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A Geotechnical Investigation on the Failure of Road Pavements in Abakaliki, Southeastern Nigeria

Babadiya, E.G. and Igwe, E.O.
Department of Geology, Ebonyi State University, Abakaliki, Nigeria
Corresponding E-mail: ezekieloigwe@gmail.com

Abstract
A study of structural failures of some major roads in the Abakaliki region of southeastern Nigeria was carried out to assess deformation and structural design of failed pavements; in order to suggest improvement approach on the engineering properties of the pavement materials. California Bearing Ratio (CBR) and in-situ density were performed on the subbase materials while soil samples were subjected to particle size analysis, Atterberg limit, density and CBR laboratory tests. Field study revealed level of deformation for categorized sections of the studied road in the area. Results of laboratory tests showed subbase liquid limit (LL), plastic limit (PL) and plasticity index (PI) range as follows: LL 29–45%, PL 18–30%, and PI 11–16 for Presco – Ishieke Junction section with soaked subbase and CBR of 18–36% and subgrade soaked CBR between 17 and 20%. The Spera-In-Deo–Onuebonyi section has LL of 38–50%, PL of 23–35% and PI of 12–16 whereas LL range of 38–41%, PL range of 27–29%, CBR of 29–31% and PI range of 11–12 were recorded for the Spera-In-Deo–Mammy market section. Investigation revealed two different soil types used for subgrade: A–2–7 and A–7–5 both with moderate liquid limit and plasticity index values. The particle size distribution curves for AA, AO and EA indicate that AA and AO soils are well graded (poorly sorted) than EA, therefore have the fairest engineering properties. Failures were concentrated on unstabilized roads; hence sand stabilization is required on the soil types used as subbase material. Poor subbase material associated with water sources is responsible for road failures in Abakaliki.

Keywords: *Geotechnical; Subbase and subgrade; Deformation; Pavement failure; Stabilization; Nigeria*

Introduction

The Abakaliki region is a sedimentary environment underlain mainly by shale and other mudrocks of the Abakaliki Shale (Reyment, 1965). Road plays an essential role in attainment of national development and influences the overall performance and social functioning of the community (Adiat et al. 2017). Notwithstanding, failed road sections, which in most cases are caused by use of poor construction materials or being founded on an incompetent subgrade and subbase materials (Adebiyi et al. 2018) such as shale. Shales naturally do not make a good road base material, hence pose serious threat to life span of roads. Akpokedje (1985) and Uduji et al. (1994) noted that sections of road underlain by shale formation experience incessant failures. Pavements failure has persisted on the Presco – Ishieke Junction section of the Abakaliki–Enugu Road, Spera-In-Deo–Onuebonyi section of the Abakaliliki–Ogoja Road and Spera-In-Deo–Mammy market section of the Abakaliki–Afikpo Road in the Abakaliki region (Fig. 1) of southeastern Nigeria. The persistent failure of these sections of the roads has affected human and vehicular movement and created capital loss from continuous maintenance and reconstruction of these roads.

The problem of premature pavement failures in the study area has necessitated the need for further research to ascertain remote causes and means of improving pavement strength in the region. Aghamelu and Okogbue (2011) attributed the incessant pavement failures in the Abakaliki area to poor quality of subgrade and non–availability of good lateritic soil for subbase and base course layers. They further related the causes of flexible pavement failure to the predominant use of shale with poor geotechnical quality for road and highway pavement due to the scarcity of suitable construction materials and suggested stabilization of the soil in the metropolis before use in construction. Interestingly, no specific method of soil stabilization was suggested by them. Previous workers (eg., Adegoke-Anthony and Agada 1980; Ajayi 1987; Mesida 1987; Adiat et al. 2017) documented some factors known to be responsible for road failures to include geological, geomorphological, geotechnical, road usage capacity, construction practices, and maintenance. They noted that usage or poor design alone could not be attributed to be primarily responsible for road failures; but likened it poor knowledge of the behavioural characteristics of residual soils, influence of underlying geology and geomorphology during the design and construction of roads. Adiat et al. (2017) noted that geological factors considered unfavourable to road pavements include nature of subgrade materials and rock lithology, presence of geological structures such as fractures and faults, occurrence of buried ancient stream channels, and of shear zones. Engineering structures are usually placed on geological materials and structures (Momoh et al. 2008; Oladapo et al. 2008; Adiat et al. 2009; Adeyemo and Omosuyi 2012). Momoh et al. (2008) and Oladapo et al. (2008)

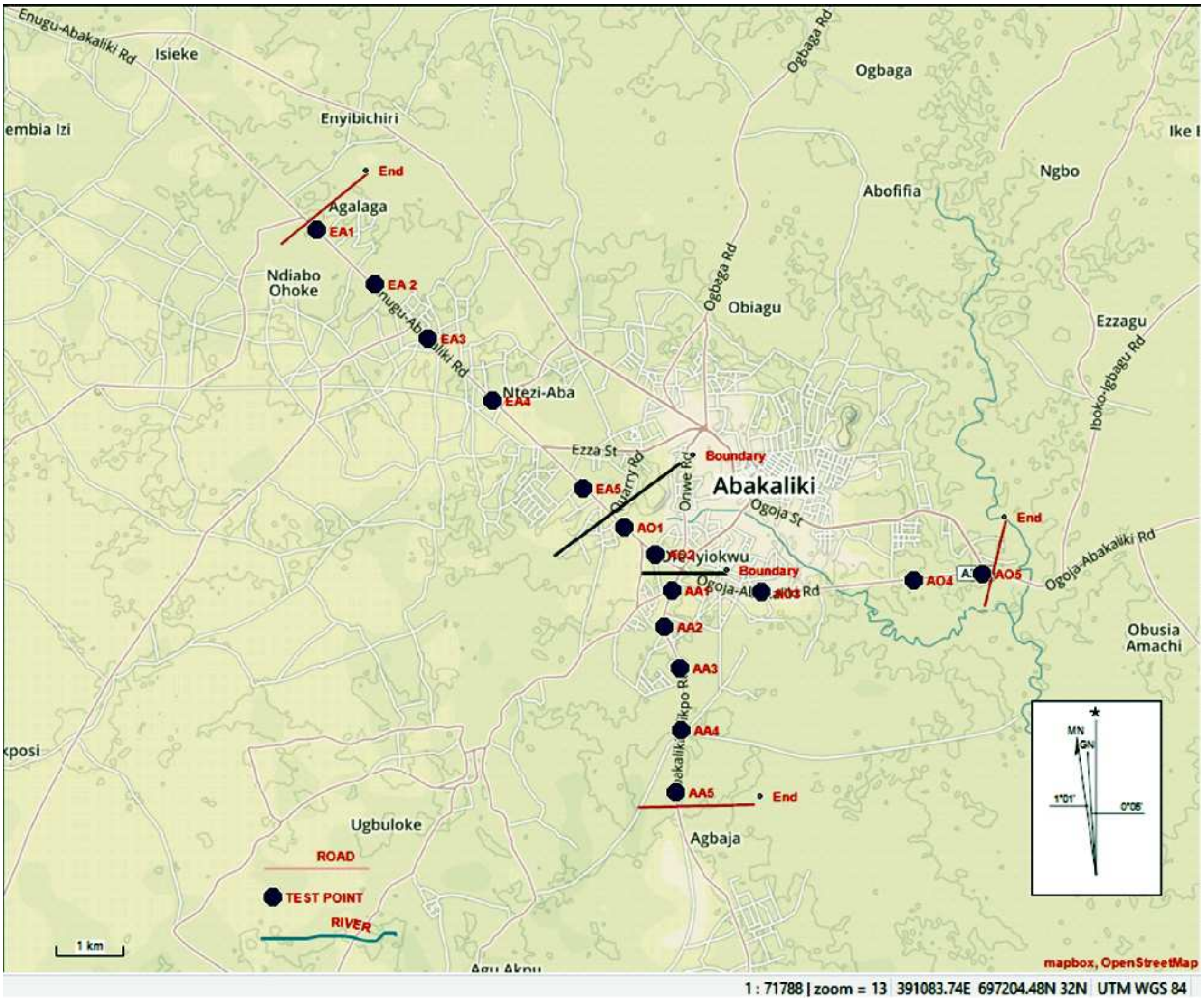

Fig. 1: The investigated dualized roads and test points

reported that poor knowledge of the underlying geology in the design of roads is the major cause of incessant road failure in Nigeria.

