Pavement Design and Comparison using Indian Road Congress and Portland Cement Association Method

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Abstract— The study aims to find most appropriate method for the design of cement concrete road for Indian standards. The design of rigid pavement is so far based on various analytical, mechanistic as well as mechanistic empirical methods and most optimum design method is so far to be known. A critical comparison between the two methods of pavement design viz. Portland cement association method and the existing Indian Road Congress method for the design of rigid pavement. The primary objective is to load repetitions on the pavement to prevent the crack initiation due to critical stress conditions and the prevailing sub base and sub grade conditions. An axle load survey is been conducted for three days to predict the existing traffic for the design road. Survey predicted a total count of 660 commercial vehicles per day with a growth factor of 75%. The pavement is designed with a tied concrete shoulder. The pavement thickness is designed for the critical edge stresses and checked for bottom up cracking and top up cracking along with temperature stresses using the IRC guidelines. The design is revised using the PCA method for fatigue and erosion damage. The most optimum design thickness is found using the methods. The resulting outcomes of the two methods are analyzed critically and the comparison of the two methodology is done by comparing the prevailing conditions adopted in the guidelines.

Key words: Portland cement association method, the existing Indian Road Congress method, IRC

I. Introduction

Design and construction standards for a pavement should provide for pavements with both long service life and low maintenance. As a guide in achieving this goal, this study aims to provide adequate designs with respect to maintenance and service. The rigid pavement designs are becoming more and more scientific from the previous times always there has been an urge to develop a more precise method. Before the World War II the slabs were laid directly over the sub grade without giving consideration to sub grade type and drainage conditions. Slabs as thin as 6 to 7 inches were laid as the traffic was very less. With the growth of traffic sub grade as well as critical stresses are analyzed more precisely .The design methods for rigid pavement were always based on analytical basis later on the methods turned empirical and with due course of time a more precise mechanistic approach as developed. With further development the design methods combined the empirical and the mechanistic approaches for more optimum designs.

The PCA has developed design charts on the basis of formulae developed by Picket & Ray (modified westergaard's formulae) and further modification by Finite element method. The data generated from various road tests, such as the AASHTO road test, the Arlington test, the Bates road test and the Maryland road test were used to develop the design methodology. The design procedure is based on the comprehensive analysis of concrete stresses and deflections at pavement joints, corners and edges by a finite element computer program. It allows considerations of slabs with finite dimensions, variable axle load placements and the modeling of load transfer at the joint between pavement and the concrete shoulder. The IRC 58 -2011 aims at rationalizing the data as far as possible. It is a mechanistic empirical approach developed for the Indian traffic and environmental conditions.

The most critical pavement stresses occur when the truck wheels are placed at or near the pavement edge and midway between the joints. Since the joints are at some distance from this location, transverse joint spacing and type of load transfer have very little effect o the magnitude of stress. In the design procedure, therefore the analysis based on flexural stresses and fatigue yield the same values for different joint spacing and different type of load mechanisms. The most critical pavement deflections occur at the slab corner when an axle load is placed at the joint with the wheels at or near the corner. In this situation transverse joint spacing has o effect on the magnitude of corner deflections but the type of load transfer mechanism has a substantial effect. This means that the design results based on the erosion criteria may be substantially affected by the type of load transfer selected especially when large numbers of trucks are being designed for a concrete shoulder reduces corner deflections considerably.

II. Design Methodology

Based on a detailed traffic survey of 24 hours for three days 660 commercial vehicles per day as found on a two lane road from NH-86 Ext. KM 66 to Gulabgunj to Andia in district Vidisha of Madhya Pradesh. Having a growth rate of 0.075 every year and designed for 20 years cement concrete pavement is been designed. The corresponding flexural strength of the mix used is 45Kg/cm^2 with a 28 days compressive strength of 400Kg/cm^2.The sub grade has CBR value of 7% and modulus of sub grade reaction derived from it is 4.80 kg/cm^3.The modulus of sub base reaction is 5.614 kg/cm^3.The maximum day and night temperatures are15.8ºC and 12.9 ºC respectively. The load safety factor is 1.2.The traffic for lateral placement is assumed to be 25% of the total traffic. The types of vehicles are illustrated in the table.

The basic approach of the IRC -58 is based on the fatigue damage caused by the vehicles. The stresses due to axle loads and also the critical temperature stresses are checked for the cumulative fatigue damage. For bottom up cracking only day traffic from 10:00 am to 4:00 pm is considered traffic count from 12:00 am to 6:00 am is considered for top down cracking.

