Design of Rigid Pavement by IRC Method and its Critical Comparison with AASHTO Method

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Abstract— In this paper a comparison of thickness design methods is being presented. The paper describes two rigid pavements, i.e. the "IRC method 'and the "AASHTO method ".Various design parameters has been compared and the basic difference between the two methods is analyzed. The paper also highlights the salient features of design and comparison of thickness has been done using Indian traffic conditions.

Key words: IRC method, AASHTO method, Wheel Loads

I. Introduction

Cement concrete pavements generally known as "rigid pavements" are now days replacing bituminous roads due to its economical advantage. A proper well connected rigid road network in a country like India can result in cost savings and economized movement of traffic over longer distances.

When properly designed and constructed concrete roads and streets are capable of carrying almost unlimited amount of any type of traffic with ease, comfort and safety. Surfaces of this type are smooth, dust free and skid resistant having a high degree of visibility for both day and night driving and generally having low maintenance cost. They are economical in many locations because of their low cost of maintenance and their low cost of maintenance and their relative performance. They are, of course, classed as high type pavements .The principal use of surfaces of this type has been in the construction of heavily traveled roads and city streets, including those in residential, business, and industrial areas . It is the standard material for urban expressways, even in states where bituminous surfaces are widely used.

In recent years, cement concrete pavements are being adopted in many new road projects in India in view of their longer service lives, lesser maintenance requirements and smoother riding surface. The current practice of constructing concrete pavement on Indian highways is to provide a granular sub-base over the sub-grade to be followed by a Dry lean concrete base with the concrete slab on top which is called "rigid pavement". As a result of nationwide high way construction, more and more length of concrete pavement are constructed. However the deterioration of the concrete pavements has become a growing concern, since the rehabilitation of such pavements is a costly exercise. Hence there is a need of development of more scientific design methodology compared to the existing ones, which will avoid premature failure of pavements. There is a increasing trend for using mechanistic approach for design of pavement. Therefore, a comparison between the two design methods is being presented in order two analyze the basic difference between the Indian as well as American concept of rigid pavement design.

II. Methodology

A. *Indian Road Congress Method:*

1) *Wheel Loads:*

One of the main design parameter for pavement design is the wheel load. Though the legal axle load limits in India are fixed as 10.2, 19 and 24 tons for single, tandem and tridem axles respectively the actual axle loads operating on highways in Indian are much higher due to lack of enforcement. It is necessary to collect the data of axle load spectrum of commercial vehicles both during the day as well as during the night hours for the analysis of fatigue damage in the slab. The percentage of heavy vehicles during the night hours may be much higher for many high ways. This will help in computation of flexural fatigue damage with higher precision and possibility of top-down cracking can also be determined from fatigue consideration.

2) *Fatigue Considerations:*

A pavement is damaged due to

- Single axles, tandem axles and tridem axle's loads.
- Warping due to temperature gradient.

According to IRC guidelines, IRC 58 has adopted the Westerguard's equation to estimate the load stress and Bradbury equation to estimate temperature stress. The load stress is the highest at the corner of the slab lesser at the edge and least in the interior. The order of variation temperature is just reverse of this .As per IRC58 is recommended that the design needs to be done for EDGE STRESS condition and subsequently check the corner stress so as to finalize the design. The new version of IRC58 (2011) has also introduced –

1) Design of pavements considering the combined flexural stress under the simultaneous action of loads and temperature gradient for different categories of axles.
2) Design for bottom-up fatigue cracking caused by single and tandem axles load repetitions.
3) Design for top down fatigue cracking caused by single, tandem and tridem axles load applications.
4) Consideration of in-built permanent curl in the analysis of flexural stresses.

B. *American Association State Highway State Highway and Transportation Officials (Aashto) Method;*

The 1993 AASHTO guide of design of pavement structures considers the following factors in the design:

1) Estimated Future Traffic (W18) over the design life. The design guide is based on the total number of equivalent standard axle loads (ESAL).
2) Reliability.(R%)- The reliability of a pavement design is the probability of roads under survival of

roads under prevailing conditions. It varies from 80% to 95%.