The expansive clays such as montmorillonite, chlorite, halloysite in the underlying shales of the Abakaliki Formation in addition to linear features such as joints, fractures and rock boundaries (Momoh et al. 2008) have been reported as some of the major reasons for the persistent failure of roads in Nigeria (Mesida 1986, 1987). It is also imperative that assessment of geotechnical factor such as atterberg test, California bearing ratio (CBR) among others are properly re-investigated to provide adequate information on road usage capacity prior to any road design and construction work. Ekeocha and Akpokodje (2012) used CBR in the assessment of subgrade of parts of southern Benue Trough. They concluded that the roads failed despite the compliance of the subgrade CBR values to FMWH (1997) specifications for Roads and Bridges in Nigeria; hence they suggested soil stabilization still, no reference to any particular method of soil improvement was mentioned. While soil stabilization techniques include compaction, dewatering and addition of chemicals or additives to the soil, the primary objective of soil stabilization is to improve the CBR value, which is the load bearing property of in-situ soils and other on-site materials to form a stable and strong subgrade, subbase or base course. Ekeocha and Akpokodje (2014) opted for cement stabilization of shale subgrade of parts of the southern Benue Trough, Southeastern Nigeria. They observed that stabilization of the residual shale soil using 8 – 12 % cement achieved some level of improvement but not high enough to guarantee all season stability and durability. Madu (1975) carried out a research on sand – laterite mixture for road stabilization using borrow pit samples collected from Yahe, Okigwe, Enugu, Abagana, and Nsukka area of southeastern Nigeria. He found out that sand stabilization decreases Atterberg limits, linear shrinkage, and optimum moisture content, thereby bringing about an increase in soil strength (CBR).

These previous researches were restricted to laboratory investigation; while in most cases, field conditions differ from laboratory conditions. Hence, there is need to carry out combined field and laboratory studies on how to manage, modify and improve the quality of the subgrade and borrowed laterites in Abakaliki region for construction of durable roads. Previously, road contractors in the region were charged by government to employ various methods of construction to enhance pavement performance in the study area. Sand stabilization, introduction of filter bed of sand, shoulder to shoulder asphalting and construction of adequate drainage system were among the methods employed to reduce the problem of road failures in the area. Since then, no effort has been made to ascertain the effectiveness of these adopted pavement improvement methods. More so, due to poor quality of construction materials and non–availability of suitable guidelines for road construction prepared based on geotechnical data obtained within the region. This is coupled with absence of published work on suitable, reliable, affordable and easily practicable pavement improvement method. This challenge has hindered government on proper costing and budgeting for road works for several years while contractors usually spend more resources than appropriated as a result of unforeseen geotechnical challenges encountered during execution of contracts.

In the light of these underlying problems, the three major dualized roads constructed by different contractors with different pavement designs in the Abakaliki region were carefully investigated to comparatively evaluate the influence of the designs and soil improvement approach on the engineering properties of the Abakaliki pavement materials (subbase and subgrade). These influences are further related to pavements durability and performances. The purpose of this study therefore, is to carry out geotechnical investigation of some major road failures in the Abakaliki region of southeastern Nigeria in the context of assessment and evaluation of the deformation and structural design of failed pavements and laboratory testing on the subbase materials

Description of Study Area

The study area lies within Abakaliki area of southeastern Nigeria; with latitudes 06°17.5' – 06°21'N and longitudes 08°4.5' – 08°09'E (Fig. 2). It is characterised by undulating relief with an elevation of less than 400 m above mean sea level. Hills of pyroclastic rocks constitute the dominant relief structures. No trend has been established by previous research of the conical shaped hills and other residual hills that spread sporadically within the area (Amajor 1987). The Abakaliki area is drained by Ebonyi River and its tributaries and other minor streams. The tributaries are seasonal and overflow their banks at the peak of raining season. The rivers collectively flow eastward direction into the Cross River in the adjoining region. The origin and distribution of the rivers are controlled by the geology of the area and the structural features such as fractures, as well as the relief of the area (Aghamelu 2013). However, the abundance of shale has assisted in low erodability of the lithology, resulting in the absence or near absence of deep cut valleys and erosion channels (Aghamelu and Okogbue 2011).

The major entrances to Abakaliki are dualized roads constructed in the year 2012, some of which have experienced pavement failures. These roads include the Abakaliki–Enugu (80 Km), Abakaliliki–Ogoja (78 Km) and Abakaliki–Afikpo Roads (75 Km). These roads have Presco – Ishieke Junction (the dualized section of Abakaliki–Enugu Road "EA"), Spera-In-Deo–Onuebonyi (the dualized section of Abakaliki–Ogoja Road "AO"), and Spera-In-Deo–Mammy market (the dualized section of Abakaliki–Afikpo Road: "AA").The study area is underlain by the Abakaliki Shale (Asu-River Group) in the southeastern Nigeria (Reyment 1965). The group is a product of first marine transgression in the Benue Trough. The Abakaliki Shale (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 (Fig. 2) unconformably underlies Eze-Aku Group (Igwe and Okoro 2016).

Materials and Method

Field Tests

The research was carried out on the entrance roads within Abakaliki area. Total of 15 test points were selected on the roads in the study area. The test stations were carefully distributed to capture both the stable and distressed portions of the roads. Garmin 78s global satellite positioning system (GPS) was used to georeference test points for accurate representation on the field map (Table 1 and see Fig. 1). With the aid of

