*G. S. Mandal's*
*Maharashtra Institute of Technology, Aurangabad.*
*Department of Civil Engineering*

# Highway Engineering (CED 403)

*(Class : B. Tech. final year)*

*Mr. Bhupal I. Welke*

*(Assistant Professor)*

*M. Tech. (Transportation Engineering & Planning) SVNIT, Surat.*

*welkebhupal@gmail.com (8055698750)*

# ***Design of Flexible & Rigid Pavement***

*Contents:*

***B. Design of Rigid Pavement.***

- *Design parameter.*
- *Westergaard Stress: Wheel Load, Temperature Stresses.*
- *Design of Joints in Rigid Pavement.*

## Difference between Flexible & Rigid Pavement

| Sr. No. | | Flexible Pavement | Rigid Pavement |
|---|---|---|---|
| 1 | IRC Code | • IRC: 37 | • IRC: 58 |
| 2 | Layers | 1. Surface Coarse (BC)<br>2. Base Coarse (WBM or WMM)<br>3. Subbase Coarse (GSB)<br>4. Subgrade (C-$\phi$ Soil). | 1. Surface Coarse (PCC or RCC)<br>2. Base Coarse (DLC or WMM)<br>3. Subgrade (C-$\phi$ Soil). |
| 3 | Load Transformation | • Load Transformation is grain to grain. | • Load Transformation is layer to layer. |
| 4 | Failure Nature | • If there is any failure at bottom layer then the failure will be appear at top. | • If there is any failure at bottom layer then for small cavity slab will act as a bridge over it. |
| 5 | Joints | • Joints are absent. | • Joints are present. |
| 6 | Cost | • Initial cost is low but maintenance cost is high. | • Initial cost is high but maintenance cost is low. |

***Stresses in Rigid Pavement***

1. *Load Stress: Due to load.*
2. *Temperature stress:*

- *Warping stress: Due to day night temperature variation.*
- *Frictional stress: Due to seasonal temperature variation.*

***Design Parameter:***

1. *Modulus of subgrade reaction: (k)*

- $k = (p/\Delta) = (p/0.125)\ kg/cm^3$ ……….. $\Delta = 0.125\ cm$

*Where,* $p$ = *Contact pressure or tyre pressure in* $kg/cm^2$

$k = kg/cm^3$

$\Delta = 0.125\ cm$

2. *Radius of Relative stiffness:* $l\ (\text{in cm}) = \left(\frac{Eh^3}{12k\,(1-\mu^2)}\right)^{1/4}$

*3. Equivalent Radius of Resisting section: b (in cm)*

- $b = \sqrt{1.6\, a^2 + h^2} - 0.675\, h$ …………. *If a/h ≤ 1.724*
- *b = a* …………. *If a/h > 1.724*
- *Effective in resisting bending moment.*
- *Radius of effective area (b), resisting bending moment.*
- *E = Modulus of elasticity (Young's modulus) of slab* ($kg/cm^2$)
- *h = Thickness of slab or pavement (cm)*
- *k = Modulus of subgrade reaction* ($kg/cm^3$)
- *μ = Poisson's ratio*
- *a = Radius of contact area (Radius of wheel load distribution) in (cm)*

**1. Load Stress:** *Stresses developed in concrete slab due to wheel load.*

***Westergaard stress equation for wheel load:***

*Magnitude,*

*a. At interior: Si = Wheel load stress at Interior location in kg/cm²*

$$Si = \frac{0.316\ P}{h^2} (4 \log_{10}(l/b) + 1.069)$$

*b. At edge: Se = Wheel load stress at edge location in kg/cm²*

$$Se = \frac{0.502\ P}{h^2} (4 \log_{10}(l/b) + 0.359)$$

*c. At corner: Sc = Wheel load stress at corner location in kg/cm²*

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

*Where,*

*P = Wheel load (kg)*

*l = Radius of relative stiffness (Pressure deformation characteristic of cement concrete) in (cm)*

