USN 1CR15CV423

Eighth Semester B.E. Degree Examination, June/July 2018
Pavement Design

Time: 3 hrs. Max. Marks:100

Note: ***Answer FIVE full questions, selecting at least TWO questions from each part.***

PART – A

1 a. What are the different layers of flexible pavements? Explain the functions of each. **(08 Marks)**

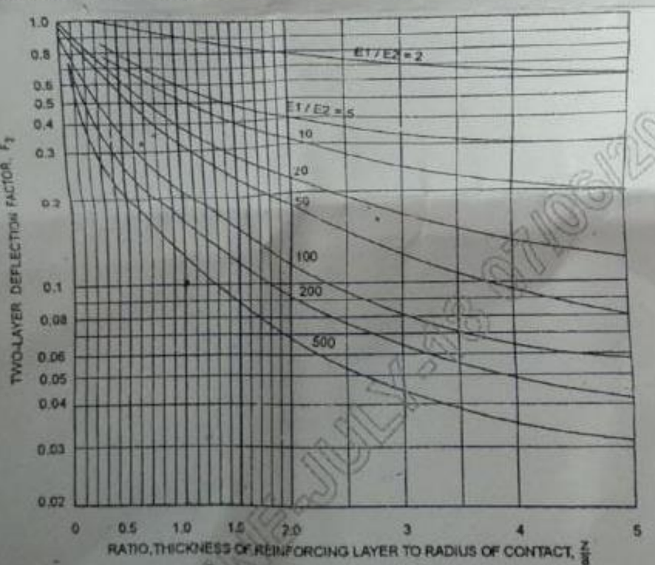
b. Bring out the points of difference between highway and airfield pavements. **(06 Marks)**

c. List the various factors to be considered for the selection of type of pavement. Also list the factors affecting pavement performance. **(06 Marks)**

2 a. Explain Frost action. What are the measures adopted to reduce it's effects. **(06 Marks)**

b. State the assumptions and limitations of Elastic Single layer theory and Burmister's two layer theory. **(06 Marks)**

c. The plate bearing tests were conducted with 30 cm plate diameter on soil subgrade and over 45 cm base course. The pressure yielded at 0.5 cm deflection are 1.25 kg/cm^2 and 8 kg/cm^2 respectively. Design the pavement section for 5100 kg wheel load with tyre pressure of 7 kg/cm^2 for an allowable deflection of 0.5 cm using Burmister's approach. (Refer chart given for Burmister's two layer deflection factors in Fig. Q2 (c)) **(08 Marks)**



Burmister's two-layer deflection factors

Fig. Q2 (c)

3 a. Calculate the ESWL of a dual wheel assembly carrying 2044 kg each for pavement thickness of 15 cm, 20 cm and 25 cm. Centre to centre tyre spacing is 27 cm and distance between the walls of the tyre is 11 cms (Use Graphical Method). **(10 Marks)**

b. Calculate the design repetitions for 20 year period for various wheel loads equivalent to 22.68 kN wheel load using the following data on a four lane road. **(10 Marks)**

Load in KN	22.68	27.22	31.75	40.82	45.36	49.90	54.43
Volume per day	30	25	20	15	10	5	1
EWLF	1	2	4	8	16	32	64

4 a. Design the pavement section by triaxial-Kansas method using the following data:
Wheel load – 41 KN
E value of base course = 40 N/mm^2
E value of subgrade soil = 10 N/mm^2
E value of wearing course = 100 N/mm^2
Radius of contact area = 150 mm
Design deflection = 2.5 mm
Sketch the pavement section. **(10 Marks)**

b. Briefly explain the procedure of CSA method for the flexible pavement, design as per IRC-37-2001. **(10 Marks)**

PART – B

5 a. Define modulus of subgrade reaction and radius of relative stiffness. **(06 Marks)**

b. Write the commonly used equations for the theoretical computation of wheel load stress by Westergaard's analysis of Interior; Edge and corner loadings. **(06 Marks)**

c. Calculate the stresses at interior, Edge and corner regions of a cement concrete pavement using Westergaard's stress equation. Use the following data:
Wheel load = 5100 kg ; E = 3×10^5 kg/cm^2 ; $\mu = 0.15$; Pavement thickness = 18 cm
Modulus of subgrade reaction = 6 kg/cm^3; Radius of contact area = 15 cm **(08 Marks)**

6 a. List the various requirements of joints in cement concrete slabs. Explain in detail with sketches: (i) Expansion joints. (ii) Contraction joints. **(10 Marks)**

b. A CC pavement has thickness of 18 cm and has two lanes of 7.2 mts with a longitudinal joint along the centre. Design the dimensions and spacings of the tie bar. The other data are –
allowable working stress in tension – 1400 kg/m^2
Unit weight of concrete – 2400 kg/m^3
Coefficient of friction – 1.5
Allowable bond stress in deformed bars in concrete – 24.6 kg/m^2. **(10 Marks)**

