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FAILURES AND STRUCTURAL STABILITY OF FLEXIBLE PAVEMENT (CASE STUDY OF UGBOR-AMAGBA ROAD BENIN CITY, EDO STATE, NIGERIA)

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ABSTRACT

The project investigates the primary causes of Flexible Pavement failures and provides viable solution (a case study on Ugbor-Amagba Road) as well as quality control. Various test were carried out on soil samples collected from failed areas of the road such as CBR test, Sieve analysis (for particle size distribution), Compaction test, Marshall Stability and Coring test amongst others. The foundational failures of the road pavement observed are caused by excess ground water penetration from the wearing course into the base and sub-base courses. Geotechnical properties of the soil were also responsible for the failure of the road pavement such as inadequate compaction, water infiltration through edge break or deflection and lack of adequate drainage system and unsuitable underlying soils.

KEYWORDS: Structural Stability, Flexible pavement, Marshall Stability, California Bearing Ratio, Asphalt, Bitumen, Compaction.

1. INTRODUCTION

Pavement failures in most developing countries especially Nigeria is worrisome and this is one of the challenges which the government of the day constantly have to pay attention to. Adequate planning and design of good pavement is germane to the development of a nation. This is because properly constructed road network enhances economic growth of any nation by encouraging efficient movement of goods and services. Thus, good road network reduces haulage vehicle accidents by minimizing human and material losses (Akintorinwa, et al, 2010). In the developing countries such as Nigeria, road network is the most developed transport mode and the most used (Okigbo, 2012). Roads represent the major areas of investment in transportation according to Oguara (Oguara, 2010) and are also the dominant travel mode accounting for over 90% of passenger and goods transport in Nigeria. Regrettably, despite huge financial resources being sunk into the transportation sector in Nigeria, its roads have continued to pose serious dangers to motorist due to its deplorable state with attendant economic losses to the populace especially as a result of loss in man hours arising from delays on several bad portions of the road. Despite its vast potentials for growth and development, the Nigeria roads have not been satisfactory in terms of its performance (Adewumi, 2008). Most of the problems leading to the deplorable state of Nigerian roads are directly or indirectly related to the poor planning of pavement design but an adequate knowledge of the effect of pavement failure on our roads will help in reducing the menace arising. Flexible pavements support loads through bearing rather than flexural action. They comprise several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath. The design ensures the load transmitted to each successive layer does not exceed the layer's load-bearing capacity. When pavements fail prematurely it is often in the best interest of the owner agency to identify the probable cause. Based on findings it will be possible to initiate corrective procedures to avoid continuing problems of similar types. These corrective actions may require changing an altering existing design, construction, material testing methods and/or specification acceptance criteria. The reliability of a failure analysis will vary depending on the information available. In some cases, the cause of failure will be obvious, such as truck loads (number and weight) having increased significantly above expected levels. In many cases the analysis will not be so straightforward and a more in-depth study will be necessary to identify the factors responsible for the undesirable pavement performance. Pavement deterioration process starts directly after opening the road to traffic. This process starts very slowly so that it may not be noticeable, and over time it accelerates at faster rates. To ensure the risk of premature deterioration is minimized, it is necessary to use the best practice method in planning, design, construction and maintenance of the road. This can be achieved by examining pavements that have failed prematurely, with the focus being on determining the causes of failure so that it can be prevented in the future.

Factors that lead to pavement failure are numerous and it is pertinent to first identify such factors and then classify them for effective understanding and management of the problems for developmental growth of a nation. It is said that pavement failure arises from functional failures and the assignment of categories makes the understanding of pavement somewhat easier. Proper identification of pavement will ultimately enable the relevant agencies to appreciate the causes of pavement failure with a view to providing remedial measures to mitigate the failure. Also, high groundwater table exerts detrimental effects on the roadway base and the whole pavement. Base clearance guidelines have been developed to prevent water from entering the pavement system in order to reduce its detrimental effects but there is few available research in the literature about the structural stability and failure of flexible pavement. The greater understanding of pavement failures that could be gained from detailed investigations could be valuable in reducing the costs associated with pavement failures in the future. In many cases the failure of pavement structure can be directly attributed to inadequate maintenance and ineffective evaluation programs. It is important to find out a method to minimize the maintenance cost and reduce failures of flexible pavement under a limited budget.

