THE STUDY OF CEMENTED TREATED BASE AND SUB-BASE WITH CRACK RELIEF INTERLAYER OF AGGREGATE BY USING OF IITPAVE SOFTWARE

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Abstract— **The Research topic is "Design of a Flexible Pavement with Cemented Base and Cemented Sub Base" consists of designing a flexible pavement using latest IRC recommendation given in IRC: 37-2012. The study aims at reducing the thickness of the pavement and provide economical design with cemented base and cemented sub base. The cemented base and cemented sub-base is an important layer in the pavement structure. It mainly acts as a structural layer helping to spread the wheel loads so that the sub grade is not overstressed. It also plays a useful role as a separation layer between the surface and sub grade and provides a good working platform on which the other paving material can be laid and compacted. It can also act as a drainage layer. The selection of material and the design of the cemented base and cemented sub-base will depend upon the particular design function of the layer and also the expected in-situ moisture conditions.**

.In place of conventional layers of GSB and WBM/WMM in sub-base and base course of the pavement, cement treated base and cement treated sub-base layers can also be provided. A crack relief layer of wet mix macadam of thickness 100 mm sandwiched between the bituminous layer and treated layer is much more effective in arresting the propagation of cracks from the cementitious base to the bituminous layer. The aggregate layer becomes stiffer under heavier loads because of high confining pressure. If there is shoving and deformation in the unbound layer caused by the construction traffic, the granular layer may be treated with 1 to 2 percent bitumen emulsion of grade MS to avoid reshaping.

Index Terms— **Flexible Pavement, IITPAVE Software, Loads, Thickness, Design.**

I. INTRODUCTION

The design in the study is carried out using traffic and soil data of a proposed 2-lane dual carriageway road of Haryana near Dhanana (Bhiwani) following latest IRC: 37-2012 guidelines. The design includes the use of both conventional materials like GSB and WMM as well as the non-conventional materials like cemented sub-base and cemented base in the pavement layers.

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The design is valid for the design of flexible pavements of new roads. This design is for main category roads such as Expressways, National Highways, Major District Roads and other roads carrying predominantly motorised vehicles. The given design is applicable for the roads having soil and traffic characteristics as mentioned in the research. The design however being general in nature can be made applicable to any other road having similar soil, traffic and roadway conditions as for the given road.

II. PAVEMENT DESIGN PROCEGURE AND USE OF IITPAVE SOFTWARE

The analysis and design of pavement may be carried out by following approach:

1. For traffic less than 2 msa, recommendation of IRC: SP: 72-2007 may be used.
2. In case of higher traffic, IITPAVE Software may be used. It is a multilayer elastic layer analysis programme.

The necessary steps required to use this software are:

A. Open the folder IRC_37_IITPAVE.
B. Double-click IITPAVE_EX_Start file in the IRC_37_IITPAVE folder. This is an executable jar file. A home screen will appear.
C. From the Home screen user can manually give input through input window by clicking on 'Design New Pavement Section'. User can also give input through properly formatted input file by clicking on 'Edit Existing File' option then browsing and opening the input file.
D. Next an input window will come. All the inputs required have to be given through that input window.
E. First, number of layers to be selected from drop down menu to fix up input boxes for different layer.
F. Next, Elastic modulus (E) values of the various layers in Mpa, Poisson's ratio and thickness of the layers in mm excluding the sub-grade thickness are to be provided.
G. Single wheel load and the tyre pressure are to be provided (tyre pressure of 0.56 Mpa has been used for calibration of the fatigue equation and the same pressure can be used for stress analysis. Change of pressure even up to 0.80 Mpa has a small effect upon stress values in lower layers.)
H. Then the number of points for stress computations is to be given through the drop down menu for Analysis points.
I. Then corresponding to different points, the values of depth Z in mm and the corresponding value of radial distances from centre (r) in mm are to be given

(wheel centre to centre distance of 310 mm is consider).

J. Provide whether analysis is for single wheel load or double wheel load by clicking 1 or 2. 2 will be the most common case.