7 a. Benkelman beam deflection studies were carried out on 15 selected points on a stretch of flexible pavement during summer season using a dual wheel load of 4085 kg at 5 kg/cm pressure. The deflection values obtained in mm after making the necessary lag correction are given below. If the present traffic consists of 750 commercial vehicles per day determine the thickness of bituminous over lay required. If the pavement temperature during the test was 39°C and the correction factor for subsequent increase in subgrade moisture content is 1.3. Assume annual rate of growth of traffic as 7.5%. Adopt IR guideline. 1.40, 1.32, 1.25, 1.35, 1.48, 1.60, 1.65, 1.55, 1.45, 1.40, 1.36, 1.46, 1.50, 1.5 1.45 mm **(14 Mark**

b. What are the causes of formation of waves and corrugations in flexible pavements? Sugge remedial measures. **(06 Mark**

8 a. Explain various types of rigid pavement failures with neat sketches. **(10 Mark**

b. Explain briefly the pavement evaluation. **(10 Mark**

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VTU Semester Examination –June 2018
Solutions

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

Sem: VIII **Branch:** CIVIL

PART-A

1. A) What are the different layers of flexible pavements? Explain the functions of each. Typical layers of a conventional flexible pavement includes seal coat, surface course, tackcoat, binder course, prime coat, base course, sub-base course, compacted sub-grade, andnatural sub-grade as shown in the Figure.

Figure: Typical cross section of a flexible pavement

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 dilutedwith 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 absorbentsurface like granular bases on which binder layer is placed. It provides bonding betweentwo layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, andforms 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 pre-

vent 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 distributeload to the base course The binder course generally consists of aggregates having lessasphalt and doesn't require quality as high as the surface course, so replacing a part of thesurface 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 courseand it provides additional load distribution and contributes to the sub-surface drainage It maybe 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 finesfrom the sub-grade in the pavement structure If the base course is open graded, then thesub-base course with more fines can serve as a filler between sub-grade and the basecourse A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered bya sub-base course. In such situations, sub-base 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 becompacted to the desirable density, near the optimum moisture content.

B) Bring out the difference between highway and airfield pavements.

S. No.	**Highway pavement**	**Airfield pavement**
1.	Width of pavement depends upon no. Of lanes and no of lanes depend upon the traffic intensity. Width of 2 lane highway is 7.0m	Width of pavement depend upon the class of airport, type of area in operations and standard clearance values width of pavement ranges from 13 to 60m.
2.	Weight of truck is less than that of an aero plane. Around 20 tonnes for dual tandem wheels.	Gross weight of aero plane ranges between 80 to 250tonnes.
3.	Design wheel load is about 5.1 tonnes.	Design wheel load is around 50 tonnes.
4.	Tyre proof pressure is about 4 to 7 kg/cm^2.	Tyre proof pressure is about 25 to 30 kg/cm^2.
5.	Normally highway pavement is not subjected to impact effect.	Airport pavements are subjected to different types of impacts during landing

		and take –off.
6.	Traffic loading on highway pavement is concentrated at edges of pavements.	Traffic load is concentrated at the centre of the pavement.
7.	Distress is developed at the edges.	More distress is developed at the centre of pavement.
8.	No of repetitions of wheel loads are more.	No of repetitions of wheel loads are less.

C) List the various factors to be considered for the selection of type of pavement. Also list the factors affecting pavement performance.

Factor for selection of type of pavement:

- Material availability
- Method of construction
- Economic consideration
- Amount and type of traffic
- Maintenance charges

There are many factors that affect pavement design which can be classified into four categories as traffic and loading, structural models, material characterization, environment.

Traffic and loading

Traffic is the most important factor in the pavement design. The key factors include contact pressure, wheel load, axle configuration, moving loads, load, and load repetitions.

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.

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 affect 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.

Axle configuration:

The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.

Moving loads:

The damage to the pavement is much higher if the vehicle is moving at creep speed. Many studies show that when the speed is increased from 2 km/hr to 24 km/hr, the stresses and deflection reduced by 40 per cent.

Repetition of Loads:

The influence of traffic on pavement not only depend on the magnitude of the wheel load, but also on the frequency of the load applications. Each load application causes some deformation and the total deformation is the summation of all these. Although the pavement deformation due to single axle load is very small, the cumulative effect of number of load repetition is significant. Therefore, modern design is based on total number of standard axle load (usually 80 kN single axle).

