Chapter 3

Pavements Design

CHAPTER HIGHLIGHTS

- *Introduction*
- *Requirements of highway pavements*
- *Difference between flexible and rigid pavements*
- *Components of pavements*
- *Flexible pavements*
- *Design methods*
- *Equivalency factor*
- *Fatigue and rutting criteria*
- *Rigid pavements*

Introduction

The road surface should be stable and non-yielding and allow the heavy wheel loads to move with least possible rolling resistance. The road surface should be even along the longitudinal profile to enable the fast moving vehicles to move safely and comfortably.

Based on structural behaviour, pavements are generally classified into two categories:

1. Flexible pavements
2. Rigid pavements

Requirements of Highway Pavements

1. Functional requirements from the view of road users.
   - Road should be firm and non-yielding under wheel load.
   - Have good riding quality.
   - Should be less slippery.
2. Structural requirements from the view of highway engineer.
   - It has to sustain heavy wheel loads and their repeated applications due to the moving traffic.

Difference between Flexible and Rigid Pavements

Flexible Pavements

- It has low flexural strength.
- It has series of layers with quality of materials reducing from top to bottom.
- Its stability depends on aggregate interlock, particle friction and cohesion.
- It reflects the deformations of subgrade and subsequent layers on the surface.
- Load transfer is by **grain to grain** to the lower layers.
- Its design is greatly influenced by subgrade strength.
- **IRC: 37–2012** is used for design.
- Designed for a life of **15 years**.

Rigid Pavements

- It has good flexural strength or flexural rigidity which is the major factor for design.
- It has concrete layer on the top with base course and soil subgrade under it.
- Distributes load over a wide area, because of its rigidity.
- Load transfer is by **slab action**.

- Total thickness of pavement and quality of aggregates are lower than in flexible pavements.
- **IRC: 58–2011** is used in design of pavement.
- Design life of pavement is **30 years**.

Components of Pavements

1. **Soil subgrade:** This is the lowest layer of pavement made of natural soil available at site and compacted. As the soil should never be over-stressed, its strength is evaluated using CBR (California bearing ratio) test, plate bearing test, dynamic cone test, direct shear test.
2. **Subbase:** It is a stabilized layer of soil, gravel, broken stone which acts as a drainage layer. It takes loads from base course.
3. **Base course:** This is the important layer for flexible pavement. It enhances the load bearing capacity of the pavement which is laid between wearing course and subbase. It is made of either graded stone, WBM or bituminous layer.
   - Under rigid pavements
     (a) It prevents mud pumping.
     (b) Protects the subgrade against frost action.
4. **Wearing course:** This is to give a smooth riding surface and made of dense materials. This resists pressure exerted by tyres and takes up wear and tear due to traffic. Generally made of bitumen or asphalt.

Flexible Pavements

Factors Considered for Design of Pavement

1. **Design traffic:** It is based on 7 day 24 hour traffic count as per IRC-9.
2. **Design life:**
   - Flexible pavement:
     Expressways—20 years.
     NH and SH—15 years
     Other roads—10–15 years
   - Rigid Pavements:
     High volume roads—30 years
     Low volume roads—20 years
3. **Anticipated traffic:**

   To find the increased traffic at the end of design life of project.

$$A = P[1 + r]^n$$

Where

A = Traffic intensity, i.e., no. of commercial vehicles per day at the end of 'n' years.

P = Number of commercial vehicles per day at last count.

r = Rate of growth of traffic **(7.5%)**

n = Number of years between the last count and till the end of life of pavement.

4. **Other factors:**
   (a) Variation in moisture content: Stability of subgrade is reduced under adverse moisture conditions. Because of variation in moisture content between centre and edge of pavement, differential settlement occurs.
   (b) Frost action
   (c) Variation in temperature:
   Bituminous binders of flexible pavement become soft due to hot weather and brittle in very cold weather. These continuous softening and hardening of the pavement affect the performance and life of pavement.
5. **Design wheel load:**
   (a) Maximum wheel load:
   - Design of pavement is based on 98th percentile of axle load.
   - Tyre pressure influences the quality of surface course.
   - Total load influences the thickness requirements of pavements.

Type of Load	Flexible Pavements	Rigid Pavements
Maximum legal axle load	8,200 kg	10.2 *t*
Maximum equivalent single wheel load	4,100 kg	5.1 *t*
Maximum tandom axle load	14,500 kg	19 *t*
Maximum tridem axle load		24 *t*

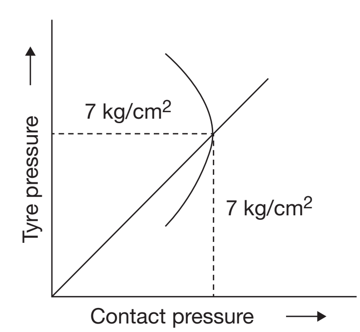
(b) Contact pressure:
Contact pressure

$$= \frac{\text{Load on wheel}}{\text{Contact area (or) area of imprint}}$$

$$= \frac{P}{A}$$

- Contact area is assumed as circle.
- At greater depth, the effect of tyre pressure diminishes as the load starts dispersing (distributing) with depth.

6. **Rigidity factor:**



Rigidity factor

$$= \frac{\text{Contact pressure}}{\text{Tyre pressure (or) Inflation pressure}}$$

= 1, for tyre pressure = 7 kg/cm^2

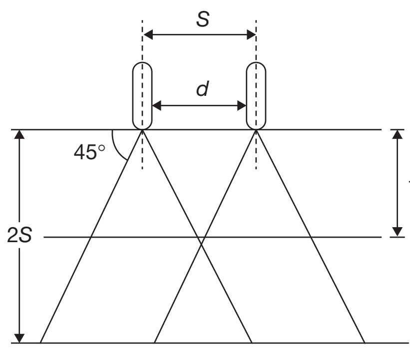
> 1, for low tyre pressure < 7 kg/cm^2

< 1, for high tyre pressure > 7 kg/cm^2

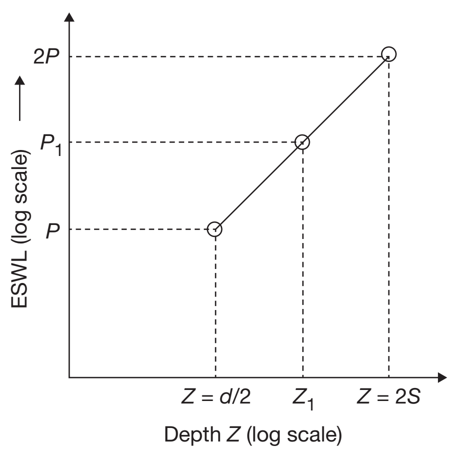
- Tyre pressure for the design is 0.8 MPa (8 kg/cm^2) in the design of rigid pavements as per IRC 58.

