3.2 STRESSES IN CC PAVEMENT

• Temperature Stresses – Due to the temperature differential between the top and bottom of the slab, curling stresses (similar to bending stresses) are induced at the bottom or top of the slab

• Frictional stresses – Due to the contraction of slab due to shrinkage or due to drop in temperature tensile stresses are induced at the middle portion of the slab

• Wheel Load Stresses – CC slab is subjected to flexural stresses due to the wheel loads

Temperature stresses -

• Temperature differential between the top and bottom of the slab causes curling (warping) stress in the pavement

• If the temperature of the upper surface of the slab is higher than the bottom surface then top surface tends to expand and the bottom surface tends to contract resulting in compressive stress at the top, tensile stress at bottom and vice versa

Notation

- E = modulus of elasticity
- Cx and Cy = Bradbury's coefficients
- T = temperature
- a = radius of contact
- h = thickness of cement concrete slab
- k = modulus of subgrade reaction
- l = raduis of relative stiffness
- t = temperature differential
- αt = coefficient of thermal expansion
- ε = strain
- μ = Poisson's ratio
- σ = stress

Temperature Differential

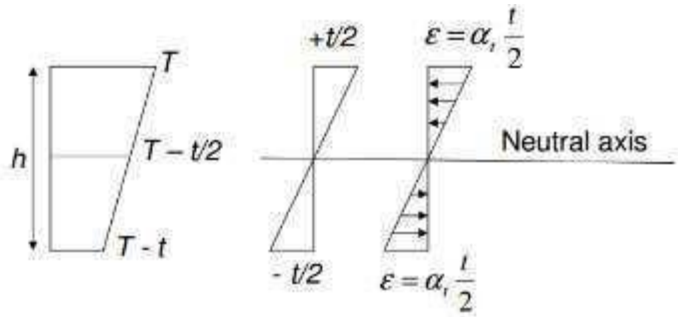


Fig: changes due to temperature

- Temperature at top = T
- Temperature differential = t
- Temperature at bottom = T – t
- Average Temperature (at mid height) = (T+ T-t)/2 = T - t/2
- Increase in temperature of top fibre above average temperature = t/2
- Decrease in temperature of bottom fibre below average temperature = t/2

Temperature Differentials

- Maximum temperature differentials occur during the day in the spring and summer months.
- During midday of summer, the surface of the slab, which is exposed to the sun, warms faster than the subgrade which is relatively cool
- During night time the surface of the slab becomes cool when compared to the subgrade.
- Usually, night time temperature differentials are one half the day time temperature differentials.
- The actual temperature differentials depend on the location..
- Temperature differential is expressed as temperature gradient per mm of slab thickness.
- The temperature gradients vary between 0.067 to 0.1 oC/mm.

FRICTIONAL STRESSES-

- The friction between a concrete slab and its foundation causes tensile stress – in the concrete, – In the steel reinforcements and – In tie bars
- For plain concrete pavements, the spacing between contraction joints is so chosen that the stresses due to friction will not cause the concrete to crack.
- Longer joint spacing than that above requires the provision of temperature steel to take care of the stresses caused by friction.
- The number of tie bars is also determined by frictional stresses.

