Unit - 5

PAVEMENT DESIGN

The surface of the roadway should be stable and non-yielding to allow the heavy wheel loads of road traffic to move with least possible rolling resistance. The road surface should also be even along the longitudinal profile to enable the fast vehicles to move safely and comfortably at the design speed. At high moisture contents, the soil becomes weaker and soft and starts yielding under heavy wheel loads.

Requirements of Highway pavements :-

The highway pavements are designed and constructed such that road vehicles are able to travel at the design speed without feel discomfort to the occupants and also the pavement structure remains stable. The highway pavements have to fulfil two major requirements namely.

1. Functional requirements from the point of view of road users.
2. structural requirements from the point of view of the highway Engineers.

The functional requirement of roadway pavement generally limited to the roadway surface conditions. The surface.

1) Should be firm and non-yielding under the wheel load
2) Should have good "riding quality".
3) Should be less slippery.

Structural Requirements of Road pavements :-

The structural design of the pavement is to be carried out considering the various design factors related to the traffic, soil type, drainage, climate and Environmental factors and the desirable design life.

The pavement structure typically consist of the following layers.

ⓐ prepared soil subgrade
ⓑ Granular sub-base course (Drainage layer)
ⓒ Base course
ⓓ Surface course.

Types of pavement Structures :-

Based on the structural behaviour road pavements are generally classified into two categories.

1) Flexible pavements
2) Rigid pavements.

Flexible pavements :-

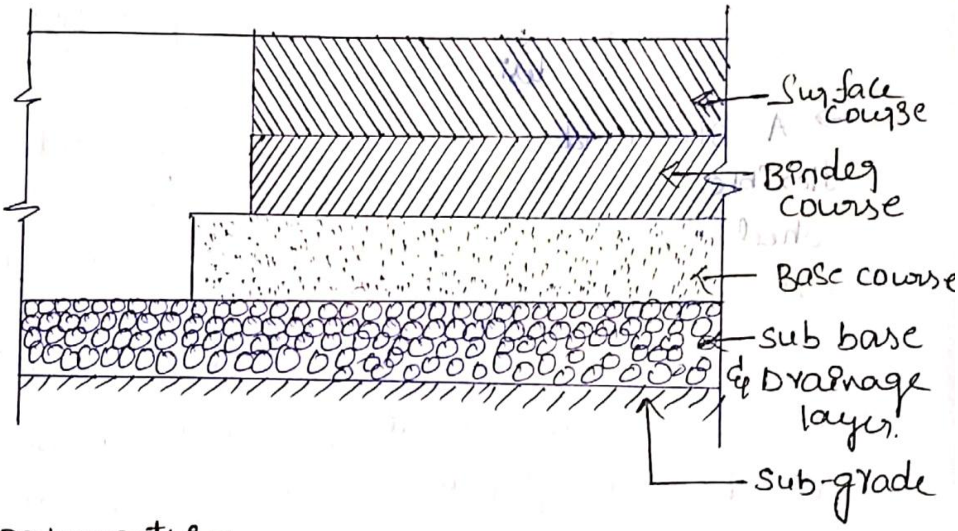
These are having low (or) negligible flexural strength and are rather flexible in their structural action under the loads. The flexible pavement may be constructed consisting of a number of layers and the top layer has to be the strongest as the highest compressive stresses are to be sustained by this layer in addition to the wear and tear due to the moving traffic and the varying factors due to the weather.

The lowest layer consist of selected soil which is impacted to the required thickness and density and is called the "Subgrade" which is laid over

Prepared / Compacted local soil (or) fill.

- Each of the flexible pavement layers above the subgrade viz, subbase, base course and the surface course may consist of one (or) more no. of layers of the same (or) slightly different materials and specifications.

The flexible pavement structure is usually design for a life of 15 years (or) more, but will need resurfacing (or) strengthening layers to be added / laid periodically surface depending on the functional and structural deterioration or damages caused due to the combined effect of traffic and weather.



Rigid pavements :-

Rigid pavements are those which possess noteworthy or significant flexural strength (or) flexural rigidity. The rigid pavements are generally made of portland cement concrete and are therefore called "C.C pavements".

Plain cement concrete pavement slabs made of specified strength characteristics are laid with (or) without steel reinforcement at the joints. Most common material used for the design and construction of rigid pavements is high.

Quality plain cement concrete meant for the pavement generally called "pavement Quality concrete" (PQC). The C.C. Pavement slabs made of PQC are generally expected to sustain upto 45 kg/cm² of flexural stresses.

In rigid pavements the stresses are not transferred from grain to grain to the lower layers as in the case of flexible pavement layers.

The c.c pavements are usually designed and constructed for a design life of 30 years (or) even higher period.

Advantages of flexible pavements:-

→ flexible pavements are generally designed and constructed for a design life of 15 years.

→ A standard design wheel load is made use of for flexible pavement design. The combined effect of wheel loads of different magnitudes, their repetitions and growth rate are taken into account in the design in terms of cummulative Standard Axles (CSA)

→ The functional elevation studies can be carried out at desired intervals and the deteriorated functional conditions of the road surface can be restored with a thin bituminous resurfacing layer

→ The structural elevation studies of the flexible pavement can be carriedout periodically and the flexible pavement structure can be strengthened by laying an appropriately designed overlay.