2.0 Experimental Work/Methodology

To examine the structural stability and failures in pavements, the experimental work includes field and laboratory testing and a randomly selected section of the highway was used as case study. Geotechnical tests includes measurement of the shear strength, consolidation of the underlying soils. Asphalt tests was used to measure the consistency by penetration and ductility. Marshall Test was used for stability and flow measurements of asphalt concrete sample and extraction test

2.1 Marshall Stability Test

Marshall Stability method is used in pavement design and stability to determine the optimum binder content in bitumen pavement and explains the physical characteristics of asphalt

Preparation of test specimen

- 1200 grams of aggregate was blended in the desired proportions is measured and heated in the oven to the mixing temperature
- Bitumen was added at the mixing temperature to produce viscosity of 170 +- centi-stokes at various percentages

- The materials are mixed in a heated pan with heated mixing tools
- The mixture is returned to the oven and reheated to the compacting temperature(to produce viscosity of 280 + or – 30 centi-stokes)
- The mixture is then placed in a heated Marshall mould with a collar and the mixture is spaded around the sides of the mould. A filter paper is placed under the sample and on top of the sample
- The mould is placed in the Marshall Compaction pedestal
- The material is compacted with 50 blows of the hammer(or as specified) and the sample is inverted and compacted in the other face with same number of blows
- After compacting, the mould is inverted. With collar on the bottom, the base is removed and the sample is extracted by pushing it out the extractor
- The sample is allowed to stand for the few hours to cool
- The mass of the sample in the air and when submerged is used to measure the density of specimen, so as to allow, calculation of the void properties

Marshall test procedure

- Specimens are heated to 60 + or – 1 degrees Celsius either in a water bath for 30 to 40 minutes or in an oven for minimum of 2 hours
- The specimens are removed from the water bath or oven and placed in lower segment of the breaking head. The upper segment is placed in position and the complete assembly is placed in the position on the testing machine
- The flow meter is placed over one of the post and is adjusted to read zero
- Load is applied at a rate of 50mm per minute until the maximum load reading is obtained
- The maximum load reading in Newton is observed. At the same instant the flow as recorded on the flow meter in units of mm was also noted.

2.2 Extraction Test

To extract the bitumen from aggregate. Tricoline was used for the extraction

Procedures for extraction

- 1000 grams of sample was measured
- The sample was poured into the Centrifuge machine
- Chemical (tricolium) was added

- The Centrifuge machine was turned on and allowed to extract the bitumen leaving behind the Aggregate
- The above process was repeated until the aggregate is clean. i.e only the chemical comes out as filtrate
- The aggregate was removed and placed in the oven
- The percentage of the bitumen is determined after drying the aggregate in the oven
- The remaining aggregate is then sieved for particle size distribution

2.3 Coring Test

It is done mainly to check the workmanship of the pavement after the asphalt is laid. It is significant for the determination of percentage compaction and other physical properties

Coring test procedure

- Using the curing machine, the specimen was taken (cut) at every 100m interval
- The specimen was then placed in the oven to heat for about 5 minutes (to separate the prime coat from the asphalt)
- The iron brush was used to gently remove the prime coat from the asphalt
- The specimen was soaked in water for about 1 hour
- After soaking, the surface of the specimen was mobbed or cleaned with dry towel.
- The specimen was weighed in air and in water to get the volume of the sample
- The specimen was placed in the wire basket under the weighing balance and allowed to fall into the water to get the weight in water

2.4 C.B.R (California Bearing Ratio) Test

The aim is to determine the strength of the compaction sample on application of load and water for a duration of time.

C.B.R (California Bearing Ratio) test procedure

- It is done with 10, 30, 65 blows each with different mould of the same volume (2287)
- Mix the 6000g of laterite with 6% of water for 10 blows, 8%of water for 30 blows and 11% of water for 65 blows
- Divide the sample into five layers and put each layer into the mould and compact with 10 blows or 30 blows or 65 bows for each mould with the rammer.

