UNDERSTANDING FAILURE IN FLEXIBLE PAVEMENT AND OPTIONS OF MAINTENANCE USING PAVEMENT CONDITION SURVEY

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Abstract

In Nigeria, the choice of a suitable and timely road maintenance option is still an issue of concern due to lack of appropriate maintenance practice. The research evaluates and determines causes of pavement failures through empirical analysis of soil stabilisation, adequate drainage, and asphalt overlay. Road material samples obtained by coring from the study site was analysed in the laboratory through geotechnical test, California Bearing Ratio (CBR), Bitumen extraction test, moisture analysis and plasticity test. The geotechnical results revealed that, plastic index of the Base course material was about 16% in excess of the recommended 10%. Appling Deep Cone Penetration test method and the California Bearing Ratio (CBR) value of the Base course resulted at about 67%, which is below the recommended 80%. Furthermore, the asphalt extraction test revealed that the bitumen content was only 4.9% against the 6.5% that is recommended. It is concluded that insufficient drainage, poor construction methods, and lack of quality control measures as indicators of maintenance options contribute to early failure of road pavement. Against the above, a suitable maintenance option using the pavement condition survey is recommended as a general guide, particularly for highway engineers.

Keywords: Asphalt, Deterioration, Flexible pavement, Maintenance

1.0 Introduction

In the last two decades, the Nigerian government has made tremendous efforts to expand and extend her road network. However, the emphasis on expansion and extension of the road network apparently relegated the issue of maintenance to the background. Unfortunately, because of increase in volume of traffic during the same period, the roads deteriorate at a rapid rate.

Flexible pavements are constructed in cumulative layers of natural granular material covered with one or more waterproof bituminous surface layers, and as the name imply, are considered to be flexible (Okikbo, 2012). A flexible pavement will flex (bend) under the load of a tyre. The objective in the design of a flexible pavement is to avoid the excessive flexing of any layer, failure to achieve this will result in the over stressing of a layer, which ultimately will cause the pavement to fail or deteriorate (Etikala, 2015). Harischandra (2004) emphasised that flexible pavements deteriorate under loading conditions and climate change effect. This effect depends on the technology and materials of the road, but the greatest effects depend on traffic loads and volumes. Magdi (2015) and Nordengen (2006) investigated the effect of poor drainage on road pavement condition and found that the increase in moisture content decreases the strength of the pavement base course.

Therefore, poor drainage causes the premature failure of the pavement, on the same line, pavement tends to crack at some point of their lives under the combined action of traffic loads and climate change conditions. Adeoti (2004) examined the methods of road maintenance in Nigeria. To do so, they defined and analysed the causes of structural failure of highway pavement and suggested some factors; climate change, unstable ground conditions and poor drainage, poor construction material and methods, post construction activities like digging of trenches along the road etc., poor workmanship and inadequate maintenance. Okikbo (2012) and Abhijit (2011) identified some of the factors that cause highway failure. These factors were; poor design and construction, poor maintenance of already built highways, use of low-quality materials in construction, poor workmanship and poor supervision of construction work and the applying of heavy traffic vehicles that were not meant for the road.

There are various forms of periodic rehabilitation that involves the application of relative layer of bituminous bound aggregate over the existing wearing course of the weakened pavement. It serves the purposes of levelling out minor surface distortions and it is a means of strengthening as well as restoring structural integrity of the pavement. When these methods are properly selected, they provide the most cost-effective method of improving existing pavement as they can be used to strengthen existing pavement, reduce maintenance cost, increase pavement lifespan, provide a smooth ride, and reduce safety hazards by improving pavement surface skid resistance (Korkiala-Tanttu, 2007).

Traditionally, ranking of pavement sections for maintenance operations in Nigeria have been based wholly on the experience and judgement of highway engineers and maintenance personnel (Abiola, 2011). It is disheartening to note that most of the road pavements in the State are in various states of disrepair. Most of the roads have become hazardous and sources of economic drain in terms of high road user cost, loss of lives and property and loss of highway investment (Hnin, 2014). Other studies have highlighted various maintenance practices, while some have evaluated causes of failure in flexible pavement. But this research aims to evaluate and determine causes of failed pavement, as well as schedule a suitable maintenance option.

