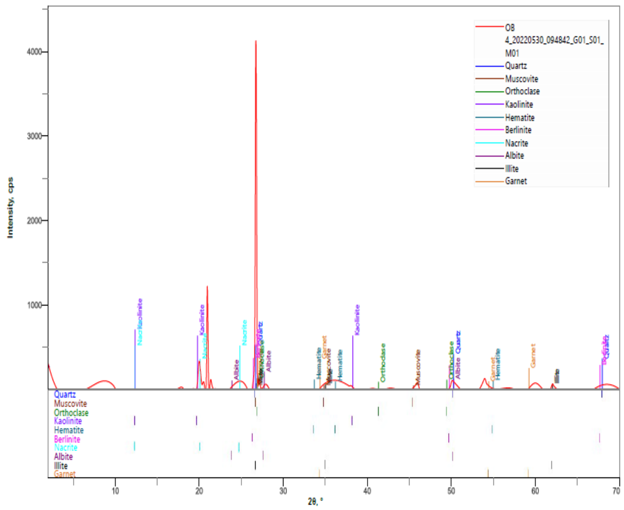
(a) (b)

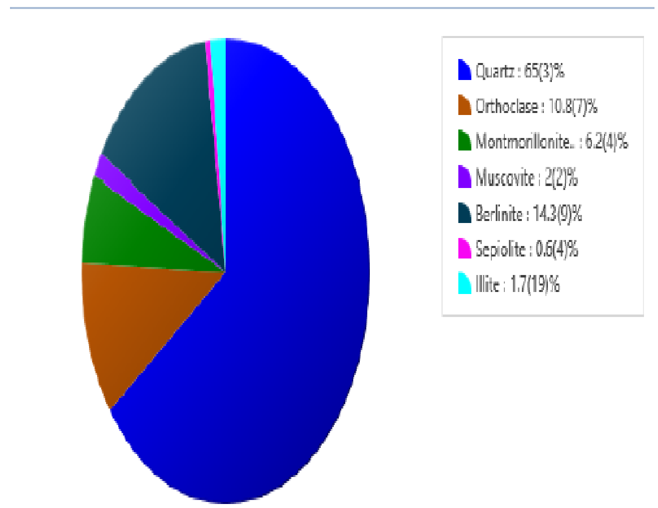
Fig 9. (a) X-ray diffractogram of sample OB8 (b) XRD results showing phase data view



(a) (b)

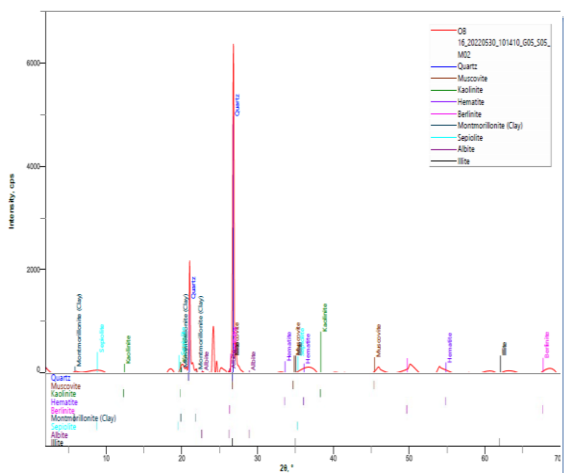
Fig 11. (a) X-ray diffractogram of sample OB7 (b) XRD results showing phase data view

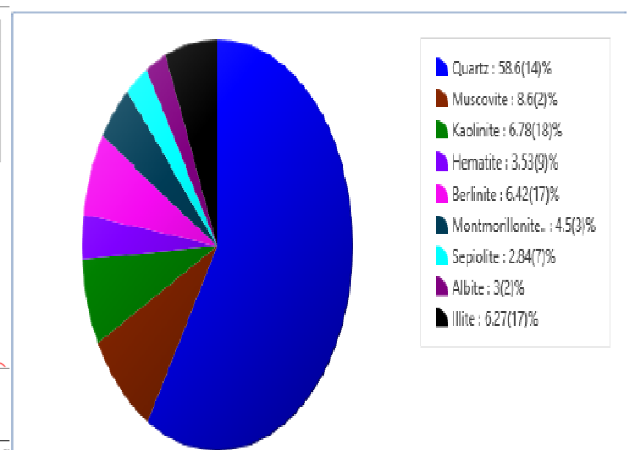




(a) (b)

