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RESEARCH ARTICLE

SOIL GEOTECHNICAL CHARACTERISATION AND ITS INFLUENCE ON THE FAILURE OF ENUGU – PORT HARCOURT EXPRESSWAY IN UMUAHIA, NIGERIA

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ABSTRACT

The Nigerian government have consistently spent billions of Naira in rehabilitating roads which have been failing repeatedly and this has become a major concern, especially in the South-eastern region of the country. This paper established the influence of the underlying geology and soil geotechnical characteristics on the attendant road (risk) failure within a (5km) section off the Enugu – Port Harcourt Expressway and its spatial variation as well. Soil samples were collected from five (5) portions of the road where cracks were noticed while secondary data was obtained from existing literatures to explain the implication of the findings. Laboratory analysis adopted assessed four (4) five (5) major soil geotechnical properties: particle size distribution, Atterberg Limit (i.e. liquid limit, plastic limit and plasticity index), compaction test (i.e. British Light and Heavy maximum dry densites and optimum moisture contents), California Bearing Ratio (i.e. soaked and unsoaked), and Hydraulic Conductivity (K), while other parameters such as coefficients of curvature and uniformity were estimated. Principal Component Analysis was adopted to analyse the data so obtained while ANOVA test was performed to ascertain if the geotechnical properties of the different soils were significantly different. This was done using Minitab statistical package. Result obtained from the sieve analysis indicated that the soil grains all ranged from medium to coarse grains, composed of low fines, exhibit a strong uni-modal curve and are poorly graded. The result of the PCA indicated that three (3) components accounted for about 97% of the persistent road failures in the portion under investigation: Plasticity Index (50%), Maximum Dry Density (30%) and Plastic Limit (15%) were identified. Also, the result of the ANOVA test, with an R^2 adjusted value of 99.16% showed that the geotechnical properties of the soils (within 2.3% of the entire expressway) were significantly different. With such results, road failure (e.g. cracks, pot holes, crevices, depressions, cut-offs etc.) is imminent and therefore calls for more critical geotechnical soil characterization for all other portions of the expressway, especially the portion within Abia State (where about 13 geologic formations have been identified). The study therefore recommended, amongst others that all relevant stakeholders discourage all practices (especially sand mining) that are capable of initiating road failures, while civil engineers should consider the varying influences of the underlying geology and the unique geotechnical characteristics of sub-grade materials before subjecting uniformly any stretch of land in the region for road pavement construction.

INTRODUCTION

Road failure or road pavement failure refers to any form of impedance of movement in a given road network which may range from cracks, potholes, bulges, gullies, and depressions (FMW&H, 1992). In order to have a smooth ride, a road network is supposed to be a continuous stretch of asphalt layer. The role of road transport in the conveyance of people, goods and services from one geographical area to the other is vital for the socio-economic development of any region or country. In fact, it is so key and indispensable that meaningful development may elude any economy that does not take it seriously. As a

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maker and breaker of cities or regions, road transport have influenced or played a significant role in the development and urbanization process in Nigeria; this cannot be overemphasised. Unfortunately, the Federal Road Safety Corps (FRSC 2011) reported that, Nigeriaranks 191 of 192 countries of the world with unsafe roads, and as a result 162 deaths per 10,000 occur from road crashes. Most accidents recorded occurred within the bad portions which are largely due to failure.

Thus, as more roads are envisaged in the near future in the country, coupled with the high cost of construction and harsh economic waves, it is necessary to learn from past failures so as to avoid repeated problems in the future.