2.0 Study Area

Uyo is a metropolitan city in the heart of Akwa Ibom State, Nigeria as shown in figure 1. It is located on 5.0377^{0}N and 7.9128^{0}E and the capital of Akwa Ibom state created in 1987 and located at the south-south region of Nigeria, thus, having tropical climate condition. Uyo has a total land area of 7,081 km^2 and an estimated population of 5.520,208 peoples. Akwa Ibom State has a total road network of 6,288Km out of which 9.6% (602km) are federal government roads (AKSG, 2023).The study was conducted on a single carriageway with ADT of 3000. The road length and width are about 3.6 km and 8m respectively. This road has been maintained several times during the last 10 years and still suffered from severe distresses. The last rehabilitation work on this road was carried out in 2022. The road has serious problems that have decreased its performance and safety. These problems include inadequate drainage system and damaged pavement surface.

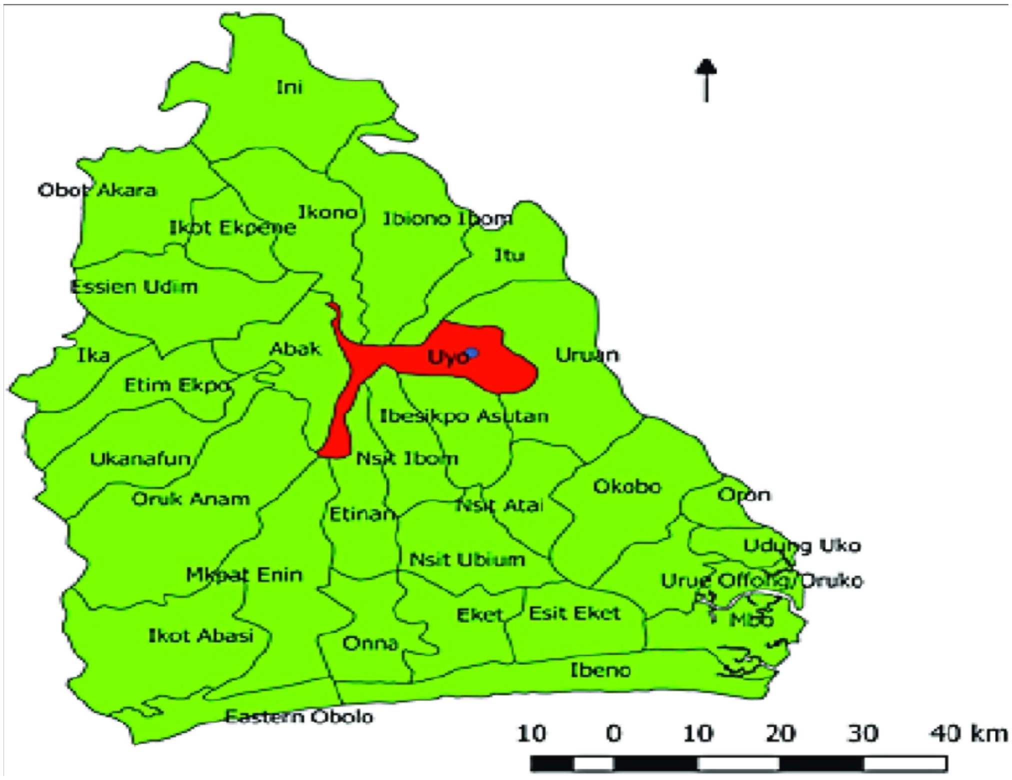

Fig. 1: Map of Akwa Ibom State

3.0 Methodology

The method followed some basic steps as follows:

i) Pavement condition survey.

ii) Experimental work

3.1 Pavement Condition Survey

Pavement condition survey is the overall evaluation of the present serviceability and performance condition of the pavement as compared to its design function. The pavement condition survey included visual examination of pavement failures. The geology and mechanics of the soil was examined as an important factor in determining the causes of the pavement failure. Survey was carried out on failed pavement sections to find out the amount, type, and condition or state of failures, as well as the effectiveness of any previously applied maintenance practice to the failed section of the road pavement.

