DESIGN ASPECTS OF CEMENT CONCRETE PAVEMENT FOR RURAL ROADS IN INDIA

Narender Singh*

*Sub-Divisional Engineer, PWD (B&R) Branch Sirsa, Haryana (India)

email: narender_nitk@yahoo.co.in

Abstract— A large proportion of India's villages has been connected with all weather roads and has low volume of traffic. The main composition of such roads is granular layer with or without thin bituminous surfacing. The common problem to rural roads is that their maintenance is neglected because of paucity of funds and poor institutional set up, and the road asset created at a great cost is lost. Cement concrete pavement offer an alternate to the flexible pavements especially when the soil strength is poor, the aggregates are costly and drainage conditions are bad. Concrete pavements have now been constructed for low volume of traffic because of their durability even under poor drainage conditions.

Rural roads connecting major roads are sometimes required to carry diverted traffic which may damage the concrete pavement slabs. Such factors may be considered while arriving at thickness of concrete pavements. It is well established that the concrete pavements demand a high degree of professional expertise at the design stage as the defective design may lead to concrete failure even if the construction is done with great care. Indian Roads Congress has issued the first revision of IRC: SP: 62 in 2014 for design and construction of concrete pavement for low volume of roads. In this paper, efforts have been made to elaborate the different design aspects of concrete pavement for rural roads which will be helpful for the young engineers and research scholars.

Keywords— Concrete pavement; design; commercial vehicles; C.B.R.; load stresses; temperature stresses; fatigue fracture; joints.

INTRODUCTION

India is an agriculture based country and more than 70 percent of the population is residing in the rural areas. The rural traffic consisting mostly agricultural tractors/trailers, goods vehicles, buses, animal driven vehicles, auto-rickshaws, motor cycles, bi-cycles, light or medium trucks carrying sugarcane, quarry material etc. The road passing through a village/built-up area usually found damaged due to poor drainage of water. Therefore, flexible pavement in the built-up area is to be substituted with the concrete pavement to make it durable and to avoid wastage of nation money on repeated treatments. The different aspects of design of concrete pavement should be taken care prior to construction for making the same durable and cost effective [1, 2].

DESIGN ASPECTS OF CEMENT CONCRETE PAVEMENT

The guidelines contained in IRC: SP: 62-2014 are applicable for low volume roads with average daily traffic less than 450 Commercial Vehicles per Day (CVPD). The code mainly deals with three design aspects of cement concrete pavement as shown in fig. 1 [3].

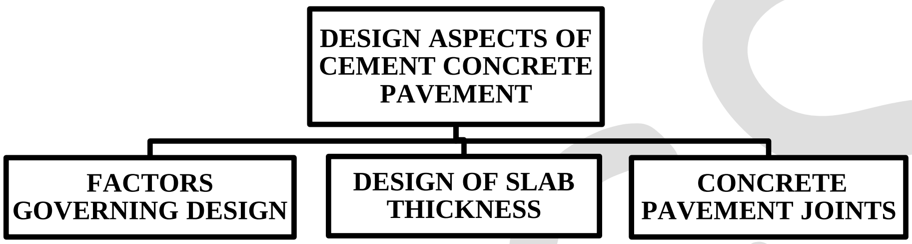

Figure 1 Design Aspects of Cement Concrete Pavement

FACTORS GOVERNING DESIGN OF CEMENT CONCRETE PAVEMENT

The factors governing design of cement concrete pavement have been discussed below:

i) Wheel Load

Heavy vehicles are not expected on rural roads. The maximum legal load limit on single axle with dual wheels in India being 100 KN, the recommended design load on dual wheels is 50 KN having a spacing of the wheels as 310 mm centre to centre.

ii) Tyre Pressure

For a truck carrying a dual wheel load of 50 KN the tyre pressure may be taken as 0.80 MPa and for a wheel of tractor trailer, the tyre pressure may be taken as 0.50 MPa.

iii) Design Period

The design period is generally taken 20 years for cement concrete pavement.

iv) Design Traffic for Thickness Evaluation

The design traffic for estimation of concrete pavement thickness has been given in table 1.