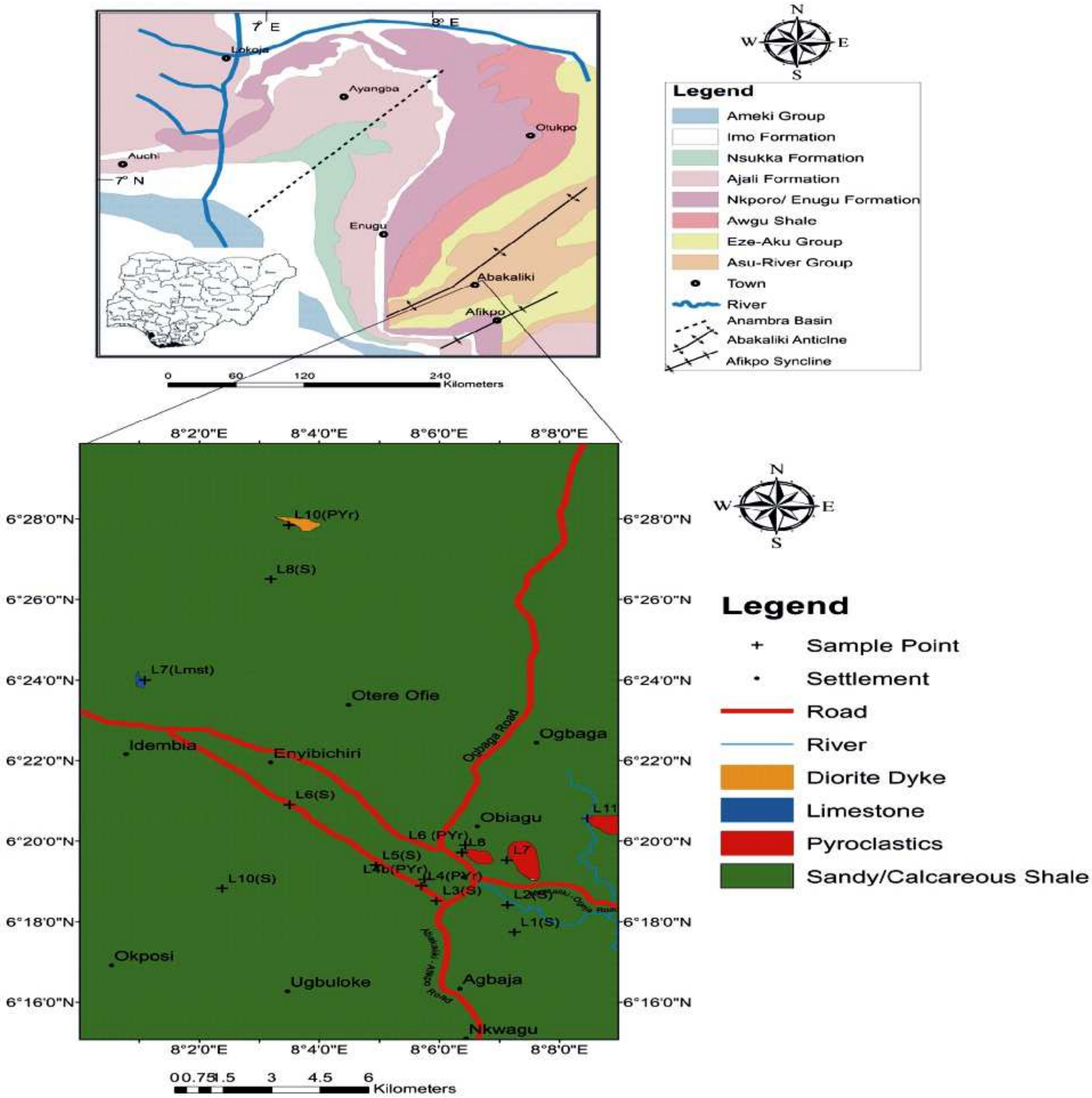

Fig. 2: Geologic map of the Abakaliki area

asphalt cutting machine, the upper asphaltic concrete and stone base layers were carefully removed to expose the subbase layer for in-situ CBR and field density testing. These were immediately followed with geotechnical boring of exploratory holes to collect samples of the different pavement layers on the roads.

The pavement materials beneath the asphaltic and stone base layers were subjected to Dynamic Cone Penetration (DCP) test to evaluate the in–situ CBR. A penetrometer consists of a thin rod with a conical tip, a meter rule and 8.0 kg hammer. Adopting ASTM D6951 (2003) standard, the hammer was raised to the height of 575 mm and dropped to enhance penetration of the 600 tip cone into the undisturbed surface. The penetrations in millimeters were recorded against the blow counts. Using WinDCP 5.0 computer software, the variation in in-situ CBR values with depth below the pavement were calculated.

The soil water content was determined on the field with the aid of speedy moisture tester in compliance with ASTM D4944 (2004). The moisture content was directly read out on the calibrated scale of the equipment. The scale reading was proportional to the quantity of pressure inserted by acetylene gas produced from the reaction between soil moisture and carbide. In accordance with BS 1377-7 (1999), sand replacement

Table 1: Coordinates of test stations

	Station No.	Latitude (°)	Longitude (°)	Chainage (Km)	Position
Presco –Ishieke junction section of Enugu–Abakaliki Road	EA1	6.3536416	8.05236	5 + 580	CTL
	EA2	6.3465053	8.0602138	4 + 470	RHS
	EA3	6.3392515	8.0671981	3 + 580	CTL
	EA4	6.3310759	8.0757311	2 + 280	LHS
	EA5	6.319455	8.0878282	0 + 470	CTL
Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road	AO1	6.3142316	8.0932072	0 + 340	LHS
	AO2	6.3106863	8.0973172	0 + 890	CTL
	AO3	6.3055639	8.1114043	2 + 620	RHS
	AO4	6.3071991	8.1317693	4 + 880	CTL
	AO5	6.3080782	8.1408523	5 + 850	RHS
Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road	AA1	6.3057679	8.0996692	0 + 330	CTL
	AA2	6.3010256	8.0985613	1 + 020	RHS
	AA3	6.2955441	8.1006493	1 + 470	LHS
	AA4	6.2872745	8.1008583	2 + 590	CTL
	AA5	6.2789738	8.1001263	3 + 430	RHS

method was employed to determine the level of compaction of the undisturbed subbase layer of the pavements in this study. Laboratory calibrated sand (sand of known density) was poured into the excavated pit of specified dimension. The mass of the sand occupying the pit and volume of the test pit were determined. The wet density of the excavated soil was calculated from its mass and the volume of the test pits hence the field dry density.

Flexible pavement structurally consists of subgrade, subbase, base and bituminous layers or courses. Each of these layers is expected to certify a particular design and quality specifications. The specifications in Road Note 31 (1993) and FMWH (1997) were used as standards in this investigation. Test pits of 1.0m deep with dimensions of 0.6m x 0.6 m were dug on each of the test points immediately after the in–situ density test. The exploratory boring facilitates the measurement of thicknesses of wearing, binder and stone base and subbase courses. The different pavement layers were measured with the metre rule.

Field Sampling

The materials from the individual pavement layers were carefully sampled to prevent mix up. With a scoop, digger, and shovel, a minimum of 16 kg of materials from the subbase and subgrade layers were carefully collected and labelled in airtight bags for laboratory analysis. Samples were collected from subbase layer at the depth between 400 and 500 mm while the remaining two (2) are subgrade samples collected within the depth of 600 and 800 mm.

Laboratory Tests

The collected soil samples were subjected to classification and strength tests. The classification tests comprised of consistency or Atterberg limits (liquid limit, plastic limit and plasticity index determination) and particle size distribution tests. The strength tests included compaction to determine the optimum moisture content and maximum dry density, as well as CBR, aimed to evaluate load bearing strength. The standard forces of 13.24 and 19.96 KN were used to compute the percentage of load readings at penetrations of 2.5 and 5.0 mm. The percentage of force/load gauge reading at penetrations of 2.5 and 5.0 mm of the corresponding standard forces is the CBR of the tested soil.

Results and Discussion

Drains, Medians and Shoulders

The field investigation revealed that the three investigated roads: the Abakaliki–Enugu, Abakalliki–Ogoja and Abakaliki–Afikpo Roads have similarly designed concrete drains and shoulders but different medians (Table 2). The drains are U-shaped with an average dimension of 900 mm in all the investigated roads (Fig. 3a)**.** The slopes of the drains are perfect such that they all discharge water easily, thus preventing silt and water accumulation. The investigated roads have well drained concrete shoulders (Fig. 3a) of 1.3m each which also serve as a walkway for pedestrians. A well constructed concrete shoulder has advantage of preventing erosion, water ingress, shoulder drop and failure under traffic load. The shoulders of all the investigated roads are in good condition and pose no threat to the stability of the roads. The medians of Presco – Ishieke section of Enugu–Abakaliki Road and Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road are similar; characterised by very low but wide (3.3 m) and carpeted with grasses (Figs. 3b and c). The bases of the medians were poorly protected with weak concrete before placement of soil to enhance the growing of grasses, flower and trees. In contrast, the median of Spera-In-Deo–Mammy market section of Abakaliki–AfikpoRoad is in the form of raised barrier (Fig. 3c).

