

Undulate - Recent

Values of

Level of Service, B, C, D and E ~~fail to~~ decrease with increase in the traffic vol. or vol. to capacity ratio as well as the operating speed of faster vehicles and their opportunities to overtake decreases.

Transportation Engineering - II

Section - A Unit - I

☒ Types of Pavement Structure:-

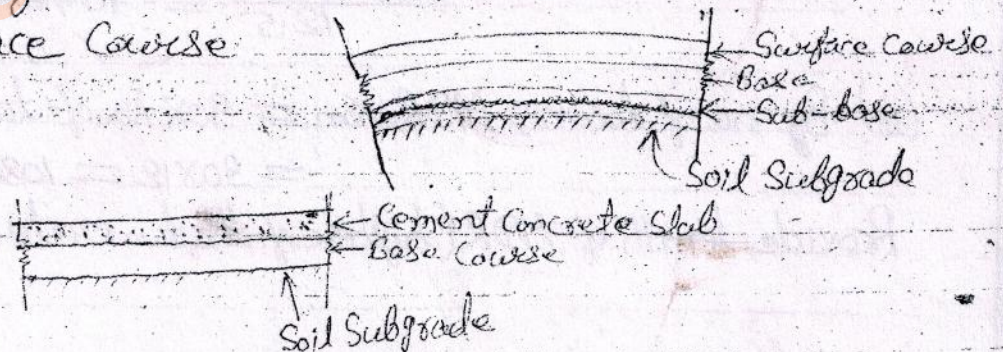
(i) Flexible Pavements, and (ii) Rigid Pavements

(i) Flexible Pavements:-

- These are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads.
- If the lower layer of the pavement or soil subgrade is undulated ^{hinged} undulated, the flexible pavement surface also get undulated ^{hinged}.
- A typical flexible pavement consists of four components:

(i) Soil Subgrade (ii) Sub-base course (iii) base course

(iv) Surface course



8) The area of a certain district in India is 13400 km^2 and 12 towns as per 1981 census. Determine the lengths of different categories of roads to be provided in this district by the year 2011.

Ans: $\rightarrow$

(i) Length of NH, km = $\frac{\text{Total length of the country}}{50}$ ^{area}
 $= 13400/50 = 168 \text{ km}$

(ii) Length of SH,

(a) By area, SH km = $\frac{\text{Total length of the country}}{2.5}$
 $= 536 \text{ km}$

(b) By area and no. of towns, SH km =
 $(62.5 \times \text{No. of towns}) - (\text{area of the state}/50)$

$= (62.5 \times 12) - \frac{13400}{50} = 482 \text{ km}$

Adopt length of SH (higher of two criteria) = 536 km

(iii) Length of MDR in the district

(a) By area, MDR km = $\frac{\text{Total area of the country}}{12.5}$
 $= \frac{13400}{12.5} = 1072 \text{ km}$

(b) By no. of towns, MDR km = $90 \times \text{No. of towns}$
 $= 90 \times 12 = 1080 \text{ km}$

Provide length of MDR (higher of the two criteria) = 1080 km

13400 km²
lengths
el in

(iv) Total length of all categories of road may be assumed to provide an overall density of road length equal to 82 km per 100 km² area by the year 2001.

Calcutta/50

$$NH + SH + MDR + ODR + VR = 13400 \times \frac{82}{100} = 10988 \text{ km}$$

$$\text{Length of } NH + SH + MDR = 268 + 536 + 1080 = 1844 \text{ km}$$

1/25

$$\therefore \text{Total length of rural roads consisting of } ODR + VR = 10988 - 1844 = 9104 \text{ km}$$

2)

(i) Primary system of NH = 268 km

(ii) Secondary system consisting of SH = 536 km and MDR = 1080, total length = 1616 km

km

(iii) Tertiary system of rural roads consisting of ODR and VR = 9104 km

(iv) Total length of road = 10988 km

1/12.5

9 km
= 1080 km

* Cement concrete Pavement Construction

Cement concrete pavement may be constructed with three different patterns -

- (i) Cement grouted layer
- (ii) Rolled Concrete layer
- (iii) Cement concrete slab

(i) In cement grouted layer, mixing of aggregates is done and aggregate mix is prepared with the minimum aggregate size 18 to 25 mm.