Table 1 Design Traffic for Estimation of Concrete Pavement Thickness

Sr. No.	Traffic (CVPD)	Stresses Considered for Thickness Estimation
1.	Up to 50	Only wheel load stresses for a load of 50 KN on dual wheel need to be considered
2.	50 to 150	Total stresses results from wheel load of 50 KN & temperature differential need to be considered
3.	>150 and up to 450	Fatigue can be the real problem and thickness could be evaluated on the

		basis of fatigue fracture

For the fatigue analysis of a concrete pavement the cumulative number of commercial traffic at the end of design period can be estimated from the following equation:

$$N = A\left[\frac{(1+r)^n - 1}{r}\right]365 \qquad \textit{(eq. 1)}$$

Where, **A** = Initial CVPD after the completion of the road = $\mathbf{P_I}\,(\mathbf{1+r})^{\mathbf{x}}$

r = Rate of traffic increase in decimal (for 5% rate of increase in traffic, **r** = 0.05)

$\mathbf{P_I}$ = Initial/ Present CVPD as per traffic census

x = Construction period

n = Design period in years (recommended as 20 years)

N = Total number of cumulative commercial vehicles at the end of the design period

v) Characteristics of the Sub-grade

The strength of sub-grade is expressed in terms of modulus of sub-grade reaction (k). Since, the sub-grade strength is affected by the moisture content, it is desirable to determine it soon after the monsoons. The approximate k value corresponding to California Bearing Ratio (CBR) value is given in table 2.

Table 2 Value of Modulus of Sub-grade Reaction (k)

Soaked Sub-grade CBR (%)[a]	**2**	**3**	**4**	**5**	**7**	**10**	**15**	**20**	**50**
K value (MPa/m)	21	28	35	42	48	50	62	69	140

[a]The minimum CBR of the soil sub-grade shall be 4 %

vi) Sub-base

A good quality compacted foundation layer provided below a concrete pavement is commonly termed as sub-base. It provides the concrete pavement a uniform & firm support and acts as a leveling course below the pavement. Sub-base can be provided below the concrete pavement in three ways depending upon volume of traffic as shown in table 3.

Table 3 Different Ways of Providing Sub-base

Traffic up to 50 CVPD	**Traffic from 50 to 150 CVPD**	**Traffic from 150 to 450 CVPD**
75 mm thick WBM (G-III) /WMM over 100 mm thick GSB or 150 mm thick cement/ lime/ lime-fly ash treated with marginal aggregates/ soil layer	75 mm thick WBM (G-III) /WMM over 100 mm thick GSB or 100 mm thick cementitious granular layer (Dry lean concrete)	150 mm thick WBM (G-III) /WMM over 100 mm thick GSB or 100 mm thick cementitious granular layer (Dry lean concrete) over 100mm cementitious layer with naturally occurring material

The effective modulus of sub-grade reaction (k) over granular and cement treated sub-base is shown in table 4. The effective k value for the Granular Sub-Base (GSB) may be taken 1.2 times the k value of the sub-grade. Similarly, for cementitious sub-base, the effective k value may be taken 2 times the k value of soil sub-grade.

Table 4 Effective k value over Granular and Cementitious Sub-bases

Soaked Sub-grade CBR (%)	**2**	**3**	**4**	**5**	**7**	**10**	**15**	**20**	**50**
K value over GSB (150 to 250 mm), MPa/m	25	34	42	50	58	60	74	83	170
K value over Cementitious sub-base (150 to 200 mm), MPa/m	42	56	70	84	96	100	124	138	280

Reduction in stresses in the concrete pavement slab due to higher sub-grade CBR is marginal, since only fourth root of '**k**' matters in stress computation, but the loss of support due to erosion of the poor quality foundation below the pavement slab under wet condition may damage it seriously.

vii) Concrete Strength

Since, concrete pavement fails due to bending stresses, it is necessary that their design is based on the flexural strength of concrete (eq. 2).

$$f_f = 0.7\sqrt{f_{ck}} \qquad \text{(eq. 2)}$$

Where, $\mathbf{f_f}$ = Flexural strength, MPa

$\mathbf{f_{ck}}$ = Characteristics compressive cube strength, MPa

For low low volume roads, it is suggested that the 90 days strength may be used for design since concrete keeps on gaining strength with time. The 90 days flexural strength may be taken as 1.10 times the 28 days flexural strength. For concrete pavement construction for rural roads, it is recommended that the characteristic 28 days compressive strength should be at least 30 MPa and corresponding flexural strength shall not be less than 3.8 MPa.