→ The curing period for bituminous surface course is less and hence the surface can be opened to traffic within 24 hours.

Disadvantages of flexible pavements :-

→ These are having poor drainage so that if the surface Exposed to stagnout water the pavement get deteriorated.

→ It is essential to carryout routine and periodic maintenance of the drainage system, shoulders and pavement surface.

→ It is difficult or very Expensive to carryout repairs of damaged bituminous pavements or patching of pot-holes.

→ It needs more materials to construct.

→ For longer life the life cycle cost is more.

→ Night visibility of bituminous surface is very poor.

Advantages of Rigid or C.C pavements :-

→ These are do not get damage under wet weather conditions and when Exposed to stagnent water.

→ These are designed and constructed for 30 years and more.

→ The life cycle cost is much lower.

→ The total thickness of c.c pavements and the quantity of hard aggregates required are lower than flexible.

→ Good night visibility Even under wet weather conditions.

Disadvantages of rigid pavements :-

→ It is not possible to restore a failed or badly cracked c.c pavements.

→ The surface of the c.c pavement is likely to become too smooth and slippery during the long service life.

→ Generally a long curing period of 28 days is required before opening to traffic. This may be drawback for the construction of the c.c pavement on busy urban roads.

→ It is not possible to make cross cutting of the C.C pavement.

Flexible pavement - components & their functions:-

The components of a typical flexible pavement structure from the bottom to the top consist of

1) Prepared soil subgrade
2) Granular sub-base cum drainage layer.
3) Granular base course.
4) Bituminous binder and/or surface course.

The top surface of the pavement has to sustain the highest magnitude of stresses and wear and tear due to the moving traffic loads. The surface course has also to withstand the adverse effects of rain-fall, flow of surface water and the resultant adverse effects of variations in water content and tempera-ture due to climatic conditions of the locality.

functions of soil subgrade:-

The soil subgrade is a layer of natural or selected soil from identified borrow pits fulfilling the specified requirements and well compacted in layers to the desired density to required thickness. The subgrade is the lowest layer of the pavement layer system which ultimately supports all other pave-ment component layers and the traffic loads.

The minimum thickness of compacted subgrade is 500mm on national and state highways. And 300mm for rural roads which carry low volume of traffic.

The strength tests commonly adopted for the evaluation of soil subgrade are:

1) California bearing ratio (CBR) test
2) Dynamic cone penetrometer (DCP) test.
3) Triaxial compression or direct shear test.
4) plate bearing test.

functions of granular sub-base and drainage layer:-

The granular sub-base (GSB) course has to serve as an effective drainage layer of the pavements and also has to sustain lower magnitude of compressive stresses than the base course. Therefore aggregates of lower strength having good permeability may be used in the GSB layer. Crushed stone aggregates are used for an effective drainage layer.

The GSB -cum - drainage layer is laid above the subgrade covering the full width of the formation between the longitudinal drains.

functions of granular Base course:-

The granular base course is considered as the most important component of flexible pavement layer which sustains the wheel load stresses and disperses through larger area on to the GSB layer below

A good base course Enhances the load carrying capacity of the flexibile pavement structure good quality aggregates are generally used in the granular base course of flexible pavements. The aggregates used in the base course should have low aggregate impact value (less than 30%) and low Los angles abrasion value (Less than 40%).

Functions of thin Bituminous surface:-

The thin bituminous surface course prevents the Entry of surface water into the pavement layers during the rains and thus protects the base course and other pavement layers below.

functions of thick bituminous binder and surface courses:-

Thicker layers of dense graded bituminous surface course along with a dense graded bituminous binder course are generally adopted on stretches of Expressways, National and state highway roads which carry heavy to very heavy traffic volume with a high proportion of heavy commercial vehicles.

Factors for the flexible pavement:-

Design of flexible pavement consist of two parts

1) Mix design of materials to be used in Each pavement component layer.

2) Thickness design of the pavement and the component layers.

The materials used in the pavement layer have to withstand the Expected stresses and deterioration caused by traffic loads and various other climatic and Environmental factors.

The various factors to be considered for the design of flexible pavements are given below.

(a) wheel loads of heavy vehicles or the traffic loads.

(b) subgrade soil

(c) climatic factors

(d) pavement component materials in different layers.

ⓔ Drainage and Environmental factors.

Magnitude of wheel loads:-

The thickness design of flexible pavement primarily depends upon the various factors associated with wheel loads of heavy vehicles. Higher magnitude of wheel load Obiviously need thicker pavement, provided other design factors are the same.

Wheel load and contact pressure:-

The magnitude of the wheel load (p) and the loaded area (A) are the contact pressure (p) are to be taken into account for the analysis of stresses and the stress distribution with in the pavement.

$$\therefore \text{contact pressure } (p) = \frac{\text{Load on wheel}}{\text{Contact area}} = \frac{P}{A}$$

Subgrade Soil:-

The properties of the soil subgrade and its support to the pavement layers above are important in deciding the thickness requirement of flexible pavements. All other design factors being the same, a subgrade with lower stability requires thicker pavement to protect it from the traffic loads during the design life.

climatic factors:-

The climatic variations cause the following major effects on the road pavements.