K. The output of the programme will provide stresses, strains and deflections at the desired points. Next check if the computed strains are less than the permissible strain in the VIEW HERE icon. If not, then click BACK TO EDIT and run the program with a new thickness combination till the permissible strain values are achieved. epT, epR and epZ will be the outputs that will of interest. For cemented base, tensile stress at the bottom of the cemented layer SigmaT / SigmaR are needed for cumulative fatigue damage analysis.

L. In most cases the tensile strain at the bottom of the bituminous layer is higher in the longitudinal direction (epT) rather than in radial direction (epR). If tensile strain in the bituminous layer is high, increase the thickness of the bituminous layer.

M. Tensile strains in the cementitious bases also are to be computed for design. If the Tensile strain/stress in the cemented layer is higher, increase the thickness of the Cemented layer.

N. Vertical sub-grade strain (epZ) should be less than the permissible value for the design traffic. If the vertical sub-grade strain is higher, increase the thickness of sub-base layer.

O. Stress values can also be easily computed by changing directly the input file which is to be written in a illustrated in the manual and browse the input file by clicking 'Edit Existing File on home screen of IITPAVE'.

III. CALCULATION OF STRAIN

Allowable Horizontal Tensile Strain in Bituminous Layer (For 80% reliability)

Since N_f is less than 30 *msa* for design life of 5 years.

So, Bitumen Grade = VG 30

a) For n = 5 years, N_f = 14.98 *msa* (From equation 3.11)

$N_f = 2.21*10^{-04} \times [1/€_t]^{3.89} * [1/M_R]^{0.854}$

$14.98*10^{06} = 2.21*10^{-04} \times [1/€_t]^{3.89} \times [1/1700]^{0.854}$

$= 320.95 * 10^{-06}$

Therefore, $€_t = 320.95 * 10^{-06}$

Allowable Horizontal Tensile Strain in Bituminous Layer (For 90% reliability)

$N_f = 0.5161*C*10^{-04}*[1/M_{R\ \text{bituminous layer}}]^{0.854}$

(From equation 3.12)

Where, $C = 10^M$

And $M = 4.84*[V_b / (V_a + V_b) - 0.69]$

V_a = Volume of air voids.

V_b = Volume of bitumen

Since N_f is greater than 30 *msa* for design life of 10, 15 and 20 years.

So, Bitumen Grade = VG 40

$V_a = 3\%$

$V_b = 13\%$

So, $M = 4.84*[13 / (13+3) - 0.69]$

$= 0.5929$

And $C = 10^{0.5929}$

$= 3.9165$

a) For n = 10 years, N_f = 34.10 *msa*

For Equation (3.12)

$34.10*10^{06} = 0.5161*3.9165*10^{-04}*[1/€_t]^{3.89}*[1/3000]^{0.854}$

$[1/€_t]^{3.89} = 1.57247*10^{14}$

Therefore, $€_t = 224.12*10^{-06}$

b) For n = 15 years, N_f = 58.50 *msa*

For Equation (3.12)

$58.50*10^{06} = 0.5161*3.9165*10^{-04}[1/€_t]^{3.89}*[1/3000]^{0.854}$

$[1/€_t]^{3.89} = 2.6976489*10^{14}$

Therefore, $€_t = 195.08*10^{-06}$

c) For n = 20 years, N_f = 89.64 *msa*

For Equation (3.12)

$89.64*10^{06} = 0.5161*3.9165*10^{-04}[1/€_t]^{3.89}*[1/3000]^{0.854}$

$[1/€_t]^{3.89} = 4.1346863*10^{14}$

Therefore, $€_t = 174.81*10^{-06}$

4.6.3 Allowable Vertical Compressive Strain in the sub-grade (For 80% reliability)

Since N is less than 30 *msa* for design life of 5 years. (From equation 3.13)

$N = 4.1656 \times 10^{-08} [1/€_v]^{4.5337}$

Where, N = Number of cumulative standard axles, and

$€_v$ = Vertical strain in the Sub grade

a) For n = 5 years, N = 14.98 *msa*

For Equation (3.13)

$14.98*10^{06} = 4.1656 \times 10^{-08}\,[1/€_v]^{4.5337}$

$[1/€_v]^{4.5337} = 3.596120607*10^{14}$

Therefore, $€_v = 615.76*10^{-06}$

Allowable Vertical Compressive Strain in the sub-grade (For 90% reliability)

Since N is greater than 30 *msa* for design life of 10, 15 and 20 years.