(c) Equivalent single wheel load (ESWL):

- To carry greater load and to reduce the intensity on road, it is necessary to provide dual wheel assembly to rear axles of road vehicles.
- The pressure at any depth lies between single load and two lines load carried by any one wheel.



- ESWL may be calculated either by equivalent deflection or equivalent stress criterion.
- Equivalent deflection criteria is more reliable.



7. Repetition of loads:

$P_1N_1 = P_2N_2$

P_1, P_2 = Corresponding loads of vehicles.

N_1, N_2 = Number of repetitions

- Load method is based on 1 million repetitions = 10^6 load repetitions.

Design Methods

1. **Empirical:**
   - These are based on physical properties or strength parameters of soil subgrade and experience or performance studies of the flexible pavements.
   - GI method, CBR, stabilitometer and MC load methods.
2. **Semi-empirical or semi-theoretical:** When the design is based on stress-strain function and modified based on experience, it may be called semi-empirical or semi-theoretical.
   Tri-axial test method is modified by Kansas state highway department.
3. **Theoretical method:** Burmister method

CBR Method

- It is based on design curves and is a simple method.
- Higher the load, larger will be the thickness of pavement.
- The curves are drawn for CBR value versus depth of construction with number of commercial vehicles varying for each curve.
- For certain load values (or vehicles per day) and material CBR value, the thickness of pavement is found.

IRC Guidelines

- CBR test is performed based on OMC (Optimum moisture content) for new roads and FMC (field moisture content) for existing roads.
- Specimen is soaked in water for 4 days (minimum 3 specimens) and tested.
  For subgrade CBR = 8% and cumulative standard axle = 100 msa
  (a) 200 mm Granular subbase.
  (b) 250 mm Granular base.
  (c) 140 mm dense bituminous macadam.
  (d) 50 mm bituminous surface course.

Limitations of CBR Method

1. This gives the total thickness of pavement as a whole and it is based on the CBR value of subgrade alone. Thickness of individual layers is not specified.
2. Damaging effect of heavier loads and their frequency are not taken into consideration.
3. The test conditions of CBR and the pavement may not be same throughout the life of the pavement.
4. The load-penetration curves do not vary if the road is single lane or multi-lane.

Modified CBR (IRC–37:2012)

- Design is based on cumulative number of standard axles in the traffic lane.

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

Where

N = Million standard axles (msa)
r = Rate of traffic growth per year
n = Design life in years
A = Traffic at the time of completion of construction (cv/day)
F = Vehicle damage factor (VDF)
D = Lane distribution factor (LDF)

LDF for Various Roads

Type of Traffic	LDF
Single lane road (cv in both directions are considered)	1.0
Two lane single carriage way roads (cv in both directions are considered)	0.75
Four-lane single carriage way roads (cv in both directions are considered)	0.4
Dual two lane carriage way roads (cv in one direction is considered)	0.75
Dual 3 or 4 lane carriage way roads (cv in one direction is considered)	0.6/0.45

cv – Commercial vehicles

VDF Values

Realistic value of VDF should be taken after conducting axle load surveys.

Initial Traffic Volume in Terms of Number of cv/day	Terrain	
	Rolling/plain	Hilly
0–150	1.5	0.5
150–1500	3.5	1.5
> 1500	4.5	2.5

NOTE

Traffic in one direction is equal to half of the total traffic in both the directions. If significant difference between two streams occur then maximum traffic should be considered for the design.

SOLVED EXAMPLES

Example 1

A two-lane undivided carriage way whose CBR = 6%
Initial traffic $A = 400$ cv per day
Traffic growth rate $r = 5\%$ per year
Design life = 15 years
Vehicle damage factor = 2.5
Find the cumulative standard axle on the road (in msa)

(A) 3 (B) 4
(C) 5 (D) 6

Solution

$$\text{CSA} = \frac{365\left[(1+r)^n - 1\right]\text{ADF}}{r}$$

$$= \frac{365\left[(1+0.05)^{15} - 1\right] \times 400 \times 0.75 \times 2.5}{0.05}$$

As per IRC, for 2 lane undivided road lane distribution factor $D = 0.75$

$\therefore$ CSA = 5.9 msa

$\cong$ 6 msa

Hence, the correct answer is option (D).

NOTE

For express ways, NH and SH, subgrade dry density γ < 1.75 g/cc

CBR%	Maximum Variation
5	±1
5–10	±2
11–30	±3
> 31	±5

- Minimum 3 samples are to be tested, with maximum variation as in above table.
- If variations are more than specified values, 6 samples are to be tested.

Equivalency Factor

To find the damaging effect of any load with respect to standard load

- Single axle load = $\left(\dfrac{\text{Axle load in kg}}{8200}\right)^4$
- Tandem axle load = $\left(\dfrac{\text{Axle load in kg}}{14500}\right)^4$

Fatigue and Rutting Criteria

The total cumulative standard axles to be used for the design of the pavement should include fatigue and rutting criteria also.

