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Optimization of Rigid Pavement

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Abstract: ***The construction of national highways nowadays is preferred by using rigid pavements as they are durable, have the high flexural strength, can withstand different heavy axle loads, higher design span and moreover they can sustain adverse environmental conditions more efficiently with better ease. Considering their remarkable qualities, the national highways should be constructed by providing the tied shoulders and dowel bars in the transverse joints because they can better resist the fatigue accumulations on the slab with minimum safe thickness which ultimately leads to reduction in the cost of making the road efficiently. In this chapter, for the two different CBR conditions (CBR-9 & CBR-10) and three concrete mix design grades namely (M40, M45, M50) along with different shoulders and dowel bars conditions, the trial methods were carried on the IRC-58 Software for bottom-up cracking fatigue analysis for single and tandem axle for day-time (6 hour) traffic and positive temperature differential and top-down cracking fatigue analysis for single, tandem and tridem axle for day-time (6 hour) traffic and negative temperature differential for evaluating the flexural stresses and cumulative fatigue damage values for the slab having dimensions of (3.5m x 4.5m). For determining the safe design, different trails on the thickness parameter of the slab were being adopted so as to get the cumulative fatigue values of BUC and TDC for single, tandem and tridem axles less than one.***
The results obtained showed that for which grade and CBR condition, the values of flexural stresses and cumulative fatigue damage determined is maximum. It was concluded that the rigid pavements should be constructed by using higher grades like M45 and M50 as the fatigue stresses and cumulative fatigue damage values due to variable single, tandem and tridem axle load repetitions obtained are less as compared to M40 grade.
Keywords: California Bearing Ratio (CBR); Bottom Up Cracking (BUC); Top Down Cracking (TDC); Mix Design Grade Value (M), Indian Road Congress (IRC); Flexural Stresses; Cumulative Fatigue Damage(CFD)

I. INTRODUCTION

The construction of national highways nowadays is preferred by using rigid pavements as they are durable, have the high flexural strength, can withstand different heavy axle loads, higher design span and moreover they can sustain adverse environmental conditions more efficiently with better ease. The pavement construction should be able to provide a rideable surface with suitable skid resistance, good light reflecting properties, and low noise pollution. A highway pavement is a structure made up of stacked layers of processed materials over the natural soil sub-grade, with the primary purpose of distributing vehicle loads to the sub-grade. The ultimate goal is to ensure that the transmitted stresses caused by wheel load are decreased to the point where they do not exceed the sub-bearing grade's capability. There are two types of pavements that are commonly used for this purpose: flexible pavements and rigid pavements.

A. Rigid Pavement

Rigid pavements have enough flexural strength to disperse wheel load strains across a larger region. Rigid pavements are laid directly on the prepared sub-grade or on a single layer of granular or stabilised material, as opposed to flexible pavement. This layer can be referred to as the base or sub-base course because there is only one layer of material between the concrete and the sub-grade. The slab action distributes force in rigid pavement, and the pavement behaves like an elastic plate sitting on a viscous medium. Depending on the soil strength and loading circumstances, reinforcement is built into the slab. Surface courses made of pre-stressed concrete slabs can also be employed. For rigid pavement, Portland cement concrete is commonly utilised as the principal structural element. Depending on the soil strength and loading circumstances, reinforcement such as dowel bars and tie bars are used in the slab so as to transfer the loads to the other slab and to hold the slab in the firm and rigid condition.

B. Design Governing Factors

The main factors governing design of rigid pavements are design period, design lane, design commercial traffic volume, composition of commercial traffic in terms of single, tandem, tridem and multi-axles, axle load spectrum, tyre pressure, lateral placement characteristics, directional distribution, strength of foundation including CBR and modulus of subgrade reaction(k) data, temperature consideration, flexural strength of concrete, expected repetitions, allowable repetitions (n) and stress computations, type

and number of dowel and tie bars used and climatic considerations. Considering their remarkable qualities, the national highways should be constructed by providing the tied shoulders and dowel bars in the transverse joints because they can better resist the fatigue accumulations on the slab with minimum safe thickness which ultimately leads to reduction in the cost of making the road efficiently.

