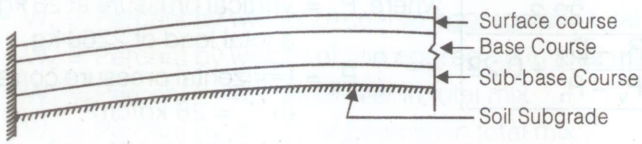
FLEXIBLE PAVEMENTS

Flexible pavements are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads.

A typical flexible pavement consists of four components : 1. soil subgrade 2. sub-base course 3. base course 4. surface course.



(i) Stress Under Road Surface as per Boussineq's Equation,

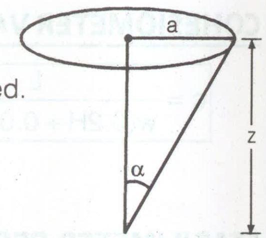
$$\sigma_z = q\left[1-\cos^3\alpha\right], \text{ where } \cos\alpha = \frac{z}{\sqrt{a^2+z^2}}$$

where, σ_z = vertical stress at depth z.

q = surface pressure.

z = depth at which σ_z is computed.

a = radius of loaded area.



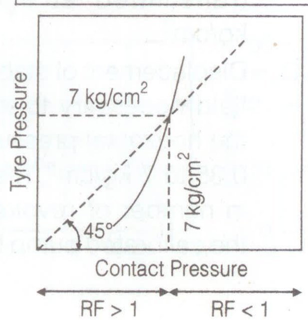
(ii) As Per IRC

Maximum legal axle load = 8170 kg

Equivalent single wheel load = 4085 kg.

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

(iv) $$\text{Rigidity factor } (R \cdot F) = \frac{\text{Contact pressure}}{\text{Tyre pressure}}$$

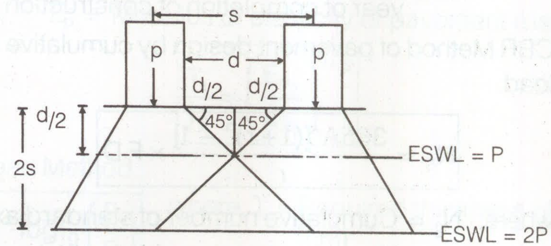


Remember

- Tyre pressure is important for upper layers.
- Contact pressure is important for deeper layers.

(v) Equivalent Single Wheel Load (ESWL)

$$(\text{ESWL}) \text{ at } \frac{d}{2} \text{ depth} = P \qquad (\text{ESWL}) \text{ at } 2s \text{ depth} = 2P$$



METHODS OF FLEXIBLE PAVEMENT DESIGN

(i) Group Index Method

$$G \cdot I = 0.2a + 0.005ac + 0.01bd$$

(ii) C.B.R Method

(a) $$C \cdot B \cdot R \text{ values} = \frac{\text{Load on soil sample}}{\text{Standard load}} \times 100$$

Penetration	Standard load
2.5 mm	1370 kg
5.0 mm	2055 kg

(b) Thickness of Pavement, (T)

$$T = \sqrt{P}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]^{1/2} \quad \text{or} \quad T = \left[\frac{1.75P}{CBR} - \frac{A}{\pi}\right]^{1/2}$$

where, P = Wheel load in kg.

CBR = California bearing ratio in percent

p = Tyre pressure in kg/cm^2

A = Area of contact in cm^2.

$$A = \pi a^2$$

a = Radius of contact area.

(c) Number of heavy vehicle per day for design (A),

$$A = P[1+r]^{(n+10)}$$

where, A = No.of vehicles at the end of design period.

P = Number of heavy vehicles per day at least count.

r = Annual rate of increase of heavy vehicles

n = Number of years between the last count & the year of completion of construction.

(d) CBR Method of pavement design by cumulative standard axle load.

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

where, N_S = Cumulative number of standard axle load

A′ = Number of commercial vehicle per day when construction is completed considering the number of lanes.

n = Design life of pavement, taken as 10 to 15 years.

F = Vehicle damage factor.

