UNIT-III

DESIGN OF FLEXIBLE AND RIGID PAVEMENTS

1. **What is the Equivalent Wheel load? (NOV/DEC 2019), (April/May 2015)**

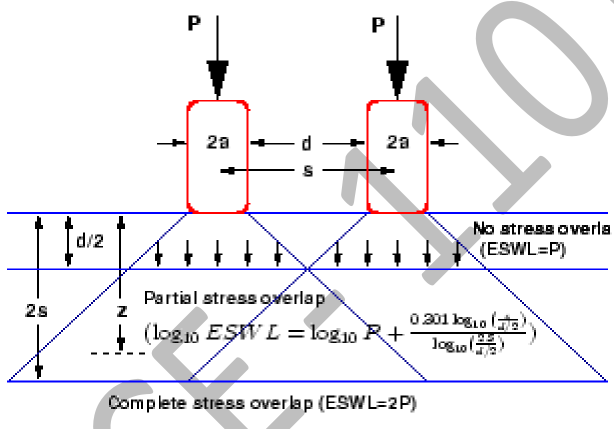
    To carry maximum load within the specified limit and to carry greater load, dual wheel, or dual tandem assembly is often used. Equivalent single wheel load (ESWL) is the single wheel load having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth.

    This is a semi-rational method, known as Boyd and Foster method, based on the following assumptions:

    • Equalancy concept is based on equal stress;

    • Contact area is circular;

    • Influence angle is 45˚; and Soil medium is elastic, homogeneous, and isotropic half space.



The ESWL is given by:

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}(\frac{z}{d/2})}{\log_{10}(\frac{2S}{d/2})}$$

where P is the wheel load, S is the center to center distance between the two wheels, d is the clear distance between two wheels, and z is the desired depth.

2. **What are the requirements of an Ideal Pavement? (Nov/Dec2019), (Nov/Dec2016)**

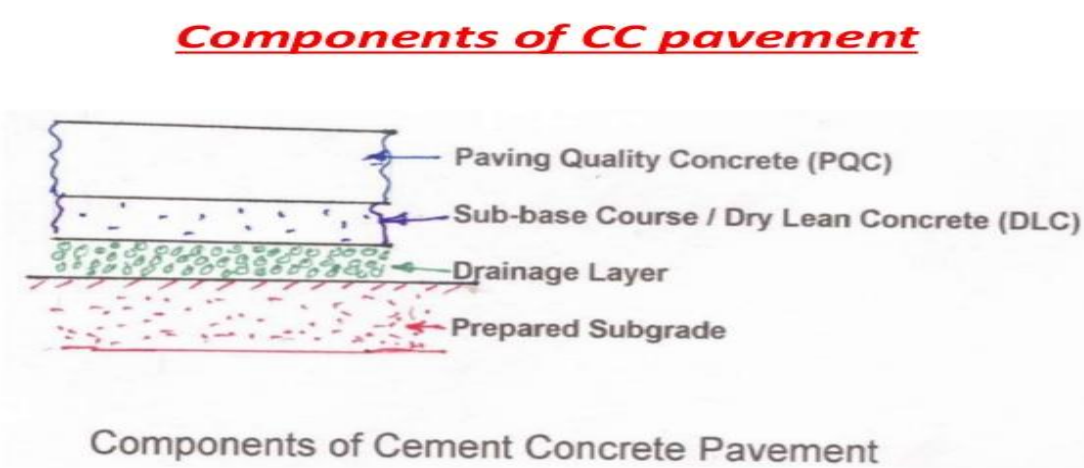
    An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the subgrade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility,
- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

3. **Difference between rigid and flexible pavement in pavement design (April/May 2019), (Nov/Dec2018)**

S.No.	characteristics	Flexible pavement	Rigid pavement
1	Normal loading	Undergoes deformation under the load	Resists deformation and acts as a Cantilever beam.
2	Excessive loading	Local depression take place	A crack on the surface may appear due to rupture
3	After effects of heavy load	Pavement is flexible and thus adjusts itself by deformation.	Permanent rupture or cracks forms and remains
4	Temperature effects	Not affected	Stresses produced based on temperature
5	Sub grade strength	Uniform sub grade is necessary	Sub grade may be non uniform

4. **Draw the typical rigid pavement with its vital components (April/May 2019), (Nov/Dec2018)**



Components of Cement Concrete Pavement

5. **Define modulus of sub-grade reaction (April/May 2018)**
   - Modulus of sub-grade reaction is the reaction pressure sustained by the soil sample under a rigid plate of standard diameter per unit settlement measured at a specified pressure or settlement.
   - IRC specifies that the K value be measured at 1.25 mm settlement.
   - To calculate the Modulus of Subgrade Reaction, Plate Bearing Test is conducted.
   - In this a compressive stress is applied to the soil pavement layer through rigid plates of relatively large size and the deflections are measured for various stress values.
   - The exact load deflection behavior of the soil or the pavement layer in-situ for static loads is obtained by the plate bearing test.

