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# Life Cycle Cost Analysis of Different Types of Pavements

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**ABSTRACT**: Significant research has been conducted over the past decade to enhance probabilistic pavement lifecycle cost analysis (LCCA) models, yet the drawing of broad conclusions from different studies is difficult because of the significant variation in scope and sources of uncertainty. Specifically, these two issues make it difficult to infer from existing research (a) which parameters are significant contributors to uncertainty for a specific context and (b) how context affects the analysis. The goal of this research was to address this problem by implementing an LCCA model in a range of scenarios that vary in location, traffic conditions, design life (e.g., year to first rehabilitation), analysis period, maintenance schedule, and discount rate. Results from the analysis indicated that, in relation to the drivers of variation, uncertainty about initial cost was the principal driver of variation across the case studies. Other parameters, such as the predicted performance of pavement over time, could also be important drivers of variation and in particular a matter for lower-volume roads, for which thinner pavement designs are used. In terms of contextual decisions, some decisions, such as whether to use mechanistic–empirical pavement designs instead of the paving design manual of a state department of transportation to determine future maintenance events, seem to have a larger impact than do others. For example, analysis period and design life, though important, affect the final results significantly less, although in some instances they can play a role in differentiating between alternative designs.

KEYWORDS: pavement designs, analysis period and design life, cycle cost analysis (LCCA) models.

# I. INTRODUCTION

The first evidence of road development in the Indian subcontinent can be traced back to approximately 4000 BC from the ancient cities of Harappa and Mohenjodaro of the Indus Valley Civilization.

Ruling emperors and monarchs of ancient India had constructed numerous brick roads in the cities. One of the most famous highways of medieval India was the Grand Trunk Road. The Grand Trunk Road built by Sher Shah Suri 1540 to 1545, began in Sonargaon near Dhaka in Bangladesh and ended at Peshawar in modern-day Pakistan. In India, it linked several important cities from Kolkata in the east to Amritsar in the west, while passing through the cities of Patna, Varanasi, Kanpur, Agra, Delhi, Panipat, Pipli, Ambala, Rajpura, Ludhiana, and Jalandhar.

India inherited a poor road network infrastructure at the time of its independence in 1947. Beyond that, between 1947 and 1988, India witnessed no new major projects, and the roads were poorly maintained. Predominantly all roads were single lane, and most were unpaved. India had no expressways, and less than 200 kilometres of 4-lane highways. In 1988, an autonomous entity called the National Highways Authority of India was established in India by an Act of Parliament, and came into existence on 15 June 1989. The Act empowered this entity to develop, maintain and manage India's road network through National Highways.

Road transport is vital to India's economy. It enables the country's transportation sector to contribute 4.7 percent towards India's gross domestic product, in comparison to railways that contributed 1 percent, in 2009–2010.



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Table 1 Types of roads and their lengths

Type of road	Length (km)
Expressways	200
National Highways	92,851.07
State Highways	1,31,899
Major District Roads	4,67,763
Rural and Other Roads	26,50,000

#### **OBJECTIVES OF THE STUDY**

The study entitled 'Comparative analysis of LCC for different types of Pavements has the following main objectives: •To design a conventional flexible pavement, perpetual pavement and conventional rigid pavement .

•To perform the life cycle cost analysis of above mentioned pavements.

•To highlight the advantages of perpetual pavement over the conventional flexible and conventional rigid pavements in terms of life, initial cost, and life cycle cost.

# II. RELATED WORK

#### 2.1 IRC GUIDELINES

The conventional flexible pavement and perpetual pavements are designed as per the guidelines of IRC-37 2012, the conventional rigid pavement have been designed as per the guidelines as per IRC-58 2011. These guidelines are discussed in detailed in this chapter.

# 2.1.1 GUIDELINES OF IRC-37 2012 FOR THE DESIGN OF CONVENTIONAL FLEXIBLE PAVEMENT

The guidelines of IRC: 37-2012 recommend that the following aspects should be given consideration while designing to achieve better performing pavements:

•Incorporation of design period of more than fifteen years.