## **2. Warping stress or Temperature stresses:** *in kg/cm²*

- *Warping stress is developed due to day-night temperature variation. Under warping, effective temperature gradient exist between top and bottom of slab.*

*Magnitude,*

*a. At Interior:*

$$S\ (ti) = \frac{E * \alpha * T}{2}\ \left(\frac{Cx + \mu * Cy}{1 - \mu^2}\right)$$

*b. At edge:*

$$S\ (te) = \frac{Cx * E * \alpha * T}{2}\ OR\ \frac{Cy * E * \alpha * T}{2}$$

*……… Take maximum value from both*

*c. At corner:*

$$S\ (tc) = \frac{E * \alpha * T}{3\ (1 - \mu)} \sqrt{\frac{a}{l}}$$

*Where,*

*α = Coefficient of thermal expansion (per °c)*

*T = Change in temperature (Temperature difference between top and bottom of pavement surface) in (°c)*

- *Cx & Cy are the factor (Warping stress coefficient) which depends upon Lx/l & Ly/l respectively.*
- *Lx = length of slab (Spacing between two transverse joint)*
- *Ly = Width of slab (Spacing between two longitudinal joint)*

**3. Frictional Stress (Sf):** *Due to seasonal temperature variation in* $kg/cm^2$

- *Frictional force developed by half of slab is resisted by tensile force at center.*
- *Sf =* $\frac{f * \gamma * L}{2 * 10^4}$

*Where,*

- *f = Coefficient of friction between pavement surface and subgrade soil.*
- *L = Length of pavement section.*
- $\gamma$ *= Density = Weight/Volume in* $kg/cm^3$

- *Frictional resistance at corner position is always zero.*
- *In summer season frictional stresses are developed which are compressive in nature.*

***Critical Combination of stresses:***

*1. Critical combination for edge & interior location when pavement is constructed in summer.*

- ***I & E (in Summer) = Wheel load stress + Temperature stress – frictional stress***
- *Interior = Si + S (ti) – Sf*
- *Edge = Se + S (te) – Sf*

*2. Critical combination for edge & interior location when pavement is constructed in winter.*

- ***I & E (in Winter) = Wheel load stress + Temperature stress + frictional stress***

*3. Critical combination of stresses at corner location.*

- ***Corner = Wheel load stress + Temperature stress***

***Question:***

- *A pavement slab 22 cm thick is constructed over a soil subgrade having modulus of subgrade reaction of 18 kg/cm$^3$. Spacing between transverse joints & longitudinal joints are 5.5 m & 4.2 m respectively. Find out the stresses due to lead, temperature & worst combination of stresses by using the following data.*
- *Wheel load (P)= 4500 kg*
- *Temperature difference (T)= 20$^o$c*
- *Radius of load contact (a)= 15 cm*
- *Elastic modulus of cement concrete (E) = 3 * 10$^5$ kg/cm$^2$*
- *Poisson's ratio (μ) = 0.15*
- *Coefficient of friction (f) = 1.5*
- *Coefficient of thermal expansion (α) = 12 * 10$^{-6}$ per $^o$c*
- *Cx = 1.05 & Cy = 0.9*

***Answer:***

*Given, h = 22 cm, k = 18 kg/cm³ , Lx = 5.5 m, Ly = 4.2 m*

*Step 1: Design parameter*

$$k = p/0.125 = \frac{P/\mu a^2}{0.125} = \frac{4500/\mu * 15^2}{0.125} = \textbf{18 kg/cm}^3$$

$$l = \left(\frac{Eh^3}{12k\,(1-\mu^2)}\right)^{1/4} = \left(\frac{3 * 10^5 * 22^3}{12 * 18\,(1-0.15^2)}\right)^{1/4}$$

