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ECONOMIC AND STRUCTURAL DESIGN ASSESSMENT OF RIGID AND FLEXIBLE PAVEMENTS: A METHODOLOGICAL APPROACH

Hunendra Kumar[1], Meghal Dewangan[2], Kaminee Rathore[3] and Dr Jayant Supe[4]
[1]M. Tech Scholar,[2-3]Asst. Professor, [4]Asso. Professor,
[1-4]Department of Civil Engineering, Rungta College of Engineering and Technology, Bhilai, India

ABSTRACT

This article offers a detailed evaluation of the economic and structural designs of rigid and flexible pavements through various methodologies. Flexible pavements, made up of multiple layers, have lower initial costs but may require more maintenance over time due to wear and deformation. Rigid pavements, typically concrete, have higher initial costs but provide longer service life and reduced maintenance, making them more cost-effective in the long run.

The evaluation examines different design methods, such as the Group Index method, California Bearing Ratio (CBR), and AASHTO for flexible pavements, and the PCA method for rigid pavements. Each method is assessed based on factors like load distribution, material properties, and subgrade strength. The findings suggest that flexible pavements are more suitable for low-traffic areas due to their lower initial costs, while rigid pavements are ideal for high-traffic areas because of their durability and lower life-cycle costs.

The analysis underscores the need to consider both initial and long-term costs, as well as structural performance, when choosing the appropriate pavement type for specific applications. This approach ensures an optimal balance between economic efficiency and structural integrity.

Pavements are crucial for smooth, safe, and organized traffic flow and are mainly categorized into flexible and rigid types. Flexible pavements, which have low flexural strength, adapt under loads, while rigid pavements exhibit significant flexural strength and rigidity. Flexible pavements are often preferred over concrete roads due to their ability to be incrementally strengthened as traffic increases and their surface can be milled and recycled. They also typically cost less initially and require lower maintenance.

Although rigid pavements are initially more expensive, they need less maintenance and have a longer lifespan. The economic assessment for pavement design involves analyzing results from various design methods and their respective layer thicknesses. In our study, we determine the thickness of flexible pavements by comparing different design methods, including the Group Index (GI) method, California Bearing Ratio (CBR) method, California Resistance Value Method, and Triaxial method. Rigid pavement design follows the Indian Road Congress (IRC) method. The maximum thickness derived from these design methods is selected for constructing flexible pavements.

Keywords: Design of flexible pavement, GI, CBR, Shrinkage, Montmorillonite, Volcanic, Expansive.

1. INTRODUCTION

Pavement design and cost analysis are critical components in the development of highway infrastructure, particularly in India where diverse climatic conditions and heavy traffic demand robust and economically viable solutions. The pavement design process involves selecting appropriate materials and structural layers to ensure durability and safety. This task becomes complex due to the varying load-bearing capacities required across different regions and the need to accommodate both present and future traffic volumes. The cost analysis aspect, on the other hand, focuses on optimizing financial resources by evaluating initial construction costs, maintenance expenses, and life cycle costs.

In India, flexible pavements are predominantly used due to their cost-effectiveness and ease of maintenance. However, the selection between flexible and rigid pavements often hinges on a detailed cost-benefit analysis. Research indicates that while rigid pavements may have higher initial costs, their long-term maintenance requirements are significantly lower, potentially making them more economical over their lifespan [1, 5]. Incorporating advanced pavement management systems (PMS) helps in making informed decisions about material selection, design methodologies, and maintenance strategies [3]. Thus, a comprehensive approach to pavement design and cost analysis not only enhances the longevity and performance of highways but also ensures economic efficiency in the long run.

For the economic and efficient construction of highways, designing the correct pavement thickness based on traffic conditions and sub-grade properties is crucial. Historically in India, pavement design was often based more on the experience of road engineers than on precise data, leading to either excessive costs or structural failures. The absence of standardized design criteria resulted in generally uneconomical road construction.

A stable and non-yielding pavement surface is essential to support heavy traffic with minimal rolling resistance. The road should have an even longitudinal profile to ensure safe and comfortable travel at design speeds. Effective pavement layers distribute wheel load stress over a larger area, enhancing durability and minimizing elastic deformation within permissible limits. This allows the pavement to endure repeated load applications throughout its design life.

