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Geotechnical Investigation of some Failed Sections of Umuahia-Uzuakoli and Uzuakoli-Ozuitem Roads in Bende Area, Southeastern

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Abstract: *Durability of a highway is influenced by the engineering properties of subgrade soils and pavement materials. Roads fail when their pavement is built on an active zone of expansive soil subgrade, which experiences seasonal volume changes, leading to shrink and swell behavior that results to pavement distress. This study focuses on the geotechnical investigation of the km 16 Umuahia – Uzuakoli (Ubani) and km 8 Uzuakoli – Ozuitem (Isiegbu) highways in Umuahia Bende Area, southeastern Nigeria to identify the causes of indiscriminate road failures. The engineering properties of disturbed expansive subgrade soils from the Ameki formation were assessed through field, physical, geological and laboratory tests focusing on grain size distribution, specific gravity, natural moisture content, Atterberg limits, compaction and California bearing ratio (CBR). The study revealed natural moisture content values ranging from 23.7% to 35.6% (29.7%), liquid limit values between 50.60% and 51.90% (51.25%), plasticity index values between 17.50% and 24.60% (21.05%). Linear shrinkage values between 10% and 14% (12%). Maximum dry densities were 1.48 Mg/m³ to 1.56Mg/m³ (1.52 Mg/m³) and CBR values ranged from 10% to 11% (11% unsoaked) and 5% (5% soaked) for both locations. Grain size results showed that none of the soils have particles coarser than 2.36mm, having up to 60% passing sieve 200 (75microns) and as such are classified as fine grained soil. Casagrande plasticity chart classified them as CH and MH soils, recognized to be inorganic fat clay and elastic silt respectively. Failed sections of the road were due to high values of liquid limit (LL), plasticity index (PI) and linear shrinkage which are indicators of the expansive nature of subgrade soils derived from Ameki Formation in the study area. The study recommends appropriate drainage systems and chemical stabilization with lime and cement.*

KEYWORDS: *Subgrade, Geotechnical test, Road pavement, Road failure, Expansive Soil, Ameki Formation*

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1. INTRODUCTION

Failures on a road network are usually noticed when a road pavement is constructed on an active zone of expansive soil subgrade usually caused by seasonal volume changes in the water content of the soil leading to its shrink and swell behavior causing cracks, potholes, surface defects, subsided and completely collapsed thereby resulting to the hindrance of free movement of traffic.

In Nigeria, the occurrence of high number of failed road sections has become so unbearable and challenging with responsible factors attributed to climatic conditions of the region, geology and geotechnics of the subgrade unit, geomorphology, poor engineering design, inferior quality of construction material and selection, poor technical knowhow of construction procedure and practices, poor usage and lack of maintenance polices reveling extensive potholes, depressions, cracks, edge failure and shoving of the pavement surface layer (Agbede and Osuolale, 2005; Nwachukwu et al., 2022).

Ajah et al., (2019) described the geophysical and geotechnical investigation of failed section of Orsu-Ihiala Road Southeastern Nigeria, they narrated that the road failed shortly after repair causing traffic obstruction. 2-D pseudo-section was employed during the investigation and it was determined that the area was underlain by moderate to low resistivity corresponding to partially stable and failed section of the road, VES Investigation was further used for deeper section of the failed zones and it showed that the area was underlain by four layers; clayey top soil, clay, clayey-sand and sand. Ogbuchukwu et al., (2019) described the failure of roads in Awka area Southeastern Nigeria, due to occurrence of expansive soils in the area (Ameki Formation). The likely causes of failures are due to poor drainage construction and clayey material found as subgrade (Ameki Formation) in the study area.

Additionally, Ogbuchukwu and Okeke,(2021) and Okeke et al. (2015) described the use of cement and lime as additives in the modification of the geotechnical properties of expansive soils in Awka and Environs and Awgu Area, respectively so as to reduce the swelling potentials of foundation soils which were superficially expressed as cracks on roads and buildings within the study area. They determined that lime and cement stabilization of expansive soils in study area have the general effects of reducing the swelling indicators (liquid limits, plasticity index and linear shrinkage) and increasing the shear strength characteristics (MDD and CBR) in the presence of water.

The aim this study is to investigate the geotechnical distinctiveness of subgrade soil in km 16 Umuahia - Uzuakoli and km 15 Uzuakoli - Ozuitem road in Bende area of Abia State Southeastern Nigeria using geotechnical characterization which will help identify the causes of prevailing road failures within the area.

Fig 1: Failed section of Umuahia-Uzuakoli (Ubani) road caused by expansive soil derived Ameki Formation

II. DESCRIPTION OF STUDY AREA

A. Physiography and climate of study area

Geographically, the study area being km 16 Umuahia - Uzuakoli and km 8 Uzuakoli - Ozuitem roads lies within the tropical rainforest zone of the Niger Delta basin Southeastern Nigerian Sedimentary complex of present day Abia State (Fig.2), Situated between latitude 5°28' N to 5°40' N and longitude 7°26' E to 7°43' E. According to Reyment, (1965) he described the area as an extension of the Lower Benue Trough.

The climate of the area alternates between the rainy and dry season with total mean annual rainfall of 2,000mm to 3,000mm and above distributed over the month of April to October with maximum peak of rainfall in June. November to March was observed as dry season in the area (Nigerian Metrological Agency, 2007). The study area is characterized with high temperature levels throughout the year between 20°C to 30°C with the hottest period occurring in dry season, a high relative humidity of about 76° and dense evergreen vegetation composed of different species of tall shrubs, forest trees and grasses (Iloeje, 1971).

The topography of the area from the North is composed of rugged cuestas and plateau escarpment with steep slopes while the southern part is composed of gentle hills and valleys. The area is drained by few rivers which include Niger River, Ase River, Imo River, Kaw ibo River, Orashi River, Ikwu River and Inagang River etc, forming a dendritic drainage pattern, with its tributaries joining the collector stream roughly at right angles, structurally controlled and expressed as rectilinear channel geometry (Obioha et al, 2021; Iloeje, 1971 and Nwajide, 2013).