- After compaction, clean or scrape the top of each mould to give a flat surface and measure mould + sample for the 3 different moulds.
- Close the mould properly and soak for soak for 96hrs for each mould
- After 96hrs, penetrate with the C.B.R tester and some calculations follows to ascertain sample strength on penetration i.e. loadings.

2.5 Compaction Test

- The essence of compaction in general is to close all voids in the compacted sample
- Compaction test also helps to determine the M.D.D & O.M.C (M.D.D =maximum dry density, O.M.C=optimum moisture content)

Compaction test procedure

- Weigh 6000g of the sample and pour into 4 different trays.
- Mix the samples completely with 6%, 8%, 10%, and 12% of water for each.
- With one tray divide the sample into 5 layers.
- Put each layer into the mould and compact with 56 blows for each layers.
- Take the weight of the empty mould + sample and the different moisture can to be used.
- The process is followed by series of calculation and a graph of dry density against moisture content is drawn to ascertain the OMC (optimum moisture content) and MDD (Maximum dry density).

3.0 Data analysis and discussion of results

3.1 Coring

In table 2 below for coring test, Asphalt samples were taken at every 100m interval starting from chainage 0+250m. As observed, the test seeks to adequately check if the wearing course of the flexible pavement (asphalt) was completely compacted. Samples were taken from the On-going Ugbor-Amagba Road Construction.

3.2 Extraction

As shown in table 4 below for extraction, the bitumen content was ascertained for adequate proportioning. It was also observed that the addition of tricolium (chemical used for the removal of bitumen from aggregate), the bitumen offers little resistance in the removal process by the centrifuge machine.

The percentage of the bitumen is determined after drying the aggregate in the oven and also the aggregate after oven drying is sieved with different sieve sizes ranging from 0.075um to 19mm for particle size distribution.

3.3 C.B.R

In the course of the California Bearing Ratio test(table 3), the different water percentage (6%, 8%, 11%) added to the three different sample of the same mould size of 2287 reacts differently on the addition of load which represents 10, 30 and 65 blows respectively and samples were soaked for about 96 hours to test for extreme conditions. A graph was plotted for the penetration against the gauge radii for each of the three samples to ascertain the materials reaction to loading and moist conditions.

3.4 Analysis for Marshall Stability

*Max theoretical density

$G_{mm} = 100/\ (100\text{-}P_a/SG\ Agg) + (P_a/SG\ Bit)$

Where

P_a= Bitumen Content = 5.11

$G_{mb} = 2.385$

$G_{sd} = 2.684$

Sg = Specific gravity of bitumen = 1.02

$G_{mm} = 100/\ (100\text{-}5.11/2.684) + (5.11/1.02)$

$= 100/\ (94.89/2.684) + (5.11/1.02)$

$=100/35.35 + 5.0$

$=100/40.35$

$G_{mm} = 2.48$

*Air Voids

$V_a = 100^*\ (G_{mm}\text{-}\ G_{mb})/\ G_{mm}$

$100^*(2.48 – 2.385)\quad /2.48$

$= 100^*(0.095)/\ 2.48$

$=9.5/2.48$

$=3.7$

*Voids in mineral Aggregate

$V_{ma} = 100 – (G_{mb}{}^*(100 - P_a)/G_{sd}$

=100 – (2.385*(100 – 5.11)/2.684

100 – (2.385*(94.89)/2.684

100 – (226.31)/2.684

=100 – 84.32

=15.68

=15.7

*Voids Filled with Bitumen

$V_{fa} = 100*(V_{ma} – V_a)/V_{ma}$

$V_{fa} = 100*(15.7 – 3.7)/15.7$

100*(12)/15.7

V_{fa}= 100*0.76

V_{fa}= 76.3

Table 1: Computations Of Properties Of Asphalt Mixtures Marshall Methods.