In the other method called PCA method consideration of fatigue damage to the slab due to repetitive loading are worked out using the strength characteristics of the concrete used. The additional criteria for the erosion of the material placed below the slab are added to the analysis. The cumulative damage due to the two phenomenon is found and the total damage must be less than 100 percent for the survival of the pavement.

III. PRESENT CASE STUDY

A. IRC 58-2011 Design:

Assuming a trial thickness of 30 cm.

Cumulative number of repetitions in 20 years = $\frac{365 X 660\{(1+0.075)^{30}-1\}}{0.075}$ = 10432097.7

- Average axles (Steering/Single/Tandem/Tridem) per C V=2.43
- Total two way axle load repetitions during design period = 25347702.79
- No of axle in one direction (0.5 X Two way direction) = 12673851.39
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- Design traffic 25% of total traffic for lateral placement= 0.25
- Number of axles in predominant direction = 3168463
- Percentage of traffic traveling during night 12 hours=0.65
- Percentage of traffic traveling during day 12 hours = 0.35
- Day time 12-hours traffic = 1108961.997
- Day-time 6-Hour axle load repetitions for Bottom up cracking analysis = 554481
- Night-time 12-Hour axle load repetitions = 2059501
- Night -time 6 hour__axle load repetitions= 1029750.426
- % of vehicle with front & rear axle less than 4.5m = 55
- Hence, night time 6 hours traffic for top down crack (TDC) analysis is = 566362.7341

B. Axle Load Spectrum:

Single Axle Loads		**Tandem Axle Loads**		**Tridem Axle Loads**	
load in tonne	**Expected Repetitions**	**load in tonne**	**Expected Repetitions**	**load in tone**	**Expected Repetitions**
>19.5		>40		>56	
18.5-19.5	18.15	38-40	14.50	53-56	5.23
17.5-18.5	17.43	36-38	10.50	50-53	4.85
16.5-17.5	18.27	34-36	3.63	47-50	3.44
15.5-16.5	12.98	32-34	2.50	44-47	7.12
14.5-15.5	2.98	30-32	2.69	41-44	10.11
13.5-14.5	1.62	28-30	1.26	38-41	12.01
12.5-13.5	2.62	26-28	3.90	35-38	15.57
11.5-12.5	2.65	24-26	5.19	32-35	13.28
10.5-11.5	2.65	22-24	6.30	29-32	4.55
9.5-10.5	3.25	20-22	6.40	26-29	3.16
8.5-9.5	3.25	18-20	8.90	23-26	3.10
<8.5	14.15	<18	34.23	<23	17.58
Total	100.00	Total	100.00	Total	100.00

Table 1: Axle load spectrum

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

Table 2:

C. Fatigue Analysis 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**
Single Axle						
21			0.00		INFINITE	0.00
20	24.0		0.00	0	INFINITE	0.00
19	22.8	21.64	0.4372	15096	INFINITE	0.00
18	21.6	20.61	0.4165	14497	INFINITE	0.00

17	20.4	19.59	0.3958	15196	INFINITE	0.00
16	19.2	18.56	0.3750	10796	INFINITE	0.00
15	18.0	17.54	0.3543	2479	INFINITE	0.00
14	16.8	16.51	0.3336	1347	INFINITE	0.00
13	15.6	15.49	0.3129	2179	INFINITE	0.00
12	14.4	14.46	0.2922	2204	INFINITE	0.00
11	13.2	13.44	0.2715	2204	INFINITE	0.00
10	12.0	12.41	0.2508	2703	INFINITE	0.00
9	10.8	11.39	0.2300	2703	INFINITE	0.00
8	9.6	10.36	0.21	11769	INFINITE	0.00
Tandem Axle						
			0.00		INFINITE	0.00
41	49.2	19.97	0.44	0	INFINITE	0.00
39	46.8	19.08	0.3855	20100	INFINITE	0.00
37	44.4	18.19	0.3675	14555	INFINITE	0.00
35	42.0	17.30	0.3495	5032	INFINITE	0.00
33	39.6	16.41	0.3315	3466	INFINITE	0.00
31	37.2	15.52	0.3135	3729	INFINITE	0.00
29	34.8	14.63	0.2955	1747	INFINITE	0.00
27	32.4	13.74	0.2775	5406	INFINITE	0.00
25	30.0	12.85	0.2595	7194	INFINITE	0.00
23	27.6	11.96	0.2415	8733	INFINITE	0.00
21	25.2	11.06	0.2235	8872	INFINITE	0.00
19	22.8	10.17	0.2055	12337	INFINITE	0.00
18	21.6	9.73	0.20	47450	INFINITE	0.00