Agbonkhese *et al*. (2013) discovered that percolation of surface water from the carriageway and shoulder into the subgrade is one of the factors responsible for road failure. The investigated roads except for Spera-In-Deo–Mammy Market section of Abakaliki–Afikpo Road are designed with wide median (3000 mm) with a poorly concreted layer below a fill of laterite with a view to prevent water ingress and facilitate the growth of grasses. The concrete is so in some places such that it allows ingress of water, as water was observed seeping

Table 2: Visual inspection data

Structures	Enugu – Abakaliki Road (EA)	Abakaliki – Ogoja Road (AO)	Abakaliki – Afikpo Road (AA)
Drainage Type	U -type	U –type	U -type
Drainage Width (mm)	900	900	900
Median Type	wide (grass)	wide (grass)	narrow
Median Type (m)	3.3	3.3	
Types of Failure	Pot-holes, rutting, depression, fatigue, slippage.	Fatigue, slippage, pot holes.	none

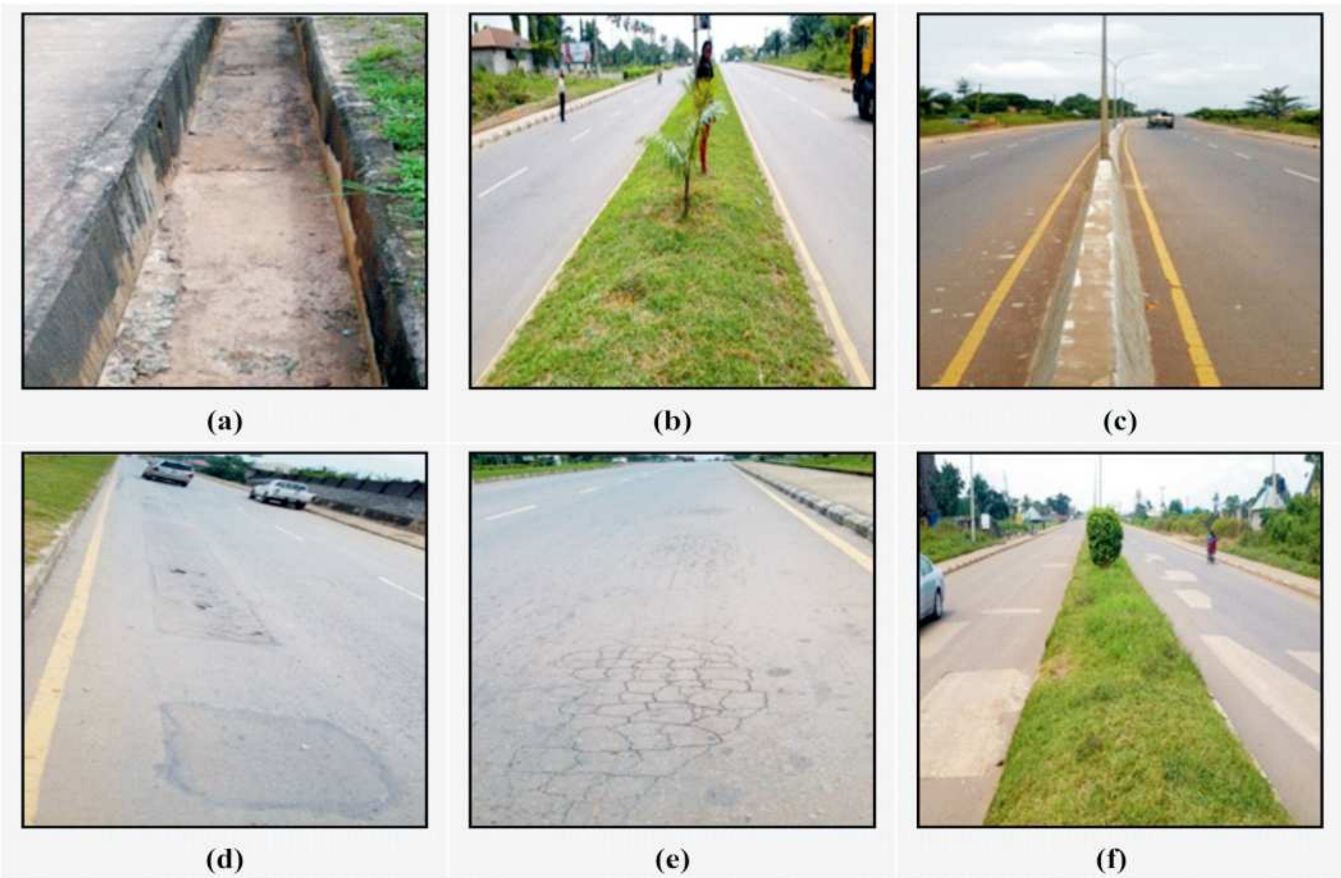

Fig. 3: Field investigation: (a) "U" Drain and concrete shoulder on Enugu–Abakaliki Road (b) Median on Enugu–Abakaliki Road (c) Median on Abakaliki–Afikpo Road (d) Ruts and potholes on Enugu–Abakaliki Road (e) Alligator crack on Enugu–Abakaliki Road (f) Concrete patch and fatigue on Abakaliki–Ogoja Road

out visibly in some sections of the medians. The Spera-In-Deo–Mammy Market section of Abakaliki–Afikpo Road is designed with 600 mm (height) solid but narrow concrete median which prevents water ingress. Several factors are responsible for the failure on Nigeria roads and they include geotechnical properties of the soil, topography and drainage (Osadebe and Omange 2005). The drainage systems of the investigated roads are aided by the presence of suitable concrete drains. An Adequate drainage system is of help in sustaining the lifespan of roads (Adams and Adetoro 2014).

Surface Deformations and Failures

With the exception of the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road that showed no significant failure, physical inspection reveals that other investigated roads are charcterised by failures of various types and magnitudes. The Presco – Ishieke Junction section of Enugu–Abakaliki Road suffered most severe deformations. The failures on the road include; fatigue cracks, ruts, stripping and in few places potholes. Despite the frequent maintenance which had left the road with numerous patches, the road still diplays long but discontinous streches of alligator cracks and ruts. EA1, EA2, EA4 and EA5 are seriously deformed with rutting and fatigue cracking. EA3 is relatively stable with no crack nor depression. The Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road displays similar failures but in smaller extent. Failures at AO1, AO2 are insignificant cracks, localise stripping and fatigue cracking compared to AO3, AO4 and AO5 that are severely deformed by alligator cracking. Some of the failed sections that were previously patched with cement concrete still express fatigue cracking (Figs. 3e and f). It was generally observed that the fatigue or the alligator cracking concentrate along the wheel path.