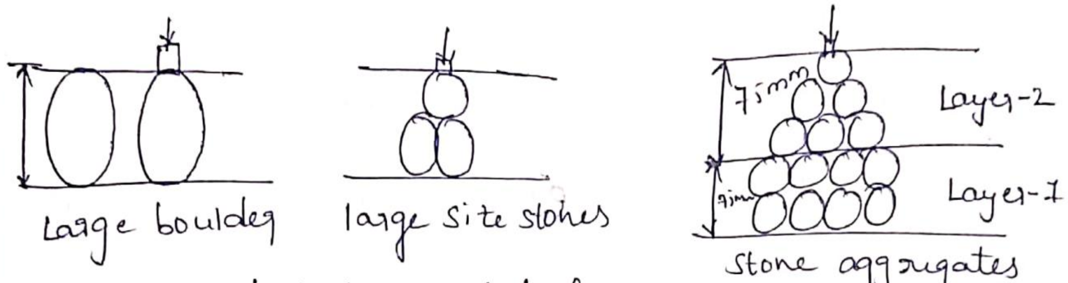
① Variation in moisture condition.

② Frost action

③ variation in temperatures

Pavement Component material :-

The soil subgrade plays the most important role as this has to ultimately support all the pavement layers laid above along with the anticipated traffic loads. The stress distribution characteristics through the granular pavement component layers depend on characteristics of materials used in these layers. The type of aggregates used, their shape factors and gradiation play important role in load dispersion characteristics of the granular base and sub-base courses.



Drainage and Environmental factor :-

The local and Environmental factors including the relative level of the subgrade with respect to adjoining land type of land use on either side of the road, height of Embankment and its foundation details, depth of cutting if any depth of subsurface water table etc;

Difference b/w Flexible and Rigid Pavement :-

S.No	Flexible Pavements	S.No	Rigid Pavements
(1)	Deformation in the subgrade is transferred to the upper layers.	(1)	Deformation in the subgrade is not transferred to subsequent layers.
(2)	Design is based on load distributing characteristics of the component layers.	(2)	Design is based on flexural strength (or) slab action.
(3)	Have low flexural strength.	(3)	Have high flexural strength.
(4)	Load is transferred by grain to grain contact	(4)	No such phenomenon of grain to grain load transfer exists.
(5)	Have low completion (Initial) cost but repairing cost is high	(5)	Have low repairing cost but completion (Initial) cost is high.
(6)	Have low life span (High Maintenance Cost).	(6)	~~Ha~~ Life span is more as compare to flexible (low maintenance cost).
(7)	Surfacing cannot be laid directly on the subgrade but a "sub base" is needed.	(7)	Surfacing can be directly laid on the subgrade.
(8)	No thermal stresses are induced as the pavement have the ability to contract and expand freely.	(8)	Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete.
(9)	[illegible]		

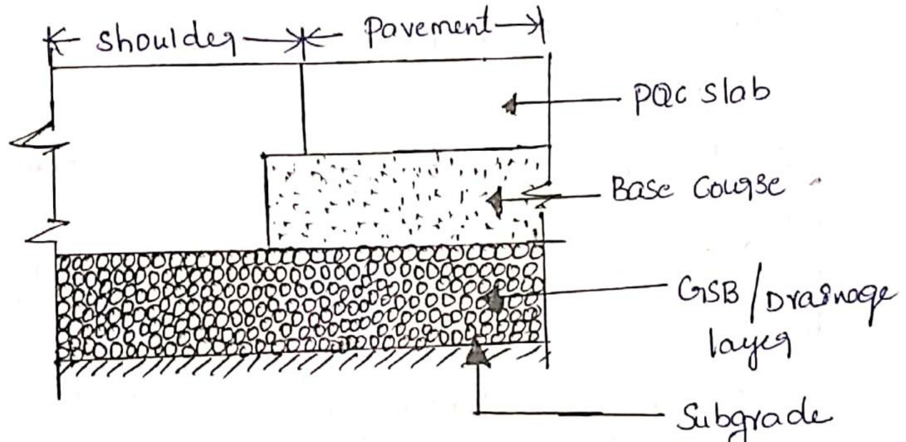
Sl.No	Flexible Pavements.	Sl.No	Rigid Pavements
(9)	Thats why expansion joints are not needed.	(9)	Thats why expansion joints are needed.
(10)	Strength of the road is highly dependent on the strength of the sub grade	(10).	Strength of the road is less dependent on the strength of the sub grade.
(11)	Rolling on the surfacing is needed	(11)	Rolling on the surfacing is not needed.
(12)	Road can be used for traffic with in 24 hours.	(12)	Road cannot be used until 14 days of curing.
(13)	force of friction is less deformation in the subgrade is not transferred to the upper layers.	(13).	Force of friction is high.
(14)	Damaged by oils and Certain chemicals.	(14)	No damage by oils and Greases.

Rigid pavements

Components of Rigid pavements:-

The components of a typical rigid pavement or Cement concrete (CC) pavement structure (from bottom to top) consists of

1. Compacted soil subgrade at the bottom or lowest layer
2. Granular sub-base (GSB) course and drainage layer
3. Base course
4. CC/ PQC pavement slab



The C.C pavement supported by a prepared soil subgrade, Sub-base and base course. As the C.C pavement slab has to withstand flexural stresses caused by moving traffic loads and warping action of the slab due to daily variation in temperatures the C.C slab is made of "high Quality cement concrete" and is commonly called "pavement Quality concrete" (PQC)

Functions of the components of CC pavement:-

Subgrade:- The Sub-grade is the lowest layer of this components of the C.C pavement which ultimately supports all other components layers and the traffic loads. If the sub-grade settles (or) yields due to inadequate compaction or any other cause different types of failures starts developing in the rigid pavement also. However a compressive stress transmitted by the rigid pavement to the top of the subgrade will be very low. The strength test commonly adopted for the ~~etc~~ evaluation of soil subgrade for rigid pavement design is "plate bearing test" using relatively large diameter plate.

