12.7.15

UNIT-III

Design of Highway Pavements

Objectives:

In order to provide a stable and even surface for the traffic, the roadway is provided with a suitably designed and constructed pavement structure.

Thus, a pavement consisting of a few layers of pavement material is constructed over a prepared soil sub-grade to serve as a Carriageway.

The pavement carries the wheel loads & transfer, the load stresses through a wider area on the soil sub-grade below. Thus, the stresses transferred to sub-grade soil through the pavement layers are considerably lower than contact pressure or compressive stresses under the wheel load on pavement surface.

The reduction in the wheel load stress due to the pavement depends both on its thickness & the characteristics of pavement layers.

Main Objective of pavement is to keep the elastic deformation of pavement within the permissible limits, so that the pavement can sustain a large no of repeated load applications during the design life.

Types of Pavement Structure

i) Flexible pavements
ii) Rigid pavements.

Flexible Pavement

- Design of flexible pavement is based on the principle that the wheel loads of vehicle are dissipated to the natural soil through successive layers of granular materials.
- The intensity of load decreases with depth as the area of dissipation is increased. Hence, the higher quality of material is placed at top.
- The strength of the sub-grade decides the th of flexible pavement.
- WBM roads, stabilised roads, earth roads, gravel roads, etc., consist of layers of road making materials, compacted to form an elastic bed, are grouped under flexible pavements.

Components of Pavements

Sub-Grade.

It is defined as the supporting structure on which the pavement surface and its special undercourses rest.

Main func is to provide sufficient support to the pavement.

Sub-grade should possess sufficient stability under adverse climate & loading conditions.

Sub-base

Economy is the prime factor to be considered in the design of sub-base course.

It is generally recommended to use locally available material for sub-base

The main purpose is to permit the construction of pavement at a low cost.

Obj ⇒

i) To add to the structural support for the over-lying layers, (i-e base & surface courses.

ii) To improve drainage.

iii) To reduce frost heave in cold weather conditions.

Base - Course

It is provide under the wearing course or pavement.

They have to satisfy the following requirements

i) Thickness should be adequate to distribute the heavy wheel load pressure gradually to the sub-grade through a sub-base.

ii) Should have sufficient structural stability so as to resist the vertical pressures & shear stresses due to moving vehicles

iii) Should have enough resistance to weathering.

iv) Should be compacted well to have sufficient density.

Wearing / Surface Course

→ This course comes into contact with the wheels of vehicles.

→ The main purpose is to resist the pressure exerted by the tyres and to be smooth, so that the vehicles will have large mileage & less wear & tear for tyres.

→ It serves as water-resistant membrane not allowing the surface water getting into the base & n't allowing the capillary water to pass through the wearing course.

→ It adds adequate strength to entire pavement structure.

Bituminous materials as surfacing in flexible pavement.

Cement concrete layer act as wearing surface.

Overlays

If the pavement surface is deteriorated due to age/ or otherwise or it is intended to increase the traffic or allow heavy vehicles, it is necessary to strengthen the pavement surface.

Strengthening is done by providing additional thickness of pavement in one or more layers over the existing pavement, which is called an overlay.

Materials used are : bituminous or cement concrete.

Rigid Pavement

The design of rigid pavement is based on the strength of the structural slab which tends to distribute the load over a wide area of soil.

The pavement slab is of portland cement concrete which has high rigidity resists the deformation of surface.

Semi-Rigid Pavement.

Cement grouted, lean cement concrete, soil cement pavement, etc. may fall under this group.

Design Factors

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

i) Design wheel load

ii) Sub-Grade Soil

iii) Climatic factors

iv) Pavement Component materials

v) Environmental factors

vi) Special factors in the design of different type of pavements.

Design of wheel load

Tk of pavement depends on the design of wheel load only.

Higher wheel load $\xrightarrow{\text{Need}}$ Tk Pavement

Various wheel load factors are

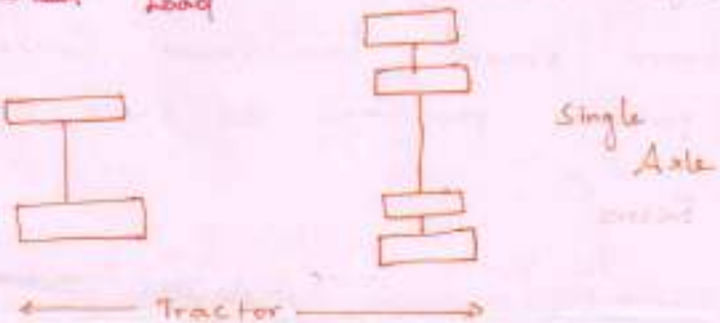
i) Maximum wheel load.

ii) Contact Pressure

iii) Dual or multiple wheel loads & ESWL.

iv) Repetition of load

Maximum Wheel Load



For highways, the maximum legal axle load as specified by Indian Road Congress is 8170kg with a max. equivalent Single wheel load of 4085 kg.