Specific Gravity of Bitumen 1.02 SG Agg: G_{sd} 2.684

Bitumen Content Pa 5.11 Location: Ch. 6+000 – Ch. 6+400

			1	2	3
	Specific Gravity		1	2	3
	Temperature	^{0}C			
a	Flask + Sample + Solution	g			
b	Flask + Sample	g			
c	Flask	g			
d	Sample (b-c)	g			
e	Solution (a-b)	g/ml			
f	Specific Gravity Solution	ml			
g	Volume of Flask	ml			
h	Volume of Solution (e/f)	ml			
i	Volume of Sample (g-h)	g/ml			
j	Specific Gravity (d/i)	g/ml		G_{mm}	
k	Max Theoretical density(100/(100-P_a/SG Agg)+ (P_a%/SG Bit)	g/ml	**2.478**		
	Unit Weight				
l	Weight of Sample in Air	g	1197	1193	1199
m	Weight of Sample in Air (SSD)	g	1198	1194	1200
n	Weight of Sample in Water	g	695.06	693.58	697.49
o	Volume of Sample (m-n)	g/ml	502.94	500.42	502.51
P	Unit Weight (l/o)	g/ml	2.382	2.386	2.388
q	Unit Weight Average (G_{mb})	g/ml		**2.385**	
	Marshall Stability				
r	Thickness	mm	64	65	64
s	Maximum Load	Kn	590	510	600
t	Correction 41.5/(r-22)		0.988	0.965	0.988

u	Correction Stability (s*t)	Kn	583.0	492.2	592.9
	Proving ring factor		0.0253	0.0253	0.0253
	Stability		14.7	12.5	15.0
v	Stability Average	Kn	**14.1**		
w	Flow	mm/10	3.1	3.3	3.5
x	Flow Average	mm/10	**3.3**		
Voids					
y	Difference	g/ml	0.092		
V_a	Air Voids		3.7		
	Voids Filled With Bitumen				
V_{ma}	Voids in Mineral Aggregate $V_{ma} = 100-(G_{mb}*(100-P_a)/G_{sd})$	%	15.7		
V_{fa}	Voids Filled With Bitumen $V_{fa} = 100*(V_{ma}-V_a)/V_{ma}$	mm/10	76.3		

Table 2: Summary of Coring Specimen.

Proving ring factor 0.0253 SG Bit 1.02 Gsd 2.688

SG AGG 2.682

S/No	B/C	Chainage	SSD Wt.	Wt. in water	Volume of Sample	Unit Wt	Max Theoritical Density	Voids			Compaction (gcc)
								Air Voids	VMA	VFA	
1	5.74	0+250	716.7	409.7	307	2.335	2.453	4.8	18.1	73.5	98%
2		0+350	876.73	504.1	372.63	2.353		4.1	18.1	77.6	98.6%
3		0+450	762.35	435.76	326.59	2.334		4.8	18.1	73.4	97%
4	5.2	0+550	790.93	453.76	337.7	2.342	2.473	4.5	17.4	74.1	98%
5			813.5	458.5	355.05	2.291		7.3	17.4	57.9	96%
6			913.3	524.2	407.11	2.288		7.5	17.4	57.0	95%
7	5.5		796.3	436.1	360.29	2.210	2.461	10.2	22.3	54.2	92.7%
8			858.1	484.0	374.1	2.294		6.8	22.3	69.5	96%
9			809.6	453.2	356.37	2.272		7.7	22.3	65.4	95%

Table 3: California Bearing Ratio (Aashto-193).

Method of Compaction AASHTO-193 Soaked hour: 96 hours

Volume of Mould 2287 Wt. of Rammer: 4.5kg

Mould		**A**		**B**		**C**	
No of Layer		5 Layers		5 Layers		5 Layers	
No of Blows		10 Blows		30 Blows		65 Blows	
Wt. of wet sample + moud	g	8717		9669		9899	
Wt. of moud	g	4561		4848		4747	
Wt. of sample	g	4156		4821		5152	
Wet density	gcc	1.817		2.108		2.253	
Container No		26	27	22	24	16	17
Wt. of wet sample + container	g	118.0	118.1	130.2	130.7	113.5	114.0
Wt. of dry sample +	g	111.0	111.1	121.6	122.1	106.7	107.0

container							
Wt. of container	g	9.6	9.9	9.7	9.7	9.6	9.6
Wt. dry sample	g	101.4	101.2	111.9	112.4	97.1	97.4
Wt. of water		7	7	8.6	8.6	6.8	7
Moisture Content	%	6.9	6.9	7.7	7.0	7.0	7.2
Average Moisture Content	%	6.9		7.4		7.1	
Dry Density	gcc	1.7		2.0		2.1	

