GEOTECHNICAL INVESTIGATION OF OLD OWERRI – ABA ROAD FAILURE, SOUTHEASTERN NIGERIA, USING SUB-BASE QUALITY EVALUATION

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Abstract

The study was aimed at investigating the causes of deterioration of Old Owerri – Aba Road, Southeastern Nigeria. Field relative density test using sand replacement method and laboratory measurement geotechnical properties such as atterberg limit, sieve analyses, linear shrinkage, dry density/moisture content and CBR were carried out on 10 samples obtained from the field. The field dry density recorded a range of 1.782mg/m^3 to 1.82mg/m^3 with its relative density (%) between 92.0 and 94.8 %. The result shows poor degree of compaction when compared with its laboratory 100 % maximum dry density (MDD), which is considerably high ranging from 1.89 mg/m^3 to 1.98 mg/m^3. The cause of the road deformations found in the study area may be traced to the recorded degree of compaction which is less than 100% as determined in the laboratory standard compaction. The laboratory geotechnical properties result confirmed that the samples collected have the characteristics of sub-base material for road construction. Their characteristics, as determined in the laboratory included the following: Liquid limit (LL) is 30.9 to 37.0 % with an average of 33.3 %, plasticity index (PI) is 9.01 to 11.72 with an average of 10.41, sieve analyses is 13.33 to 27.01 % with an average of 20.72 %, linear shrinkage is 3.9 to 4.8 % with an average of 4.5 %, soaked CBR (24 hrs) is 31.5 to 38.6 with an average of 34.6 %, unsoaked CBR is 83.7 to 98.4 with an average of 90.9 %, OMC is 9.0 to 12.0 % with an average of 10.7 % and MDD is 1.89 to 1.98 mg/m^3 with an average of 1.92 mg/m^3 . All the laboratory geotechnical properties are within the specified limits of sub-base material for road construction. The PI values indicated that the soil has low swelling potential, while the linear shrinkage is within non-critical as classified in the degree of expansion in soils. Failure to compact the road's sub-base to 100 % is one of the factors that led to the pavement failures.

Keywords: Road failure, Owerri-Aba road, Sub-base, Relative density, Dry density

1.0 Introductions

The study area, Old Owerri – Aba road had been an economical road linking the market hub city of Aba and serves as an accessible road through which businesses are transacted through Aba – Owerri – Onitsha cities. The quality of the pavement had deteriorated, hence there was need to understand the causes of the failure with an attempt to finding permanent solution.

Vinay and Hemanth Yadav (2015) in their study on the "comparison of soil compaction between laboratory and field to simulate field compaction for rural roads" stated that compaction play a major role in pavement strength and durability. Proper compaction helps to achieving certain dry density in the site, enhances engineering designing properties of fill, strength and stability.

Abynayaka (1977) stated that road failure may be as a result of natural and anthropogenic factors. Other factors such as geological, geomorphological, geotechnical, road usage, design and construction inadequacies, and maintenance are responsible for road failures (Adegoke-Anthony and Agada, 1980; Ajayi, 1981).

Transport Road Research Laboratory (1991) argued that climatic factors can affect the strength of structure. The temperature fluctuations and acid rain attack on the base material of the road in water-logged area can weaken the sub-base of the road material capillary action, thereby reducing the supporting power of the road pavement.

Arumala and Akpokodje (1987) in their investigation of pavement condition of roads in Niger Delta and the geotechnical properties of the soil material used resolved that pavement deformation and failures occur in the seasonally flooded fresh/salt water swamp. The Plate 1 shows the typical deformation found in the study area.

The dry density of the compacted soil is a common measure of the amount of the compaction achieved during road construction. A known field dry density and its moisture content would aid in calculating the relative density (%). The sand replacement method was used in measuring the compaction of the road in the study area of which its basic principle is to measure the in-situ volume of hole from which the material was excavated from the weight of sand with known density filling the hole. The geotechnical properties assisted in the proper knowledge of the material and its effect on the pavement.