Table 3: Fatigue Analysis bottom up cracking Fatigue Analysis for Day time (6 hour) traffic and Positive Temperature Differential

D. Top down Cracking Fatigue Analysis for Night Traffic and Negative Temperature:

Axle load	AL * LSF	Stress from Charts	Stress Ratio	Expected repetition	Allowable repetitions	Fatigue Life, N
Single Axle						
21			0.00		INFINITE	0.00
20			0.00	0	INFINITE	0.00
19	22.8	23.48	0.4743	15419	3644380	0.00
18	21.6	23.00	0.4645	14808	8692543	0.00
17	20.4	22.51	0.4548	15521	28509685	0.00
16	19.2	22.03	0.4450	11027	INFINITE	0.00
15	18.0	21.54	0.4352	2532	INFINITE	0.00
14	16.8	21.06	0.4255	1376	INFINITE	0.00
13	15.6	20.58	0.4157	2226	INFINITE	0.00
12	14.4	20.09	0.4060	2251	INFINITE	0.00
11	13.2	19.61	0.3962	2251	INFINITE	0.00
10	12.0	19.13	0.3864	2761	INFINITE	0.00
9	10.8	18.64	0.3767	2761	INFINITE	0.00
8	9.6	18.16	0.37	12021	INFINITE	0.00
Tandem Axle						
	0.0		0.00		INFINITE	0.00
40	48.0		0.00	0	INFINITE	0.00
39	46.8	23.72	0.4792	20531	2540190	0.01
37	44.4	23.24	0.4694	14867	5468517	0.00
35	42.0	22.75	0.4597	5140	14919749	0.00
33	39.6	22.27	0.4499	3540	INFINITE	0.00
31	37.2	21.79	0.4401	3809	INFINITE	0.00

29	34.8	21.30	0.4304	1784	INFINITE	0.00
27	32.4	20.82	0.4206	5522	INFINITE	0.00
25	30.0	20.34	0.4108	7349	INFINITE	0.00
23	27.6	19.85	0.4011	8920	INFINITE	0.00
21	25.2	19.37	0.3913	9062	INFINITE	0.00
19	22.8	18.89	0.3815	12602	INFINITE	0.00
18	21.6	18.64	0.38	48466	INFINITE	0.00
Tridem Axle						
	0.0		0.00		INFINITE	0.00
	0.0		0.00	0	INFINITE	0.00
54.5	65.4	23.08	0.4662	4443	7393238	0.00
51.5	61.8	22.59	0.4564	4120	22642681	0.00
48.5	58.2	22.11	0.4466	2922	INFINITE	0.00
45.5	54.6	21.63	0.4369	6049	INFINITE	0.00
42.5	51.0	21.14	0.4271	8589	INFINITE	0.00
39.5	47.4	20.66	0.4173	10203	INFINITE	0.00
36.5	43.8	20.18	0.4076	13227	INFINITE	0.00
33.5	40.2	19.69	0.3978	11282	INFINITE	0.00
30.5	36.6	19.21	0.3880	3865	INFINITE	0.00
27.5	33.0	18.72	0.3783	2685	INFINITE	0.00
24.5	29.4	18.24	0.3685	2634	INFINITE	0.00
21.5	25.8	17.76	0.36	14935	INFINITE	0.00
Total cumulative fatigue damage=0.0184						

Table 4: Top down cracking Fatigue Analysis for night traffic and negative temperature

Since the cumulative fatigue damages are less than 1 the thickness is sufficient to sustain the traffic.

– Check for temperature stresses- The total temperature stress is 23.72kg/cm^2. Hence the design is safe.

E. PCA Design:

– Assuming a trial thickness of 10.5”(27 cm.)