Total load $\xrightarrow{\text{Influences}}$ Tk of Pavement.

Tyre pressure $\xrightarrow{\text{Inf.}}$ quality of surface (wearing) course.

The eqn for vrl stress computations under a UDL circular load based on Bousineq's theory is given by

$$\sigma_z = p\left[1 - \frac{z^3}{(a^2+z^2)^{3/2}}\right]$$

where, σ_z → vrl stress at depth z

p → Surface pressure.

z → Depth @ which σ_z is computed.

a → Radius of loaded area.

This Value is higher than Unity for lower tyre Pressure & less than Unity for tyre pressure higher than 7 kg/cm².

R.F depends on the degree of of tension developed in the walls of tyres.

Equivalent Single Wheel Load

To maintain the maximum wheel load within the specified limit and to carry greater load it is necessary to provide dual wheel assembly to the rear axles of the road vehicles.

In doing, so the effect on the pavement through a dual wheel assembly is obviously not equal to 2 times the load on any one wheel. In other words, " The pressure at a certain depth, below the pavement surface cann't be obtained numerically adding the pressure caused by one wheel. The effect is in b/w the single load & two times load carried by any one wheel.

In order to simplify, the analysis, The load dispersion is assumed to be at an angle of 45°

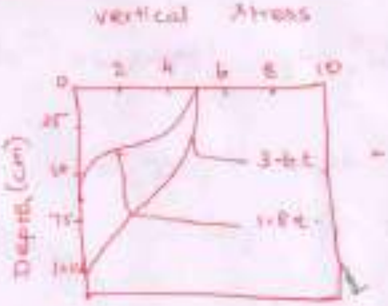
Let, d be clear gap b/w the two loads,

S be spacing b/w centres of wheels

a be radius of circular contact area of each wheel.

Then, $\boxed{S = d + 2a}$

Contact Pressure



Influence of tyre pressure is pre-dominating in the upper layers.

Tyre pressure of high magnitudes therefore demand high quality of materials in upper layers in pavements.

Sample:

The stresses on the pavement surface under the steel tyred wheels of bullock carts are very high. This demands use of very strong & hard aggregate for the wearing surface of the pavement.

Generally, the wheel load is assumed to be distributed over a circular area.

Important Terms are
- Tyre Pressure } Same
- Inflation Pressure } Same
- Contact Pressure.

$$\text{Contact Pressure} = \frac{\text{Load on wheel}}{\text{Contact Area (or) Area of imprint.}}$$

The ratio of Contact Pressure to Tyre pressure is defined as **Rigidity factor.**

Value of R.F is 1.0 for an avg tyre pressure of 7kg/cm^2

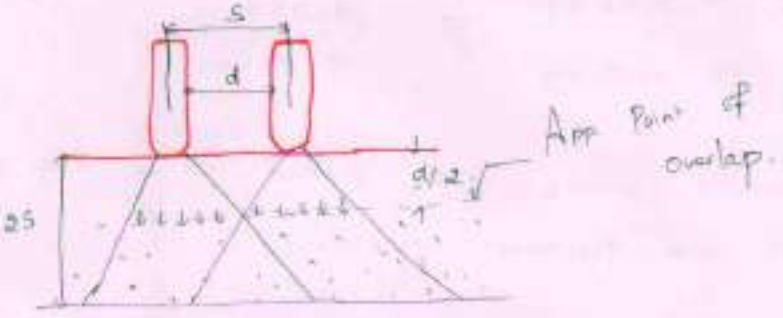


Fig: Stress Overlap due to Dual wheels.

Upto the depth of d/2 each wheel load 'P' acts independently and after this point, the stresses induced due to each load begins to overlap. At depth 2S and above the stresses induced are due to effect of both wheels as the area of overlap is considerable.

So, the ~~depth~~ total stresses due to dual wheels at any depth greater than 2S is considered to be equivalent to a single wheel load of magnitude 2P.

Pblm: Calculate ESWL of a dual wheel assembly carrying 2004 kg each for pavement th of 15, 20, 25 cms Centre - centre tyre spacing = 27 cm & Dist b/w the walls of tyres is 11 cm.