3.2 Experimental Work

The experimental work included field and laboratory testing. Field density testing was carried out to assess the percentage (%) compaction of the pavement materials. The conventional field tests carried out included Dynamic Cone Penetration (DCP) test, and the failures on the pavement were also measured. Coring was done on pavement structure to ascertain if the pavement layers were built according to the plans and specifications and to collect samples for experimental test. Atterberg's Limit test, California Bearing Ratio (CBR) tests, Marshall tests for stability and flow, and extraction test on the asphalt concrete sample were among the test conducted.

4.0 Results and Discussion

The pavement was travelled upon by foot and then by car to ascertain the actual length of the road and then the extent of the road that is being affected by the different stresses. It was observed during the inspection process that the total length of the road pavement was 3.6KM.An evaluation plan was drawn out to divide the study road into three sections, (A,B,C) each of same length 1.2km,and the basis for evaluation was on these three sections. A thorough review and analysis of the existing construction records, the contract documents and test results were examined.

4.1 Field Survey of Failed Pavement Section

A comprehensive visual survey of pavement surface was conducted by walking through the study surface area and closely observing, identifying, and recording the defects on failed pavement sections. The data collected from the field survey of the existing pavement surface failures were analysed. The measured and observed states of failures with different levels of severity are given in Table 1 and figure 2.

Fig. 2: Various failed sections of Edet Akpan Avenue

Table 1: Severity levels of the measured stresses

Distress	Section A	Section B	Section C
Rutting	Heavy	Moderate	Light
Depression	High	High	Moderate
Potholes	Low	Moderate	Low
Cracking	High	Moderate	Moderate
Ravelling	High	High	High
Polishing	High	Moderate	Low
Patching	Moderate	High	Low

4.2 Experimental Work

The experimental work program consists of two tasks; field work and laboratory test. Three trail pitholes of one meter depth were excavated in the road, a pithole in each section. Disturbed soil samples were collected at 1m depth to represent the pavement soil. The tests performed included, Atterberg limits, compaction and California Bearing Ratio (CBR) tests, Deep Cone penetration test, Asphalt extraction and marshal stability and flow test. The test results summary is given in Tables 2 to 5.

4.3 Results and Discussion

Table 2 indicates that the subgrade soils in sections C and B compared to A have high values of liquid limit and plasticity index and low CBR values. These soils of sections B and C can be classified as expansive clay. While the subgrade soil in section A has low liquid limit and plasticity index and relatively high CBR and classified as non- expansive soil. Thus, the subgrade soils in sections B and C are considered as weak subgrade. The base material plasticity index was also above 10% which exceeded the project requirements or specification, and that of the sub-base material barely met the project specification (12-15%).

The Dynamic Cone Penetration (DCP) tests result as shown in Table 3 were carried out on the pavement structure at three locations. The penetration depth measured up to 75 cm below the base course level. The data from DCP tests were used to determine the penetration resistance (mm/blow), which is simply the distance that the cone penetrates with each drop of the hammer. The field CBR value was determined using Transportation Research Laboratory (TRL) correlation as follows: Log (CBR) = 2.48 – 1.057 Log (DCP).

The test results from the dynamic cone penetration test revealed that the thickness of the base layer varied between 180-210mm whereas the sub-base ranged from 205-350mm, but the specification for the project required 250mm and 400mm respectively for the base course and sub-base course layers. Using empirical relationships, the California Bearing Ratio (CBR) were determined from the DCPT results, the average CBR values of the base, sub-base and embankment materials are 67%, 37% and 18% respectively. The results illustrated that the base materials do not comply with the specifications (i.e. CBR ≥ 80%). While the sub-base and embankment materials barely complied with the specifications. Analysis on the test result from the DCPT revealed that there was no clear distinction between the quality of the base and the sub-base layer material since the lateritic gravelly sandy soils with trace of clay were practically dumped on the sub-base layer.