6. **What are dowel bars? (April/May 2018)**

The dowel bar is to effectively transfer the load between two concrete slabs and to keep the two slabs in same height. The dowel bars are provided in the direction of the traffic (longitudinal). The design considerations are:

- Mild steel rounded bars,
- Bonded on one side and free on other side

7. **Differentiate between Tack coat Prime coat and Seal coat (April/May 2017)**

Tack coat	Prime coat	Seal coat
Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.	Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.	Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

8. **What are the types of Rigid Pavements? (April/May 2017)**

Rigid pavements can be classified into four types:

Jointed plain concrete pavement (JPCP),

Jointed reinforced concrete pavement (JRCP),

Continuous reinforced concrete pavement (CRCP), and

Pre-stressed concrete pavement (PCP)

9. **Define: Rigidity Factor (Nov/Dec2017)**

The ratio of contact pressure to tyre pressure is defined as Rigidity factor. Thus value of rigidity factor is 1.0 for an average tyre pressure of 7kg/cm^2 . Rigidity factor is higher than unity for lower tyre pressures and less than unity for tyre pressures higher than 7kg/cm^2

10. What are the various factors considered for the design of pavements? (Nov/Dec2017), (May/June 2016)

i) Wheel load.
ii) Axle configuration.
iii) Contact pressure.
iv) Vehicle speed.
v) Repetition of loads.
vi) Subgrade type.
vii) Temperature.
viii) Precipitation.

11. What is the radius of resisting section? (Nov/Dec2016)

When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. Westergaard's suggested an equivalent radius of resisting section, b, in terms of radius of load distribution and slab thickness, as

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

Where a=radius of wheel load distribution, cm

h=slab thickness

When a is greater than 1.72h, the value of b=a

12. Define Critical Load Positions. (May/June 2016)

There are three typical locations namely the interior, edge and corner, where differing conditions of slab continuity exist. These are termed as critical load positions.

13. What are the effects of Temperature on Rigid Pavements? (Nov/Dec2015)

- Expansion and
- Contraction

14. Explain rigid pavement? (April/May 2015)

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

PART-B

1. Design the pavement for construction of a new bypass with the following data: (Nov/Dec 2019), (April/May 2017), (May/June 2016)

1. Two lane carriage way
2. Initial traffic in the year of completion of construction = 400 CVPD (sum of both directions)
3. Traffic growth rate = 7.5 %
4. Design life = 15 years
5. Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial vehicle
6. Design CBR of sub-grade soil = 4%.

Solution

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Solution

1. Distribution factor = 0.75
2. $$\begin{aligned} N &= \frac{365 \times \left[(1+0.075)^{15}-1\right]}{0.075} \times 400 \times 0.75 \times 2.5 \\ &= 7200000 \\ &= 7.2\ msa \end{aligned}$$
3. Total pavement thickness for CBR 4% and traffic 7.2 msa from IRC:37 2001 chart1 = 660 mm
4. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).
   (a) Bituminous surfacing = 25 mm SDBC + 70 mm DBM
   (b) Road-base = 250 mm WBM
   (c) sub-base = 315 mm granular material of CBR not less than 30 %

2. Design the pavement for construction of a new two lane carriage way for Design life 15 years using IRC method. The Initial traffic in the year of completion of construction 150 CVPD (sum of both directions), Traffic growth rate = 5 % Vehicle damage factor based on

axle load survey = 2.5 standard axle per commercial vehicle. Design CBR of sub-grade soil = 4%. (April/May 2019),

Solution

1. Distribution factor = 0.75
2. $$\begin{aligned} N &= \frac{365 \times \left[(1+0.05)^{15} - 1)\right]}{0.05} \times 300 \times 0.75 \times 2.5 \\ &= 4430348.837 \\ &= 4.4\ msa \end{aligned}$$
3. Total pavement thickness for CBR 4% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm
4. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).
   (a) Bituminous surfacing = 20 mm PC + 50 mm BM
   (b) Road-base = 250 mm Granular base
   (c) sub-base = 280 mm granular material.

3. Explain the California Bearing Ratio (CBR) Method (April/May 2018)

California division of highways in the U.S.A. developed CBR method for pavement design. The majority of design curves developed later are base on the original curves proposed by O.J.porter.

One of the chief advantages of CBR method is the simplicity of the test procedure. The CBR tests were carried out by the California state highway department on existing pavement layers including subgrade, subbase and base course.

Based on the extensive CBR test data collected on pavement which behaved satisfactory and those which failed, an empirical design chart was developed correlating the CBR value and the pavement thickness. The basis of the design chart is that a material with a given CBR required a certain thickness of pavement layer as a cover.

A higher load needs a thicker pavement layer to protect the sub-grade. Design curves correlating the CBR value with total pavement thickness cover were developed by the California state highway department for wheel loads of 3175kg and 5443 kg representing light and heavy traffic.