This mix is laid on the prepared subgrade or base course and is dry rolled. The loose thickness is compacted to provide 80% of the rolled thickness. Grouting is prepared by mixing cement, coarse sand and water.

The proportion of cement to sand should be $1:1\frac{1}{2}$ to $1:2\frac{1}{2}$. The prepared grout is then laid on the surface and is allowed to seep through aggregate matrix.

(ii) Rolled Concrete layer, concrete is prepared with the help of cement, sand, water and cement. The prepared mix is laid on the surface subgrade or base course. The loose thickness is compacted to provide

ction $\Rightarrow$ 20% more than rolled thickness. Tandem rollers are recommended. The rolling operation is done before the final setting time. Curing is done with conventional method.

Both cement grouted layer and concrete rolled concrete layer are done only in case of base course.

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(iii) Cement Concrete Slab $\Rightarrow$

This is done by two methods:

(a) alternate bay method

(b) continuous bay method

Alternate bay method is adopted where ~~no~~ more traffic ^{doesn't} exist. It is not best method because in it this method is done in a number of steps like constructing a bay or a slab in alternate succession leaving the next or intermediate bay to follow up after a gap of one week.

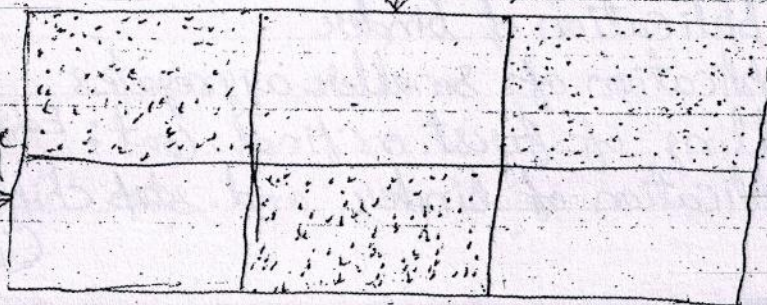
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longitudinal
joint



Drawbacks:->

- (i) Large number of transverse joints are to be provided. This will result in increase of cost and unsmoothness riding surface. (g)
- (ii) During rains, water collects on the subgrade. (h)
- (iii) Construction is sprayed to full width of the road and hence traffic problems occurs. (ii)

* Bituminous Construction :->

- (i) Surface dress dressing (e)
- (ii) Grouted or penetration macadam
- (iii) Built-up spray grout
- (iv) Bitumen bound macadam (f)
- (v) Bituminous carpet (g)
- (vi) Bituminous concrete (h)

Bituminous

(i) Surface dressing:-

- (a) Preparation of existing surface (Se)
- (b) Tack coat or priming prime coat (b)
- (c) Application of binder (B)
- (d) Application of smaller aggregates (Sig)
- (e) Rolling of first or final coat: Edge to centre
- (f) Application of binder and ~~stop~~ chipping stones (if required)

- (g) Rolling of second (if required) :- tandem roller
(h) Finishing and opening to traffic ^{with 10 tonnes}

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res.

(ii) Grouted or Penetration Macadam :- ^(prime)

(a) Preparing of existing surface, (a') Tack coat

(b) Spreading the coarse aggregates :-

50 mm thickness = 0.60 m^3 per 10 m^2

75 mm thickness = 0.90 m^3 per 10 m^2

(c) Rolling :- Overlap recommended 30 cm

(d) Bitumen/binder application :-

50 kg per 10 m^2 - 50 mm thickness

68 kg per 10 m^2 :- 75 mm thickness

(e) Spreading of key aggregates :-

0.15 m^3 per 10 m^2 - 50 mm thickness

0.18 m^3 per 10 m^2 - 75 mm thickness

(f) Seal or final coat :- if another surface is not reqd.

(g) Finishing :- By checking cross profile with template
and longitudinal profile by straight
edge.

(h) opening to traffic :- After 24 hours

Same steps are adopted for all other
bituminous construction

But decrease, coarse aggregate and key aggregates
size, bitumen/binder

centre

stones
quired)

* Tar :->

Tar is the viscous liquid obtained when natural organic material such as wood and coal carbonized distilled in the absence of air. Based on the material from which tar is derived, it is referred to as wood tar or coal tar. Latter it is more widely used for road work because it is superior.

