CMR
INSTITUTE OF
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Solutions

Sub: Pavement Design **Code:** 10CV833

Sem: VIII **Branch:** CIVIL

1. Briefly explain the factors which affect the design of rigid pavements.

Factors affecting design

- ✓ Wheel load and its repetition
- ✓ Properties of sub-grade
- ✓ Properties of concrete
- ✓ External conditions
- ✓ Joints
- ✓ Reinforcements

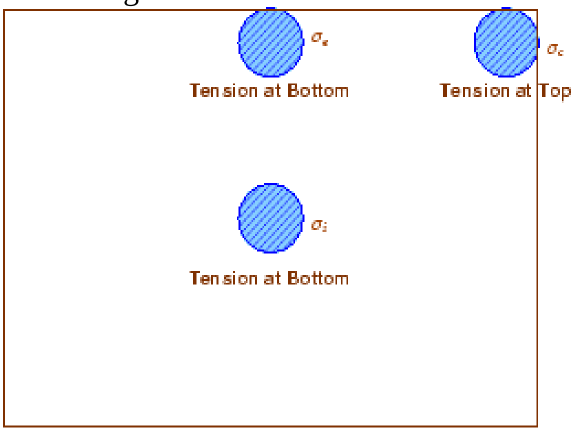
Loading

- Standard axle load – 8200kg
- Basic design of slab – 98th percentile axle load
- Checked for fatigue consumption during its deisgn life
- Axle load multiplied by a Load Safety Factor (LSF) (account for unpredicted heavy truck loads)
- Important roads – 1.2
- Less important roads -1.1
- Residential and other streets – 1.0

Impact of loads

- Important at joints
- Effective load transfer devices are available – 25 percent increase in stresses due to static wheels
- If not available – increase by 50%
- Similar effect due to number of repetitions of wheel load
- Increase in repetitions decreases serviceability index
- Concrete suffers fatigue
- Repetitions can be assessed by knowing present and expected rate of growth of traffic over the design period
- IRC suggests a design period of 30 years after construction
- If not able to predict the traffic intensity – assume 20 years
- Growth rate of traffic- 7.5%
- Normally a design period of 20%
- **Area of contact of wheel**
- Wheel load transmitted to slab by pneumatic tyre over a contact area determined by tyre pressure
- Tyre pressure – range – 0.53 -0.63 Mpa
- Tyre pressure in India – 0.8 Mpa
- Contact area – assumed to be circular (for simplification)
- **Location of load**
- Interior loading – tensile stresses at bottom of slab
- Edge loading- tensile stresses at the bottom of the slab parallel to the edge and another smaller tensile stress at the top of the slab at right angles to the edge

- Corner loading – tensile stresses at the top of the slab parallel to the bisector of the corner angle



- **Subgrade strength and properties**
- Strength of soil subgrade – influences slab design
- If soil has uniform bearing power –simplified design
- Supporting power is generally measured by Plate Bearing test (75 cm dia circular plate)
- Measures modulus of subgrade reaction – K
- Measure of resistance of the soil to deformation under pressure caused by bending of slab
- Drainage characteristics, susceptibility to volumetric changes, susceptibility to frost action
- **Strength of concrete**
- Crushing strength – most reliable
- Concrete has high crushing strength and rarely fails in compression in a pavement
- Important is flexural strength
- Tested by 150mm * 150 mm square section * about 700mm long
- Span is equal to four times the depth and load applied at the third point of the span
- Check for "modulus of rupture"
- If 28 day compressive strength concrete has a minimum modulus of rupture of 4Mn/m2
- **Modulus of elasticity**
- E' increases with strength
- Determined by static method by stress- strain relationship or by the dynamic method
- For concrete having flexural strength 3.8 – 4.2 MN/m^2 - E = 3*10^5 kg/cm^2