•Computation of effective CBR of subgrade for pavement design.

•Use of rut resistant surface layer.

•Use of fatigue resistant bottom bituminous layer.

•Selection of surface layer to prevent top down cracking.

•Use of bitumen emulsion/foamed bitumen treated Reclaimed

•Asphalt Pavements in base course.

•Consideration of stabilized sub-base and base with locally available soil and aggregates.

•Design of drainage layer.

•Computation of equivalent single axle load considering (a) single axle with single Wheels (b) single axle with dual wheels (c) tandem axle and (d) tridem axles.

•Design of perpetual pavements with deep strength bituminous layer.

# 2.2 CONVENTIONAL FLEXIBLE PAVEMENT

A pavement structure that maintains intimate contact with and distributes <u>loads</u> to the subgrade and depends on aggregate interlock, different layers as shown in Fig 3.1, and each layer is discussed in detail below.



Fig 1 cross section of conventional flexible pavement



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#### 2.3 IRC GUIDELINES FOR THE DESIGN OF PERPETUAL PAVEMENT

The pavement having a life of 50 years or longer is termed as a perpetual pavement. If the tensile strain caused by the traffic in the bituminous layer is less than 70 micro strains, the endurance limit of the material, the bituminous layer never cracks (Asphalt Institute, MS-4, 7th edition 2007). Similarly if vertical subgrade strain is less than 200 micro strains, there will be little rutting in subgrade. Design of such a pavement is illustrated in the guideline. Different layers are so designed and constructed that only the surface layer is the sacrificial layer which is to be scrapped and replaced with a new layer from time to time. There is now enough evidence worldwide that deep strength bituminous pavements suffer damage only at the top and nowhere else, the relation between strain and pavement is shown in Fig 2



#### Fig 2 Relation between strain and pavement life

#### 2.4GUIDELINES OF IRC 58-2011 FOR THE DESIGN OF RIGID PAVEMENT

The guidelines of IRC: 58-2011 recommend that the following aspects should be given consideration while designing to achieve better performing pavements:

- 1. Design of pavements considering the flexural stress under the simultaneous action of load and temperature gradient for different categories of axles.
- 2. Design considering bottom up and top-down cumulative fatigue damage caused by single, tandem and tridem axle load applications.
- 3. Consideration of in-built permanent curl in the analysis of flexural stresses.
- 4. Design guidelines for pavements without concrete shoulders and with tied concrete shoulders.
- 5. Consideration of Concrete slabs with unbounded as well as bonded cement bound subbase.
- 6. Design of pavements with widened outer lanes.

#### 2.4.1CONCRETE PAVEMENT TYPES

Several types of concrete pavements have been used in different countries depending upon the climate, availability of materials, soil types, experience and traffic. Typical cross sections of a few pavements are shown in Fig 3.4 When PQC is laid over a bituminous surface during the hot weather it is important to whitewash the surface of BC/DBM-I (Figure 1 (b) &(c)) because black body absorbs heat which may be injurious to concrete.



Fig 3 Typical Cross Sections of Concrete Pavements



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#### III. METHODOLOGY

# 2.5 METHODS OF DESIGN OF FLEXIBLE PAVEMENT

#### 2.5.1 CBR Method

This method is used for design of our research problem. This method is based on the concept of all cumulative standard axle loads and not on the total number of all commercial vehicles as was being done earlier. The mixed commercial vehicles with different axle loads are converted in terms of the cumulative number of standard axle load Ns (value taken in million standard axle) given as

Ns =  $[365 \times A \times (1+r) n - 1] \times r \times F \times D \dots (2.1)$ 

#### 2.5.2 CALIFORNIA (HVEEM) Method

The pavement design by this method involves three major considerations, namely:

- a) Traffic Load
- b) Strength of sub grade material
- c) Strength of construction material
- The traffic index is calculated as follows:

 $TI = 9*(ESAL / 106)0.119 \dots (2.2)$ 

# 2.6 PRESENT TREND IN BITUMINOUS PAVEMENT DESIGN

The pavement practice in vogue in different countries can be classified into two major categories namely:

- a) The empirical or semi-empirical design procedure and
- b) The mechanistic design procedure.

