GEOLOGICAL AND GEOTECHNICAL INVESTIGATION OF ROAD FAILURES IN NIGERIA: A CASE STUDY OF PARTS OF IMO- ABIA STATES, SOUTHEASTERN NIGERIA

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ABSTRACT

Bad conditions of roads and their negative effects on environment and National development necessitated this research on road failures in parts of Imo and Abia States, Southeastern Nigeria, using integrated geological mapping, electrical resistivity measurements and geotechnical analyses, to determine geological factors causing road failures in these areas and proffer sustainable solutions to them. Results reveal the most complex deformations occurred in the Asu River Groups, Eze-Aku, Bende Ameki and Imo Shale formations. These formations consist of alternating sequences of incompetent rocks like clays, shales and mudstones, with resistivity range of 3.5 Ω m - 22.0 Ω m, occurring down to depths of 50.0 m in places. The in-situ moisture content ranges from 5.0–21.5 %, with mean of 13.25 %. Sieve analysis shows the lithology consists average fines >80%, sand 15%, gravel<3%, are poorly graded and texturally immature. The drainage system is poor; the water table is shallow with low permeability, causing periodic swelling and shrinkage, which aggravate environmental deformation and road failure. In the northern parts of the area, the NNE – SSW trending faults and folded Okigwe – Abakaliki escarpment zone increases frequency of road failures. In the southern parts Aba, Owerri, Umuahia and Orlu failures are mainly due to unconsolidation, topography/slope instability, erosion and poor engineering practice. For effective performance and durability, pre-construction site investigation and materials standardization involving geologists, engineers and government is necessary. Improvement by surface / subsurface pumping techniques, suitable drainage systems, excavation, filling and stabilization with appropriate geo-textiles are suggested.

Keywords: Road failures, geological factors, environmental aesthesis, electrical resistivity measurements, sustainable solutions, complex deformations.

1. INTRODUCTION

A road failure is the defective physical environmental condition that arises when a road and / or its pavement has developed cracks, flaked off, suffered face or surface defects, dissected, deformed, developed potholes, subsided and/or collapsed completely, thereby obstructing free flow of traffic. Hence the road can no longer serve the purpose for which it was constructed. The deplorable conditions of roads in Nigeria, particularly those in the southeastern parts of the country and their negative consequences on agricultural productivity, transportation and communication system, general environmental degradation, economic lose and national development necessitated the study of the geological and geotechnical factors affecting road failures in the country. Road failures can be classified into three broad headings based on their causative factors, these are: failures due to natural causes, failures due to anthropogenic activities, and failures occasioned by poor engineering design and construction. All roads are built on the earth surface which is composed of geological materials, hence, geology plays very vital roles in road pavement performance, stability and / or failures.

In addition to the three broad factors outlined above, methods of urbanization, settlements / land use system, poor agricultural practices, among others can also affect road failure. In recent years torrential rain-falls, flooding, gulling / mass movement, rising temperatures and pressures on the ecosystem, all threatening global environmental changes, combine to aggravate road failures in Nigeria and globally. The present study aims at contributing to solving this ravaging problem using integrated geological, geotechnical and geophysical approaches and proffering sustainable solutions to them.

1.1. Consequences of Road Failures

Geological factors causing road failures include all processes that are controlled by nature, such as physical, biological, chemical, mineralogical, weathering / erosional, hydrogeological processes, environmental and tectonic forces. These contribute to causing road failures, which have far reaching consequences on individuals, companies, local, state and national governments. These encompass high rates of accidents often occasioning death and high rate of fatality, esthetic menace, high cost of transportation / communication, reduced agricultural productivities, resulting in shortage and consequent high cost of food and living, environmental degradation and devastation, and many others. The study also aims at finding solutions and ways of ameliorating these socio-cultural and economic problems.