viii) Modulus of Elasticity (E) and Poisson's Ratio (μ)

The Modulus of Elasticity of concrete and Poisson's ratio may be taken as 30,000 MPa and 0.15 respectively.

ix) Co-efficient of Thermal expansion (α)

The co-efficient of thermal expansion of concrete may be taken as 10×10^{-6} per ^{o}C.

x) Fatigue behavior of Concrete Pavement

Fatigue means weakening or breakdown of concrete material subject to repeated series of stresses. For rural roads with traffic exceeding 150 CVPD, fatigue behavior of pavement slab may be calculated from the fatigue equation (eq. 3).

$$log_{10}N_f = \frac{SR^{-2.222}}{0.523} \qquad \text{(eq. 3)}$$

Where, $\mathbf{N_f}$ = Fatigue life of concrete pavement = Allowable load repetitions

Stress Ratio (**SR**) = $\frac{\text{Flexural stress due to wheel load and temperature}}{\text{Flexural Strength}}$

The ratio of expected load repetitions (**N_e**) and allowable load repetitions (**N_f**) is termed as cumulative fatigue damage and its value should be less than 1.

$$\text{Cumulative fatigue damage} = \frac{N_e}{N_f} < \mathbf{1} \qquad \text{(eq. 4)}$$

Assuming that only 10% of the total traffic has axle loads equal to 100 KN, the number of repetitions of 100 KN axle loads expected in 20 years can be calculated from eq. 1.

$$N_e = \text{Expected load repetitions} = 10\% \text{ of } N = 0.1 \times N \qquad \text{(eq. 5)}$$

DESIGN OF SLAB THICKNESS

1) Critical Stress Condition

Two different regions in a concrete pavement slab i.e. edge and corner are considered critical for pavement design. Effect of temperature gradient is very less at the corner, while it is much higher at the edge. Concrete pavement undergo a daily cyclic change of temperature differentials, the top being hotter than the bottom during the day and opposite is the case during the night. The consequent tendency of pavement slab to curl upwards (top convex) during the day and downwards (top concave) during the night, and restraint offered to the curling by self weight of the pavement induces stresses in the pavement, referred to commonly as curling stresses. These stresses are flexural in nature, being tensile, at bottom during the day (fig. 2a) and at top during the night (fig. 2b).

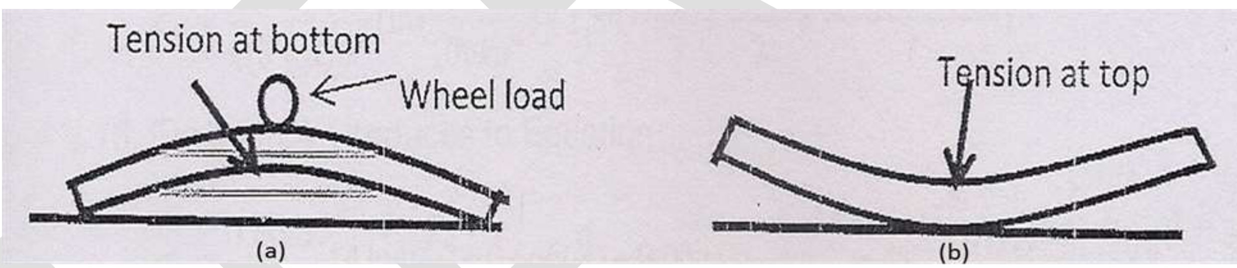

Figure 2 (a) Tensile Stresses at the bottom during day (b) Tensile Stresses at the top during night

As the restraint offered to curling would be a function of weight of the slab, it is obvious that corners have little of such restraint. Consequently the temperature stresses induced in the pavement are negligible in the corner region. The maximum tensile stresses in the edge region of slab will be caused by simultaneous occurrence of wheel loads and temperature differentials. This would occur during the day at the bottom in case of interior and edge regions [4, 5].