Fatigue Criteria

The number of cumulative standard axles to produce 20% cracked surface area of bitumen is:

$$N_F = 2.21 \times \left(\frac{1}{\in}\right)^{3.89} \left(\frac{1}{E}\right)^{0.854} \times 10^{-4}$$

Where

$\in$ = Tensile strain at bottom of stiff bituminous layer
E = Modulus of elasticity (MPa) of bituminous layer

Rutting Criteria

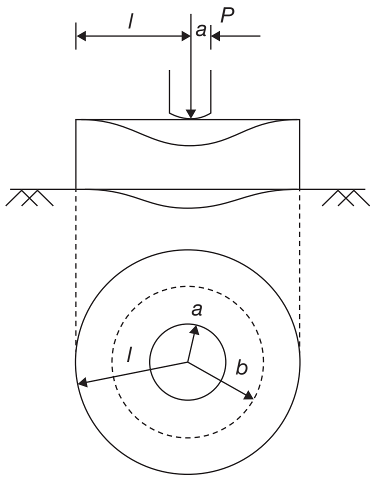
Number of cumulative standard axles to produce rutting of 20 mm is.

$$N_r = 4.1656\left(\frac{1}{\in}\right)^{4.5337} \times 10^{-8}$$

Where, $\in$ = Vertical subgrade strain, (micro strain).

Rigid Pavements

Load carrying capacity of rigid pavements is mainly due to rigidity and high modulus of elasticity of the slab itself, i.e., **slab action**.



a = Radius of contact between road and tyre
b = Radius of resisting section
l = Radius of relative stiffness.

- Load transfer is by bending/slab action/flexual action.

Factors Affecting Design and Performance of CC Pavements

1. Design axle load (wheel load).
2. Temperature variations at locations on the road.
3. Types of joints and their spacing.
4. Subgrade and the other supporting layers below the CC pavement slab.
5. Drainage characteristics.

Design Parameters of Subgrade

- Strength: CBR
- Stiffness: Modulus of subgrade reaction (K)

Radius of Relative Stiffness (l)

- A certain degree of resistance to slab action is offered by the subgrade. The relative stiffness of the slab with respect to subgrade support depends upon properties of the slab and pressure–deformation characteristics of the subgrade material.

  Westergaard defined this term as:

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4}$$

Where
l = Radius of relative stiffness, cm
h = Slab thickness, cm
E = Modulus of elasticity of cement concrete (kg/cm^2)
μ = Poissons ratio concrete = 0.15
K = Subgrade modulus or modulus of subgrade reaction, kg/cm^3.

Example 2

Compute the radius of relative stiffness of 15 cm thick cement concrete slab using following data:

Modulus of elasticity of cement concrete = 2.1×10^5 kg/cm^2

Poisons ratio for concrete = 0.15

Modulus of subgrade reaction, $K = 3$ kg/cm^3

(A) 67 cm (B) 53 cm
(C) 47 cm (D) 32 cm

Solution

For $K = 3.0$

$$L = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$$

$$= \left[\frac{2.1\times10^5\times15^3}{12\times3(1-0.15^2)}\right]^{1/4}$$

= 67 cm.

Hence, the correct answer is option (A).

Critical Positions of Loading

- Interior
- Edge
- Corner

Equivalent Radius of Resisting Section (b)

With the load concentrated on a small area of the pavement, Westergaard designed for the equivalent radius of resisting section as

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

Where
b = Equivalent radius of resisting section, cm
a = Radius of wheel load distribution, cm
h = Slab thickness, cm

Example 3

Find equivalent radius of resisting section of 20 cm thick slab if radius of contact area of wheel load is 15 cm

(A) 12 cm (B) 14 cm
(C) 16 cm (D) 18 cm

Solution

$$\frac{a}{h}=\frac{15}{20}=0.75<1.724$$

$$b=\sqrt{1.6a^2+h^2}-0.675h$$

$$=\sqrt{1.6(15)^2+20^2}-0.675\times 20$$

$$= 14.07 \text{ cm}$$

Hence, the correct answer is option (B).

Loads on rigid pavements:

- DL (self weight) is ignored [∴has no effect on rigid pavement]
- LL (wheel load)

Westergaard's Equations for Wheel Loads

1. Load stress due to interior loading (tensile stress at the bottom of slab)

$$S_i=\frac{0.316P}{h^2}\left[4\log_{10}(l/b)+1.069\right]$$

2. Load stress, due to edge loading (tensile stress at the bottom of slab)

$$S_e=\frac{0.572P}{h^2}\left[4\log_{10}(l/b)+0.359\right]$$

3. Load stress, S_c due to corner loading (tensile stress at slab top)

$$S_c=\frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

Where

S_i, S_e, S_c (kg/cm^2) = Maximum stress at interior, edge and corner regions of the slab respectively due to applied load P kg/cm^2

h = Slab thickness, cm

If the corner load stress exceeds the flexural strength of concrete, crack is likely to develop across the diagonal on top surface of pavement. This maximum stress occurs at some distance, X along the diagonal $X = 2.58\sqrt{al}$

Where

X = Distance from apex of slab corner to section of maximum stress along the corner bisector or diagonal.

a = Radius of wheel load distribution, cm

l = Radius of relative stiffness, cm

Modified Equations for Wheel Load Stress

1. Edge load stress by Teller and Sutherland:

$$S_e=0.529\frac{P}{h^2}(1+0.54\mu)\times\{4\log_{10}(l/b)+\{\log_{10}b-0.4048\}$$

2. Corner load stress equation by Kelley:

$$S_c=\frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$$

Temperature Stresses (Secondary Stresses)

These stresses arise due to variations in slab temperature.

1. Warping stresses due to difference in temperature between top and bottom of pavement due to daily variation of temperature at a location.
2. Frictional stresses by overall difference in temperature caused by seasonal variation of temperature.

