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Design and analysis of Cement Treated Base for Flexible Pavement as per IRC 37-2018.

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Abstract

Majority of Indian highways are flexible pavements. The conventional type flexible pavements have granular base course over which bituminous courses are laid. These pavements have no or very negligible flexural strength instead they are flexible in nature. As per IRC 37-2018, Cement Treated Base for flexible pavement is permitted. In this study a Major District Road (MDR) namely Teesta Mahananda Link Canal (TMLC) Road at Jalpaiguri District in West Bengal is selected. The base and sub-base layers of the selected road are granular type. In this study an attempt is made to design the flexible pavement with Cement Treated Base as per the IRC 37-2018 and analysis of the flexible pavement is done with the help of IITPAVE software. The economic comparison is also done between the Cement Treated Base and the granular type.

Keywords: Flexible pavement, Cement Treated Base, IITPAVE, IRC 37-2018.

1. Introduction

Flexible pavements are by definition flexible in nature which means the load transference mechanism in mainly due to grain to grain contact among the materials present in the pavement and at the same time deformation occurs in the underneath layers will be visible on the top layer. Flexible pavements are mainly constructed with granular sub-base and base course and at top there will be one or more bituminous layers to provide structural and functional requirement within its intended life span.IRC37-2018 also allows Cement Treated base and sub-base for flexible pavement which will be advantageous over conventional granular base and sub-base courses. In this study a study a Major District Road (MDR) namely Teesta Mahananda Link Canal (TMLC) Road at Jalpaiguri District in West Bengal is selected. The existing pavement crust consists of granular base course. The State PWD is doing Strengthening work by means of overlaying of bituminous layers. An attempt will be made in the study to design and analyse cement treated base (CTB) for the road. Cement treated base are those where cementitious materials like cement , lime , lime-fly ash or any other commercially stabilising agents are mixed in aggregates or soil-aggregate mixtures. Cost comparison of the flexible pavement with CTB and with conventional granular base is also done.

2. Objectives & Methodology

The main objective of the study is to evaluate the justification of replacing conventional granular base with modern type cement treated base. Cement treated base has many advantages like long lasting, higher load taking ability, has some flexural strength etc. Apart from these benefits the CTB will reduce the thickness of bituminous layer which most expensive part of pavement construction.

As per IRC37-2018, the CTB should be checked for fatigue and Cumulative Fatigue Damage in addition to other checks viz. subgrade rutting and fatigue cracking for bituminous layers check. The mechanistic parameters like elastic modulus, poisson's ratio etc. are the design inputs. The analysis of the CTB will be done with IITPAVE software. The maximum strains are determined and the values should be within the limiting value. The strains are evaluated on the critical locations as mentioned in the code. In the present study, the design of CTB has been carried out as per IRC 37-2018. The cost of construction of flexible pavement with CTB and cost of construction with conventional granular base is also done as per the Schedule of Rates, PWD (Roads & Bridge works -2018) Govt. of West Bengal. The cost analysis is done in accordance with MORTH specification fifth revision also.

3. Design and Analysis of flexible pavement.

The design of flexible pavement as per IRC37-2018 is based on mechanistic-empirical approach. The linear elastic theory is used where pavements are modelled as a multi-layered system. To begin with the design traffic is determined based on traffic census and CBR test and other geotechnical tests are carried out. A trail composition is then selected based on experience or provisions envisaged in the Code. The maximum strains at critical locations are obtained from IITPAVE software. The elastic modulus, poisson's ratio and thickness of the different layers are the inputs. For dual wheel configuration a design load of 20KN is applied with 0.80MPa tire pressure for analysis of CTB layer. In case of granular layer a tire pressure of 0.56 MPa is considered. The maximum strain values are compared with the limiting strain values which obtained from the performance criteria mentioned in the code.

3.1 Technical details of the road.

The present width of the road is 5.50m and the existing surface is Semi Dense Bituminous Concrete (SDBC) over Bituminous Macadam (BM). The top surface of the road has got hungry at places. So proper strengthening work with bituminous overlay with Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC) has been considered by the executing agency. The Commercial vehicles per day (CVPD) as per the traffic survey results of seven day twenty four hours comes as 638. The California Bearing Ratio (CBR) value is 6%. From axle load survey data, Vehicle Damage Factor (VDF) is 52.5.