It is possible to extend the CBR design curves for various loading conditions, using the expression:

$$t = \sqrt{p}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]$$

$$t = \sqrt{p}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]^{\frac{1}{2}}$$

$$t = \left[\frac{1.75p}{CBR} - \frac{A}{\pi}\right]^{\frac{1}{2}}$$

Hence,

t= pavement thickness, cm

p=Wheel load, kg

CBR= California bearing ratio, percent

P=tyre pressure, kg/cm^2

A= area of contact.cm^2

IRC Recommendations:

a) The CBR tests should be performed on remoulded soils in the laboratory. The specimens should be prepared by static compaction wherever possible and otherwise by dynamic compaction.

b) For the design of new roads, the sub grade soil sample should be compacted at OMC to proctor density whenever suitable compaction equipment.

c) The CBR test samples may be soaked in water for four days period before testing .the annual rainfall is less than 50 cm and the water table is too deep to affect the sub grade and imperable surfacing is provided to carrying out CBR test.

d) If the maximum variations in CBR value of the three specimens exceed the specified limits, the design CBR should be average of at least six samples.

e) The top 50 cm of sub grade should be compacted at least up to 95 to 100 percent of proctor density.

f) An estimate of the traffic should be carried by the road pavements at the end of expected in view the existing traffic and probable growth rate of traffic.

g) The traffic for the design is considered in units of heavy vehicles per day in both directions and is divided into seven categories A to G.The design thickness is considered applicable for single axle loads up to 8200 kg and tandom axle loads up to 14,500 kg.

h) When subbase course materials contain substantial proportion of aggregates of size above 20mm, the CBR value of these materials would not be valid for the design of subsequent layers above them.

The CBR method of pavement design gives the total thickness requirement of the pavement above a sub grade and thickness value would remain the same quality of materials used in component layers.

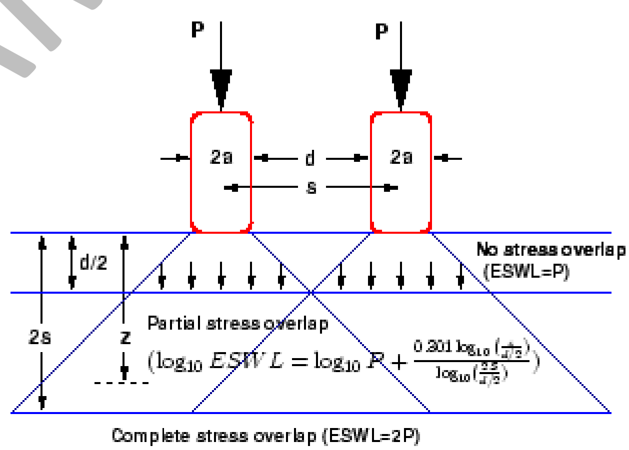
4. Compare the flexible and Rigid pavements (April/May 2018)

Difference between Flexible Pavements and Rigid Pavements:

	Flexible Pavement	Rigid Pavement
1.	It consists of a series of layers with the highest quality materials at or near the surface of pavement.	It consists of one layer Portland cement concrete slab or relatively high flexural strength.
2.	It reflects the deformations of subgrade and subsequent layers on the surface.	It is able to bridge over localized failures and area of inadequate support.
3.	Its stability depends upon the aggregate interlock, particle friction and cohesion.	Its structural strength is provided by the pavement slab itself by its beam action.
4.	Pavement design is greatly influenced by the subgrade strength.	Flexural strength of concrete is a major factor for design.
5.	It functions by a way of load distribution through the component layers	It distributes load over a wide area of subgrade because of its rigidity and high modulus of elasticity.
6.	Temperature variations due to change in atmospheric conditions do not produce stresses in flexible pavements.	Temperature changes induce heavy stresses in rigid pavements.
7.	Flexible pavements have self healing properties due to heavier wheel loads are recoverable due to some extent.	Any excessive deformations occurring due to heavier wheel loads are not recoverable, i.e. settlements are permanent

5. Describe about Equivalent single wheel load (April/May 2018)

In order to have maximum wheel load, dual wheel assembly is provided to the rear axles of the load vehicles. Because of this, the load due to both the wheels is not to be transferred to the pavement. But there will be overlap pressure after a certain depth. The actual effects are in between a single wheel load and double the load carried by any one wheel. Stress overlap is presented in fig below



It is assumed that up to a depth of d/2 the loads act independently beyond which the stresses overlap.

The area of overlap becomes more beyond a depth of 2S.hence it may be considered that the load the total stress due to the dual wheels at any depth greater than 2S, is to be equivalent to a single wheel load of 2P magnitude. However, this stress due to 2P is to be slightly greater than the duel wheel assembly which is on the safe side.

This equivalent single wheel load can be determined by equivalent deflection or equivalent deflection or equivalent stress criterion.

For example, based on deflection criterion it is to state that the maximum deflection caused at a particular depth z (say, depth equivalent to the thickness of pavement) by a dual wheel load Assembly is also caused by an equivalent single wheel load acting at the surface of the pavement.

