Tero-Drainage Affectance in Life Cycle Costs of Road Pavements at an Intersection in Nigeria: A Case Study of Muiti-Route Intersection of Iwo Road, Ibadan, Oyo State

O. Joy Oladejo

Abstract-Achieving the design life at planned costs of road pavements at intersections is crucial to the stakeholders who are tax payers, routes pliers and the dispensing authorities. The fact that as road pavements at intersections evolve, drainages too evolve, there is therefore call for terotechnology activities to keep the pavement structures in restored status through it design lifetime. Hence, this study investigates tero-drainage affectance in life cycle costs of road pavements at Iwo road multi route intersection in Ibadan, Nigeria. The Iwo road multi route intersection with a 500 m diameter rotary was studied, with emphasis on the drainage conditions: evaluation of adequacy and sufficiency of drainage, drainage rating, cambering and pavement design. Life cycle costs of road pavement, evaluation of Costs of Maintenance and reparatory costs of pavement deterioration from 2000 – 2015. Tero-drainage activity: introduction of measure to curb waste disposal into drainage structure and removal of waste incursion. Analysis revealed that camber has dropped from 3% to 1% as opposed to 4% to 6% resulting in reduced pavement drainage efficiency and subsequent pooling and ponding of the pavement, consequence of which is the frequent damage to the pavement structure and extra restoration costs. In addition, drainage structures along certain routes were not provided, leading to inadequacy of pavement drainage at such points, furthermore, waste incursion in drainage structures have drastically made them inefficient. If drainage structures have been provided at the time of construction of the intersection, maintenance costs within the period under review would have been limited to 3.9%, meeting the standard of between 3% and 6% of construction costs, as against 164.55% incurred on maintenance and reparatory costs during the period. Consistent pavement failure from unrestored drainage results in large amount of costly repairs or replacements long before reaching their design life. Thus, provision of paved covers on the rotary drains has solved the drainage problems associated with environmental incursions. The drainability of road pavements should therefore be planned from the design stage, bearing in mind the maintenance culture of the stakeholders.

Keywords: Intersection, Maintenance, Road pavement, Tero-technology

1 INTRODUCTION

Achieving the design life of road pavements at intersections is crucial to total human traffic to routes merging at intersections. Due to the increasing population and economic development, there has been the need for additional activities in area of commercial, industrial and other land demanding activities over time. Hence, creation of access to these new development, cities, towns, have brought about emerging junctions to the existing highways. Just as road pavements evolve, drainages too evolve, as in most cases they are usually not part of the initial plan of the highway, but become necessities as new routes join the existing roadway.

In Iwo road, the second intersection (plate 1) which is a multi-leg Rotary, links the north, the east and the west of the Nation and has a poor drainage condition.

Department of Civil Engineering University of Ibadan, Ibadan, Nigeria
ojoyoladejo@yahoo.co.uk

The drainage situation and frequent pavement deteriorations makes the Iwo Road intersection very ideal for investigation on effects of drainage on the traffic systems. The residents or traders in this area complained about various incidences of flooding around the area. They also noted the various efforts of different government agencies to repair the deterioration that develop regularly in the pavement. Such efforts have not been able to address the root causes of the problem because the deterioration reappear after the next rainy season that follows such repairs. This presupposes that further investigation is required to identifty the root causes of this pavement failure. Such deterioration can occur due to any of the following three factors:The strength of the soil materials within the pavement structure, the inability of the pavement to withstand the traffic loading and the capacities and layout of the drainage structures in the area. Iwo Road multileg interchange apart from having a poor

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drainage condition also has a very frequent traffic congestion problems.

Generally, in considerations for pavements design, emphasis has been on traffic volume for axle load, traffic density and stability of the soils, without due considerations for drainage and plan for restoring it. This is evident in the fact that most road pavements in Nigeria are designed based on the CBR (California Bearing Ratio) design method. This design method presumed drainage incorporation, while AASHTTO [1] method of road pavement design incorporates drainage as a crucial parameter in design. Gurjar et al [6] re-iterated that drainage is a key element in the design of pavement systems. However, inadequate drainage continues to be identified as a major cause of pavement distress. Water is a leading factor in causing damage to pavements. Extensive field tests and observations have indicated that rates of damage and loss in serviceability of both rigid and flexible types of pavements are much greater when structural section contain free water. The inadequacy of drainage provision and the provision of pavements without drainage consideration at design and construction stage cumulate to reduce the life cycle of intersection infrastructures.