II. EXPERIMENTAL WORK

A. *Design Procedure*

1) For bottom-up cracking, the flexural stress at the edge due to the combined action of single or tandem rear axle load and positive temperature differential is considered. This stress is calculated by using the regression equations. Similarly, for assessing the top-down fatigue damage caused by repeated cycles of axle loads and negative temperature differential, flexural stress can be estimated using regression equations.

2) Firstly, for the given design data of loads and their axle proportions, design traffic volume is calculated which depicts cumulative no. of commercial axles repetitions during the design period of 30 years for the BUC analysis for 6 hr. period during day and TDC analysis for 6 hr. period during night which was further being calculated according to the proportion of the axles considered. Corresponding to the different mid loads of single, tandem and tridem axles considered, Expected Repetitions is calculated according to their proportions taken. The stress ratios were optimized corresponding to flexural stresses determined from the regression equations which further evaluate the values of allowable repetitions of axles.

3) For the estimation of fatigue damage, ratio of expected and allowable repetition is calculated. If the sum of cumulative fatigue damages due to wheel load and curling stresses at the bottom and the top is less than 1, the pavement is safe. Thus if CFD (BUC) + CFD (TDC) ≤ 1, the pavement is **SAFE** from large scale cracking as the concrete slab undergoes fatigue damage through crack growth induced by repeated cycles of loading.

B. *Design Data*

1) *Axle Load Data:* To estimate the repetitions of single, tandem, and tridem axles in each direction predicted during the design period, data on axle load spectrum of commercial vehicles is used for optimizing the flexure stresses and fatigue damage by working out the bottom up cracking and top down cracking analysis.

Table 1
Axle Load Spectrum Data for Single, Tandem and Tridem Axle Load

Single Axle		Tandem Axle		Tridem Axle	
Axle Load Class kN	Frequency (% of Single Axles)	Axle Load Class kN	Frequency (% of Tandem Axles)	Axle Load Class kN	Frequency (% of Tridem Axles)
185-195	18.15	380-400	14.5	530-560	5.23
175-185	17.43	360-380	10.5	500-530	4.85
165-175	18.27	340-360	3.63	470-500	3.44
155-165	12.98	320-340	2.5	440-470	7.12
145-155	2.98	300-320	2.69	410-440	10.11
135-145	1.62	280-300	1.26	380-410	12.01
125-135	2.62	260-280	3.9	350-380	15.57
115-125	2.65	240-260	5.19	320-350	13.28
105-115	2.65	220-240	6.3	290-320	4.55
95-105	3.25	200-220	6.4	260-290	3.16
85-95	3.25	180-200	8.9	230-260	3.1
< 85	14.15	< 180	34.23	< 230	17.58
	100		100		100

2) The design period of 30 years is considered and design of lane 4-lane divided is considered.

3) Temperature Consideration

- Max. day-time Temperature Differential in slab (for bottom-up cracking) = 16.8ºC (Bihar)
- Night-time Temperature Differential in slab (for top-down cracking) = 13.4ºC

4) For CBR-9& M50

- 28-day Flexural Strength of cement concrete grade for M50 = 5 MPa
- Modulus of subgrade reaction corresponding to CBR-9= 52.67 MPa/m
- Effective modulus of subgrade reaction of foundation, MPa/m= 292.34 MPa/m

III. RESULTS

The calculations are carried out in IRC-58 Software, for evaluating the safe design, different trails on the thickness parameter of the slab were being adopted so as to get the cumulative fatigue values of BUC and TDC for single, tandem and tridem axles less than one.

A. For CBR-9, M50 Grade (No Tied Concrete Shoulders+ Transverse Joints Have Dowel Bars)

1) Radius of Relative stiffness=0.70584 m

2) Trial Thickness of Concrete Slab = 0.305m

Table 2

Bottom Up Cracking Analysis for Day-time (6 hour) traffic and Positive Temperature Differential

Load(kN)	Single Axle		Load(kN)	Tandem Axle	
	Flexure Stress (MPa)	Fatigue Damage		Flexure Stress (MPa)	Fatigue Damage
80	1.663	0.000	170	1.453	0.000
90	1.764	0.000	190	1.534	0.000
100	1.865	0.000	210	1.615	0.000
110	1.967	0.000	230	1.696	0.000
120	2.068	0.000	250	1.777	0.000
130	2.169	0.000	270	1.858	0.000
140	2.271	0.000	290	1.940	0.000
150	2.372	0.000	310	2.021	0.000
160	2.473	0.000	330	2.102	0.000
170	2.574	0.059	350	2.183	0.000
180	2.676	0.220	370	2.264	0.000
190	2.777	0.598	390	2.345	0.000
Fatigue Damage from Single. Axles =0.877			Fatigue Damage from Tandem Axles = 0.000		

