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Design of Concrete Pavement (A Case Study of Farm Road, Along Zaria-Sokoto Road, Nigeria)

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Key-Words: concrete, pavement, aggregates, growth-rate, structural, capacity, traffic- flow.

Abstract

The aim of this research article is to justify the use of concrete pavement and to design a good concrete pavement that will be durable and serve the community, for its design life without any failure or problem. A traffic count has been conducted to determine the Annual Daily Traffic Flow (ADTF). This was used to determine the growth rate at the design period, which was found to be 3% growth rate. The results were presented below: sub-grade type was normal; and the minimum thickness of the Sub-Base required was 80mm. While the minimum thickness of the concrete slab (unreinforced) required was 155mm. The cumulative number of common vehicles (Tn) was $0.44x10^6$ cum.no.com.veh. The cumulative equivalent number of standard axle (T) was $0.2x10^6$ standard axle. Materials such as cement content, fine aggregate, coarse aggregate, and water were determined as 1014611kg, 1623375.24kg, 2435067.36kg and 209kg/m^3 respectively. The total estimated cost of cement, fine aggregate, coarse aggregate, and water were calculated as #15219750, #650000, #2435000, and #50731 respectively, amounting to #18,355,481 only.

The total estimated cost of labour, hand-tools, and equipment were calculated as #3276000, #586000, and #5460000 respectively, amounting to #9,322,000 only. Also, the comparison of flexible and concrete pavements was calculated as #3,753,180 and #9, 772,000 respectively. Considering the figures above, it shows that, the concrete pavement was far beyond the flexible pavement in terms of cost comparison based on the method of construction. The road was designed using the Road Note 29 Design method, the Sub-Base thickness was selected based on the Sub-Grade CBR value and the cumulative number of standard axle during design life of the pavement structure. The California Bearing Ratio (CBR) was found to be 3% and a Sub-Base thickness of 80mm. The surfacing thickness was 155mm which was determined from the chart. From the design mix ratio 1:2:4, the quantities of materials (cement, water, fine and coarse aggregates) and cost were estimated. An investigation was carried out recently in India on the comparative economy of a flexible pavement and a concrete pavement. This has proved that on the overall economic

consideration, a concrete pavement is far more economical than the flexible pavement. Recommendations such as: the concrete pavement should be adequately roughened so as to provide skid resistance to vehicles plying the road, care must be taken in order to ensure that the mix design of the concrete used is standard, care should be taken when constructing, so that the chamber of the pavement will provide a free fall for water on the pavement surface into the drainage provided, care must also be taken to ensure that the sub-base layer is graded and compacted to a smooth hard surface, effective supervision mechanism should be adopted by the Federal and the State Government, drainage should be properly supervised, constructed, and maintained after the construction, suitable materials should be used for pavement construction, and, quality control test should be properly carried out.

1. Introduction

In developing countries like Nigeria, the use of flexible pavement for roads both in urban and rural areas its most commonly adopted. This is so because of the availability of the materials for the pavement and also because of the low cost involved during construction as well as the availability of technological know-how involved in the process of design and construction. But, over the years, these flexible pavements have the tendency of failing easily before they attain their design life, (Mohammed, 2007).Concrete pavement regarded as rigid pavements are made of cement, water, aggregates (fine and coarse aggregates) and sometimes admixtures are often use of (Khanna and Justo, 2001). According to a research, (Sani, 2001), the concrete pavement has its own failure, but it has been proven to be more durable and requires little or no maintenance throughout its design life. According to a research, (Hassan, 2006), the concrete pavement (because of its rigidity and high modulus of elasticity) tends to distribute the load applied on it over a relatively wide area of soil, and the major factor considered in the design of concrete is the strength of concrete itself. In Nigeria, the use of concrete pavement is very low and where available, is only used where flexible pavements have failed. Considering the fact that Nigeria is a country whereby the act of maintenance is lacking, concrete pavement will be most desirable considering its durability (Amina, 2013).

The reference point for the design of concrete pavement is the Farm Road along Zaria-Sokoto Road. This is due to the presence of heavy traffic (Trucks, Lorries, etc.) that plying the road in the process of transferring farm produce from the farm to their place of storage for consumption. This pavement type is preferred due to its high modulus of elasticity as well as its rigidity to the flexible pavement (Khanna and Justo, 2001).

The use of concrete pavement has been the trend in the past twenty to thirty years in the developed countries (Mustapha, 2005). This is probably because of its durability, awareness and low cost of maintenance of the concrete pavement. In America, where the highest number of concrete pavement is recorded, the proportion of the used of concrete pavement is well over 50% of the total roadway and this pavement is used mostly at residential areas, industrial areas as well as major roadways whereby traffic volume is high (Amina, 2013). The challenges of the new technology associated with concrete pavement design with a view of producing positive results on the users, technique and materials as well as its being cost effective needs to be addressed in the developing countries.