Similarly by the stress criterion the ESWL producing the same stress value at a depth z as that produced by a dual wheel load assembly.

A linear relationship is assumed between the ESWL and the depth in a log-log scale. A linear plot is got, as shown in fig. By plotting a point A with coordinates z=d/2 and P and point B with coordinates z=2S and 2P.

6. **Calculate the stresses at interior, edge and corner regions of a cement concrete pavement using Westergaards stress equations. Use the following data.(Nov/Dec 2017)**

Wheel load, P = 5200 Kg

Modulus of elasticity of cement concrete, E = 3.0×10^5 kg/cm^2

Pavement thickness, h = 18 cm

Poisson's ratio of concrete, μ = 0.15

Modulus of subgrade reaction, K = 6.0 kg/cm^3

Radius of contact area, a = 15cm

Solution:

Radius of relative stiffness (l) is given by

$$l = \left[\frac{Eh^3}{12K\left(1-\mu^2\right)}\right]^{\frac{1}{4}} = \left[\frac{3.0x10^5\,x18^3}{12x6\left(1-0.15^2\right)}\right]^{\frac{1}{4}} = 70.6cm$$

The equivalent of resisting section is given by:

a/h = 15/8=0.833 <1.74

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

$$= \sqrt{1.6x15^2 + 18^2} - 0.675x18 = 14.0cm$$

Stress at the interior,(S_i)

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

$$= \frac{0.316x5100}{18^2}\left[4\log 10\left(\frac{70.6}{14.0}\right) + 1.069\right] = 19.3kg/cm^2$$

Stress at the edge,(S_e)

$$S_e = \frac{0.572p}{h^2}\left[4\log 10^{\frac{l}{b}} + 0.359\right]$$

$$= \frac{0.572x5100}{18^2}\left[4x0.7027 + 0.359\right] = 28.54kg/cm^2$$

Stress at the corner (S_c)

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

$$= \frac{3x5100}{18^2}\left[1-\left(\frac{15\sqrt{2}}{70.6}\right)^{0.6}\right] = 24.27kg/cm^2$$

7. Explain any two methods of flexible pavement design (Nov/Dec 2017)

The flexible pavement is built with number of layers. In the design process it is to be ensured that under the application of load none of the layers is overstressed.

The maximum intensity of stresses occurs in the top layer of the pavement .The magnitude of load stresses reduces at lower layers.

In the design of flexible pavements, it has yet not been possible to have a rational design method wherein design process and service behavior of the pavement can be expressed by mathematical laws.

Flexible pavement design methods are accordingly either empirical or semi empirical. In these methods, the knowledge and experience gained on the behavior of the pavements in the past are usefully utilized.

Various approaches of flexible pavement design may be thus classified into three groups:

i) Empirical method
ii) Semi-empirical or Semi theoretical method
iii) Theoretical method

Empirical methods are either based on physical properties or strength parameters of soil sub grade. When the design is based on stress strain function and modified base on experience it may be called semi-empirical or semi-theoretical. There are design methods based on theoretical analysis and mathematical computations.
Out of the flexible pavement design method available is

i) Group index method
ii) California bearing ratio method
iii) California R value (or) Stabiliometer method
iv) Triaxial test method
v) McLeod method
vi) Burmister method

Group index method:

Group index value is an arbitrary index assigned to the soil type in numerical equations base on the percent fines liquid limit and plasticity index.

The design chart for group index method for determining the pavement thickness. The traffic volume in this method is divided in three groups.

Traffic volume	No of vehicles per day
Light	Less than 50
Medium	50 to 300
Heavy	Over 300

The design of the pavement thickness by this method, first the G1 value of the soil is found the anticipated traffic is estimated and is designated as light, medium or heavy as indicated

The G1 method of pavement design is essentially an empirical method based on physical properties of the subgrade soil. This method does not consider the strength characteristics of the subgrade soil and therefore is open to question regarding the reliability of the design based on the index properties of the soil only.

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The CBR method of pavement design gives the total thickness requirement of the pavement above a sub grade and thickness value would remain the same quality of materials used in component layers.

California Resistance Value Method:

In this design method based on stabliometer R-value and cohesiometer C-value .Based on performance data it was established by pavement thickness varies directly with R value and algorithm of load repetitions. It varies inversely with fifth root of c value.The expression for pavement thickness is given by the empirical equation:

$$T = \frac{K(T_1)(90-R)}{C^{\frac{1}{5}}}$$

Hence,

T=total thickness of pavement, cm

K=Numerical constant 0.166

T_1=traffic index

R= stabiliometer resistance value

C=Cohesiometer value

In the design of flexible pavements based on California resistance value method for the following data are needed:

R-value of soil subgrade

T_1 value

Equivalent C-value

R value of soil subgrade is obtained from the test using stabliometer.The computation of T_1 value has been explained.

