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ROAD PAVEMENT FAILURE INDUCED BY POOR SOIL PROPERTIES ALONG GOMBI-BIU HIGHWAY, NIGERIA

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ABSTRACT

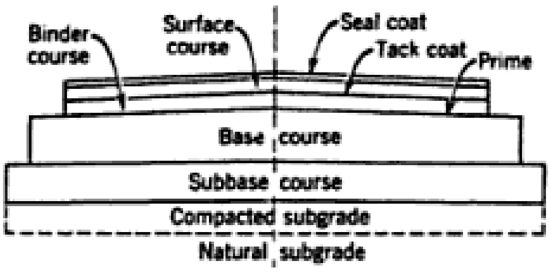
This article investigates highway pavement failure on critical locations due to poor soil properties along Gombi – Biu Road. Visual observation of the affected areas revealed substantial structural failure. Laboratory test results of the disturbed soil samples collected from the failed sections of the road showed that the natural soil moisture ranged from 7.0% to 15.9%, the liquid limits and Plasticity Indexes did not conform to specification. The CBR values ranged from 5.1% to 31.1% indicating poor soil or strong reduction in the strength of the soil materials used in the construction of the road. Excess fines and very low liquid limit values combined with a very low CBR value to cause the failure of the pavement at this locality. The geotechnical properties indicated substandard paving properties for Nigerian roads. Therefore, soil stabilization is suggested to improve the strength of the soil and prolong the useful life and durability of the road.

Keywords: *Pavement, Materials, Failure.*

INTRODUCTION

A pavement is the durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway. In the past cobblestones and granite setts were extensively used, but these surfaces have mostly been replaced by asphalt or concrete [9]. The pavement structure normally consists of a few layers of strong materials to ensure adequate stability under traffic loads. For a flexible pavement which is considered in this research, the layers usually comprise of:

a. Surface layers comprising of wearing and binder courses. These layers are in contact with traffic loads and normally contain the highest quality materials. They provide characteristics such as friction, smoothness, noise control, rut and shoving resistance and drainage. In addition, they serve to prevent the entrance of excessive quantities of surface water into the underlying base, sub base and sub grade [4].
b. Base course which comprises of high quality granular or stabilized material able to withstand high stresses. The base is a major load carrying component of a flexible pavement.
c. Sub base is placed on the sub grade and is intended to further reduce the stresses transmitted to the sub grade. Where a good quality granular sub grade exists, or where anticipated loading is light, the sub base may often be omitted.
d. Sub grade which consists of the naturally occurring material on which the road is built, or the imported fill material used to create an embankment on which the road pavement is constructed [7]. Pavement performance is expressed in terms of pavement materials and thickness. Although pavements fail from the top, pavement systems generally start to deteriorate from the bottom (sub grade), which often determines the service life of a road.



Although a pavement's wearing course is most prominent, the success or failure of a pavement is more often than not dependent upon the underlying sub grade - the material upon which the pavement structure is built [9]. Sub grades can be made of a wide range of materials although some are much better than others. It is stated in [7] that a sub grade's performance generally depends on three of its basic characteristics (all of which are interrelated):

1. Load bearing capacity: The sub grade must be able to support loads transmitted from the pavement structure. This load bearing capacity is often affected by degree of compaction, moisture content, and soil type. A sub grade that can support a high amount of loading without excessive deformation is considered good.
2. Moisture content: Moisture tends to affect a number of sub grade properties including load bearing capacity, shrinkage and swelling. Moisture content can be influenced by a number of things such as drainage, groundwater table elevation, infiltration, or pavement porosity (which can be assisted by cracks in the pavement). Generally, excessively wet sub grades will deform excessively under load.
3. Shrinkage and/or swelling: Some soils shrink or swell depending upon their moisture content. Additionally, soils with excessive fines content may be susceptible to frost heave in northern climates. Shrinkage, swelling and frost heave will tend to deform and crack any pavement type constructed over them.

A pavement is said to have failed when it is no longer able to absorb and transmit the wheel loading through the fabric of the road without causing fairly rapid further deterioration of the road pavement.

Previous researches had shown that roads failed due to various reasons like negligence of road maintenance and poor soil properties like low CBR [5]. Inadequacies in design and poor workmanship, improper mix proportion, poor quality control during construction, poor drainage, inadequate thickness of the pavement section to support the loads that travel across the asphalt and weak or unstable sub grade components could also lead to the failure of a pavement. Poor soils can seriously impede construction of adequate sub grades, as well as affect the long-term performance of a pavement during its service life [7].