1.2 Study Area

The study area covers parts of the present Abia and Imo states and adjacent areas in Southeastern Nigeria (Fig.1). The area is situated in the tropical rain forest zone of the Niger Delta and Anambra – Afikpo Basins of Southeastern Nigeria sedimentary complex. Reymont (1965) defined this area as an extension of the Lower Benue Trough. The area is bound within Latitudes $4^{\circ}40' - 6^{\circ}30'N$ and Longitudes $6^{\circ}30' - 8^{\circ}30'E$ (Fig. 1). It comprises of an area of more than $12,689 \text{ km}^2$, with high density of human population, and has many road networks which link it to other parts of the country. The prominent among which include the north-south Port Harcourt – Aba – Umuahia – Okigwe - Enugu Expressway, the Orlu – Okigwe – Afikpo – Abakaliki Ogoja Highway and the Onitsha – Owerri – Aba – Calabar roads. The area is characterized by high annual rainfall range of 1500mm to 2500mm, with mean daily temperature of about $27^{\circ}C$, a high relative humidity of about 80° , and evergreen vegetation (Iloeje, 1971). The northern part of the area is composed of cuestas and plateau

escarpments with steep slopes, while the southern part is relatively flat with gentle slopes. The area is drained by many rivers which include the Imo, Okitankwu, Orashi, Njaba, Otamiri rivers etc, forming a fairly trellis drainage pattern, with structurally controlled rivers running parallel to one another (Iloeje, 1971).

2.0 GEOLOGICAL SETTING AND STRATIGRAPHY

The geology of Southeastern Nigeria has been extensively studied (Kennedy, 1964; Reyment, 1967; Murat, 1970; Olade, 1975; Petters, 1978; Doust and Omatsola, 1989; Agumanu, 2009, 2011; Moshood et al., 2010; Obioha, 2018; Obioha et al., 2020) and many others. They show that the geology of Nigeria comprise about 50 % sedimentary and 50 % basement rocks. The stratigraphy of Southeastern Nigeria is summarized in Table 1. The Table shows that the sedimentary units in Southeastern Nigeria comprise about eleven Cretaceous to Tertiary lithostratigraphic formations, namely; Asu River Group, Eze Aku Shale, Awgu Shale, Nkporo Shale, Mamu Formation, Ajali Formation, Nsukka Formation, Imo, Bende Ameki, Ogwashi Asaba and Benin formations. These formations consist of alternating lithostratigraphic sequences of shales, sands, sandstones, clays, siltstones and lignites intruded by igneous bodies in places. The basement geology of southeastern Nigeria had also been investigated. Recently Ukwang (2009), Ekwueme (2010), Obioha and Ekwueme (2011), all recognized the area is characterized by high grade migmatites, gneisses, amphibolites and schists intruded by granitic rocks, dolerites and aplites.

3. METHODS OF STUDY

The study involved both field investigation and laboratory analysis.

3.1 Field Investigation

The field work comprised geological mapping and geophysical measurements. The geological mapping and observation were carried out at the beginning of (March-April) and ending (October – November) of the rainy and dry seasons respectively for effective outcrop identification. Rock samples were collected with hand augers. Undisturbed samples were properly labeled, for easy identification during laboratory analysis. All samples for moisture content analysis were immediately put in the pre-weighed moisture content sample cans. All recognized fossil samples, their types, counts, diversity, genera, species and abundance were noted against point of collection. These enabled easy identification, analysis and interpretation of the depositional environment of the rocks. A total of 15 roads measuring about 1500km were investigated, which represent a reasonable network of roads in the study area (Fig 1). The roads traverse all the geological formations in the study area southeastern Nigeria.

Table 1: Stratigraphy of study area, showing the relationship between Formations, Lithofacies and Road Failures.