The studies of Abam (2005) and Emujakporue (2012) revealed that the causes of road failure in Nigeria can be attributed to poor construction materials, poor design and specification, road usage, poor drainage, geological and geotechnical factors. Previous studies have stressed on the fact that theintegrity of the

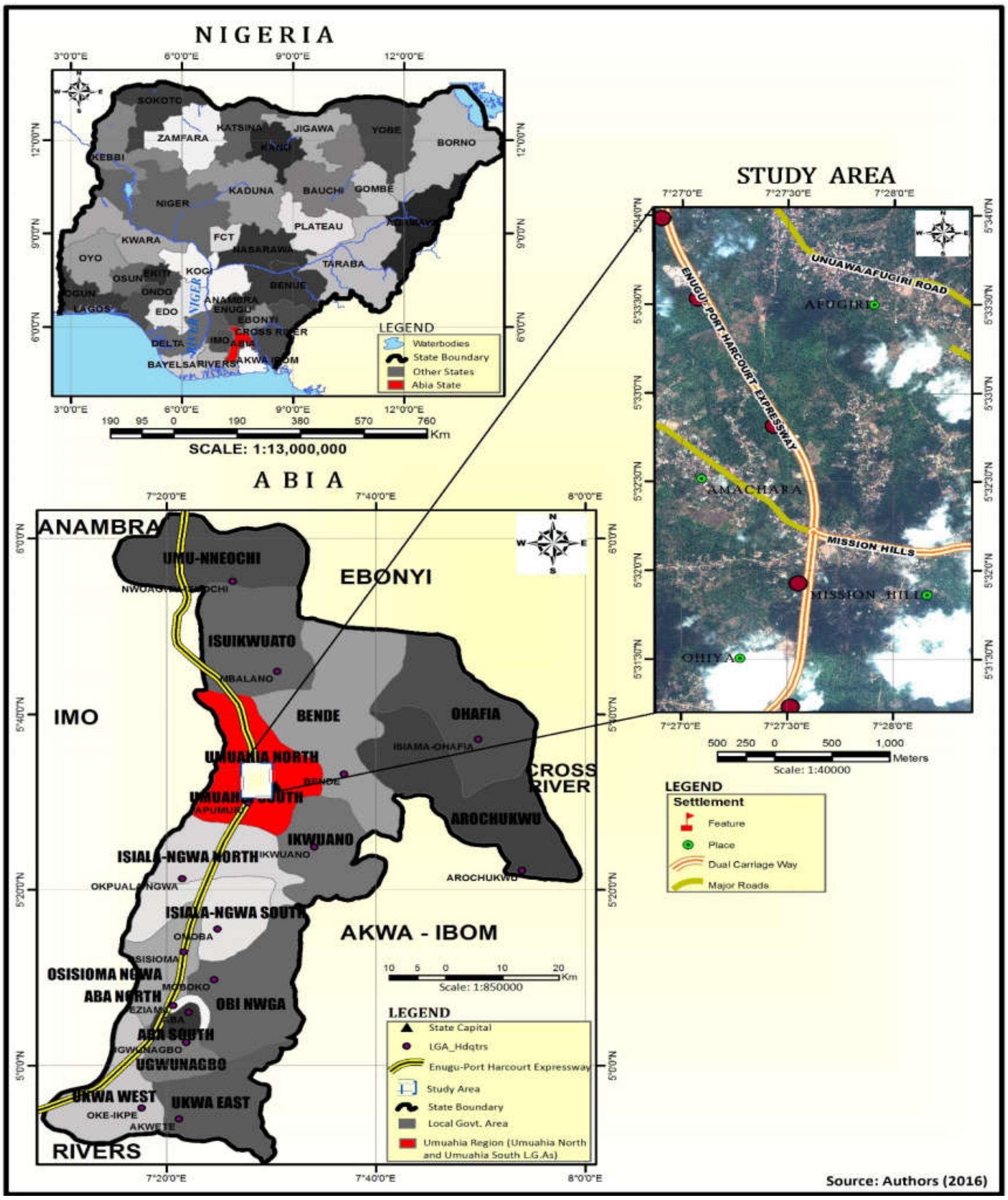

Figure 1[A]: Top Left – Map of Nigeria showing Abia State
1[b]: Bottom Left – Map of Abia State showing Umuahia region, Enugu – Port Harcourt Expressway and the area of study
1[c]: Middle Right Hand Side – Map of the Study Area showing the road portion under investigation