McRobert et al. [7] expressed drainage as the central and most important aspect of design, construction and maintenance of any road, including unsealed roads. Drainage of unsealed roads can be of even greater importance because lower quality design and construction standards and marginal materials are generally used, which are more permeable to water. Poor drainage will reduce the life of the pavement and have serious environmental impacts if left unchecked. Drainage quality is an important parameter which affects the highway pavement performance. Excessive water content in the pavement base, sub-base, and sub-grade soils can cause early distress and lead to a structural or functional failure of pavement. Dawson [4] presents no less than six adverse effects related to excess water: reduction of shear strength of unbound materials, differential swelling on expansive sub grade soils, movement of unbound fines in flexible pavement base and sub base layers, pumping of fines and durability cracking in rigid pavements, frost-heave and thaw weakening, and stripping of asphalt in flexible pavements. Rokade et al. [10] reveals that the drainage design criteria used in the past have been based on the assumption that both the flow of water through pavements and the drainage of pavement layers can be represented with saturated flow assumptions. The detrimental effects of water can be reduced by preventing water from entering the pavement, providing adequate drainage to remove infiltration, or building the pavement strong enough to resist the combined effect of load and water. Agbonkhese [3] puts it that effective drainage of the road pavement may be achieved by having a road cross fall of 4 - 6 % i.e. 145 – 195 mm fall from centre line on a 2-way cross fall pavement design. Pavement service life can be increased by 50% if infiltrated water can be drained without delay. Similarly, pavement systems incorporating good drainage can be expected to have a design life of two to three times that of un-drained pavement sections. Shailendra et al [5] further opined that inadequate sub- surface drainage continues to be identified as a major cause of pavement distress. The entrapment of water within the pavement leads to a "bathtub" condition resulting in premature failures and chronic pavement distresses. This leads to large amount of costly repairs or replacement to the pavements long before they reach their design life. A study of Werkmeister et al. [11] suggests that the influence of a small change in moisture content (1%) has a significant effect on the deformation properties of the unbound granular materials and the shakedown limits. The increase of stresses from increasing the moisture content from 4 to 5% is quite small, but the shakedown limits decrease considerably. However, a good drainage system and adequate water permeability of the unbound granular layers is very important and unbound granular materials used in pavement construction should be not too sensitive to water, because high moisture content of the material may indicate a high risk for rutting [11]. Poor drainage can lead to a failed pavement. Water trapped within the pavement system can lead to subgrade pumping and reduced subgrade and base support strengths, which result in pavement distresses. A drainable base layer day lighting to side ditches or drained through the use of a sub drain system can reduce the risk of trapped water, but increased permeability can have a direct effect on the material's stability. Drainage should be optimized without sacrificing stability. Oladejo and Agbede [8] recommend that there is need to define construction techniques to minimize the effect of water on dynamic pavement subgrade interaction.

In situations where drainages are provided, the effects of each of, or a combination of poor maintenance, negative and unethical practices of residents/road users, poorly executed construction, as well as non adherence to existing master plans has contributed to rendering these drainages near ineffective or outright useless. As a result, roads are in various states of disrepair, deterioration and many have become hazardous and sources of economic drain in terms of high road users' cost, loss of lives and properties, and loss of highway investments [2],[9] demand for intersection usage by tax payers necessitates the development stakeholder to forced reparatory works to achieve a level of life for the deteriorated infrastructures. The Tero-drainage activities result in reduced life cycle costs. The aim of this research therefore, is to investigate the tero-drainage activities that can comparatively affect the restored life cycle and costs of road pavements at intersections. Thus, the impact of improving quality of drainage on pavement life cycle viz-a-viz maintenance cost is discussed in this paper.