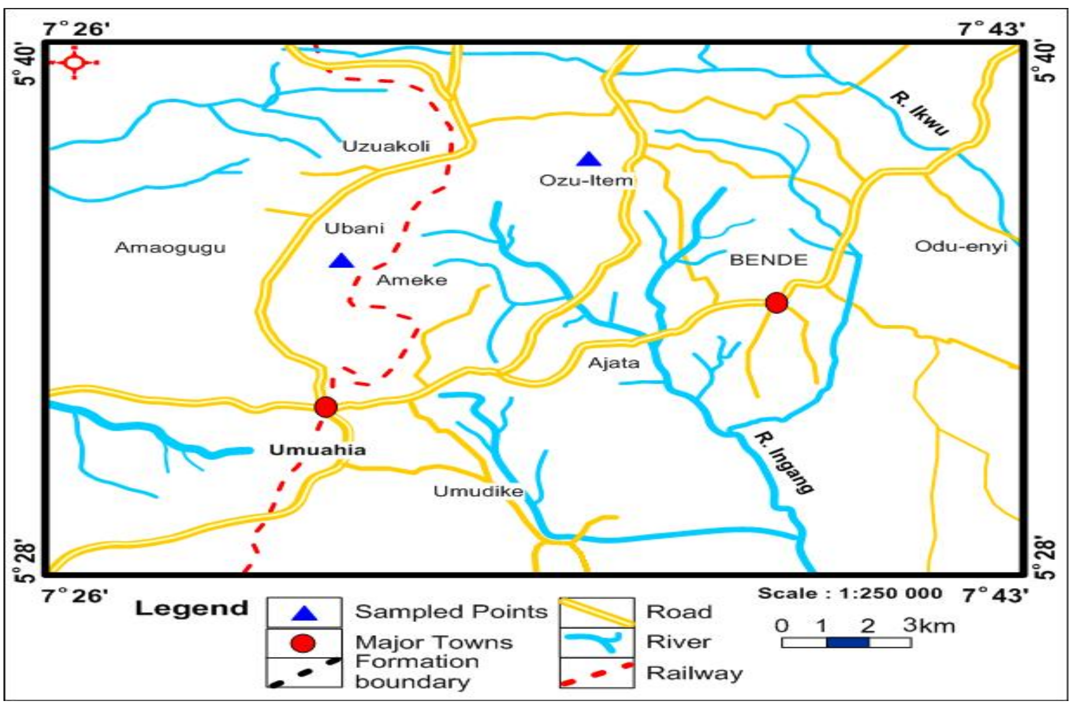

Fig 2: Location map of the study area.

B. Geology of the study area

The study area is located within the Niger Delta Basin in Southeastern Nigeria. The Niger Delta Basin is geographically situated in the Gulf of Guinea and can be delineated between latitudes 3° and 6°N and longitudes 5° and 8°E (Nwajide, 2013). The stratigraphy of southeastern Nigeria sedimentary basins are characterized by three (3) sedimentary episodes (Short and Stäuble, 1967; Murat, 1972; Obi et al., 2001) within that period, the axis of the sedimentary basin shifted. The three (3) episodes are: (1) Abakaliki-Benue episode (Aptian-Santonian), (2) Anambra-Benin episode (Campanian- Early Palaeocene), and (3) Niger Delta episode (late Paleocene-Pliocene). Total succession of Niger Delta consists of the Paleogene system composed of Imo Formation, Ameki Group, and Ogwashi Formation (Table 1), with a composite thickness of about 3,500m. It began with the transgressive Imo Formation (Paleocene) which constitutes of blue-grey clays, shallow-marine shale and sandstone, limestone and calcareous sandstone.