CBR DATA Proving ring factor = 0.120

Pen. mm	**Standard load**	**Mould A**				**Mould B**				**Mould C**			
		Gauge Reading	**Test load**	**CBR Corr.**		**Gauge Reading**	**Test load**	**CBR Corr.**		**Gauge Reading**	**Test load**	**CBR Corr.**	
				KN	**%**			**KN**	**%**			**KN**	**%**
			KN				**KN**				**KN**		
0.0		0	0.0			0	0			0	0.0		
0.5		3	0.36			7	0.84			20	2.4		
1.0		4	0.48			13	1.56			40	4.80		
1.5		5	0.60			20	2.40			59	7.08		
2.0		6	0.72			27	3.24			74	8.88		
2.5	13.3	7	0.84	6.3		34	4.08	30.7		89	10.68	80.3	
3.0		8	0.96			41	4.92			103	12.36		
3.5		9	1.08			48	5.76			117	14.04		
4.0		10	1.20			54	6.48			129	15.48		
4.5		11	1.32			60	7.20			139	16.68		
5.0	19.9	12	1.44	7.2		66	7.92	39.8		147	17.64	88.6	
5.5		13	1.56			72	8.64			154	18.48		
6.0		14	1.68			77	9.24			160	19.20		
6.5		14	1.68			82	9.48			165	19.80		
7.0		14	1.68			87	10.44			169	20.28		