*l* = ***62.36 cm***

$$b = \sqrt{1.6\,a^2 + h^2} - 0.675\,h = \sqrt{1.6 * 15^2 + 22^2} - 0.675 * 22$$

*b* = ***14.20 cm***

## ***Step 2: Stresses***

1. *Wheel load stresses: (in kg/cm²)*

a. $Si = \frac{0.316\,P}{h^2}\,(4\,log_{10}(l/b) + 1.069) = \frac{0.316 * 4500}{22^2}\,(4\,log_{10}(62.36/14.20) + 1.069)$

$Si =$ ***10.69 kg/cm²***

b. $Se = \frac{0.502\,P}{h^2}\,(4\,log_{10}(l/b) + 0.359) = \frac{0.502 * 4500}{22^2}\,(4\,log_{10}(62.36/14.20) + 0.359)$

$Se =$ ***15.57 kg/cm²***

c. At Corner, $Sc = \frac{3\,P}{h^2}\,(1 - (\frac{a\sqrt{2}}{l})^{0.6}) = \frac{3 * 4500}{22^2}\,(1 - (\frac{15\sqrt{2}}{62.36})^{0.6})$

$Sc =$ ***13.28 kg/cm²***

## 2. Warping Stresses: (in $kg/cm^2$)

a. $$S(ti) = \frac{E * \alpha * T}{2} \left( \frac{Cx + \mu * Cy}{1 - \mu^2} \right) = \frac{3 * 10^5 * 12 * 10^{-6} * 20}{2} \left( \frac{1.05 + 0.15 * 0.9}{1 - 0.15^2} \right)$$

$S(ti) = \mathbf{43.64\ kg/cm^2}$

b. $$S(te) = \frac{Cx * E * \alpha * T}{2} \text{ OR } \frac{Cy * E * \alpha * T}{2}$$

$$S(te) = \frac{Cx * E * \alpha * T}{2} = \frac{1.05 * 3 * 10^5 * 12 * 10^{-6} * 20}{2}$$

$S(te) = \mathbf{37.8\ kg/cm^2}$

c. At Corner, $$S(tc) = \frac{E * \alpha * T}{3(1 - \mu)} \sqrt{\frac{a}{l}} = \frac{3 * 10^5 * 12 * 10^{-6} * 20}{3(1 - 0.15)} \sqrt{\frac{15}{62.36}}$$

$S(tc) = \mathbf{13.84\ \ kg/cm^2}$

## *3. Frictional Stresses:*

$$Sf = \frac{f * \gamma * L}{2 * 10^4} = \frac{1.5 * 2400 * 5.5}{2 * 10^4} = \mathbf{0.99\ kg/cm^2}$$

***Step 3: Worst combination of stresses:*** *(in $kg/cm^2$)*

- *In Summer, (At Interior : S (I) = Si +S (ti) – Sf = 10.69 + 43.64 – 0.99 =* ***53.34***

  *(At edge) : S (E) = Se + S (te) – Sf = 15.57 + 37.8 – 0.99 =* ***52.38***

- *In Winter, (At Interior) : S (I) = Si + S (ti) + Sf = 10.69 + 43.64 + 0.99 =* ***55.32***