Source: GIS Lab, Kogi State University, Anyigba (2016) geological features and/or engineering characteristics of theunderlying geologic/geoelectric sequences (Adeleye, 2005; Oladapo,*et al*., 2008). According to Momoh, *et al.* (2008), Okogbue and Aghamelu (2011) and Onuoha, Onwuka and Obienusi (2014), road failures exist and are persistent due to inadequate knowledge of the geotechnical characteristics and behaviour of residual soils on which the roads are built and also

due to the non-recognition of the influence of the underlying geology during the construction phase. It is expected that before the construction of roads, detailed geotechnical and geophysical survey, even at a micro scale than a more generalized approach ought to be embarked upon, to avoid large sums of money to be spent on road repairs that should have been injected into other vital sector of the economy (Aigbedion, 2007; and Ifabiyi and Kekere, 2013).

The Enugu- Port Harcourt expressway is a typical model and example of Nigerian roads whose failure bugs the mind of regular users (Onu, *et al.,* 2012). Almost every section of the road usually fail after a period of about 6 months of rehabilitation resulting to loss of lives and properties; human injuries and increased stress, high risk of accidents to retardation of the rate of economic growth and development in affected towns or communities, and the flow of economic activities and numerous cases of armed robbery attacks along affected areas. This issue is becoming increasingly worrisome especially as it is a financial burden on the Federal, State and Local Governments, as earlier mentioned.

From another perspective, which demands careful consideration is the fact that in Abia State, characterized with thirteen (13) geological formations, numerous old and new gullies that have emerged from which many of the old gullies have grown rapidly to disaster levels leading to increasing road transport risk in the region (Akpokodje et al., 2010; Nwilo, 2011; Ugada, *et al*., 2013). From this point of view, it is stressed here that road pavement construction in the region will require more than a generalized study or survey as embarked upon by different authors (Emujakporue, 2012; Ifabiyi and Kekere, 2013; Ebhohimen, 2013; Onuoha and Onwuka, 2014; etc.), before now. Thus, this paper tends to look deeper into the level of variation of soil geotechnical properties (under the Benin formation), along a distance of 5km to explain the possible causes of the incessant failure of a section of the Enugu – Port Harcourt expressway in the Umuahia Region. This will aid to investigate the uniformity and/or local variations in sub-grade properties of soils in the portion considered to aid best practices and quality control in road pavement design and construction in the region.

Aim And Objectives

The aim of this study is to perform a geotechnical characterization of soils from different sites off Enugu – Port Harcourt expressway with a view to elucidate its influence on road failure in Umuahia region, as well as its spatial variation. This will be achieved using the following objectives:

1. To ascertain the geotechnical characteristics of the soils collected from different sites (where noticeable road failures exist) within Umuahia region,
2. To ascertain the major geotechnical characteristics of the soils that influence road failure in the region in line with the Federal Ministry of Works & Housing (FMW&H) standards.
3. To ascertain if there is a significant difference in soil geotechnical properties obtained from different sites in the region.

Research Hypothesis

H_o: There is no significant difference between the geotechnical properties of soils collected from Umuahia region along Enugu – Port Harcourt Expressway.

Description of The Study Area

The Enugu - Port Harcourt Expressway is a flexible structure that consist of asphalt surface constructed on stabilized base and sub base course and runs through almost the entire area of Abia State, extending from Enugu State in the North and Rivers State in the South. The road is located on Federal link-node system on Link A343 Enugu and A231 Port Harcourt with an approximate distance of about 217km. However, the portion of the highway under investigation is absolutely located at Latitude 5^o29'N and 5^o34'N and Longitude 7^o26'E and 7^o27'E, at an area within the boundaries of Umuahia North and Umuahia South L.G.As. The portion of the highway under investigation covers a distance of 5km, from NNPC Mega Station in Umuahia North L.G.A to Ohiya Car Park in Umuahia South L.G.A. See Figure 1.