3.2 Determination of Design traffic

As per the guidelines given in code, for estimation of the present day average traffic a seven day 24 hours traffic volume count is done.

The commercial vehicle per (CVPD) having gross weight of 3tonnes or more = 638

The vehicle damage factor is obtained as 52.2 from axle load survey.

The lateral distribution factor is taken as 0.75 for intermediate lane (5.5m)

$A = P \times (1 + r)^{x}$

Where

A = No. of commercial vehicles per day at the end of "n" years during project

P = No. of commercial vehicles per day at last count=638

r = Annual growth rate =5%

x = Number of years between the last count and the year of completion of construction =1.5 years

Therefore A= 686.443

Design traffic will be obtained by the formula given below.

$$N_{Des} = \frac{365 \times [(1+r)^{n}-1]}{r} \times \mathrm{A} \times \mathrm{D} \times \mathrm{F}$$

Where

A= No. of commercial vehicles per day at the end of "n" years during project =686.443

D= Vehicle damage factor (VDF) =52.5

F= Lateral distribution factor =0.75

r = Growth rate=5%

n= Design period, in years =15 years

N_{Des} =212892808

= 212.89 msa

3.3 Determination of effective CBR/Resilient Modulus of soil subgrade

CBR test have been carried on 4 days soaked soil sample on various spots along the road stretch. The design CBR is taken the 90th percentile subgrade CBR value. The design CBR value is 6%. Hence resilient modulus of the subgrade will determined from the formulae given below.

$$M_{RS} = 10.0 * CBR \quad \text{for CBR} \leq 5\,\%$$

$$M_{RS} = 17.6 * (CBR)^{0.64} \quad \text{for CBR} > 5\,\%$$

Where
M_{RS} = Resilient Modulus of subgrade soil in MPa
CBR= California bearing ratio (in percent) of subgrade soil.
Here for 6% CBR value, Resilient Modulus of subgrade soil is 55.4 MPa. The subgrade is improved by River bed materials (RBM) layer of 100mm thickness whose CBR value is 20%. The resilient modulus of existing RBM layer is 119.72 MPa. Therefore effective CBR is to be determined using IITPAVE software. The poisson's ratio of subgrade soil is taken as 0.35. From IITPAVE software, maximum surface deflection is obtained as 2.174 mm.

```
No. of layers              2
E values (MPa)          119.72   55.40
Mu values                 0.350.35
thicknesses (mm)        100.00
single wheel load (N) 40000.00
tyre pressure (MPa)       0.56
Single Wheel
  Z        R      SigmaZ      SigmaT     SigmaR     TaoRZ      DispZ      epZ        epT        epR
  0.00    0.00-0.5525E+00-0.6665E+00-0.6665E+00 0.0000E+00 0.2174E+01-0.7180E-03-0.2004E-02-0.2004E-02
```

Now using the maximum surface deflection, the resilient modulus of the equivalent single layer is determined from the formula given below.

$$M_{RS} = \frac{2(1-\mu^2)pa}{\delta}$$

where
p = contact pressure = 0.56 MPa
a = radius of circular contact area, which can be calculated using the load applied(40,000 N) and the contact pressure 'p' (0.56 MPa) = 150.8 mm
μ = Poisson's ratio
δ = Maximum surface deflection
From the above formula, resilient modulus of the equivalent single layer is obtained as 68.17 MPa. This value will be used in design. The corresponding effective CBR value is 8.30%.

3.4 Design and Analysis of Cement Treated Base.

Initially the following compositions are considered.
a) 100mm thick bituminous course comprising of bituminous concrete and dense bituminous macadam with VG40 grade bitumen.
b) 100mm granular crack relief layer.
c) 150mm cement treated base course
d) 250mm cement treated sub-base course.
e) Subgrade
The elastic properties of different layers are as follows.

Sl no	Layer details	Elastic modulus in MPa	Poisson's ratio	Reference
1	Bituminous layer	3000	0.35	Table 11.1 ,IRC37-2018
2	Granular crack relief layer	450	0.35	Do
3	Cement treated base	5000	0.25	Do
4	Cement treated sub-base	600	0.25	Do
5	Soil subgrade	68.17	0.35	Do

Table: 1

Subgrade rutting check

Following performance models are used for subgrade rutting cheek for different percentage of reliability. Here 90% reliability is considered since the design traffic is more than 20msa.