3) Total Bottom-up Fatigue Damage due to single & tandem axle loads = 0.877+0.000=0.877

Table 3

Top Down Cracking Analysis for Night-time (6 hour) traffic and Negative Temperature Differential

Load (kN)	Single Axle		Load (kN)	Tandem Axle		Load (kN)	Tridem Axle	
	Flexure Stress (MPa)	Fatigue Damage		Flexure Stress (MPa)	Fatigue Damage		Flexure Stress (MPa))	Fatigue Damage
80	1.722	0.000	170	1.745	0.000	215	1.683	0.000
90	1.769	0.000	190	1.792	0.000	245	1.729	0.000
100	1.816	0.000	210	1.839	0.000	275	1.776	0.000
110	1.862	0.000	230	1.885	0.000	305	1.823	0.000
120	1.909	0.000	250	1.932	0.000	335	1.870	0.000
130	1.956	0.000	270	1.979	0.000	365	1.917	0.000
140	2.003	0.000	290	2.026	0.000	395	1.963	0.000
150	2.049	0.000	310	2.072	0.000	425	2.010	0.000
160	2.096	0.000	330	2.119	0.000	455	2.057	0.000
170	2.143	0.000	350	2.166	0.000	485	2.104	0.000
180	2.190	0.000	370	2.213	0.000	515	2.150	0.000
190	2.237	0.000	390	2.260	0.000	545	2.197	0.000
Fatigue Damage from Sing. Axles = 0.000			Fatigue Damage from Tandem Axles = 0.000			Fatigue Damage from Tridem Axles = 0.000		

Total Top-Down Fatigue Damage due to single, tandem & tridem axle load = 0.000+0.000+0.000=0.000

Sum of CFD for BUC & TDC= 0.877< 1, therefore design is **SAFE.**

B. For CBR-9, M50 Grade (Tied Concrete Shoulders+ No Transverse Joints Have Dowel Bars)

1) Radius of Relative stiffness=0.67965 m

2) Trial Thickness of Concrete Slab = 0.29 m

Table 4
Bottom Up Cracking Analysis for Day-time (6 hour) traffic and Positive Temperature Differential

Load (kN)	Single Axle		Load (kN)	Tandem Axle	
	Flexure Stress (MPa)	Fatigue Damage		Flexure Stress (MPa)	Fatigue Damage
80	1.570	0.000	170	1.275	0.000
90	1.646	0.000	190	1.343	0.000
100	1.721	0.000	210	1.410	0.000
110	1.796	0.000	230	1.478	0.000
120	1.871	0.000	250	1.546	0.000
130	1.947	0.000	270	1.614	0.000
140	2.022	0.000	290	1.682	0.000
150	2.097	0.000	310	1.750	0.000
160	2.173	0.000	330	1.818	0.000
170	2.248	0.000	350	1.885	0.000
180	2.323	0.000	370	1.953	0.000
190	2.399	0.000	390	2.021	0.000
Fatigue Damage from Single Axles =0.000			Fatigue Damage from Tandem Axles =0.000		

4) Total Bottom-up Fatigue Damage due to single and tandem axle loads = 0.000+0.000=0.000

Table 5
Top Down Cracking Analysis for Night-time (6 hour) traffic and Negative Temperature Differential