Poisson's ratio

- By static method – 0.15
- By dynamic method- 0.24
- Most important property for concrete
- **Shrinkage properties**
- Concrete expands slightly during setting due to hydration of cement
- After subsequent drying it shrinks and causes stresses
- Change in moisture content also leads to shrinkage or expansion – causes stresses
- **Fatigue behaviour of concrete**
- Repetitive stresses – progressive permanent internal structural damage
- Stress Ratio (ratio of flexural stress to the flexural strength) increases – concrete resists fewer repetitions
- Stress ratio within 0.55 – concrete withstands unlimited stress repetitions without any reduction in load carrying capacity

- For design purposes - assume 0.45
- **Temperature changes**
- Changes in temperature gradient causes differential expansion or contraction between the top or bottom of the slab
- Slab then tend to warp but restricted due to slab weight and friction at load transferring devices
- Expansion or contraction of the slab due to temperature changes is restrained due to friction between subgrade and slab
- Induces stresses
- **Friction between slab and sub-base**
- Determines the restraint imposed expansion and contraction due to temperature changes
- Spacing is also affected by this friction
- Compacted sand and gravel covered with waterproof paper - smooth surface
- Water-bound macadam, soil gravel mix, rolled lean concrete, lime pozzolana concrete -rough surfaces
- **Arrangement of joint**
- Joints are needed for allowing for expansion, contraction and warping of the slab caused by all above stresses
- Spacing and arrangement of joints govern the stresses induced in the slab
- **Reinforcement**
- Slab can be reinforced or non reinforced
- Amount of reinforcement influences design
- Recent advancement – continuously reinforced concrete pavements (CRCP)

2. Explain the following with respect to rigid pavement design:

(i) Radius of relative stiffness

A certain degree of resistance to slab deection is o_ered by the sub-grade. The sub-grade deformation is same as the slab deection. Hence the slab deection is direct measurement of the magnitude of the sub-grade pressure. This pressure deformation characteristics of rigid pavement lead Westergaard to the de_ne the term radius of relative sti_ness l in cm is given by the equation

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

(ii) Equivalent Radius of resisting section

When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. Westergaard's gives a relation for equivalent radius of the resisting section in cm in the equation 29.2.

$$b = \begin{cases} \sqrt{1.6a^2 + h^2} - 0.675\ h & \text{if a} < 1.724\text{ h} \\ a & \text{otherwise} \end{cases} \quad (29.2)$$

where a is the radius of the wheel load distribution in cm and h is the slab thickness in cm.

(iii)Critical Loading 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.

(iv) **Temperature Stresses**

Temperature stresses are developed in cement concrete pavement due to variation in slab 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 overall change in the slab temperature. The former results in **warping** stresses and the later in **frictional** stresses.

3. Calculate the stresses at interior, edge and corner regions of a cement concrete pavement using Westergaard's equation using the following data: Wheel load =51kN Modulus of elasticity of concrete = 0.3 x 10^5 N/mm^2 , Poisson's ratio of concrete = 0.15,Pavement Thickness=18cm, Modulus of subgrade reaction = 6 x10^4kN/m^3 Radius of contact area= 15cm.

Given:

$p = 51$ kN

$E = 0.3 \times 10^5$ N/mm^2

$h = 180$ mm

$\mu = 0.15$

$K = 6 \times 10^{-2}$ N/mm^3

$a = 150$ mm

$\therefore b = \sqrt{1.6a^2 + h^2} - 0.675h = 140$ mm

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4} = 706.11 \text{ mm}$$

$$S_i = \frac{0.316P}{h^2}\left[4\log_{10}(l/b) + 1.069\right] = 1.92 \text{ N/mm}^2$$

$$S_e = \frac{0.572P}{h^2}\left[4\log_{10}(l/b) + 0.359\right] = 2.85 \text{ N/mm}^2$$

$$S_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right] = 3.81 \text{ N/mm}^2$$

4. What are the various types of joints in Cement concrete pavement? Explain their functions with neat sketches.

29.5.1 Expansion joints

The purpose of the expansion joint is to allow the expansion of the pavement due to rise in temperature with respect to construction temperature. The design consideration are:

- Provided along the longitudinal direction,
- design involves finding the joint spacing for a given expansion joint thickness (say 2.5 cm specified by IRC) subjected to some maximum spacing (say 140 as per IRC)

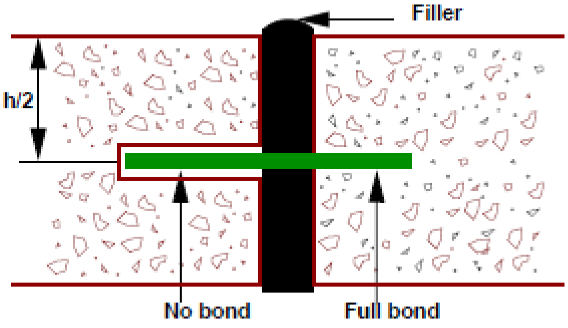


Figure 29:2: Expansion joint

29.5.2 Contraction joints

The purpose of the contraction joint is to allow the contraction of the slab due to fall in slab temperature below the construction temperature. The design considerations are:

- The movement is restricted by the sub-grade friction
- Design involves the length of the slab given by:

$$L_c = \frac{2 \times 10^4 S_c}{W.f} \tag{29.10}$$

  where, S_c is the allowable stress in tension in cement concrete and is taken as 0.8 kg/cm^2, W is the unit weight of the concrete which can be taken as 2400 kg/cm^3 and f is the coefficient of sub-grade friction which can be taken as 1.5.

- Steel reinforcements can be use, however with a maximum spacing of 4.5 m as per IRC.

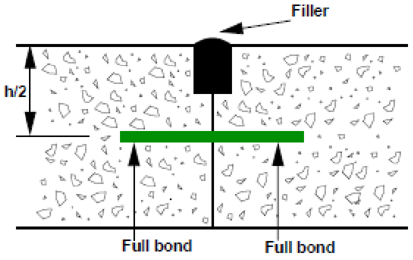


Figure 29:3: Contraction joint

5. Describe the step by step procedure in design of dowel bars. Indicate the equations used.

Bradbury's analysis

Bradbury's analysis gives load transfer capacity of single dowel bar in shear, bending and bearing as follows:

$$P_s = 0.785\, d^2\, F_s \qquad (29.11)$$

$$P_f = \frac{2\, d^3\, F_f}{L_d + 8.8\delta} \qquad (29.12)$$

$$P_b = \frac{F_b\, L_d^2\, d}{12.5\,(L_d + 1.5\delta)} \qquad (29.13)$$

where, P is the load transfer capacity of a single dowel bar in shear s, bending f and bearing b, d is the diameter of the bar in cm, L_d is the length of the embedment of dowel bar in cm, δ is the joint width in cm, F_s, Ff, F_b are the permissible stress in shear, bending and bearing for the dowel bar in kg/cm^2.

Design procedure

Step 1 Find the length of the dowel bar embedded in slab L_d by equating Eq. 29.12=Eq. 29.13, i.e.

$$L_d = 5d\sqrt{\frac{F_f\,(L_d + 1.5\delta)}{F_b\,(L_d + 8.8\delta)}} \qquad (29.14)$$

Step 2 Find the load transfer capacities P_s, P_f, and P_b of single dowel bar with the L_d

Step 3 Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor f as

$$\max\left\{\frac{0.4P}{P_s}, \frac{0.4P}{P_f}, \frac{0.4P}{P_b}\right\} \qquad (29.15)$$

Step 4 Spacing of the dowel bars.

- Effective distance upto which effective load transfer take place is given by 1.8 l, where l is the radius of relative stiffness.
- Assume a linear variation of capacity factor of 1.0 under load to 0 at 1.8 l.
- Assume a dowel spacing and find the capacity factor of the above spacing.
- Actual capacity factor should be greater than the required capacity factor.
- If not, do one more iteration with new spacing.