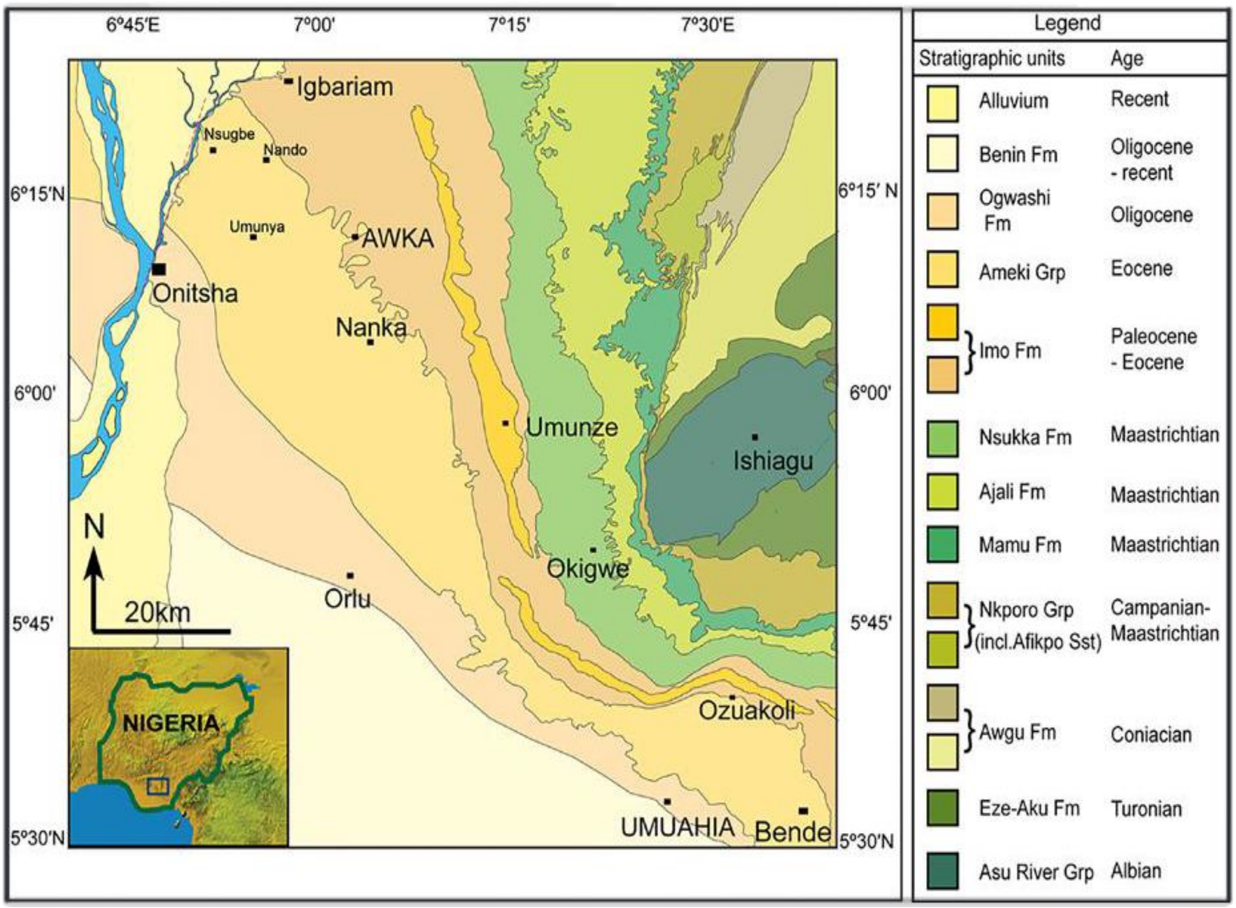

Fig 3: Geologic map of southeastern Nigeria showing the Paleogene formations (adapted from Ekwenye et al., 2020)

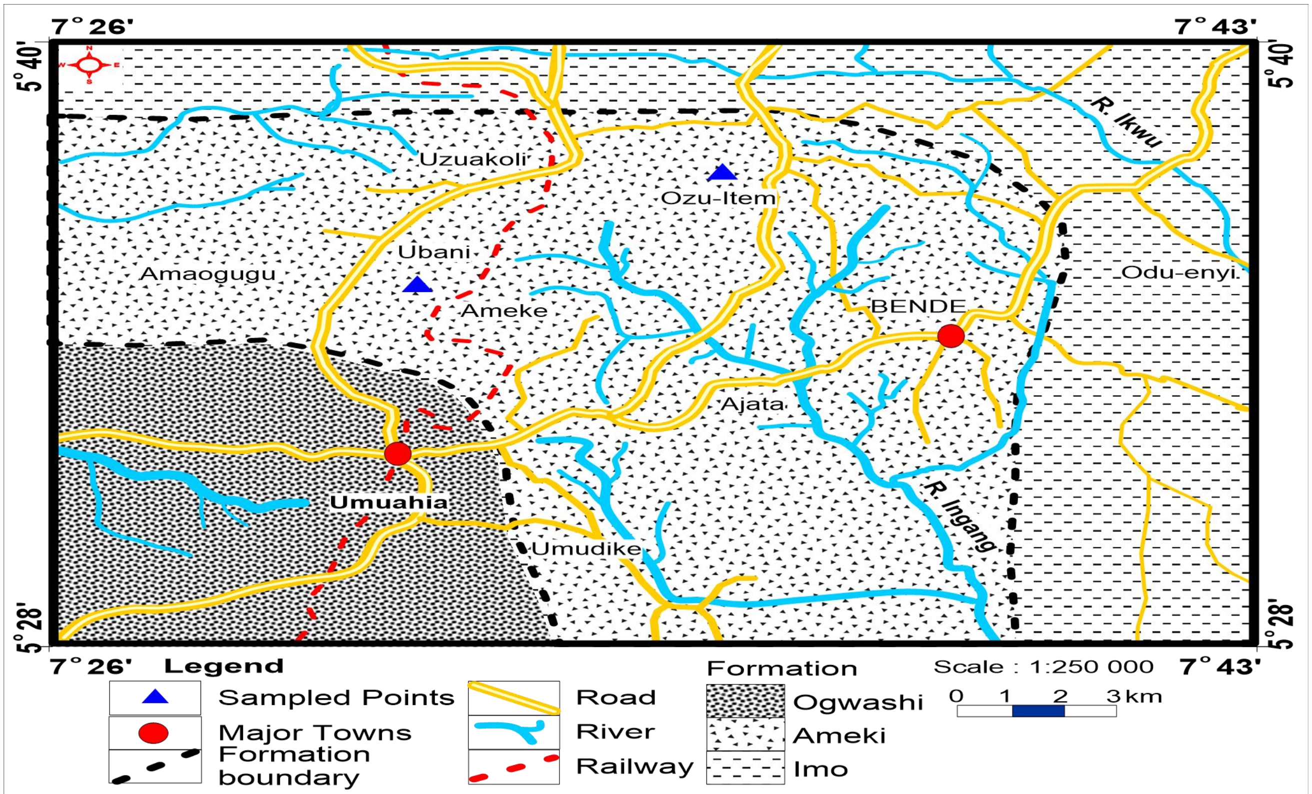

Fig 4: Geologic map of the study area (modified from Chiaghanam et al, 2017).

The table below illustrates the stratigraphic sequence of soils derived in Bende (Niger Delta Basin) area and their lateral equivalence.

Table 1: Stratigraphic sequence of Niger Delta and Anambra Basin (Modified from Nwajide, 2005).

Age	Basin	Stratigraphic Units						
Oligocene-Recent	Niger Delta	Ogwashi-Asaba Fm						
Eocene	Niger Delta	Ameki/Nanka Fm/Nsugbe Sandstone (Ameki Group)						
Thanetian	Niger Delta	Imo Formation						
Danian	Anambra Basin		Nsukka Formation					
Maastrichtian	Anambra Basin		Ajali Formation					
Maastrichtian	Anambra Basin		Mamu Formation					
Campanian	Anambra Basin	Nkporo Fm	Nkporo Shale	Enugu Fm	Owelli Ss	Afikpo Ss	Otobi Ss	Lafia Ss

III. MATERIALS AND METHODS

A. Sample collection

Two (2) disturbed soil samples (clay) were collected along the failed road sections of Ubani and Isiegbu, burrowed with a spade for visual examination of the geological formations after reconnaissance survey along the road stretch. Soil samples collected were sealed in a polythene bags to preserve their in-situ moisture contents. The two samples were labeled 1 & 2; sample 1 Umuahia - Uzuakoli and sample 2 Uzuakoli - Ozuitem respectively as presented in table 2 below.