Stresses Due to Friction

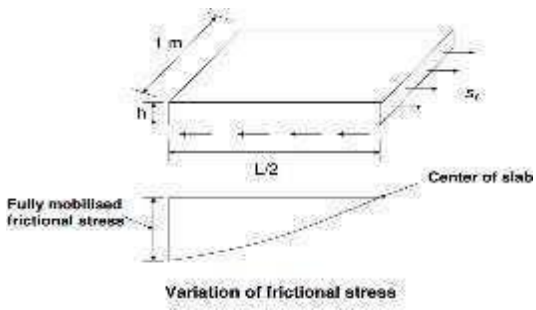


Fig: Variation of frictional stress

Stresses Due to Friction -

•Frictional force per unit width of slab γc × h × 1 × (L/2) × fa = (γ h L fa)/2

Where,

γc = unit weight of concrete, kN/ m 3

h = thickness of slab,

m L = length of slab, m

•Tensile force in the slab at the middle – Sf = sf × h ×1 = sf h –

Where, Sf = tensile force, kN; sf = tensile stress, kN/m 2

•Equating the two – sf = (γc L fa)/2

The frictional stress σ_f in kg/cm ^{2} is given by the equation

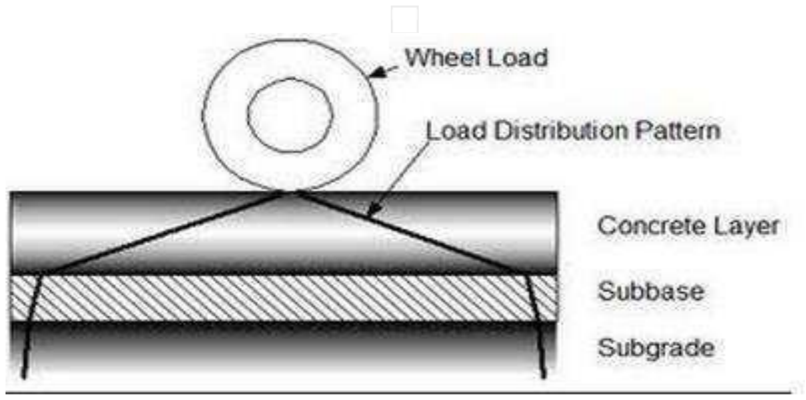
$$\sigma_f = \frac{WLf}{2 \times 10^4}$$

WESTERGAARD'S THEORY FOR RIGID PAVEMENTS

Rigid Pavements are constructed with some rigid materials like Cement Concrete(Plain, reinforced or prestressed).

Here the load is transferred through the slab action not like in the flexible pavements. Westergaard's theory is considered good to design the rigid pavements.

He considered rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed to be a dense liquid. So, here the upward reaction is assumed to be proportional to the deflection, i.e. p = K.d, where K is a constant defined as modulus of subgrade reaction. Units of K are kg/cm^3.



Concrete Pavement

- Westergaard's modulus of sub-grade reaction:

Modulus of sub-grade reaction is proportional to amount of deflection d. Displacement level is taken as 0.125 cm in calculating K i.e. d = 0.125 cm, so modulus of sub-grade reaction
K = p/d = p/0.125 kg/cm^2

- Radius of relative stiffness of slab to sub-grade:

Amount of deflection which will occur on the pavement surface depends on the stiffness of the slab and also on the stiffness of the sub-grade. Same amount of deflection will occur on the top surface of the sub-grade.

This means that the amount of deflection which is going to occur in the rigid pavement pavement layer depends both on relative stiffness of the pavement slab with respect to that of sub-grade.

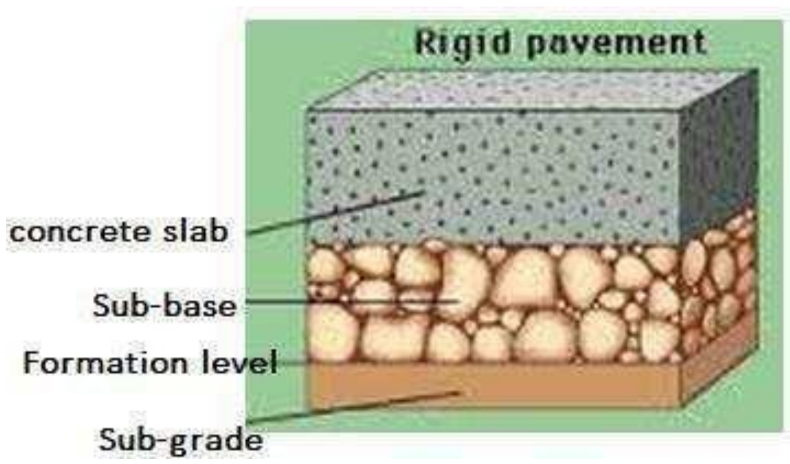
Westergaard defined this by a term "Radius of relative stiffness" which, can be written numerically as below:

l = [Eh^3/ (12K(1-U^2)]^(1/4)

Where, l = radius of relative stiffness, cm
E = Modulus of elasticity of cement concrete kg/cm^2
U = Poisson's ratio for concrete = 0.15
K = Modulus of Sub-grade reaction in kg/cm^2

Traffic Parameters:
(1) Design Wheel Load
(2) Traffic Intensity

- Critical Load Positions:



Rigid Pavement - a 3D view

When the wheel load is applied on the pavement surface, flexural stresses are induced in the pavement. There are three critical positions which are to be checked for maximum stresses.

