International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 05 | May - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Analysis and Design of Flexible Pavement and Cost Comparison with Cement-Treated Base and Subbase Material

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Abstract: Road transport is important in economic, social; and a country's overall development. Various commercial vehicle classes have utilized roads with different axle configurations and loads. Due to the cumulative effect of wheel loads and the aging of bitumen binder flexible pavement starts deteriorating. The bitumen pavement failure is mainly due to fatigue cracking as well as rutting deformation. Thus, proper load analysis for the intended period of pavement planned life needs to be analyzed and the pavement designed accordingly. The development of software such as IITPAVE enables the calculation of stress and strain values at required points across various pavement layers. The project's goal is to gather traffic data as well as soil CBR values from the field to design a flexible pavement following IRC: 37-2018 guidelines. The pavement would be analyzed using IITPAVE Software to obtain the actual strains at required critical points.

Pavement design is influenced by factors such as properties of subgrade soil, wheel load, climatic conditions, and pavement materials. Pavements are built according to IRC guidelines and MORTH specifications. Excessive strain along with the deformation at the critical locations in pavement are the primary causes of bitumen pavement failure.

This research aims to design a flexible pavement and compare the cost of traditional pavement layer composition with cement-treated base as well as sub-base materials.

Keywords: Flexible Pavement, Cement treated base (CTB) and Subbase (CTSB), Cost Comparison.

1. Introduction

Pavements are structures designed, built, and maintained to carry vehicular loads. Conventional flexible pavement's typical layers include the Surface course, binder course, Granular base course, Granular Subbase (GSB), and Subgrade. In this project flexible pavement design has been carried out with traditional layers of materials and also by replacing GSB and WMM with the Cement-Treated Base and subbase layers and their cost comparison has been carried out to select the best suitable pavement considering the economy and durability aspects.

In IRC-37-2018, the mechanistic approach is integrated with the empirical approach in the selection of limiting values of strains, deflections, and stresses that cause failure pavements. The association among the phenomenon of stress, strain deflection, and failure is explained by the empirically obtained relationships that estimate the number of load repetitions to failure.

2. Objectives

•To design flexible pavement as per soil conditions and traffic for the particular stretch of highway.

•To determine optimum thickness for pavement layers with alternate base and subbase material.

•To compare traditional pavement layer cost with the cost of pavement layers with cement-treated bases and subbases material.

•Also, the crack prevention layer has been introduced in between cement treated base and DBM (Dense Bituminous Macadam) layer as per codal provisions to avoid cracks propagation, if any, from the CTB to layers of bituminous in long run.

3. Scope of the Project

This project aims to create a flexible pavement following pavement design principles and IRC: 37-2018 guidelines, and then analyze it using IITPAVE. Soil samples are collected along the road alignment to determine the soil C.B.R. values. Also, 24x7 traffic survey data and axle load data were collected for the stretch, based on that design traffic computed. The current research attempts to analyze the traffic and design the flexible pavement for a short route between Km 230 to 270 of NH 544 connecting Salem in Tamilnadu and Kochi in Kerala.

4. Design Approach

According to the IRC 37 -2018, The mechanistic approach is integrated with the empirical approach in the selection of limiting values of stresses, strains, and deflections that cause failure of pavements. The relationship between the phenomenon of stress, strain, and deflection and the failure is explained by empirically obtained relationships that estimate the number of load repetitions to the failure. Design is the determination of each pavement layer thickness to withstand the design load during the design life. Analysis is the determination of stresses and strains developed at the time of the design life. The pavement design according to the IRC–37-2018 "Guidelines for the design of flexible pavement". IIT Pave software had been utilized for the Analysis.

5. Methodology

5.1 Data Collection

1) **Classified traffic volume Survey**

The vehicle volume count survey with vehicle classification was carried out by installing an automatic metro count device to get 24-hour traffic for 7 days. This system counts the vehicles with their type on the project location in both directions. The Metro Count is a popular traffic monitoring system widely used all over the world. From the 7 days classified volume count survey commercial vehicles per day (CVPD) can be calculated, CVPD is the average of 7 days count of commercial vehicles.