Load (kN)	Single Axle		Load (kN)	Tandem Axle		Load (kN)	Tridem Axle	
	Flexure Stress (MPa)	Fatigue Damage		Flexure Stress (MPa)	Fatigue Damage		Flexure Stress (MPa)	Fatigue Damage
80	1.910	0.000	170	1.945	0.000	215	1.850	0.000
90	1.980	0.000	190	2.015	0.000	245	1.921	0.000
100	2.051	0.000	210	2.086	0.000	275	1.992	0.000
110	2.121	0.000	230	2.156	0.000	305	2.062	0.000
120	2.192	0.000	250	2.227	0.000	335	2.133	0.000
130	2.262	0.000	270	2.297	0.000	365	2.203	0.000
140	2.333	0.000	290	2.368	0.000	395	2.274	0.000
150	2.403	0.000	310	2.438	0.000	425	2.344	0.000
160	2.474	0.000	330	2.509	0.003	455	2.415	0.000
170	2.544	0.028	350	2.579	0.018	485	2.48	0.001
180	2.615	0.086	370	2.650	0.136	515	2.556	0.009
190	2.686	0.210	390	2.720	0.400	545	2.626	0.030
Fatigue Damage from Single Axles = 0.325			Fatigue Damage from Tandem Axles = 0.556			Fatigue Damage from Tridem Axles = 0.041		

5) Total Top-Down Fatigue Damage due to single, tandem & tridem axle load = 0.325+0.556+0.041=0.922

Sum of CFD for BUC & TDC= 0.922 < 1, therefore design is **SAFE.**

IV. CONCLUSIONS

1) The rigid pavement having slab thickness of 0.305m in which shoulders are not tied and dowel bars are provided in the transverse joints, results obtained were maximum as follows: -

Table 6
Results induced in pavement type (No Tied Concrete Shoulders+ Transverse Joints Have Dowel Bars)

S. No.	BUC analysis for CBR-9 condition & M50 grade		
	RESULTS	Single Axle Load (190KN)	Tandem Axle Load (390KN)
1.	Maximum Fatigue Stresses	2.777 MPa	2.345 MPa
2.	Maximum Cumulative Fatigue Damage	0.598	0.000

2) The rigid pavement having slab thickness of 0.29m in which shoulders are tied and dowel bars are not provided in the transverse joints, results obtained were maximum as follows: -

Table 7
Results induced in pavement type (Tied Concrete Shoulders+No Transverse Joints Have Dowel Bars)

S. No.	TDC analysis for CBR-9 condition & M50 grade			
	RESULTS	Single Axle Load (190KN)	Tandem Axle Load (390KN)	Tridem Axle Load (545KN)
1.	Maximum Fatigue Stresses	2.686 MPa	2.720 MPa	2.626 MPa
2.	Maximum Cumulative Fatigue Damage	0.210	0.400	0.030

3) The rigid pavement having slab thickness of 0.305m in which shoulders are not tied and dowel bars are provided in the transverse joints, results obtained were maximum as follows: -

Table 8
Results induced in pavement type (No Tied Concrete Shoulders+ Transverse Joints Have Dowel Bars)

S. No.	BUC analysis for CBR-10 condition & M50 grade		
	RESULTS	Single Axle Load (190KN)	Tandem Axle Load (390KN)
1.	Maximum Fatigue Stresses	2.776 MPa	2.343 MPa
2.	Maximum Cumulative Fatigue Damage	0.591	0.000

4) The rigid pavement having slab thickness of 0.29m in which shoulders are tied and dowel bars are not provided in the transverse joints, results obtained were maximum as follows: -

Table 9
Results induced in pavement type (Tied Concrete Shoulders+ No Transverse Joints Have Dowel Bars)

S. No.	TDC analysis for CBR-9 condition & M50 grade			
	RESULTS	Single Axle Load (190KN)	Tandem Axle Load (390KN)	Tridem Axle Load (545KN)
1.	Maximum Fatigue Stresses	2.684 MPa	2.719 MPa	2.625 MPa
2.	Maximum Cumulative Fatigue Damage	0.207	0.395	0.030

5) If we provide only dowel bars in the slab, fatigue damage determined approximately 0.000 in the TDC analysis in most cases vice a versa if we provide only the tied concrete shoulders in case of BUC analysis i.e. this concludes that if we either provide only one of them, the safe design thickness requirements of the slab starts rising.

6) It can also be concluded that the safe design thickness requirements are less in the rigid pavement having shoulders tied and dowel bars are provided in the transverse joints and fatigue damage is very less in the BUC analysis and approximately 0.000 in the TDC analysis.

7) This can be concluded by the following table that as we increase the grade of the concrete mix, the safe design thickness requirements of the slab decreases.