Constructing the pavement above the maximum groundwater level is advisable to keep the sub-grade dry, even during monsoons. High moisture content weakens the soil, increasing its susceptibility to deformation under heavy loads, thus raising tractive resistance. Implementing a judicious design methodology based on accurate traffic load estimation and sub-grade bearing capacity can lead to more economical and durable road construction

Types of pavements

Based on the structural behavior, pavements are generally classified into the following three categories:

1. Flexible pavement
2. Rigid pavement
3. Semi-rigid pavement.

Different methods of design of pavements

1. Group index method
2. California resistance value method
3. California bearing ratio method
4. Tri axial method

Cost analysis of Pavement

Cost estimates are made at various times during the development of solutions to identified transportation needs and deficiencies. These estimates support funding and program decisions. The estimating approach that is used at these various times must conform to the information available when the estimate is prepared. For example, when only concept information is available, then conceptual estimating methods are used to determine planning–level cost projections. Cost estimating management is practiced as projects are identified and developed. Cost estimating management methods will also vary depending on the level of project scope definition and cost details provided in the estimates.

Methodology and materials used

Methodology is the systematic, theoretical analysis of the methods applied to a field of study. It comprises the theoretical analysis of the body of methods and principles associated with a branch of knowledge.

A methodology does not set out to provide solutions - it is therefore, not the same as a method. Instead, a methodology offers the theoretical underpinning for understanding which method, set of methods, or best practices can be applied to a specific case, for example, to calculate a specific result..

Red soil

Red soil is an important soil resource, which bears substantial implication for sustainable development of agriculture and healthy growth of economy. We also summarized how the iron redox cycling may be affected by other biogeochemical processes or active constituents, such as the nitrogen cycling, the sulfur cycling and humic substances. Finally, future research needs pertaining to iron redox cycling coupled to the fate of heavy metals are suggested. The results summarized in this review may provide insights for solving the heavy metal pollution of paddy soils in the red soil regions.

2. PAVEMENTS DESIGN

The following characteristics of an ideal pavement should be met:

- **Sufficient Thickness**: The pavement must have adequate thickness to distribute wheel load stresses to a safe value on the sub-grade soil, preventing damage to the underlying layers.
- **Structural Strength**: It should be structurally robust to withstand various stresses imposed by traffic, weather, and other factors, ensuring durability and longevity.
- **Coefficient of Friction**: The pavement must provide an adequate coefficient of friction to prevent vehicle skidding, enhancing road safety.
- **Smooth Surface**: A smooth surface is essential for providing comfort to road users, even at high speeds, and ensuring safe and efficient travel.
- **Noise Reduction**: The pavement should produce minimal noise from moving vehicles, contributing to a quieter environment.
- **Dust-Proof Surface**: A dust-proof surface is crucial to prevent impairing traffic safety by reducing visibility due to dust generation.
- **Impervious Surface**: The surface must be impervious to protect the sub-grade soil from water infiltration, maintaining the pavement's integrity even during adverse weather conditions.
- **Long Design Life with Low Maintenance Cost**: The pavement should be designed for a long lifespan with minimal maintenance requirements, optimizing cost-effectiveness over its service life.

DESIGN OF FLEXIBLE PAVEMENTS

A. Group index method

In order to classify the fine grained soils within one group and for judging their suitability as sub grade material, an indexing system has been introduced in HRB classification which is termed as Group Index. Group Index is function of percentage material passing 200 mesh sieve (0.074mm), liquid limit and plasticity index of soil and is given by equation: (0.074mm) . Liquid limit and plasticity index of soil and is given by equation:

$GI=0.2a+0.005ac+0.01bd$

Here,

a=that portion of material passing 0.074mm sieve, greater than 35 And not exceeding 75 %

b=that portion of material passing 0.074mm sieve, greater than 15

And not exceeding 35%

c = that value of liquid limit in excess of 40 and less than 60

d = that value of plasticity index exceeding 10 and not more than 30

Or

GI= (F-35) 0.2+0.05(WL -40) +0.01(F-15) (IP-10)

DATA:

F =66%

WL=55%

IP =31%

GI = (F-35)0.2+0.05(WL -40)+0.01(F-15)(IP-10)

=17.35

So Pavement Thickness =700mm

Thickness of Surface Course =35mm

Thickness of DBM =145mm

Thickness of Base Course=200mm

Thickness of Sub Base=320mm.

B. California Resistance Value Method

In 1948, F.M. Hakeem and R.M. Carmeny presented a design approach based on the cohesiometer Computer-value and stabilometer R-value.Hveem and Car many established that pavement thickness varies directly with R value and logarithm of load repetitions based on performance data. It fluctuates in opposition to the computer value's fifth root. The empirical equation provides the pavement thickness expression.