Commercial Vehicles per day		
	Direction -A	Direction- B
Day-1	5593	7391
Day-2	4281	4803
Day-3	5444	6682
Day-4	6538	6985
Day-5	6667	7009
Day-6	6630	7228
Day-7	6815	7478
Total	41968	47576
Average	5995.43	6796.57
CVPD (Say)		6800

2) Axial load Survey

An axle load survey was conducted down the project road for a full day for a duration of 24 hours continuously as per the requirement mentioned in IRC 37-2018, In this project axle load data obtained from the toll plaza at Panniyankara on the project stretch were used for getting the axle load data. In the toll plaza weigh-in motion sensors are there and are recorded on the system automatically.

3) Material data

Subgrade soil has a CBR of 10 %, Two layers of Bituminous layers are considered in the design, a base layer of dense bituminous macadam with VG-40 bitumen and a surface layer of bituminous concrete with natural rubber-modified bitumen.

The bituminous mix is having an air void of 3.0% and the effective bitumen in the mix is 11.0% by percentage by volume of the mix. An elastic modulus value of 3000 MPa was taken for bituminous material based on the annual average temperature of the project area as per IRC -37-2018. Cement- OPC -43 Grade Portland pozzolana has been used for stabilization of granular material, for base 7% and subbase 4.5 % of cement by total weight of mix was used. Aggregates of size 40mm,20 mm, and 10 mm are used in the mix with fine Aggregates.

5.2 Design Traffic

According to IRC 37-2018 “cumulative number of standard axles to be catered at the time of the design period has been provided by

Cement Stabilized Mix Design			
Sr No.	Material Type	Type of Layer	
		Stabilized Sub Base	Stabilized Base
1	Cement OPC-43	4.50%	7.00%
2	Aggregate - 40 mm	23%	21.50%
3	Aggregate- 20 mm	17.50%	19.00%
4	Aggregate- 10mm	5.50%	6.50%
5	Fine Aggregates	49.50%	46.00%
6	Maximum Dry Density	2.09 gm/cc	2.14 gm/cc
7	Optimum Moisture Content	9.20%	8.50%
8	Unconfined Compressive Strength-7 days	1.9 MPa	5.2 MPa
8	Limits UCS - 7 days	1.5to3 MPa	4.5 to 7 MPa

$$\boldsymbol{ESALor\ N_{des}} = \mathbf{365} \times \left(\frac{(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{n}}-\mathbf{1}}{\boldsymbol{r}}\right) \times \boldsymbol{A} \times \boldsymbol{D} \times \boldsymbol{L} \times \boldsymbol{VDF}$$

Description	P (cv/day)	x (in year)	r	A (cv/day)	VDF	n (in year)	D	N des (MSA)
Design Traffic	6800	1	0.08	7344	6.5	20	0.6	478.4

Where,

N = Cumulative number of standard axles to be catered in the design in msa

A = Initial Traffic in the completion year of construction in terms of CVPD

x	Number of years between the last count and the year of completion of construction
n	Design life in years (20 years)
P	Number of commercial vehicles per day as per last count”
D	Lane Distribution Factor
r	commercial vehicles’ annual growth rate in percentage
VDF	Vehicle Damage Factor

6. Pavement Analysis and Design

Design is the determination of the thickness of the constituent pavement layer for design load during the design life. Analysis is the determination of stresses and strains developed during the design life. The pavement design is as per IRC – 37-2018 "Guidelines for the design of flexible pavement". IIT Pave software was used for the Analysis.