Warping Stresses (by Bradbury)

1. **At interior:**

$$S_{w(i)}=\frac{E\alpha t}{2}\left[\frac{C_x+\mu C_y}{1-\mu^2}\right]$$

Where

$S_{w(i)}$ = Warping stress at interior, kg/cm^2

E = Modulus of elasticity of concrete, kg/cm^2

a = Thermal coefficient of concrete per °C

t = Temperature difference between top and bottom of slab, °C

C_x, C_y = Coefficients in x and y direction, based on L_x/l and L_y/l respectively. (x short and y long direction)

μ = Poissons ratio of cement concrete (0.15)

2. **At edge:**

$$S_{w(e)}=\frac{C_xE\alpha t}{2}\text{ (or) }\frac{C_yE\alpha t}{2}\text{ (higher of both)}$$

3. **At corner:**

$$S_{w(c)}=\frac{E\alpha t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

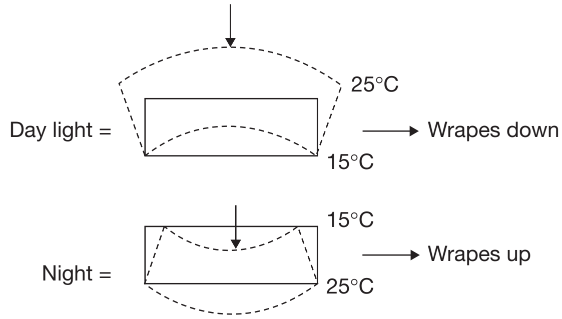
Where

a = Radius of contact

l = Radius of relative stiffness

NOTES

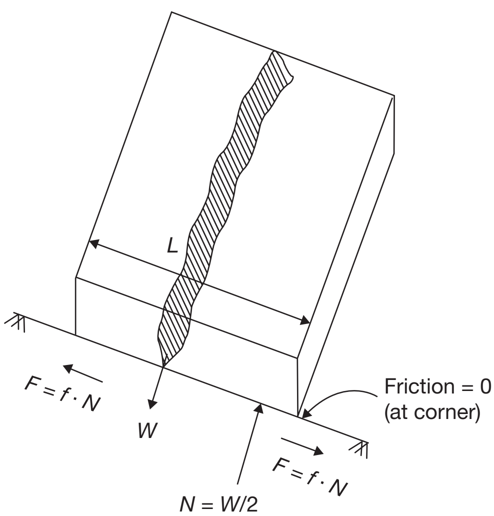
1. If the pavement is free to warp, no stress develops.
2. Over warped surface if wheel load is placed, the nature of warping stress will be same as wheel load stress.



Frictional Stresses

- As the slab is in contact with soil, due to seasonal variation in temperature, the slab movements are restrained by frictional force between slab and base course.
- Half the slab length is considered in resisting the frictional force.

Frictional force = Resisting force



$$f \cdot N = (S_f) \times (B \times H)$$

$$f\left(\frac{W}{2}\right) = S_f (B \times H)$$

$$f \cdot \gamma_c \left(\frac{L \times B \times H}{2}\right) = S_f (B \times H)$$

$$\boxed{S_f = \frac{\gamma_c f L}{2}}$$

Where

S_f = Stress due to inter-face friction in cement concrete pavement per unit area, (kg/m^2)
γ_c = Unit weight of concrete, (2400 kg/m^3)
f = Coefficient of friction at interface (max value = 1.5)
L = Spacing between contraction joint = Slab length (m)
B = Slab width, (m)

NOTES

1. In summer pavement tries to expand, but soil below the pavement is obstructing free expansion. Therefore compression develops in pavement. As concrete is strong in compression, no problem to pavement in summer.
2. In winter pavement tries to contract, but soil resist. Therefore tension develops in pavement. This is critical as concrete is weak in tension.
   - For safety $S_f \not> $ Permissible tensile strength of concrete (modulus of rupture $= f_{cr} = 0.7\sqrt{f_{ck}}$.

Critical Combination of Loads

1. **Summer (mid-day):** Edge region is critical.

$$\boxed{S_{critical} = (S_{WL})_e + (S_W)_e - S_f}$$

2. **Winter (mid-day):** Edge region is critical.

$$\boxed{S_{critical} = (S_{WL})_e + (S_W)_e + S_f}$$

3. **Winter (mid-night):** Corner is critical.

$$\boxed{S_{critical} = (S_{WL})_c + (S_W)_c}$$

(S_f = 0 at corner)

S_{WL}, S_W, S_f are stresses due to wheel load, warping and frictional stresses respectively.

Joints in Rigid Pavement

- Joints are provided to relieve part of the stresses developed due to temperature variations in slabs.
  (a) Longitudinal joints
    (i) Warping joints
    (ii) Contraction joints
    (iii) Construction joints
  (b) Transverse joints
    (i) Contraction joints
    (ii) Expansion joints
    (iii) Construction joints
  - Shrinkage cracks generally develop in CC pavement slabs supported on the base course during initial stage of curing, when length or width exceed 4.5 m–5.0 m.

Expansion Joints (in Transverse Direction)

These joints are provided to give allowance for expansion of pavement slab due to increase in temperature after a number of contraction joints. These are provided to full depth with about 20 mm gap between the two slabs.

- Because of this gap, there is no load transfer across the joint.

- Mastic asphalt/mastic pad is filled in the gap at expansion joint. It should compress minimum 50% because of expansion of pavement.
- Design of expansion joint is based on
  (a) Maximum temperature variation
  (b) Width of joint
  (c) Dowel bars placed
- 50% of expansion joint gap = Expansion of slab

$$\frac{\delta}{2} = L\,\alpha\,t$$

$$\boxed{L = \frac{\delta}{2\alpha t}}$$

Spacing of joint
δ = Gap at expansion joint
$\alpha_c = 12 \times 10^6$/°C
L = Length of the expansion joint
T = Increase in temperature form construction temperature $= t_2 - t_1$ (°C)

Example 4

A cement concrete pavement is constructed at a temperature of 12°C. The peak summer temperature is 45°C. The coefficient of temperature is 10×10^{-6}/°C. The gap at the expansion joint is 2.5 cm. The spacing of expansion joint is
(A) 37.8 m
(B) 45.6 m
(C) 55.4 m
(D) 75 m