2) Calculation of Stresses

i) Load stresses at edge

Westergaard's equation for edge loading is recommended for computation of edge stresses caused by single or dual wheel at the edge of concrete pavement slab (eq. 6) [6, 7].

$$\sigma_e = \frac{0.803P}{h^2}\left[4log\left(\frac{\ell}{a}\right)+0.666\left(\frac{a}{\ell}\right)-0.034\right] \qquad (eq.\ 6)$$

Where, σ_e = Load stress in the edge region, MPa

h = Pavement slab thickness, mm

E = Modulus of elasticity for concrete, MPa

ℓ = Radius of relative stiffness, mm = $\sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$

μ = Poisson's ratio for concrete

k = Modulus of sub-grade reaction of the pavement foundation, MPa/m

a = Radius of the equivalent circular area in mm = $\sqrt{\frac{P}{\pi p}}$, for single wheel at edge

$= \sqrt{\frac{0.8521P_d}{\pi p} + \frac{S_d}{\pi}\sqrt{\left(\frac{P_d}{0.5227p}\right)}}$, for dual wheel at edge

P = Single wheel load, N

P_d = Load on one wheel of dual wheel set, N

S_d = Spacing between the centers of dual wheel, mm

p = Tyre pressure, MPa

ii) Temperature stresses at edge

The stress for the linear temperature gradient across depth of slab can be calculated by using Bradbury's equation (eq. 7) [7, 8].

$$\sigma_{te} = \left(\frac{E\alpha t}{2}\right)C \qquad (eq.\ 7)$$

Where, σ_{te} = Temperature stresses in the edge region, MPa

α = Coefficient of thermal expansion

t = Temperature difference (^oC) between the top & the bottom of the slab

C = Bradbury's coefficient and depends on $\frac{L}{\ell}$

L = Joint spacing

The values of temperature differentials in different zones in India as recommended by Central Road Research Institute (CRRI) are given in table 5 [9].

Table 5 Recommended Temperature Differentials for Concrete Slabs

Zone	**States**	**Temperature Differentials ^{o}C in Slabs of Thickness**		
		150 mm	**200 mm**	**250 mm**
i)	Panjab, Harayana, U.P., Uttranchal, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Arunachal Pradesh, Tripura, Himachal Pradesh, Rajasthan, Gujrat and North M.P., excluding hilly regions	12.5	13.1	14.3
ii)	Bihar, Jharkhand, West Bengal, Assam and Eastern Orissa excluding hilly regions and coastal areas	15.6	16.4	16.6
iii)	Maharashtra, Karnataka, South M.P., Chattisgarh, Andhra Pradesh, Western Orissa and North Tamil Nadu excluding hilly regions and coastal areas	17.3	19.0	20.3
iv)	Kerala and South Tamil Nadu excluding hilly regions and coastal areas	15.0	16.4	17.6
v)	Coastal areas bounded by hills	14.6	15.8	16.2
vi)	Coastal areas unbounded by hills	15.5	17.0	19.0

The values of Co-efficient 'C' can be calculated from table 6.

Table 6 Recommended Values of Co-efficient 'C'

$\frac{L}{\ell}$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12 & above**
C	0.000	0.040	0.175	0.440	0.720	0.920	1.030	1.077	1.080	1.075	1.050	1.000

CONCRETE PAVEMENT JOINTS

Low volume roads have generally a single-lane carriageway with a lane width of 3.75 m which is concreted in one operation. For rural roads, no longitudinal joint need to be provided except when the pavement width exceeds 4.5 m [10]. There are mainly four types of joints provided in cement concrete pavement as discussed under:

i) Contraction Joints

These are transverse joints whose spacing may be kept 2.5 to 4 m. These can be formed by sawing the pavement slabs within 24 hrs of casting of concrete (fig. 3).

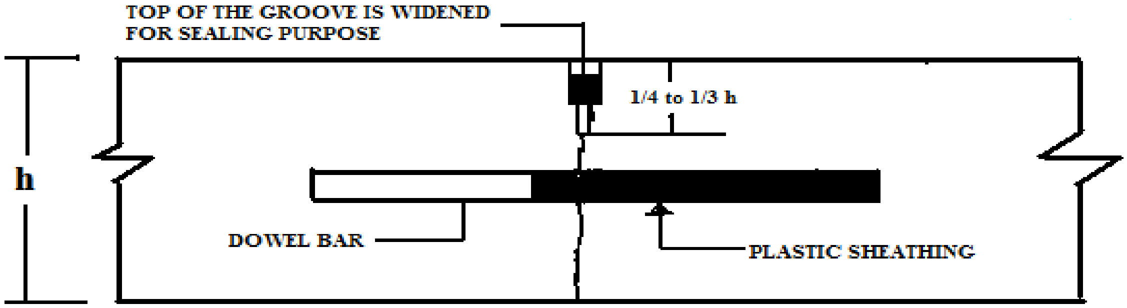

Figure 3 Contraction Joint

The dowel bars are not satisfactory for slabs of small thickness and shall not be provided for slabs of thickness less than 200 mm. However, for slab thickness 200 mm and above, the dowel bars must be provided at contraction joints. The recommended diameters and length of dowel bars with respect to slab thickness has been given in table 7 [11].