2 METHODOLOGY

2.1 Analysis of the Drainage Capacities of Iwo Road Drainage Structures

The capacities and layouts of the drainage structures in the area were evaluated to determine the ability to effectively discharge the runoff from the contributory catchment. This was done by: Drainage condition assessment, Determination of the runoff from the contributory catchment and checking of the cross section areas of the drainage structures in relations to the runoff.

2.2 Drainage Condition Assessment

The measurement of the width, depth, and the internal circumference of the drainage round the rotary was carried out. This was done by using steel tape rule to get the length of the circumference of the rotary.

The total value gotten for the external circumference of the drainage is 500 m and this was divided into five chain ages, each of 100 m. at each chainage point, the condition of the drainage around that particular point was noted and also, measurement of the depth of the water inside the drainage at each chainage point were taken at different time intervals, i.e., 6am, 1pm and 6pm for 7 consecutive days.

This was done so as to deduce how often water fills the drainage as well as show how often its gets dry and by which means, i.e., maybe there is an outlet for the water to flow out or it gets dry by sipping into the drainage wall and from there to the sub-grade of the road.

2.3 Determination of the Runoff from the Contributory Catchment – Determination of the Camber

After careful study of the Iwo-road interchange, it was necessary to determine the camber of the road to know whether or not it is adequate. This was carried out by determining the elevation at the centre of the road, the elevation at the edge of the road and the distance between the centre of the road and the edge of the road. This was further calculated using the slope formula given below:

$$Slope = \frac{H_a - H_b}{L} \quad (1)$$

Where:

H_a –elevation at the centre of the road

H_b–elevation of the edge of the road

L –Horizontal distance between H_a and H_a

2.4 Life Cycle Cost Analysis for Iwo-Road Intersection Pavement

In general, life cycle cost can be expressed by the equation:

$$LCC = PV_o = B_o + V_o - R_o + T_o + M_o \quad (2)$$

$$LCC = PV_o = B_o + V_o - R_o + T_o + M_o + EI_{NF} \quad (3)$$

Where:

$LCC = PV_o$ = Life cycle cost: present value of all cost between year 0 and N with year o as basis of comparism.

EI_{NF} = Environmental incursion

B_o= Construction cost (in year 0)

V_o = Present value of all maintenance

R_o= Present value of a possible remaining value of the construction and maintenance costs at the end of the period.

T_o= Present value of possible excess costs for the ushers in the period

M_o= Present value of possible environment costs in the period

Year 0= Basis of Comparison

PV_o = Present value of all repaying cost between year 0 and N with year 0 as basis of comparison

The present values are calculated by the equation

$$PV_O = \Sigma K_n / (1 + r)^n \quad (3)$$

Where;

N= number of years in the period for the analysis

K_n = costs in year n and

r = discount rate

The field survey revealed frequent pavement deterioration and its attendant repairs (Table 3.7)

at this intersection which forces motorists to reduce speed at the failed spots resulting in heavy traffic congestion.

3 RESULTS AND DISCUSSION

Table 3.1 displays Drainage Condition Rating and Frequency of repairs statistics over an 11 year period between 2000 and 2011. It can be observed that persistent reparatory works on the pavement, owing to problems associated with insufficient or inefficient drainage has in the long run led to the distortion of the pavement camber percentage from a more appreciable 3% at year 1 (year