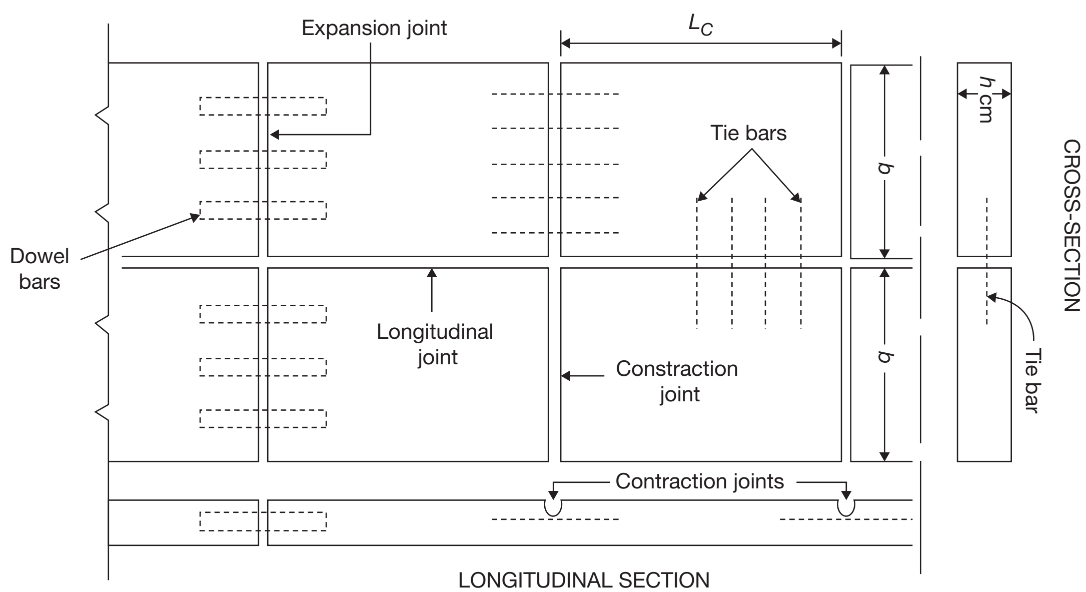
Solution

$$\frac{\delta}{2} = L\alpha t$$

$$\frac{2.5}{2} \times 10^{-2} = L \times 10 \times 10^{-6} \times (45-12)$$

$$L = 37.87 \text{ m.}$$

Hence, the correct answer is option (A).



NOTES

1. Winter season is best for construction of rigid pavement because the tensile stresses developed due to decrease in temperature will be minimum.
2. IRC recommends to stop construction of rigid pavement in summer, if day temperature is more than 40°. In such cases construction during nights is preferred.

Contraction Joints

- These joints are provided to allow the contraction of the slab due to fall in slab temperature the construction temperature.
- The movement is restricted by the subgrade friction.
- This works only in water (as contraction, when 't' reduces)

1. **For PCC (plain cement concrete slab):** Frictional resistance upto $L_c/2$ = Allowable tension in CC

$$(\gamma_c \times B \times \frac{L_c}{2} \times h) \times f = S_c \times h \times b$$

Spacing of contraction joint,

$$\boxed{L_c = \frac{2S_c}{\gamma_c \cdot f}}$$

Where
S_c = Allowable tensile stress in concrete ($0.7\sqrt{f_{ck}}$)
γ_c = Unit weight of concrete
f = Coefficient of friction (as per IRC = 1.5)

L_c = Slab length or spacing of contraction joints.
h = Slab thickness
B = Width of slab.

2. **For RCC:**
   - To prevent widening of fine cracks, steel reinforcement is provided across the contraction joints.
   - It is assumed that all tensile stress is taken by reinforcement alone.

$$(\gamma_c \times B \times \frac{L_c}{2} \times h) \times f = S_s \times A_s$$

A_s = Total area of steel per entire width 'B'
S_s = Allowable tensile stress in steel.
Spacing of contraction joint

$$L_c = \frac{2S_s A_s}{Bh\gamma_c f}$$

   - If steel reinforcement is used at the joint, maximum spacing between joints is 4.5 m as per IRC.

Design of Tie Bars

- Provided across longitudinal joint at mid depth
- Ensures the two adjacent slabs of longitudinal joint to remain firmly together.
- These are not load transfer devices.
- Bars are designed to withstand tensile stress induced due to friction at bottom.

1. **Cross-section of tie bars:** Considering one metre length of joint,

$$A_s = \frac{Bhf\gamma_c}{S_s}$$

Where

A_s = Area of steel in cm²/m length.
B = Lane width in 'm'
S_s = Allowable working stress in steel (1400 to 1750 kg/cm²)

Assuming 8 to 15 mm diameter HYSD bars for the design.

2. **Length of tie bar:** Tensile force developed in each tie bar = Bond force developed on each embedded half-length of tie bar.

$$S_s\left(\frac{\pi d^2}{4}\right) = S_b\left(\frac{\pi d L_t}{2}\right)$$

Minimum length of tie bar

$$L_t = \frac{dS_s}{2S_b}$$

- Permissible bond stress of concrete,
  - S_b in plain bars = 17.5 kg/cm²
  - S_b in deformed bars = 24.6 kg/cm²
- To prevent warping at joint, maximum diameter of tie bars may be limited to 20 mm
- To avoid concentration of tensile stresses, spacing of the bars < 75 cm.

Longitudinal Joints

These are provided if pavement width is more than 4.5 m. Tie bars are provided across longitudinal joint.

Fatigue behavior of cement concrete: Due to repeated application of wheel loads, (bending effect) progressive fatigue damage takes place in cement concrete slab in the form of gradual development of micro-cracks.

$$\text{Stress ratio (SR)} = \frac{\text{Flexural stress due to load}}{\text{flexural strength of concrete}}$$

Fatigue life, $N = \infty$ … if SR< 0.45

$$N = \left\{\frac{4.2577}{\text{SR} - 0.4325}\right\}^{3.268} \ldots$$

If $(0.45 \le \text{SR} \le 0.55)$

$$N = \frac{0.9718 - \text{SR}}{0.0828} \ldots$$

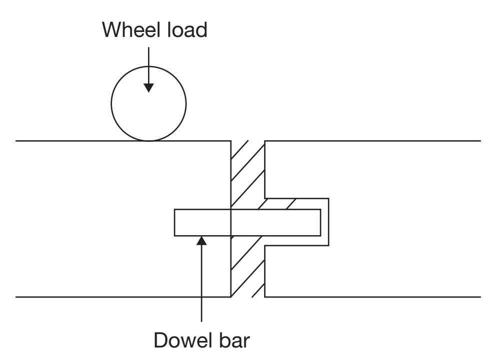
If SR > 0.55

- Fatigue life consumed

$$= \frac{\text{Expected repetitions of axle load}}{\text{Fatigue life}}$$

If fatigue life consumed < 1, pavement is safe.