Table 7 Recommended Diameters and Length of Dowel Bars

Slab Thickness (mm)	Dowel Bars		
	Diameter (mm)	Length (mm)	Spacing (mm)
200	25	360	300
230	30	400	300
250	32	450	300
280	36	450	300
300	38	500	300
350	38	500	300

ii) Construction Joints

Transverse construction joints shall be provided wherever concreting is completed after a day's work or is suspended for more than 90 minutes.

iii) Longitudinal Joints

Where the width of concrete slab exceeds 4.5 m, it is necessary to provide a longitudinal joint in mid width of slab as per detail shown in fig. 4. The detail of tie bars provided in the longitudinal joints of concrete pavement is given in table 8 [11].

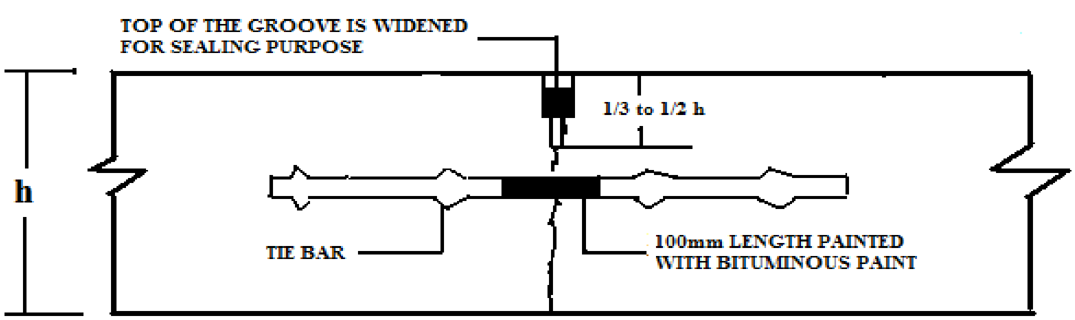

Figure 4 Longitudinal Joint

Table 8 Detail of Tie Bars for Longitudinal Joints

Slab Thickness (mm)	Diameter (mm)	Maximum Spacing (mm)		Minimum Length (mm)	
		Plain Bars	Deformed Bars	Plain Bars	Deformed Bars
150	8	330	530	440	480
	10	520	830	510	560
200	10	390	620	510	560
	12	560	900	580	640
250	12	450	720	580	640
300	12	370	600	580	640
	16	660	1060	720	800
350	12	320	510	580	640
	16	570	910	720	800

iv) Expansion Joints

There are full depth joints provided transversely into which pavement can expand, thus relieving compressive stresses due to expansion of concrete slabs, and preventing any tendency towards distortion, buckling, blow up and spalling. The current practice is to provide expansion joints only when concrete slab abuts with bridge or culvert (fig. 5) [12].

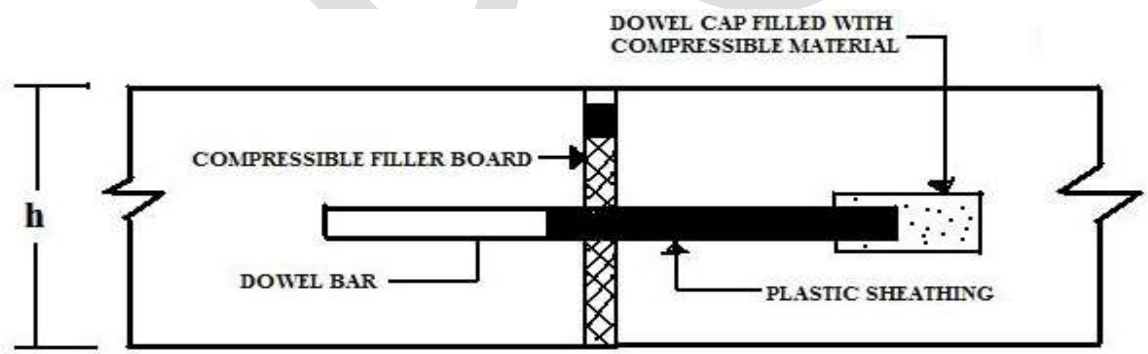

Figure 5 Expansion Joint

CASE STUDY

The cement concrete pavement with 5.5 m carriageway has been designed for road from Nathusari Kalan to Rupana Bishnoian in Sirsa (Haryana) in year 2014 [13]. The detailed design has been discussed as under:

$\mathbf{P_I}$ = 169 CVPD

r = 5% rate of increase in traffic = 0.05

x = 1 year

n = 20 years

Using eq. 1 $\mathbf{N} = 177\left[\frac{(1+0.05)^{20}-1}{0.05}\right]365 = 2136226$

$$\mathbf{A} = 169\,(1 + 0.05)^1 = 177$$

Since, the present CVPD are greater than 150 CVPD, fatigue can be a real problem and the thickness could be evaluated on the basis of fatigue fracture.

Design Data

Grade of concrete = M-30

CBR = 5%

P_d = 50 KN = $50\text{x}10^3$ N

p = 0.80 MPa

S_d = 310 mm

μ = 0.15

E = 30,000 MPa

α = $10\text{x}10^{-6}$ per ^{o}C

k = 50 MPa/m or $50\text{x}10^{-3}$ MPa/mm, for granular sub-base (as per table 4)

Sub-base

150 mm WMM over 100 mm GSB (as per table 3)

Concrete Strength

28 day compressive strength for M-30 grade of concrete = 30 MPa

Using eq. 2 28 day flexural strength = $f_f = 0.7\sqrt{f_{ck}}$ = 3.834 MPa

90 day flexural strength = f_f = 1.10x3.834 = 4.22 MPa

Trial-I

Assuming,

Pavement thickness (h) = 170 mm

Joint spacing (L) = 2.75 m = 2750 mm

$$\ell = \sqrt[4]{\frac{30{,}000\,(170)^3\,10^3}{12(1-0.15^2)50}} = 708.03 \text{ mm}$$, for granular sub-base

$$a = \sqrt{\frac{0.8521\text{ x}50\text{x}10^3}{0.8\pi} + \frac{310}{\pi}\sqrt{\left(\frac{50\text{x}10^3}{0.5227\text{x}0.8}\right)}} = 226 \text{ mm}$$, for dual wheel at edge

Using eq. 6 $$\sigma_e = \frac{0.803\text{x}50\text{x}10^3}{170^2}\left[4log\left(\frac{708.03}{226}\right)+0.666\left(\frac{226}{708.03}\right)-0.034\right] = 3.00 \text{ MPa}$$

Using eq. 7 $$\sigma_{te} = \left(\frac{30{,}000\text{x}10\text{x}10^{-6}\text{x}12.5}{2}\right)0.409 = 0.767 \text{ MPa}$$

$[C = 0.409$, for $\frac{L}{\ell} = \frac{2750}{708.03} = 3.884]$

Total stress = $\sigma_e + \sigma_{te}$ = 3.00 + 0.767 = 3.767 MPa < 4.22 MPa Therefore, safe.

Using eq. 3 $\log_{10} N_f = \frac{0.893^{-2.222}}{0.523} = 2.458$ $[SR = \frac{3.767}{4.22} = 0.893]$

$N_f = 287.08$

Using eq. 5 N_e = 10% of N = 213623

Using eq. 4 Cumulative fatigue damage = $\frac{N_e}{N_f} = \frac{213623}{287.08} = 744.12 > 1$ Therefore, unsafe

Trial-II

Assuming, h = 200 mm and L = 2750 mm

$$\ell = \sqrt[4]{\frac{30{,}000\ (200)^3\ 10^3}{12(1-0.15^2)50}} = 799.81 \text{ mm}$$

$$\sigma_e = \frac{0.803 x 50 x 10^3}{200^2}\left[4\log\left(\frac{799.81}{226}\right)+0.666\left(\frac{226}{799.81}\right)-0.034\right]=2.358 \text{ MPa}$$

$$\sigma_{te}=\left(\frac{30{,}000 x 10 x 10^{-6} x 13.1}{2}\right)0.291=0.572 \text{ MPa}$$

$[C = 0.291$, for $\frac{L}{\ell} = \frac{2750}{799.81} = 3.438]$

Total stress = 2.358 + 0.572 = 2.93 MPa < 4.22 MPa Therefore, safe.