1. Interior loading
2. Edge Loading
3. Corner loading

Whenever loading is applied at the interior of the slab, remote than the edges and corner, this is called interior loading.
When loading is applied on the edges, remote than the corners is called edge loading.
When the loading is applied on the corner angle bisector and loading is touching the corner the edges.

- Equivalent Radius of Resisting section:

When the loading is at the interiors there is a particular area which will resist the bending moment. Westergaard assumed that the area will be circular in plan and its radius is called as Equivalent radius of Resisting section.
Numerically,

$$b = (1.6.a^2 + h^2)^{(1/2)} - 0.675.h$$

Here,
b = equivalent radius of resisting section, cm when 'a' is less than 1.724.h
a = radios of wheel load distribution, cm
h = slab thickness, cm
When 'a' is greater than 1.724.h, b =a.

- In case of corner loading, maximum stresses are not produced at corner but they are produced at a certain distance X along the corner bisector. This is given by the relation:

$$X = 2.58.(a.l)^{1/2}$$

Here, X = distance from apex of the slab corner to section of maximum stress along the corner bisector, cm.
a= Radius of wheel load distribution, cm
l = Radius of relative stiffness, cm.

Here is an image which shows you the formulas used to calculate the amount of stresses developed at the three critical positions due to the given wheel load P.

Interior Loading

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

Edge Loading

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

Corner Loading

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

Here,

S_i, S_e, S_c = maximum stress at interior, edge and corner loading, kg/cm^2

h = slab thickness, cm

Rigid Pavement- Stresses at interior, edges and corners - Westergaard's theory

Temperature stresses

Temperature stresses are developed in cement concrete pavement due to variation inslab temperature. This is caused by (i) daily variation resulting in a temperature gradient across the thickness of the slab and (ii) seasonal variation resulting in overallchange in the slab temperature. The former results in warpingstresses and the later in frictional stresses.

Warping stress

The warping stress at the interior, edge and corner regions, denoted as $\sigma_{t_i}, \sigma_{t_e}, \sigma_{t_c}$ in kg/cm ^{2} respectively and given by the equation.

$$\sigma_{t_i} = \frac{E\epsilon t}{2}\left(\frac{C_x + \mu C_y}{1-\mu^2}\right) \tag{6}$$

$$\sigma_{t_e} = \mathrm{Max}\ \left(\frac{C_x E\epsilon t}{2}, \frac{C_y E\epsilon t}{2}\right) \tag{7}$$

$$\sigma_{t_c} = \frac{E\epsilon t}{3(1-\mu)}\sqrt{\frac{a}{l}} \tag{8}$$

where E is the modulus of elasticity of concrete in kg/cm ^{2} (3 $\times$ 10 ^{5}), ϵ is the thermal coefficient of concrete per ^{o}C (1 $\times$ 10 $^{-7}$) t is the temperature difference between the top and bottom of the slab, C_x and C_y are the coefficient based on L_x/l in the desired direction and L_y/l right angle to the desired direction, μ is the Poisson's ration (0.15), a is the radius of the contact area and l is the radius of the relative stiffness.

Frictional stresses

where W is the unit weight of concrete in kg/cm ^{2} (2400), f is the coefficient of sub grade friction (1.5) and L is the length of the slab in meters.

Critical load positions

Since the pavement slab has finite length and width, either the character or the intensity of maximum stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface. There are three typical locations namely the interior, edge and corner, where differing conditions of slab continuity exist. These locations are termed as critical load positions.

Combination of stresses

The cumulative effect of the different stress give rise to the following thee critical cases

- Summer, mid-day: The critical stress is for edge region given by $\sigma_{critical} = \sigma_e + \sigma_{t_e} - \sigma_f$

- Winter, mid-day: The critical combination of stress is for the edge region given by $\sigma_{critical} = \sigma_e + \sigma_{t_e} + \sigma_f$
- Mid-nights: The critical combination of stress is for the corner region given by

$$\sigma_{critical} = \sigma_c + \sigma_{t_c}$$