DESIGN AND COMPARISION OF FLEXIBLE AND RIGID PAVEMENTS

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Abstract - *Indian road network of almost 3.5 million km comprising both paved and unpaved surface is world's second largest. A very small share of roads in the country is made of concrete. The satisfactory performance of pavementwillresult in higher savings in terms of vehicle operation cost and travel time, which has a bearing on the overall economicfeasibility of project. Although in our country there are manyhighways(or) roadways, the failure of that roads are a common problem. Pavements are of two types flexible and rigid pavements. As compared with flexible pavements, rigid pavementswillattain less failures. The project compares the design and analysis of flexible and rigid pavements by using IRC guide lines and estimate of both flexible and rigid pavements for 2.4 km of road from Penamaluru to Ganguru in Vijayawada(A.P)*

Key Words: Economic feasibility ,Highway Design, IRC, Flexible and Rigid pavements

1. INTRODUCTION

Traffic Data (Max Wheel Load, Traffic Volume Daily& Hourly)

An accurate estimate of the traffic that is likely to use the project road is very important as it forms the basic input in planning, design, operation and financing. A thorough knowledge of the travel characteristics of the traffic likely to use the project road as well as other major roads in the influence area of the study corridor is, therefore, essential for future traffic estimation. Hence, detailed traffic surveys are carried to assess the present day traffic and its characteristics.

Soil Sub Grade Data

For flexible pavement
C. B. R of soil sub grade = 8 % Liquid limit = 55%

Plastic limit = 24% Plasticity index (PI) = 31% O. M. C = 25%

Standard proctor density (gr./cc) = 1.71 gm/cc

For rigid pavement

C. B. R of soil sub grade = 8%
Modulus of sub grade Reaction K = 5 Kg/cm^2

Design of Flexible Pavement By California Bearing Ratio Method

The following sub sections describe the various variables and parameters involved in design of flexible pavement of road as per IRC 37 - 2001.
Design Traffic
Computation of design Traffic In terms of cumulative number of standard axle to be carried by the pavement during design life.

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

Where
N = The cumulative number of standard axles to be catered for in design in terms of million standard axles - msa.
A = Initial traffic in the year of completion of construction duly modified as shown below.
D = Lane distribution factor
F = Vehicle damage factor, VDF n = Design life in years

r = Annual growth rate of commercial vehicles {this can be taken as 5% if no data is available}

2. Design of Flexible Pavement

To Design the pavement for the construction of new road with the following data:

Data

I. Two-lane single carriage way
II. Initial traffic in the year of Design of opening =3414 vehicles per day
III. Type of soil = Black cotton soil[CH]
IV. Type of terrain = Plain terrain

Design calculations

Cumulative number of vehicles per day over the road obtained from the traffic volume study =3414

Step 1 Consider, the laying of the pavement will be completed in six months

Then, the initial traffic after the year of opening $A = P(1 + r)^x$ = $3414(1+0.05)^{0.5}$ = 3498

Step 2

i. Vehicle damage factor F = 4.5 (taken from IRC: 37- 2001, clause 3.3.4.4) as the location of site is plain terrain.

Table -1

Initial traffic volume in terms of no. of commercial vehicles per day	Terrain	
	Rolling/pla in	Hilly
0-150	1.5	0.5
150-1500	3.5	1.5
>1500	4.5	2.5

ii. Lane distribution factor for a 2-lane carriage way D = 0.75 (from IRC: 37-2001 clause 3.3.5.1)

iii. Assume the design life of the pavement = 15 years.

Step 3 Computation of design traffic:

Cumulative number of standard axles to be catered in terms of design msa

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

Number of standard axles catered for 5 years,

$$N = \frac{365 \times [(1+0.05)^5 - 1] \times 3498 \times 0.75 \times 4.5}{0.05} = 23.8 = 23\text{msa}$$

Number of standard axles catered for 10 years $N = \frac{365 \times [(1+0.05)^{10} - 1] \times 3498 \times 0.75 \times 4.5}{0.05}$ =54.1=54msa

Number of standard axles catered for 15 years Number of standard axles catered for 15 years

$$N = \frac{365 \times [(1+0.05)^{15} - 1] \times 3498 \times 0.75 \times 4.5}{0.05} = 92 = 92 \text{ msa}$$

No. Of cumulative standard axles catered during different design periods

Table -2

Year	2017	2023	2028	2033
Design Traffic in terms of msa	4	23	54	92

Step 4 : The California bearing ratio (C.B.R) of the sub-grade black cotton soil = 8% .