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2000)– which falls close to the generally acceptable standard of 4 to 6% – to a detrimental 1% at year 11 (year 2011). This is grossly inadequate as it hinders runoff water from the pavement surface from finding its course into the drains. This often results in pooling and ponding of the pavement with its attendant detrimental effects on the pavement superstructure, as well as its substructure. Figure 3.1 shows all tero-activities carried out within a particular year, the frequency or number of times it was carried out that year and the cost incurred. Fig. 3.2, a pie chart, gives as some insight into the relative yearly cost of maintenance within the year. The largest sector of the pie chart represents the year when the largest cost was incurred which is year 7, further information from Fig. 3.1 shows the magnitude of reparatory works done on the intersection. This was the year the pavement experienced massive flooding, suffering severe damage, owing to the inadequate and insufficient drainage structures available at the intersection. Unwholesome practices from road users and the local communities like dumping of refuse into drains, erecting structures on drainage path or dumping of soil into the drains to create vehicular access ways resulted in rendering the available drainage structures useless. It can be observed further from the statistics displayed (see Fig. 3.3) that about 86% of the maintenance cost (Occasioned construction – 43.1% and Scarification 42.6%) for the period under review went to rectifying problems resulting from inefficient drainage. An interesting trend can be seen in Fig. 1 from year 13 where there is reduction and uniformity in the number and cost of maintenance activities carried out. This was as a result of restoration of drainage and installation of drainage covers to prevent environmental incursion and silting of the drains (see Plates 5 and 6). Table 3.3 presents the LCC cost analysis from the year of construction of the intersection (1990) till date (May 2015). The percentage difference in the actual LCC and the expected LCC shows a whopping 164% which infers that if provision had been made for adequate and efficient drainage systems, a lot of maintenance costs would have been saved by all major stakeholders – users and local authorities alike – over the period. Information from the percentage differences shows that only 3.9% of the initial construction costs would have been expended on keeping the structures up and running. Thus, Consistent pavement failure from unrestored drainage results in large amount of costly repairs or replacements long before reaching their design life. The drainability of road pavements should therefore be planned from the design stage, bearing in mind the maintenance culture of the stakeholders.

Table 3.1: Drainage Condition Rating and Frequency of repairs

Freq. of drain.	**Pavement Thickness**	**Camber**	**CB**	**Freq. of pavement**
4	325	3	47	2
4	322	2.5	30	1
2	312	2.3	30	1
2	320	2.2	43	1
1	334	2	47	1
1	340	1.9	47	2
4	342	1.8	60	2
1	345	1.6	31	1
1	329	1.4	30	1
1	330	1.2	43	1
2	358	1	62	2

Table 3.2 Comparison of field evaluated and the predicted flexible pavement thickness

Intersection	Loading	Drainage Rating	Drainage Coefficient	Recommended Thicknesses (mm)	Field Thicknesses (mm)
Iwo-road		Excellent	1.40	611.86	348.3
			1.35	619.46	348.3
			1.30	627.66	348.3
			1.20	646.11	348.3
		Good	1.35	619.46	348.3
			1.25	636.52	348.3
			1.15	656.52	348.3
			1.00	694.05	348.3
		Fair	1.25	636.52	348.3
			1.15	656.52	348.3
			1.00	694.05	348.3
			0.80	765.96	348.3

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3.1 LIFE CYCLE COST ANALYSIS OF IWO ROAD INTERSECTION

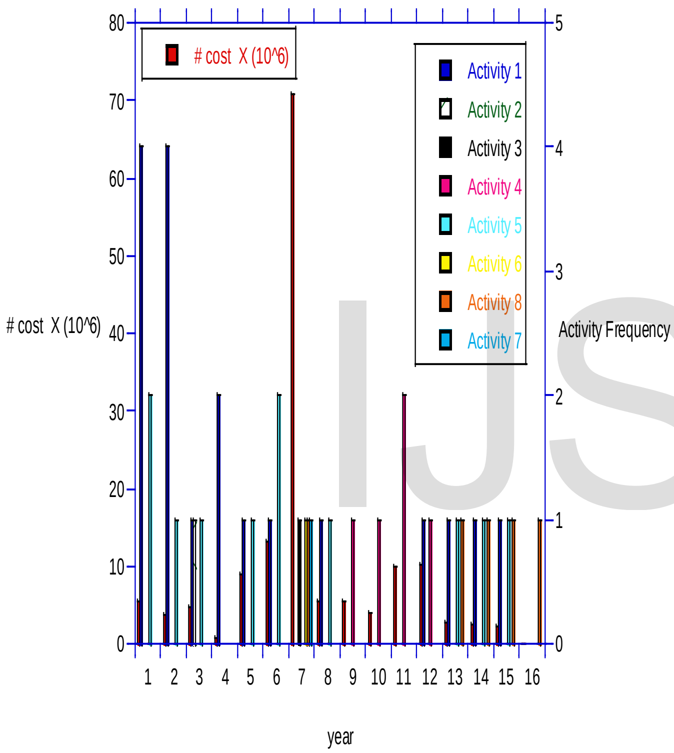
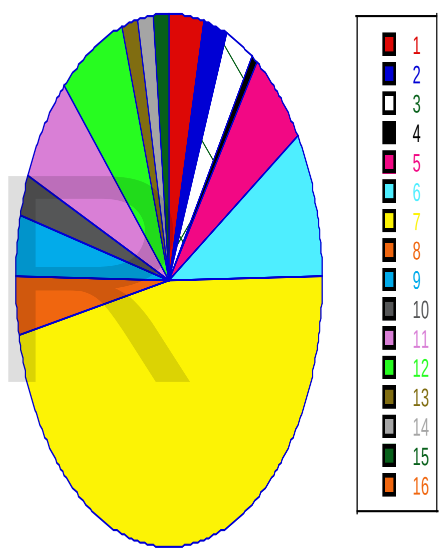