2. Methods

The road has been designed using the Road Note 29 Design Method, the sub-base thickness was selected on the basis of sub-grade CBR (California Bearing Ratio) and the cumulative number of standard axles during the design of the pavement structure. A traffic count was conducted to determine the Annual Daily Traffic Flow (ADTF). This was used to determine the growth rate at the design period. The traffic information collected from census data enables one to estimate the number of commercial vehicles per day (either in each or in both directions). A growth rate, as specified in Road Note 29, of 3-4% was be used.

2.1 Design Steps:

Step 1: Find the number of commercial vehicles per day at the construction and traffic growth rate.
Step 2: Decide on the design life.
Step 3: From chart for particular growth rate obtain cumulative number of commercial vehicles for the design life.
Step 4: Multiply the cumulative number of commercial vehicles by the appropriate factor from table to obtain cumulative number of axle loads (factor is based on the type of road to be constructed).
Step 5: Reduce the number of cumulative axle loads to equivalent standard axles.
Step 6: From the tables, obtain the sub-base thickness for the appropriate sub-grade CBR and cumulative number of standard axle.
Step 7: Obtain from the tables the thickness for Base and surfacing from the appropriate base materials and cumulative number of standard axles.

3. Results

Data:

- The CBR value of sub-grade = 13%
- Number of commercial vehicles in both directions daily = 90
- The design life = 20 years (though RN 29 recommends a maximum design life of 40 years)
- Growth Rate = 3%

Table 3.1 Classification of Sub-Grade for Concrete

Type of sub-grade	Definition	Minimum thickness of sub-base required
Weak	All sub-grade of CBR value 2% or less	150mm
Normal	Sub-grade other than those defined by the other categories	80mm
Very stable	All sub-grade of CBR value of 15% or more	0mm

Source: Babatunde and Mahmoud (2000).

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Using formula;

$$T_n = \frac{365\, F_o\, [\,(1+r)^N - 1]\, P}{R}$$

Where; T_n= Cumulative Number of commercial Vehicles

F_o= Initial Daily Traffic in one direction

R = Growth Rate

P = Lane Distribution factor

N = Design Life

$T_n = \frac{365x45[(1+0.03)^{20}-1.0]x1.0}{0.03} = 0.44x10^6$ cum.No.Comm.Vhc

Also; from $T = T_n$ x D

Where; T= Cumulative equivalent number of standard axle

D = Conversion factor

Therefore; T= $0.44x10^6$ x 0.4

T = $0.2x10^6$ standard axle

From the Design Mix Ratio of 1:2:4, the quantities of materials (cement, water, fine and coarse aggregates) needed are estimated below:

Volume to be constructed = 1.155m x 6m x 2175m = 2022.75m^3

Taking shrinkage wastage to be 20%

$\frac{20}{100}$ x 2022.75m^3 + 2022.75m^3 = 2427.30m^3

From the formula,

$$\frac{W}{1000pW} + \frac{C}{1000pC} + \frac{AC}{1000pA} = 1m^3$$

Where; W = Water content in kg/m^3

C = Cement content

A = Aggregates content in kg/m^3

p_W, p_C, p_A= specific Gravity of W, C, A respectively

p_W= 1, p_C= 3.5, p_A = 2.65

W/C = 0.5, W = 0.5C

A/C = 4; A = 4C

A = $A_1 + A_2$

Where; A_1 = Fine Aggregate Ratio (FAR)

A_2 = Coarse Aggregate Ratio (CAR)

FAR:CAR

40:60 = 100

Fine aggregate: 40/100 x 4C = 1.6C

Therefore; 0.6C/1000(1) + C/1000(3.5) + $\frac{1.6C+2.4C}{1000(2.65)}$ = 1m^3

C = Cement content = 418kg/m^3

C = 418kg/m^3 x 2427.30m^3 = 1014611.4kg

1 Bag of cement = 50kg

No. of bags of cement required = 20,293 bags

For Fine Aggregate:

1.6 x 418 = 668.8kg/m^3

668.8 x 2427.30 = 1623378.24kg

1 Tipper = 5000kg

No. of Tippers = 325 tippers

For Coarse Aggregate:

2.4 x 418 = 1003.2 x 2427.3 = 2435067.36kg

1 Tipper = 5000kg

No. of Tippers = 487 Tippers

For water

0.5 x 418 = 209kg/m^3

209 x 2427.30 = 507305.70kg = 507.31 Tones

From the above quantities, an estimate is done for the surfacing

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Table 3.2 Estimation of Cost of Materials

S/NO	MATERIAL	QUANTITY	UNIT	RATE	TOTAL
1	Cement	20,293	Nil	750	15,219,750
2	Fine aggregate	325	Nil	2000	650,000
3	Coarse aggregate	487	Nil	5000	2,435,000
4	water	507.31	Nil	100	50,731