In the area, Umuahia, the rain begins usually in January/February with full commencement of rainy season in March and stopping in November of each year (Olabaniyi,*et al*., 2006). The dry season lasts between four to five months. The high intensity tropical rainfall in the area produces high volume of overland flow and run-off that possess high erosive energy. This combines with the high erodibility (dispersion) properties of the sandy soil to produce the numerous severe complex gullies that have affected road pavements in different parts of the Umuahia Region and Abia State as well (Nwilo, 2011).

Geologically, there are about 13 different geologic formations in Abia State (Igbokwe and Amos-Uhegbu, 2014; Ugada, *et al*., 2013) and a part of the Cenozoic Niger-Delta province of Nigeria which was formed as a result of the interplay between subsidence and deposition arising from a succession of sea transgressions and regressions (Hosper, 1965 and Ugada, *et al*., 2013) that gave rise to the deposition of three lithostratigraphic

units in the Niger Delta (Short and Stauble, 1965).These units are Marine Akata Formation, Paralic Agbada Formation, and the Continental Benin formation. The road portion under investigation falls under the coastal plain sands of the Benin formation (See Table 1 and Figure 2).

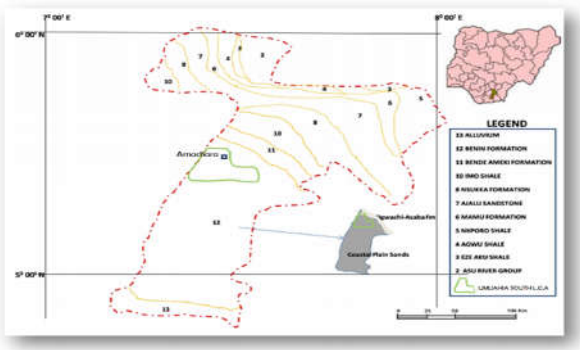

Figure 2 *Geologic Map of Abia State*

Source:*Adapted and modified from Ugada et al. (2013)*

The samples were first air-dried under the sun to allow moisture to escape before basic test was performed. The tests were conducted in accordance with the British Standard in the Soils and Materials Laboratory, Dept. of Civil Engineering, Nnamdi Azikiwe University, Awka, Nigeria for which five (5) major soil geotechnical properties were analyzed. See Table 3 below:

Sieve analysis was used to perform the particle size distribution test from which a grain size curve was plotted and used to compute other estimated parameters necessary for the analysis (i.e. Coefficient of Uniformity and Coefficient of Curvature).

Table 1 Stratigraphic correlation chart of Cenozoic Eastern Niger delta outcrops and subsurface.

AGE	SURFACE OUTCROP EQUIVALENT FORMATION	SUBSURFACE FORMATION	MEGA DEPOSITIONAL ENVIRONMENT
Miocene – Recent	Coastal Plain Sand	Benin Formation	Paralic Continental
Oligocene - Recent	Ogwashi-Asaba Formation	*Afam Clay Member*	Continental Delta Plain
Eocene - Recent	Bende-Ameki Formation	Agbada Formation	Paralic Delta Front
Paleocene – Recent	Imo Formation	Akata Formation	Marine Pro-Delta

Source: *Adapted and modified from Amajor (1986), and Short and Stauble 1967.*

METHODOLGY

The study adopted an experimental approach. This involved the collection of soil samples from five (5) sites in the study areawhere road failures (i.e. cracks and potholes) were noticed. Global Positioning System (GPS) was used to obtain coordinates of the sites under investigation from which the map of the study was produced. See Figure 1 and Table 2.

The result of laboratory analysis obtained was subjected to Principal Component Analysis (PCA) on the whole and this was used to reduce the variables to a few original components that are capable of influencing the persistent road failures in the portion under investigation. Again, the study adopted the use of Analysis of Variance (ANOVA) to ascertain if there exist any significant difference in the soil geotechnical characteristics from the sites.

Table 2 Sample sites description.