3) overall standard deviation (So)- An overall standard deviation of 0.25 to 0.35 for traffic is recommended for rigid pavements
4) Effective Modulus of Sub grade Reaction (K in psi)-Effective Modulus of sub grade reaction is used to estimate the support of cement concrete slab by layer below.
5) Concrete elastic modulus (E).it can be estimated from the cube strength of concrete and its value is represented in psi.
6) Concrete modulus of rupture (Sc)-The modulus of rupture to be incorporated in the mean value after 28 days of curing, using three points loading.
7) Load transfer coefficient (J)-This coefficient is used to account for the ability of a concrete pavement structure to transfer load across discontinuities, such as joints or cracks.

III. THICKNESS DESIGN

As the comparison of thickness of pavements has been presented on the Indian traffic conditions therefore similar traffic data have been taken into an account. Traffic data has been taken by 7 days 24 hours survey. Total number of commercial vehicles is 660cvpd. The axle load spectrum has been analyzed .The modulus of sub grade reaction, modulus of elasticity and modulus of rupture of cement concrete were taken as 4.80 kg/cm3 , 300000kg/cm2 and 45 kg/cm2.These all values according to AASHTO has been changed in the standard form as per AASHTO. It is further assumed that there is no concrete shoulder to share the load. Axle load spectrum has been shown below for AASHTO load is being converted into kips.

A. Axle Load Spectrum:

Single Axle		**Tandem Axle**		**Tridem Axle**	
Axle class (KN)	**Frequency (% of single)**	**Axle class (KN)**	**Frequency (% of tandem)**	**Axle class (KN)**	**Frequency (% of tridem)**
185-195	18.15	380-400	14.50	530-560	5.23
175-185	17.43	360-380	10.50	500-530	4.85
165-175	18.27	340-360	3.63	470-500	3.44
155-165	12.98	320-340	2.50	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	3.90	350-380	15.57
115-125	2.65	240-260	5.19	320-350	13.28
105-115	2.65	220-240	6.30	290-320	4.55
95-105	3.25	200-220	6.40	260-290	3.16
85-95	3.25	180-200	8.90	230-260	3.10
<85	14.15	<180	34.23	<230	17.58
	100		100		100

Table 1: Axle load spectrum

B. Design as Per IRC58 (2011):

Assume thickness as 30 cm we check pavement for fatigue and temperature stresses.

Axle load Category	**Proportion of Axle Category**	**Category wise axle repetitions for Bottom-Up Cracking Analysis (Day time)**	**Category wise axle repetitions for Top-Down Cracking Analysis (Night time)**
Front Steering Axle	0.45	249516	254863
Rear Single	0.15	83172	84954
Tandem	0.25	138620	141591
Tridem	0.15	83172	84954
		554481	566363

Bottom up cracking Fatigue Analysis for Day time (6 hour) traffic and Positive Temperature Differential						
Axle load	**AL * LSF**	**Stress from Charts**	**Stress Ratio**	**Expected repetition**	**Allowable repetitions**	**Fatigue Life, N**
1	2	3	4	5	6	7
Single Axle						
21			0.00		INFINITE	0.00
20			0.00	0	INFINITE	0.00
19		21.64	0.4372	15096	INFINITE	0.00
18		20.61	0.4165	14497	INFINITE	0.00
17		19.59	0.3958	15196	INFINITE	0.00
16		18.56	0.3750	10796	INFINITE	0.00
15		17.54	0.3543	2479	INFINITE	0.00
14		16.51	0.3336	1347	INFINITE	0.00
13		15.49	0.3129	2179	INFINITE	0.00
12		14.46	0.2922	2204	INFINITE	0.00
11		13.44	0.2715	2204	INFINITE	0.00
10		12.41	0.2508	2703	INFINITE	0.00
9		11.39	0.2300	2703	INFINITE	0.00
8		10.36	0.21	11769	INFINITE	0.00
Tandem Axle						
			0.00		INFINITE	0.00
41		19.97	0.44	0	INFINITE	0.00
39		19.08	0.3855	20100	INFINITE	0.00
37		18.19	0.3675	14555	INFINITE	0.00
35		17.30	0.3495	5032	INFINITE	0.00
33		16.41	0.3315	3466	INFINITE	0.00
31		15.52	0.3135	3729	INFINITE	0.00
29		14.63	0.2955	1747	INFINITE	0.00
27		13.74	0.2775	5406	INFINITE	0.00
25		12.85	0.2595	7194	INFINITE	0.00
23		11.96	0.2415	8733	INFINITE	0.00
21		11.06	0.2235	8872	INFINITE	0.00
19		10.17	0.2055	12337	INFINITE	0.00
18		9.73	0.20	47450	INFINITE	0.00
Cumulative Fatigue Damage / Life Consumed for Bottom up Cracking						0.0000
Check for Fatigue Life						*SAFE*