$N_R = 4.1656 \times 10^{-08} [1/\varepsilon_v]^{4.5337}$ (for 80 % reliability)

$N_R = 1.4100 \times 10^{-08} [1/\varepsilon_v]^{4.5337}$ (for 90 % reliability)

Where

N_R = subgrade rutting life (cumulative equivalent number of 80 kN standard axle loadsthat can be served by the pavement before the critical rut depth of 20 mm or moreoccurs)

ε_V = vertical compressive strain at the top of the subgrade calculated using linear elastic layered theory by applying standard axle load at the surface of the selected pavement system

Substitute NR with design traffic to obtain allowable vertical strain ε_V.

ε_V allowable = 0.00027

Now find maximum vertical compressive strain using IITPAVE software.

ε_V= 0.00022 which is less than allowable strain. Hence safe.

Fatigue cracking check for bituminous layer

Following performance models are used for fatigue cracking check for bituminous layer for different percentage of reliability. Here 90% reliability is considered since the design traffic is more than 20msa.

$N_f = 1.6064*C*10^{-04} [1/\varepsilon_t]^{3.89}* [1/M_{Rm}]^{0.854}$ (for 80 % reliability)

$N_f = 0.5161*C*10^{-04} [1/\varepsilon_t]^{3.89}* [1/M_{Rm}]^{0.854}$ (for 90 % reliability)

Where

$C = 10^M$, and $M = 4.84 \left(\frac{Vbe}{Va+Vbe} - 0.69\right)$

V_a = per cent volume of air void in the mix used in the bottom bituminous layer

V_{be} = per cent volume of effective bitumen in the mix used in the bottom bituminouslayer

N_f = fatigue life of bituminous layer (cumulative equivalent number of 80 kN standardaxle loads that can be served by the pavement before the critical cracked area of 20% or more of paved surface area occurs)

ε_t = maximum horizontal tensile strain at the bottom of the bottom bituminous layer(DBM) calculated using linear elastic layered theory by applying standard axle loadat the surface of the selected pavement system

M_{Rm} = resilient modulus (MPa) of the bituminous mix used in the bottom bituminous layer.

Here as per the guidelines given in the code(12.3,page no 37), for flexible pavement with CTB , V_a and V_{be} are taken as 3.5% and 11.5% respectively and factor C will be 2.35. Resilient modulus for above equation is 3000 MPa. Substituting N_f as the design traffic to obtain allowable tensile strain at the bottom of the bituminous layer.

Allowable tensile strain ε_t =0.000122.

Maximum strain at bottom of the bituminous layer is obtained using IITPAVE software.

Maximum strain ε_t =0.000128 which is greater than the allowable strain, Unsafe.

Hence increase the depth of bituminous layer to 110mm.

Now with increased depth of bituminous layer, maximum tensile strain is 0.000121 which is less than the allowable strain. Hence safe.