S/No.	Site_ID	Appro. Road Setback (m)	Absolute Location (UTM)		Relative Location
			Longitude (m)	Latitude (m)	
1	P_01	39	328130	615443	Opposite Seventh Day Adventist Church, after Umuafiaka Road Junction, Umuahia North
2	P_02	42	328445	614607	Along the Enugu-Port Harcourt Expressway, Umuawa, Umuahia North
3	P_03	40	329110	613284	Along the Enugu-Port Harcourt Expressway, before the Abia Tower, Amachara, Umuahia South
4	P_04	64	329318	611645	Close to Ezeugon Filling Station, Ohiya, Umuahia South
5	P_05	75	329248	610368	Immediately after the New Park, Ohiya, Umuahia South

Source: Author's field survey (2016)

Table 3 Variables used for the study and their empirical formulae.

S/No.	Broad Group		Variables	Unit
1.	Particle Size Distribution (PSD)		Sand	Percentage (%)
2.			Silt (passing sieve <75um)	
3.	Atterberg Limit		Liquid Limit (LL) Plastic Limit (PL) Plasticity Index (PI)	
4.	Compaction	British Heavy	Maximum Dry Density (BH_MDD)	kg/m^3
5.			Optimum Moisture Content (BH_OMC)	
6.		British Light	Maximum Dry Density (BL_MDD) Optimum Moisture Content (BL_OMC)	
7.	California Bearing Ratio (CBR)		Soaked (CBR_s) Unsoaked (CBR_u)	Percentage (%)
8.			Hydraulic Conductivity (K)	
9.	Estimated Parameters		Coefficient of Uniformity (C_u)	
10.			Coefficient of Curvature (C_c)	

Source: Authors' laboratory analysis (2016)

RESULT AND DISCUSSION

The result of the laboratory analysis obtained for the study is presented in Table 3. The Particle Size Distribution (PSD) of the samples analysed and plotted to obtain a grain-size curve (See Figure (4) shows an almost uniform distribution except for stations P_01 and P_03 that deviated from the general pattern. The grain size curve was further used to estimate D_{10}, D_{30} and D_{60} which were used to compute for the Coefficient of Uniformity and Coefficient of Curvature as shown in the result of soil geotechnical characterization in Table 4. From table 4, it is clear that there exist slight variation in sand and fine composition from all the sites and this can be attributed to the fact that most of the samples were located in the same sedimentary mega depositional environment.

Thus, the grain size curve revealed that the samples all ranged from medium to coarse sands with a moderately strong uni-modal curve. This all imply that the foundation materials all tended to be more poorly graded with high percentage of sandy soil (with very low fine) composition which affects the rate of compaction of the road. This is a major problem that can result in road failure since this tends to affect the bonding of soil and its sheer strength.

The result (Table 4) shows that British Standard Light Optimum Moisture Content (BL_OMC) range from 11.87 – 34.32%; British Standard Heavy Optimum Moisture Content (BH_OMC) range from 9.47 – 25.34%, while British Standard Light Maximum Dry Density (BL_MDD) ranges from 1414.47 – 1966.5 kg/m^3 and British Heavy Maximum Dry Density (BH_MDD) range from 1963.63 – 2146.6 kg/m^3

Table 4 Soil Geotechnical Properties of Soils collected for the Study

S/No.	PARAMETERS	SAMPLE SITES				
		P_01	P_02	P_03	P_04	P_05
1	SAND	86.034	79.358	75.386	89.756	89.036
2	SILT	13.966	20.642	24.614	10.244	10.964
3	LL	46.000	35.000	40.000	46.000	39.000
4	PL	21.348	20.450	22.701	22.801	22.793
5	PI	24.652	14.550	17.299	23.199	16.207
6	BL_MDD	1414.470	1966.500	1673.040	1805.050	1905.680
7	BL_OMC	34.320	11.870	16.550	13.560	12.820
8	BH_MDD	2100.250	2083.030	1963.630	2134.619	2146.600
9	BH_OMC	25.340	12.816	14.580	12.430	9.470
10	CBR_S	1.000	6.000	3.000	1.000	3.000
11	CBR_U	9.000	21.000	10.000	10.000	15.000
12	CU	18.750	6.100	21.250	6.000	8.670
13	CC	2.800	0.980	0.580	1.170	1.180
14	K	0.002	0.015	0.012	0.003	0.000