Subgrade Strength (CBR)

The results showed moderate to high in-situ and laboratory subgrade CBR of 9 – 24% and 12 – 19% respectively (Table 3). According to Road Note 31 (1993), the insitu subgrade of 2 – 5 % using dynamic cone penetrometer (DCP) is considered suitable for flexible pavement design. The closeness in subgrade CBR values of the three roads is an indication that the roads were built on a similar subgrade material. This confirmation substantiates similar subgrade material, adequate subgrade field compaction, moderate or optimum subgrade field moisture and uniform groundwater condition in all the investigated roads. Bandyopadhyay and Bhattacharjee (2010) in their research concluded that the variations between laboratory CBR values by Indian Standard (IS) and DCP method are 4 to 10% for unsoaked and 22 – 24% in case of 4 days soaked condition. Subgrade CBR is used in road structural design; it influences pavement performance and durability. Ali (2003) with respect to IS method stated that proper design of both the asphalt mix and pavement structure significantly improves performance of pavements. The field and laboratory CBR values obtained from all investigated roads are in line with Oversea Road Note 31 (1993) considered suitable for flexible pavement.

Table 3: Results of dynamic cone penetration test

Road	Station	Delineated layers (m)	Layers thicknesses from subbase Level (mm)	In-situ CBR (%)	Failure pattern
Presco –Ishieke junction section of Enugu–Abakaliki Road	EA 1	4	208, 232, 248, 112	6, 27,5,10	rutting, and fatigue cracking
	EA2	4	200, 200, 288, 112	7, 30, 6,10	fatigue cracking
	EA3	4	120, 248, 24, 408	78, 26, 51, 23	none
	EA4	8	72, 264, 72, 240, 200, 48, 56, 96	7, 16, 8, 14, 11, 14, 11, 11	fatigue cracking
	EA5	4	176, 152, 96, 376	9, 15, 6, 12	rutting, and fatigue cracking
Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road	AO 1	4	64, 104, 248, 384	15, 26, 10, 16	none
	AO2	5	32, 112, 192, 72, 392	17, 24, 11, 17,11	none
	AO3	6	32, 96, 128, 328, 416, 128	14, 11, 21, 11, 28, 24	fatigue cracking
	AO4	9	56, 72, 56, 120, 72, 168, 144, 40, 72	17,13, 20, 17, 34, 9, 31, 28, 26	fatigue cracking
	AO5	4	168, 32, 72,528	18, 39, 15, 24	none
Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road	AA 1	3	56, 144, 560	20, 30, 14	none
	AA2	3	32, 208, 560	20, 29, 15	none
	AA3	3	64, 194, 542	15, 29, 16	none
	AA4	3	40, 192, 568	17, 29, 14	none
	AA5	3	64, 144,592	21, 32, 15	none

Subbase Compaction

The results of field density test in Table 4 show that the Spera-In-Deo –Presco junction section of Abakaliki–Enugu Road is the least compacted with the highest field moisture while Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road is the most densely compacted with the least field moisture content. The dynamic cone penetration test results confirm irregular compaction or heterogeneous nature of the material components of the pavement. Basically, a flexible dual carriage pavement should consist of 5 structural layers. These consist of one or more waterproof or bituminous surface layers, base course (stone base), subbase, selected or improved sub grade/ fill and subgrade (Overseas Road Note 31 1993). Each of the layers should be well designed, homogenous and uniformly compacted to the specfied thickness. With this, it is expected that the delineated layers' strengths beneath the stone base layer should not exceed three (3) ie subbase, fill and natural subgrade. Instead, muliple layers with inconsistent CBR, density and relative compaction values were delineated on Presco –Ishieke junction section of Enugu–Abakaliki Road and Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road. This can be as a result of the nonselective use of materials in pavement construction, irregular compaction, swelling of part of the pavement or combination of all of these. Apart from these factors, the soil used in construction in Abakaliki are derived from shale. Hussein and Moruf (2013) work on Imo shale and Ameki revealed that shale derived soils are known for relatively low campaction values.Spera-In-Deo–Mammy Market section of Abakaliki–Afikpo Road shows consistency in both pavement structural layers, pavement strengths and thicknesses. The DCP results show that each layer of the Spera-In-Deo–Mammy Market section of Abakaliki–Afikpo Road is well and uniformly compacted to the required or acceptable thickness.

Table 4: Results of field moisture content and density tests

Road	Station	Field moisture content (%)	Field dry density g/cm	Compaction level (%)
Presco –Ishieke junction section of Enugu–Abakaliki Road	EA 1	18.2	1.9	95
	EA2	18.0	1.92	97
	EA3	8.2	2.1	101
	EA4	17.6	1.99	99
	EA5	16.8	1.91	97
Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road	AO1	11.2	2.05	100
	AO2	12.2	2.05	100
	AO3	12.8	2.02	98
	AO4	12.2	1.99	99
	AO5	12.2	2.06	101
Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road	AA1	9.6	2.09	101
	AA2	10.6	2.06	102
	AA3	12.8	2.11	102
	AA4	14.0	2.08	103
	AA5	10.8	2.06	101

Pavement Moisture

The average subbase field moisture content of the Presco –Ishieke junction section of Enugu–Abakaliki Road is the highest (8.2 – 18.2 %), followed by the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road(11.2 – 12.8 %) while the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road has the least field moisture content 9.6 – 14.0 %) (see Table 4). The higher moisture content recorded in Presco –Ishieke junction section of Enugu–Abakaliki Road is attributed to high percentage of fine in the clayey subbase material and tendency of the fine to absorb water. The water absorption can be from surface water ingress or capillary action of the groundwater or combination of the two options. The slight reduction in the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road is due to the presence of filter bed of sand which helps in reduction or stoppage of the capillary water in the clayey subbase. The sand and laterite mix used as subbase on the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road lowered the absorption property of the clayey laterite dominant in Abakaliki area. the sand increases the permeability, and reduces the water retention properties of the clayey laterite as excessive fines of moderate to high plasticity in pavement material enhances water absorption, induce swelling and consequently reduce CBR or strength (Inan *et al.* 2016). Similarly, for the same reasons the laboratory optimum moisture content results (Table 5) follow the same trend as the field moisture; the highest values were recorded on the Presco –Ishieke junction section of Enugu–Abakaliki Road while the least was obtained on the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road.

Pavements Strength (CBR)

The subbase of the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road exhibited field (in-situ) CBR of 29 – 30%, and laboratory CBR of 29 – 32% (see Tables 3 and 5) . The subgrade has field and laboratory CBR values of 12 and 15% respectively. The subgrade soaked CBR value greater than or equal to 15% (after 4days soaking) and subbase CBR value not less than 30% (after 24 hours soaking) are recommended in the specifications for Road and Bridges by FMWH (1997) in Nigeria. Thus, the values meet the specification requirements for subbase and subgrade. The subbase of the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road has in-situ and laboratory CBR values of CBR of 21 – 24% and 21 – 29% respectively. These values are slightly lower than