Three stages for the production of road tar are:-

- (i) Carbonization of coal to produce crude tar
- (ii) Refining or distillation of crude tar
- (iii) Blending of distillation residue with distillate oil fraction to give the desired road tar.

There are five grades of road tar are:-

RT-1, RT-2, RT-3, RT-4 and RT-5, based on their viscosity and other properties-

RT-1 is the lowest viscosity and is used for surface painting under exceptionally cold weather as this has very low viscosity.

RT-2 is recommended for standard surface painting under normal Indian Climatic Conditions

RT-3 may be used for surface painting, renewal coats.

RT-4 is generally used for premixing tar macadam in base course.

• For grouting purposes RT-5 may be adopted, which has the highest viscosity among the road tars.

* Bitumen:→

Crude petroleum obtained from different places are quite different in their composition.

Bitumen is the viscous liquid obtained by distillation of crude petroleum.

Three stages for the production of road bitumen are:-

- (i) Carbonization of coal to produce crude petroleum
- (ii) Refining or distillation of crude petroleum
- (iii) Blending of distillation residue with distillate oil fraction to give the desired road bitumen.

Requiseiment of bitumen:-

(a) mixing

(b) to provide stability to mixing

(c) to maintain stability under transverse adverse weather conditions

(d) to maintain sufficient flexibility

(e) to avoid cracking of bituminous surface

(f) to have sufficient adhesion with the aggregates in the mix in presence of water.

* Adzing:→ Adzing of sleepers is the process of cutting wooden sleepers to provide inward slope of 1 in 20 at rail seat.

* Tilting:→ Tilting of rails is the art of placing the rails of a track at an inward slope of 1 in 20.

Remainings of Flexible Pavements

- The flexible pavement layers transmit the vertical or compressive stresses to the lower layers by grain to grain transfer through the points of contact in the granular structure.
- A well compacted granular structure consisting of strong graded agg. can transfer the compressive stresses through a wider area and thus forms a good flexible pavement layer.
- Bituminous Concrete is one of the most best flexible pavement layer material.
- The flexible pavement may be constructed in a no. of layers and the top layer has to be the strongest as the highest compressive stresses are to be sustained by this layer, in addition to the wear & tear due to traffic.
- The lowest layer is the prepared surface consisting of the local soil itself, called the subgrade.
- Each of the flexible pavement layers above the subgrade, viz. sub-base, base course and the surface course may consist of one or more no. of layers of the same or slightly different materials and specifications.

☒ Rigid Pavements :->

- These are those which possess not worthy flexural strength or flexural rigidity.
- The stresses are not transferred from grain to grain to the lower layer as in the case of flexible pavement layers.
- The rigid pavements are made of portland cement concrete - either plain, reinforced or prestressed conc.
- The cement concrete pavement slab can very well serve as a wearing surface as well as effective base course.
- Providing a good base or sub-base course layer under the cement concrete slab, increases the pavement life and therefore works out more economical.

☒ Functions of Pavement Components :->

(1) Subgrade Soil Subgrade and its evaluation :-

- It is a layer of natural soil prepared to receive the layers of pavement material placed over it.
- The loads on the pavement are ultimately received by the soil subgrade for dispersion to the earth mass.
- It is essential that at no time, the soil subgrade is overstressed. It means that the pressure transmitted on the top of the subgrade is within the allowable limit, not to cause excessive stress condition or to deform the same beyond the elastic limit.

• It is desirable that at least top 50 cm layer of the subgrade soil is well compacted under controlled conditions of optimum moisture content and max. dry density.

• The common strength tests for the evaluation of soil subgrade are:

- ⇒ California bearing ratio test
- ⇒ California Resistance value test
- ⇒ Triaxial Compression test
- ⇒ Plate bearing test

2) Sub-base and Base Courses and their evaluation:

• These layers are made of broken stones, bound or unbound aggregate.

• Smaller size graded agg. or soil agg. mixes or soft agg. is better to use due to interlocking property, so do not sink in the weak subgrade soil when wet.

• When the subgrade consists of fine grained soil and when the pavement carries heavy wheel loads, there is a tendency for these boulder stones or bricks to penetrate into the wet soil resulting uneven pavement surface.

• Base course and sub-base courses are used under flexible pavement primarily to improve the load supporting capacity by distributing the load through a finite thickness.