#### 2.6.1 Shell Method

This is based on the concept of the mechanistic pavement design. On the basis of fatigue and rutting criteria, the thickness design curves are evolved with bound surfacing layer and unbound base layer for various sub-grade modules, asphalt mix type, traffic or design period, and temperature. The structure is regarded as a linear multi-layered system and the layers are assumed to homogeneous, isotropic, and horizontally infinite in dimensions. The design criteria using the Shell method are as follow:

- a) Large horizontal tensile strain at the bottom of the asphalt layer causes cracks in the bituminous layer.
- b) Large compressive strain at the top of the surface of the surface of the sub-grade causes permanent deformation.

The number of standard axle load applications expected during the design life is computed so that the critical strains do not exceed permissible values. Typical Shell pavement design charts are shown in figure 2.1.



#### Fig4 An example of Shell pavement design chart (Chart No. HN21 Shell Manual)

#### 2.7 PRESENT TREND IN CONCRETE PAVEMENT DESIGN

Since concrete pavements fail due to bending stresses, it is necessary that their design is based on flexural strength of concrete. Concrete pavement is sometimes placed directly over the sub-grade, but the chances of mud pumping and frost heave being more, designers prefer to use a base course over the concrete pavement.



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#### 2.7.1 PCA METHOD

The PCA method is developed by the Portland Cements Association, USA. The PCA method is based on Westergaard, Picket, and Ray's work and further theoretical analysis by the finite element method (FEM). The PCA design method is based on the following two considerations:

a) Consideration of fatigue damage to the concrete slab due to repetitive application of traffic load. The fatigue characteristics of the concrete are used to develop this criterion.

b) Considerations of possibilities of erosion of pavement materials placed below the concrete slab. The rate at which the slab is deflected due to axle load is used as a criterion for erosion. The computed corner deflection, pressure, and the radius of relative stiffness are used in the analysis.

The steps involved in the design of concrete pavement by the PCA method are:

a. The stresses developed for a trail thickness of the concrete slab are calculated for various axle loading configurations and the critical one is chosen.

b. The ratio between the developed stresses and the modulus of rupture is calculated. Recall Section 10.8 where it is defined as stress ratio.

c. The allowable repetitions from fatigue considerations are obtained from the fatigue characteristics of concrete for a given stress ratio. Similarly, the erosion factor is calculated from the stress ratio where from the allowable repetitions from erosion considerations are obtained.

d. The individual damage fraction is calculated by dividing the actual traffic repetitions by the allowable repetitions of that particular axle load.

e. The process is repeated for various axle loads and the cumulative damage is calculated. The cumulative damage should be equal to one for pavement to be just safe, otherwise the trail thickness is changed and the design process repeated

#### 2.8 INDIAN ROADS CONGRESS METHOD

The modulus of sub-grade reaction k is the necessary strength parameter used for the design of concrete pavements. The k value is derived from the plate load test.

The load stress is the highest in the corner of pavement, less at the edge, and the least in the interior of the pavement. The order in which the temperature stress varies is maximized and that the maximum combined stress is considered for design of thickness. IRC: 58-1988 recommends that both the combined corner stress and the combined edge stress should be checked for finding out the most critical stress between the two. The following are the various expressions used for estimation of stress as per the IRC: 58-1988 guidelines.