Fig1: Typical Pavement Deformations found in the Study Area

2.0 Study Area Description

2.1 Location of the Study Area

The study area is located on the right hand side of Old Owerri – Aba road, starting from Naze junction (Km 3+025) to Ulakwo (Km 4+125). It is a single carriage way, accessible through Owerri city and Aba – Owerrinta roads; and a total of 11 km from Naze junction was investigated in this study.

2.2 Geology of the Study Area

The study area is underlain by the Benin Formation (Fig 1). It consists mainly of friable sands, conglomerates, very coarse sandstone and isolated gravel units and intercalation of shale/clay lenses of Pliocene to Miocene age (Horton, 1965; Short and Stauble, 1967; Ananaba, Onu and Iwuagwu, 1993).

The sources of the lateritic sub-base material used in the road construction of the old Owerri – Aba road may be from Onyeagocha's (1980) observation that the study area is overlain by a considerable thickness of earth (laterite) composed of iron-stained regolith formed by the weathering and subsequent ferruginization of the weathered materials.

The top soil contains slight to moderate amount of humus and has a pH range of 4.5 to 4.9 (Chikezie, Eswaran, Asawalam and Ano, 2010).

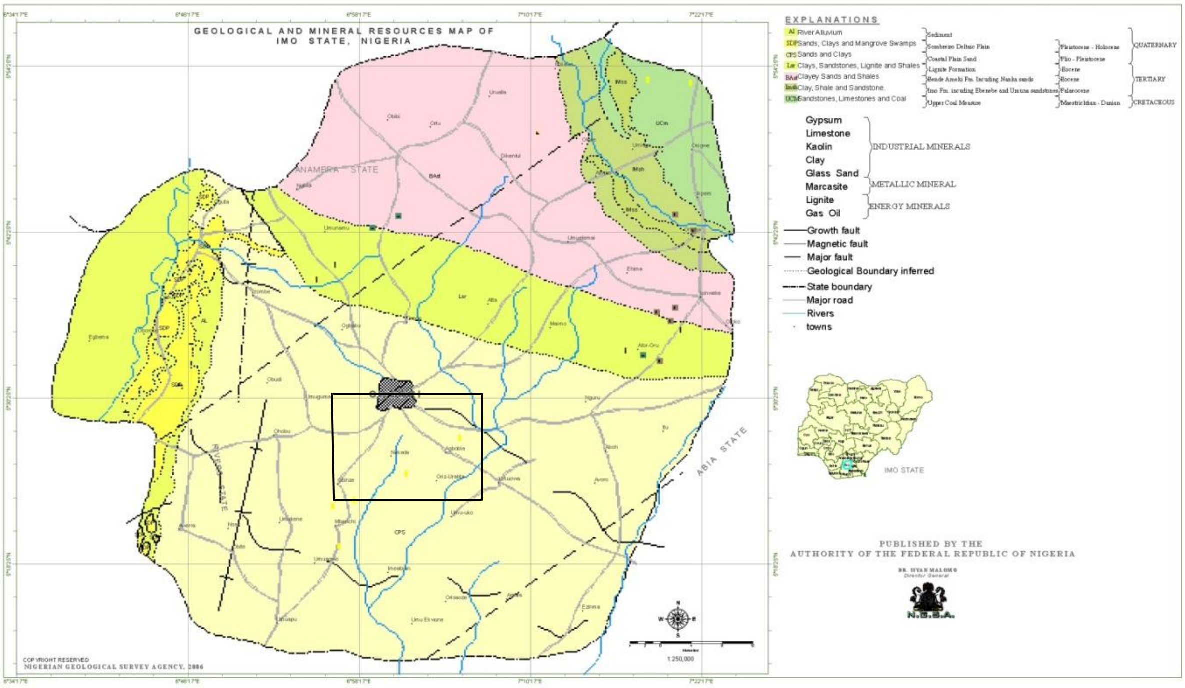

Fig 2: Geological and Mineral Resources Map of Imo State, Nigeria showing the Study Area (After NGSA, 2006)

3.0 Material and Method

3.1 Field Study/Measurement and Samples Collection

It was observed that the thickness of the asphaltic course overburden is in the average of 25cm and there was no stone base course used in the construction of Old Owerri – Aba road. The samples collected were lateritic soils and are reddish brown , as confirmed in Okeke , Ogbunyiba and Chukwujekwu's (2013) "geotechnical evaluation of laterictic soil deposits in parts of Abuja, for road construction".