• They have main function to provide a stress transmitting medium to spread the surface wheel loads to prevent shear and consolidation deformations.

Plate bearing, CBK 06 Stabilometer test are p

3) Wearing Course and its evaluation: →

- The purpose of the wearing course is to give a smooth riding surface that is dense.
- It resists pressure exerted by tyres and take up wear and tear due to traffic.
- It also offers a water tight layer against the surface water infiltration.
- In flexible pavement, normally a bituminous surfacing is used as a wearing course.
- In rigid pavement, the cement concrete acts like a base course as well as wearing course.
- There is no test for evaluating the structural ability stability of the wearing course.
- Plate bearing test & Bankman Beam tests are also sometimes made use of for evaluating the wearing course and the pavement as a whole.

* Design Factors:

* Factors to be considered in Design of Pavements:

- Pavement design consists of two parts:-
 - (i) mix design of materials to be used in each pavement component layer.
 - (ii) thickness design of the pavement and the component layers.

The various factors to be considered for this are:

- (i) Wheel load design (ii) Subgrade soil
- (iii) Climatic factors (iv) Pavement component materials
- (v) Environmental factors
- (vi) Special factors in the design of diff. types of pavements.

• The thickness design of pavement primarily depends upon the design wheel loads. Higher wheel load needs thicker pavement, provided other design factors are same.

• The properties of the soil subgrade are imp. in deciding the thickness requirement of pavements. A subgrade with lower stability requires thicker pavement to protect it from traffic loads.

• Among the climatic factors, rain-fall affects the moisture conditions in the subgrade & pavement layers. The daily and seasonal variations in temp. has significance in the design and performance of rigid pavements and bituminous pavements.

• The stress distribution char. of the pavement component layers depend on char. of the materials used. The fatigue behaviour of these materials and their ~~char.~~ durability under adverse conditions of weather should also be given due consideration.

Materials
The environmental factors such as ht. of embankment and its foundations details, depths of cutting, depth of subsurface water table etc. affect the performance of the pavement.

Design of Flexible Pavements

Following are the some imp. methods:-

- (i) Group index (ii) California Bearing Ratio
- (iii) California Resistance Ratio Value or Stabilometer
- (iv) Triaxial test (v) McLeod (vi) Burmister

Group index — Grain Size Analysis (Plastic limit etc.)
CBR — Done (with IRC guidelines)
Triaxial — done in SM

(ii) California Resistance Value or Stabilometer Method :-

- F.M. Hveem and R.M. Carmany in 1948 provided design method based on stabilometer R-value and cohesionometer C-value.
- The stabilometer consists of a cylindrical mould which can accommodate a specimen 10 cm dia. & 6.25 cm ht. resting over a rigid metal cylinder.
- The specimen is encased in the rubber membrane which acts as an inner wall of the mould.

diagram-P.No. -324

- Fluid pressure can be applied through the membrane.
- The confining fluid pressure-is applied by rotating a handle and is measured by a pressure gauge.
- The vertical pressure is applied through the loading head placed on the loading machine.

The Stabilometer and Cohesionmeter value are calculated by

$$S = \frac{22.2}{\frac{P_h - D_2}{P_v - P_h} + 0.222}$$

Here,

S = Relative Stability

P_v = Vertical Pressure at 28 kg/cm² or Total load of 2268 kg

P_h = Hor. pressure corresponding to $P_v = 28 \text{ kg/cm}^2$

D_2 = Displacement on Specimen

$$C = \frac{L}{w(0.2H + 0.0176H^2)}$$

Here,

C = Cohesionmeter value

L = wt. of shots in gm

w = dia. or width of specimen (cm)

H = ht. of specimen (cm)

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The Stabilometer resistance R-values is determined by placing the specimen in the stabilometer and applying the lateral and vertical pressure. The R-value of soil is calculated by:

$$R = 100 - \frac{100}{\frac{2.5}{D_2} \left(\frac{P_v}{P_h} - 1 \right) + 1}$$

Here,

P_v = Ver. Pres (11.2 kg/cm²)

P_h = Hor. Pressure corr. to $P_v = 11.2$ kg/cm²

D_2 = displacement of stabilometer fluid

al

(V) McLeod Method :-

kg/cm²

- Norman W. McLeod through Canadian Department of Transport conducted extensive plate bearing tests on airfield & highway pavements & developed a design method.
- From plate load tests

$$T = K \cdot \log_{10} \frac{P}{S}$$

Here, T = thickness reqd. of gravel base (cm)

P = Gross wheel load (kg)

K = Base Course constant

It is found that the base course constant K depends on the loaded area.