6.1 Critical Mechanistic Parameters

a) Horizontal Tensile strain at the bottom Bituminous layer

For Bituminous Layer fatigue criteria - Horizontal Tensile strain (ε_t)at the bottom is given by equation 3.10

$\mathbf{N_f}$ = 0.5161 x C x 10^{-04} x $[1/\varepsilon_t]^{3.89}$ x $[1/M_{Rm}]^{0.854}$

(ε_t) is calculated as **107.563** micro strain.

b) Horizontal Tensile strain at the bottom of the CTB layer

For the Cement-treated base – Horizontal tensile strain (ε_t)at the bottom of the CTB layer is given by equation 3.11 $N = RF\left(\frac{\left(\frac{113000}{e^{0.804}}+191\right)}{\varepsilon t}\right)^{12}$ and (ε_t) determined as **58.805** micro strain.

b) Compressive Strain at the top of Subgrade

For Subgrade, Compressive strain at top of subgrade (ε_v) for rutting criteria is given by equation 3.9. $\mathbf{N_R}$ = 1.4100 x 10^{-08} $[1/\varepsilon_v]^{4.5337}$

(ε_v **)** is determined as **225.863** micro strain

6.2 Pavement Design

Design Parameters applied for the analysis and design are provided in Table below.

A. Design Parameters	Values
Pavement Temperature	35^{0}C
CBR Subgarde	10%
Elastic Modulus of Bituminous mix	3000 MPa
Elastic Modulus of Granular Layer	248 MPa
Elastic Modulus of Subgrade	77 MPa
Elastic Modulus of Cementitious Base	5000MPa
Elastic Modulus of Cementitious Sub Base	600 MPa
Elastic Modulus of Crack relief Layer	450 MPa
Poisson Ratio of Bituminous Mix	0.35
Poisson Ratio of Granular Layer	0.35
Poisson Ratio of Subgrade	0.35
Poisson Ratio of Cementitious base	0.25
Poisson Ratio of Crack Relief Layer	0.35
Tyre Pressure	0.56 MPa
Wheel Load	20000 N

Analysis points are considered to get the strain values on the required points under the wheel loads. Analysis was carried out separately for the pavement with conventional layer and for the pavement trial sections with CTB and CTSB layer.

Trial sections are assumed to get the strains at the required points as per IRC 37-2018 and compared with the permissible strains obtained as per the empirical equations. Analysis was out carried separately for each trial section assumed for respective cumulative standard axles required and generated strains were compared with the permissible strains as per the performance equations. If generated strains are less than permissible, then the assumed sections are found to be meeting the design life for cumulative standard axles. The design thickness of each layer and developed strains as per the analysis carried out in IIT pave are given in below table.

Sr No	Description	Cumulative Depth. mm	Strain, μf	
			Permissible	IIT Pave
479 MSA – Conventional Design				
1	Bituminous Mix- Bottom	240	107.563	101.00
2	Subgrade Top	740	225.863	161.30
479 MSA – Non-Conventional Design				
1	Bituminous Mix- Bottom	140	107.563	101.40
2	Cementitious Base- Bottom	360	58.8	56.88
3	Subgrade Top	590	225.863	170.00

7. Cost Comparison

A comparison of cost for executing the conventional and non-conventional pavement has been carried out as given in the table below.

Considering 1 km of roadway having 11.5 m width (3lane) width for Conventional Flexible Pavement							
Item of Work	**L (m)**	**B(m)**	**D(m)**	**Quantity**	**unit**	**Rate (Rs)**	**Amount(Rs)**
GSB	1000	11.5	0.25	2875	Cum	3290.7	9460762.50
WMM	1000	11.5	0.25	2875	Cum	3260.62	9374282.50
DBM	1000	11.5	0.20	2300	Cum	7678.16	17659768.00
BC	1000	11.5	0.04	460	Cum	12044.13	5540299.80
Primecoat for DBM	1000	11.5		11500	Sqm	57.82	664930.00
Tackcoat for BC	1000	11.5		11500	Sqm	10.72	123280.00
Tackcoat for DBM	1000	11.5		11500	Sqm	10.72	123280.00
						Total Amount	**42946602.80**