PERIOD	EPOCH	FORMATION	LITHOFACIES	ROAD FAILURE
TERTIARY	HOLOCENE-OLIGOCENE	Benin formation (BFM) Ogwashi-Asaba formation (OAF)	Continental Fresh Water Sands, Pebbly Gravel, Silts, Clays, Shales, Lignite series	Ow-Orlu (OOr) Ow-PH (Ow-PH) PH-Umuahia-Okigwe express way (PAUOEW) Owerri-Okigwe (Ow-Ok)
	EOCENE	Ameki Formation (BAF) (Oshosun Formation)*	Lignite series, Clays, Sandstone, Limestone	Umuahia-Bende (UmBr) Umuahia-Ikot Ekpene (UmIEr) Orlu-Ideato (Or-Id)
	PALEOCENE	Imo State (ISH) (Ewekoro Formation)*	Laminated Shales, Claystones, Limestone, Marks and Calc. Sst	Owerri-Okigwe (Ow-Okr) Umuahia-Uzoabam (Um-Uzr)
CRETACEOUS		Nsukka Formation (NF/UCM) (Abeokuta Fm)* (in west rest on basement)	Shales (dark grey), Sandstone, Clays, Coal Seams	Okigwe-Leru-Lokpa-Enugu Express way (OLEEw)
	MAASTRICHTIAN-CAMPANIAN	Ajali Formation (AFM)	F-M-C grained Sands, xbd Friable Sandstone**	Umuahia-Bende-Abriba-Ohafia road (UBAOr)
		Mamu Formation (MF/LCM)	F-M, xbd, sst, shales, & coal seams	Umuahia-Bende-Abriba-Ohafia road (UmBAOr)
		Nkporo shale (NSH) (Enugu Shale)* (angular unconformity)	Dark shales, mudstone, with thin beds of sandstone, with angular unconformity**	Leru-Enugu Express way (LEEw); Okigwe-Afikpo road (OAr)
	LOWER SENONIAN	Awgu Shale (AGS)** (Makurdi Formation) **Awgu Ndeaboh Shale	Well bedded shale, blue-grey calc, sandstone and shally 1 st	Not Traversed (or not Recognized but occurs off Okigwe-Leru-Enugu Region)
	TURONIA	Ezeaku Formation (ESH) (Odukpani Formation)*	**Hard grey-black shales, silts, sst and sdy, shale	Ishiagu-Ezeaku-Amasiri-Afikpo (IEAAR)
	CENOMANIA NA-LBIAN	Asu River Group (ARG)	Thick Shales, fossiliferous 1 st , (Ammonite, Forams, Echinoderm)	Abakaliki-Ogoja (Ab-OR)

(Key: *Modified after Desauvogie and Fayose, 1970. **Modified after Reymont, 1965).

3.2 Geophysical Studies

The Geophysical surveys were carried out at more complex road failure locations to further characterize the rocks and structure of the formations. A total of 30 geo-electric stations were occupied. The vertical electrical sounding (VES) technique was adopted using Schlumberger array. The field geophysical principles and techniques were based on Al-Sadi, (1980), Dobrin and Savit, (1988) and Telford et-al (1988). The VES studies enabled determination of the variability in litho-depth, structures and their horizontal distribution within the study area. Selected representative geo-electric curves of the VES surveys are presented (Figs: 2a – 2d).

3.3 Geotechnical studies

Geotechnical studies were carried out, which include sedimentation analysis, liquid limit, plastic limit, and plasticity index tests. Also determined were the texture, grading and sorting of the various rock samples, using the mechanical sieving techniques. The laboratory techniques and Interpretation were based on the ASTM (1990). BS-1377 (1990), AASHTO (1986) and BS 5930 (1981) Laboratory procedures. The uniformity coefficient (CU) was determined based on the technique after Casagrande (1932, 1947). The unified soil classification scheme (USC) was used in the grading and classification of the soil.