Table 2: Sample location, coordinates, sampling depth and color.

S/No	Sample No.	Sample Location	Longitude	Latitude	Depth of sampling	Sample color
1	Sample 1	Ubani	7°26'E	5°28' N	0.5m	Grayish brown clay
2	Sample 2	Isiegbu	7°43' E	5°40' N	0.5m	Dark grey clay

B. Laboratory analysis

Geotechnical tests like natural moisture content test, particle-size determination test, atterberg limits test, linear shrinkage test, specific gravity test, bulk and dry density test were carried out at the geological laboratory of the Department of Geology, Federal University of Technology Owerri, Imo State in accordance to the British Standard Institute (BS1377, 1990). California bearing test (CBR) was soaked and unsoaked for 24hrs in accordance to the guideline provided by the Federal Ministry of Works and Housing (FMWH, 1997).

IV. RESULTS AND DISCUSSION

A. Natural moisture content

Presented in table 3 below, natural moisture content test values of both samples are 23.7% for Ubani and 35.6% for Ozuitem area respectively which falls above the 5 - 15% specified by the FMHW (1997) standard limit favorable for engineering construction, indicating that they are moderate to highly expansive, have high affinity for water and low transitivity. With this carefully taken note of infers the presence of smectite (montmorillonite) rich soils which has a very high ability retain moisture/water.

Table 3: Geotechnical result summary / specifications for subgrade materials adopted from (FMWH, 1997) of the study area

Parameter	**Ubani (Ameki FM)**	**Isiegbu (Ameki FM)**	**Average**	**FMHW (1997)**
Natural Moisture Content (%)	**23.70**	**35.60**	**29.70**	**-**
Liquid Limit (LL) %	**50.60**	**51.90**	**51.25**	**< 36**
Plastic Limit (PL) %	**33.10**	**27.30**	**30.20**	**_**
Plasticity Index (PI) %	**17.50**	**24.60**	**21.05**	**< 12**

Linear Shrinkage (LS) %	**10.00**	**14.00**	**12.0**	**< 8**
Specific Gravity (Gs)	**2.81**	**2.67**	**2.74**	**0.94**
Clay fraction %	**19.00**	**17.00**	**18.00**	**_**
Activity of clay	**0.92**	**1.44**	**1.18**	**_**
% passing sieve 200	**72.30**	**98.70**	**85.50**	**< 35**
Gravel %	**21.00**	**-**	**21.00**	
Sand %	**11**	**10**	**10.5**	
Silt %	**49**	**73**	**61**	
Clay %	**19**	**17**	**18**	
USCS classification	**MH**	**CH**	**-**	**-**
Maximum Dry Density(MDD)(Mg/m³)	**1.48**	**1.56**	**1.52**	**> 1.76**
Optimum Moisture Content (OMC) %	**13.50**	**12.80**	**13.15**	**-**
CBR (Soaked) %	**5**	**5**	**5**	**> 15**
CBR (Unsoaked) %	**10**	**11**	**11**	**>40**
Dry Density (Mg/m³)	**1.13**	**0.995**	**1.06**	

B. Atterberg limit

Atterberg limits result presented in table 3 showed results from both locations to be of medium to high liquid and plastic limit values which suggests the occurrence of moderate to high proportions of clay minerals. These clay minerals (montmorillonite) are well known for their vulnerability to high volume changes, capable of distension in the presence of moisture and shrink when dry thereby causing an alternate swell and shrink behaviour of subgrade which would likely cause road pavement failures at these road sections. The presence of these montmorillonite clay minerals decreases permeability, hinder water conductivity and causes edge cracking of road pavement.