Total pavement thickness for CBR 8% and traffic 92msa (from Chart -1 of IRC:37-2001) = 640mm

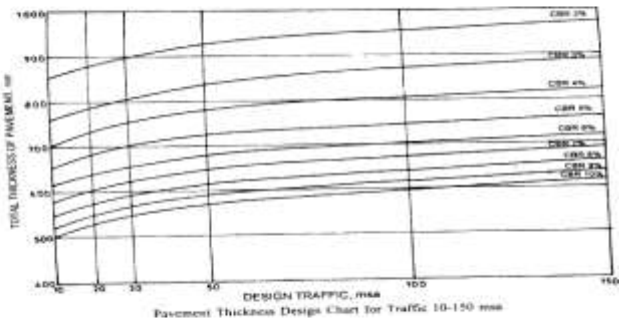

Chart -1:

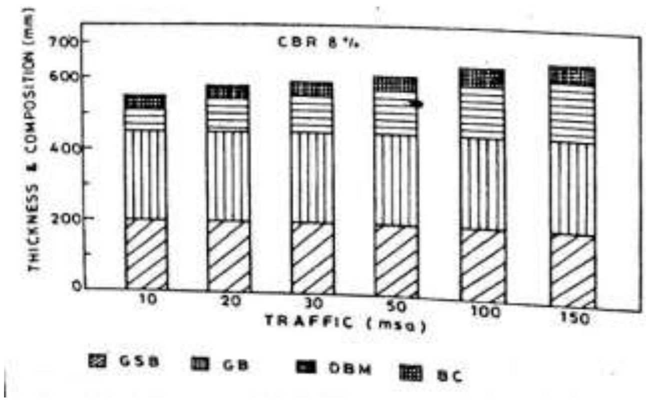

Chart -2

Step 5: Pavement Design Catalogue

Chart-2 Recommended design for traffic range 10-150 msa

Table -3

CBR 8%				
Cumulative traffic msa	Total pavement thickness(mm)	Pavement Composition		
		Bituminous surfacing		Granular Base And Sub Base
		BC(mm)	DBM(mm)	
10	550	40	60	Base = 250 Sub base = 200
20	575	40	85	
30	590	40	100	
50	610	40	120	
100	640	50	140	
150	660	50	160	

Pavement composition interpolated from Plate 2, CBR 8%

(a) Bituminous surfacing = 50mm BC +140mmDBC
(b) Road base= 250mm
(c) Sub-base = 200mm granular material of CBR not less than 30 %.

3. Design of rigid pavement

Design a cement concrete pavement for a two-lane single carriage way. The total two-way traffic is 3498 commercial vehicles per day at the end of construction period.
The design parameters are:
Grade of the cement concrete =M40 CBR value of sub-grade= 8%

Modulus of sub-grade reaction (k) =5 kg/cm^2 Elastic modulus of concrete= 3 x 10^5 kg/cm^2 Poison's ratio = 0.15

Coefficient of thermal coefficient of concrete
=10 x 10^{-6}/ °C
Rate of traffic increase= 0.05(AS PER IRC 37:2012)

Design

Present traffic = 3414 CVPD, Design life = 30 years

Annual growth of traffic= 0.05
Cumulative repetition in 20 yrs
= 3414 x 365 $\left[\frac{(1+0.05)^{30}-1}{0.05}\right]$
= 82790112 commercial vehicles
Design traffic = 25 percent of total repetitions of commercial vehicles= 0.25 x 82790112 = 20697528
Assuming the design axle load of 8160 kg Grade of concrete = M 40

i.e.

characteristic compressive strength of concrete=40 MPa Flexural strength of concrete = 0.7 $\sqrt{f_{ck}}$ = 0.7 x $\sqrt{40}$
= 4.427 N/mm^2 = 4.5 N/mm^2
For 90 days there is 20 per cent increase in the strength of 28 days= $\frac{100+20}{100}$ x 4.427 =5.312 N/mm^2

Trail thickness = 270 mm

Warping stresses:
Length of the slab L_X = 4.5 m Width of contraction joint L_Y = 3.5 m

Radius of relative stiffness $l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}}$
E = 3 X 10^5 kg/cm^2, K = 5 kg/cm^2 , h = 27 cm, $\mu = 0.15$, t=20.58

$\therefore l = \sqrt[4]{\frac{3\times10^5\times27^3}{12\times5(1-0.15^2)}}$=100cm

$L_X/l = \frac{450}{100} = 4.5 \rightarrow C_X = 0.63$; $L_Y/l = \frac{350}{100} = 3.5 \rightarrow C_y = 0.38$;