Dowel Bars



- Half of the length is bonded in one CC slab and the rest half kept free for movement in other slab.
- Dowel bars are mild steel round bars (coated with zinc/lead based paints/epoxy coats)

- Maximum load transferred through dowel bars is **(40% of maximum axle load)**
- Not required if slab thickness < 150 mm
- Bearing stress in concrete is responsible for the performance of the joints for the dowel bars.
- Maximum bearing stress between concrete and dowel bar

$$\sigma_{max} = \frac{kp_t(2+\beta z)}{4\beta^3 EI}$$

$$\beta = \left(\frac{kb}{4EI}\right)^{1/4}$$

Where

β = Relative stiffness of the bar embedded in concrete.
k = (Modulus of dowel)/Concrete interaction (Dowel support kg/cm^3/cm)
b = Diameter of dowel, cm
z = Joint width, cm
E = Modulus of elasticity of the dowel, g/cm^2
P_t = Load transferred by a dowel bar.
I = Moment of inertia by a dowel bar, cm^4.

- Allowable bearing stress on concrete,

$$F_B = \frac{(10.16-b)}{9.525}$$

- Dowel bars provided up to a distance of **1.0 × relative stiffness**, from the point of load application are effective in load transfer.
- Minimum dowel length = $L_d + \delta$

Reinforcement in Cement Concrete Slab

- Without increasing the flexural strength, but to control cracking reinforcement is provided to counteract the tensile stresses due to shrinkage due to temperature or moisture changes.
- Maximum tensile force in the slab is in the middle of the slab, where cracks occur first.
- Longitudinal and transverse steel in slab is given by the

$$\boxed{A_s = \frac{Lf\gamma_c}{2S_s}}$$

Where

A_S = Area of steel in cm^2/m length or width of slab
L = Distance in 'm' between free tranverse joints
f = (1.15) Coefficient of friction between concerete and subbase/base
γ_c = Weight of slab in kg/m^2
S_s = Allowable working stress in steel (g/cm^2)

(Usually 50–60% of minimum yield stress of steel which is 1400 kg/cm^2)

Design Requirements as per IRC

1. **Reinforcement** in RCC pavement: Top face only (effective cover = 50 mm)
2. Minimum cement: 350 kg/m^3
3. Maximum cement: 425 kg/m^3
4. Maximum nomial size of aggregate: 25 mm
5. AIV: < 30% for wearing surfaces
6. Los Angeles abrasion value < 35%
7. Water absorption: 2% maximum by weight
8. Flexural strength of concrete 38–42 kg/cm^2
9. In all cases use $E = 3 \times 10^5$ kg/cm^2, $\mu = 0.15$ and $\alpha = 10 \times 10^{-6}$/°C
10. Required minimum compressive strength: 35 MPa
11. Minimum $k = 6$ kg/cm^3(modulus of subgrade reaction)
12. Separation layer between sub base and pavement: 125 micro polythene sheet (as per IRC: 15–2002)

Example 5

A cement concrete pavement has a thickness of 25 cm and lane width of 3.5 m. Allowable working stress in steel tie bars S_s = 1200 kg/cm^2. Allowable tensile stress in deformed tie bar, S_s = 2000 kg/cm^2, allowable bond stress in deformed bars S_b = 24.6 kg/cm^2. Use 12 mm ϕ bars, find the length of tie bar

(Assume f = 1.2 and γ_c = 2400 kg/m^3)

(A) 1.2 m c/c (B) 1.75 m c/c
(C) 2.6 m c/c (D) 4.4 m c/c

Solution

Total area of steel tie bar per m length of longitudinal joint

$$A_{st} = \frac{f(\gamma_c \times B \times h \times 1)}{2S_s}$$

$$A_{st} = 1.2\frac{(2400 \times 3.5 \times 0.25 \times 1)}{2 \times 2000}$$

$$= 0.63 \text{ cm}^2/\text{m}.$$

$$1 \text{ m} \rightarrow 0.63 \text{ cm}^2 = 63 \text{ mm}^2$$

Area of each steel bar, a

$$= \frac{\pi}{4} \times 12^2 = 113 \text{ mm}^2$$

$$(63 \text{ mm}^2 = A_s) - 1000 \text{ mm}$$

$$113 \text{ mm}^2 \rightarrow ?$$

$$\therefore \text{ spacing } L_c = 1793 \text{ mm c/c} \simeq 1750 \text{ mm c/c}$$

$$\therefore L_c = 1.75 \text{ m c/c}$$

Hence, the correct answer is option (B).

Exercises

1. The penetration test for bitumen is conducted at a temperature of
(A) 60°C (B) 37°C
(C) 25°C (D) 50°C

2. The total thickness of pavement by CBR methods depends on the CBR value of
(A) base course (B) surface course
(C) subgrade (D) all layers

3. The width of expansion joint gap is 2.5 cm in a cement concrete pavement. The spacing between expansion joint for a maximum rise in temperature of 25°C is (assuming a coefficient of thermal expansion of concrete as 10×10^{-6} per degree C)
(A) 5 m (B) 50 m
(C) 100 m (D) 25 m

4. The modulus of subgrade reaction is obtained from the plate bearing test in the form of load deformation curve. The pressure corresponding to the following settlement value should be used for computing modules of subgrade reaction.
(A) 0.375 cm (B) 0.175 cm
(C) 0.125 cm (D) 0.250 cm