Source: Authors' laboratory analysis (2016)

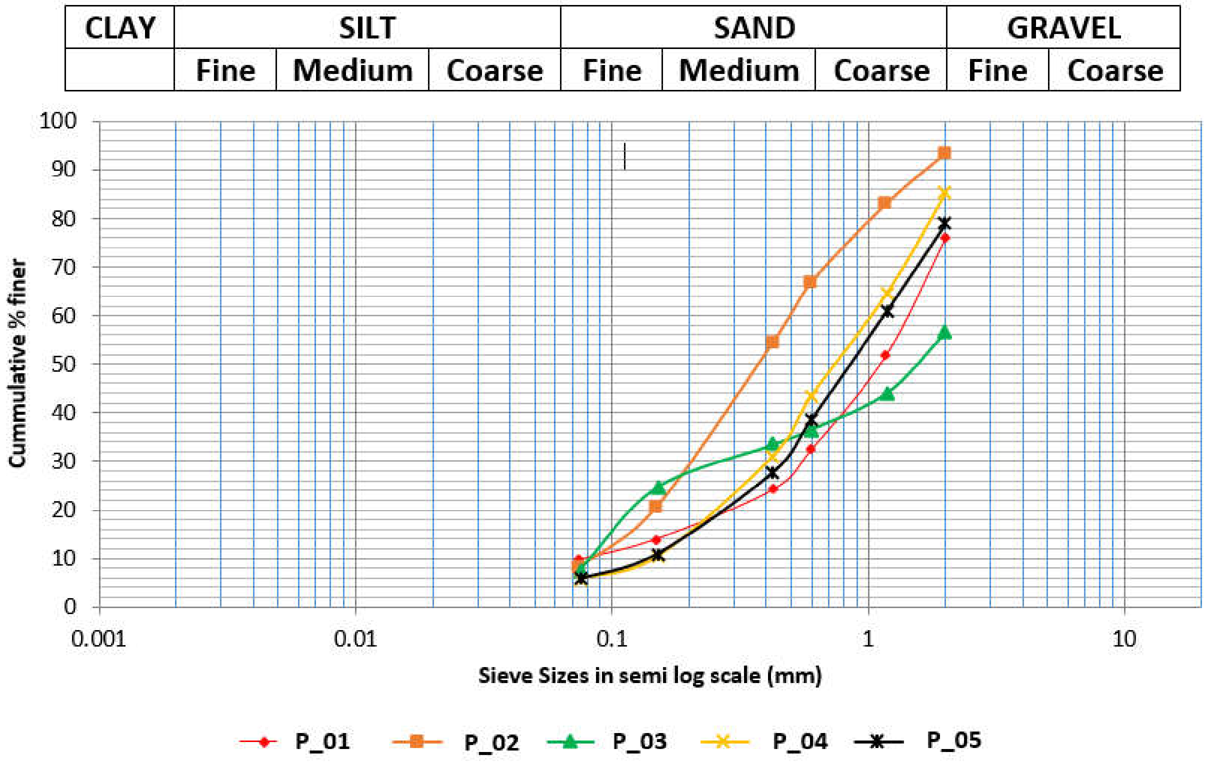

Figure 3 Grain-Size Curve

Source: Authors' laboratory analysis (2016)

The value for MDD of foundation soil ranges from 1800 – 1900kg/m3 according to O'Flaherty (2001), and all soil samples obtained meet this standard for compaction level – for flexible pavement condition for low volume vehicle but the increasing volume of heavy duty vehicles plying this road with so many tonnes of materials and people is another source of concern as this may decrease the strength of the soil and increase its potential for deformation and/orinstability. The result of the Atterberg Limit analysis showed that the Plasticity index (PI) of the soils (which is a computation of their corresponding Liquid Limits (LL) and Plastic Limit (PL)) ranges from 14.55 – 24.65%. Based on Clause 6103 of the standard set by the FMW&H (1997), well graded lateritic soils ought not to be less than 10% but should not exceed 20%. To this end, while all samples were above 10%, stations P_01 and P_04 were above 20%. Such a soil usually has the ability to retain appreciable amount of water (moisture) especially by absorption, there by decreasing its permeability and hydraulic conductivity (K). This again, may be responsible for road failure in the region.