6. Determine the warping stresses at interior, edge and corner regions in a 25cm thick cement concrete pavement with transverse joint at 11m interval and longitudinal joint at 3.6m intervals. The modulus of subgrade reaction k=6.9 kg/cm^3. Assume temperature differential for day conditions to be 0.6°C per cm slab thickness. Assume radius of loaded area as 15cm for computing warping stress at the corner. Take e = 10 x10 $^{-6}$ per °C, E = 0.3x10^5 N/mm^2 and μ=0.15. Use chart 1 for the suitable data.

$e = 10 \times 10^{-6}$ per °C

$E = 3 \times 10^5$ kg/cm²

$\mu = 0.15$

$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4} = 87.23\text{cm}$

$t = 0.6 \times 25 = 15°C$

$\frac{L_x}{l} = \frac{11.0}{0.8723} = 12.61$ $\frac{L_y}{l} = \frac{3.6}{0.8723} = 4.13$

$C_x = 1.01$ $C_y = 0.58$

$S_{tc} = \frac{Eet}{(1-\mu)}\sqrt{\frac{a}{l}} = 7.32\ \text{kg/cm}^2$

$S_{te} = \frac{C_x Eet}{2}$ $S_{te} = \frac{C_y Eet}{2} = 22.73\ \text{kg/cm}^2$

$S_{ti} = \frac{Eet}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right] = 25.25\ \text{kg/cm}^2$

7. Write short notes on flexible pavement failures and measures for maintenance and evaluation.

   The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Two design methods have been used to control rutting: one to limit the vertical compressive strain on the top of subgrade and other to limit rutting to a tolerable amount (12 mm normally). Thermal cracking includes both low-temperature cracking and thermal fatigue cracking.

   The general failures that occur in the flexible pavements are

1. Alligator(Map) cracking
2. Shear Failure
3. Frost Heaving
4. Longitudinal cracking
5. Consolidation failure
6. Wearing of the Surface
7. Reflection cracks

- **Alligator Cracking:**

  Alligator or map cracking occurs on the surface of the flexible pavement due to the relative movement of the material or failure of the materials of the pavement layers. This may be caused by the repeated application of the heavy wheel loads resulting in fatigue failure due to the moisture variations resulting in swelling and shrinkage of sub-grade and other pavement materials. A localized weakness of the under-lying base course would also cause a cracking of the surface course in this pattern.

- **Shear Failure:**

  Shear failure of the flexible pavement occurs due to the weakness of the pavement mixtures, the shearing resistance being low due to in-adequate stability of excessive heavy loading. The shear failure causes upheaval of pavement material by forming a fracture or cracking.

- **Frost Heaving:**

  Areas having cold climates, are prone to frost heaving. When the water present in the pores of the layers turns into ice, it causes swelling of the ice, and therefore results in the upheaval of the area affected by the frost.

  It must be remembered that the difference between the frost heaving and the shear failure is that in shear failure the depression is followed by the upheaval of the adjacent area but in case of the frost heaving, there is no depression.

- **Longitudinal Cracking:**

  Longitudinal cracking may occur due the differential settlement of the pavement due to the differential volume change. The area of the pavement near to the pavement edge is more prone to moisture and therefore it may swell more as compare to the interior region of the pavement sub-grade.

  This will cause a differential volume change of the pavement and therefore may lead to the longitudinal cracking of the pavement. Generally, these longitudinal cracks traverse through the full pavement thickness.

- **Consolidation Failure:**

  Consolidation of the subgrade due to the continuous action of the wheel load along the wheel path results in the formation of the ruts along the wheel path.

- **Wearing of the Surface:**

  Generally wearing of the surface may be caused due to the use of inferior material or due to the lack of the inter-locking of the surface layer with the bottom layers.

  Lack of the interlocking may be a result of the non-use of the prime and tack coat. Specifically in case of the overlays over the existing cement concrete pavements or the soil cement roads have poor inter-locking.

- **Reflection cracks:**

  Reflection cracks are formed in the overlays laid over the existing cement concrete pavements. In such overlays, if any cracks are there in the existing cement concrete pavements, will get reflected in the surface layer also. These cracks are known as the reflection cracks.