Effect due to load

IRC: 58-1988 has adopted the analysis by Westergard (modified by Teller and Sutherland). The load stress in the critical edge region is given by:-

 $\sigma le = (0.529 (1 - .54\mu)/h2)^* (4log 10(l/b) + log 10b - 0.4048) \dots (2.8)$ 

Edge Stress due to temperature

The edge stress due to temperature considered by IRC: 58-1988 is given by

 $\sigma\tau\epsilon = E\alpha\Delta TC/2 \ \dots \ (2.9)$ 

#### CHECK FOR SAFETY

The actual values of strain as calculated using IIT-PAVE software should be less than permissible values of strain

#### Table 2.Actual strains vs Allowable

Year	`Design thickness (mm)	Allowable strain		Actual strain from IIT-PAVE		Check
		€t ( µ)	€v (µ)	€t (µ)	€v (µ)	
0-15	200 GSB+250WMM+120DBM+50BC	167	313	160	255	SAFE
15-25	200 GSB+250WMM+170DBM+40BC	136	263.3	127.1	211	SAFE
25-35	200 GSB+250WMM+220DBM+40BC	115	228.7	101.3	187.6	SAFE
35-45	200 GSB+250WMM+270DBM+40BC	99.6	201	81.4	169.4	SAFE
45-50	200 GSB+250WMM+320DBM+30BC	92.9	190	70.9	146.3	SAFE



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#### **III. EXPERIMENTAL RESULTS**

# 4.1 PAVEMENT CROSS-SECTION

The thickness of the conventional pavement provided is 620 mm thick and the cross section of the pavement is shown in the Fig 4.1.





# Fig 5 Cross-section of conventional flexible pavement for the first 15 years.

## 4.2 DESIGN OF PERPETUAL PAVEMENT

A perpetual pavement has been designed for a four lane divided national highway with two lanes in each direction. It is assumed that the highway is to be constructed in Vuyyuru in the state of Andhra Pradesh.

Table 5. Output of H1-17(VE									
Z	R	SigmaZ	SigmaT	SigmaR	TaoRZ	DispZ	epZ	epT	epR
390.00	0.00	-	0.2796E	0.2472E	0.1665E-	0.2417E	0.7457E-	0.6196E-	0.4686E-
		0.1296E-			02		04	04	04
		01							
	0.00	-	0.1157E-	-0.7645E-	-	0.2417E	0.1892E-	0.6198E-	0.4685E-
390.00L		0.1297E-	04	03	0.1665E-		03	04	04
		01			02				
390.00		-	0.2980E	0.2682E	0.2742E-	0.2456E	0.8004E-	0.6540E-	0.5148E-
	155.00	0.1366E-			02		04	04	04
		01							
	155.00	-	0.8026E-	-0.6342E-	-	0.2456E	0.19120E-	0.6539E-	0.5146E-
390.00L		0.1363E-	04	03	0.2751E-		03	04	04
		01			02				

#### Table 3. Output of IIT-PAVE

# 4.2.1 Check for Safety

The actual values of strain as calculated using IIT-pave software should be less than permissible values of strain the comparison of these values are tabulated in Table 4.

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#### Table- 4 allowable strain vs actual strain.

Design thickness (mm)	Allowable strain	Actual strain from IIT-PAVE	Check
50BC+340DBM	$\in t = 70 * 10^{-6}$	65.3*10 <sup>-6</sup>	SAFE
	€v =200*10 <sup>-6</sup>	191.8*10 <sup>-6</sup>	

# **4.2.2 PAVEMENT CROSS-SECTION**

The thickness of the perpetual pavement provided is 390 mm thick and the cross section of the pavement is shown in the Fig 4.3.



# Fig 6 Cross section of perpetual pavement

# 4.3 CONVENTIONAL RIGID PAVEMENT DESIGN

The conventional rigid pavement and bonded rigid pavement are designed for subgrade C.B.R of 8%, by using IRC: 58-2011. The design has been carried out for tied shoulder conditions.

# 4.3.1 Check for Safety

Cumulative fatigue damage values for different trail thickness (26, 26.5, 27 and 28 cm) for Bottom Up and Top down Cracking are shown in Table 4.22.