Reconnaissance survey was carried out to mark the areas that are highly deformed and also count the number of vehicular passage per minutes. This count took place on Monday morning between 7am to 12noon, as Mondays are believed to be busy days. The number of vehicular passage was in the average of 57 per minute. Heavy duty vehicles were in the average of 15 per minutes.

Field dry density test and samples were collected at the areas where the pavement cracked or deformed. Asphaltic layers were cut off at the edge of the road with filing machine to get a clear surface of the lateritic base of about 450 mm square. Field density test by sand replacement method as designated by IS: 2720 – part 28 was used to determine the in – place density of compacted lateritic sub-base or road fills. The apparatus used are: sand pouring cylinder and tray, tools for levelling and digging, containers, calibrated sand (passing sieve no 600μm), electronic balance (1.0g sensitivity). All the apparatus were calibrated to the standard.

A total of 10 samples were collected in a neat polythene bag, each, at the same points where field density tests were done at 30 cm depth. The sampling was done in line with Sampling Method for Standard Test Procedures (STP, 2001), Road and Highways Department Specification, Republic of Bangladesh. The moisture content was determined in-situ using speedy moister tester as stated by ASTM D4944 - 11. The samples were labelled and transported to the laboratory for analyses and was done as designated in ASTM D 4220. Plates 2 and 3 shows typical sampling and field relative density test procedures respectively.

Fig 3: Typical Sampling Procedure

Fig 4: Performing Field Relative Density and Moisture Content Test

Field dry density Calculation:

W1 = calibrated sand bulk density (g) (sand passing sieve 600μm)
W2 = sand in cone (g)
W3 = wet soil from hole (g)
W4 = sand before pouring (g)
W5 = sand after pouring (g)
W6 = sand in hole + sand in cone (g)
W7 = sand in hole (g)
V1 = wet density (kg/m^3)
V2 = moisture content (%)
V3 = dry density (kg/m^3)
V4 = laboratory control maximum dry density (MDD) (kg/m^3)
Dr = relative density (%)
Ds = specified density (%)

Where,

V1 (kg/m^3) = W1 × W3 / W7

V3 (kg/m^3) = V1/V2 + 100 × 100

Dr(%) = V3/V4 × 100

3.2 Laboratory Analyses

The soil samples were tested of their geotechnical properties in the laboratory unit of Arab Contractors O.A.O Nig. Ltd, Imo State. The geotechnical properties were tested accordingly from the outlined standards: CBR (IS – 2720 part – 16, 1979), atterberg limit (ASTM D 4318), sieve analyses (IS: 2386 - part 1, 1963), dry density/moisture content compaction (ASTM D 696) and shrinkage limit (ASTM D 4943 - 02). The CBR was tested as soaked (24 hours) and unsoaked as outlined in Federal Ministry of Works and Housing FMWH (1997).

4.0 Results and Discussion

The field compacted relative dry density results revealed moisture contents range of 9.5 to 10.5 % with an average of 10.1 % while the dry density is between 1.78 and 1.82mg/m^3. The degree of compaction/relative density (%) ranges from 92.0 to 94.8 % revealing poor degree of compaction, as none of the sampling points attained the requirement of 100 % laboratory maximum dry density. The results of the laboratory geotechnical properties are in the following ranges: Liquid limit (LL) 30.9 to 37.0 % with an average of 33.3 %, plasticity index (PI) 9.0 to 11.7 with an average of 10.4, sieve analyses 13.3 to 27.0 % with an average of 20.7 %, linear shrinkage 3.9 to 4.8 % with an average of 4.5 %, soaked CBR (24 hrs) 31.5 to 38.6 with an average of 34.6 %, unsoaked CBR 83.7 to 98.4 with an average of 90.9 %, OMC 9.0 to 12.0 % with an average of 10.7 % and MDD 1.89 to 1.98mg/m^3 with an average of 1.92mg/m^3.