Asphalt deteriorates when weather and traffic wear "fines" aggregates away. When the "fines" are worn away, there is nothing to bind the larger aggregates together and the surface begins to unravel. This weakens the pavement section and eventually allows water to penetrate the sub grade, which leads to pavement failure [6]. About 90% of the time when we have pavement failure, it is a problem with the sub grade. Inadequate support in the base and soil directly beneath the pavement can cause alligator cracking and other pavement failures [8].

MATERIALS AND METHODS

The research was carried out along Gombi – Biu road. The road is of 165km length with a pavement width of 7.50m and shoulder widths of 2.0m. The road was overlaid in 1979. Disturbed soil samples were collected at eight locations at intervals of 15km along the road. Both insitu and laboratory tests were conducted to ascertain the geotechnical properties of the soil. All tests conducted were in conformity with [1].

The insitu tests that were carried out on the soil samples were IN-SITU DRY DENSITY and MOISTURE CONTENT tests.

The soil samples collected were subjected to the following laboratory tests:

SIEVE ANALYSIS

1. Percentage retained (kg) = $\frac{Weight\ of\ soil\ retained}{Total\ weight\ of\ sample}$ x 100
2. Percentage passing (kg) = 100 - cumulative percent retained.

SPECIFIC GRAVITY

Specific Gravity = $\frac{Density\ of\ soil}{Density\ of\ water}$

MOISTURE CONTENT:

Moisture content (%) = $\frac{Weight\ of\ water\ in\ soil}{Weight\ of\ dry\ soil}$ x 100

ATTERBERG LIMIT

1. Plasticity index = Liquid limit - Plastic limit
2. Linear shrinkage (%) = $\frac{Change\ in\ length}{Original\ length}$ x 100%

COMPACTION TEST

1. Bulk density ℓ (kgm^{-3}) = $\frac{Weight\ of\ compacted\ soil}{Volume\ of\ soil}$
2. Dry density (kgm^{-3}) = $\frac{\ell}{1 + w}$

Where

ℓ = Bulk density

w = moisture content

CALIFORNIA BEARING RATIO (CBR)

California Bearing ratio = $\frac{\text{Test load}}{\text{Standard load}}$ x 100%

RESULTS AND DISCUSSIONS

Mechanical Sieve Analysis: American Association of State Highway and Transportation Official (AASHTO) classification of soils showed that all the samples are predominantly A–2 (A–2–6), while samples A for the base and Sub-base were A-2 (A-2-4) and the sub grade of sample C, G and H were all A-2 (A-2-7) indicating that the soils are fine sand, silts or clayey gravel and sand.

Atterberg Limits: All the samples except samples 1 and 7 have liquid limits and plasticity Indices greater than the requirements of 35% and 12% respectively specified for sub base [3] indicating that the materials are inorganic clays of low plasticity gravely clays, sandy clays [2].

Specific Gravity: The values of the Specific Gravity of all the samples (1-8) are shown in the table below. The values range from 2.67 to 2.86. They are adequate for sub grade, sub base, and base course materials. These values may also be an indication of the presence of Illite (or Silicate clay minerals).

Natural Moisture Content: The values for the natural moisture content ranged from 7.0% to 17.7%, 5.1% to 15.9%, and 6.9% to 13.4% for the sub grade, sub base, and base courses respectively. These were considered adequate for the layers.

Compaction Characteristics: The Optimum Moisture Content of the sub grade, sub base, and base courses range from 10.0% to 14.0%, 10.0% to 14.5%, and 9.5% to 13.8% respectively. The Maximum Dry Density (MDD) ranged from 2.10g/cc to 2.36g/cc, 2.09g/cc to 2.29g/cc, and 1.97g/cc to 2.28g/cc for the sub grade, sub base, and base respectively. The field Dry Density ranged from 1.75g/cc to 1.94g/cc, 1.74g/cc to 1.92g/cc, and 1.75g/cc to 1.93g/cc for sub grade, sub base, and base courses respectively. The values for the laboratory Dry Densities and field Dry Densities differ very much. Obviously, the 100% of the MDD and OMC did not exist on the pavement layers, hence, the failure conditions in the form of rutting, pot-holes, and cracks because the layers were not strong enough.

California Bearing Ratio (CBR): The California Bearing Ratio of the samples range from 5.1% to 20.3% and 5.7% to 31.1% for the sub base and base courses respectively. These do not meet the requirement of the Nigerian General specification for roads and bridges [3] that the CBR should not be less than 30% and 80% for sub base and base layers respectively. Low CBR values may be due to the presence of Illite mineral in the soil [5]. At pit 3 and 4 for the sub grade, the values have not met the requirement of 15% minimum for sub grade material.