S.NO	Trail thickness (mm)	C.F.D for bottom up	C.F.D for top down	Combined C.F.D	Check
1	260	4.024	2.204	6.23	UNSAFE
2	265	2.504	1.406	3.91	UNSAFE
3	270	1.505	0.866	2.37	UNSAFE
4	275	0.864	0.511	1.38	UNSAFE
5	280	0.467	0.286	0.76	SAFE

# Table 5 Cumulative fatigue damage values for different trial thickness

# **Rehabilitation of Conventional Rigid Pavement**

Conventional rigid pavement has a design life of 30 years hence it is to be rehabilitated at the end of design life by providing a PQC layer of 0.28m thick over the existing pavement

# **4.3.2 PAVEMENT CROSS-SECTION**

The thickness of the conventional rigid pavement provided is 580 mm thick and the cross section of the pavement is shown in the Fig 4.4.

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# 4.4 LIFE CYCLE COST ANALYSIS

With increasing public scrutiny, government agencies are under great obligation to demonstrate their stewardship of public funds. It would be wise to perform Life Cycle Cost Analysis (LCCA) for the evaluation of all major investment decisions in order to increase the effectiveness of the decisions. The goal is to achieve and sustain a desired state of good repair over the life-cycle of the assets at minimum practicable cost. LCCA identifies the most cost-effective pavement alternatives for the long-term (initial costs plus rehabilitation costs.)

#### 4.4.1 LCCA OF CONVENTIONAL FLEXIBLE PAVEMENT

LCCA is the sum of initial costs and rehabilitation costs. These initial costs and rehabilitation costs are discussed below. The rates adopted for various items of work are





# Fig 8 Share of initial cost and rehabilitation cost of conventional flexible pavement

Hence, life cycle cost of conventional flexible pavement is  $\gtrless 2.816$  crores per km (at present day rates) for one side of 7.0 m width of the dual carriageway road. The share of initial cost and rehabilitation cost is shown in Fig 5.1. It is observed that rehabilitation cost of conventional flexible pavement is about 1.5 times the initial cost of construction.



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# 4.4.2 LCCA OF PERPETUAL PAVEMENT

The section of pavement re	The section of pavement required for design life of 50 years				
Life cycle cost	= Initial costs + Rehabilitation costs.				
Initial cost	= ₹1.756 crores				
Rehabilitation cost	= ₹0.802 crores.				



# Fig 9 Share of initial cost and rehabilitation cost of perpetual pavement

Hence, life cycle cost of perpetual pavement is  $\gtrless$  2.56 crores per km (at present day rate). For one side of 7.0 m width of the dual carriageway road. The share of initial cost and rehabilitation cost is shown in Fig 5.2. It is observed that rehabilitation cost of perpetual pavement is about 0.45 times the initial cost of construction.

# 4.4.3 LCCA OF CONVENTIONAL RIGID PAVEMENT

Conventional rigid pavement has a design life of 30 years hence when an analysis period of 50 years is considered the conventional rigid pavement is to be rehabilitated at the end of 30 years therefore the life cycle cost is sum of initial cost and rehabilitation cost.

Life cycle cost	= Initial costs + Rehabilitation costs.
Initial cost	= ₹1.585 crores.
Rehabilitation cost	= ₹1.1195 crores.







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Hence, life cycle cost of conventional rigid pavement is ₹2.78 crores (at present day rate) for one side of 7.0 m width of the dual carriageway road. The share of initial cost and rehabilitation cost is shown in Fig 5.3. It is observed that rehabilitation cost of conventional rigid pavement is about 0.7 times its initial cost of construction.

#### 4.5 DISCUSSION ON LCCA OF PAVEMENTS

The best pavement alternative is the one which is most economical and involves less disturbance to the traffic during initial construction and rehabilitation. The life cycle costs of all the pavement alternatives considered in the design are presented in Table 5.10 and Fig 5.5 from fig 5.5 it is observed that initial cost is minimum in case of conventional flexible pavement and maximum in case of perpetual pavement. It is also observed that rehabilitation cost is minimum in case of perpetual pavement and maximum in case of conventional flexible pavement. From fig 5.5 it can be observed that the perpetual pavement is the most expensive alternative in terms of initial investment but over a period of 50 years this pavement proves to be the more economical than both conventional rigid pavement and conventional flexible pavement. However, the life cycle cost of bonded rigid pavement is even less than the perpetual pavement.

