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Design Criteria of Concrete Pavement for Plain and Lean Concrete Roads

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Abstract: A significant number of villages in India are now connected by all-weather roads with low traffic volume. These roads typically consist of a granular layer, sometimes with a thin bituminous surfacing. Rural roads commonly face the challenge of inadequate maintenance due to limited funds and a weak institutional setup, resulting in the loss of valuable road assets created at a substantial cost. In such scenarios, cement concrete pavements present a viable alternative to flexible pavements, particularly when dealing with poor soil strength, expensive aggregates, and suboptimal drainage conditions. Concrete pavements have become a preferred choice for low-traffic scenarios due to their durability, even in challenging drainage conditions. Rural roads that connect to major routes may experience diverted traffic, posing a potential risk of damage to concrete pavement slabs. Consideration of such factors is essential in determining the appropriate thickness for concrete pavements. Recognizing that concrete pavements require a high level of professional expertise during the design phase is crucial, as even meticulous construction practices may not prevent concrete failure if the design is flawed. The Indian Roads Congress issued the first revision of IRC: SP: 62 in 2014, providing guidelines for the design and construction of concrete pavements for low-volume roads. This paper aims to delve into various design aspects of concrete pavement for rural roads, offering valuable insights for young engineers and research scholars.
Plain concrete is a brittle material with low tensile strain and strength capacities. The use of short, discontinuous fibers to strengthen and toughen such materials, which are much weaker in tension than in compression, goes back to ancient times.
Lean concrete is made up of low cementations material content. It is primarily poured through chutes, conveyor buckets, or pumps. It is used in various areas where support and strength are not critical. The mixture is highly liquid when compared to real concrete and is self-leveling, making it ideal for saving time.

Keywords – Concrete Pavement, Design, Commercial Vehicles; C.B.R., Load Stresses, Temperature Stresses; Fatigue Fracture, Joints

I. INTRODUCTION

India, predominantly an agrarian nation with over 70 percent of its population residing in rural areas, experiences rural traffic primarily comprising agricultural tractors/trailers, goods vehicles, buses, animal-driven vehicles, auto-rickshaws, motorcycles, bicycles, and light or medium trucks transporting sugarcane, quarry materials, etc. Roads passing through villages or built-up areas often suffer damage due to poor water drainage. Therefore, replacing flexible pavement in these built-up areas with concrete pavement is essential to enhance durability and prevent the unnecessary expenditure of national resources on repeated treatments. Prioritizing various design aspects of concrete pavement is crucial to ensure its longevity and cost-effectiveness during construction [1, 2].

II. DESIGN CRITERIA 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].

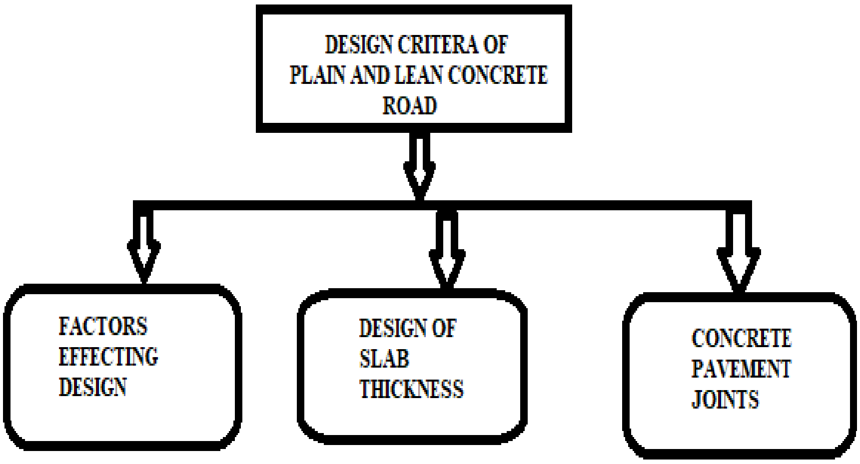

Figure 1: Design criteria of plain and lean Concrete Pavement

2.1 Factors Effecting 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 canbe estimated from the following equation:

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

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

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 effectivek 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).

$$f_f = 0.7\sqrt{f_{ck}} \quad (2)$$

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 °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

$$\log_{10} N_f = \frac{SR^{-2.222}}{0.523} \tag{3}$$

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

$$Stress\ Ratio = \frac{Flexural\ stress\ due\ to\ wheel\ load\ and\ temperature}{Flexural\ Strength} \tag{4}$$

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

$$Comulative\ Fatigue\ Damage = \frac{N_e}{N_f} < 1 \tag{5}$$

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

$$N_e = Expected\ Load\ \mathrm{Re}\ petitions = 10\%\ of\ \ N = 0.1 \times N \tag{6}$$

III. DESIGN OF SLAB THICKNESS

1) Critical Stress Stage

In the plan of substantial asphalt, two explicit districts are recognized as basic: the edge and the side of the asphalt chunk. The effect of temperature slope is somewhat insignificant at the corner, while it is essentially higher at the edge.