Fig. 3. 1:Cost and Frequency of individual activities over the 16 year period

1. Activity 1 – De-silting of drains only
2. Activity 2 – De-silting of Culverts, catchment pits only
3. Activity 3 – De-silting of Drains/Culverts, and removal of obstruction only
4. Activity 4 – Scarification, asphalt and de-silting of drains only
5. Activity 5 – Scarification of failed area, removal of unsuitable material, provision of lateritic/stone base, priming and asphalt
6. Activity 6 – Construction of 2.5m x 2.5m open channel drain at Ife out bound leg and Collector pipe culvert from Iwo inbound leg
7. Activity 7 – Paving of walkway at Iwo road Interchange, Oyo State
8. Activity 8 – Vegetation control, clearing and Cleaning of Iwo Road Interchange.

De-silting Only = N 14,027,231.57 (8.98%)
Occasioned Construction Only = N 67,276,428.08 (43.1%)
Vegetation control/Cleaning = N 2,623,005.01 (1.68%)
Scarification = N 66,537,817.32 (42.62%)
Environmental Incursion = N 5,661,098.71 (3.63%)
Total Maintenance cost = N 156,125,580.71



Total Yearly cost (excluding environmental Incursion cost) = N150,464.482

Fig. 3.2: Yearly Cost of Maintenance from year 1 – year 16

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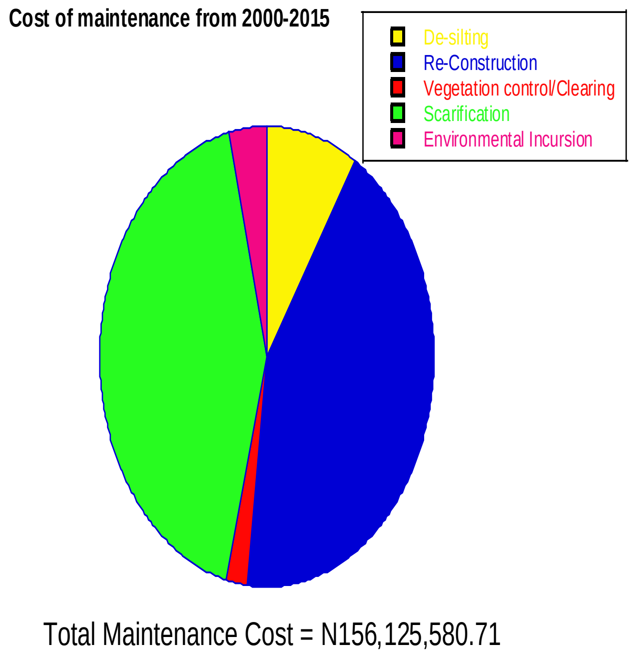

Fig. 3.3: Costs of Maintenance from 2000 – 2015

Percentage Differences

Without environmental incursion = 155.8%
Without De-silting only = 143.4%
Without Re-construction Only = 64.6%
Without Vegetation Control/Cleaning Only = 160.3%
Without Scarification only = 65.6%

Percentage Differences of Combinations

Without EI_{nf} and De-silting only = 135.02%
Without Construction and Scarification only = 33.04%
Without EI_{nf}, De-silting, Construction & Scarification = 3.9%