$N = 1.41 \times 10^{-08} \times [1/€_v]^{4.5337}$ (From equation 3.14)

a) For n = 10 years, N = 34.10 *msa*

For Equation (3.14)

$34.10*10^{06} = 1.41 \times 10^{-08} \times [1/€_v]^{4.5337}$

$[1/€_v]^{4.5337} = 2418439716*10^{15}$

Therefore, $€_v = 404.43*10^{-06}$

b) For n = 15 years, N = 58.50 *msa*

For Equation (3.14)

$58.50*10^{06} = 1.41 \times 10^{-08} \times [1/€_v]^{4.5337}$

$[1/€_v]^{4.5337} = 4.148936170*10^{15}$

Therefore, $€_v = 359.04*10^{-06}$

c) For n = 20 years, N = 89.64 *msa*

For Equation (3.14)

$89.64*10^{06} = 1.41 \times 10^{-08} \times [1/€_v]^{4.5337}$

$[1/€_v]^{4.5337} = 6357446809*10^{15}$

Therefore, $€_v = 326.78*10^{-06}$

Computation of Actual Horizontal Tensile Strain in Bituminous Layer & Actual Vertical Compressive Strain on Sub-grade using IITPAVE Software

Actual strain is calculating using IITPAVE software and output file is given in below table 4.7, 4.8, 4.9 and 4.10. Critical Location for Strain is given in below fig. 4.4.

Granular Base and Granular Sub-base

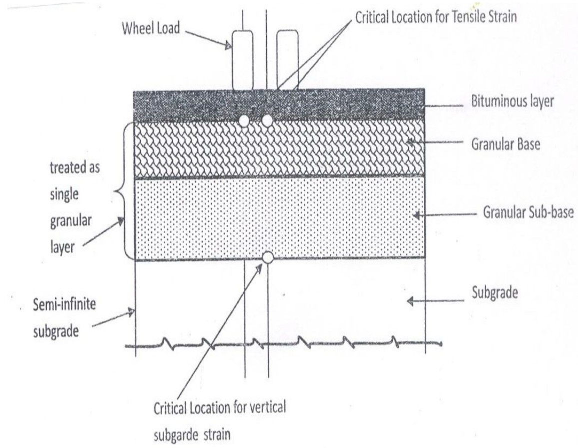

Fig 4.4 Critical Location for Strain Calculation

IV. ANALYSIS OF DESIGN

Computation of Actual Horizontal Tensile Strain in Bituminous Layer & Actual Vertical Compressive Strain on Sub-grade using IITPAVE Software given below Table:

Table 4.8 Output File of IITPAVE software for 5 years design life

Number of layers	3								
E values (Mpa)	3000.00	200.00	62.00						
Mu values	0.40	0.35	0.25						
Thicknesses (mm)	115.00	470.00							
Single wheel load (N)	20500.00								
Tyre pressure (Mpa)	0.56								
Dual Wheel									
Z	R	σ_Z	σ_T	σ_R	TaoRZ	DispZ	EpZ	epT	EpR
115.00	155.00	-0.1219E	0.7700E	0.3055E	0.6272E-01	0.4778E	0.1841E-03	0.2321E-03	0.1557E-04
115.00L	155.00	-0.1219E	0.1149E-01	-0.4355E-01	-0.6272E-01	0.4778E	0.5131E-03	0.2321E-03	0.1557E-04
115.00	0.00	-0.1430E	0.9648E	0.7860E	0.1746E-01	0.4658E	0.2814E-03	0.2356E-03	0.1523E-03
115.00L	0.00	-0.1430E	0.1118E-01	-0.2344E-01	-0.1746E-01	0.4658E	0.6546E-03	0.2356E-03	0.1523E-03
585.00	0.00	-0.2082E-01	0.2873E-01	0.2484E-01	-0.3544E-02	0.3162E	0.1979E-03	0.1368E-03	0.1106E-03
585.00L	0.00	-0.2083E-01	0.3937E-02	0.2727E-02	-0.3544E-02	0.3162E	0.3629E-03	0.1368E-03	0.1100E-03