Structural models

The structural models are various analysis approaches to determine the pavement responses (stresses, strains, and deflections) at various locations in a pavement due to the application of wheel load. The most common structural models are layered elastic model and visco-elastic models.

Layered elastic model:

A layered elastic model can compute stresses, strains, and deflections at any point in a pavement structure resulting from the application of a surface load. Layered elastic models assume that each pavement structural layer is homogeneous, isotropic, and linearly elastic. In other words, the material properties are same at every point in a given layer and the layer will rebound to its original form once the load is removed. The layered elastic approach works with relatively simple mathematical models that relates stress, strain, and deformation with wheel loading and material properties like modulus of elasticity and poissons ratio.

Material characterization

The following material properties are important for both flexible and rigid pavements.

- When pavements are considered as linear elastic, the elastic moduli and poisson ratio of subgrade and each component layer must be specified.
- If the elastic modulus of a material varies with the time of loading, then the resilient modulus, which is elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.
- When a material is considered non-linear elastic, the constitutive equation relating the resilient modulus to the state of the stress must be provided.

However, many of these material properties are used in visco-elastic models which are very complex and in the development stage. This book covers the layered elastic model which require the modulus of elasticity and poisson ratio only.

Environmental factors

Environmental factors affect the performance of the pavement materials and cause various damages. Environmental factors that affect pavement are of two types, temperature and precipitation and they are discussed below:

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.

Precipitation

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

2. A) Explain Frost Action. What are the measures adopted to reduce it’s effects.

Frost Action

Frost action can be detrimental to pavements and refers to two separate but related processes:

1. Frost heave. An upward movement of the subgrade resulting from the expansion of accumulated soil moisture as it freezes.
2. Thaw weakening. A weakened subgrade condition resulting from soil saturation as ice within the soil melts.

Frost Heave

Frost heaving of soil is caused by crystallization of ice within the larger soil voids and usually a subsequent extension to form continuous ice lenses, layers, veins, or other ice masses. An ice lens grows through capillary rise and thickens in the direction of heat transfer until the water supply is depleted or until freezing conditions at the freezing interface no longer support further crystallization. As the ice lens grows, the overlying soil and pavement will "heave" up potentially resulting in a cracked, rough pavement (see Figure 1). This problem occurs primarily in soils containing fine particles (often termed "frost susceptible" soils), while clean sands and gravels (small amounts of fine particles) are non-frost susceptible (NFS). Thus, the degree of frost susceptibility is mainly a function of the percentage of fine particles within the soil.

The three elements necessary for ice lenses and thus frost heave are:

1. Frost susceptible soil (significant amount of fines).
2. Subfreezing temperatures (freezing temperatures must penetrate the soil and, in general, the thickness of an ice lens will be thicker with *slower* rates of freezing).
3. Water (must be available from the groundwater table, infiltration, an aquifer, or held within the voids of fine-grained soil).

By removing any of the three conditions above, frost effects will be eliminated or at least minimized. If the three conditions occur uniformly, heaving will be uniform; otherwise, differential heaving will occur resulting in pavement cracking and roughness.

Differential heave is more likely to occur at locations such as:

- Where subgrades change from clean not frost susceptible (NFS) sands to silty frost susceptible materials.
- Abrupt transitions from cut to fill with groundwater close to the surface.
- Where excavation exposes water-bearing strata.
- Drains, culverts, etc., frequently result in abrupt differential heaving due to different backfill material or compaction and the fact that open buried pipes change the thermal conditions (i.e., remove heat resulting in more frozen soil).

Additional factors which will affect the degree of frost susceptibility (or ability of a soil to heave):

- Rate of heat removal.
- Temperature gradient
- Mobility of water (e.g., permeability of soil)
- Depth of water table
- Soil type and condition (e.g., density, texture, structure, etc.)

B) State the assumptions and limitations of Elastic Single layer theory and Burmister's two layer theory.

Boussinesq's theory:

Assumptions:

1. Soil is homogenous
2. Soil is isotropic
3. Soil is elastic
4. Stress distribution is symmetrical about z-axis
5. Soil mass is considered as weight less and unstressed.
6. Expression to determine the stress is for a concentrated mass.

Limitations:

1. Soil is not homogenous

2. Soil is not isotropic
3. Soil is not elastic
4. Valid for materials obeying Hooke's law
5. Soil also has layers with the increase in depth

Burmister's method:
Assumptions:
1. Soil is homogenous
2. Soil is isotropic
3. Soil is elastic
4. Top layer is assumed to be infinite in horizontal direction and finite in vertical direction
5. It is free from sharing and normal stresse outside the loaded area
6. E1> E2>E3

Limitations:
1. Soil is not homogenous, isotropic and elastic
2. E1> E2>E3 is not valid
3. There is osme amount of shearing and normal strikes from outside
4. Bottom layer cannot be assumed to be infinite in average direction.