T=K (TI) (90-R)/C1/5

Here T=total thickness of pavement, cm

K=numerical constant=0.166

TI=traffic index

R=stabilometer resistance value

C =Cohesiometer value

The annual value of equivalent wheel load (EWL) here is the accumulated sum of the products of the constant and the number of axle loads .The various constant for the different number of axles in group are given below

Table.01 The various constant for the different number of axles

Number of axles	EWL Constant(Yearly basis)
2	330
3	1070
4	2460
5	4620
6	3040

DATA

K =0.166, TI =9.66, R = 44, C =61

Pavements thickness is given by the empirical equation:-

T=K(TI)(90-R)/C1/5

Calculation
TI = 1.35(EWL)0.11

TI=1.35(32729750)0.11

TI=9.66

T=K(TI)(90-RC)/C1/5

T=0.166(9.66)(90-44)611/5

T=730 mm

So Pavement Thickness =730mm

Thickness of Surface Course =35mm

Thickness of DBM =145mm

Thickness of Base Course=210mm

Thickness of Sub Base=340mm

C.Design of Flexible Pavement by California Bearing Ratio Method
The following sub sections describe the various variables and parameters involved in design of flexible pavement of road as per IRC 37 - 2001.

Traffic- CV/Day Annual traffic census 24 X 7
For structural design, commercial vehicles are considered. Thus vehicle of gross weight more than 8 tonnes load are considered in design. This is arrived at from classified volume count.

Wheel loads
Urban traffic is heterogeneous. There is a wide spectrum of axle loads plying on these roads. For design purpose it is simplified in terms of cumulative number of standard axle (8160 kg) to be carried by the pavement during the design life. This is expressed in terms of million standard axles or msa.

Design Traffic
Computation of design Traffic In terms of cumulative number of standard axle to be carried by the pavement during design life.

$$N = \frac{365\, A\, [(1+r)n - 1]}{r} \times F \times D$$

Where

N = the cumulative number of standard axles to be catered for in design in terms of million standard axles - msa.

A = Initial traffic in the year of completion of construction duly modified as shown below.

D = Lane distribution factor

F = Vehicle damage factor, VDF

n = Design life in years

r = Annual growth rate of commercial vehicles {this can be taken as 7.5% if no data is available}

OBSERVATION DURING PENETRATION AND DETERMINATION OF CBR

Table 2 penetration and determination of CBR

S.No	Penetration Y (mm)	Standard load Value (p)(kgf)	Proving Ring Dial Gauge Reading (R)	Plunger Load on (Pt)=R x f =R x 1.282 (kgf)
1	0		0	0
2	0.5		10	12.82
3	1.0		18	23.07
4	2.0		33	42.30
5	2.5	1370	54	69.22
6	3.5		63	80.76
7	4.0		71	91.02
8	5.0	2055	78	99.99
9	7.5		85	108.97
10	10.0		91	116.66
11	12.5		102	130.76

D. DESIGN OF FLEXIBLE PAVEMENT BY CBR

Data

1. Length of Road= 3.45/00 km
2. Traffic intensity as worked out =1001 CV/D Average
3. Growth rate of traffic (assumed) = 7.5%
4. Total Period of Construction =4 months
5. Design C.B.R. of Sub grade Soil=5.00%
6. Design Period of the Road= 10 Years
7. Initial Traffic in the Year of Completion of Construction

A = P x (1 +r) x

Where:

A = Traffic in the year of completion of construction CV/ Day

P = Traffic at last Count April 2013

r = Annual growth rate of traffic

x = Number of years between the last census and the year of completion of construction

A =1001 x (1 + 0.075) x1 1076 CV / Day

(As per Clause 3.3.4.4 Table 1 of IRC -37 -2001)

8. Vehicle Damage Factor =3.5Standard Axle per CV
9. Design Calculation

Initial traffic in design lane = Initial traffic x Distribution factor

= 1076 x 0.75 = 807.05 CVPD

N = [365 x {(1+r) x - 1} x A x F] / r

=365 x [{(807(1 +0.075)^10-1}x3.5]/0.075 = 14.58 msa

Say 15.00 msa

10. Total Pavement Thickness for design C.B.R. = 660 mm

(As per Plate - 2 of IRC-37-2001)

The thickness of individual component layers of flexible pavement by CBR method is given below:

So pavement thickness =660mm

Thickness of surface course =40mm

Thickness of DBM =70mm

Thickness of base course=250mm

Thickness of sub base=300mm.

3. COST COMPARISON OF PAVEMENTS

Flexible Pavement

S. No	Method Used	Cost for construction of 3Km road in Rs
1	Group Index	1394451.45
2	California Resistance Value method	1442136.15
3	California Bearing Ratio method	1412085.15
4	Tri axial method	1449648.9

Rigid pavement

S. No	Method Used	Cost for construction of 3Km road in Rs
1	Group Index	1444406.04

4. CONCLUSION

Analyzing the current condition and all the variables that affect the structure in the future is crucial during the design and construction of pavements. First and foremost, the demands of the users and the surrounding environment—which encompasses the topography, weather, operational circumstances, and traffic volume—must be taken into account. Based on it, the ultimate choice of suitable pavement structure may be made after conducting a techno-economic study. It is vital to establish the priorities and selection criteria for the necessary pavement based on these basic phrases and maybe certain special features.

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