Table 1 summarises the laboratory and field measurements, Table 2 compared the field dry densities and the laboratory maximum densities and Table 3 showed the results of field relative densities with its degree of compaction.

Table 1: Results Summary of the Laboratory and Field Geotechnical Properties of the Study Area

S/No	Location In Chainage	Atterberg Limit		Sieve Analyses (%)	Shrinkage Limit (%)	CBR (%)		Standard Laboratory Compaction		Field Compaction Moisture/dry density		Field Compaction Relative Density (%)
		LL (%)	PI			Soaked 24hrs	Unsoaked	OMC (%)	MDD (mg/m3)	Moisture content (%)	Dry density (mg/m3)	
1	14+125	31.0	10.7	13.3	3.9	38.6	98.4	9.7	1.98	10.5	1.82	92.0
2	12+350	30.9	9.7	13.4	4.6	32.5	96.8	10.5	1.91	9.5	1.80	94.5
3	11+150	31.5	9.0	16.1	4.4	36.5	93.2	10.9	1.91	10.5	1.79	93.6
4	9+725	34.0	9.2	21.0	4.7	35.9	87.8	11.7	1.93	10.5	1.81	93.9
5	8+650	34.0	10.5	23.6	4.4	33.1	84.6	11.4	1.91	10.0	1.81	94.5
6	5+400	31.0	9.4	17.2	4.2	36.2	89.0	11.1	1.92	9.5	1.81	94.3
7	5+025	34.8	11.7	23.6	4.8	34.2	92.4	10.2	1.92	9.6	1.80	93.8
8	4+400	33.7	10.8	26.3	4.5	35.1	83.7	12.0	1.89	10.5	1.78	94.8
9	4+150	37.0	11.5	27.0	4.6	32.8	93.5	9.0	1.89	10.5	1.80	94.8
10	3+200	34.6	11.0	25.4	4.4	31.5	89.6	10.3	1.92	10.0	1.81	94.5

Table 2: Comparative Analyses of Field Compacted Density and Laboratory Maximum Dry Density in the Study Area

V3	Field Dry density	mg/m^3	1.80	1.80	1.78	1.80	1.81	1.81	1.81	1.80	1.80	1.82
V4	Laboratory control maximum dry density (MDD)	Mg/m^3	1.92	1.89	1.89	1.92	1.92	1.91	1.93	1.91	1.91	1.98
Dr	Relative density	%	94.5	94.8	94.3	93.8	94.3	94.5	93.9	93.6	94.5	92.0
Dr	Specified density	%	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100

Table 3: Results of the Field Compaction /Relative Densities and Moisture Contents in the Study Area

		Locations in chainage/km									
	Location	**Units**	14+125	12+350	11+150	9+725	8+650	5+400	5+025	4+400	4+150	3+200
W1	Sand bulk density (g) (sand passing sieve 600µm)	(g)	1.389	1.389	1.389	1.389	1.389	1.389	1.389	1.389	1.389	1.389
W2	Sand in cone (g)	(g)	505	505	505	505	505	505	505	505	505	505
W3	Wet soil from hole	(g)	2635	2694	2701	2706	2709	2711	2717	2843	2699	2699
W4	Sand before pouring	(g)	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
W5	Sand after pouring	(g)	660	610	590	591	595	601	605	500	598	635
W6	Sand in hole + sand in cone	(g)	2340	2390	2410	2409	2405	2399	2395	2500	2402	2395
W7	Sand in hole	(g)	1835	1885	1905	1904	1900	1894	1890	1995	1897	1860
V1	Wet density	mg/m^3	2.00	1.98	1.97	1.97	1.98	1.99	2.00	1.98	1.98	2.02
V2	Moisture content	%	10.0	10.5	10.5	9.6	9.5	10.0	10.5	10.5	9.5	10.5
V3	Dry density	mg/m^3	1.81	1.80	1.78	1.80	1.81	1.81	1.81	1.79	1.80	1.82
V4	laboratory control maximum dry density (MDD)	mg/m^3	1.92	1.89	1.89	1.92	1.92	1.91	1.93	1.91	1.91	1.98
Dr	Relative density	%	94.5	94.8	94.3	93.8	94.3	94.5	93.9	93.6	94.5	92.0
Ds	Specified density	%	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100