Considering 1 km of roadway having 11.5 m width (3 lane) for Flexible Pavement with CTB and CTSB							
Item of Work	**L (m)**	**B(m)**	**D(m)**	**Quantity**	**unit**	**Rate (Rs)**	**Amount(Rs)**
Geo Composite Drainage Layer	1000	11.5		11500	Sqm	125.40	1442100.00
Cement treated Subbase	1000	11.5	0.20	2300	Cum	4103.33	9437659.00
Cement treated Base	1000	11.5	0.15	1725	Cum	4172.14	7196941.50
Crack Relief Layer(WMM)	1000	11.5	0.10	1150	Cum	3260.62	3749713.00
DBM	1000	11.5	0.10	1150	Cum	7678.16	8829884.00
BC	1000	11.5	0.04	460	Cum	12044.13	5540299.80
Primecoat for DBM	1000	11.5		11500	Sqm	57.82	664930.00
Tackcoat for BC	1000	11.5		11500	Sqm	10.72	123280.00
Tackcoat for DBM	1000	11.5		11500	Sqm	10.72	123280.00
						Total Amount	**37108087.30**
Net Savings with Non Conventional pavement per Km of 3 lane Road							**5838515.50**

8. Results and Discussions

Pavement thickness for conventional pavement is found to be 740 mm, while the cement–treated non-conventional is 590 mm excluding subgrade, subgrade thickness is the same for both cases. There is a significant cost reduction of 13.6 % with the usage of pavement with cement-treated base and cement-treated subbase layers par with the conventional pavement as per cost analysis carried out for both designed pavement sections. The aggregate consumption for non-conventional pavement is 20% less than that of conventional pavement.

we can conclude that the design of Flexible Pavement using non-conventional layers requires less thickness of bituminous layers and accordingly less quantity of bitumen is consumed. Bitumen is one of the costlier material of pavements, there is a considerable reduction of granular layer thickness is also there in the non-conventional pavement design, which leads to less usage of material specifically the aggregates which is good for an environmental conservation point of view. Saving bitumen and more usage of cement is a better practice as the cement is easily available whereas bitumen availability is less and the cost of bitumen is also higher. As bitumen usage gets reduced, non-conventional pavement can reduce emissions of CO2 & Carbon Footprints during the construction of road projects. Reduction in construction costs, and longevity of pavement life with minimal upkeep costs are additional benefits of using CTB and CTSB layers.

Also, it is possible to use high-quality locally sourced soil instead of fine aggregates in the design mix for cement-treated sub-base and base courses, and that in turn reduces the cost as the fine aggregates get replaced by the soil.

9. References

1. E J Yoder and M W Witczak, Principles of Pavement Design, Second Edition, Wiley
2. Yang H Huang, Pavement Analysis and Design, Second Edition, Pearson, 2009.
3. Komershetty Gouthami, Dr KSR Murthy, D. Sandya Rani (7) (2017), “Flexible pavement design and Comparison of alternative Pavements using IRC 37-2012 IIT PAVE”, International journal for scientific Research and Development, vol-5, Issue-6, 2017, ISSN: 2321-0613
4. IRC: 37-2018 “Guidelines for the Design of Flexible Pavements”,
5. RC: SP: 89 (Part-II):2018 Guidelines for the Design of Stabilized Pavements
6. I.S: 2720 (Part – XVI), 1979: Indian Standard Methods of test for Soils, Laboratory Determination of CBR.
7. “Gayle and King Et.al, “polymer modified Bitumen”, Third International Road Federation, Middle East Regional Meeting, Riyadh, Saudi Arabia, February 1998.
8. NPTEL Course- Analysis and Design of flexible pavements
9. Soil Stabilization of Base Layer by using Cement and Additive, International Journal of Engineering Research & technology (ijert), Volume-10, issue-12 (December-2021)
10. AASHTO T 307 Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials
11. IRC:16-2008 Standard Specifications and Code of Practice for Prime and Tack Coat (Second Revision)
12. Donia Savio, M.R. Nivitha, B.K. Bindhu, J.M. Krishnan. "Overloading Analysis of Bituminous Pavements in India Using M-E PDG", Transportation Research Procedia,2016.
13. Donia Savio, Pranjal Paul, J. Murali Krishnan "Statistical Analysis of Axle Load Distributions in India", International Conference on Transportation and Development 2016, 2016