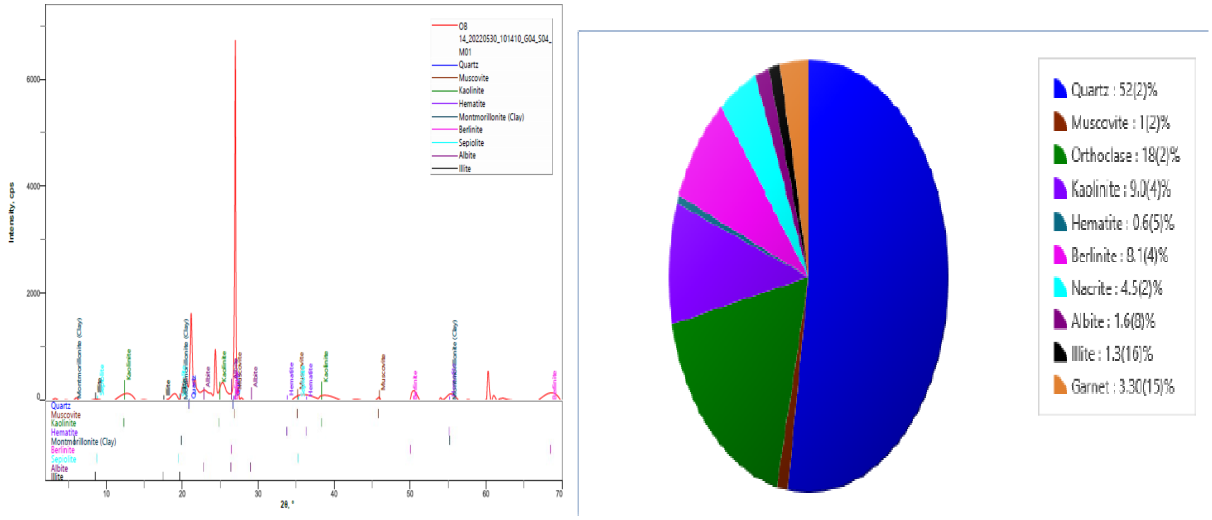
Fig 10. (a) X-ray diffractogram of sample OB4 (b) XRD results showing phase data view





(a) (b)

Fig 12. (a) X-ray diffractogram of sample OB16 (b) XRD results showing phase data view



(a) (b)

Fig 13. (a) X-ray diffractogram of sample OB14 (b) XRD results showing phase data view

Geotechnical properties of the soils

The results of the particle size distribution of soils taken from the subgrade layer of the soils reveals soil type A-7 to be characterized by the highest percentage the range of percentage fines (94%) and soil type A-2 exhibit lowest percentage of fines (20%). All the soil types encountered in the subgrade layer where >20% fines and are thus only suitable as subgrade (table 3).

Most of the soil types revealed low to medium plasticity <50% with few exceptions as observed in samples A-2 and A-7 with 56% and 63% (table 4).

Table 3: Range of percentage fines for subgrade soils

Soil types	No. of samples	Range of percentage fines
A-2	8	20 – 35
A-4	5	41 – 93
A-5	2	41 – 49
A-6	4	38 – 43
A-7	26	35 – 94

Table 4: Range of Liquid limit and plasticity index values for the soil group for subgrade layer in the study area

Soil types	No. of samples	Liquid Limit (%)	Plasticity Index	AASHTO Classification
A-2	8	43 – 56	14 – 28	A-2
A-4	5	28 – 34	8 – 10	A-4
A-5	2	36 – 47	8 – 10	A-5
A-6	4	22 – 34	11 – 15	A-6
A-7	26	22 – 63	13 – 31	A-7

According to Ugbe (2011) maximum dry density increases as the amount of fines decreases. Thus soil type A-2 with the lowest amount of fines (35%) encountered in the subgrade is characterized by the highest maximum dry density 1.98 kg/m^3 (table 5).

Table 5: Range of maximum dry density and optimum moisture content for subgrade layer in the study area

Soil type	No. of samples	Maximum dry density (kg/m^3)	Optimum moisture content (%)
A-2	8	1.65 – 1.98	12.4 – 15.7
A-4	5	1.60 – 1.74	15.2 – 19.1
A-5	2	1.62 – 1.70	15.8 – 17.2
A-6	4	1.57 – 1.62	15.4 – 19.4
A-7	26	1.53 – 1.85	13.5 – 20.5

Liquid limits(LL) and Plasticity index (PI) for 45 tests on the sub-base, The LL and PI values range from 29% to 62% and 6% to 35% , respectively, where as the average value of LL is 49% while for PI is 18%. As explained, the existing sub-base materials does not comply with this requirement in many areas. The grain size study is crucial for assessing the strength of the soil and the distribution of particle sizes in the examined soils Naresh and Nowatzki (2006).

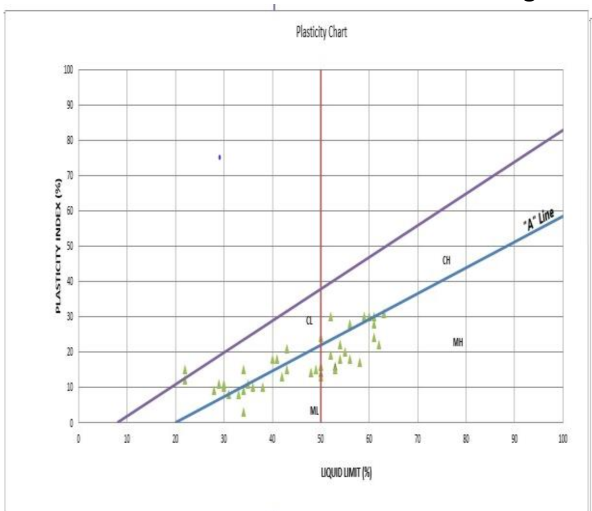


Fig 14. Plasticity chart of the subgrade samples.