Granular sub-base and drainage layer:-

The granular sub-base (GSB) course has to serve as an effective drainage layer of the rigid pavement to prevent early failures due to excessive moisture content in the subgrade soil. ~~failures due to excessive moisture content in~~ Crushed stone aggregates are preferred in the granular sub-base course as this material has high permeability and serves is an effective drainage layer.

Base course:-

The granular base course is generally provided under the C.C pavement slab in low-volume roads and also in roads with moderate traffic loads. However on roads carrying heavy to very heavy traffic loads, high quality base course, it such as "Lean cement concrete" (or) "Dry lean". "Dry lean concrete (DLC) are preferred in the base course of the C.C pavements as they are designed for a life of 1 year (or) more.

PQC pavement slab:-

M-40 cement concrete mix with a minimum flexural strength of 45 kg/cm² is recommended by the IRC for use in the C.C

pavements of highways with heavy to very heavy traffic.

The C.C pavement slab is expected to withstand the flexural stresses caused by

1. The heavy traffic loads.
2. The warping effects in the C.C slabs due to the temperature difference between top and bottom of slab.

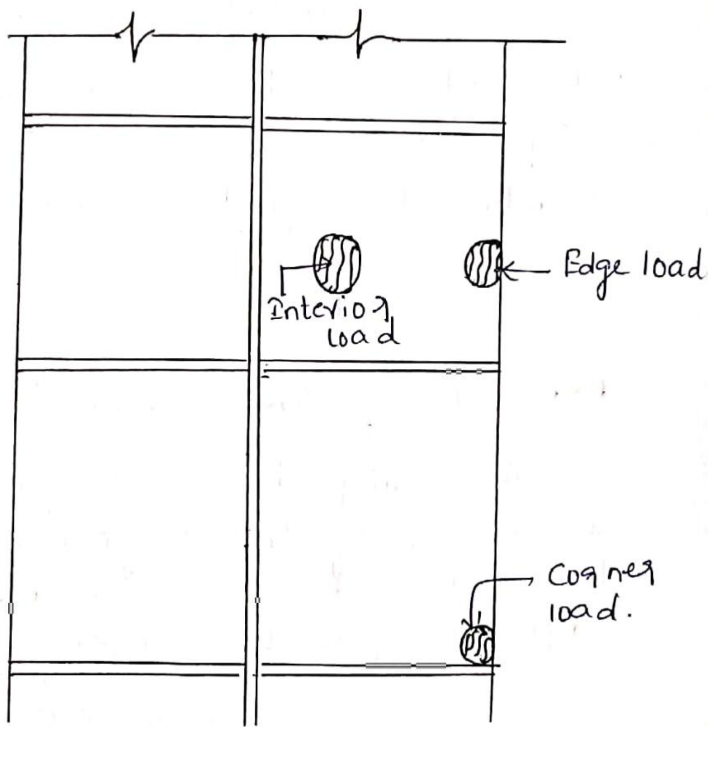
Critical Load positions :-

The pavement slab has finite length and width, either the character or intensity of maximum stress induced by the application of a given wheel load is independent on the position (or) location of the load on the pavement slab. Three typical positions namely they are followed. They were considered by westergaard with reference to this continuity of the rigid pavement slab. These are termed as "critical load positions".

when load is applied in the interior of the slab surface at any place a remote from all the edges it is called "interior loadings".

when load is applied on an Edge of the slab at any place remote from a corner it is called "Edge loading".

when the centre of load applied 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, it is called "corner loading".



Stresses in Rigid pavements :-

The major types of Stresses in C.C pavements construction of

1. wheel load stresses caused by the heavy wheel loads.
2. Warping stresses caused by temperature.

Westergaard's analysis :-

Westergaard's providing the rational approach to the analysis of stresses in rigid pavements, westergaard's in his theoritical analysis considered the rigid pavement slab to be a thin Elastic plate resting on soil subgrade which is assumed as a dense liquid.

Thus it is assumed that the subgrade provides an upward reaction P, which is directly proportional to the deflection.

$\therefore P/\Delta$ = a constant K ($K = kg/cm^3$).

K = modulus of subgrade reaction.

The Equations for determination of stresses in rigid pavement were Expressed by westergaard's using the properties such as modulus of sub grade reaction - K,

Radius of relative stiffness - l

Equivalent radius of resisting section - b

The Critical position of the wheel loadings are also considered.

Modulus of subgrade reaction :-

$$K = \frac{P}{\Delta} = \frac{P}{0.125} \ kg/cm^2$$

Radius of relative stiffness :-

A certain degree of resistance to slab deflection is offered by the subgrade. The relative stiffness of the slab with respect to the subgrade support is dependent upon the properties of the slab.

∴ Radius of relative stiffness 'l' $= \left[\dfrac{Eh^3}{12K(1-\mu^2)}\right]^{1/4}$

h = slab thickness, cm.