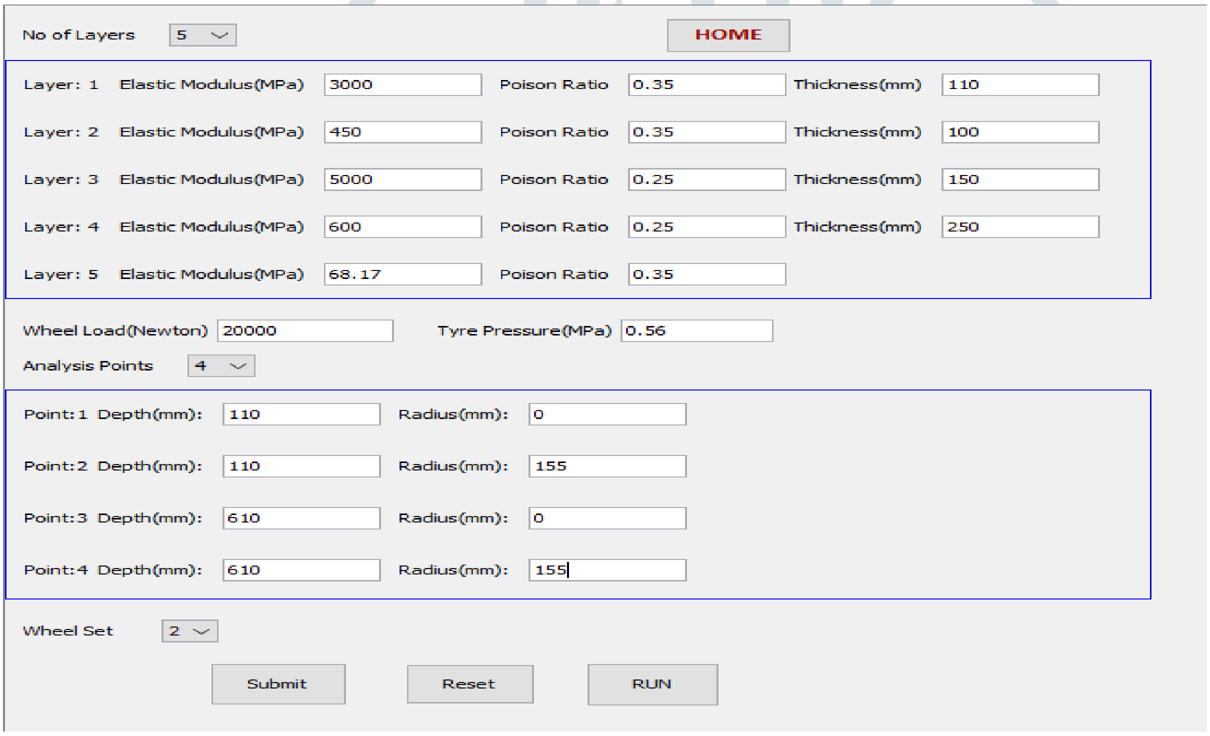

Figure: 1

```
No. of layers                5
E values (MPa)          3000.00  450.00 5000.00  600.00   68.17
Mu values                  0.350.350.250.250.35
thicknesses (mm)         110.00  100.00  150.00  250.00
single wheel load (N) 20000.00
tyre pressure (MPa)        0.56
Dual  Wheel
  Z        R       SigmaZ       SigmaT      SigmaR      TaoRZ       DispZ       epZ         epT         epR
110.00     0.00-0.2419E+00 0.3832E+00 0.2976E+00-0.1464E-01 0.2619E+00-0.1600E-03 0.1212E-03 0.8273E-04
110.00L    0.00-0.2419E+00-0.5322E-01-0.6605E-01-0.1464E-01 0.2619E+00-0.4447E-03 0.1212E-03 0.8273E-04
110.00   155.00-0.1761E+00 0.1979E+00-0.1725E+00-0.7459E-01 0.2582E+00-0.6166E-04 0.1066E-03-0.6006E-04
110.00L 155.00-0.1761E+00-0.5091E-01-0.1065E+00-0.7460E-01 0.2582E+00-0.2689E-03 0.1066E-03-0.6006E-04
610.00     0.00-0.1115E-01 0.4791E-01 0.4232E-01-0.1587E-02 0.2108E+00-0.5618E-04 0.6686E-04 0.5522E-04
610.00L    0.00-0.1114E-01 0.6967E-03 0.1056E-03-0.1587E-02 0.2108E+00-0.1675E-03 0.6686E-04 0.5515E-04
610.00   155.00-0.1175E-01 0.5047E-01 0.4691E-01-0.2065E-02 0.2142E+00-0.6017E-04 0.6947E-04 0.6205E-04
610.00L 155.00-0.1175E-01 0.7549E-03 0.3803E-03-0.2065E-02 0.2142E+00-0.1783E-03 0.6947E-04 0.6205E-04
```

Figure: 2

Fatigue performance check for CTB

As per code the formula given below is to be used for fatigue performance check for CTB.

$$N = RF\left[\frac{\left(\frac{113000}{E^{0.804}}+191\right)}{\varepsilon_t}\right]^{12}$$

Where

RF = reliability factor for cementitious materials for failure against fatigue

N = No of standard axle load repetitions which the CTB can sustain

E = elastic modulus of CTB material (MPa)

εt = tensile strain at the bottom of the CTB layer (micro strain).