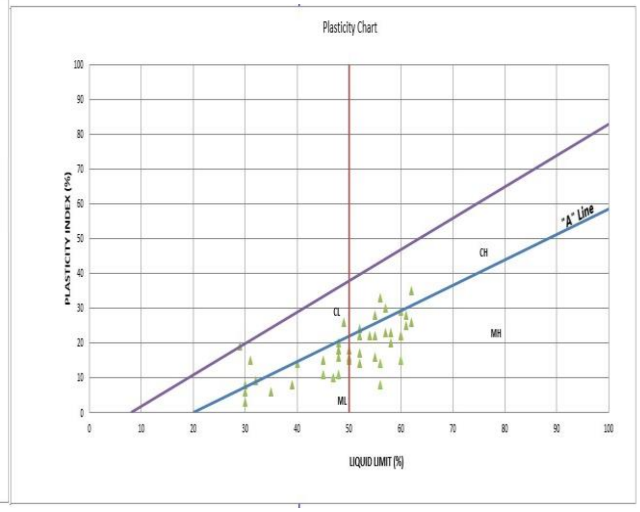


Fig 15. Plasticity chart of the subbase samples.

According to Ola (1983), soils with a plasticity index of less than 25% have a low to medium swelling potential. The study's findings were represented on the plasticity chart. (Fig. 14-15) Consequently, it can be seen that 45% of the soils were plotted in the field of clays, whereas 55% of the soils were plotted in the field of silts for subgrade. While 36% of the soils were plotted in the field of clays, whereas 64% of the soils were plotted in the field of silts for subbase. The soil in the examined area are of a medium to high plasticity. Additionally, the criteria for a significant swelling potential is met when the plasticity index is between 20 and 35% and it must be between 25 and 41% to meet the requirement for a high degree of expansion Gopal and Rao,(2011). It is the main deciding factor in the choice of materials for subgrade and subbase. Compared to grain size data, it provides far more precise information on the characteristics and behavior of clays (Lambe, 1951). According to Adeyemi (1995, 2002), excessive plasticity typically causes fluctuations that come from plastic flow when load is applied, and soils with exceptionally high liquid limits are frequently prone to having low bearing capacities. According to Cassagrande, (1947), soil that are low, medium, and high in plasticity will also be low, medium, and high in compressibility. The liquid limit (LL) of the subgrade, sub base, and base course was found to be higher than the suggested value of 35% (Table 5-6) and the plasticity index to be higher than the stipulated value (12%) in most of the locations.

FMWH (1997) recommends subgrade soils to possess less than 35% amount of fines. The results obtained in comparison with FMWH (1997) shows that thirty seven (37) for sub-grade and thirty three (33) soil samples did not meet the specification from a total of 45 samples each.

FMWH (1997) recommends that soils should be in the range of 1.50–1.78 g/m^3 for the MDD and optimum moisture content (OMC) of 8.56–12.02%.

The OMC of both the sub-grade and sub-base range from 8.8% to15%(that is also a typical range for the lateritic gravel materials). (FMWH 1997) proposed that California Bearing Ratio (CBR) should be greater than 10% for subgrade materials. The results revealed that the CBR values of some soils are lower than the recommended value. The corresponding low values of CBR are partly responsible for the failure of highway pavement in the study area.

When the textural characteristics and consistency results were evaluated, the soil samples classified as clayey of intermediate to high plasticity, predominantly GM, SC and SM according to the Unified Soil Classification System, and as A-7-5 and A-7-6 soils using the AASHTO (1993) classification system, all implying that they are of poor quality as subgrade and subbase materials in pavement construction. It can be inferred from the result that the soils maybe susceptible to frequent shrinkage and swelling potentials due to variation in climatic seasons which are usually the characteristics of the environmental condition of the study location. The high percentage of fines had been linked to the predominance of clay which feasibly exerts a dominant control on the mass behavior of soil which makes it unfit. The present sub-base materials and sub-grade course have fallen short of their requirements, as has been shown in various sections of this study.

CONCLUSION

The field investigation of Abakaliki-Obubra road has been carried out. The fine content of the sub-base and sub grade materials has exceeded its maximum limit in many places. Further to that, it has high liquid limit and plasticity. The Natural moisture in some sections exceed the optimum moisture content despite the investigation was carried out at the peak of dry season, this is an indication that the depth to water table is shallow. Unavailability of good construction materials (Laterite) around the study area of the road project will therefore encourage consideration of rigid pavement in case of total reconstruction.

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