C) The plate bearing tests were conducted with 30cm plate diameter on soil subgrade and over 45cm base course. The pressure yielded at 0.5 cm deflection are 1.25 kg/cm2 and 8kg/cm2 respectively. Design the pavement section for 5100 kg wheel load with tyre pressure of 7kg/cm2 for an allowable deflection of 0.5cm using Burmister's approach. (Refer chart for Burmister's two layer deflection factors)

2c) a) Plate load test on subgrade or single layer

$\Delta_1 = 0.5\,cm$, $p = 1.25\,kg/cm^2$, $a = 15\,cm$, $F_2 = 1$

$\Delta_1 = (1.18\,p.a.F_2)/E_2$

$E_2 = 44.25\,kg/cm^2$

b) Plate load test on base course of thickness 45 cm

$\Delta_1 = 0.5$, $p_1 = 10\,kg/cm^2$, $a = 15\,cm$, $h = 45\,cm$, $E_2 = 44.25\,kg/cm^2$

$\Delta_1 = (1.18\,p_1\,a.F_2)/E_2$

$F_2 = 0.125$

From Burmister's Two-layer Deflection Factor chart

$\frac{h}{a} = 3.0$, $F_2 = 0.125$, ratio $\frac{E_1}{E_2} = 50$

c) Design wheel load (Flexible plate)

$P_2 = 5100\,kg$, $p_2 = 7.0\,kg/cm^2$, radius of circular load $a_2 = 15.23\,cm$

$E_2 = 44.25\,kg/cm^2$

$\Delta = 0.5 \Rightarrow \Delta = (1.5\,p_2\,a_2\,F_2)/E_2$

$F_2 = 0.138$

From Burmister's two layer deflection factor chart, using curve for $E_1/E_2 = 50$,

Ratio of pavement thickness T to radius of wheel load $\frac{T}{a_2} = 2.5$

Therefore design thickness of flexible pavement,

$T = 2.5\,a_2 = 2.5 \times 15.23$

$= 38.1\,cm$

Design thickness of flexible pavement = 38.1 cm

3. A) Calculate the ESWL of a dual wheel assembly carrying 2044kg each for pavement thickness of 15cm, 20cm and 25cm. Centre to centre spacing is 27cm and distance between the walls of the tyre is 11cms. (Use graphical method)

Given:

P = 2044 kg.   S = 270 mm   d = 110 mm.

2P = 4088 kg.   2S = 540 mm $\frac{d}{2}$ = 55 mm

Points X and Y which are (P, d/2) and (2P, 2S) respectively are plotted on a log-log graph between ESWL and pavement thickness.

X coordinates (P, d/2) = (2044, 110/2)

= (2044, 55)

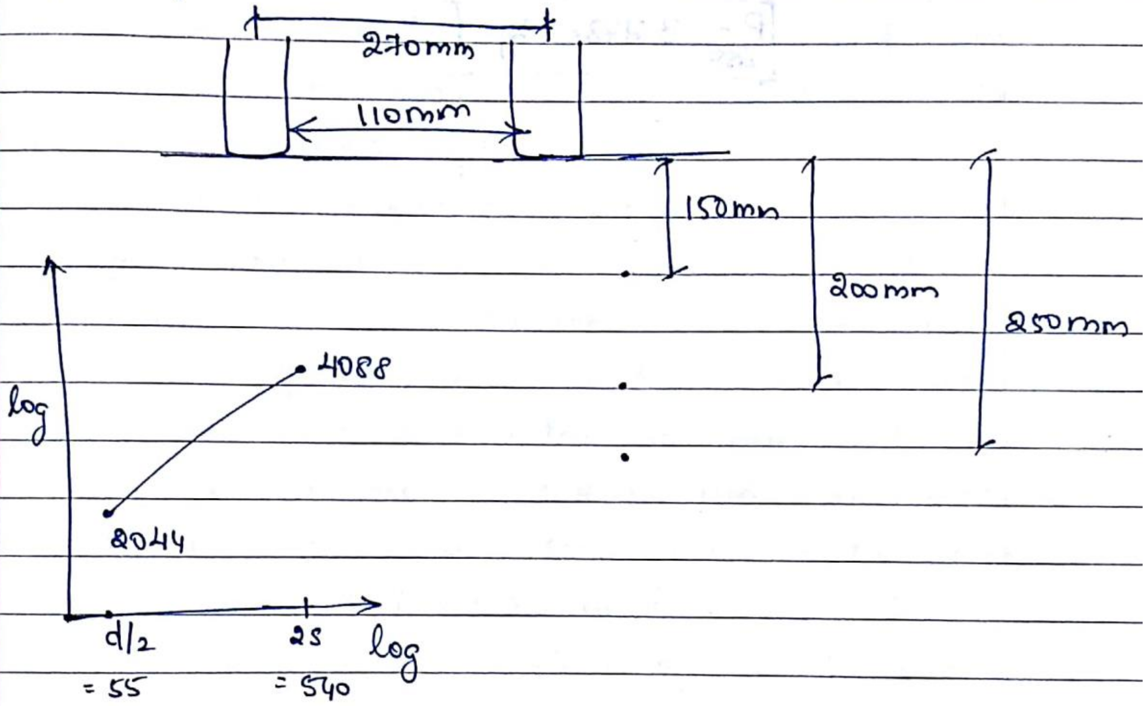
Y coordinates (2P, 2S) = (4088, 540)