D = Lane distribution factor

(iii) California Resistance Value Method

(a)

$$T = \frac{k(TI)(90 - R)}{C^{1/5}}$$

where, T = Total thickness of pavement, (cm)

k = Numerical constant = 0.166

T.I = Traffic Index

$$T.I = 1.35(EWL)^{0.11}$$

R = Stabilometer resistance value

C = Choesiometer value.

or,

$$T = \frac{0.22(EWL)^{0.11}(90 - R)}{C^{0.20}}$$

- $$\frac{T_1}{T_2} = \left(\frac{C_2}{C_1}\right)^{1/5}$$ where, T_1 & T_2 are the thickness values of any two pavement layers & C_1 & C_2 are their corresponding Cohesiometer values.

(iv) Triaxial Method

(a) Thickness of pavement required for single layer, (T_S)

$$T_S = \sqrt{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2}$$

where, T_S = Thickness in cm

P = Wind load in kg

X = Traffic coefficient

Y = Rainfall coefficient

E_S = Modulus of elasticity of subgrade soil (kg/cm²)

a = Radius of contact area (cm)

Δ = Design deflection (0.25 cm)

(b) Thickness of Pavement Consist of Two layer system,

$$T_P = \left\{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2\right\}\left(\frac{E_S}{E_P}\right)^{1/3}$$

where, E_P = Modulus of elasticity of pavement material

$$\frac{T_1}{T_2} = \left(\frac{E_{P_2}}{E_{P_1}}\right)^{1/3}$$

(v) MC Load Method

$$T = k \cdot \log_{10}\left(\frac{P}{S}\right)$$

where, T = Required thickness of gravel base (cm)

P = Gross wheel load, (kg)

k = Base course constant.

(vi) Burmister Method (Layered System)

Displacement equations given by Burmister are,

(a) $$\Delta = 1.5\frac{Pa}{E_s} \cdot F_2$$ → for flexible plate

(b) $$\Delta = 1.18\frac{Pa}{E_s} \cdot F_2$$ → for rigid plate.

$$\mu_s = \mu_P = 0.5$$

where, μ_S & μ_P are Poisons ratio for soil subgrade & pavement.

For single layer, $F_2 = 1$

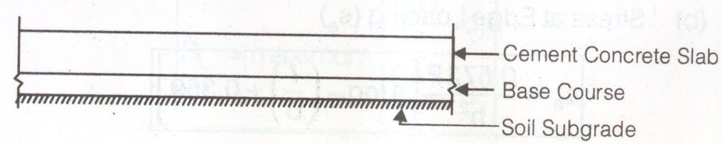
P = Yielded pressure

E_S = Subgrade modulus

a = Radius of loaded area

RIGID PAVEMENT

Rigid pavements are those which posses note worthy flexural strength or flexural rigidity. The stresses are not transferred from grain to grain to the lower layers as in the ease of flexible pavement layers. The rigid pavements are made of Portland cement concrete-either plain, reinforced or prestressed concrete. The plain cement concrete slabs are expected to take-up about 40 kg/cm² flexural stress.



(i) Modulus of subgrade reaction (k),

$$k = \frac{P}{\Delta}$$

where, k = Modulus of subgrade reaction (kg/cm²/cm

P = Pressure required for 'Δ' deflection (kg/cm²)

Δ = Deflection (cm).

For 75 cm dia plate, $\Delta = 0.125$ cm.

(ii) Radius of Relative Stiffness (l)

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

where, l = Radius of relative stiffness, cm

E = Modulus of elasticity of cement concrete (kg/cm²)

μ = Poisson's ratio for concrete = 0.15

h = Slab thickness (cm)

k = Subgrade modulus or modulus of subgrade reaction (kg/cm³)

(iii) Equivalent Radius of Resisting Section (b)

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

when a < 1.724 h

(b) $b = a$ when a > 1.724 h

where, a = Radius of contact area (cm)

h = Slab thickness (cm)

(iv) Glodbeck's Formula for Stress due to Corner Load

$$S_C = \frac{3P}{h^2}$$

where, S_C = Stress due to corner load (kg/cm²)

P = Corner load assumed as a concentrated point load, (kg)

h = Thickness of slab (cm).

(v) Westergards Stress Equation

(a) Stress at Interior Loading (s_i)

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

(b) Stress at Edge Loading (s_e)

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

(c) Stress at Corner Loading (s_c)

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

where, h = Slab thickness (cm)

P = Wheel load (kg)

a = Radius of contact area (cm)

l = Radius of relative stiffness (cm)

b = Radius at resisting section (cm).