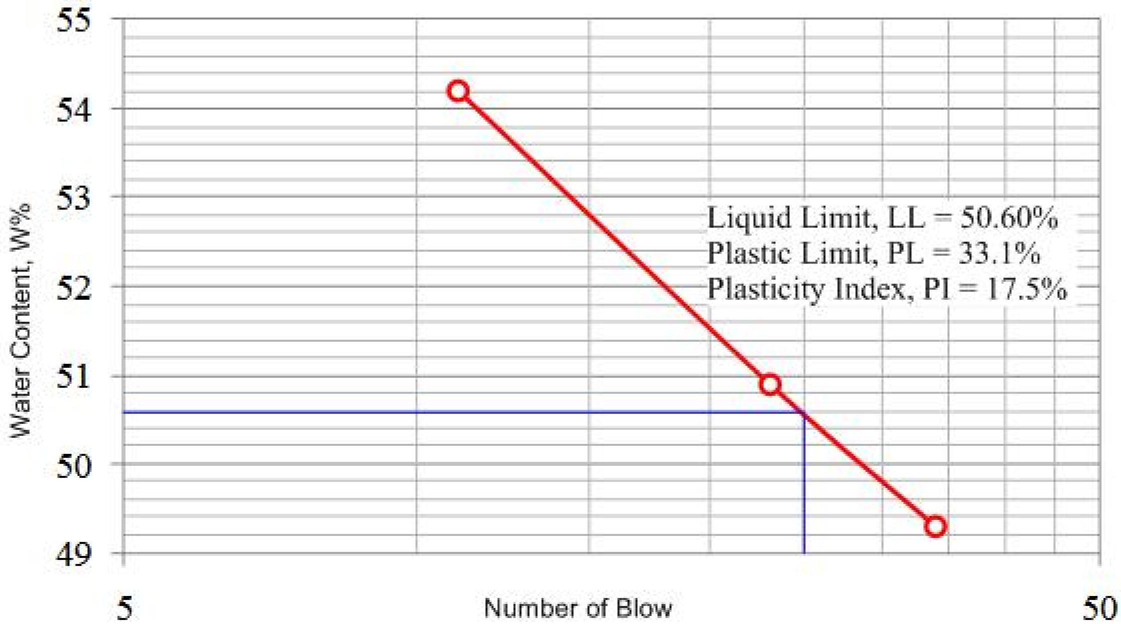

Fig 5: Liquid limit test plot for Ubani road failed section

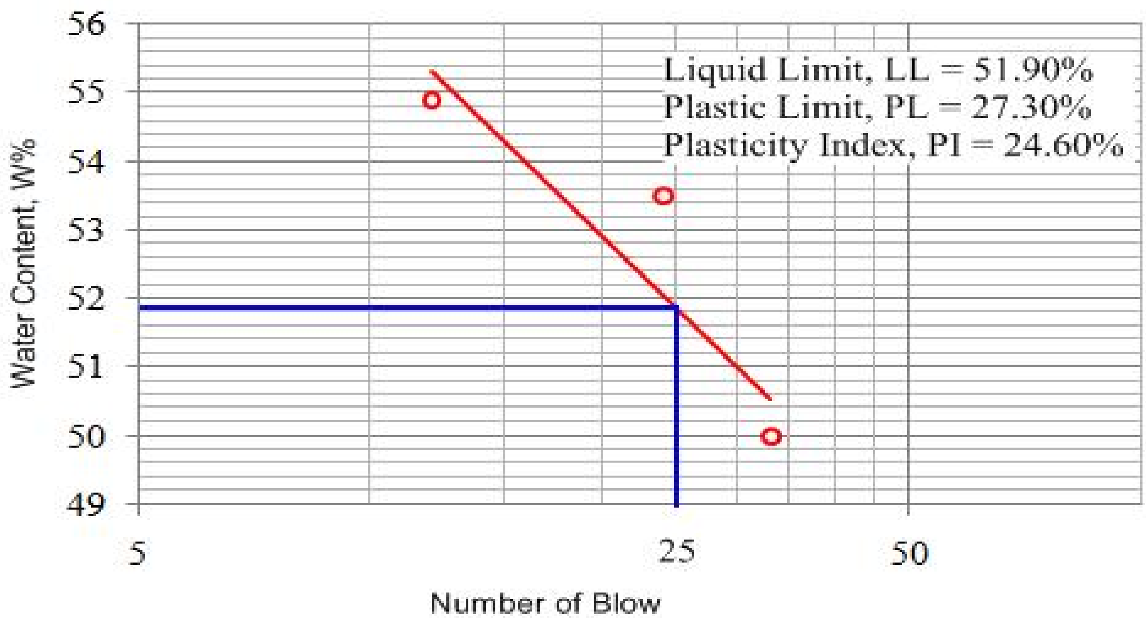

Fig 6: Atterberg limit test plot for Isiegbu failed section

Table 4 below show the relationship between liquid limit, plasticity and degree of expansion by Ola (1981) and Holtz & Gibbs (1956).

Table 4: Relationship between liquid limit, plasticity and degree of expansion by Ola (1981) and Holtz & Gibbs (1956).

Liquid limit (LL)% Holtz and Gibbs (1956)	Plasticity Index (PI) Ola (1981)	Swelling Potentials
< 35	0 - 15	Low
35 – 50	15 - 25	Medium
50 – 70	25 - 35	High
>70	>35	Very high

a. Classification of Ubani and Isiegbu subgrade soils using plasticity index parameters

Adopting Ola (1981) classification scheme, Isiegbu has the highest value of 24.60% which indicates a high degree of swelling potential while Ubani has a medium value of 17.50% indicating a medium degree of swelling. Concisely and taking look at the average PI of 21.05% for the studied area, I will conclude by saying subgrade soils of Ameki formation has between medium to high degree of plasticity index which makes it not suitable for a good subgrade material.

Table 5: Plasticity index classification scheme after Ola (1981)

Plasticity index (PI)(%) Ola (1981)	Swelling potential	PI of Sampled location
0 - 15	Low	-
15 - 25	Medium	Ubani
25 - 35	High	Isiegbu
>35	Very High	-

C. Linear shrinkage

Linear shrinkage is the decrease in length of a soil sample when oven-dried, starting with a moisture content of the sample at the liquid limit. The results expressed in table 3 are 10% for location 1 (Ubani) and 14.00% for location 2 (Isiegbu) respectively which complied with Kantey and Brink (1952) proposal on the possibility of identifying the degree of expansion on soil particles. They expressed that linear shrinkage greater than 8% indicates expansiveness. Linear shrinkage boundaries which correspond to water changes was established by Attimeyer (1956) and adopted by Ola (1981).

Table 6: Relationship between linear shrinkage and degree of expansion after Attimeyer (1956)

Linear shrinkage (%) (Attimeyer, 1956)	Degree of expansion
0 – 5	Non - critical
5 – 8	Marginal
>8	Critical

D. Activity (A)

Attewel and Farmer, (1976) expressed activity of the soil to be the ratio of contribution of clay minerals present in the soil to the swelling potential of the soil. If activity is less than 0.75, the soil becomes inactive with dominant clay minerals like kaolinite present but when activity lies within 0.75 – 1.25, the activity of the soil is termed normal with dominant clay minerals like illite and montmorillonite present; but when once above 1.25 the activity of the soil becomes high with dominant clay minerals predominately Ca based montmorillonite and as such exhibits large volume changes when wet and high shrinkage behaviour when dry (Skempton, 1954).

The activity of the soil as it relates to the study area has values of 0.92 for Ubani area categorized to as normal clay and 1.44 for Isiegbu area categorized as active clay respectively. It can also be used to describe the varying degree of water present in a clay soil sample because of the smectite clay minerals in them (Okoro et al., 2019).

a. Specification of Ubani and Isiegbu subgrade soils using Federal Government of Nigeria standard specification for roads and bridges 1997.

According to the specifications put in place by Federal Ministry for Works and Housing for both subgrade and sub-base materials, it was proposed that for durability determination of all engineering structures such as buildings and road constructions, the listed geotechnical parameters in table 3 above must be strictly adhered to before the soil can be used as building foundations (FMHW, 1997).

Laying emphasis on the aforementioned specification and drawing conclusions from various geotechnical parameters listed in table 3 above; subgrade soil materials collected from Ubani and Isiegbu study area is not suitable for use as subgrade for road pavement construction hence the need for a soil stabilization technique to be adopted to help modify the soil thereby making it suitable for construction of durable road pavements.