The output file as obtained using IITPAVE software as shown above. From this data the maximum value of both horizontal tensile and vertical compressive strain is chosen as

Maximum Horizontal Tensile Strain $=235.6*10^{-06}$

Maximum Vertical Compressive Strain $= 362.9*10^{-06}$

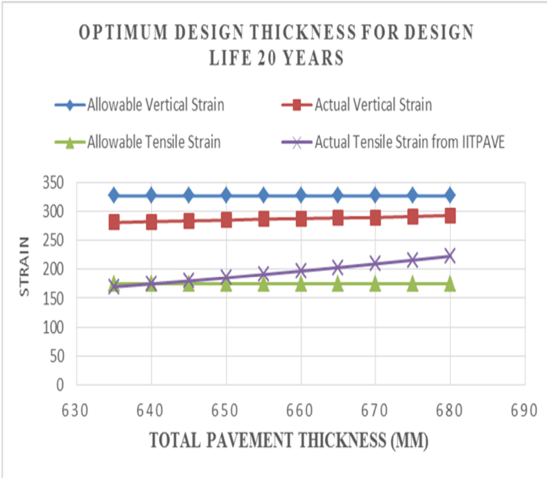

Fig. 4.8 Comparison of Strain and Total Pavement Thickness

5. CUMULATIVE FATIGUE DAMAGE ANALYSIS

Since there are plenty of single, tandem and tridem axle loads which are far higher than standard axle loads used for pavement design, thickness of cement layer must be checked for sudden fracture of the brittle material like cemented base due to higher axle loads using cumulative damage principle. One tandem axle is taken as two single axles and one tridem axle is taken as three axles carrying equal weight since the interference of stresses at the cemented base are little due to axle loads being about 1.30 to 1.4 m apart. All multiple axle vehicles are combination of single, tandem and tridem axles. Result shown in below Table:

Table 1: Cumulative Fatigue Analysis for Single Axle for 5 years design life

Axle Load Class	Axle Load	% of Axles	Expected Repetition	Single Wheel Load	Stress in Mpa from IITPAVE	Stress Ratio	Fatigue life from eqn. 3.15	Fatigue life Consumed
1	2	3	4	5	6	7	8	9 = 4/8
185-195	190	1.1834	30252.01426	47500	0.7839	0.560	9.88E+04	0.3061605
175-185	180	1.4793	37816.29601	45000	0.7500	0.536	1.94E+05	0.1947006
165-175	170	1.3018	33278.74951	42500	0.7155	0.511	3.86E+05	0.0861299
155-165	160	4.142	105884.6063	40000	0.6802	0.486	7.81E+05	0.1355789
145-155	150	1.4793	37816.29601	37500	0.6440	0.460	1.61E+06	0.0235298
135-145	140	1.7751	45378.02139	35000	0.6072	0.434	3.35E+06	0.0135572
125-135	130	2.3668	60504.02852	32500	0.5696	0.407	7.08E+06	0.0085422
115-125	120	3.5503	90758.59915	30000	0.5311	0.379	1.53E+07	0.0059475
105-115	110	4.7337	121010.6134	27500	0.4918	0.351	3.34E+07	0.0036225
95-105	100	4.7337	121010.6134	25000	0.4516	0.323	7.44E+07	0.0016254
85-95	90	4.4378	113446.3317	22500	0.4106	0.293	1.69E+08	0.0006729
< 85	85	13.7869	352443.3796	21250	0.3898	0.278	2.55E+08	0.0013809
Total		44.9701		Cumulative Damage				0.7814484

Table 2: Cumulative Fatigue Analysis for Tandem Axle for 5 years design life

Axle Load Class	Axle Load	% of Axles	Expected Repetition	Single Wheel Load	Stress in Mpa from IITPAVE	Stress Ratio	Fatigue life from eqn. 3.15	Fatigue life Consumed
1	2	3	4	5	6	7	8	9 = 4/8
390-410	400	0	0	50000	0.8170	0.584	5.11E+04	0.0000000
370-390	380	0	0	47500	0.7839	0.560	9.88E+04	0.0000000
350-370	360	1.4792	37813.739	45000	0.7500	0.536	1.94E+05	0.1946874