Here RF is taken as 1 for design traffic more than 10 msa, E is taken as 5000 MPa and limiting tensile strain is obtained by substituting the N with design traffic.

Limiting tensile strain is 75.28 micro strain

Now using IITPAVE software, determine the tensile strain at the bottom of CTB for 80 KN standard axle (single axle dual wheels) load with 0.80 MPa contact pressure.

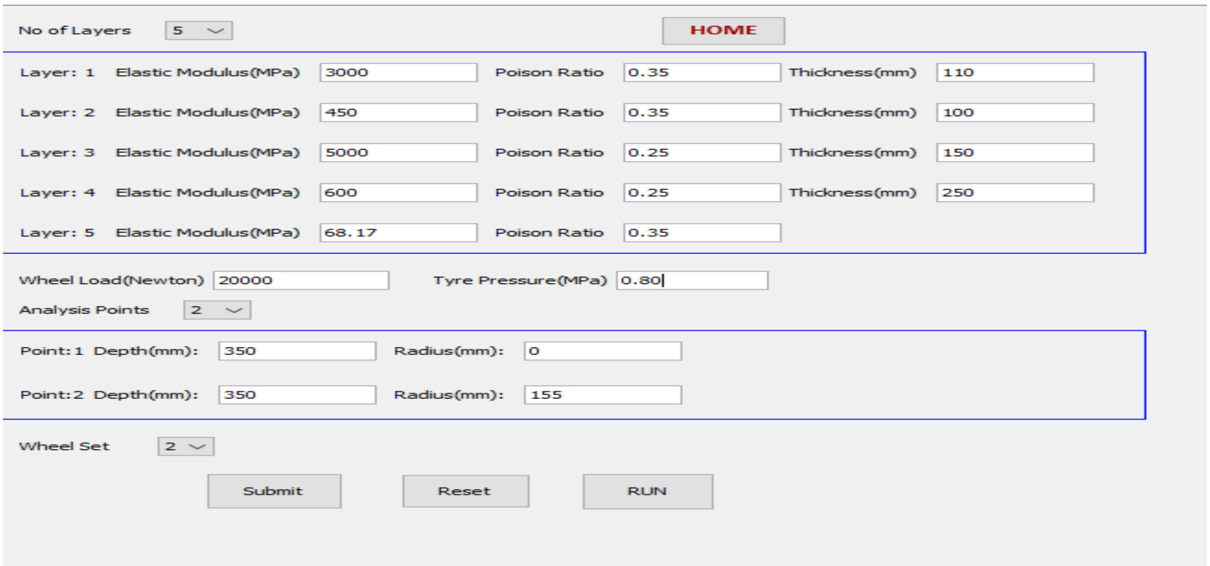

Figure: 3

```
No. of layers              5
E values (MPa)          3000.00  450.00 5000.00  600.00   68.17
Mu values                   0.350.350.250.250.35
thicknesses (mm)          110.00  100.00  150.00  250.00
single wheel load (N) 20000.00
tyre pressure (MPa)         0.80
Dual  Wheel
  Z        R      SigmaZ       SigmaT      SigmaR      TaoRZ       DispZ       epZ         epT         epR
350.00    0.00-0.4595E-01 0.2221E+00 0.1759E+00-0.1894E-01 0.2264E+00-0.2909E-04 0.3792E-04 0.2637E-04
350.00  155.00-0.5070E-01 0.2404E+00 0.1955E+00-0.3892E-01 0.2314E+00-0.3194E-04 0.4083E-04 0.2962E-04
```

Figure: 4

Maximum tensile strain =40.83 micro strain which less than the limiting value.

Hence safe.