are plotted on the log scale. The points X and Y are joined by a straight line.

On the X axis, points corresponding to pavement thickness of 150, 200 and 250 mm are marked and vertical lines are drawn from these points to intersect the line XY. Horizontal lines are now drawn from these points on line XY to meet the Y axis, to obtain the ESWL values @ the desired depths/ pavement thickness values. The ESWL values thus obtained are.

Thickness, mm	ESWL, kg
150	2760
200	8000
250	3230

By interpolation method,



SOLUTION:

$\log d/2 = 1.74$ $\log(2044) = 3.310$

$\log 2S = 2.73$ $\log(4088) = 3.612$

$\log 150 = 2.176$

$\log 200 = 2.301$

$\log 250 = 2.398$

By interpolation,

for 150 mm depth : $\frac{2.73-1.74}{2.176-1.74} = \frac{3.612-3.310}{x-3.310}$

$\frac{0.99}{.436} = \frac{0.302}{x-3.310} \Rightarrow x = 3.443 \Rightarrow \boxed{P_{150} = 2773.32 \text{ kg}}$

For 200mm depth,

$$\frac{0.99}{0.302} = \frac{2.301 - 1.74}{x - 3.31}$$

$$x = 3.481$$

$$P_{200} = 3026.91$$

For 250mm depth,

$$\frac{0.99}{0.302} = \frac{2.398 - 1.74}{x - 3.31}$$

$$x = 3.511$$

$$P_{250} = 3243.4\ kg$$

B) Calculate the design repetitions for 20 year period for various wheel loads equivalent to 22.68kN wheel load using the following data on a four lane road.

Load in KN	22.68	27.22	31.75	40.82	45.36	49.90	54.43
Volume per day	30	25	20	15	10	5	1
EWLF	1	2	3	8	16	32	64

Load in KN	Volume (per day)	For 20 years period(Volume *20*365)	ELF	Final value
22.68	30	219000	1	219000
27.22	25	182500	2	365000
31.75	20	146000	4	584000
40.82	15	109500	8	876000
45.36	10	73000	16	1168000
49.90	5	36500	32	1168000
54.43	1	7300	64	467200
			Total	4.8*10^6

Repetitions = 4.8 msa

Repetitions per lane = 4.8 / 4 = 1.08 msa

4. A) Design the pavement section by Triaxial-Kansas method using the following data:
   Wheel load – 41kN
   E value of base course= 40 N/mm2
   E value of Sub grade soil= 10 N/mm2
   E value of Wearing course= 100 N/mm2
   Radius of contact area = 150 mm
   Design deflection = 2.5mm
   Sketch the pavement section

$$T_s = \sqrt{\left(\frac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2} \times \left(\frac{E_s}{E_b}\right)^{1/3}$$

$$T_s = \sqrt{\left(\frac{3 \times 41 \times 1.5 \times 0.9 \times 10^3}{2 \times \pi \times 10 \times 2.5}\right)^2 - 150^2} \times \left(\frac{10}{40}\right)^{1/3}$$