E = Modulus of Elasticity kg/cm²

μ = Poisson's ratio for concrete 0.15.

K = Modulus of Subgrade reaction kg/cm³

Equivalent radius of resisting section (b):-

Considering the case of interior loading the maximum bending moment occurs at the loaded area and acts radially in all directions. According to westergaard's the Equivalent radius of resisting section is approximated in terms of radius of load distribution and slab thickness.

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

b = Equivalent radius of resisting section, an(when a is less than $1.724h$)

Radius of wheel load distribution cm.

slab thickness, cm.

where; a is greater than $1.724h$, the value of $b = a$.

Stresses due to wheel loads:-

In westergaard's theoritical analysis of stresses in rigid pavements, the cement concrete slab is assumed to be a homogeneous, thin elastic plate with subgrade reaction being vertical and proportional to the deflection.

Load stress, S_i due to interior loading:-

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

Load stress, S_e due to Edge loading:-

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

Load stress, S_c due to corner loading:-

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

S_i, S_e, S_c = Maximum stress at interior, Edge and corner regions of the slab respectively due to applied load P kg/cm²

h = Slab thickness.

P = wheel load kg.

a = Radius of wheel load distribution, cm.

l = Radius of relative stiffness, cm

b = Radius of resisting section cm.

Maximum stress produced by a wheel load at corner does not exist around the load, but it occurs at some distance x - along the diagonal. This distance x - ~~for~~ from the corner is given by the refraction.

$$x = 2.58\sqrt{al}$$

Types of joints in c.c pavements and their functions:-

Joints form an important component of c.c pavement and they have important functions to perform. Different types of joints are provided in c.c pavements in order to relive of the stresses developed due to the temperature variations on the slabs.

The joints in CC pavements are broadly classified as:

(a) Longitudinal joints

(b) Transverse joints.

The transverse joints are further subdivided as.

i) Expansion joints

ii) contraction joints

iii) construction joints.

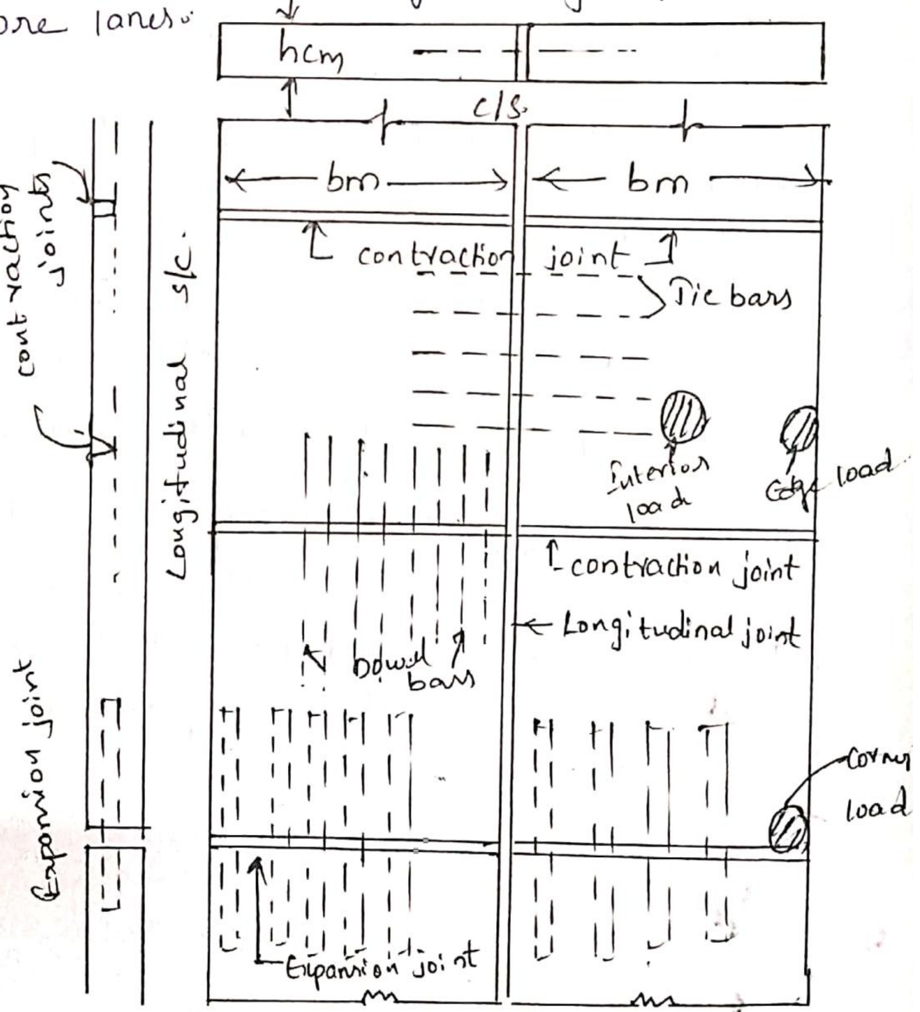
Longitudinal joints :-

Shrinkage cracks generally develop in C.C pavements slabs supported on the base course during the intial period of curing, when the length (or) width of the slabs Exceeds 4.5 to 5.0m. Therefore in pavements of width more than 4.5 m, there is a need to provide a longitudinal joint, However the lane width of highway permanent are generally 3.5m to 3.75m, longitudinal joints of c.c pavements are provided between Each traffic lane. The longitudinal joints functions as:

i) contraction joints and prevent development of conditional shrinkage cracks in the longitudinal direction.

ii) warping joints and relieve part of warping stress.

iii) Lane demacration /markings in highways with two or more lanes.