E. Specific gravity

Specific gravity result of soil samples can be expressed as the bearing capacity of the soil which represents the quality of its engineering properties provided water can be kept out (Idowu, 2015). As shown in table 3, Ubani area has a specific gravity of 2.81 and Isiegbu area 2.67 which suggests that samples studied are stable enough for a road pavement construction provided water is kept out. This implies that the shear strength of the soil would likely reduce with increased influx of water especially during the rainy season.

F. Grain size distribution test

The results of the grain size distribution test presented in table 3 above shows that at location 1 (Ubani) has 19% clay, 49% silt, 11% sand and 21% gravel and at location 2 (Isiegbu) has 17% clay, 73% silt, 10% sand and 0% gravel which implies that none of the soils have particles coarser than 2.36mm, having up to 60% passing sieve 200 (75microns) and as such are classified as fine grained soil. It is very evident that subgrade soil particles from both locations fell below the acceptable fines limit for a good subgrade material and can be classified as being poorly graded with high proportions of silt/clay fractions and deficient of coarse sand (Okagbue & Uma, 1988; Jegede, 1997; Akpan, 2005).

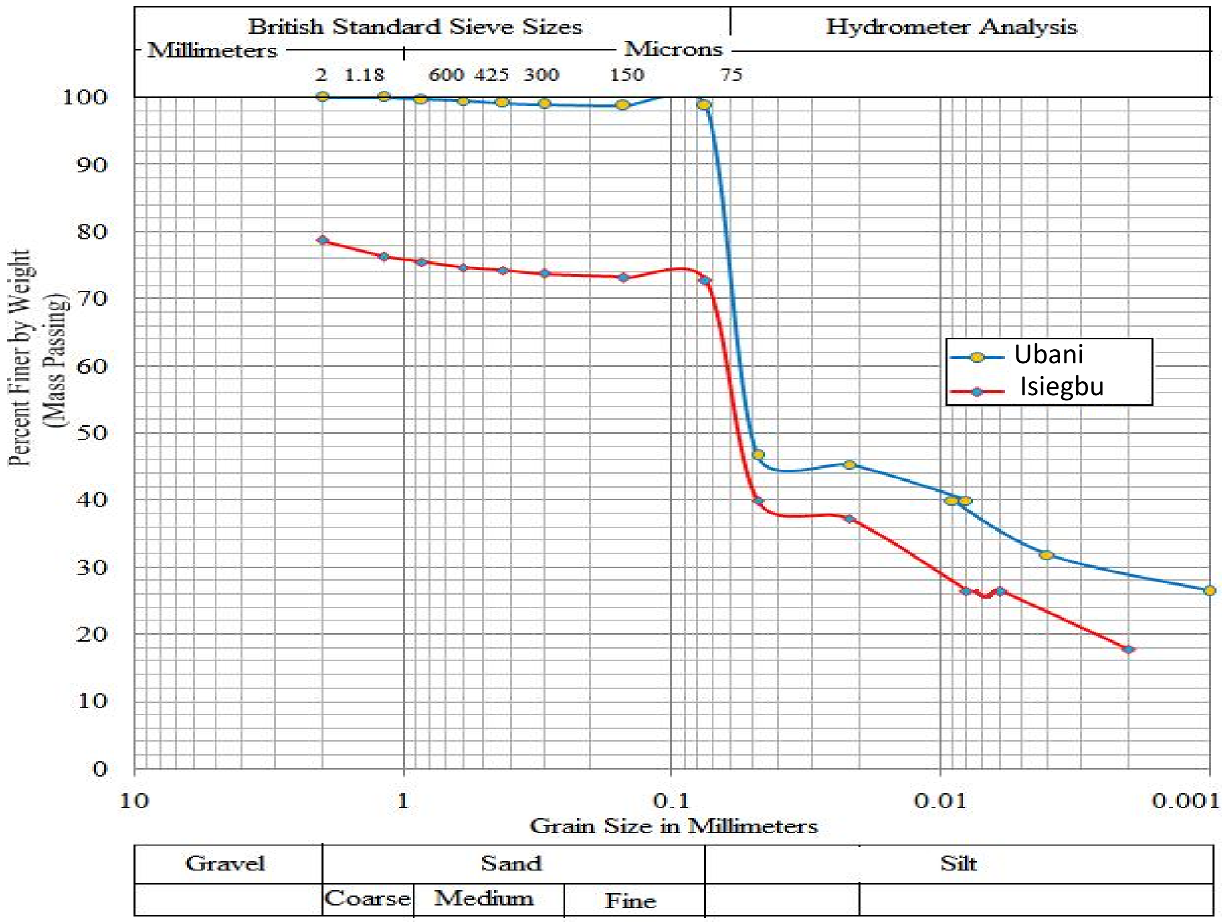

Fig 7: Grain distribution test derived from Ubani and Ozuitem

Grain size distribution test is a very important test which determines the mean size of particles, employed to estimate the proportions of various sizes of grade materials. It is a very important tool known for its geotechnical distinctiveness, used for the determination of engineering and physical properties of subgrade soils which is highly dependent on its textural characteristics. In accordance to the specifications of Federal Ministry of Works and Housing (1997), they stated that clay content for both sub-grade, sub-base and base materials must not exceed 35% therefore, a good subgrade should have ≤ 35% passing 75 microns or 200 sieve (FMWH. 1997).

G. West African compaction test

Results obtained from West African compaction test presented in table 3 showed that Maximum dry density (MDD) for location 1 (Ubani) is 1.96 Mg/m^3 and location 2 (Isiegbu) 1.78 Mg/m^3 while optimum moisture content (OMC) of location 1 (Ubani) is 13.50% and location 2 (Isiegbu) is 13.50 % respectively. This implies that maximum dry density (MDD) increased while optimum moisture content (OMC) decreased with increase in compactive energies which is in agreement with Proctor, (1933); Craig, (2004); Mustapha, (2007) and Job et al., (2009).