– Modulus of subgrade reaction=173 psi
– Modulus of rupture = 595 pci
– Load safety factor =1.2
– Growth factor = 1.8
– Total no of axles in the design period = 365 X 20 X 660 X 1.8 =5203440

Single Axle				Tandem Axle			
Axle Load	**Axles Per 1000 Trucks**	**Adjusted**	**Axles In Design Period**	**Axle Load**	**Axles Per 1000 Trucks**	**Adjusted**	**Axles In Design Period**
>19.5				>40			
18.5-19.5	1.84	3.8	15818.458	38-40	1.45	3	1873.239
17.5-18.5	1.76	3.7	15402.182	36-38	1.05	2.2	1373.709
16.5-17.5	1.85	3.9	16234.733	34-36	0.36	0.8	499.5304
15.5-16.5	1.31	2.7	11239.43	32-34	0.25	0.5	312.2065
14.5-15.5	0.3	0.6	2497.6512	30-32	0.27	0.6	374.6478
13.5-14.5	0.16	0.3	1248.8256	28-30	0.13	0.3	187.3239
12.5-13.5	0.27	0.6	2497.6512	26-28	0.39	0.8	499.5304
11.5-12.5	0.27	0.6	2497.6512	24-26	0.52	1.1	686.8543
10.5-11.5	0.27	0.6	2497.6512	22-24	0.63	1.3	811.7369
9.5-10.5	0.33	0.7	2913.9264	20-22	0.64	1.3	811.7369
8.5-9.5	0.33	0.7	2913.9264	18-20	0.89	1.9	1186.385
<8.5	1.43	3	12488.256	<18	3.42	7.1	4433.332

single axle					
equivalent stress	132.78	stress ratio	0.20747	erosion factor	2.24
tandem axle					
equivalent stress	129.94	stress ratio	0.20303	erosion factor	2.25

Table 5:

Axle Load	Design Load	Expected Repititions	Fatigue Analysis		Erosion Analysis	
			Allowable	Damage	Allowable	Damage
Single Axle						
20	53.04					
19	50.388	15818.46	101000	0.156618392	3000000	0.0052728
18	47.736	15402.18	300000	0.051340608	4000000	0.0038505
17	45.084	16234.73	500000	0.032469466	6000000	0.0027058
16	42.432	11239.43	600000	0.018732384	10000000	0.0011239
15	39.78	2497.651	10000000	0.000024976	11000000	0.0002271
14	37.128	1248.826	INFINITE	0	22000000	0
13	34.476	2497.651	INFINITE	0	60000000	0
12	31.824	2497.651	INFINITE	0	INFINITE	0
11	29.172	2497.651	INFINITE	0	INFINITE	0
10	26.52	2913.926	INFINITE	0	INFINITE	0
9	23.868	2913.926	INFINITE	0	INFINITE	0
8	21.216	12488.26	INFINITE	0	INFINITE	0
TOTAL DAMAGE				0.259185826		0.0131802
HENCE THE DESIGN IS SAFE FOR A PERIOD OF 20 YEARS.						

Table 6:

Axle load	Design load	Expected repititions	Fatigue analysis		Erosion analysis	
			Allowable	Damage	Allowable	Damage
Tandem axle						
42	105.84					
40	100.8	1873.239	101000	0.018546921	2100000	0.000892
38	95.76	1373.709	300000	0.004579029	3000000	0.0004579
36	90.72	499.5304	800000	0.000624413	11000000	0
34	85.68	312.2065	3000000	0.000104069	12000000	0
32	80.64	374.6478	10000000	0	INFINITE	0
30	75.6	187.3239	INFINITE	0	INFINITE	0
28	70.56	499.5304	INFINITE	0	INFINITE	0
26	65.52	686.8543	INFINITE	0	INFINITE	0
24	60.48	811.7369	INFINITE	0	INFINITE	0
22	55.44	811.7369	INFINITE	0	INFINITE	0
20	50.4	1186.385	INFINITE	0	INFINITE	0
18	45.36	4433.332	INFINITE	0	INFINITE	0
TOTAL DAMAGE				0.023854431		0.0014214
HENCE THE DESIGN IS SAFE FOR A PERIOD OF 20 YEARS.						

Table 7:

The thickness is sufficient since the cumulative fatigue damage is less than 1.

IV. Results and Discussions

The two methods compared in the study yields a pavement thickness of 30 cm and 12.5 inches by IRC and PCA method respectively. The thickness is a bit increased in case of PCA design method . However increasing the initial thickness results in the higher cost but the later maintenance costs are reduced .The FEM based method indicates that the flexural stresses are affected little by tyre pressure. The temperature stresses are not considered in the PCA design method whereas in IRC method the erosion damage is neglected.

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