Layout of different joints in c.c pavements

Transverse joints:-

Three types of transverse joints are provided in c.c pavements. They are

ⓐ contraction joints
ⓑ Expansion joints
ⓒ construction joints.

Contraction joints:-

The contraction joints are formed by cutting grooves of width not less than 3mm and depth about 25 to 30% of the pavement thickness. So that the fine shrinkage crack is formed below each groove at the weakend section during the initial period of curing of the pavement. These dummy groove type contraction joints are formed in transverse direction of c.c pavement slabs at about 4 to 5m.

In order to prevent widening of these fine shrinkage cracks. Steel reinforcement may be provided across the contraction joints. If these dummy contraction joints are formed without inserting steel reinforcement rods during construction, the pavement is called "plain jointed concrete pavement".

closely spaced construction joints help to relieve part of the warping stresses developed due to temperature differential between the top and bottom of the c.c pavement slab.

Design of Dowel Bars :-

Objectives of dowel bars :-

Expansion joints and construction joints are formed as through joints across the full depth of the slab. A small gap of about 20mm is provided at expansion joints to allow for expansion of long C.C pavement slabs during summer season. This gap or joint width helps to relive the compressive stresses during expansion and also helps to prevent buckling of the slab near the joint. Steel dowel bars are embeded at mid depth during construction as specified in the design in order to strengthen these weak locations and to provide desired load transfer to the adjoining slab.

Functioning :-

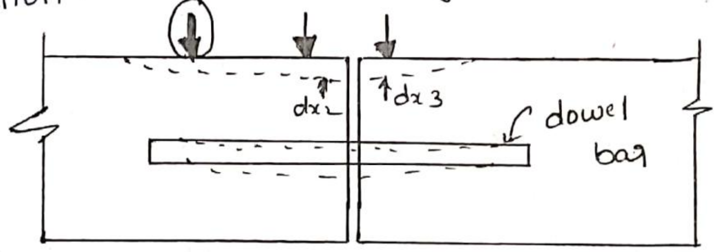
When wheel load is placed at the edge of the slab adjoining the expansion joint, a part of the deflection and load are transferred across to the adjoining slab with the help of a group of dowel bars.

Rounded steel bars of diameter 25 to 32mm, and length about 500mm are placed at intervals of 250mm to 300mm as per the design. About 50mm less than half length of the rounded steel dowel bars are embeded during concreting along one slab, so as to develop bond with the concrete. The other half length of the dowel bars (plus 50mm) are covered with a suitable plastic sheating to prevent development of bond b/w, the dowel bars and the concrete of the adjoining slab. This de-bonded half length of the dowel bars can slide into the adjoining slab.

Expansion Joint :-

During the hot season of the year the cc pavement slabs expand due to overall increase in temperature of pavement. Similarly during cold season they contract. Therefore in order to accomodate the variation in length of c.c pavement at fairly long intervals after a number of contraction joints. The expansion joints are formed as through joints across the full depth of the slab with about 20mm gap between the two slabs.

Thus the cc pavement slab is separated across the expansion joint and therefore there is no load transfer across the expansion joint, resulting in weak c/s of c.c pavement across these joints. In order to strengthen these locations of the c.c pavement slab and to provide load transfer across the expansion joint, suitable steel "dowel bars" are designed and installed during construction.



Construction joints :-

During the construction of cc pavements when the concreting work is stopped due to any other reason, a construction having is suspended due to any other reason, a construction joint is formed. As the construction joints are formed as through joints across the full depth of the slab, it is necessary to provide suitably designed "dowel bars" for load transfer.

Maximum bearing stress :-

- The bearing stress between concrete and dowel bar depends mainly on diameter of the dowel bar and spacing between them. The maximum bearing stress between the concrete and the dowel bar is given by the Equation.

$$\boxed{S_{bm} = M_e P_t (2+\beta z)/4\beta^3 E_s I}$$

S_{bm} = Maximum bearing stress b/w concrete & dowel bars

M_e = Modulus of dowel-concrete interaction on the dowel support.

P_t = maximum load transferred by dowel bar.

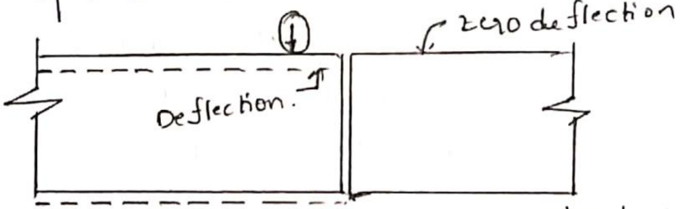
b = diameter of rounded dowel bar.

z = joint width.

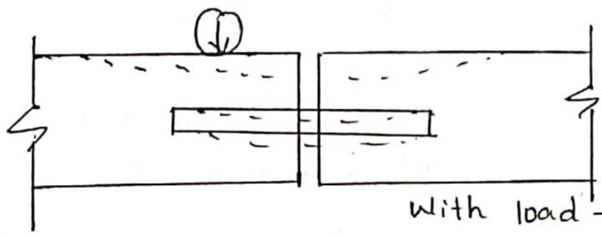
E_s = Modulus of Elasticity of the steel dowel $= 2\times10^6$ kg/cm^2

I = Moment of Inertia of the dowel bar.