Equivalent C-value:

The cohesiometer value c is obtained for each layer of pavement material separately from tests. However the composite or equivalent C-value of the pavement may be estimated if the thickness of each component layer and the c-value of the material of the layer are known. while designing a pavement as the thickness of the pavement is not known, it is easier if the pavement is first assumed to consist of any one material like gravel base course with known C-value. Subsequently the individual thickness of each layer is converted in terms of gravel equivalent by using relationship:

$$\frac{t1}{t2} = \left(\frac{C_2}{C_1}\right)^{\frac{1}{5}}$$

t1 and t2 are the thickness values of any two pavement layers.c1 and c2 are their corresponding cohesiometer values.

8. **Calculate the stresses at interior, edge and corner regions of a rigid pavement using Westergaard's method. (April/May 2018)**

   Wheel load P=4100Kg;

   E=3X10^{5}kg/cm^2,

   h=slab thickness 20cm,

   μ=Poisson's ratio for concrete =0.15,

   k= Modulus of sub grade reaction 4.0kg/cm^2

   a=Radius of wheel load distribution 15cm.

Solution:

Stresses in interior

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

$$l = \left[\frac{Eh^3}{12K1-\mu_2}\right]^{\frac{1}{4}} = \left[\frac{3\times10^5\times20^3}{12\times4.01-0.15^2}\right]^{\frac{1}{4}} = 84.56\text{cm}$$

$$b = \sqrt{1.6a^2+h^2} - 0.675 = h\sqrt{1.6\times15^2+20^2} - 0.675x = 20\ 14.06\text{cm}$$

$$S = \frac{0.316\times4100}{20^2}\left[4\log_{10}\left(\frac{84.56}{14.06}\right)+1.069\right] = 13.55\,\text{kg/cm}^2$$

Stress in edge

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

$$= \frac{0.572\times 4100}{20^2}\left[4\log_{10}\left(\frac{84.56}{14.06}\right)+0.359\right]$$

$$= 20.37\,\mathrm{kg/cm^2}$$

Stress in corner

$$S = \frac{3P}{h^2}\left[L\left(\frac{a\sqrt{2}}{\ell}\right)\right]$$

$$= \frac{3\times 4100}{20^2}\left[1-\left(\frac{15\sqrt{2}}{84.56}\right)\right] = 23.03\,\mathrm{kg/cm^2}$$

Result

Stress at interior=13.55kg/cm^2

Stress at edge=20.37kg/cm^2

Stress at corner=23.03kg/cm^2

9. Explain the design procedure for the design of rigid pavements.

(April/May17)(Nov/Dec 16)

(i) Wheel load

The design wheel load may be taken as 4100 kg with a tyre inflation pressure of 5.3 to 6.3 kg/cm^3.

(ii) Traffic volume

The growth of traffic volume after 20 years of construction has to be considered in the design.

The following formula may be used to estimate the demand $A_d=P^1(1+r)^{n+20}$

Where

A_d=number of commercial vehicles per day for laden weight greater than 3 tonnes.

P^1=the number of commercial vehicles per day at least count.

r=annual rate of increase in traffic intensity

n=number of years between the last traffic count and the commissioning of new cement concrete pavement.

Traffic Classification	Design traffic intensity, A_d (number of vehicles of ωt > 3 tonnes per day) at the end of design life	Adjustment in design thickness of cement concrete pavement, cm
A	0 to 15	-5
B	15 to 45	-5
C	45 to 150	-2
D	150 to 450	-2
E	450 to 1500	0
F	1500 to 4500	0
G	> 4500	+2

(iii) Annual temperature

The mean daily and annual temperature cycles are to be collected. The temperature difference, depending on the place where the road is intended to be constructed is taken from the standard table provided for various states and regions for a given thickness of slab.

(iv) Modulus of sub grade reaction

Modulus of sub grade reaction, K, is determined using a 75 cm diameter plate and the pressure corresponding to 0.125cm deflection. If the pavement is to be laid on the sub grade soil then K should be not less than 5.5kg/cm^3 otherwise a suitable sub base course is to be provided.

(v) Properties of concrete

The flexural strength of cement concrete to be used for the pavement should be less than 40 kg/cm^3.

The cube strength of concrete should be 280kg/cm^2, modulus of elasticity E=3X10^5 and poisons ratio=0.15.these properties may also be determined experimentally.

Co efficient of thermal expansion may be taken as 10x10^{-6}per ^{o}C for design purpose.

(vi) Computation of stresses

Wheel load stresses at the edge and corner regions are calculated as per modified Westergaard's analysis.

Temperature stress at the edge region is calculated as per Westergaards analysis using Bradbury's coefficient.

(vii)Slab thickness

The length and width of slab are decided based on the joint spacing's and lane width.

A trial thickness of slab is assumed. The warping stress at edge region is calculated which is deducted from the allowable flexural stress. The resulting strength in the pavement has to support the edge loads.

The stress due to load at the edge is calculated. The factor of safety is computed comparing the strength and the edge stress. If the factor of safety is less than one, thickness is increased and the calculations are repeated till the factor of safety is above1.this is the design thickness h.