Soln:

here, $P = 2044$ kg.

$2P = 4088$ kg.

$d = 11$ cm

$S = 27$ cm

here, $P = 2044$ kg $d = 11$ cm.

$2P = 4088$ kg $S = 27$ cm.

x and y points are plotted on a log. graph b/w ESWL and pavement thickness

x has co-ordinates $(P, d/2) = (2044, 5.5)$

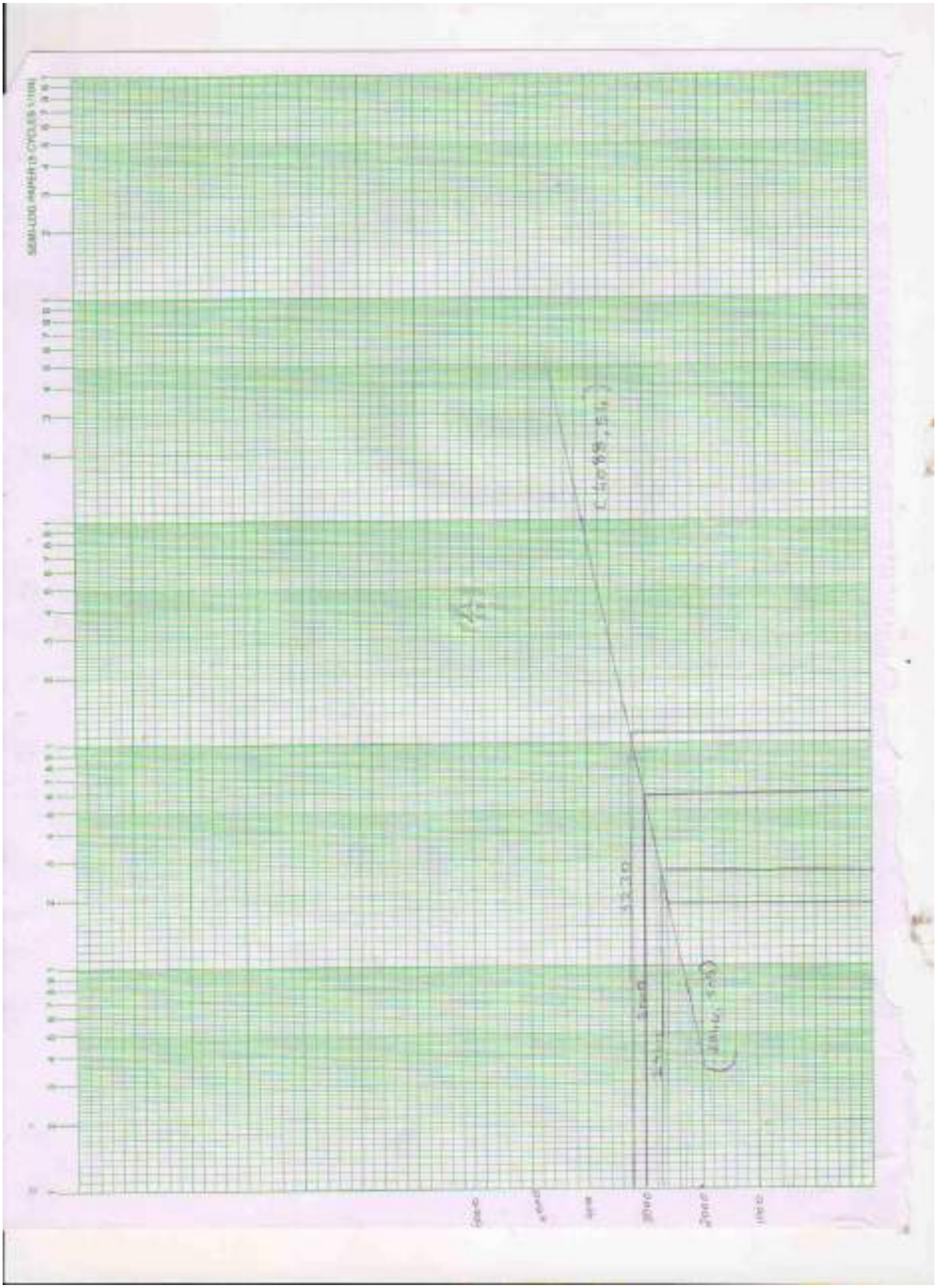
y has co-ordinates $(2P, 25) = (4088, 54)$

Pavement Thickness (cm)	ESWL (kg)
15	1760
20	2000
25	3230

Reptition of Loads

The deformation of pavement or sub-grade due to a single application of wheel load may be small. But due to repeated application of load there would be increased magnitude of plastic and elastic deformations.