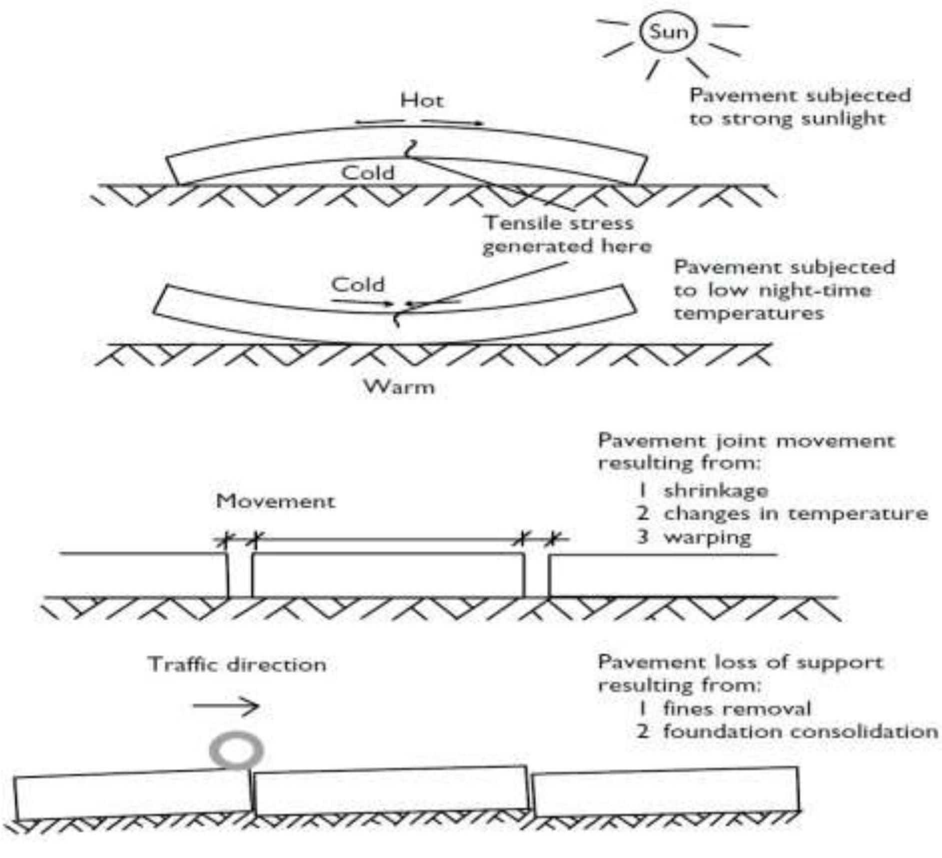

Figure 2: Tensile Stresses at the bottom during (a) day and (b) night

Substantial asphalts experience everyday temperature differentials, with the top being more sizzling than the base during the day as well as the other way around evening time. Accordingly, the asphalt piece will in general twist up (top raised) during the day and descending (top curved) during the evening. One load of the asphalt gives protection from this twisting, creating stresses inside the asphalt known as twisting anxieties. These anxieties are flexural in nature, displaying ductile powers at the base during the day (Figure 2a) and at the top during the evening (Figure 2b).

As the restriction proposed to twisting would be an element of weight of the piece, clearly corners have little of such limitation. Thus the temperature stresses actuated in the asphalt are unimportant in the corner locale. The most extreme pliable anxieties in the edge area of chunk will be brought about by synchronous event of wheel burdens and temperature differentials. In the case of the interior and edge regions, this would take place during the day at the bottom [4, 5].