The stress due to corner load is computed and checked using the above h. if this stress value is less than allowable flexural stress in concrete then the slab thickness h is adequate. If not the thickness may be suitably increased till the above condition is satisfied.

The design thickness h is then adjusted for traffic intensity as given in table to obtain the final adjusted slab thickness.

(viii) Joint spacing

For all slab thicknesses with rough foundation the maximum spacings recommended for 25mm wide expansion joint ios 140m.for smooth foundation the maximum spacing may be 90m for slab thickness up to 20cm, 120m for slab thickness up to 25cm when the construction is made in summer.if the construction is made in winter the spacing may be restricted to 50 and 60m respectively. In unreinforced slab for all slab thicknesses the spacing of construction joint is 4.5m.in reinforced slab the spacing is 13m for m15cm thickness slab with steel reinforcement of 2.7kg/cm^2 and 14m spacing for 20cm thick slabs with steel reinforcement of 3.8kg/cm^2.

(ix) Dowel bars

Dowel bars are designed based on Bradbury's analysis for shear, bending and bearing in concrete.

The minimum dowel length is taken as (L_d+δ).the load bearing capacity of the dowel system is assumed to be 40% of the design wheel load. The dowel bars is considered to be effective 1.8 times the radius of relative stiffness l on the either side of the load position.

Dowel bars are provided for thickness of slab more than 15cm or more.IRC recommends 2-5cm dia bars of 50cm length with 20cm spacing for 15cm thick slab and spaced at 30cm in case of 20cm thick slab.

(x) Tie bars

Designed for longitudinal joints with permissible bond stress in deformed bars 24.6kg/cm^2 and in plain bars 17.5kg/cm^2.allowable working stress in tensile steel is taken as 1500kg/cm^2.

(xi) Reinforcement

Nominal reinforcement in cement concrete pavements is intended to prevent deterioration of the cracks. It is not provided to increase the flexural strength of uncracked slab. The area of longitudinal and transverse steel required per meter width or length of slab is computed using the following formula.

A=Lfw/(2S)

Where

A=area of steel required per meter width or length of the slab, cm^2

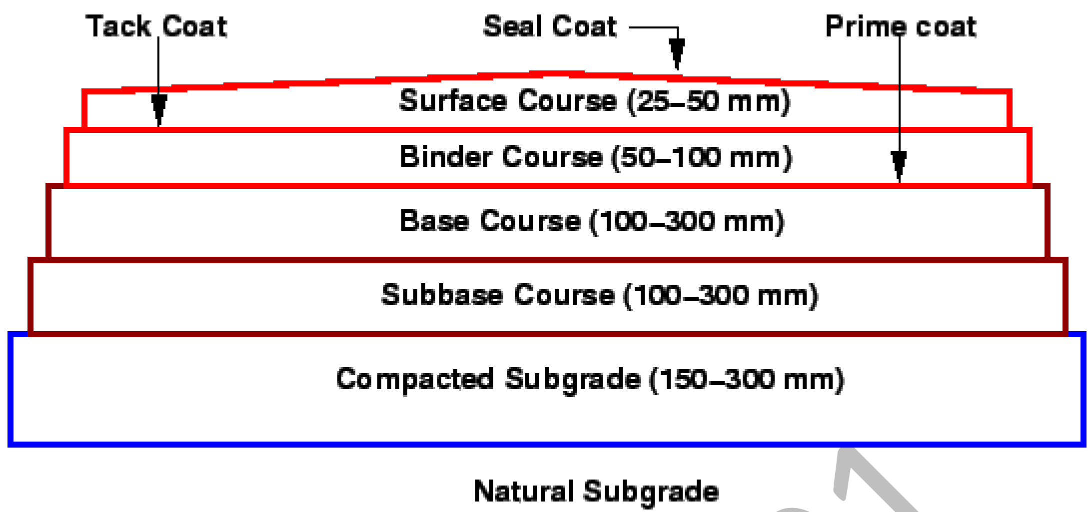
L=dist6ance between free transverse joints for longitudinal or transverse steel, m.

w=weight of unit area of pavement slab, kg/cm^2.

The reinforcement is to be provided at 5cm below the surface of slab. it is continued across dummy groove joints to serve the purpose of tie bars. The reinforcement is kept at least 5cm away from the face of joint or edge.

10. Explain the functions of the components of flexible pavements.(Nov/Dec 2015)

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural subgrade.



Seal Coat:

Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat:

Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat:

Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete(AC).

The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade

- It must be tough to resist the distortion under traffic and provide a smooth and skid resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course

This layer provides the bulk of the asphalt concrete structure. It's chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff subgrade may not need the additional features offered by a sub-base course. In such situations, subbase course may not be provided.