4.0 RESULTS

4.1 Geological

The results of the field geological survey of road failures in parts of SE Nigeria are summarized in (Tables 1 and 2). Table 1 shows the relation that at Ajata – Ibeku along Umuahia – Bende Road in the Bende – Ameki Formation (BAF). The road was built on dark brown silty shales. The rocks are often weathered and ferruginized and range from less than 2m to 5m thickness. The silty shale is directly underlain by very thick (~ 40 m) deposit of clays, as indicated by the geologic cross section and corroborated by the geo-electric measurement (Fig. 3). These lithofacies are nearly horizontally bedded, striking NW-SE (0 – 30°) and dipping gently SE at about 1° to 4°. The road runs across a natural divide with seasonal streams draining in NE and SW directions away from the divide. More than 340m of the roads here have failed, subsided and collapsed to depths of more than 1m to 5m, thus making traffic flow very difficult. Some vehicles follow cut off tracks. The water table is shallow and the drainage system poor due to the impermeability of the clay and the underlying shale and claystone sequences. The cracks, subsidence and / or collapse are inferred to result from repeated compaction and cyclic swelling and shrinkage of the clay minerals and related rocks. The summarized geological mapping results are presented in (Table 2).

4.2 Geophysical

The results of electrical resistivity measurements carried out are presented in (Figs. 2 a – d and Tables 2 a-d). They show that the region consists of about three to seven geo-electric layers, with resistivity range of 3.5ohm-m to about 250ohm m, occurring down to depths of about 0.4m to 112m (Fig. 2), indicating alternation of competent litho-logs mainly sandstones and gravels sequences with the incompetent rocks such as clays, shales and mudstones (which are prone to seasonal swelling and shrinkage during rainy and dry seasons) in most of the locations, thus causing further deformations and failures of the roads. The geotechnical analysis result (Table 3) corroborates. The geophysical finding shows that the in-situ moisture content ranges from minimum of 5.52% in the Ajali Formation (AF) in Bende area, along Ohafia – Bende Road (OBR), through 14.36%, 14.81% in the Nsukka and Mamu formations respectively at Okigwe – Water works along Okigwe – Umuna - Owerri Road (OUR) and around Lokpaukwu – Lokpanta along Port-Harcourt – Aba – Okigwe – Enugu Expressway.

Fig. 2 A/Table 2Da.: VES survey at Nkwerre along Owerri – Orlu Road

Fig. 2 B/Table 2dB. VES survey at Okigwe-Enugu Road

Fig. 2 C. /Table 2c: VES survey at Enugu Port Harcourt Express Way

Fig. 2 D/Table 2d: VES survey at Isi-Owerre Nkworji along Orlu-Umuahia Road

4.3 Geotechnical Result

The mechanical sieve analysis result shows that the Bende- Ameki Formation at Ajata Ibeku along Umuahia Bende Road (UBR) is poorly sorted and poorly graded, with more than 88% fines (Table 3). The Ameki Formation at Umuahia (sample UB1) shows uniform grading, poorly sorted (Table 3), with mean grain size of 0.001 – 1.2mm, which indicates clay + silt + sand mixture.

Table 3: Summary of Geotechnical Results

ROAD	Geologic Setting		Sample No.	Moisture Content (W% Insitu)	Liquid Limit (LL)	Plasticity Limit (PI)	% Sorting /Grading	Sorting/ Grading Description	Mean Size (mm)	% Passing (P%)
	Formation	Lithology								
Umuahia-Bende	Ameki (Ajata Ibeku)	Sandy, Claystone, Mudstone and fossiliferous Limestone	UB2	21.83	60.0%	35.1%	24.90%	Poor/Poor	80% <0.03	75.7% <0.002
Bende-Ohafia -Abirirba	Ajali (Ivo)	Friable Planar cross-bedded sandstones	BO2	5.52	NA	-----	-----	Uniform/Poor	1.30	(<2% <0.06)
Umuahia – Bende	Bende-Ameki (Ajata Ibeku)	Sandy, ferruginised Claystone, Mudstone	UBI	20.50	58.0%	32.2%	25.80%	Uniform/Poor	0.12	>12% <0.06
Okigwe-Umuahia -Anara-Owerri -Okigwe	Nsukka-Imo Shale (Amuro)	Clays, Silty Shales	OU3 OPI	14.36 21.55	89.8% 54.35	32.9% 25.0%	56.9% 29.35%	Fair / Moderate	(0.87µm)	
	Mamu (Ihube)	Dark Shale	POE4	14.81	74.9	34.0	40.9	Uniform/Poor	25.2µm	>300% <0.002
Port Harcourt–Okigwe –Enugu	Benin (Isu)	Loose Loamy, Silty Sands	OU4	8.45	NP	NA	NA			>32% <0.002
Orlu–Nkwerre–Mbano –Umuahia	Benin	Loose Sands with pocket / lenses of clays	OU5	8353	NA	NA	NA	Fair/Poor	0.41	<2.3% <0.002
Owerri–Umuagwo –Elele – Port Harcourt										<0.83% <0.062
$\bar{X} = \frac{\sum X}{N}$				$\frac{87.55}{6} = 14.59$	$\frac{282.70\%}{4} = 70.68$	$\frac{134.2}{4} = 33.55$	$\frac{148.5}{4} = 37.13$			