For clay, MDD may fall between 1.44 Mg/m^3 and 1.685 Mg/m^3 and OMC may fall between 20-30 %, in silty clay, MDD usually ranged between 1.76 and 2.165 Mg/m^3 and OMC between 8 and 15 % while in sandy soil, MMD may fall between 1.6Mg/m^3 and 1.74Mg/m^3 and OMC between 6 and 10%

(Ogbuchukwu et al., 2019). Therefore, looking at the results of the soil samples, it could be comfirmed that soil samples from both locations are silty clay.

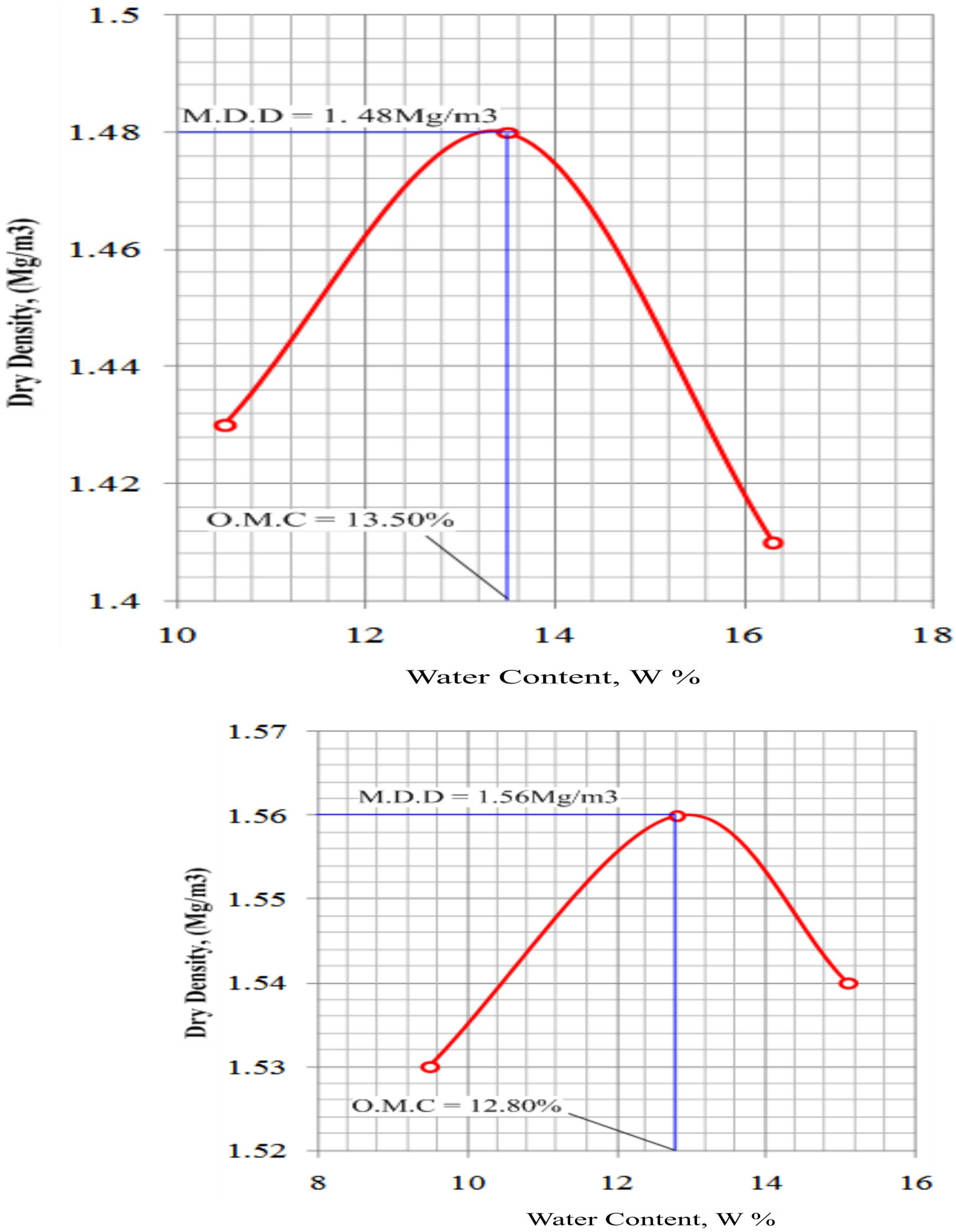

Fig 8: Compaction test results for samples collected from Ubani and Isiegbu

H. California Bearing Ratio (CBR)

California bearing ratio can be expressed as the resitance a subgrade soil possess under load, it is a function of bulk density and water content characteristics. Table 6 indicates that the Un-soaked CBR values of location 1 (Ubani) to be 10% and location 2 (Isiegbu) to be 10% while soaked CBR of location 1 (Ubani) to be 5% while location 2 (Isiegbu) to be 5% respectively. It is very clear that these values falls below 30% and 80% recommendation for highway sub-base and subgrade soils specified by Federal Ministry of Works and Housing Nigeria (FMWH, 1997).