Sub-grade

The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

11. Explain the Design of Joints (May/June 2016)

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 considerations 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)

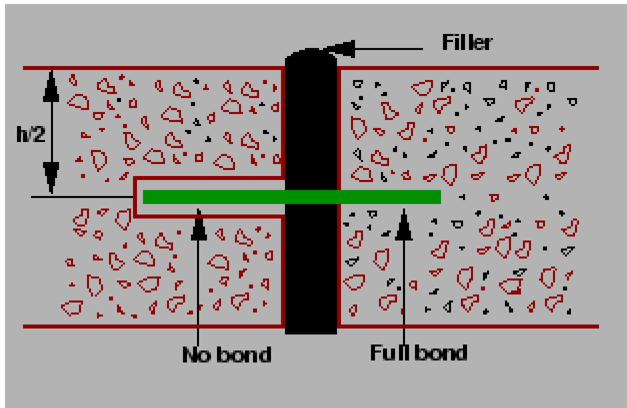


Figure: Expansion joint

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:

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

- 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.

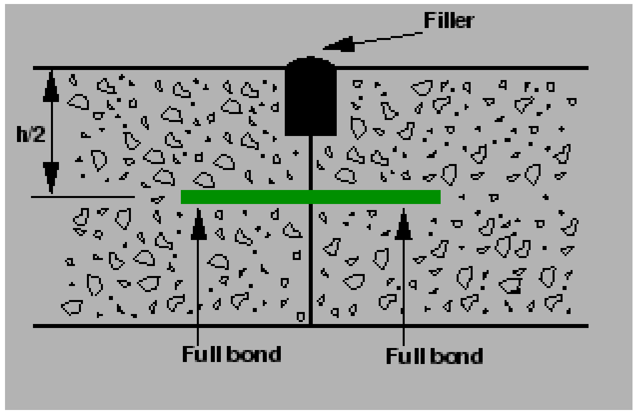


Figure: Contraction joint

12. Explain the following the following (i) Exceptional gradient (ii) Minimum gradient (iii) summit curve (iv) Valley curve (April/May 2015)

(i) Exceptional gradient

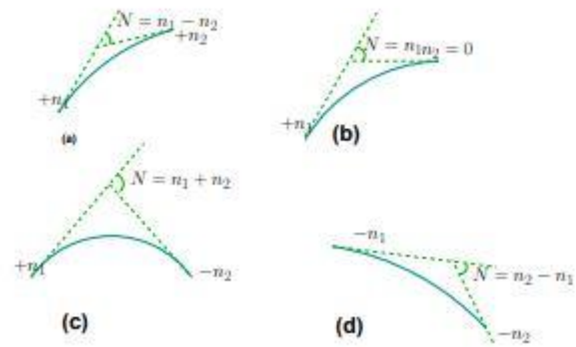
Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 metres at a stretch. In mountainous and steep terrain, successive exceptional gradients must be separated by a minimum 100 metre length gentler gradient. At hairpin bends, the gradient is restricted to 2.5%.

(ii) Minimum gradient

This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains requires some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the rain fall, type of soil and other site conditions. A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains are found to give satisfactory performance..

(iii) Summit curve

The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration. That is, a driver should be able to stop his vehicle safely if there is an obstruction on the other side of the road.



Equation of the parabola is given by $y = ax^2$, where $a = N/2L$, where N is the deviation angle and L is the length of the In deriving the length of the curve, two situations can arise depending on the uphill and downhill gradients when the length of the curve is greater than the sight distance and the length of the curve is greater than the sight distance.

(iv) **Valley curve**

Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet as illustrated in figure 1 in any of the following four ways:

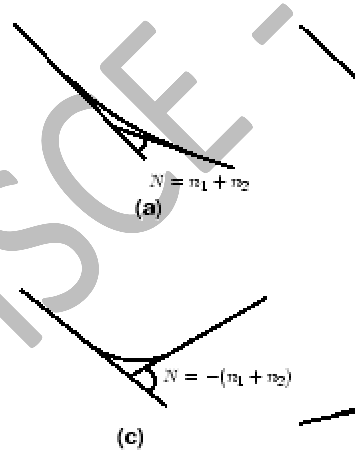


Figure 1: Types of valley curve

13. List the various factors influencing the design of Rigid Pavements and describe the design procedures as per IRC 58 (Nov/Dec 2015)

(Refer Part B- Question no.9)

14. (i) A two-lane carriage way carries a traffic 150 cv/ day. Rate of traffic growth is 5% pa. Pavement design life is 15 years. VDF = 2.5. Soil CBR is 6%. Calculate cumulative number of standard axles to be catered for, in the pavement design. (Nov/Dec 2015)

(ii) For the above data, determine the total pavement thickness based on the IRC method and the thickness of the different layers forming the total composition.

(iii) What is PMB? How it improves the quality of pavement?

(i) A two-lane carriage way carries a traffic 150 cv/ day. Rate of traffic growth is 5% pa. Pavement design life is 15 years. VDF = 2.5. Soil CBR is 6%. Calculate cumulative number of standard axles to be catered for, in the pavement design.