1) Calculation of Stresses

i) Load stresses at edge

Westergaar'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].

$$\sigma_e = \frac{0.803P}{h^2}[4\log(\frac{r}{a}) + 0.666(\frac{a}{r}) - 0.034] \tag{7}$$

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

h = Pavement slab thickness, mm

E = Modulus of elasticity for concrete, MPa

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

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

$= \sqrt{\frac{0.821P_d}{\pi p} + \frac{S_d}{\pi}\sqrt{\left(\frac{P_d}{0.5227P}\right)}}$ 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].

$$\sigma_{te} = \left(\frac{E_{at}}{2}\right)C \tag{8}$$

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

α = Coefficient of thermal expansion

t = Temperature difference (°C) between the top & the bottom of the slab

C = Bradbury‟s coefficient and depends on L/P

L = Joint spacing

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

Table 5: Recommended Temperature Differentials for Concrete Slabs

Zone	States	Temperature Differentials °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'

L □	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

IV. CONCRETE PAVEMENT JOINTS

The majority of low-volume roads consist of a single-lane carriageway that is concreted in one operation and has a lane width of 3.75 meters. For provincial streets, no longitudinal joint should be given aside from when the asphalt width surpasses 4.5 m [10]. In cement concrete pavement, there are primarily four types of joints, as described below:

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 within24 hrs of casting of concrete (fig. 3).