Table 3.3 Cost Summary of Flexible Pavement (Labour Based Method of Construction)

ITEM	FLEXIBLE PAVEMENT	
	Cost (#)	%
Labour	2,542,850	68
Hand-Tools	871,560	23
Equipment	160,000	04
Sub-total	3,574,410	95
Supervision	178,770	05
Grand-Total	3,753,180	100

Source: Babatunde and Mahmoud (2000)

Table 3.4 Cost Comparison of Flexible and Concrete Pavements (Summary of Labour Based Method of Construction)

ITEM	FLEXIBLE PAVEMENT	CONCRETE PAVEMENT
	Cost	Cost
Labour	#2,542,850 68%	#3,276,000 33.5%
Hand-Tools	#871,560 23%	#586,000 06.0%
Equipment	#160,000 04%	#5,460,000 55.9%
Sub-total	#3,574,410 95%	#9,322,000 95.4%
Supervision	#178,770 05%	#450,000 04.6%
Grand-Total	#3,753,180 100%	#9,772,000 100%

4. Discussion

From table 3.1, the sub-grade type was normal; and the minimum thickness of the Sub-Base required was 80mm; while the minimum thickness of the concrete slab (unreinforced) required was 150mm. The cumulative number of commercial vehicles (Tn) was 0.44×10^6 cum.no.com.veh. The cumulative equivalent number of standard axle (T) was 0.2×10^6 std axle. Materials such as cement content, fine aggregate, coarse aggregate, and water were determined as 1014611kg, 1623375.24kg, 2435067.36kg and 209kg/m^3 respectively. The other detail results are presented in the Appendix.

From table 3.2, the total estimated cost of cement, fine aggregate, coarse aggregate, and water were calculated as #15219750, #650000, #2435000, and #50731 respectively, amounting to #18,355,481 only.

From table 3.3, the total estimated cost of labour, hand-tools, and equipment were calculated as #3276000, #586000, and #5460000 respectively, amounting to #9,322,000 only. Also, from table 3.4, the comparison of flexible and concrete pavements was calculated as #3,753,180 and #9, 772,000 respectively. Considering the figures above, it shows that, the concrete pavement was far beyond the flexible pavement in terms of cost comparison based on the method of construction.

5. Conclusion

From the cost analysis, the materials for the concrete pavement are quite higher than that of the flexible pavement (because of the availability of materials used for the asphalt concrete are cheaper). But, on the other hand, the use of a flexible pavement along this road will require at least 40mm asphaltic concrete laid over 50mm to 70mm bituminous macadam. If these requirements are selected, then the argument about the high initial cost of concrete pavement to that of the flexible pavement will no longer be valid.

Consequently, the construction of construction of concrete pavement, using labour based method is higher than that of the flexible pavement, but, considering the type of traffic on this road, the flexible pavement, despite being the cheapest will fail before it attains its design life; and will require 2 to 3 times maintenance. With these, the argument that the flexible pavement is relatively cheaper than the concrete (rigid) pavement will no longer hold.

6. Acknowledgement

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8. Appendix

Table 8.1 Schedules of Resources and Cost Estimate for Farm Road

S/No	RESOURCES	QUANTITY	UNIT	RATE/DAY	AMOUNT	TOTAL
1	LABOUR:					
	Unskilled	200	Wd	700	140,000	3,276,000
	Skilled	20	Wd	800	16,000	
2	HAND-TOOLS:					
	Shovel	20	Nil	800	16,000	
	Wheel	20	Nil	5000	100,000	
	Barrows	400	Nil	1000	400,000	
	Farm work	20	Nil	300	6,000	586,000
	Cutlass	20	Nil	200	4,000	
	Hoe	20	Nil	1000	20,000	
	Pick-axe	20	Nil	2000	40,000	
3	EQUIPMENT					
	Grader	1	Nil	50,000	50,000	
	Compacting	5	Nil	2,000	10,000	5,460,000
	Machine	4	Nil	30,000	120,000	
	Others	4	Nil	20,000	80,000	
	TOTAL (21 Days)	-	-	-	-	9,322,000

Table 8.2 Cost Comparison of Flexible and Concrete Pavements (Summary of Labour Based Method of Construction)

ITEM	FLEXIBLE PAVEMENT	CONCRETE PAVEMENT
	Cost	Cost
Labour	#2,542,850 68%	#3,276,000 33.5%
Hand-Tools	#871,560 23%	#586,000 06.0%
Equipment	#160,000 04%	#5,460,000 55.9%
Sub-total	#3,574,410 95%	#9,322,000 95.4%
Supervision	#178,770 05%	#450,000 04.6%
Grand-Total	#3,753,180 100%	#9,772,000 100%