Equivalent load factors are employed to convert daily traffic count for each category of wheel load for design purposes.



Equivalent Wheel Load factors

⑥

Wheel load (kg)	Repetitions to failure, (No)	Equivalent to 2268 kg	Equivalent load factors
2268	105,000	1.0	1
~~22~~ 2722	50,000	2.0	2
3175	22,500	4.5	4
3629	13,000	8.2	8
4082	6,500	16.3	16
4536	3,300	32.0	32
4990	1,700	62.0	64
5443	1,000	105.0	128.

Pblm: 2 Calculate design repetitions for 20 years, period for various wheel loads equivalent to 2268kg wheel load using the following traffic survey data on a four lane road. (Question Detail - Refer back)

Soln:

Wheel Loads (kg)	A·D·T (Both Direction)	Percentage for each Load	Days/ years	No of Years	Equivalent load factor	Design repetitions equivalent of 2268 kg Load.
2268	216 ×	13.17/100 ×	365	× 20 ×	1	= 206,703
2722	215 ×	15.3/100 ×	365	× 20 ×	2	= 480,267
3175	215 ×	11.76/100 ×	365	× 20	4	= 738,293
3629	215 ×	14.11/100 ×	365	× 20	8	= 1771,652
4082	215 ×	6.81/100 ×	365	× 20	16	= 1590,455
4536	215 ×	5.84/100 ×	365	× 20	32	= 2,933,082

(two direction) Total estimated repetitions = 77 29,452.

Design repetitions equivalent of 2268 kg wheel load per lane = 7729452/4

= 19,32,363

Wheel Load(kg)	Avg. Daily Traffic (Both Directions)	Percentage of total traffic volume
2268	Total Value (consideration traffic Growth) 215	13.17
2722		15.30
3175		11.76
3629		14.11
4082		6.21
4536		5.84

Strength Characterstics of Pavement Materials:

i) California Bearing Ratio (CBR) Value

2) Elastic moduli.

California BR

The Strength Values so obtained for the materials tested are of relative significance and do not provide as absolute measure. There are design methods which employ the CBR Strength values of materials used o different pavement layers.

Elastic Modulii

Depending upon, the design methods, the elastic moduli of different pavement materials are evaluated.

Determined by i) Plate bearing test

ii) Triaxial Compression Test.

The elastic moduli values of the following are determined by plate bearing tests:

i) Sub grade modulus

ii) Elastic moduli of base course & Sub-base course materials

The max vt deflection, Δ at the surface and the centre of a flexible plate is given by

Boussinesq's eqn

$$\boxed{\Delta = \frac{1.5\,p\,a}{E_s}}$$

Here, P → Uniform pressure on the flexible loaded plate of radius 'a'.

E_s → Modulus of elasticity of soil.