CONCLUSIONS AND RECOMMENDATIONS

From the results of the tests carried out, it was discovered that poor geotechnical properties of the soils making up the pavement led to its failure. These are indications of substandard material properties used for the construction of the road. All the test results showed a non conformity to specification. The low CBR value is also a noted cause of highway pavement failure. Proper soil investigations are a necessity for any construction work. Therefore, some method of soil improvement, such as soil stabilization is required to improve the strength of the soil and prolong the useful life and durability of the road. When considering an additive; like lime, fly ash, cement or asphalt, lab tests like the Atterberg limits and AASHTO T-99 can be used with trial mixes to determine engineering properties and optimum proportions for the modified or stabilized materials.

Good drainages should be provided to avoid the ingress of water into the road pavement thereby minimizing the risk of weakening the properties of the soil that might have been used in the pavement design. Proper pavement maintenance practices, guidelines and policies should be employed in executing any road design and construction project. Rehabilitation of the existing pavement should be carried out while keeping in mind the variation that may have taken place in the volume of traffic since its commissioning.

APPENDIX

SUMMARY OF LABORATORY SOIL TESTS RESULTS

Sample No.	Pavement Layer	Layer Thickness (mm)	LL (%)	PL (%)	PI	AASHTO Classification	GI	OMC (%)	MDD (g/cm^3)	Unsoaked C.B.R (%)	Soaked C.B.R (%)
1	**Base**	180	27.0	19.3	7.7	A-2-4	0	10.2	2.12	31.1	6.1
	Sub-base	230	34.0	23.2	10.8	A-2-4	0	10.5	2.10	7.7	4.2
	Sub-grade	----	27.0	11.5	15.5	A-2-6	0	10.0	2.10	17.0	4.8
2	**Base**	230	49.0	32.0	19.9	A-2-7	0	13.8	2.12	6.4	4.8
	Sub-base	290	34.0	19.2	26.0	A-2-6	0	13.5	2.29	20.3	11.0
	Sub-grade	-----	45.0	21.2	16.6	A-2-7	0	10.5	2.13	29.5	8.0
3	**Base**	172	34.0	16.4	19.0	A-2-6	0	10.9	2.23	14.3	7.9
	Sub-base	190	35.0	24.1	18.0	A-2-6	0	11.0	2.12	6.0	3.7
	Sub-grade	-----	41.0	27.0	14.8	A-2-7	0	10.0	2.26	10.7	6.4
4	**Base**	182	27.0	22.1	11.8	A-2-6	0	9.8	1.99	20.0	3.3
	Sub-base	187	36.0	16.3	17.3	A-2-6	0	10.0	2.16	19.8	11.3
	Sub-grade	----	39.0	19.5	9.0	A-2-6	0	10.5	2.21	8.7	6.0

Sample No.	Pavement Layer	Layer Thickness (mm)	LL (%)	PL (%)	PI	AASHTO Classification	GI	OMC (%)	MDD (g/cm^3)	Unsoaked C.B.R (%)	Soaked C.B.R (%)
5	**Base**	200	27.0	15.1	11.9	A-2-6	0	13.0	2.05	23.3	4.2
	Sub-base	215	36.0	22.1	13.9	A-2-6	0	14.5	2.19	9.3	5.4
	Sub-grade	----	23.0	8.0	15.0	A-2-6	0	14.0	2.13	17.6	11.6
6	**Base**	190	27.0	12.0	15.0	A-2-6	0	8.5	1.97	10.7	7.4
	Sub-base	189	36.0	18.5	17.5	A-2-6	0	13.0	2.09	5.1	3.2
	Sub-grade	-----	30.0	19.2	10.8	A-2-6	0	10.0	2.35	24.0	5.4
7	**Base**	192	20.0	16.0	4.0	A-2-6	0	13.0	2.15	8.7	5.1
	Sub-base	174	31.0	26.3	4.7	A-2-6	0	12.0	2.19	8.1	5.6
	Sub-grade	-----	43.0	27.8	15.2	A-2-7	0	10.5	2.29	17.3	5.3
8	**Base**	170	27.0	15.2	12.5	A-2-6	0	10.0	2.28	5.7	3.0
	Sub-base	182	23.0	9.5	13.5	A-2-6	0	14.5	2.28	16.8	4.4
	Sub-grade	----	41.0	16.2	24.8	A-2-7	0	11.0	2.36	17.7	5.4

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