1. Two lane carriage way

2. Initial traffic in the year of completion of construction = 300 CVPD (sum of both directions)

3. Traffic growth rate = 7.5 %

4. Design life = 15 years

5. Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial

(ii) Distribution factor = 0.75

(ii) For the above data, determine the total pavement thickness based on the IRC method and the thickness of the different layers forming the total composition.

Total pavement thickness

Total pavement thickness for CBR 6% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).

(a) Bituminous surfacing = 20 mm PC + 50 mm BM

(b) Road-base = 250 mm Granular base

(c) sub-base = 280 mm granular material.

(iii) (What is PMB? How it improves the quality of pavement?

Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations.

It must be noted that the performance of PMB and CRMB is dependent on strict control on temperature during construction. The advantages of using modified bitumen are as follows Lower susceptibility to daily and seasonal temperature variations

- Higher resistance to deformation at high pavement temperature Better age resistance
- Properties Higher fatigue life for mixes
- Better adhesion between aggregates and binder Prevention of cracking and reflective
- Cracking

15. What are the most important factor in the pavement design? (April/May 2017)

(i) Temperature

The effect of temperature on asphalt pavements is different from that of concrete pavements. Temperature affects the resilient modulus of asphalt layers, while it induces curling of concrete slab. In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed. While in flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes differential settlements and pavement roughness. Most detrimental effect of frost penetration occurs during the spring break up period when the ice melts and subgrade is a saturated condition.

(ii) Precipitation

The precipitation from rain and snow affects the quantity of surface water in filtrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

(iii) Traffic and Loading

There are three different approaches for considering vehicular and traffic characteristics, which affects pavement design. Fixed traffic: Thickness of pavement is governed by single load and number of load repetitions is not considered. The heaviest wheel load anticipated is used for design purpose. This is an old method and is rarely used today for pavement design.

(iv) Fixed vehicle:

In the fixed vehicle procedure, the thickness is governed by the number of repetitions of a standard axle load. If the axle load is not a standard one, then it must be converted to an equivalent axle load by number of repetitions of given axle load and its equivalent axle load factor.

(v) Variable traffic and vehicle:
In this approach, both traffic and vehicle are considered individually, so there is no need to assign an equivalent factor for each axle load. The loads can be divided into a number of groups and the stresses, strains, and deflections under each load group can be determined separately; and used for design purposes. The traffic and loading factors to be considered include axle loads, load repetitions, and tyre contact area.

(vi) Contact pressure:
The tyre pressure is an important factor, as it determine the contact area and the contact pressure between the wheel and the pavement surface. Even though the shape of the contact area is elliptical, for sake of simplicity in analysis, a circular area is often considered.

(vii) Wheel load:
The next important factor is the wheel load which determines the depth of the pavement required to ensure that the subgrade soil is not failed. Wheel configuration affects the stress distribution and deflection within a pavemnet. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.

(viii) Axle configuration:
The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.

16. Explain in sequence the steps followed in design of cement concrete pavement. (Nov/Dec 2019)

(Refer the question no.9 in Part B)

17. Explain the IRC design procedure for rigid pavement (April/May 2019)

(Refer the question no.9 in Part B)

18. Explain in details the various design practices normally adopted in rigid pavement design as per IRC Standards (Nov/Dec 2018)

(Refer the question no.9 in Part B)

19. Explain in brief various design principles to be adopted in flexible pavement design (Nov/Dec 2018)

(Refer the question no.7 in Part B)

PART C

1. **A cement concrete pavement has a thickness of 18cm and has two lanes of 7.2 m with a longitudinal joint along the centre. Design the dimension and spacing of tie bar using the following details. (Nov/Dec 2017)**

Given data:

Allowable working stress in tension = 1400kg/cm²

Unit weight of concrete =2400 kg/m³

Coefficient of friction =1.5

Allowable bending stress in deformed bars in concrete =2.5 kg/cm²

Thickness =18 cm, Lanes =2, Width =7.2m

S_s=1400kg/cm², w= 2400 kg/m³

Co efficient of friction =1.5, S_b =2.5 kg/cm²

Solution :

Area of steel required per meter of longitudinal joint is given as

$$As = \frac{bfhw}{dx100Ss}$$

$$As = \frac{\left[\frac{7.2}{2}\right] x1.5x\ 18x2400}{100\ x\ 1400}$$

$$As = 1.66\text{cm}^2/m$$

Tie bars of 1cm diameter may be used.
Area of cross section of each bar **a_a =0.785 cm²**

$$\text{Spacing of tie bars} = \frac{100 \text{ x } 0.785}{1.66}$$

$$\text{Spacing of tie bars} = 47.28 \text{ cm}$$

$$\text{Length of the bar Lt } = \frac{ds}{2Sb}$$

$$\text{Spacing of tie bars} = \frac{1 \text{ x } 1400}{2 \text{ x } 2.5}$$

$$\text{Spacing of tie bars} = 280 \text{ cm}$$

Length of tie bar of 280 cm at 45 to 50 cm c/c   may be considered