(vi) Burmister's (Layered System) Method :->

• Donald M. Burmister developed the layered system analysis.

• Following are the assumptions:

(i) the materials, in the pavement layers are isotropic, homogenous and elastic.

(ii) the surface layer is infinite in hor. direction and finite in vertical direction.

(iii) the layers are in continuous contact; the top layer is free of shearing and normal stresses outside the loaded area.

The displacement eqs are,

For flexible Plate, $\Delta = 1.5 \frac{P_0}{E_s} \cdot F_2$

For rigid Plate, $\Delta = 1.18 \frac{P_0}{E_p} \cdot F_2$

For single layer, $h=0$, & $\frac{E_s}{E_p} = 1$ / $F_2 = 1$

Unit-II

Rigid Pavements Design

☒ Westergaard's theory:→

- Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil subgrade, which is assumed as a dense liquid.
- Here it is assumed that the upward reaction is proportional to the deflection i.e. $P = k \Delta$, where the constant k is defined as modulus of subgrade reaction. The unit of k is kg/cm^2 per cm deflection

i.e. kg/cm^3

$k \propto \text{displacement } (\Delta = 0.125)$

$$k = \frac{P}{\Delta} = \frac{P}{0.125} \text{ kg/cm}^3$$

A/ this theory, Relative Stiffness Radius is

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

Here, l = Relative Stiffness Radius

E = Modulus of elasticity of cement concrete, kg/cm^2

μ = Poisson Ratio for concrete = 0.15

h = Slab thickness, cm

k = Subgrade modulus, kg/cm^3

The stresses acting on a rigid pavement are:

- (i) wheel load stresses
- (ii) temperature stresses

(i) Wheel load Stresses:-

A.T. Goldbeck formula for stress due to corner load is given by:

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

Here, S_c = Stress due to corner load, kg/cm^2

P = Corner load assumed as a concentrated point load, - kg

h = thickness of slab, cm

Westergaard's Stress equation:-

The cement concrete slab is assumed to be a homogeneous, thin elastic plate with subgrade reaction being vertical and proportional to the deflection.

Interior Loading,

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

Edge Loading,

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

are:

corner Loading,

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

Here,

S_i, S_e, S_c = Max. Stress at interior, edge and corner loading resp., 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

ted

(ii) Temperature Stresses:->

- Temp. stresses are developed in cement concrete pavement due to variation in slab temp.
- The variation in temp. across the depth of the slab is caused by daily variation whereas an overall increase or decrease in slab temp. is caused by seasonal variation in temp.
- During the day, the top of the pavement slab gets heated under the sun light when the bottom of the slab still remains relatively colder.
- The max. diff. in temp. b/w the top & bottom of slab cause ~~warp~~ or bend.
- Warping stresses are developed late in the evening.
- During summer season, as the temp. of the slab

increases, the concrete pavement expands towards the expansion joints.

- Due to frictional resistance at the interface, compressive stress is developed at the bottom of the slab, as it tends to expand.
- Frictional stresses are developed due to seasonal variation in temp.

* Critical load Position :->

There are three typical locations, where differing conditions of slab continuity exist.

Interior Loading: When load is applied ^{In the interior} on an edge ^{all edges} of the slab at any place remote from a corner.

Corner Loading: When the centre of load app. is located on the bisector of the corner angle formed by two intersecting edges of the slab, and the loaded area is at the corner touching the two corner edges.

Edge Loading: When load is applied on an edge of the slab at any place remote from a corner.

✶ Critical Combination of Stresses :-

Following conditions are considered to provide the critical combinations:

(i) During Summer:-

The critical combinations at interior and edge regions during mid day occur when the slab tends to warp downward. During this, max. tensile stress is developed at the bottom fibre.

(ii) During Winter:-

The critical combination of stresses at the above regions occurs at the bottom fibre when the slab contracts and the slab warps downward during the mid day. The frictional stress is tensile during contraction.

(iii) At corner region the critical combination occurs at the top fibre of the slab, when the slab warps upwards during the mid nights. There is no frictional stress at the corner region.