Table 2: Sud-grade test result

Test	**Section A**	**Section B**	**Section C**
Liquid limit(%)	26	33	50
Plasticity limit (%)	15	18	27
Plasticity index (%)	11	15	23
Max dry density (g/cm^3)	1.66	1.60	1.48
Optimum moisture content (%)	13.5	15	18.5
Soaked CBR (%)	22	14	12

Table 3: Deep cone penetration DCP test result

Location	Layer Thickness(mm)	DCP(mm/blow)	CBR (%)
Section A	180 220 400	4.5 6.4 17.4	62 32 15
Section B	210 205 300	4.1 7.2 15.2	68 37 17
Section C	200 320 420	3.9 6.6 12.6	72 41 21

The asphalt sample carried for the Asphalt Marshall test in Table 5 revealed that, 70mm thickness asphalt was used. The Asphalt Marshall Stability and Flow test was carried out according to the specifications of ASTM D1559-89, and the results revealed that the average stability and flow from the three samples in the different sections was within acceptable range with the specification of the project, and it is sufficient to resists plastic deformation.
The extraction test(table 4)on the other hand revealed that the average percentage binder content in the asphalt concrete was too low and that has greatly affected the durability of the asphalt concrete resulting in the ravelling observed on the road pavement.

Table 4: Asphalt extraction test

Sample	Height(mm)	Stability (N)	Flow (mm)	Correction	Corrected value
A	61.3	6566	3.6	1.06	6960
B	58.2	5600	4.6	1.15	6400
C	62.0	6800	4.2	1.04	7072
			4.1		6824

Table 5: Asphalt stability and flow test

Section	Binder content%	Bulk density g/cm^3	Void content %	Voids with binder%
A	4.6	2.673	6.68	88.85
B	4.9	2.6795	5.73	76.0
C	5.2	2.6795	5.12	79.75

4.4 Pavement Condition Rating

The results of pavement failure survey done through an effective inspection on site revealed that some stress affected the performance of the pavement more than other factors under consideration. Under this rating system, the less serious stresses are assigned values between zero (o) and five (5). Stress of a more serious nature, those directly related to the strength of the pavement are rated on a scale of zero (o)to ten (10). Hence, the extent and severity of failure along the study road is as given in the pavement rating form.

Asphalt Pavement Rating Form	
Street/Route name: Edet Akpan Avenue	
City: Uyo	Date: 12-02-2024
Length of Project:3.6KM	Width:8M
Location of Survey: Total Length	Weather:Fair
Pavement Type: Flexible Pavement	

Notes---

Stress	**Rating**	**Score**
Blockcracks	0 – 5	3
Edgecracks/alligator crack	0 – 5	3
Longitudinal/transverse crack	0 – 10	8
Rutting	0 – 10	4
Potholes	0 – 10	6
Patching	0 – 5	2
Swelling	0 – 5	1
Corrugation	0 – 5	2
Ravelling	0 – 5	4
Depressions	0 – 5	2
Deficient drainage	0 – 10	8
Riding quality	0 – 10	8
	Sum of stress	51

Condition rating = 100 – sum of stress

= 100- 48

Condition rating = 51

Legend:

Reconstruction	Overlay	Routine Maintenance
0 20	40 60	80 100

4.5 Maintenance Option

The maintenance option that was considered appropriate for this research was pavement overlay. Considering the legend in the pavement condition rating which summarised the overall pavement condition, the condition rating was 51 which falls between 40 and 80 which is the range for pavement overlay.

5.0 Conclusion

In conclusion, the material quality of the pavement as investigated through geotechnical tests was poor and resulted in significant pavement failures. Poor drainage condition of the pavement was a major cause of some of the failure. The poor construction method and quality was identified as part of the causes for the failed pavement as it is evident in the CBR test result of 67% against the recommended 80%. Finally, considering the result of the pavement condition rating, which was 51, pavement overlay was scheduled as the maintenance option.

6.0 Recommendations

- It is recommended that this research which presents an easy-to-follow pavement condition assessment approach for determining causes of failure and maintenance option in failed flexible pavement should be used as a general guide particularly for young highway engineers.
- This research was based on the geotechnical properties of the road for the determination of the causes of failure and choosing of maintenance option, further research is required on the effect of traffic loading and travel behaviour on maintenance option.

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