The overall soaked California Bearing Ratio for soaked (CBR_s) and unsoaked (CBR_u) were all low for all the soil samples analysed. The Federal Ministry of Works and Housing (FMW&H, 1997) provided a desired specification for samples not to be less than 10% for the CBR_s but all soils only ranged from 1 – 6%. Meanwhile, the CBR_u only ranges from 9 – 21%. With such values, it is evident that the soils are poor clayey lateritic soils. In addition, moisture influx would be highly detrimental to the sub-grades of pavements constructed on them – another signal for caution when used as pavement material or when ignored by construction engineers. In the light of the result obtained in this study, it is clear that the road portion (about 5km length) been investigated demands serious consideration which, perhaps may not have been critically examined during the pre-construction or pre-design stage. However, to make a better thrust on this, the study went further to examine the major components responsible for road failure and the extent of their spatial variation.

Table 5b Table of PCA loadings

Variables	PC1	PC2	PC3
SAND %	0.207	-0.404	-0.067
SILT	-0.207	0.404	0.067
LL %	0.349	-0.034	0.132
PL %	0.093	-0.151	0.619
P I	0.350	0.000	-0.008
BL_MDD	-0.304	-0.282	0.024
BL_OMC	0.296	0.231	-0.244
BH_MDD	0.106	-0.427	-0.273
BH_OMC	0.260	0.285	-0.285
CBR_S	-0.346	0.056	-0.235
CBR_U	-0.305	-0.114	-0.357
Cu	0.141	0.410	0.178
Cc	0.298	0.041	-0.398
K	-0.286	0.261	-0.046

Source: Authors' analysis (2016)

Components of Road Failure in Umuahia Region

The Principal Component Analysis (PCA) gives an idea in finding which of the analysed variables are most strongly correlated with each component.

However, in the computation of PCA the correlation matrix and the PCA loadingwere obtained, viz:

The result of the PCA presented in Table 5a and Table 5b indicates that three (3) principal components adequately (97%) explains the causes of road failure within the portion under investigation, along Enugu – Port Harcourt expressway. The first of these is Plasticity Index (52%), which shows that the persistent wetting and drying of the soil due to the alternating impact of the rainy and dry seasons changes the behaviour of the soil by making it more liquid than plastic (as indicated in the first component loading). According to Ifabiyi and Kekere (2013) this has also caused about 50% of the road failure along Ilorin-Ajase-Ipo road in Kwara State. The second component loading indicates the Maximum Dry Density (British Standard Heavy) contributes about 30% of road failure within the portion earmarked for this study. This equally has to deal with the contribution of the Liquid Limit which affects also the rate of compaction, thus, Maximum Dry Density. From this it is also implied that the materials will need more effort/attention to be properly compacted due to the uneven balance of sand to clay to ensure a well cemented body. Lastly, Plastic Limit is indicated to contribute about 15% to the road failures in the locality. In other words, as noted earlier, plastic limit of the soil which is very critical is a function of Liquid Limit and Plastic Limit, but while Liquid Limit influences road failure more, plastic limit is relatively less influential but important to account for road failures in the area.

Meanwhile, the ANOVA test which was adopted to test the null hypothesis of this study can be seen below:

From Table 6, with a p-value of 0.000 which is less than the significance level of 0.05, the null hypothesis was rejected and it was concluded that some of the sites have significantly different geotechnical properties. In other words, with R^2 and R^2 adjusted values of 99.32% and 99.16% respectively, we can confidently conclude that the geotechnical properties of the soils within 5km distance of the Enugu – Port Harcourt Express way in Umuahia region are significantly different. This is also an indication of a huge amount of spatial differentiation of the road pavement which ought to be considered during the design phase, by the civil engineers.