Assuming X = coefficient of traffic = 1.5
Y = coefficient of rainfall = 0.9

$$T_s = \sqrt{(1057.107)^2 - 150^2} \times \left(\frac{10}{40}\right)^{1/3}$$

$$T_s = 1046.41 \times 0.63$$

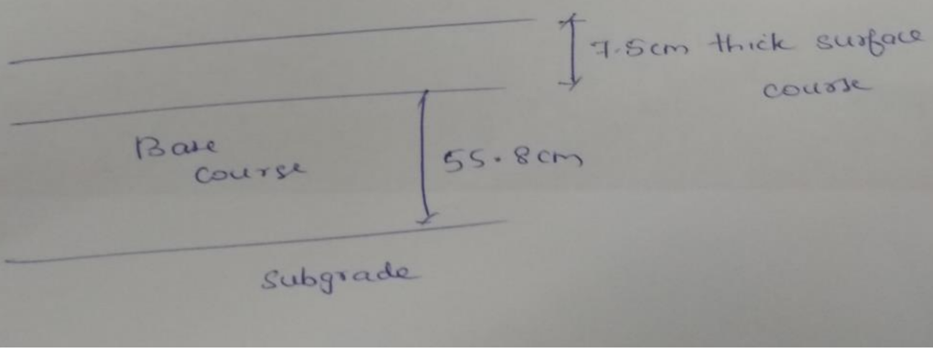
$$T_s = 659.2 \text{ mm} \approx 660 \text{ mm} = 66 \text{ cm}$$

Assuming thickness of surface course = 7.5 cm

$$\frac{t_1}{t_2} = \left(\frac{E_2}{E_1}\right)^{1/3}$$

$$\frac{7.5}{t_2} = \left(\frac{40}{100}\right)^{1/3} \Rightarrow t_2 = 10.2 \text{ cm}$$

∴ Thickness of base course = 66 cm − 10.2 cm
= 55.8 cm



B) Briefly explain the procedure of CSA method for the flexible pavement, Design as per IRC-37 – 2001.

Highlight the salient features of IRC 37-2001 guidelines for flexible pavement design:

Based on the performance of existing designs and using analytical approach, simple design charts and a catalogue of pavement designs are added in the code. The pavement designs are given for subgrade CBR values ranging from 2% to 10% and design traffic ranging from 1 msa to 150 msa for an average annual pavement temperature of 35^0C. The later thicknesses obtained from the analysis have been slightly modified to adapt the designs to stage construction. Using the following simple input parameters, appropriate designs could be chosen for the given traffic and soil strength:

i. Design traffic in terms of cumulative number of standard axles; and
ii. Pavement thickness design charts:

i. Design traffic:

The method considers traffic in terms of the cumulative number of standard axles (8160 kg) to be carried by the pavement during the design life. This requires the following information:

1. Initial traffic in terms of CVPD
2. Traffic growth rate during the design life
3. Design life in number of years
4. Vehicle damage factor (VDF)
5. Distribution of commercial traffic over the carriage way.

The mixed commercial vehicles with different axle loads are to be converted in terms of the cumulative number of standard axle load, N_s to cater for the design, using the equation:

$$N_s \text{ or } CSA = \frac{365 \times [(1+r)^n - 1]}{r} \times A \times D \times F \quad \text{in 'msa'}$$

Where,

N_s = Cumulative number of standard axles to be catered for in the design in terms of msa
A = Initial traffic in the year of completion of construction in terms of the number of commercial vehicles per day
D = Lane distribution factor
F = Vehicle damage factor
n = Design life in years
r = Annual growth rate of commercial vehicles (for 7.5% annual growth rate, r = 0.075)

ii. Pavement thickness design charts:

For the design of pavements to carry traffic in the range of 1 to 10 msa, use chart 1 and for traffic in the range 10 to 150 msa, use chart 2 of IRC:37 2001. The design curves relate pavement thickness to the cumulative number of standard axles to be carried over the design life for different sub-grade CBR values ranging from 2 % to 10 %. The design charts will give the total thickness of the pavement for the above inputs. The total thickness consists of granular sub-base, granular base and bituminous surfacing. The individual layers are designed based on the recommendations given below and the subsequent tables.

PART-B

5. **A)** Define modulus of subgrade reaction and radius of relative stiffness.

i) Modulus of Subgrade reaction (K):-

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil subgrade, which is assumed as a dense liquid. The upward reaction is assumed to be proportional to the deflection. Based on this assumption, westergaard defined as "modulus of sub-grade reaction" is the ratio of pressure sustained by the rigid plate to the displacement.

$$K = \frac{p}{\Delta} = \frac{p}{0.125} \quad \text{in } kg/cm^3$$

where,

Δ = Displacement = 0.125 cm

p = Pressure sustained by the rigid plate of 75 cm dia.

(i) Radius of relative stiffness

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

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

B) Write the commonly used equations for the theoretical computation of wheel load stress by Westergaard's analysis of Interior, Edge and corner loadings.

i) wheel load stresses :-

the commonly used equations for theoretical computation of wheel load stresses have been given by "Westergaard". He considered three typical regions of the cement concrete pavement slab for the analysis of stresses, as the interior, edge and the corner regions. The critical stresses S_i, S_e & S_c at the typical locations ie; interior, edge and corner are given in below equations.