$\log_{10} N_f = \frac{0.694^{-2.222}}{0.523} = 4.305$ $[SR = \frac{2.93}{4.22} = 0.694]$

$N_f = 20195$

Cumulative fatigue damage = $\frac{N_e}{N_f} = \frac{213623}{20195} = 10.58 > 1$ Therefore, unsafe

Trial-III

Assuming, h = 215 mm and L = 2750 mm

$$\ell = \sqrt[4]{\frac{30{,}000\ (215)^3\ 10^3}{12(1-0.15^2)50}} = 844.39 \text{ mm}$$

$$\sigma_e = \frac{0.803 x 50 x 10^3}{215^2}\left[4\log\left(\frac{844.39}{226}\right)+0.666\left(\frac{226}{844.39}\right)-0.034\right]=2.114 \text{ MPa}$$

$$\sigma_{te}=\left(\frac{30{,}000 x 10 x 10^{-6} x 14.3}{2}\right)0.243=0.52 \text{ MPa}$$

$[C = 0.243$, for $\frac{L}{\ell} = \frac{2750}{844.39} = 3.256]$

Total stress = 2.114 + 0.52 = 2.634 MPa < 4.22 MPa Therefore, safe.

$\log_{10} N_f = \frac{0.624^{-2.222}}{0.523} = 5.453$ $[SR = \frac{2.634}{4.22} = 0.624]$

$N_f = 283792$

Cumulative fatigue damage = $\frac{N_e}{N_f} = \frac{213623}{283792} = 0.753 < 1$ Therefore, safe

It is therefore, recommended to provide 215 mm thick cement concrete pavement (M-30) over 100 mm GSB and 150 mm WBM/WMM. Since, the thickness of concrete pavement is greater than 200 mm it is desirable to provide 25 mm dia dowel bars, 360 mm long @ 300 mm c/c at contraction joints.

CONCLUSION

The concrete pavement for rural roads perform well under poor drainage conditions and thus avoid wastage of resources on repeated treatment of flexible pavement. The proper design of concrete pavement will definitely help to make it durable and cost effective. The technical institutions should enforce the design aspects of concrete pavement for the optimum benefit of young engineers and research scholars.

REFERENCES:

[1] IRC: SP: 20-2002, "Rural Road Manual".

[2] IRC: SP: 42-1994, "Guidelines of Road Drainage".

[3] IRC: SP: 62-2014, "Guidelines for Design and Construction of Cement Concrete Pavement for Low Volume Roads (First Revision)".

[4] Dr. R. Kumar, Scientist, Rigid Pavements Division, CRRI, "Design and Construction of Rigid Pavements/Cement Concrete Roads (ppt)".

[5] Pandey, B.B., "Warping Stresses in Concrete Pavements- A Re-Examination", HRB No. 73, 2005, Indian Roads Congress, 49-58.

[6] Westergaard, H. M. (1948), "New Formulas for Stresses in Concrete Pavements of Airfield", ASCE Transactions, vol. 113, 425-444.

[7] Srinivas, T., Suresh, K. and Pandey, B.B., "Wheel Load and Temperature Stresses in Concrete Pavement", Highway Research Bulletin No. 77, 2007, 11-24.

[8] Bradbury, R. D. (1938), "Reinforced Concrete Pavements", Wire Reinforcement Inst., Washington, D.C.

[9] B. Kumar, Scientist, Rigid Pavements Division, CRRI, "Design Construction & Quality Control Aspects in Concrete Road (ppt)".

[10] IRC: 15-2011, "Standard Specifications and Code of Practice for Construction of Concrete Roads (Fourth Revision)".

[11] IRC: 58-2011, "Guidelines for Design of Plain Jointed Rigid Pavement for Highways (Third Revision)".

[12] IRC: 57-2006, "Recommended Practice for Sealing of Joints in Concrete Pavements (First Revision)".

[13] Detailed Project Report, "Upgradation of Road from Nathusari Kalan to Rupana Bishnoian in Sirsa", Haryana PWD (B&R), 2014.