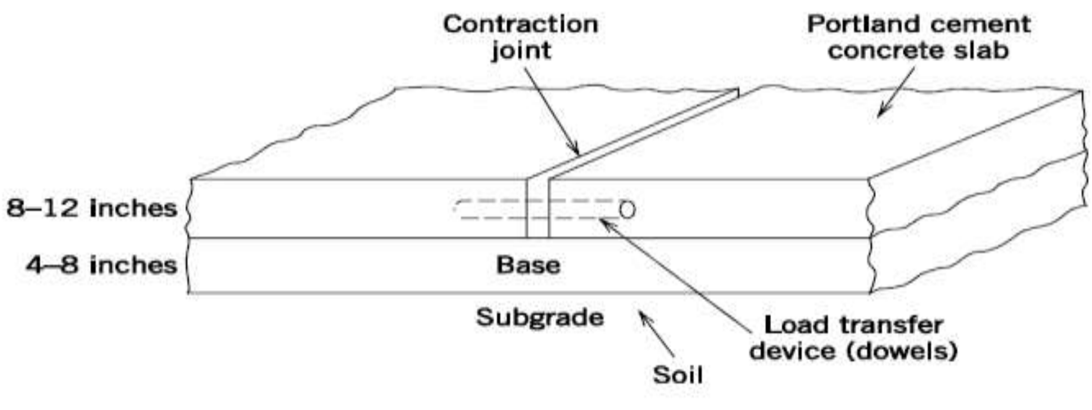

Figure 3 (a): Contraction Joint

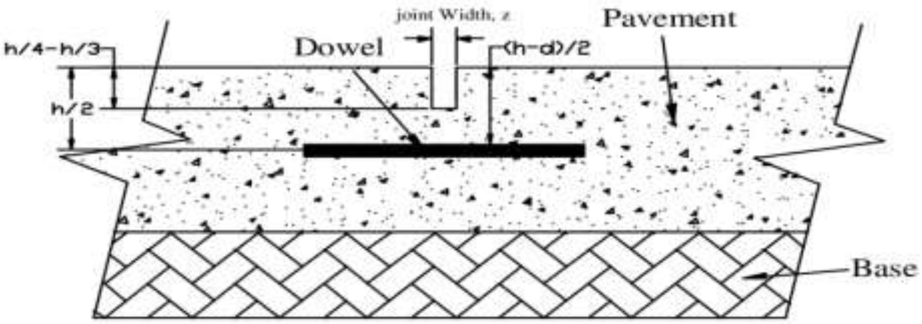

Figure 3 (b): Contraction Joint

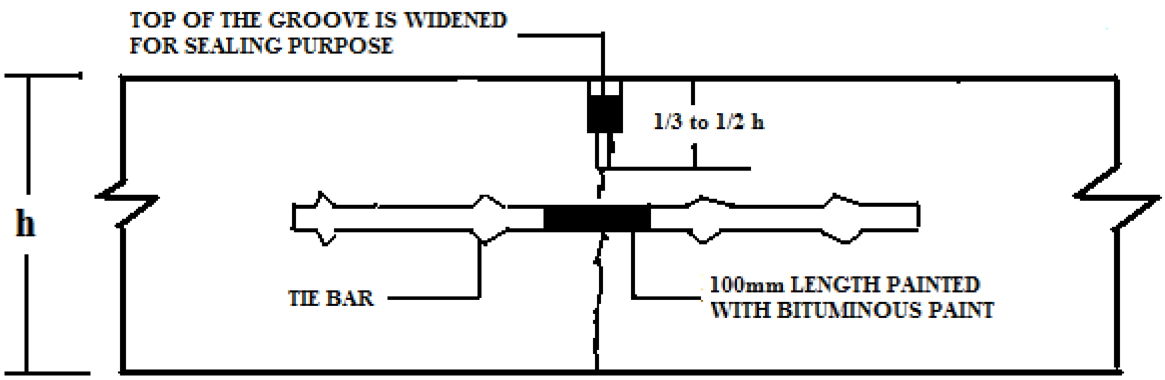

Figure 3(c): Contraction Joint

ii) Construction Joints

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

iii) Longitudinal Joints

Where the width of substantial chunk surpasses 4.5 m, it is important to give a longitudinal joint in mid width of section according to detail displayed in fig. 4. The detail of tie bars gave in the longitudinal joints of substantial asphalt is given in table 7 [11].
Slabs with a thickness of less than 200 mm should not have dowel bars provided because they are insufficient for these slabs. In any case, for piece thickness 200 mm or more, the dowel bars should be given at compression joints. Table 7 [11] provides the recommended dowel bar diameters and lengths in relation to slab thickness.

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

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

Transversely, full-depth joints allow for pavement expansion, relieving compressive stresses caused by concrete slab expansion and preventing distortion, buckling, blowing up, and spalling. The ongoing practice is to give development joints just when substantial piece adjoins with extension or course (fig. 4) [12].

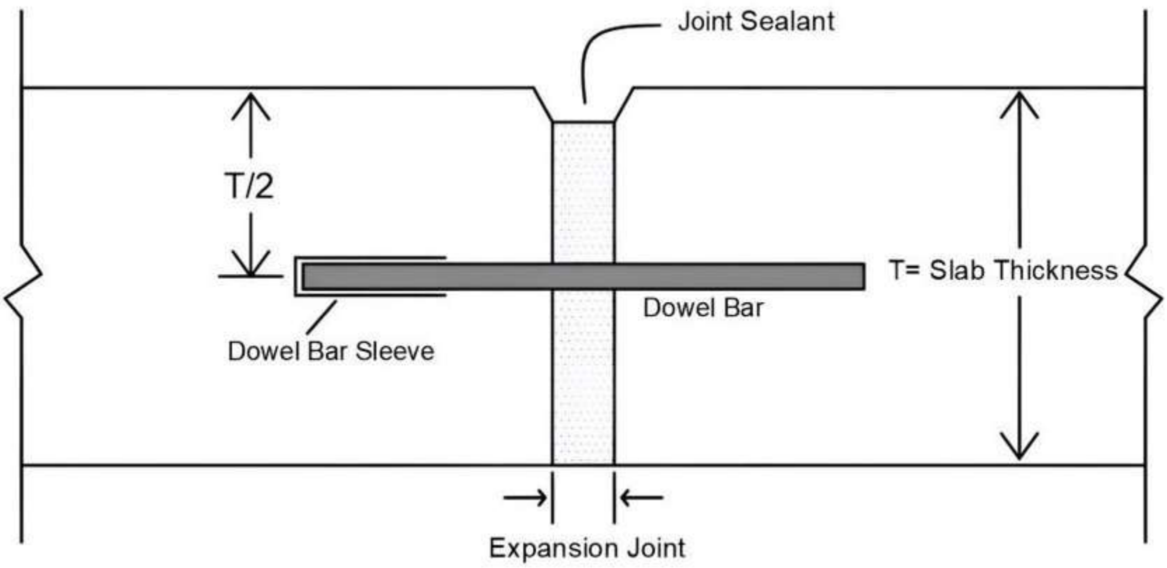

Figure 4: Expansion Joint

V. 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:

PI = 169 CVPD
r = 5% rate of increase in traffic = 0.05
x = 1 year
n = 20 years
Using eq. 1

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

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

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 = 50x10^3 N
p = 0.80 MPa
S_d = 310 mm
μ = 0.15
E = 30,000 MPa
α = 10x10^{-6} per ^{o}C
k = 50 MPa/m or 50x10^{-3} MPa/mm, for granular sub-base (as per table 4)
Sub-base
150 mm WMM over 100 mm GSB (as per table 3)

VI. CONCLUSION

Concrete pavements designed for plain and lean roads demonstrate robust performance, particularly in challenging drainage conditions, preventing unnecessary expenditure on recurrent treatments for flexible pavements. Ensuring the proper design of concrete pavements is essential for enhancing durability and cost-effectiveness. Technical institutions play a crucial role in promoting the understanding and implementation of concrete pavement design aspects, providing optimal benefits for young engineers and research scholars.

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