5. In the plate bearing test, if the load applied is in the form of an inflated type of wheel, then this mechanism corresponds to
(A) rigid plate (B) flexible plate
(C) semi-rigid plate (D) semi-elastic plate

6. Base course is used in rigid pavements for
(A) prevention of subgrade settlement
(B) prevention of slab cracking
(C) prevention of pumping
(D) prevention of thermal expansion

7. The standard plate size in a plate bearing test for finding modulus of sub grade reaction (K) value is
(A) 100 cm diameter
(B) 50 cm diameter
(C) 75 cm diameter
(D) 25 cm diameter

8. The minimum value of CRB (%) required for granular subbase as per Ministry of Surface Transport (MoST) specification is
(A) 5 (B) 10
(C) 15 (D) 20

9. Temperature stresses in concrete pavements may cause the slab to crack. If slab cools uniformly then the crack will develop at which of the following locations of the slab
(A) at centre
(B) near edges
(C) at corners
(D) near edges and at corners

10. In the content of flexible pavement design, the ratio of contact pressure to tyre pressure is called the Rigidity Factor. This factor is less than unity when the tyre pressure is
(A) less than 0.56 N/mm^2
(B) equal to 0.56 N/mm^2
(C) equal to 0.7 N/mm^2
(D) more than 0.7 N/mm^2

11. Bituminous concrete is a mix comprising of
(A) fine aggregate and filler and bitumen
(B) fine aggregate and bitumen
(C) coarse aggregate, fine aggregate, filler and bitumen
(D) coarse aggregate, filler and bitumen

12. What is the Equivalent single wheel load of a dual wheel assembly carrying 20,440 N each for pavement thickness of 20 cm? Centre spacing of tyres is 27 cm and the distance between the walls of tyres is 11 cm.
(A) 27,600 N (B) 32,300 N
(C) 40,880 N (D) 30,190 N

13. A two lane single carriage way is to be designed for a design life period of 15 years. Total two way traffic intensity in the year of completion of construction is expected to be 2000 commercial vehicles per day. Vehicle damage factor = 3.0, lave distribution factor = 0.75. Assuming an annual rate of traffic growth as 7.5%, the design traffic expressed as cumulative number of standard axles is
(A) 42.9×10^6 (B) 22.6×10^6
(C) 10.1×10^6 (D) 5.3×10^6

14. In a concrete pavement
A. Temperature stress is tensile at bottom during day time
B. Load stress is compressive at bottom
(A) Both the statement A and B are correct
(B) Statement A is correct and B is wrong
(C) Statement B is wrong and A is correct
(D) Both statement A and B are incorrect

15. The data given below pertain to the design of a flexible pavement
Initial traffic = 1213 cvpd
Traffic growth rate = 8% per annum
Design life = 12 years
Vehicle damage factor = 1.0
The design traffic in terms of million standard axles (msa) to be catered would be
(A) 0.06 msa (B) 8.4 msa
(C) 21.0 msa (D) 32.26 msa

16. The following observations were made of an axle load survey on a road.

Axle Load (kN)	Repetition Per Day
35–45	800
75–85	400

The standard axle load is 80 kN. Equivalent daily number of repetitions for the standard axle load are

(A) 450 (B) 480
(C) 800 (D) 1200

17. Using IRC: 37–1984 ‘Guidelines for the Design of Flexible Pavements’ and the following data, choose the total thickness of the pavement. Number of commercial vehicles when construction is completed = 2723 veh/day

Annual growth rate of traffic = 5.0%

Design life of the pavement = 10 years

Vehicle damage factor = 2.4

CBR value of the sub grade soil = 5%

Data for 5% CBR value

No of Standard Axles (msa)	Total Thickness, (mm)
20	620
25	640
30	670
40	700

(A) 620 mm (B) 640 mm
(C) 670 mm (D) 700 mm

18. For a 25 cm thick concrete pavement, analysis of stresses gives the following values

Wheel load stress due to edge loading: 30 kg/cm^2

Wheel load stress due to corner loading: 32 k/cm^2

Warping stress at corner region during summer: 9 kg/cm^2

Warping stress at corner region during winter: 7 kg/cm^2

Warping stress at edge region during summer: 8 kg/cm^2

Warping stress at edge region during winter: 6 kg/cm^2

Frictional stress during summer:

5 kg/cm^2

Frictional stress during winter: 4 kg/cm^2

The most critical stress value for this pavement is

(A) 40 kg/cm^2 (B) 42 kg/cm^2
(C) 44 kg/cm^2 (D) 45 kg/cm^2

19. In case of governing equations for calculating wheel load stress using Westergaards approach, the following statements are made

I. Load stresses are inversely proportional to wheel load

II. Modulus of subgrade reaction is useful for load stress calculation

(A) Both statements are True
(B) I is True and II is False
(C) Both statements are False
(D) I is False and II is True

20. A two lane single carriage way is to be designed for a design life of 15 years. Total two way traffic intensity in the year of completion of construction is expected to be 2000 commercial vehicles per day, vehicles damage factor = 3.0 lane distribution factor = 0.75. Assuming an annual rate of traffic growth as 7.5%, the design traffic expressed as cumulative number of standard axles, is

(A) 42.9×10^6
(B) 22.6×10^6
(C) 10.1×10^6
(D) 5.3×10^6

21. The load penetration data from a California bearing ratio (CBR) test is provide in the following table. Indicate whether any correction is required for the calculated CBR value. Find the CBR value of the soil from the data provided (in %)

Penetration	Load in kgf (kg Force)
0	0
0.5	4
1.0	13
1.5	29
2.0	40
2.5	50
3.0	58
4.0	70
5.0	78
7.5	93
10	103
12.5	112

Area of plunger is given as 19.6 cm^2. Pressure for standard crushed stones at 2.5 mm and 50 mm are 70 kg/cm^2 and 105 kgf/cm^2 respectively.

22. Dowel bars in concrete pavement are placed

(A) along the direction of traffic.
(B) perpendicular to the direction of traffic.
(C) along 45° to the direction of traffic.
(D) can be placed along any direction.