Cumulative fatigue damage analysis

The cumulative fatigue damage of CTB layer is due to the application of axle loads of different categories and magnitudes applied over design life period. The fatigue life Nfi of the CTB material when subjected to a specific number of applications (ni) of axle load of class 'i' during the design period, is given below.

$$log_{10}N_{fi} = \frac{0.972-(\sigma\, t/M_{Rup})}{0.0825}$$

Where

Nfi = Fatigue life of CTB material which is the maximum repetitions of axle load class 'i' the CTB material can sustain

σt = tensile stress at the bottom of CTB layer for the given axle load class.
MRup = 28-day flexural strength of the cementitious base.
σt/MRup = Stress Ratio.
The cumulative fatigue damage (CFD) caused by different repetitions of axle loads of different categories and different magnitudes expected to be applied on the pavement during its design period is estimated using the formula given below.

$$CFD = \Sigma(n_i/N_{fi})$$

Where
ni = Expected (during the design life period) repetitions of axle load of class 'i'
Nfi = Fatigue life or maximum number of load repetitions the CTB layer would sustain if only axle load of class 'i' were to be applied.
If the estimated CFD is less than 1.0, the design is considered to be acceptable. If the value of CFD is more than 1.0, the pavement section has to be revised.

Axle load spectrum is prepared with the help of axle load survey data.

Single Axle Single wheel		Single Axle Dual wheel		Tandem Axle	
Axle Load class (KN)	Expected Repetitions	Axle Load class (KN)	Expected Repetitions	Axle Load class (KN)	Expected Repetitions
150-140	5475	290-280	10950	560-540	5475
140-130	5475	280-270	10950	540-520	5475
130-120	5475	270-260	27375	520-500	10950
120-110	0	260-250	82125	500-480	5475
110-100	21900	250-240	76650	480-460	5475
100-90	197100	240-230	93075	460-440	0
90-80	202575	230-220	93075	440-420	0
80-70	142350	220-210	54750	420-400	5475
70-60	87600	210-200	71175	400-380	5475
60-50	142350	200-190	21900	380-360	5475
50-40	147825	190-180	21900	360-340	0
40-30	76650	180-170	21900	340-320	0
30-20	10950	170-160	21900	320-300	0
		160-150	32850	300-280	0
		150-140	10950	280-260	0
		140-130	10950	260-240	0
		130-120	54750	240-220	0
		120-110	32850	220-200	5475
		110-100	49275	200-180	0
		100-90	10950	180-160	0
		90-80	10950	160-140	0
		80-70	0	140-120	0
		70-60	0	120-100	10950
		60-50	27375	100-80	49275
		50-40	43800	80-60	16425
		40-30	5475		
		30-20	10950		

Table: 2

Cumulative fatigue damage analysis for Single Axle Single Wheel
Modulus of Rapture (flexural strength) of the cementitious base =1.4MPa
Stress ratio= Tensile stress at the bottom of the CTB due to applied load divided by Modulus of Rapture.

The tensile stress at the bottom of the CTB each axle load will be obtained using IITPAVE software.

Table:3 Cumulative fatigue damage analysis for Single axle single wheel configuration					
Single Axle Load (KN)	Expected Single Axle Repetitions (ni)	Tensile Stress at the bottom of CTB σt (Mpa)	Stress Ratio (σt/Mrup)	Fatigue Life (Nf)	Fatigue life Consumed (ni/Nf)
145	5475	0.53	0.38	15598167.98	0.00
135	5475	0.5	0.36	28367029.01	0.00
125	5475	0.48	0.34	42264333.63	0.00
105	21900	0.4	0.29	208264246.1	0.00
95	197100	0.37	0.26	378752038	0.00
85	202575	0.33	0.24	840766356	0.00
75	142350	0.3	0.21	1529028514	0.00
65	87600	0.26	0.19	3394188289	0.00
55	142350	0.23	0.16	6172714500	0.00
45	147825	0.19	0.14	13702396704	0.00
35	76650	0.15	0.11	30417035393	0.00
25	10950	0.11	0.08	67520745613	0.00
				total	0.00