  *(At edge) : S (E) = Se + S (ti) + Sf = 15.57 + 37.8 + 0.99 =* ***54.36***

- *At Corner, S (C) = Sc + S (tc) = 13.28 + 13.84 =* ***27.12***

***Design of Joints in Rigid Pavement:***

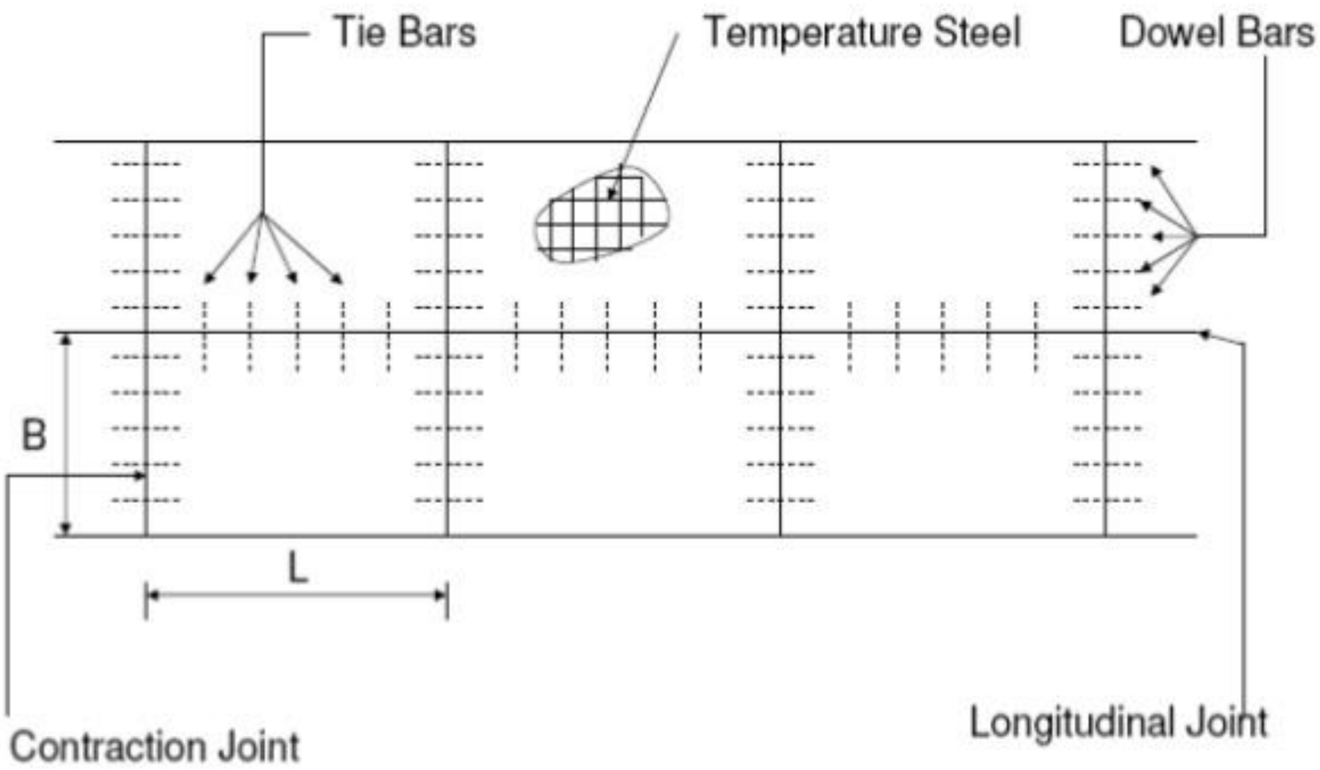
1. *Transverse joints: Provided in transverse direction of slab.*