Table 3.3: Cost analysis of Iwo road intersection

INITIAL CONSTRUCTION FOR 1990	EXPECTED CONSTRUCTION FOR 1990 (LCC)	LEVEL OF REPAIR FROM 2000 -2015	2010 COST OF CONSTRUCTION
1891550 22,543,871.21 (CONCERTED)	5666774.229 67,537,391.07 (CONCERTED)	156,125,580.71	87010671

Life Cycle Cost (LCC) FOR THE PAVEMENT IN 2015
= 22,543,871.21 + 156,125,580.71= 178,669,451.92
EXPECTED LCC FOR THE PAVEMENT IN 2015
= 67,537,391.07

Difference between actual and expected LCC = 178,669,451.92 – 67,537,391.07 = 111,132,060.85
PERCENTAGE DIFFERENCE
= 111,132,060.85 / 67,537,391.07 x 100 = **164.55%**

Table 3.4 Pavement Design with Tero-drainage affectance using AASSTO method at Iwo-road intersection

Location	Loading	Drainage rating	Water removed	% exposure	Drainage coef.	Layer	Thickness (mm)
IWO ROAD	16602.6			>25 %	1	Surfac Base Sub Total	141.11 406 146.54 694.05
		Fair	1 week	<1%	1.25	Surfac Base Sub Total	112.89 406 117.23 636.52
				1% - 5%	1.15	Surfac Base Sub Total	122 406 127.42 656.52
				5%-25%	1	Surfac Base Sub Total	141.11 406 146.54 694.05
				>25	0	Surfac Base	176.39 406

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%	.8	Sub Total	183.17 765.96

Table 3.5: Assessment of the catchment area

SN	Location	Position	Structure	Condition	Size(m)	Discharge Outlet	Remark
1	Lagos Leg Ramp	From Lagos	None	Erosion of Shoulder		Free Fall	Inadequate
		To Lagos	None	Erosion of Shoulder		Free Fall	Inadequate
2	Ojoo Leg Ramp	From Ojoo	None	Erosion of Shoulder		Free Fall	Inadequate
		To Ojoo	None	Erosion of Shoulder		Free Fall	Inadequate
3	Iwo Road Rotary	Inner Bound	Concrete/Bk Drains	Damaged and silted	0.6x 0.6	Cross fall	
		Outer Bound	None			Free Flow	Inadequate
4	Ife Leg	From Ife	Concrete Channel	Good	1.5X 1.5	Gorge	Adequate
		To Ife	Block Work	Partially Damaged and silted	0.6x 1.0	Gorge	Inadequate
5	Gate Leg	From Gate	Concrete		0.6x 1.0	Gorge	
		To Gate	Concrete		0.9x 2.8	Gorge	
6	Iwo Leg	From Iwo	Block Work	Fair and silted	0.6X 0.6	Free fall to Rotary Pavement	Inadequate
		To Iwo	Block Work	Fair and silted	0.6X 0.6	Channel	Inadequate

4 CONCLUSION

- The results of this research strongly agree with the assertions of Agbonkhese, et al [3], that when erected structures and facilities such as drainages and road pavements are poorly maintained, their service lifespan is drastically reduced.
- Drainage quality is an important factor not only in the design of pavements, but also in the ability of pavements to withstand adverse usage and conditions.
- Efficient drainage especially at roadway intersections is a critical requirement for ensuring stability and preventing the failure of pavement.
- Poor or inadequate drainage provisions result in pavement distress, failure and adverse effects on its life cycle cost.
- Consistent pavement failure from unrestored drainage results in large amount of costly repairs or replacements long before reaching their design life.
- Proper and well maintained drainage systems provided to road pavements will increase their life span but improper and not well maintained drainage systems causes failure of road pavements at its early age thereby drastically reducing their service lifespan.
- If drainage structures have been provided at the time of construction of the intersection, maintenance costs within the period under review would have been limited to 3.9%, meeting the standard of between 3% and 6% of construction costs, as against 164.2% incurred on maintenance and reparatory costs during the period.

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Plate 1:Aerial view of Iwo road Muitileg Intersection

Plate 2: Rotary Gate/Lagos leg of the intersection

Plate 3: Water Incursion at the Rotary drainage

Plate 5: Restored condition of the rotary drainage

Plate 4: Deteriorated pavement surface at the intersection

Plate 6: Restored condition of the rotary drainage