The critical Stress Combination =
(load stress + warping stress + frictional stress)
at edge & corner region
= (load stress + warping stress) at corner region

✳ Spacing of expansion joints: →

- The width or the gap in expansion joint depends upon the length of slab.
- Greater the distance b/w the expansion joints, the greater is the width reqd. of the gap for expansion.
- The dannels would develop high bending and bearing stresses with wider openings.
- It is recommended not to have a gap more than 2.5 cm in any case.
- The IRC has recommended that the max. spacing b/w expansion joints should not exceed 140 m for rough interface layer.

$$\delta' = L_e C [T_2 - T_1]$$

where,

δ' = Max. expansion in a slab

L_e = Length of slab

T_2, T_1 = Temp.

C = Thermal expansion of concrete

The joint filler may be assumed to be compressed upto 50% of its thickness and therefore, the expansion joint gap should be twice the allowable expansion in concrete i.e. $2\delta'$.

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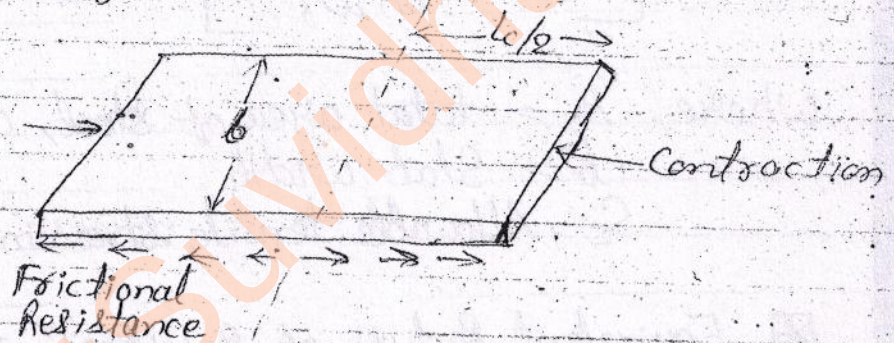
L_e
i.e.

The spacing of expansion joint is given by

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

✳ Spacing of Contraction joints: →

- The slab contracts due to the fall in slab temp. below the construction temp.
- This movement is resisted by the subgrade drag or friction b/w the bottom fibre of the slab and the subgrade.



Total frictional resistance upto $L/2$
 $= W \times b \times (L/2) \times (h \times 100) \times f$

Allowable tension in cement concrete
 $= S_c \times h \times b \times 100$

Equating both eqns, we get

Length of slab to resist the frictional drag
i.e. spacing of contraction joints

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

where, L_c = Slab length or spacing b/w contraction joints, m

h = Slab thickness, cm

f = Coefficient of friction = 1.5

W = Unit wt. of cement concrete = 2400 kg/m^3

S_c = allowable stress in tension = 0.8 kg/cm^2

When Reinforcement Provided,

$$W \times b \times \frac{L_c}{2} \times \frac{h}{100} \times f = S_s A_s$$

$$\text{or, } \left[L_c = \frac{200 S_s A_s}{b h W f} \right]$$

where, A_s = total area of steel, cm^2

b = Slab width

S_s = Allowable tensile stress in steel = 1400 kg/cm^2

☒ Equivalent Radius of Resisting Section:->

• In the case of interior loading, the max. bending moment occurs at the loaded area and acts radially in all directions.

• According to Westergaard, the equivalent radius of resisting section is approximated, in terms of radius of load distribution and slab thickness,

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

reaction

Here, b = equivalent radius of resisting section (cm):
when ' a ' is less than $1.724h$

a = Radius of wheel load distribution, cm

h = Slab thickness, cm

when ' a ' is greater than $1.724h$, the value of $b = a$

kg/m^3

kg/cm^3

* Joints :-

1) Transverse Joints :-

- (a) Expansion joints (b) Contraction joints
- (c) Warping joints (d) Construction joint

2) Longitudinal joints :-

Following are the requirements of a good joint:-

- (a) Joint must move freely
- (b) Joint must not allow infiltration of rain water and ingress of stone grits
- (c) Joint must not produce out the general level of the slab.

kg/cm^2

moment
all

actual

f

ress,

Arrangement of joints :-

- (a) Staggered arrangement
- (b) Uniform arrangement
- (c) Skew arrangement