Table 2: Design as per IRC58 (2011)

Top Down cracking Fatigue Analysis for Night time (6 hour) traffic and Negative Temperature Differential						
Axle load	**AL * LSF**	**Stress from Charts**	**Stress Ratio**	**Expected repetition**	**Allowable repetitions**	**Fatigue Life, N**
1	2	3	4	5	6	7
Single Axle						
21			0.00		INFINITE	0.00
20			0.00	0	INFINITE	0.00
19		23.48	0.4743	15419	3644380	0.00
18		23.00	0.4645	14808	8692543	0.00
17		22.51	0.4548	15521	28509685	0.00
16		22.03	0.4450	11027	INFINITE	0.00
15		21.54	0.4352	2532	INFINITE	0.00
14		21.06	0.4255	1376	INFINITE	0.00
13		20.58	0.4157	2226	INFINITE	0.00
12		20.09	0.4060	2251	INFINITE	0.00
11		19.61	0.3962	2251	INFINITE	0.00
10		19.13	0.3864	2761	INFINITE	0.00
9		18.64	0.3767	2761	INFINITE	0.00
8		18.16	0.37	12021	INFINITE	0.00
Tandem Axle						
			0.00		INFINITE	0.00
40			0.00	0	INFINITE	0.00
39		23.72	0.4792	20531	2540190	0.01
37		23.24	0.4694	14867	5468517	0.00
35		22.75	0.4597	5140	14919749	0.00
33		22.27	0.4499	3540	INFINITE	0.00
31		21.79	0.4401	3809	INFINITE	0.00
29		21.30	0.4304	1784	INFINITE	0.00
27		20.82	0.4206	5522	INFINITE	0.00
25		20.34	0.4108	7349	INFINITE	0.00
23		19.85	0.4011	8920	INFINITE	0.00
21		19.37	0.3913	9062	INFINITE	0.00
19		18.89	0.3815	12602	INFINITE	0.00
18		18.64	0.38	48466	INFINITE	0.00
Tridam Axle						
			0.00		INFINITE	0.00
			0.00	0	INFINITE	0.00
54.5		23.08	0.4662	4443	7393238	0.00
51.5		22.59	0.4564	4120	22642681	0.00
48.5		22.11	0.4466	2922	INFINITE	0.00
45.5		21.63	0.4369	6049	INFINITE	0.00
42.5		21.14	0.4271	8589	INFINITE	0.00
39.5		20.66	0.4173	10203	INFINITE	0.00
36.5		20.18	0.4076	13227	INFINITE	0.00
33.5		19.69	0.3978	11282	INFINITE	0.00
30.5		19.21	0.3880	3865	INFINITE	0.00
27.5		18.72	0.3783	2685	INFINITE	0.00
24.5		18.24	0.3685	2634	INFINITE	0.00
21.5		17.76	0.36	14935	INFINITE	0.00

Table 3:

Cumulative Fatigue Damage / Life Consumed for Bottom up Cracking	**0.0184**
Check for Fatigue Life	
Maximum Load Stress	23.72 Kg/cm^2
Total Temperature Stresses	23.72 Kg/cm^2
Check for Temperature Stress	*SAFE*

Assumed slab thickness is adequate because CFD is more than 1

C. Aashto Pavement Design:

AASHTO rigid pavement design contains different parameters as compared to IRC such as mixed traffic is converted into ESAL. Therefore we have converted our values into AAHTO values such as kg/cm2 into pci and kg/cm3 into pci/inch .Tonnes are converted into kip. We have taken ESAL count for single .tandem and tridem axles. Take growth factor as 43.30.