Table 5: Results of laboratory compaction and CBR Tests on the tested samples

Road	Station	MDD (g/cm^3)	OMC (%)	Laboratory CBR (%)	Pavement layer
Presco – Ishieke junction section of Enugu–Abakaliki Road	EA 1	1.99	14.2	25	Subbase
	EA2	1.98	15.1	24	
	EA3	2.06	9.6	36	
	EA4	2.01	14.8	32	
	EA5	1.97	15.6	18	
	EA3	2.17	10.6	17	Subgrade
	EA5	2.28	10.8	20	
Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road	AO1	2.04	12.8	22	Subbase
	AO2	2.02	13.4	23	
	AO3	2.08	11.9	21	
	AO4	2.01	11.6	24	
	AO5	2.04	12.6	29	
	AO1	1.78	14.2	12	Subgrade
	AO3	1.81	13.8	10	
Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road	AA1	2.07	10.4	30	Subbase
	AA2	2.01	10.8	31	
	AA3	2.07	10.5	32	
	AA4	2.02	12.0	29	
	AA5	2.04	10.4	30	
	AA2	2.01	14.6	10	Subgrade
	AA5	2.04	14.8	13	

the specification requirement for sub base. However, the road has minimum subgrade CBR of 10% and 21 – 29% respectively. These values are slightly lower than the specification requirement for sub base. However, the road has minimum subgrade CBR of 10%. The Presco –Ishieke junction section of Enugu–Abakaliki Road exhibited the least subbase field CBR (9 – 78%) but moderate laboratory CBR (18 – 36%) The field CBR is predominantly low, the recorded 78% CBR was as a result of localised patching with at location EA3. Notwithstanding, the subgrade CBR is between 10 and 23%. The variation in the sand and fine proportion is the basis for the variation in the subbase CBR values recorded in this investigation. Purwana *et al*. (2012) explained that both the clay content and the air drying period have an impact on the CBR. He further explained that the amount of water present in the soil has no significant effect on the CBR when it has 100% sand. Sand stabilisation is responsible for the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road's suitable sand and fine fractions; thus consequently influences high and consistent CBR values and pavement strength. Increase in CBR increases the pavement strength (Yashas *et al*. 2016). The design CBR ≥ 5% is considered suitable for flexible pavement design (Overseas Road Note 31 1993). The obtained soaked subgrade CBR supports the conclusion of Aghamelu and Okogbue (2011) that the soaked CBR values of Abakaliki shales are very satisfactory for use as general fill and embankment.

Index Properties of the Investigated Pavement Soils

The index properties of the investigated roads are related to specification limits as recommended in the general specification for roads and bridges by FMWH (1997). The subgrades of all the investigated roads are similar, with closely related index properties. The subgrade, mainly GM (silty gravel with sand) and SM (silty sand with gravel) according to Unified Soil Classification System is silty with moderate plasticity (Tables 6 and 7). Following the AASHTO (1986) M145 classification guideline, the subgrades soil are under A-2-6, A-2-7 and A-7-5 soil groups with group index of 0 to 1. The low group index confirms the suitability of the materials as subgrade. The soil that has lower value of group index is likely to perform better as a highway subgrade material (Braja 2002). All the properties indices; liquid limit (LL) and plasticity index (PI) slightly exceeded the specification limits for subgrade layer. The liquid limit (LL) is 46 – 58, higher than specified 35 maximum and plasticity index (PI) is 13 – 19 higher than specified maximum limit of 12. The failure to meet standard requirement is simply because the investigated roads subgrades are predominantly silty soils formed from the bedrock of shale that underlies the entire project area. Shale is generally known for fine particle size and high Atterberg limits (Aghamelu *et al*. 2012). Regardless of the above mentioned deficiency, the subgrade is still considered suitable in line with clause 6122 of the FMWH (1997) general specifications for roads and bridges. The document considered clay material with liquid limit less than 80% and Plasticity index less than 55 as suitable for subgrade.

The percentage fine (passing sieve #200) in the subbase layers of the investigated pavements is low to moderate. However, the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja (AO) Roadand the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo (AA) Road have acceptable limit of fines (not greater than 35%) using the FMWH (1997) general specifications for roads and bridges as a standard (Table 8). The exception is on the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road. Relatively, the subbase liquid limit values obtained from this road section are the lowest among the three tested roads (see Table 7). The modeled particle size distribution curves for AA, AO and EA (Fig. 5) indicate that AA and AO soils are well graded (poorly sorted) than EA from the particle size analysis and therefore have the fairest engineering properties in the studied area. This is in

Table 6: Results of soil particle size distribution analysis

Road	Station	Fines fraction	Sand fraction	Gravel fraction	Pavement layer
Presco – Ishieke junction section of Enugu– Abakaliki Road	EA1	34	49	17	Subbase
	EA2	38	36	26	
	EA3	33	47	20	
	EA4	33	44	23	
	EA5	38	36	26	
	EA3	24	72	4	Subgrade
	EA5	32	29	39	
Spera-In-Deo– Onuebonyi section of Abakaliki– Ogoja Road	AO1	35	21	44	Subbase
	AO2	32	35	33	
	AO3	34	48	18	
	AO4	35	42	23	
	AO5	35	39	26	
	AO1	30	32	38	Subgrade
	AO3	34	32	34	
Spera-In-Deo– Mammy market section of Abakaliki– Afikpo Road	AA1	29	56	15	Subbase
	AA2	30	66	4	
	AA3	30	57	13	
	AA4	28	56	16	
	AA5	30	61	9	
	AA2	30	34	36	Subgrade
	AA5	38	38	24	

agreement with the surface deformation on the roads (see Figs. 3d, and e). As can been in the figure, these are low plastic soils with moderate clay content hence, good drainage system away from the pavement is required. The plasticity index values of the subbase layer of both the Presco – Ishieke junction section of Enugu – Abakaliki Road and the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road did not meet with the specification requirements of the FMWH (1997). Among the three investigated roads, only the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road has the specified Plasticity Index (less than or equal to 12). The reduction in percentage of fines, liquid limit and plasticity index of this road section compared to others is attributed to the addition of river sand to the subbase laterite during construction according to the information gathered from the Civil Engineering Department of the Ministry of Works and Transport Ebonyi state. The subbase PI of the AA Road is the lowest; as sand stabilisation reduces all parameters of consistency including plasticity index (Bahia and Ramdane 2012). Madu (1975) established that mixture of sand to laterites reduces the Atterberg limit and the linear shrinkage.

Comparison of Subbase Laboratory and Field Dry Densities

The correlation between the field and laboratory dry densities of the subbase layer for the investigated roads shows that the field density represented by a continuous line on the plots, is higher in all tested locations on the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road (Figs. 6a–b and 7a). However, the laboratory dry density represented by the dotted line in is higher in all the tested points on the Presco –Ishieke junction section of Enugu–Abakaliki Road (except EA3) and locations onthe Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road (EO3 and EO4). The field and laboratory dry densities relationship are graphically (Figs 8a – c). The reduction in field dry density is as a result of volume change or swelling of the subbase layer, especially in the vicinity of the wide median where there is easier water ingress into the pavement.

Comparison of the Subbase Laboratory and Field CBR

The correlation of the subbase field and laboratory CBR of the investigated roads (see Figs. 7b, 9a and b) showed

Fig. 4: Pavement Structure of ; (a) Presco –Ishieke junction section of Enugu–Abakaliki Road (b) Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road and (c) Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road.