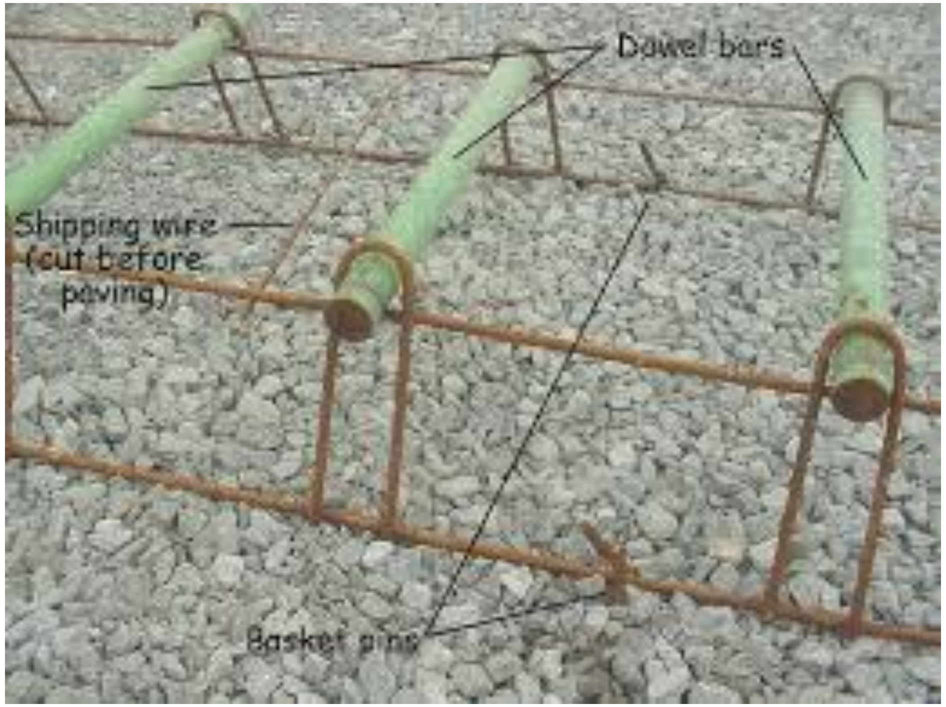
a. *Contraction Joints*

b. *Expansion Joints*

2. *Longitudinal Joints: Provided in longitudinal direction of slab.*

# Jointed CC Pavement



- *Contraction & expansion joints are provided in rigid pavement due to temperature variation. (Increases or decreases)*

***Contraction Joints:***

- *Provided in transverse joints to allow contraction of slab section with respect to construction temperature & decrease in temperature of slab.*

*Case 1: When PCC used (Without Dowel bar)*

- *Frictional force generated by half of slab = Resisting force by concrete at center*
- $f\,(\gamma * \frac{L}{2} * B * h) = Sf * B * h$
- $L = \frac{2 * Sf}{\gamma * f}$

- $\gamma$ = *Density of concrete in kg/m³*
- $f$ = *Coefficient of subgrade restrained = 1.5*
- $Sf$ = *Allowable stress in tension in cement concrete in kg/cm²*

- *Spacing between two contraction joints:*
- $L = \frac{2 * Sf}{\gamma * f} * 10^4$

*As per IRC,*

- *The spacing between two contraction joint for PCC is ≤ 4.5 m*

*Case 2: When Dowel bar used.*

- *Frictional force generated by half of slab = Resisting force by steel*
- $f\,(\gamma * \frac{L}{2} * B * h) = \sigma(st) * A(st)$
- $L = \frac{2 * \sigma(st) * A(st)}{\gamma * f * B * h}$

*Where,*

- *$\sigma(st)$ = Allowable tensile stress in steel*
- *$A(st)$ = Area of steel provided for entire width of the pavement in $cm^2$*

***Question:***

- *Design the spacing between two contraction joint if maximum tensile stress of concrete is 0.8 kg/cm² and coefficient of friction is 1.5 (Assume $\gamma$ = 2400 kg/m³)*

***Answer:***

- $L = \frac{2 * Sf}{\gamma * f} * 10^4 = \frac{2 * 0.8}{2400 * 1.5} * 10^4$
- $L = 4.44\ m \leq 4.5\ m$ *(Safe)*

***Question:***

- *Calculate the spacing between contraction joints by using the following data.*
- *Width of slab (B) = 4.52 m*
- *Thickness of slab (h) = 25 cm*
- *Coefficient of friction (f) = 1.5*
- *Diameter of bar ($\phi$)= 12 mm*
- *Spacing between the bar = 300 mm*
- *Allowable tensile stress in steel ($\sigma(st)$) = 1400 kg/cm²*