smectite) and mudstones. This includes Eze-Aku Shales (ESH), Mamu Formation (MF/LCM), Nsukka Formation (NF/UCM), Imo Shales (ISH) and Bende-Ameki Formations (BAF).

Table 4: Summarized Result of Field Survey Conditions of the Road.

ROAD	Geologic Formation	Year of Completion	Distance(Km)	Cracking	Surface Deformation	Surface Defects	Failed/Collapsed Areas	Landslide	Subsidence	Flowage	Shoulder Condition*	Drainage Condition+
Owerri-Mbaise	BFM	1982	32	Moderate	Moderate	-	Slight	-	Moderate	-	1	1
Mbaise-Umuahia	BFM	1982	29	Severe	Severe	-	Severe	-	-	-	1	1
Umuahia-Bende	BFM,BAS	1978	20	Severe	Severe	Severe	Severe	-	-	-	1	2-4
Bende-Ohafia	ISH,UCM,AST	1976	30	Slight	Slight	Slight	-	Severe	Severe	-	2-3	2-4
Ohafia-Abiririba	AFM,UCM	1975	28	Moderate	Moderate	Moderate	Moderate	-	-	-	2-3	1-3
Abiririba-Okigwe	AFM,LCM	-	24	Severe	Severe	Severe	Severe	-	-	-	2-3	1-2
Anara-Okigwe	UCM,AFM,MF	1974	36	Severe	Severe	Severe	Severe	-	Slight	Slight	1	1-2
Okigwe-Umuna-Anara	UCM,ISH,BAF	1974	34	Severe	Severe	Severe	Severe	-	Moderate	Slight	1	3-4
Anara – Owerri	BFM	1976	32	Slight	Slight	Slight	Slight	-	-	Slight	1	1
Owerri – Aba	BFM	1975	68	Slight	Slight	Slight	Slight	-	-	Slight	1	1-2
Aba – Umuahia –Okigwe	BFM,OAF	1981	130	Slight	Slight	Moderate	Moderate	Moderate	-	-	-	1-3
Owerri -Umuagwo	,BAF BFM	1980	100	Moderate	Moderate	Severe	Severe	-	-	-	1-3	2-4

ARG = Asu River Group; ESH = Ezeaku Shale Formation; AGW = Awgu Formation; NSH = Nkporo Shales; MF/LCM = Mamu Formation / Lower Coal Measures; AFM = Ajali Formation; UCM = Nsukka Formation/Upper Coal Measures; ISH = Imo Shales; BAF = Bende – Ameki Formation / Owerri Coastal Plain Sands. These characteristics are based on the International Association of Engineering Geologist (IAEG) Specifications. The Laboratory Procedures were based on the American Standard for Testing and Materials (ASTM) Specifications. * Based on number, depth, length, aerial extent/ coverage and degree of dissection by erosion, shoulder condition is hereby classified into three; 1. Slightly, 2. Moderate 3. Severe dropped and defected. + Similarly, drainage condition have been classified into five; (a) no defect-0 (b) slightly defect – 1 (c) moderately defected -2-3 (d) severely defected-4 (e) blocked -5.