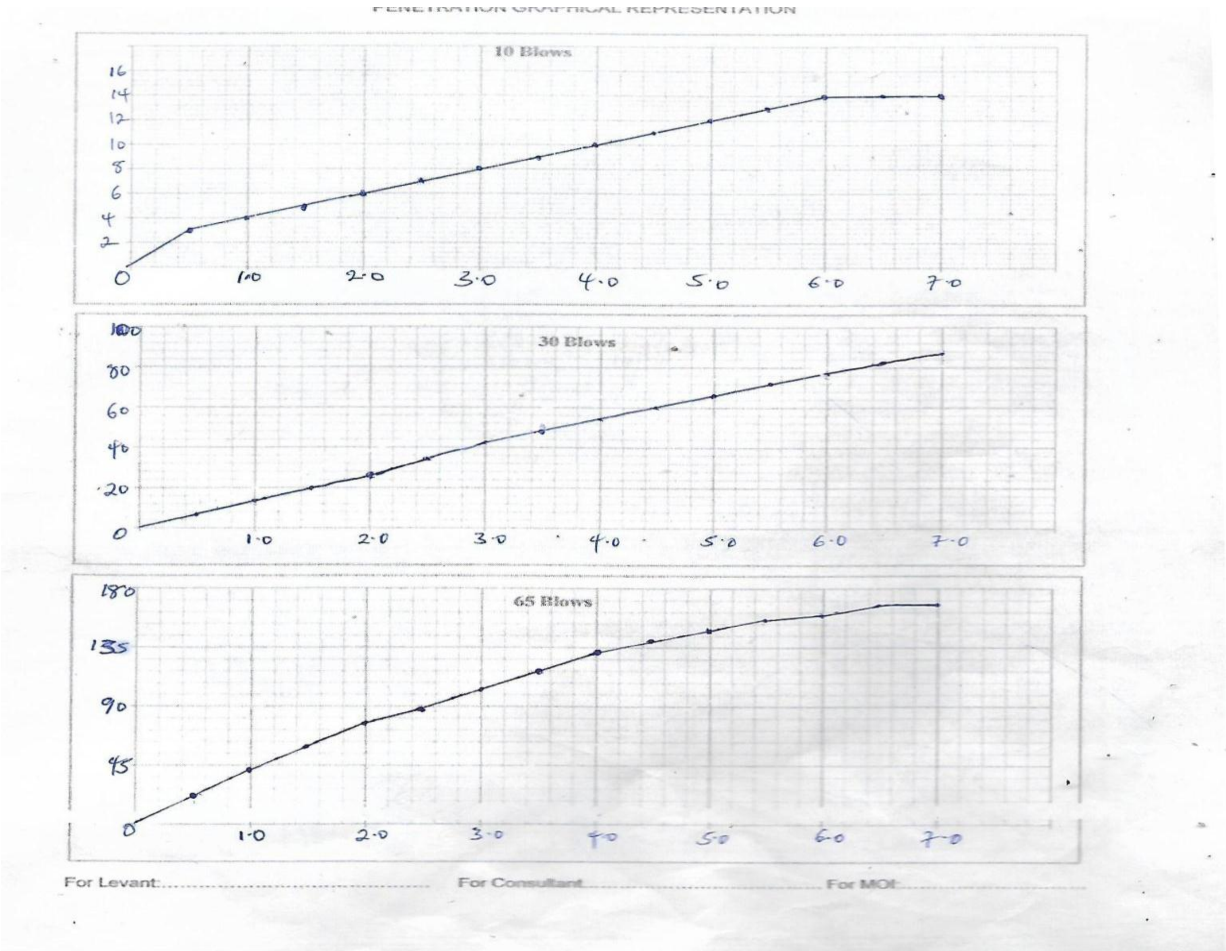

Figure 1: Penetration Graphical Representation.

Table 4: Bitumen Extraction Test

Total Weight of Sample: 977.38 Source of material: Asphalt Plant koko

Total Weight after Wash: 800 Gms Location: Ch.6 + 000 – Ch.6 + 400

Gradation

Sieve Size	Retained	Retained	Passing	on	
19.0	0	0	100	100	100
12.5	23	2.4	97.6	85	100
9.5	98	10.0	87.6	75	92
6.3	126	12.9	74.7	65	82
2.8	162	16.6	58.2	50	65
1.25	156	16.0	42.2	36	51
0.600	105	10.7	31.4	26	40
0.300	92	9.4	22.0	18	30
0.150	73	7.5	14.6	13	24
0.075	54	5.5	9.0	7	14
passing 0.075	88.4	9.0			
Total	889				

Extraction

Ref	Description	Unit	Values
A	wt. of mix + bowl	gms	
B	wt. of bowl	gms	
C	wt. of mix	gms	1030
D	wt. of filter before	gms	17.89
E	wt. of filter paper after before	gms	20.27
F	wt. of material on paper (E-D)	gms	2.38
G	wt. of Aggregate in bowl	gms	975
H	wt. of total Aggregate (F+G)	gms	977.38
I	wt. of bitumen (C-H)	gms	52.62
J	% bitumen by wt. of mix (I/C*100)	%	5.1
K	% bitumen by wt. of Agg. (I/H*100)	%	5.4