			65					
330-350	340	0	0	42500	0.7155	0.511	3.86E+05	0.0000000
310-330	320	2.6627	68068.310 27	40000	0.6802	0.486	7.81E+05	0.0871574
290-310	300	0	0	37500	0.6440	0.460	1.61E+06	0.0000000
270-290	280	2.071	52942.303 14	35000	0.6072	0.434	3.35E+06	0.0158171
250-270	260	0	0	32500	0.5696	0.407	7.08E+06	0.0000000
230-250	240	0	0	30000	0.5311	0.379	1.53E+07	0.0000000
210-230	220	0	0	27500	0.4918	0.351	3.34E+07	0.0000000
190-210	200	0	0	25000	0.4516	0.323	7.44E+07	0.0000000
170-190	180	0	0	22500	0.4106	0.293	1.69E+08	0.0000000
< 170	170	13.0177	332779.82 6	21250	0.3898	0.278	2.55E+08	0.0013039
Total		19.2306		Cumulative Damage				0.2989658

Design life n = 10 years

Table 3: Cumulative Fatigue Analysis for Single Axle for 10 years design life

Axle Load Class	Axle Load	% of Axles	Expected Repetition	Single Wheel Load	Stress in Mpa from IITPAVE	Stress Ratio	Fatigue life from eqn. 3.15	Fatigue life Consumed
1	2	3	4	5	6	7	8	9 = 4/8
185-195	190	1.1834	68862.102 29	47500	0.6666	0.476	1.02E+06	0.0672343
175-185	180	1.4793	86080.537 37	45000	0.6365	0.455	1.87E+06	0.0461221
165-175	170	1.3018	75751.803 93	42500	0.6059	0.433	3.44E+06	0.0220527
155-165	160	4.142	241023.17 7	40000	0.5748	0.411	6.39E+06	0.0377454
145-155	150	1.4793	86080.537 37	37500	0.5432	0.388	1.20E+07	0.0071799
135-145	140	1.7751	103293.15 34	35000	0.5111	0.365	2.27E+07	0.0045432
125-135	130	2.3668	137724.20 46	32500	0.4784	0.342	4.36E+07	0.0031563
115-125	120	3.5503	206592.12 59	30000	0.4451	0.318	8.47E+07	0.0024377
105-115	110	4.7337	275454.22 82	27500	0.4114	0.294	1.66E+08	0.0016601
95-105	100	4.7337	275454.22 82	25000	0.3771	0.269	3.29E+08	0.0008379
85-95	90	4.4378	258235.79 31	22500	0.3421	0.244	6.61E+08	0.0003909
< 85	85	13.7869	802260.36 68	21250	0.3244	0.232	9.40E+08	0.0008534
Total		44.9701		Cumulative Damage				0.1942139

Table 4: Cumulative Fatigue Analysis for Single Axle for 15 years design life

Axle Load Class	Axle Load	% of Axles	Expected Repetition	Single Wheel Load	Stress in Mpa from IITPAVE	Stress Ratio	Fatigue life from eqn. 3.15	Fatigue life Consumed

1	2	3	4	5	6	7	8	9 = 4/8
185-195	190	1.1834	118139.4458	47500	0.6791	0.485	7.98E+05	0.1479893
175-185	180	1.4793	147679.2988	45000	0.6489	0.464	1.46E+06	0.1013172
165-175	170	1.3018	129959.3802	42500	0.6182	0.442	2.69E+06	0.0483471
155-165	160	4.142	413498.0433	40000	0.5869	0.419	5.02E+06	0.0824215
145-155	150	1.4793	147679.2988	37500	0.5550	0.396	9.48E+06	0.0155846
135-145	140	1.7751	177209.1687	35000	0.5225	0.373	1.81E+07	0.0097831
125-135	130	2.3668	236278.8916	32500	0.4895	0.350	3.50E+07	0.0067562
115-125	120	3.5503	354428.3204	30000	0.4558	0.326	6.85E+07	0.0051764
105-115	110	4.7337	472567.7662	27500	0.4215	0.301	1.36E+08	0.0034833
95-105	100	4.7337	472567.7662	25000	0.3866	0.276	2.72E+08	0.0017371
85-95	90	4.4378	443027.9133	22500	0.3511	0.251	5.52E+08	0.0008025
< 85	85	13.7869	1376353.494	21250	0.3367	0.241	7.36E+08	0.0018710
Total		44.9701		Cumulative Damage				0.4252695