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

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

→ Corner Loading, $S_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$

where, S_i, S_e, S_c = wheel load stresses at interior, edge and corner loading respectively, kg/cm^2

h = slab thickness, cm

P = wheel load, kg

a = Radius of wheel load distribution, cm

l = Radius of relative stiffness, cm

b = Radius of resisting section, cm

C) Calculate the stresses at interior, edge and corner regions of a cement concrete pavement using Westergaard's stress equation. Use the following data:
Wheel load = 5100kg, E = 3*10^5 kg/cm2, µ = 0.15, Pavement thickness = 18cm, Modulus of subgrade reaction = 6 kg/cm2, radius of contact area = 15cm

$P = 51$ 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

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

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

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

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

6. A) List the various requirements of joint in cement concrete slabs. Explain in detail with sketches:
   (i) Expansion joints (ii) Contraction joints

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)

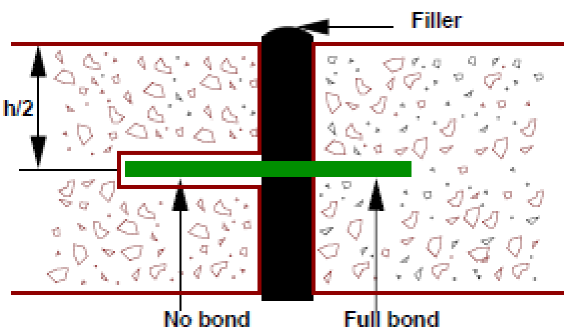


Figure 29:2: Expansion joint

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.

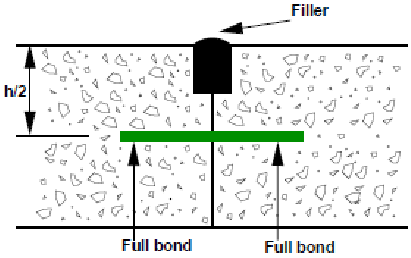


Figure 29:3: Contraction joint

B) A CC pavement has thickness of 18cm and has two lanes of 7.2m with a longitudinal joint along the centre. Design the dimensions and spacings of the tie bar. The other data are

Allowable working stress in tension = 1400 kg/m2

Unit weight of concrete = 2400 kg/m2

Co-efficient of friction = 1.5

Allowable bond stress in deformed bars in concrete = 24.6 kg/m2

Sol^n

Data

$h = 18\ cm$

width of 2 lanes = 7.2m

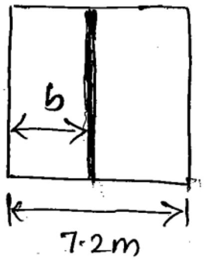
$S_s = 1400\ kg/cm^2$

$W = 2400\ kg/m^3$

$f = 1.5$

$S_b = 24.6$

$b = \frac{7.2}{2} = 3.6m$



1) Area of steel per meter length

$$A_s = \frac{b f h W}{100 S_s} = \frac{3.6 \times 1.5 \times 18 \times 2400}{100 \times 1400}$$

$$\boxed{A_s = 1.66\ cm^2/cm}$$

2) Area of Cross-section of 1 bar

Assume dia of bar = 0.8cm to 1.5cm

$\therefore\ a_s = \frac{\pi d^2}{4}$ Take dia of bar $\boxed{d = 1\ cm}$

$$a_s = \frac{\pi \times 1^2}{4} = \boxed{0.785\ cm^2}$$

4) Length of Tie bar

$$L_t = \frac{d S_s}{2 S_b} = \frac{1 \times 1400}{2 \times 24.6} = 28.45\ cm \approx \boxed{30cm}$$

3) Spacing of Tie bar

$$\text{Spacing} = \frac{100\ a_s}{A_s} = \frac{100 \times 0.785}{1.66} = \boxed{47.28\ cm} \approx \boxed{45\ cm}$$

$\therefore$ Provide 1 cm diameter tie bars of length 30cm at 45 cm centre to centre

7. A) Benkelmen beam deflection studies were carried out on 15 selected points on a stretch of flexible pavement during summer season using a dual wheel load of 4085 kg at 5kg/cm pressure. The deflection values obtained in mm after making necessary la corrections are given below. If the present traffic consists of 750 CV per day determine the thickness of bituminous overlay required. If the pavement temperature during the test was 39℃ and the correction factor for subsequent increase in subgrade moisture content is 1.3. Assume annual rate of growth of traffic as 7.5%. Adopt IRC guidelines 1.4,1.32,1.25.,1.35, 1.48,1.60,1.65,1.55,1.45,1.40,1.36,1.46,1.50,1.53,1.45mm

Mean Deflection :

$$\bar{D} = \frac{\Sigma D}{n} = \frac{2174}{15} = 1.45 \text{ mm}$$

Standard deviation $= \sqrt{\frac{\Sigma(\bar{D}-D)^2}{n-1}} = 0.107$ mm

$D_c = \bar{D} + \sigma = 1.557$ mm

Deflection after temperature correction

$1.557 - (39-35)\, 0.0065 = 1.531$ mm

Corrected deflection for subgrade moisture $= 1.531 \times 1.3$

$= 1.99$ m.