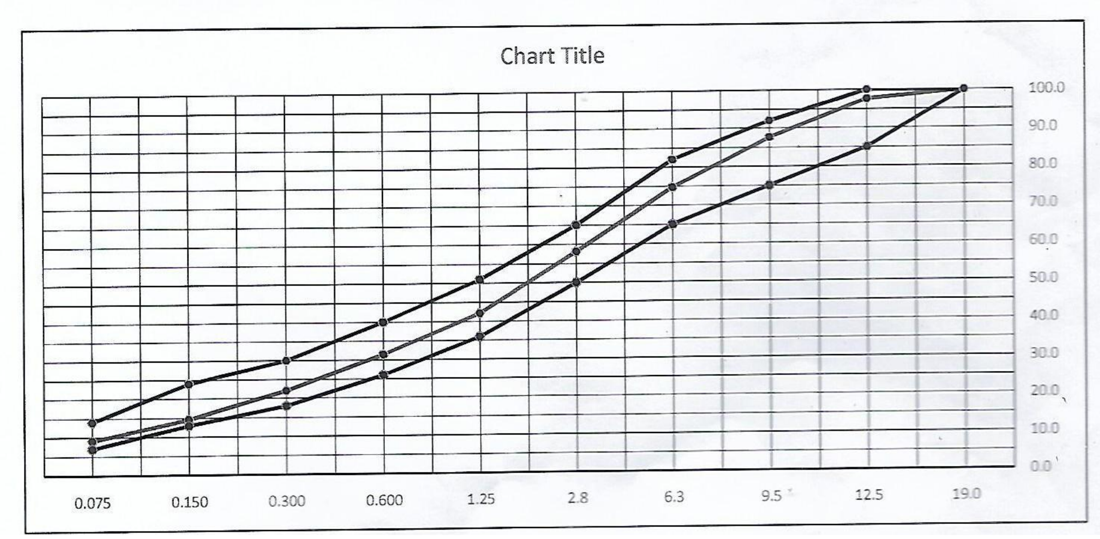

Figure 2: Retained Against Seive Sizes.

Table 5: Compaction Test

Type of Test: West African Compaction Test No of blows: 56

Weight of Rammer: 4.5kg Mould Size: 2287

Moisture Content/ Dry Density Relationship Weight (Kg/Hrs.)

Volume (M^3/Ft^3)

TEST DATA									
Wt. of wet sample + mould	(gr)	9439		9921		9929		9774	
Wt. of mould	(gr)	4747		4747		4747		4747	
Wt. of wet sample	(gr)	4692		5174		5182		5027	
Volume of sample	(cm^3)	6000		6000		6000		6000	
Wet density	(gr/cm^3)	2.05		2.26		2.27		2.20	
Container No.		16	17	24	26	27	49	22	39
Wt. of wet sample + cont.	(gr)	136.7	136.1	114.2	114.4	104.1	104.3	117.1	118.5
Wt. of dry sample + cont.	(gr)	129.4	128.9	106.3	106.3	95.7	95.7	105.8	106.9
Wt. of water	(gr)	7.3	7.2	7.9	8.1	8.4	8.6	11.3	11.6

Wt. cont.	(gr)	9.6	9.6	9.7	9.7	9.9	9.6	9.7	9.9
Wt. of dry sample	(gr)	119.8	119.3	96.6	96.6	85.8	86.1	96.8	97.0
Moisture Content	%	6.1	6.0	8.2	8.4	9.8	10.0	11.7	12.0
Average moisture content	%	6.1		8.3		9.9		11.9	
Dry density	(gr/cm^3)	1.932		2.087		2.066		1.966	

4. CONCLUSION

In pursuit of the meaningful completion of this project a lot of investigation were embarked on with the principles and practice of road construction and maintenance.

A. Soil analysis, gave the proper constitute of the soil with reference to the application of load (wheel Load) which was carried out to ascertain the bearing capacity of the soil.

B. Flexible pavement failures are affected by various factors such as subgrade soil drainage climate, traffic and environmental condition etc. There is not just one reason for each type of failure, this attempt is made to give guidance and supply some vital information as regards the structural stability.

C. However, localized settlement of any component layer of the flexible pavement structure could be strong enough to cause pavement failure. The aging and oxidization of bituminous films lead to the deterioration of bituminous pavement, therefore frequent maintenance on the pavement should be done.

D. Finally, to obtain optimum performance of the road, the causes identified in this research should be corrected adequately with the specified remedies.

5. RECOMMENDATION

To reduce the further spread of defects and cracks on pavements, the following should be done.

A. A proper drainage system or good protection measure (toe beam) against moisture should be put in place. It elongates pavement life.

B. Regular maintenance and re-surfacing of failed sections of the pavement which may affect other stable section is paramount in extending the pavement life

C. Re-construct the edge or support the edges of pavement with paving stones and patching were necessary

D. Also, to construct roads with high traffic volume, the thickness of the wearing course (Asphalt Layer) must be increased to at least 5 to 6cm (To avoid defects that are due to high traffic volumes

E. In the cases of heavy duty vehicles like lorries the sub-case courses are better done with Hard-core or Macadam Layer Preferably to increase its bearing capacity

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