Warping stress at edge
Ste = CEet/2 =0.63x3x10^5x10x10^{-6}x20.58/2=19.44kg/cm^2 Residual strength in concrete slab at edge region

= 45-19.44=25.55kg/cm^2
Stress at corner at region = $3p/h^2(1-a\sqrt{2}/l)$
= $3x8160/27^2(1-21.5\sqrt{2}/100)$ =23.3kg/cm^2

Factor of safety = 25.5/23.3=1.09>1 (hence safe) Hence trail thickness of 27 cm is safe

Equivalent radius of resisting section,

$$b = \begin{cases} \sqrt{1.6a^2 + h^2} - 0.675h & \text{if } a < 1.724\,h \\ a & \text{otheriwse} \end{cases}$$

Radius of contact area a = $\left(\frac{8160}{5.62\times\pi}\right)^{0.5}$= 21.5 cm 1.724 x 20 = 34.48 > a

$\therefore b = \sqrt{1.6 \times 21.5^2 + 27^2} - 0.675 \times 27$ = 20 cm. Warping stress at interior portion

=21.69 kg/cm^2
Warping stress at corner portion

$\sigma_{ti} = \frac{E\alpha t}{2}\left(\frac{C_x+\mu C_y}{1-\mu^2}\right) =$
$\frac{3\times10^5\times10\times10^{-6}\times20.58}{2}\left(\frac{0.63+0.15(0.38)}{1-0.15^2}\right)$

$\sigma_{tc} = \frac{E\alpha t}{3(1-\mu)}\sqrt{\frac{a}{l}} = \frac{3\times10^5\times10\times10^{-6}\times20.58}{3(1-0.15)}\sqrt{\frac{21.5}{100}} = 11.22$

kg/cm^2

Warping stress at the edge portion

$\sigma_{te} = \frac{E\alpha tc}{2} = \frac{3\times10^5\times10\times10^{-6}\times20.58\times0.63}{2}$

Winter mid-day
$\sigma_{critical} = \sigma te+\sigma e+\sigma f$=19.44+23.6+0.81=43.04kg/cm^2 Mid nights

$\sigma_{critical} = \sigma c+\sigma tc$=25.46+11.22=36.68kg/cm^2 Total edge stresses = 23.6+19.44=43<45kg/cm^2

Total corner stresses = 25.46+11.22=36.68<45kg/cm^2
Hence trail thickness is safe. so provide cc slab thickness as 270 mm

Design of dowel bars

Assume the diameter of the dowel rod = 3.2 cm Percentage of load transfer =40

Spacing between the dowel bars = 0 to 1. 8l = 0 to 158 cm
But, assume spacing between the dowel bars as 300 cm and length of the dowel bar as 50 cm (as per IRC recommendation).
Permissible bearing stress

$F_b = \frac{(10.16-b)f_{ck}}{9.525} = \frac{(10.16-3.2)400}{9.525}$

= 292 kg/cm^2

Frictional stresses
$\sigma_f = \frac{Wlf}{2\times10^4} = \frac{2400\times4.5\times1.5}{2\times10^4}$
= 0.81 kg/cm^2
= 19.44 kg/cm^2
Number of dowel bars required for the load transfer = $1+\frac{l}{spacing} = 1+\frac{100}{30}$ = 5 bars

Assuming that the load transferred by first dowel is P_t and assuming that the load on the dowel bar at a distance of l
Stress due to load at edge potion
$\sigma_e = \frac{0.529P}{h^2}(1+0.54\mu)\left[4\log_{10}\left(\frac{l}{b}\right)+\log_{10}b-0.4048\right]$
from the first dowel bar to be zero, the total load transferred by the dowel bar system
$=\left(1+\frac{100-30}{100}+\frac{100-60}{100}+\frac{100-90}{100}+\frac{100-120}{100}\right)P_t = 2P_t$
Load carried by the outer dowel bars

Corner stress

$$\sigma_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right] = \frac{3\times8160}{27^2}\left[1-\left(\frac{21.5\sqrt{2}}{100}\right)^{1.2}\right]$$

$$=\frac{0.529\times8160}{27^2}(1+0.54\times0.15)\left[4\log_{10}\left(\frac{100}{20}\right)+\log_{10}20-0.4048\right]$$

=23.6 kg/cm²

$P_t = \frac{P}{\text{Total load transfered}} \times$ percent load transfered

$= \frac{8160}{2} \times 0.4$= 1632 kg

Check for bearing stress:

= 25.46 kg/cm² Combination of stresses Summer mid-day:

$\sigma_{critical}$= σe+σte-σf=23.6+19.44-0.81=42kg/cm²

Moment of inertia of the bar $= \frac{\pi\times b^4}{64} = \frac{\pi\times3.2^4}{64}$= 5.147 cm² Relative stiffness of the bar