$n = 2,$

$$A = P(1+r)^{n+10} = 750(1+0.075)^{12}$$

$= 1768$ cv/day

As per IRC recommendations, allowable deflection $= \Delta a = 1$ mm,

Overlay thickness of granular material

$$h_o = 550 \log_{10}\left(\frac{\Delta c}{\Delta a}\right)$$

$= 165$ mm

Assuming an equivalency factor 2, for Bituminous concrete overlay,

Design thickness $= 16.5 \times \frac{1}{2} = 8.25$ cm.

B) What are the causes of formation of waves and corrugations in flexible pavements? Suggest remedial measures.

Transverse undulations appear at regular intervals due to the unstable surface course caused by stop-and-go traffic.

Fig-9 shows a pavement with corrugation.

8. A) Explain various types of rigid pavement failures with neat sketches.

The following 5 form of failures are commonly found in rigid pavement

Scaling of cement concrete
Shrinkage cracks
Joint spalling
Warping cracks
Pumping

SCALING OF CEMENT CONCRETE


Scaling

Scaling of rigid pavement simply means, peeling off or flaking off of the top layer or skin of the concrete surface. This may be due to the following reasons

- Improper mix design
- Excessive vibration during compaction of concrete
- Laitance of concrete

- Performing finishing operation while bleed water is on surface

SHRINKAGE CRACKS

Shrinkage cracking

Formation of hairline shallow cracks on concrete slab is the indication of shrinkage cracks. Shrinkage cracks develop on concrete surface during the setting & curing operation. These cracks may form in longitudinal as well as in transverse direction.

JOINT SPALLING

Joint spalling is the breakdown of the slab near edge of the joint. Normally it occurs within 0.5 m of the joints. The common reasons for this defect are

- Joint spalling
- Faulty alignment of incompressible material below concrete slab
- Insufficient strength of concrete slab near joints
- Freeze-thaw cycle
- Excessive stress at joint due to wheel load

WARPING CRACKS

In hot weather, concrete slab tends to expand. Therefore the joints should be so designed to accommodate this expansion. When joints are not designed properly, it prevents expansion of concrete slab and therefore results in development of excessive stress. This stress cause formation of warping cracks of the concrete slab near the joint edge.

This type of crack can be prevented by providing proper reinforcement at the longitudinal and transverse joints. Hinge joints are generally used to relieve the stress due to warping.

PUMPING

Pumping

When material present below the road slab ejects out through the joints or cracks, it is called pumping. When soil slurry comes out it is called mud pumping.

The common reasons for this defect are

- Infiltration of water through the joints, cracks or edge of the pavement forms soil slurry. Movement of heavy vehicles on pavement forces this soil slurry to come out causing mud pumping.
- When there is void space between slab and the underlying base of sub-grade layer
- Poor joint sealer allowing infiltration of water
- Repeated wheel loading causing erosion of underlying material

Pumping can also lead to formation of cracks. This is because; ejection of sub-grade material below the slab causes loss of sub-grade support. When traffic movement occurs at these locations, it fails to resist the wheel load due to reduction of sub-grade support and develops cracks.

This type of defect can be identified when there is presence of base or sub-grade material on the pavement surface close to joints or cracks.

B) Explain briefly pavement evaluation.

Explain briefly the pavement Evaluation.

The primary objective of Pavement Condition Evaluation is to assess as to whether & to what Extent the pavement fulfils the intended requirements so as to plan for the Maintenance & strengthening works

The pavement Evaluation are classified into two groups

(i) <u>structural Evaluation of Pavement</u> : The structural Evaluation for both flexible & rigid pavement is carried out By plate bearing test. the structural Capacity of pavement is assessed by amount of deflection at a specified load on plate. The Most Commonly used Equipment to asses the structural Evaluation is Benkelman beam. there are Non destructive testing techniques for assesing the load Carrying Capacity of the Pavement.

(ii) <u>Evaluation of Pavement surface Condition</u>: The Surface Condition of flexible pavement in Evaluated by the unevenness, ruts, patches & Cracks and of rigid pavements by Cracks developed & by the faulty joints affecting the riding quality of Pavement. A Bump integrator is an Equipment Capable of integrating the uneveness of pavem- -ent surface to cumulative scale which gives uneveness index of surface in cm/km length of road.