According to the Federal Ministry of Works and Housing's General Specification for Roads and Bridges (1997), the laboratory geotechnical properties of the lateritic samples collected conformed to the materials referred as sub-base for road construction (Table 4). It is required that all sub-base materials shall have liquid limit (LL) of less than 35 %, PI of less than 12, shrinkage limit less than 6 %, percentage passing sieve no 200 (75µm) shall be less than 35 %, CBR (24 hrs soaked) shall be greater than 30 % while unsoaked CBR shall be greater than

80 %. All the samples are within the limits as stated by FMWH (1997) and are suitable for sub-base course for road construction. The PI values showed that the soils have low swelling potential (Table 5), as classified in Ola (1981) while the linear shrinkage is within non-critical (Table 6) as classified in Attimeyer's (1956) degree of expansion. The MDD is considerably high (average: 1.92mg/m^3), revealing an increased density through laboratory compactive effort. The CBR (soaked and unsoaked) which determines load-deformation, recorded excellent sub-base material for road construction.

According to Ebels, Lorio and Van der Merwe (2016), compaction of soil improves its characteristics such that it provides more mechanically stable pathways that were more suitable for their purpose. The pavement's failure may be traced to the poor compaction of the sub-base course. Other causes included lack of drainage that may result to surface water stagnation and the thickness of the sub-base which was found to be 350 mm, above the required 150 to 250 mm standard. The degree of compaction is inversely proportional to the layer thickness, i.e. for a given compactive effort, thicker layer will be less compacted as compared to thin layer (Ebels, *et al 2016*).

Table 4: Specifications for Sub-base Materials, Federal Ministry of Works and Housing (Adapted from FMWH 1997)

Parameters	**Specification for Sub-base Material (FMWH, 1997)**
Sieve analyses % passing No 200 (75µm)	<35%
Atterberg limits -LL -PI	 >30% >80%
CBR (24hours soaked) -Soaked -Unsoaked	 >30% >80%
Linear Shrinkage	0-6%
Field dry density	>100%

Table 5: Classification of expansive soils on the basis of plasticity index (PI)

Swelling Potential	**Ola, 1981; PI**
Low	<15
Moderate/median	15-25
High	25-35
Very high	>35

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

Degree of Expansion	**Linear Shrinkage (%)**
Non-Critical	<5
Marginal	5-8
Critical	>8

5.0 Conclusions

The study had given an insight of the geotechnical properties and the field relative density/degree of compaction for the lateritic sub-base used in the construction of Old Owerri – Aba road. It is concluded through laboratory geotechnical properties' results that the samples are laterite. The lateritic samples have the characteristics of sub-base material for road construction. The PI has low swelling potential while the shrinkage limit is within non-critical degree of expansion. CBR results (soaked and unsoaked) are acceptable as sub-base material for road construction.

The field dry densities range from 1.78 to 1.82 mg/m^3 while the laboratory dry densities range from 1.89 to 1.98 mg/m^3. This also corresponds to field degree of compaction of 92.00 to 94.80 %, thus the 100 % degree of compaction of laboratory maximum dry density required for pavement sub-base in the field was not met.

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ASTM D 696. American Standard Test Method for Standard Proctor Compaction Test

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