= = 0.4 $\beta = \sqrt[4]{\frac{kb}{4EI}}$ $\sqrt[4]{\frac{41500\times3.2}{4\times2\times10^6\times5.147}}$

Bearing stress in the dowel bar

4. ESTIMATION OF THE EARTH WORK

The cost of Embankment is calculated as below

$\sigma_{max} = \frac{KP_t}{4\beta^3 EI}(2+\beta Z) = \frac{1632\times25000}{4\times0.45^3\times2\times10^6\times5.147}(2+0.48\times 2.5)$

= 47.59< 292 kg/cm²

Hence the dowel bar spacing and diameter assumed is safe.

Table -4: Abstract of estimate of earthwork

Particulars	Quantity	Rate per % meter	Cost
Embankment	180236 m³	275.00	4,95,649

Design of tie bars

Allowable tensile stress in plain bars, kg/cm² = 1250 (As per IRC: 21-2000)

Allowable bond stress in plain bars, kg/cm² = 17.5 (As per IRC: 21-2000)

Spacing of the tie bar:

Area of steel bar per meter width of joint to resist the frictional force from bottom of slab

$A = \frac{bhWf}{S_s} = \frac{3.5\times1.5\times2400\times0.27}{1250}$= 2.72 cm²/m

Assuming a tie bar of diameter of 12 mm, the cross- sectional area $A = \frac{1.2^2\times\pi}{4}$= 1.13 cm²

Perimeter of the tie bar, $P = \pi \times 1.2$= 3.76 cm

Spacing of tie bars $= \frac{As}{A} = \frac{100\times1.13}{2.72}$= 41.5 cm<45 cm Provide at a spacing of 41.5 cm c/c

Length of tie bar:

Length of the tie bar $L = \frac{2 \times S_s \times A}{S_b \times P} = \frac{2 \times 1250 \times 1.13}{17.5 \times 3.76} = 42.9$ cm $\cong 43$

Increase the length of the bars by 10 cm for loss due to painting and 5 cm for placement
L = 43+10+5= 58 cm.

Adding 5% contingencies and work establishment

= 495649 x (5/100) = 24,782 /-

Total cost of embankment = 5,20,431/-

Estimation of flexible pavement:

The estimation of the flexible pavement is carried out using the laying procedure and the Standard Schedule of Rates (SOR: 2015-16).
The Estimated cost of Flexible Pavement was obtained as=8911450/-
Add 5 percent contingencies for equipment and tools and work establishment charges = 8911450 X 0.05
= Rs 4,45,572/-
Therefore, total amount required for laying of flexible pavement along with maintenance cost considering the laying of surface course for every 5 years and excluding the labour charges is = 8911450+445572
= Rs **93,57,022/-**

Estimation of rigid pavement

The estimation of the Rigid pavement is carried out using the laying procedure and the Standard Schedule of Rates(SOR:2015-16).

The Estimated cost of Rigid Pavement was obtained as=2,13,74,640 /-
Add 5 percent contingencies for work establishment and other charges = 2,13,74,640 x 0.05= Rs 10,68,732 /-
Total amount required for the laying of rigid pavement
= 2,13,74,640 + 10,68,732 = Rs **2,24,43,372/-**

5. RESULTS

Table: 5: Results Table

The total thickness of the flexible pavement crust	640 mm
The thickness of the slab of rigid pavement	270 mm
Diameter of dowel bar	32 mm
length of dowel bar	500 mm
The number of dowel bars required for the rigid pavement	5
Diameter of tie bar	12 mm
Length of tie bar	580 mm
The number of tie bars required for the rigid pavement	4
The estimated cost for the laying of flexible pavement along with the rehabilitation works(for maintenance) carried out for every 5 years	Rs. 93,57,022 /-
The estimated cost of rigid pavement	Rs. 2,24,43,372/-

6. CONCLUSIONS

The following conclusions are drawn from this study:

1. With increase in the California bearing ratio of the soil the thickness of the pavement decreases.
2. It is observed that flexible pavements are more economical .The life of flexible pavement is nearly about 15 years whose initial cost is low needs a periodic maintenance after a certain period and maintenance costs very high.
3. The life of rigid pavement is much more than the flexible pavement of about 30 years approx 2 times life of flexible pavement whose initial cost is much more than the flexible pavement but maintenance cost is very less.
4. From the results we can conclude that the cost of rigid pavement is double that of flexible pavement. so flexible pavements are more economical when compared totherigid pavement in terms of economy

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