Pavement type	Initial cost in crores	Rehabilitation overlay required at year (mm)				Life cycle cost in crores	
	(₹)	15	25 (30)	35	45	(₹)	
Conventional flexible	1.227	50 DBM +	50 DBM +	50 DBM +	50 DBM +	2.816	
pavement		40 BC	40 BC	40 BC	30 BC		
Perpetual pavement	1.676	50 BC	(50 BC)	-	50 BC	2.559	
Conventional rigid	1.62	_	(280	_	_	2 78	
pavement	1.02	_	M-40)			2.70	

#### Table 6 Life cycle costs of all the pavement alternatives



# Fig 11 Costs of all the pavement alternatives

# V. CONCLUSION

The study 'Life Cycle Cost Analysis of Flexible, Rigid, Perpetual Pavements' has brought out the pavement design and life cycle cost analysis in respect of conventional flexible pavement, perpetual pavement, conventional rigid pavement. The pavement design for all these alternatives has been evolved in terms of initial design thickness for design life of the pavement and periodical rehabilitation required as overlay thickness for life cycle of 50 years. The cost analysis has also been evolved in terms of initial cost of construction of the pavement and rehabilitation cost of pavement over life cycle of the pavement. The main conclusions drawn from the study are given in subsequent sections.

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#### 5.1Design Thickness and Rehabilitation Requirement of Pavements

1. The design thickness of conventional flexible pavement for design life of 15 years is 200 mm GSB + 250mmWMM+120mmDBM+50mmBC.

The design thickness of perpetual pavement for design life of 50 years is found to be 340 mm DBM + 50 mm BC. The design thickness for conventional rigid pavement for design life of 30 years is found to be 150 mm GSB + 150 mm DLC + 280 mm M-40 grade PQC.

The design thickness for bonded rigid pavement for design life of 30 years is found to be 250 mm GSB + 150 mm DLC + 220 mm M-40 grade PQC.

2. In case of conventional flexible pavement the rehabilitation overlay required at the end of 15, 25, and 35 year is 50 mm DBM + 40 mm BC in each case and at the end 45 years is 50 mm DBM + 30 mm BC

In case of perpetual pavement the rehabilitation overlay required at the end of 15, 30 and 45 years is 50mm BC in each case.

In case of conventional rigid pavement the rehabilitation overlay required at the end of 30 years is 280 mm M-40 PQC.

In case of bonded rigid pavement the rehabilitation overlay required at the end of 30 years is 280 mm M-40 PQC.

#### 5.2 Life Cycle Cost Analysis of Pavements

1. The initial cost of construction for conventional flexible pavement is  $\gtrless 1.117$  crores, the least of all the alternatives.

The initial cost of construction for perpetual pavement is ₹1.756 crores, the maximum of all the alternatives.

The initial cost of construction for conventional rigid pavement is ₹1.585 crores.

2. The rehabilitation cost of conventional pavement is ₹1.7 crores, the maximum of all the alternatives.

The rehabilitation cost for perpetual pavement is ₹0.8 crores, the minimum of all pavement alternatives.

The rehabilitation cost for conventional rigid pavement is ₹ 1.2 crores

3. The life cycle cost for conventional pavement is  $\gtrless 2.816$  crores, the maximum of all the alternatives.

The life cycle cost of perpetual pavement is ₹2.559 crores, 0.9 times that of conventional flexible pavement.

The life cycle cost of conventional rigid pavement is ₹2.78 crores, 0.98 times that of conventional flexible pavement.

The pavement alternatives viz perpetual pavement is more economical at the end of analysis period of 50 years.

The perpetual pavements expensive in terms of initial investment. However, after the life cycle of the pavement this turns out to be the economical pavement.

The perpetual pavements have good scope of being adopted due to their advantages over conventional flexible and conventional rigid pavements as they provide an efficient design by eliminating reconstruction costs, reduce the use of non-renewable natural resource like aggregates, have low rehabilitation-induced user delay costs and low life cycle cost of the pavement.

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