***Answer:***

- Number of bar $= n = \frac{Width\ of\ slab}{Spacing} = \frac{4.52 * 10^3}{300} = 15.06 \approx 16$ bars.
- $A(st) = n * \frac{\pi}{4} * \phi^2 = 16 * \frac{\pi}{4} * 12^2$
- $A(st) = 1809\ mm^2 = 18.09\ cm^2$
- *Spacing between contraction joint:*
- $L = \frac{2 * \sigma(st) * A(st)}{\gamma * f * B * h} = \frac{2 * 1400 * 18.09}{2400 * 1.5 * 4.52 * 0.25}$
- $L = 12.45\ m$

***Expansion Joints:***

- *Provided in transverse direction to allow expansion of slab in longitudinal direction.*
- *As per IRC, the gap of expansion joint should be designed such that even after full expansion of pavement 50 % of gap should be maintained.*
- *Allowable expansion* = $(\Delta/4 + \Delta/4) = \Delta/2 = L\alpha T$
- $L = \frac{\Delta}{2\alpha T}$ = *Spacing between expansion joints.*

*Where,*

- $\Delta$ = *Gap of expansion joints. (Maximum expansion in slab section)*

  = *Half of the gap provided for joint 2.5/2*
- $\alpha$ = *Coefficient of thermal expansion*
- $T$ = *Change in temperature*

***As per IRC,***

1. *Filler material for expansion joint must have 50 % compressibility in order to allow expansion of slab. (e.g. fiber board, cork)*
2. *The maximum gap provided, $\Delta \leq 2.5$ cm*
3. *The maximum spacing between expansion joint, $L \leq 140$ m*

- *Expansion joint provided to allow the expansion of pavement due to rise in temperature with respect to construction temperature.*
- *Dowel bars are provided only in expansion joint.*
- *The system of reinforcement transfer certain amount of load to next section is known as dowel bars.*

***Question:***

- *If the width if expansion joint is 2 cm & temperature at the time of construction of slab is 20ºC, then find the spacing between expansion joints for a maximum temperature of 45ºC. (Take $\alpha = 12 * 10^{-6}$ /ºC)*