1) *For Single Axles:*

LOAD (Kips)	No of vehicles	(g)	Design traffic	ESAL Factor	Design ESAL
18	51	43.30	80123	1.0	806123
20	17	43.30	268708	1.57	421877
22.	17	43.30	268708	2.34	628777
24	14	43.30	221289	3.36	743531
26	14	43.30	221289	4.67	1033420
28	14	43.30	221289	6.29	1391908
30	9	43.30	142257	8.28	1177888
34	16	43.30	252901	11.2	2832491
35	69	43.30	1084214	15.3	16588474
32	97	43.30	1524185	10.7	16308779
40	92	43.30	1445619	26.3	38019780
42	96	43.30	1596720	32	4845040
Total					84798083

Table 4: For single axles

2) *For Tandem Axles:*

LOAD (Kips)	No of vehicles	(g)	Design traffic	ESAL Factor	Design ESAL
33	34	43.30	554251	1.75	934938
37.	9	43.30	141419	2.74	387488
46.	5	43.30	79032	6.53	516079
50.	6	43.30	94838	9.07	853542
55	5	43.30	79032	13.3	1051121
60	4	43.30	63230	18.7	1182395
64	1	43.30	15806	24.4	379351
69	3	43.30	47085	31	1459635
72.	3	43.30	47085	39.8	187398
77	4	43.30	62780	47	2950660
82	11	43.30	172643	69.6	11567215
86	15	43.30	2325425	86	20246550
Total					39482856

Table 5: For tandem axles

3) *For Tridem Axles:*

LOAD (Kips)	No of vehicles	(g)	Design traffic	ESAL Factor	Design ESAL
50	5	43.30	78566	2.94	230984
53	1	43.30	15695	3.44	53990
60	1	43.30	15695	6.08	94170
66	1	43.30	15695	9.9	156950
73	4	43.30	62780	12.4	778472
80	5	43.30	78475	18.9	1483178
85	4	43.30	62780	25.4	1569500
93	9	43.30	142256	32.2	4580643
Total					8947887

Table 6: For tridem axles

By adding all the 3 design ESAL we have 133.47 $*10^6$ repetitions. For W18 we have equations.

$$W18=w18*D_D*D_L \quad \text{........ (1)}$$

By this equation we have W18=
$W18=133.47*10^6*0.5*0.9=$
$59.9*10^6$ 18 kip ESAL
Other design values=
M.R=640 pci
E=4267002pci
K=173 pci/inch
R=80%
So=0.39
J=3.2
Cd=1
Pi=4.5
Pt=2.5

By nomograph present in the AASHTO guide for rigid pavements thickness comes out is approximately 13 inches which is similar to 33cm.

IV. COMPARISON OF DESIGN METHODS

By the above comparison of 2 different methods i.e. empirical and mechanistic empirical methods which is AASHTO and IRC methods it has been concluded that IRC gives less thickness as compared to AASHTO methods. But the other parameter is that the AASHTO pavement design is well suited for Indian conditions as Indian traffic consists of heavy loading conditions due to densely populated and its developing parameters as well as increase in globalization.

V. CONCLUSION

1) This paper presents a comparative study of two design methods and the difference between slab thickness is evolved out. Since there is not a huge difference between the thickness of the pavement by both the methods. But IRC gives less compared to AASHTO method and proves to be well suited for Indian conditions as it contains fatigue and most important temperature stresses since India is having an extreme type of climate.
2) The other difference between the 2 methods is the Reliability and the Present serviceability index which is the parameter for AASHTO method .Reliability should be introduced in the Indian method of design so as to estimate the pavement performance.

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