Table 5: Cumulative Fatigue Analysis for Single Axle for 20 years design life

Axle Load Class	Axle Load	% of Axles	Expected Repetition	Single Wheel Load	Stress in Mpa from IITPAVE	Stress Ratio	Fatigue life from eqn. 3.15	Fatigue life Consumed
1	2	3	4	5	6	7	8	9 = 4/8
185-195	190	1.1834	181031.2107	47500	0.6744	0.482	8.77E+05	0.2064887
175-185	180	1.4793	226296.6622	45000	0.6442	0.460	1.60E+06	0.1413674
165-175	170	1.3018	199143.5103	42500	0.6134	0.438	2.96E+06	0.0673241
155-165	160	4.142	633624.5351	40000	0.5822	0.416	5.51E+06	0.1150023
145-155	150	1.4793	226296.6622	37500	0.5503	0.393	1.04E+07	0.0217451
135-145	140	1.7751	271546.8161	35000	0.5180	0.370	1.98E+07	0.0137049
125-135	130	2.3668	362062.4215	32500	0.4850	0.346	3.83E+07	0.0094645
115-125	120	3.5503	543108.9298	30000	0.4515	0.323	7.46E+07	0.0072805
105-115	110	4.7337	724140.1405	27500	0.4173	0.298	1.48E+08	0.0049090
95-105	100	4.7337	724140.1405	25000	0.3827	0.273	2.94E+08	0.0024628
85-95	90	4.4378	678874.689	22500	0.3474	0.248	5.94E+08	0.0011423
< 85	85	13.7869	2109057.968	21250	0.3294	0.235	8.51E+08	0.0024787
Total		44.9701		Cumulative Damage				0.5933701

Total Fatigue Damage = Sum of Cumulative Damage due to Single, Tandem and Tridem axle in Table 5.22 given below.

Table 6: Check for safety

Design Life in years	Total Thickness of Pavement (mm)	Cumulative Damage Factor in Single axle	Cumulative Damage Factor in Tandem axle	Cumulative Damage Factor in Tridem axle	Total Cumulative Damage Factor	Result	Remark
1	2	3	4	5	6 = 3+4+5	7	8
5	520	0.7814484	0.2989658	0.3711207	1.4515349	> 1	Unsafe
10	540	0.1942139	0.0764901	0.0967826	0.3674866	< 1	Safe
15	550	0.4252695	0.1674758	0.2115234	0.8042687	< 1	Safe
20	550	0.5933701	0.2336172	0.2949333	1.1219206	> 1	Unsafe

It can be seen that total fatigue damage is greater than 1, in case of design life 5 and 20 years. Hence the pavement is unsafe and cemented layer will crack prematurely. It can also notice that the Single axle weighing 190 KN causes maximum fatigue damage followed by Tandem axle load of 360 KN.

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CONCLUSIONS

In this study a flexible pavement has been designed using conventional as well as non-conventional layers in its structure. In conventional design various layers in the pavement structure consist of GSB in the sub base, WBM/WMM in the base course, DBM in the binder course and BC in the wearing course of the pavement. In non-conventional design of pavement, cement treated sub base and base are provided in addition to DBM and BC. A crack relief interlayer of aggregate is provided in between DBM binder course and cemented base course. The design of the pavement has been carried out with a view to determine the suitability and economics of providing non-conventional layers in the pavement. The design has been carried out using traffic and soil data of a proposed 2-lane dual carriageway road of Haryana near Dhanana (Bhiwani) following latest IRC: 37-2012 guidelines, the length of the proposed road is about 17.0 km. The main conclusions drawn from the study are:

The road is expected to carry 1690 CVPD after its completion. The vehicle damage factor for the given data of traffic is found to be 5.86. The design CBR (effective CBR) value of the subgrade soil at 90% reliability level is found to be 7.3%.

Full design life of the road has been taken as 20 years whereas provision has been made in the design for stage construction for 5 years, 10 years and 15 years design period. The design traffic for 5/10/15 and 20 years is found to be 14.98/34.10/58.50 and 89.64 msa respectively.

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