(vi) Warping Stresses

(a) Stress at Interior Region (S_{t_i})

$$S_{t_i} = \frac{E\alpha T}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$$

where, S_{t_i} = Warping stress at interior region (kg/cm²)

E = Modulus of elasticity of concrete, (kg/cm²)

α = Coefficient of thermal expansion(/°c)

C_x = Coefficient based on $\left(\frac{L_x}{l}\right)$ in desired direction.

C_y = Coefficient based on $\left(\frac{L_y}{l}\right)$ in right angle to the above direction.

μ = Poissons's ratio ~ 0.15.

L_x/l or L_y/l	C_x or C_y
4	0.6
8	1.1
12	1.02

L_x & L_y are the dimensions of the slab considering along x & y directions along the length & width of slab.

(b) Stress at Edge Region (s_{t_e})

$$S_{t_e} = \text{maximum}\begin{cases} \frac{E\alpha T}{2} \cdot C_x \\ \frac{E\alpha T}{2} \cdot C_y \end{cases}$$

(c) Stress at Corner Region (S_{t_c})

$$S_{t_c} = \frac{E\alpha T}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

where, a = Radius of contact area

l = Radius of relative stiffness

(vii) Frictional Stress (s_f) $$S_f = \frac{WLf}{2 \times 10^4}$$

where, S_F = Frictional stress (kg/cm²)

W = Unit weight of concrete, (kg/m³)

f = Friction constant or coefficient of subgrade restraint

L = Slab length (m)

B = Slab width (m)

(viii) Combination of Stresses

A. Critical Combination During Summer

(a) Stress for edge/interior regions at Bottom = (+ load stress) + (warping stress of day time) – Frictional stress

(b) Stress for corner region at top = (+ load stress + warping stress at night)

B. Critical Combination During Winter

(a) Stress for edge/interior at bottom = (+ load stress + warping stress at day time + frictional stress)

(b) Stress for Corner at Top = (load stress + warping stress at night)

DESIGN OF JOINTS IN CEMENT CONCRETE PAVEMENTS

(i) Spacing of expansion joints, (L_e)

$$L_e = \frac{\delta'}{100\,\alpha(T_2 - T_1)}$$

where, δ' = Maximum expansion in slab (cm)

L_e = Spacing of expansion joint (m)

α = Coefficient of thermal expansion of concrete (/°c)

(ii) Spacing of contraction joint, (L_c)

(a) When reinforcement is not provided

$$L_C = \frac{(2 \times 10^4)s_c}{w.f}$$

where, L_c = Spacing of contraction joint (m)

s_c = Allowable stress in tension in cement concrete.

f = Coefficient friction ~ 1.5

w = Unit weight of cement concrete (kg/m³).

(b) When reinforcement is provided

$$L_c = \frac{200 S_s A_s}{bhwf}$$

where, S_s = Allowable tensile stress in steel (kg/cm²) $\simeq$ 1400 kg/cm².

A_s = Total area of steel in cm².

(iii) Longitudinal Joints

(a) $$A_s = \frac{bfhw}{100\,S_s}$$

where, As = Area of steel required per meter length of joint (cm²)

b = Distance between the joint & nearest free edge (m)

h = Thickness of the pavement (cm)

f = Coeff. of friction $\simeq$ 1.5

w = Unit wt. of concrete (kg/cm³)

S_s = Allowable working stress in tension for steel (kg/cm²)

(b) $$L_t = \frac{d}{2} \cdot \frac{S_s}{S_b}$$

where, L_t = Length of tie bar

S_s = Allowable stress in tension (kg/cm²) $\simeq$ 1400

S_b = Allowable bond stress in concrete (kg/cm²)

= 24.6 kg/cm² for deformed bars

= 17.5 kg/cm² for plain tie bars

d = diameter of tie bar (cm).

IRC RECOMMENDATIONS FOR DESIGN OF CEMENT CONCRETE PAVEMENTS

$$A_d = P'[1+r]^{(n+20)}$$

where, A_d = Number of commercial vehicles per day (laden weight > 3 tonnes)

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

r = Annual rate of increase in traffic intensity.

n = Number of years between the last traffic count & the commissioning of new cement concrete pavement.

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