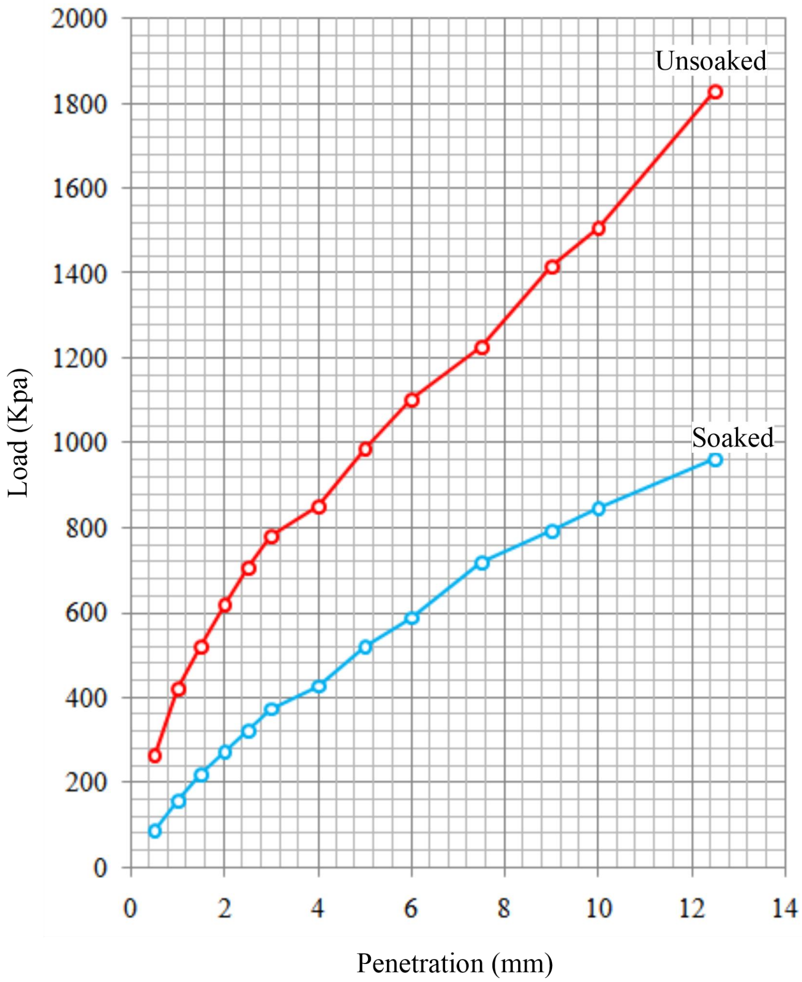

Fig 9: CBR test curve for samples collected from Ubani

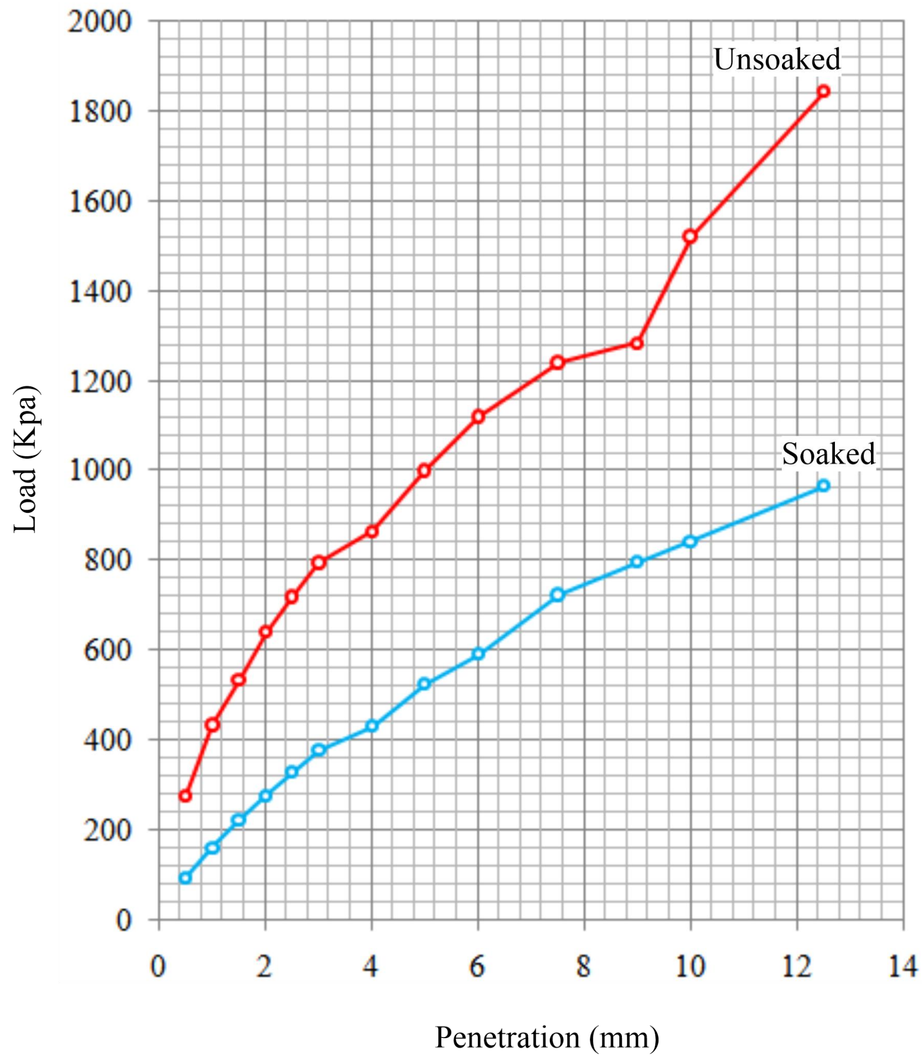

Fig 10: CBR test curve for samples collected from Ozuitem.

V. CONCLUSION

Subgrade soils collected from two (2) different locations (Ubani and Isiegbu) in Bende area were obtained from earthen shoulder of the failed sections of the road, they were extensively studied to determine their geotechnical distinctivness in accordance to the standard limits set by the Nigerian Federal Ministry of Works and Housing (1997). Engineering property values obatined from the subgrade soils ascertained to be of expansive origin (smectite group) probably montomorillonite clay mineral which has a very high affinity to water thus making the subgrade material very challenging and falling below the standard limit prescribed by Nigerian Federal Ministry of Works and Housing (FMWH) which is the reason behind the occurrence of failed sections of the road in the study area. Results obtained in this research indidcated high liquid limit, plasticity index and critical linear shrinkage. Casagarande plasticity chart classifed the subgrade (natural) soils as fat and lean clays, CH soil with an average of 51.25% liquid limit and plots above the "A" line.

That being said, failed sections of the road are as a result of water variations in the subgrade due to the distance of the water table and can be prevented by performing adequate site investigation to identify/confirm the occurrence of expansive soil at the proposed project site and applying relevant soil stabilization processes during construction (Okeke et al., 2015; Ogbuchukwu and Okeke, 2021; Ezeala et al., 2024).

Appropriate drainage systems should be designed in the area to help convey water rapidly off the road pavement and chemical stabilization technique recommended to help modify the soil up to FMWH specifications to ensure adequate compaction densities to help reduce the pore space between soil particles thereby improving the load bearing capacity of the road pavement.

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