***Answer:***

- *Given,*

$\Delta = 2\ cm = 2 * 10^{-2}\ m$

$T = 45 - 20 = 25\ ^oC$

$\alpha = 12 * 10^{-6}\ /^oC$

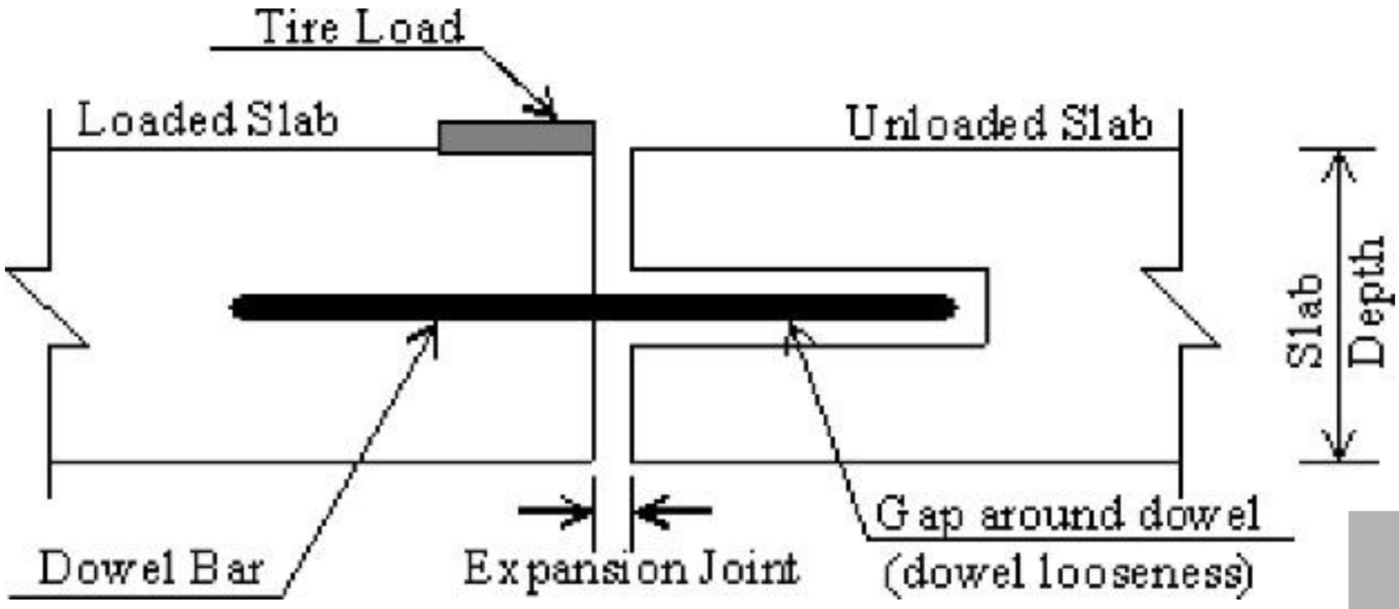
$L = ?$

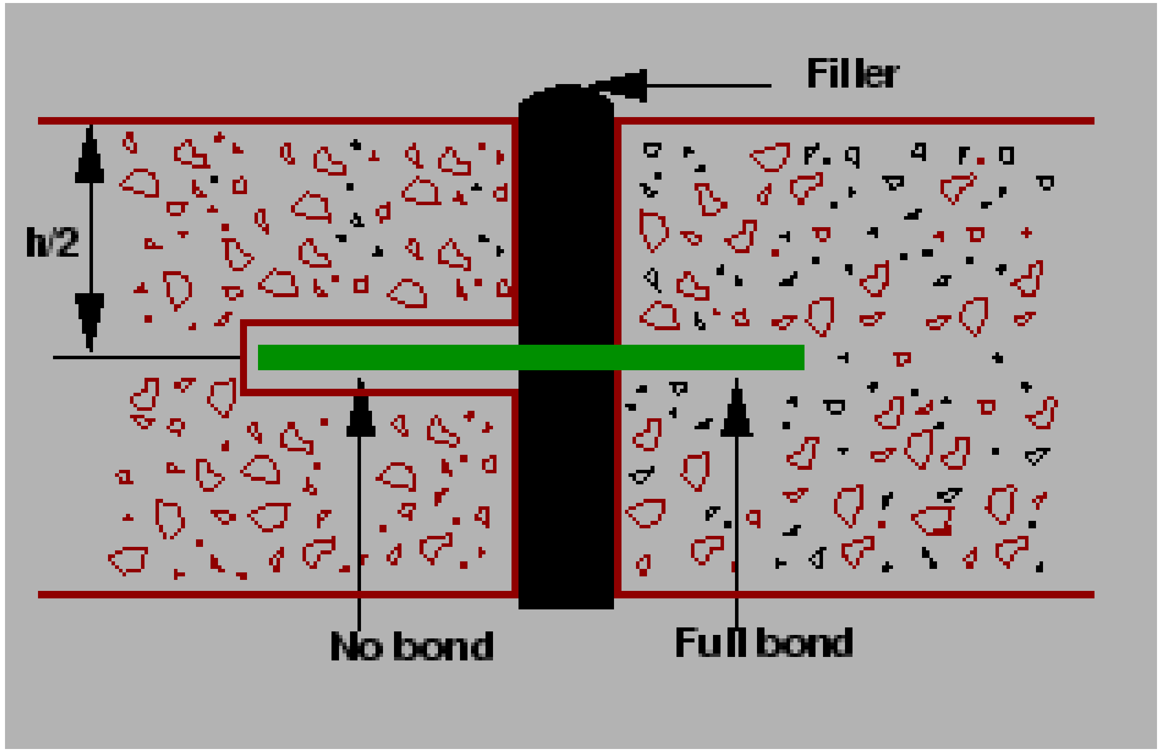
- $L = \frac{\Delta}{2\alpha T} = \frac{2 * 10^{-2}}{2 * 12 * 10^{-6} * 25} = 33.333 < 140\ m$ *(Safe)*