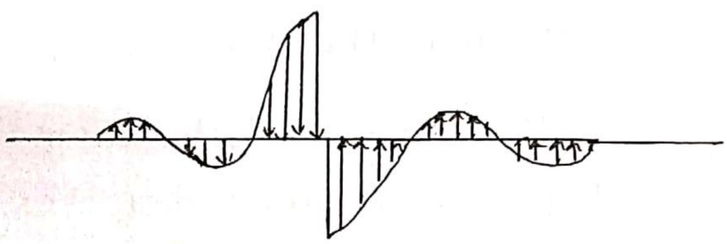
β = relative stiffness of the dowel bar $= (M_e b / 4 E_s I)^{0.25}$



Without dowel bar



With load transfer dowel bar



Load diagram for dowel bar

Allowable bearing stress :-

The bearing stress in concrete depends upon the ultimate strength of concrete and the diameter of the dowel bar

$$\boxed{F_b = F_{cs}\,(10.16 - b)\,/\,9.525}$$

F_b = allowable bearing stress in concrete
F_{cs} = ultimate compressive strength of concrete
b = dia of dowel bar.

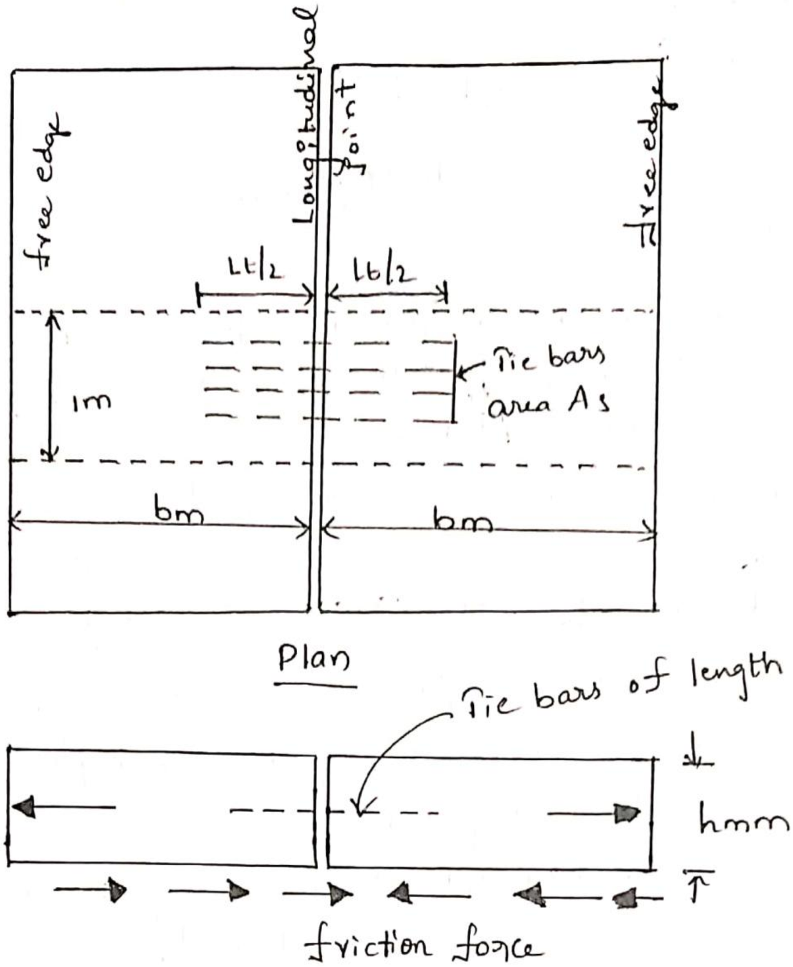
Design of TIE Bars :-

Objectives of tie bars :-

Tie bars are used across the longitudinal joints of cement concrete pavements. Tie bars are embeded at mid depth during concreting ensure the two adjacent slabs on their side of the longitudinal joint to remain firmly together and to prevent opening up of the joint. The longitudinal joints with tie bars act as hingers and help to relieve part of warping stresses in C.C pavement. The tie bars are not designed to act as load transfer devices.

The tie bars are thus designed to withstand tensile stresses. The maximum tensile force in tie bars being equal to the force required to over come frictional force between the bottom of the pavement slab and the base course.

The force is estimated between the longitudinal joint higher consideration and the adjacent joint or free edge.



Area of cross-section steel tie bars:-

The weight per metre length of the pavement slab of unit weight w kg/m^3, width Bm, and thickness h cm = $\frac{Bhw}{100}$ kg.

If the friction co-efficient b/w the bottom of the slab and the base course is f, the frictional force developed per 'm' length to pull the C.C pavement slab = $\frac{Bhwf}{100}$ kg.

The total frictional force per 'm' length is to be resisted by the steel tie bars of cross section area.