Table 7: Summary of results of Atterberg limit

Road	Station	Liquid Limit	Plastic Limit	Plasticity Index	AASHTO Group	USCS Group	Pavement Layer
Presco –Ishieke junction section of Enugu–Abakaliki Road	EA 1	45	30	15	A -2-7 (1)	SM	Subbase
	EA2	42	29	13	A -7-6 (1)	SM	
	EA3	29	18	11	A-2-6 (0)	SC	
	EA4	45	30	15	A-2-7(1)	SM	
	EA5	42	26	16	A-7-6 (2)	SM	
	EA3	58	45	13	A-2-7 (0)	GM	Subgrade
	EA5	55	40	15	A-2-7 (1)	GM	
Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road	AO1	43	30	13	A-2-7 (1)	SM	Subbase
	AO2	47	35	12	A-2-7 (0)	SM	
	AO3	50	34	16	A-2-7 (1)	SM	
	AO4	38	23	15	A-2-6 (1)	SC	
	AO5	41	27	14	A-2-7 (1)	SM	
	AO1	46	32	14	A-2-7 (2)	GM	Subgrade
	AO3	50	31	19	A-2-7 (1)	GM	
Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road	AA1	38	27	11	A-2-6 (0)	SM	Subbase
	AA2	41	29	12	A-2-7 (0)	SM	
	AA3	39	27	12	A-2-6 (0)	SM	
	AA4	40	29	11	A-2-6 (0)	SM	
	AA5	38	27	11	A-2-6 (0)	SM	
	AA2	49	34	15	A-2-7 (1)	GM	Subgrade
	AA5	53	38	15	A -7-5(2)	GM	

Table 8: Comparative analysis of test results with Nigeria FMWH (1997) specification

Parameter	FMWH (1997)	Presco –Ishieke junction section of Enugu–Abakaliki Road					Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road					Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road				
Subbase	SPEC	EA 1	EA2	EA3	EA4	EA5	AO1	AO2	AO3	AO4	AO5	AA1	AA2	AA3	AA4	AA5
Passing #200	≤ 35	47	42	19	35	39	35	32	36	36	35	34	32	29	35	30
LL (%)	≤ 35	36	42	29	45	42	43	47	40	38	41	40	41	39	35	38
PI (%)	≤ 12	14	13	11	15	13	13	12	15	15	14	11	12	12	11	11
Lab OMC (%)		14.2	15.1	9.6	14.8	15.6	12.8	13.4	11.9	11.6	12.6	10.4	10.8	10.5	12	10.4
Field NMC (%)		18.2	18	8.2	17.6	16.8	11.2	12.2	12.8	12.2	12.2	9.6	10.6	12.8	14	11
Lab Dry Density (g/cm3)		1.99	1.98	2.06	2.01	1.97	2.04	2.02	2.08	2.01	2.04	2.07	2.01	2.07	2.02	2.04
Field Density (g/cm3)		1.9	1.92	2.1	1.99	1.91	2.05	2.05	2.02	1.99	2.06	2.09	2.06	2.11	2.08	2.06
CBR Soaked	≥ 30	25	24	36	32	18	22	23	21	24	29	30	31	32	29	30
In situ CBR	≥ 30	7	11	42	26	15	30	28	17	21	31	31	31	32	30	31
Subgrade																
Passing #200	≤ 35			28		18	34		30				38			30
LL (%)	≤ 35			58		55	50		46				53			48
PI (%)	≤ 12			13		15	19		14				15			12
Lab OMC (%)				15.2		14.4	14.2		13.8				14.6			14.8
Field NMC (%)				18.2		18.6	14.8		14.2				14.8			14.2
Lab Dry Density (g/cm3)				1.88		1.95	1.78		1.81				1.78			1.75
CBR Soaked	≥ 15			20		15	12		10				17			15
In situ CBR	≥ 15			17		12	11		12				18			17

that only the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Roadexhibited field (in-situ) CBR higher than laboratory determined CBR. The laboratory CBR of this road section is greater than or very close to the 30% specified by Nigerian Federal Ministry of Works Specification for Roads and Bridges (see Table 8). All the tested locations (except EA3) on the Presco –Ishieke junction section of Enugu–Abakaliki Road

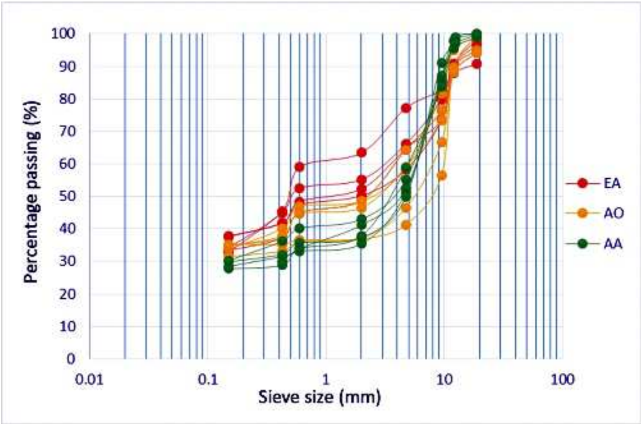

Fig. 5: Modeled particle size distribution curves for AA, AO and EA

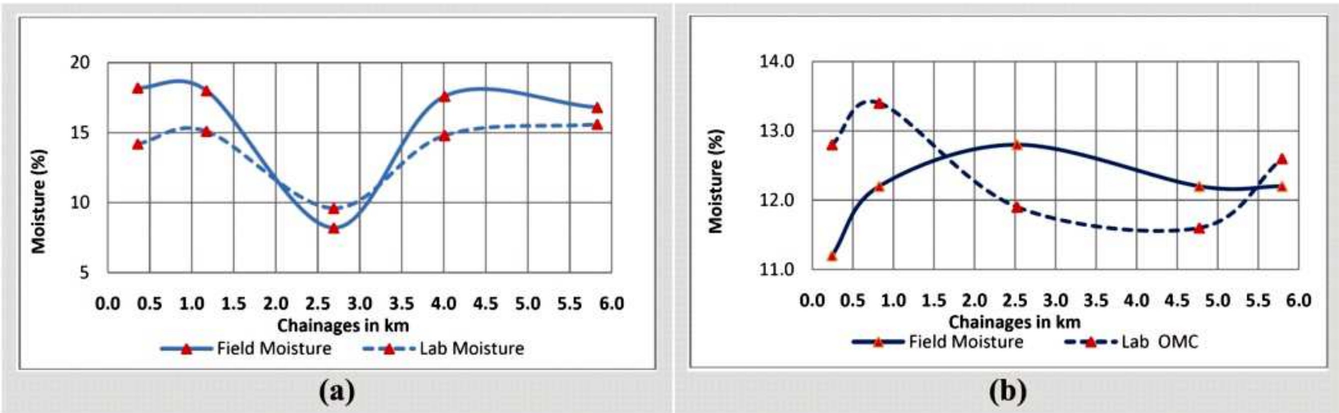

Fig. 6: (a) Field and laboratory moisture content of the Presco –Ishieke junction section of Enugu–Abakaliki Road (b) Field and laboratory moisture content of theSpera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road

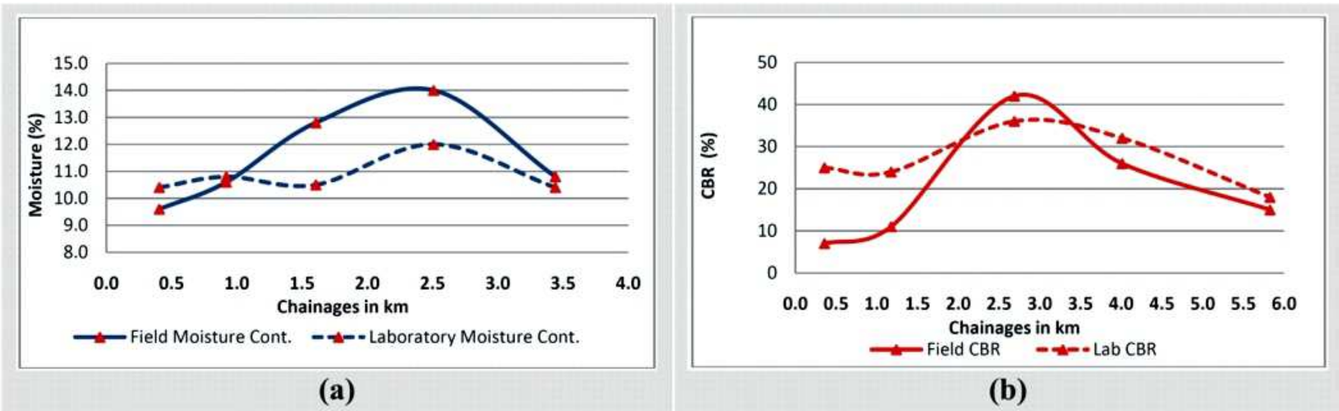

Fig. 7: (a) Field and laboratory moisture content of the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road (b) Field and laboratory CBR on the Presco –Ishieke junction section of Enugu–Abakaliki Road