Cumulative fatigue damage analysis for Single Axle Dual Wheel

Table:4 Cumulative fatigue damage analysis for Single Axle Dual Wheel configurations					
Single Axle Load (KN)	Expected Single Axle Repetitions (ni)	Tensile Stress at the bottom of CTB σt (Mpa)	Stress Ratio (σt/Mrup)	Fatigue Life (Nf)	Fatigue life Consumed (ni/Nf)
285	10950	0.90	0.64	9763.61	1.12
275	10950	0.86	0.61	21673.58	0.51
265	27375	0.83	0.59	39415.86	0.69
255	82125	0.78	0.56	106800.04	0.77
245	76650	0.75	0.54	194227.93	0.39
235	93075	0.72	0.51	353225.42	0.26
225	93075	0.69	0.49	642380.29	0.14
215	54750	0.66	0.47	1168241.06	0.05
205	71175	0.64	0.46	1740574.60	0.04
195	21900	0.61	0.44	3165431.36	0.01
185	21900	0.58	0.41	5756694.20	0.00
175	21900	0.55	0.39	10469198.15	0.00
165	21900	0.52	0.37	19039418.48	0.00
155	32850	0.49	0.35	34625331.45	0.00
145	10950	0.46	0.33	62970073.34	0.00
135	10950	0.43	0.31	114518185.69	0.00
125	54750	0.4	0.29	208264246.13	0.00
115	32850	0.37	0.26	378752037.98	0.00
105	49275	0.34	0.24	688803330.10	0.00
95	10950	0.31	0.22	1252666599.72	0.00
85	10950	0.28	0.20	2278115597.73	0.00

55	27375	0.18	0.13	16725404249.64	0.00
45	43800	0.15	0.11	30417035393.06	0.00
35	5475	0.12	0.09	55316811976.17	0.00
25	10950	0.08	0.06	122794096837.14	0.00
				Total	3.99

Cumulative fatigue damage analysis for tandem axle.

Table: 5 Cumulative fatigue damage analysis for Tandem Axles

Tandem Axle Load (KN)	Expected Single Axle Repetitions (ni)=Tandem axle X2	Tensile Stress at the bottom of CTB σt (Mpa)	Stress Ratio (σt/Mrup)	Fatigue Life (Nf)	Fatigue life Consumed (ni/Nf)
550	10950	0.86	0.61	21673.58	0.51
530	10950	0.83	0.59	39415.86	0.28
510	21900	0.78	0.56	106800	0.21
490	10950	0.75	0.54	194227.9	0.06
470	10950	0.72	0.51	353225.4	0.03
410	10950	0.69	0.49	642380.3	0.02
390	10950	0.66	0.47	1168241	0.01
370	10950	0.64	0.46	1740575	0.01
210	10950	0.34	0.24	6.89E+08	0.00
110	21900	0.18	0.13	1.67E+10	0.00
90	98550	0.15	0.11	3.04E+10	0.00
70	32850	0.12	0.09	5.53E+10	0.00
				total	1.10

Therefore Cumulative fatigue damage =0.00+3.99+1.10=5.09>1.0
Hence the pavement section is revised and the depth of the CTB is increased to 210mm and cumulative fatigue damage analysis is done.
The revised pavement compositions are as follows
110mm thick bituminous course
100mm crack relief layer
210mm CTB
250mm CTSB
Soil Subgrade

The Cumulative fatigue damage with revised composition is 0.71 which is less than 1.0. Hence safe.

4. Results of Cost Analysis of Flexible Pavement

In this work cost analysis of 1km road has been evaluated and comparison has been made with the cost of 1 km work with conventional granular type construction.

Sl no	Particular	Cost in Rupees per km
1	Flexible pavement with cement treated base	14,806,856.00
2	Flexible pavement with granular base	10,318,944.19

Table: 6

5. Conclusion

In the present study, an attempt has been made to design and analyse the Cement Treated Base flexible pavement as per IRC 37-2018. Apart from design, the cost analysis is also being done to compare the costing of modern type of flexible pavement. The following conclusions have been made from the present study.

1. The conventional flexible type of pavement in India is usually constructed having granular base and sub-base course.
2. Due to rapid growth in traffic the conventional type of flexible pavements are deteriorating within a very short time.
3. The conventional type of flexible pavements are not able to bear the overloading nature of traffic.
4. The Cement treated base and sub-base are advantageous since they are long lasting as compared to granular courses.
5. Conventional type flexible pavements require repairing and rehabilitation work within few years of construction and hence the overall thickness of the pavement increases.
6. In Cumulative fatigue damage analysis of CTB layer, the thickness of the CTB may be increased to make the summation of CFD within 1.00.
7. Thickness of the bituminous layer can be reduced in case of CTB or RAP base as compared to the conventional granular type.

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