As cm, if the permissible tensile stress in steel is Ss kg/cm^2, the total force in tie bars per 'm' length = $A_s S_s$

$$\therefore A_s S_s = Bhw f / 100$$

$$A_s = Bhw f / 100 S_s$$

Length of tie bar:-

The bond strength developed along the periphery of each tie bar up to the embeded length of each side of the concrete slab has to be equal to or more than the tensile force developed in the tie bar. Therefore the total length 'Lt' of tie bar should be atleast twice the embeded length.

$\therefore$ The total length of the bar = Lt cm.

The bond stress developed = S_b kg/cm^2

diameter = d cm

The embeded peripheral area of a tie bar on one slab = $\pi d \, Lt/2$

Total bond force developed in each half of the tie bar = $S_b \dfrac{\pi d Lt}{2}$

The tensile force developed in each tie bar of diameter 'b' cm = $\dfrac{S_b \pi d^2}{4}$

$\therefore$ The tensile force developed in each tie bar may be equated to the bond force developed on each embeded half length of the tie bar.

$$\frac{S_s \pi d^2}{4} = \frac{S_b \pi d . Lt}{2}.$$

$\therefore$ Minimum length of tie bar

$$Lt = d S_s / 2 S_b.$$

Recommended dimenssions and Spacing of tie bars:-

The recommended diameter of tie bars for C.C pavements of thickness more than 25cm are 12 and 16mm. The minimum length of deformed bars are 64 and 80 cm respectively. The maximum spacing between tie bars for slabs of thickness 25 and 30cm are in the range of 60 t 100cm.

Westergaad's Analysis:-

①

H.M. Westergaad is considered the pioneer in providing the rational approach to the analysis of stresses in Rigid pavements.

Westergaad in his theoretical analysis considered the rigid pavement slab to be a thin elastic plate resting on soil subgrade, which is assumed as a dense liquid. Thus it is assumed that the subgrade provides an upward reaction "p" which is directly proportional to the deflection "Δ".

$$\therefore \boxed{\frac{P}{\Delta} = k.}$$

k: modulus of subgrade reaction.

k (kg/cm³) (pressure $\frac{\text{kg/cm}^2}{\text{deflection cm}}$.

Modulus of Subgrade reaction (k):-

"k" is proportional to the displacement "Δ", taken as 0.125 cm

If "p" is the pressure sustained in kg/cm² by the rigid plate of diameter "75 cm" at a deflection Δ = 0.125 cm

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

Radius of a relative stiffness (l):-

A certain degree of resistance to slab deflection is offered by the subgrade. The tendency of the slab to deflect is dependent upon its flexural strength, which depends on its thickness and the strength characteristics of the pavement slab. The relative stiffness of the slab w.r.to the subgrade support is dependent upon the properties of the slab and the pressure - deformation characteristics of the subgrade material.

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

where l = radius of relative stiffness, cm.
h = slab thickness, cm.
E = modulus of elasticity of cement concrete kg/cm².
μ = Poisson's ratio for concrete = 0.15
K = subgrade modulus ~~cm~~ kg/cm³.

Equivalent radius of resisting section:-

In case of interior loading, the max. BM occurs at the loaded area and acts radially in all directions. With the load concentrated on a small area of the pavement the question arises as to what sectional area of the pavement is effective in resisting the B.M.

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

where

b = equivalent radius of resisting section, cm
~~[illegible]~~ when "a" is less than $1.724h$.
a = radius of wheel load distribution, cm.
h = slab thickness, cm.

when $a > 1.724h$, the value of $b = a$.

Stresses due to wheel loads:-

Load stress, "S_i" due to interior loading

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

Load stress, "S_e" due to edge loading, (3)

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

Load stress, "S_c" due to 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 = Max. stress at interior, edge and corner regions of the slab respectively due to applied load P, 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.

Location where corner load crack develops –

$$X = 2.58\sqrt{al}.$$

where X = distance from apex of slab corner to section of max. stress along the corner bisector (or) diagonal, cm.

a = radius of wheel load distribution, cm.

l = radius of relative stiffness, cm.

–x–

–x–.

Q:- Using the data given below, calculate the wheel load stresses at (a) interior, (b) edge & (c) corner regions of a C.C. pavement using "Westergaard's stress eq's". Also determine the probable location where the crack is likely to develop due to corner loading. (4)

Wheel load, $P = 5100\,kg$.

Elasticity modulus of C.C, $E = 3.0 \times 10^5\,kg/cm^2$.

Pavement thickness, $h = 18\,cm$.

Poisson's ratio of concrete, $\mu = 0.15$

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

Radius of contact area, $a = 15\,cm$.

Sol:- Radius of relative stiffness (l) $= \left[\dfrac{Eh^3}{12K(1-\mu^2)}\right]^{1/4} = \left[\dfrac{3.0\times10^5 \times (18)^3}{12\times 6(1-0.15^2)}\right]^{1/4}$

$$\boxed{l = 70.6\,cm}$$

The equivalent of resisting section $\dfrac{a}{h} = \dfrac{15}{18} = 0.833 < 1.74$

$$b = \sqrt{1.6a^2+h^2} - 0.675h = \sqrt{1.6(15)^2+(18)^2} - 0.675\times18$$

$$\boxed{b = 14.0\,cm}$$

(a) Stress at the interior -

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

$$S_i = \frac{0.316\times5100}{(18)^2}\left[4\log_{10}\left[\frac{70.6}{14.0}\right] + 1.069\right]$$

$$\boxed{S_i = 19.3\,kg/cm^2}$$