(exhibited laboratory CBR values higher than the field (in-situ) determined CBR. The same situation was recorded on the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road (except for EO1 and EO5). More so, there is confirmation that the laboratory CBR values of the Presco –Ishieke junction section of Enugu–Abakaliki Roadand the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Roadare slightly lower than the specification in most of the tested stations (see Table 8). This suggests that the pavement subbase is either slightly expansive in contact with water or probably was given lesser compaction during construction. The second option is not sustainable, considering the year of construction**;** with time, consolidation and repetitive loading could have brought the pavement to stability. Considering the Atterberg limit and fine proportion of the investigated pavements subgrade; it is established that the variation in CBR is as a result of soil expansion due to an increase in soil moisture.

Pavement Deformation and Cracks

Severe surface deformations which include fatigue or alligator cracking, rutting and potholes conspicuously manifested on the Presco –Ishieke junction section of Enugu–Abakaliki Road can be attributed to high percentage fine (> 35 % specified) in the subbase layer

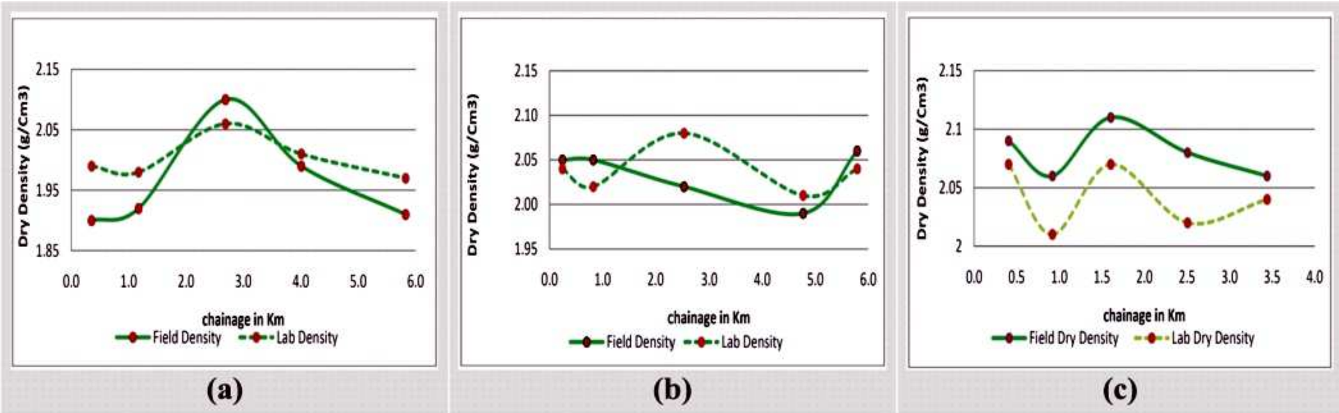

Fig. 8: (a) Field and laboratory density of the Presco –Ishieke junction section of Enugu–Abakaliki Road (b) Field and laboratory density of the Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road (c) Field and laboratory density of the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road

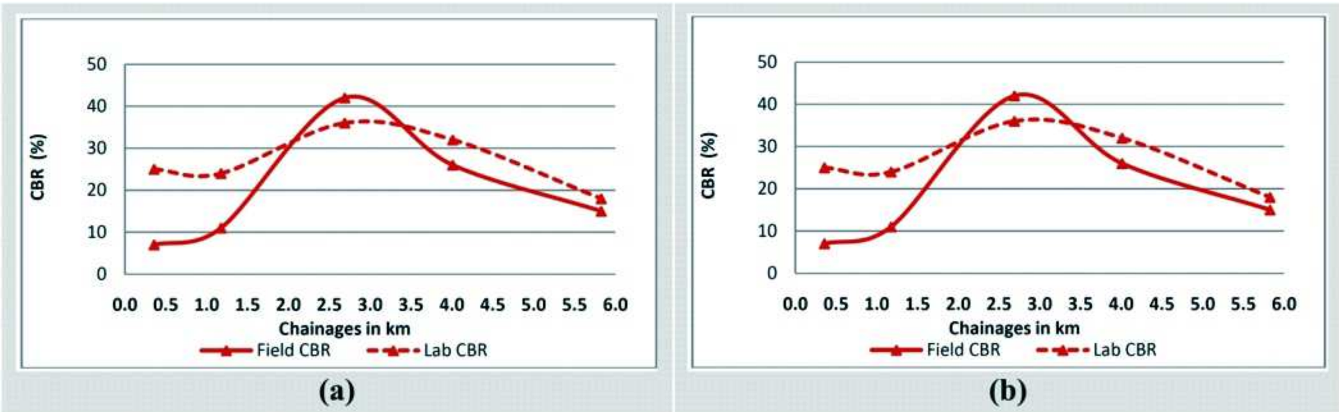

Fig. 9: (a) Field and laboratory CBR onSpera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road (b) Field and laboratory CBR on the Spera-In-Deo–Mammy market section of Abakaliki–Afikpo Road

and ingress of water from the road surface and the poorly protected wide median. The clayey subbase is susceptible to swelling in raining season and shrinkage in dry season. Water inflow from the porous median induces swelling, loss of strength (in-situ CBR), and consequently weaken the subbase layer. Rutting is caused by subgrade failure or inadequate compaction (Saharad and Gukpa 2015). Osuolale *et al*. (2002) also investigated the possible causes of highway pavement failure along Ibadan – Iseyin Road in South Western Nigeria. He concluded that the materials used as subbase have the geotechnical properties below the specification and this is likely to be responsible for the road failure within Abakaliki region.

Conclusion

The subbase material and pavement moisture is responsible for pavement deformation and road failures in the study area. The silty or clayey subbase and subgrade layers are not permeable enough to drain surface water, but good enough to induce capillarity. Soil classification test placed the subgrade of the three investigated roads on similar soil groups (SM and GM). Results of field investigation revealed that both Presco–Ishieke Junction section of Abakaliki–Enugu Road and Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road have lower field CBR, dry densities and higher field moisture than the corresponding laboratory results. In contrast, sand stabilised Spera-In-Deo –Mammy market section of Abakaliki–Afikpo Road is stable without deformation. The sand stabilised Spera-In-Deo–Mammy Market section is the most stable of the investigated roads with no visible defect. Road failures including ruts, alligator crack, potholes and depression are concentrated on the unstabilised Presco – Ishieke junction section of Abakaliki–Enugu Road and Spera-In-Deo–Onuebonyi section of Abakaliki–Ogoja Road with wider and unprotected medians but completely absent in Spera-In-Deo–Mammy Market section of Abakaliki–Afikpo Road with narrow solid median. Stakeholders who are involved in construction of pavements in the study region should adopt sand stabilised subbase to reduce fine, plasticity and swelling potential. More so, the roads should be designed with elevation far from groundwater table. AO and AA soils are more well graded (poorly sorted) soils than EA. They are low plastic soils with moderate clay content hence, good drainage system away from the pavements is also recommended.

Disclosure Statement

We state clearly, that we have no conflict of interest to declare.

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Pictorial view of the new NMGS House under construction at Abuja.