***Purpose to provide dowel bar:***

- *To transfer wheel load from one slab to another slab.*
- *To reduce the differential deflection.*

- ***Arrangement of Dowel bar at expansion joint:***



***Longitudinal joints:***

- *Provided longitudinally along the road to account lateral expansion & contraction.*
- *Tie bars used at longitudinal joint to restrain slab against lateral sliding under dynamic effect of load due to vehicle movements expansion and contraction.*

***Design of tie bars:***

- *Frictional force generated by 1 m of slab = Resistive force by steel per (m) slab.*
- $f * (\gamma * B * 1 * h) = \sigma(st) * A(st)$
- $A(st) = \dfrac{f * (\gamma * B * h)}{\sigma(st)}$ = *Area of steel in* $cm^2$ *required per metre slab.*

*Where,* $\sigma(st) = kg/cm^2$

- *B = Distance between free edge of the pavement and longitudinal joint.*
- $B = \dfrac{Width\ of\ pavement}{2}$ , *h in cm,* $f = 1.5$ , $\gamma = kg/m^3$

- *Assume, diameter of tie bar =* $\phi$
- *Number of tie bars per metre slab =* $n = \frac{Total\ area}{Area\ of\ 1\ bar} = \frac{A(st)}{\left(\frac{\pi}{4}\right) * \phi^2}$
- *Spacing between tie bar = S = 1000/n*

*As per IRC,*

- $\phi$ *= Diameter of bar ≤ 20 mm*
- *S = Spacing of bar ≤ 75 cm*

***Length of Tie bars ($L_T$):***

- *Bond force at steel per m slab length = Tensile force in steel per (m) slab length.*

$$\tau_{bd} * \left(n * \frac{L_T}{2} * \pi * \phi\right) = \sigma(st) * \left(n * \frac{\pi}{4} * \phi^2\right)$$

$$\boldsymbol{L_T = \frac{\sigma(st) * \phi}{2 * \tau_{bd}}}$$

*Where,*

- $\tau_{bd}$ = *Permissible bond stress of concrete in kg/cm*$^2$
- $\Phi$ = *Diameter of tie bar in cm*

***Question:***

- *Cement concrete pavement has a thickness of 24 cm & has two lane of width 7.2 m with a longitudinal joint in between. Design the dimension & spacing of the bar by using following data.*
- *Allowable tensile stress in steel = 1400 kg/cm*$^2$
- *Unit weight of cement concrete = 2400 kg/cm*$^3$
- *Coefficient of friction = f = 1.5*
- *Bond stress between steel bar and concrete = 24.6 kg/cm*$^2$

***Answer:***

- *Given, f = 1.5 , σ(st) = 1400 kg/cm² , γ = 2400 kg/cm³ , B = (7.2/2) = 3.6 m*

  *h = 24 cm = 0.24 m ,* $\tau_{bd}$ *= 24.6 kg/cm²*

- *Area of steel required per metre slab*
- $A(st) = \frac{f * (\gamma * B * h)}{\sigma(st)} = \frac{1.5 * 2400 * 3.6 * 0.24}{1400} = 2.22\ cm^2 = 222\ mm^2$
- *Assume, ϕ = 10 mm*
- $n = \frac{Total\ area}{Area\ of\ 1\ bar} = \frac{A(st)}{\left(\frac{\pi}{4}\right) * \phi^2} = \frac{222}{\frac{\pi}{4} * 10^2} = 2.82 \approx 3\ number$
- *Spacing, S = 1000/n = 1000/3 = 333.33 mm = 33.33 cm ≤ 75 cm (Safe)*
- $Length\ of\ Tie\ bar = L_T = \frac{\sigma(st) * \phi}{2 * \tau_{bd}} = \frac{10 * 1400}{2 * 24.6} = 284.55\ mm =$ ***28.49 cm***

# Thank You