Table 4 summarizes the relation between geology/lithology and defective conditions of the roads; including the **Geologic Formation, Distance covered (Km), Cracking, Surface Deformation, Surface Defects, Failed/Collapsed Areas, Landslide, effects Flowage, Shoulder drops and Drainage Conditions**. The sieve analysis (Fig. 5) shows that the roads consists of > 55% clay and 30% silt (i.e. 85% fines average). These include **Bende-Ameki road (BAR)**, Umuahia-Okigwe-Enugu Expressway (UOER), is underlain by high percentage of fines, lesser amount of sand and least % gravel. Some roads such as Owerri –Aba road (OAR) consisting more than 88% sand, while the Orlu-Owerri road (OOR) consists more than > 98% sand, hence deformation on these roads are due to unconsolidation and erosion and fracture. Complex road failures also occur in areas of alternating sequences of competent /

incompetent rocks such as clays, shales or mudstones alternating with sandstone and gravel, as were observed along Owerri–Amuro-Okigwe road, Aba–Ikot Ekpene and Umuahia- Ikot–Ekpene roads. However, road failures were also observed in some areas composed of competent rocks like sandstones, conglomerates and siltstones. In such areas; failures were inferred to be due to differential hydraulic conductivity of the rocks/soil layers and unconsolidation of rock materials and their friable nature.

Some failures are attributed to high rate of fracturing, folding, slope instability and unconsolidation of rock materials, faulting, and poor engineering design and construction. Such failures occur mainly in form of potholes, face/surface defects, shoulder drop off, crack and subsidence. For example along Owerri Aba road, Owerri-Onitsha road, Port-Harcourt-Aba-Umuahia-Okigwe road. The study revealed that severe erosion, gulling and mass movement were the main factors causing failures, along Okwelle-Dikenafia-Isiekenesi road, built on the Benin/Ogwashi – Asaba, Bende Ameki Formations. The results show that the geological, geophysical and geotechnical findings agree and corroborate one another.

6.0 Conclusion

The study revealed that southeastern Nigeria consists of very complex geology which plays very vital roles in pavement performance. Of the 1,500km of road network studied; more than 80% had failed. More than 50% of the failed roads are inferred to result from geological factors/controls; about 40% are due to anthropogenic factors and or lack of maintenance, while the remaining 10% are due to poor agricultural practices and engineering construction. The results show that road failures occurred most in the areas underlain by thick sequences of incompetent rocks with low resistivity, such as claystones, shales, lignites and mudstones. These lithofacies include zones underlain by the Asu River Groups, Ezeaku Shales, and Imo Shales followed by Bende-Ameki Formations and least in the Ajali and Benin Formations, which are composed of more competent rocks like sands and sandstones. The incompetent litho units have characteristically high porosity, low permeability and low hydraulic conductivities, which make them prone to cyclic swelling, shrinkage and periodic flooding, thus causing very rapid deformation of the rocks. Also the investigation revealed that mass movement, erosion, land-slide, and gulling and subsidence are prime factors contributing to road / pavement failure, particularly where the pavement is underlain by unconsolidated or friable rocks. Apart from esthetics, environmental degradation and devastation, road failures have far reaching negative consequences on transportation / communication, agriculture and food production, general economy and national development.

6.1 RECOMMENDATION

The study recommends the following as measures capable of improving, controlling or at least ameliorating these socio-economic problems weighing down our national development and growth due to road failures.

Where thick sequences of incompetent rocks like claystones, mudstones and / or shale form the bedrocks, such materials should be scrapped /excavated to depth of at least 4m and imported geo-textile used to refill the site before compaction operations. Where the sub-grade rock is too thick to be completely scrapped off, upgrading of the materials or soil treatment can be achieved by cementation or application of limestone, which is locally obtainable from Sokoto, Ewekoro, Nkalagu and many other locations in Nigeria. In areas of flooding and shallow water table, surface pumping techniques and drainage constructions can be applied to reduce flooding and maintain uniform subsurface pressure. In areas of complex topography

and steep slopes, leveling must ensure that angle of safety is not exceeded during construction.

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