Table 10
Comparison of grade with slab thickness for CBR-9

S.No.	Type of pavement considered	M40	M45	M50
1.	No Tied Concrete Shoulders + Transverse Joints Have Dowel Bars	0.33m	0.32m	0.305m
2.	No Tied Concrete Shoulders + No Transverse Joints Have Dowel Bars	0.335m	0.322m	0.306m
3.	Tied Concrete Shoulders + No Transverse Joints Have Dowel Bars	0.325m	0.31m	0.29m
4.	Tied Concrete Shoulders + Transverse Joints Have Dowel Bars	0.285m	0.275m	0.26m

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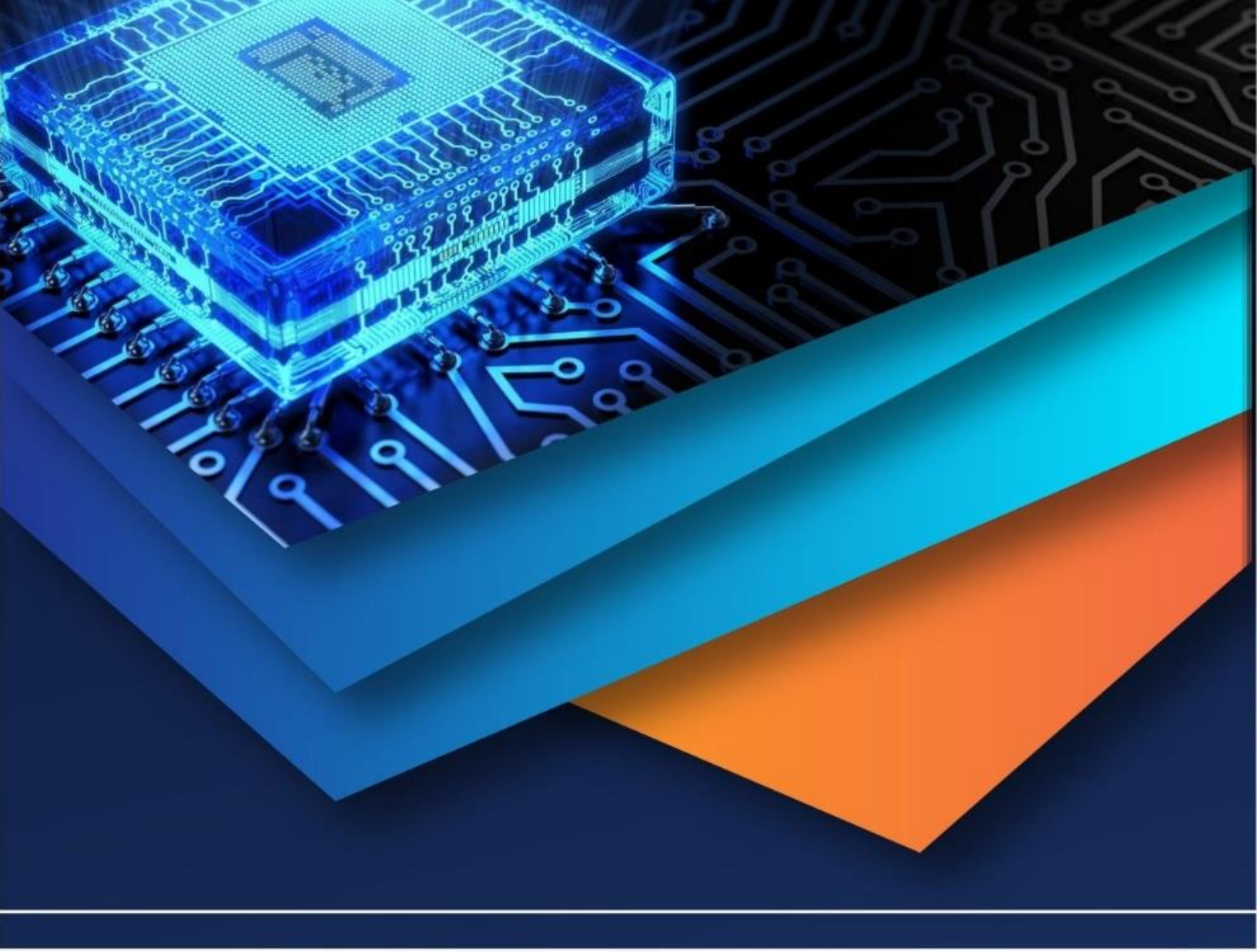

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