Previous Years' Questions

1. The following data pertains to the number of commercial vehicles per day for the design of a flexible pavement for a national highway as per IRC: 37–1984

Number of Commercial Vehicles Per Day	Vehicles Considering the Number of Lanes	Vehicle Damage Factor
Two axle trucks	2000	5
Tandem axle trucks	200	6

Assuming a traffic growth of 7.5% per annum for both the types of vehicles, the cumulative number of standard axle load repetitions (in million) for a design life of ten years is **[GATE, 2007]**

(A) 44.6
(B) 57.8
(C) 62.4
(D) 78.7

2. The width of the expansion joint is 20 mm in a cement concrete pavement. The laying temperature is 20°C and the maximum slab temperature in summer is 60°C. The coefficient of thermal expansion of concrete is 10×10^{-6} mm/mm/°C and the joint filler compresses up to 50% of the thickness. The spacing between expansion joints should be **[GATE, 2007]**

(A) 20 m (B) 25 m
(C) 30 m (D) 40 m

3. It is proposed to widen and strengthen an existing 2 lane NH section as a divided highway. The existing traffic in one direction is 2500 commercial vehicles (CV) per day. The construction will take 1 year. The design CBR of soil sub grade is found to be 5%

Given: Traffic growth rate of CV = 8%

Vehicle damage factor = 3.5 (standard axles per CV)

Design life = 10 years and traffic distribution factor = 0.75

The cumulative standard axles msa computed are **[GATE, 2008]**

(A) 35 (B) 37
(C) 65 (D) 70

4. Which of the following stress combinations are appropriate in identifying the critical condition for the design of concrete pavements?

	Type of Stress		Location
P.	Load	1.	Corner
Q.	Temperature	2.	Edge
		3.	Interior

[GATE, 2009]

(A) P–2, Q–3
(B) P–1, Q–3
(C) P–3, Q–1
(D) P–2, Q–2

5. Consider the following statements in the context of cement concrete pavements

I. Warping stresses in cement concrete pavements are caused by the seasonal variation in temperature

II. Tie bars are generally provided across transverse joints of cement concrete pavements

The correct option evaluating the above statements is/are **[GATE, 2010]**

(A) I True and II False
(B) I False and II True
(C) I True and II True
(D) I False and II False

6. A pavement designer has arrived at a design traffic of 100 million standard axles for a newly developing national highway as per IRC: 37–1984 guideline using the following data: Design life = 15 years, commercial vehicle count before pavement construction = 4500 vehicles/day, annual traffic growth rate = 8%. The vehicle damage factor used in the calculation was **[GATE, 2012]**

(A) 1.53 (B) 2.24
(C) 3.66 (D) 4.14

7. Select the strength parameter of concrete used in design of plain jointed cement concrete pavements from the following choices **[GATE, 2013]**

(A) tensile strength
(B) compressive strength
(C) Flexural strength
(D) shear strength

8. The following statements are related to temperature stresses developed in concrete pavement slabs with free edges (without any restraint)

P. The temperature stresses will be zero during both day and night times if the pavement is considered weightless.

Q. The temperature stresses will be compressive at the bottom of the slab during night time if the self-weight of the pavement slab is considered.

R. The temperature stresses will be compressive at the bottom of the slab during day time if the self-weight of the pavement slab is considered. **[GATE, 2014]**

The true statement(s) is/are

(A) P only
(B) Q only
(C) P and Q only
(D) P and R only

9. A traffic survey conducted on a road yields an average daily traffic count of 5000 vehicles. The axle load distribution on the same road is given in the following table

Axle load (tonnes)	Frequency of Traffic (%)
18	10
14	20
10	35
8	15
6	20

The design period of the road is 15 years the yearly traffic growth rate is 7.5% and the load safety factor (LSF) is 1.3. If the vehicles damage factor (VDF) is calculated from above data, the design traffic (in million standard axle load MSA) is ________.

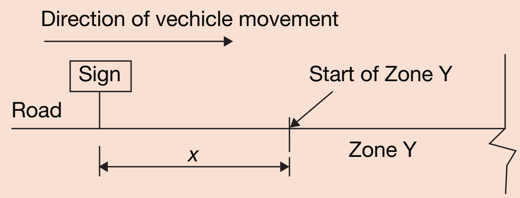
[GATE, 2014]

10. Which of the following statements CANNOT be used to describe free flow speed (u_f) of a traffic stream? **[GATE, 2015]**

(A) u_f is the speed when flow is negligible.
(B) u_f is the speed when density is negligible.
(C) u_f is affected by geometry and surface conditions of the road.
(D) u_f is the speed at which flow is maximum and density is optimum.

11. A sign is required to be put up asking drivers to slow down to 30 km/h before entering Zone Y (see figure) on this road, vehicles required 174 m to slow down to 30 km/h (the distance of 174 m includes the distance travelled during the perception-reaction time of drivers). The sign can be read by 6/6 vision drivers from a distance of 48 m. The sign is placed at a distance of *x* m from the start of Zone Y so that even a 6/9 vision driver can slow down to 30 km/h before entering the zone. The minimum value of *x* is ________ m.

[GATE, 2015]



12. In the context of the IRC:58–2011 guidelines for rigid pavement design, consider the following pair of statements:

I. Radius of relative stiffness is directly related to modulus of elasticity of concrete and inversely related to Poisson's ratio.
II. Radius of relative stiffness is directly related to thickness of slab and modulus of subgrade reaction.

Which one of the following combinations is correct? **[GATE, 2016]**

(A) I True; II True
(B) I False; II False
(C) I True; II False
(D) I False; II True

Answer Keys

Exercises

1. A **2.** C **3.** B **4.** C **5.** B **6.** C **7.** C **8.** A **9.** B **10.** D
11. C **12.** D **13.** A **14.** D **15.** C **16.** A **17.** C **18.** B **19.** D **20.** A
21. 36.5% **22.** A

Previous Years' Questions

1. B **2.** B **3.** B **4.** D **5.** D **6.** B **7.** C **8.** C **9.** 237.78
10. D **11.** 142 **12.** B