Table 6 ANOVA Test Result

Source	DF	SS	MS	F	P	R^2	R^2-Adj
Factor	13	31212926	2400994	624.94	0.000	99.32%	99.16%
Error	56	215149	3842				
Total	69	31428075					

Source: Authors' analysis (2016)

Table 5a Eigen analysis of the Correlation Matrix

Eigenvalue	7.218	4.165	2.121	0.496	0.000	0.000	0.000	0.000	0.000	0.000
Proportion	0.516	0.298	0.151	0.035	0.000	0.000	0.000	0.000	0.000	0.000
Cumulative	0.516	0.813	0.965	1.000	1.000	1.000	1.000	1.000	1.000	1.000

However, the study has only considered only about 2.3% of the total length of the express road which is also of dual carriage type. It is envisaged that these variation are equally expressed all through the road – especially as it traverses about thirteen (13) geological formations as hither to mentioned.

CONCLUSION AND RECOMMENDATION

This study has been able to perform a geotechnical characterization of soils in a part of Umuahia region and revealed its influence(s) on the persistent road failure along the Enugu – Port Harcourt express way as well as the degree of its spatial differentiation. Efforts to maintain a smooth pavement of the Enugu – Port Harcourt Expressway by government agency has always failed because, perhaps maintenance have been carried out uniformly without due consideration of the uniqueness and components active to exacerbate road pavement failures under different geologic formation or precisely, under varying sedimentary facies. Consequently, road failure has negative enormous economic impact on both local communities in the region and Nigeria as a whole. This study therefore recommends the following, that:

1. knowledge of soil geotechnical characteristics of many segments of the road as possible, must be taken into consideration before any road design and or construction project commences, for the sake of quality control and assessment.
2. there is also need for sandfill to be used for the road embankments and for the replacement of the weak, incompetent and compressible clay materials, as shown in the study, for best result.
3. small localized fatigue areas should be attended to with respect to sub-grade characteristics of the area, for which 100% compaction must be ensured.
4. due to the road pavement stress, there is need for the construction of an alternative heavy duty lane or railway line which may be subjected to toll fee collection for its maintenance.
5. there should be provision of adequate side drains, box/ring culverts and other drainage facilities in road maintenance/construction design especially in relationship with the existing terrain. The use of geofabrics on either side of the road pavement is equally recommended.
6. high intensity run-offs should be prevented from reaching road pavements as much as possible and as such enhance the stability of slopes. This method reduces both the quantity and velocity of flood water in areas of depression.
7. relevant geologists, meteorologists/climatologists and geotechnical engineers should be enlisted during pre-construction, design and planning of highway pavements.

APPENDIX I Specification Limits For Sub-Grade/Fill Materials For Roads

Material/Layer	Test	Specified Limits	Desired Limits	Requirement of Tests	Specification Clause No
Sub-grade/Fill	**Plasticity Tests**			1 per 1000mm	6181
	(a) Liquid limit	≤ 80 %	≤ 50 %		6122
	(b) Plasticity Index	≤ 55	≤ 30		6122
	Grading Test			1 per 1000mm	6181
	a) Sieve Analysis	≤ 35% Passing 75 um or 200 Sieve			6102
	Density Moisture Content			1 per 500m	6181
	a) Compaction Test	B.S. Compaction			6180
	Insitu Dry Density Test			1 per 100m	6181
	Top 600mm	≥100% of the MDD in BS Compaction			6125
	After 600mm	≥95% of the MDD in BS Compaction			6125
	Next to Structure	≥100% of the MDD in BS compaction			6125
Unsuitable	a) Peat, logs, stumps. Roots, & other perishable or combustible materials				6122
	b) Materials from swamps, marshes & bogs				6122
	c) Top soil and highly organic clay & silt				6122
	d) Clay having a liquid limit exceeding 80% or PI exceeding 55				6122
	e) Highly micaceous materials				6122

Source: Extracted from General Specification for Roads and Bridges F.M.W. (1997)

8. activities that could expose soil surfaces such as sand mining, as rampant as it is in Umuahia must be checked as this has potentials to initiate gullies and make gentle slopes steeper.

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