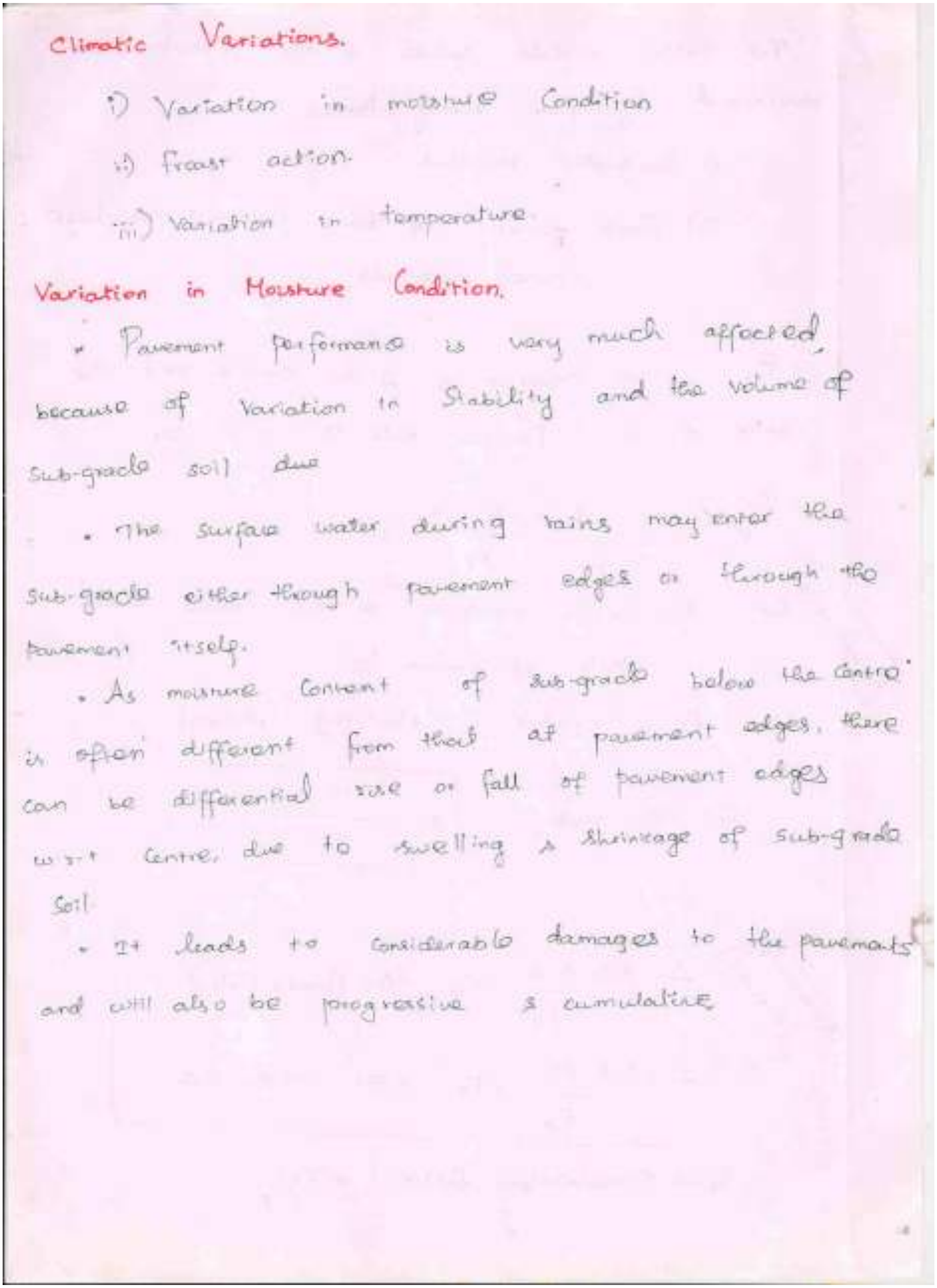
for rigid plate, $\boxed{\Delta = \frac{1.18\,p\,a}{E_s}}$

Burmister's Analysis

$$\Delta = 1.5\,\frac{p \cdot a}{E_s} \cdot F_2 \quad \text{(for flexible plate)}$$

$$\Delta = 1.18\,\frac{pa}{E_s} \cdot F_2 \quad \text{(For rigid plate)}$$

F_2 → Dimensionless factor. $= E_s/E_p$.



Climatic Variations.

i) Variation in moisture Condition

ii) Frost action.

iii) Variation in temperature

Variation in Moisture Condition.

- Pavement performance is very much affected because of Variation in Stability and the volume of sub-grade soil due

- The surface water during rains may enter the sub-grade either through pavement edges or through the pavement itself.

- As moisture Content of sub-grade below the Centre is often different from that at pavement edges, there can be differential rise or fall of pavement edges w.r.t Centre, due to swelling & shrinkage of sub-grade soil

- It leads to considerable damages to the pavements and will also be progressive & cumulative

Froast action

It refers to adverse effective due to froast heave, froast melting or thaw & alternate cycles of freezing & thawing.

The freezing & thawing which occur alternately due to variation in weather causes undulations & considerable damages to the pavement. Hence, the overall effects due to froast heave, frost melting and alternate freeze - thaw cycles is called frost action.

Depends on factors such as:

i) Froast susceptible soil.

ii) Depressed Temp. below freezing point.

iii) Supply of water.

iv) Cover.

Capillary cut-off - way to reduce the adverse effects of frost action on pavements by soil stabilization.

Variation in Temperature.

Temperature stresses of high magnitude are induced in cement concrete pavements due to daily variation in temp & consequent warping of panel

Bituminous Pavement become soft in hot weather and brittle in very Cold weather.

Design of flexible Pavements

3 Approaches
- Empirical method
  - Group index md.
  - CBR md.
  - Stabilometer
  - Mc Leod Mds.
- semi-Empirical md
- Theoretical md
  - Burmister md.
  - Triaxial method.

IRC Recommendations. CBR Test.

⇒ Performed in laboratory only.

⇒ Compaction done by Proctor Compaction Test

⇒ Top 50 cm of sub-Grade should be Compacted atleast upto 95 to 100 % of Proctor density

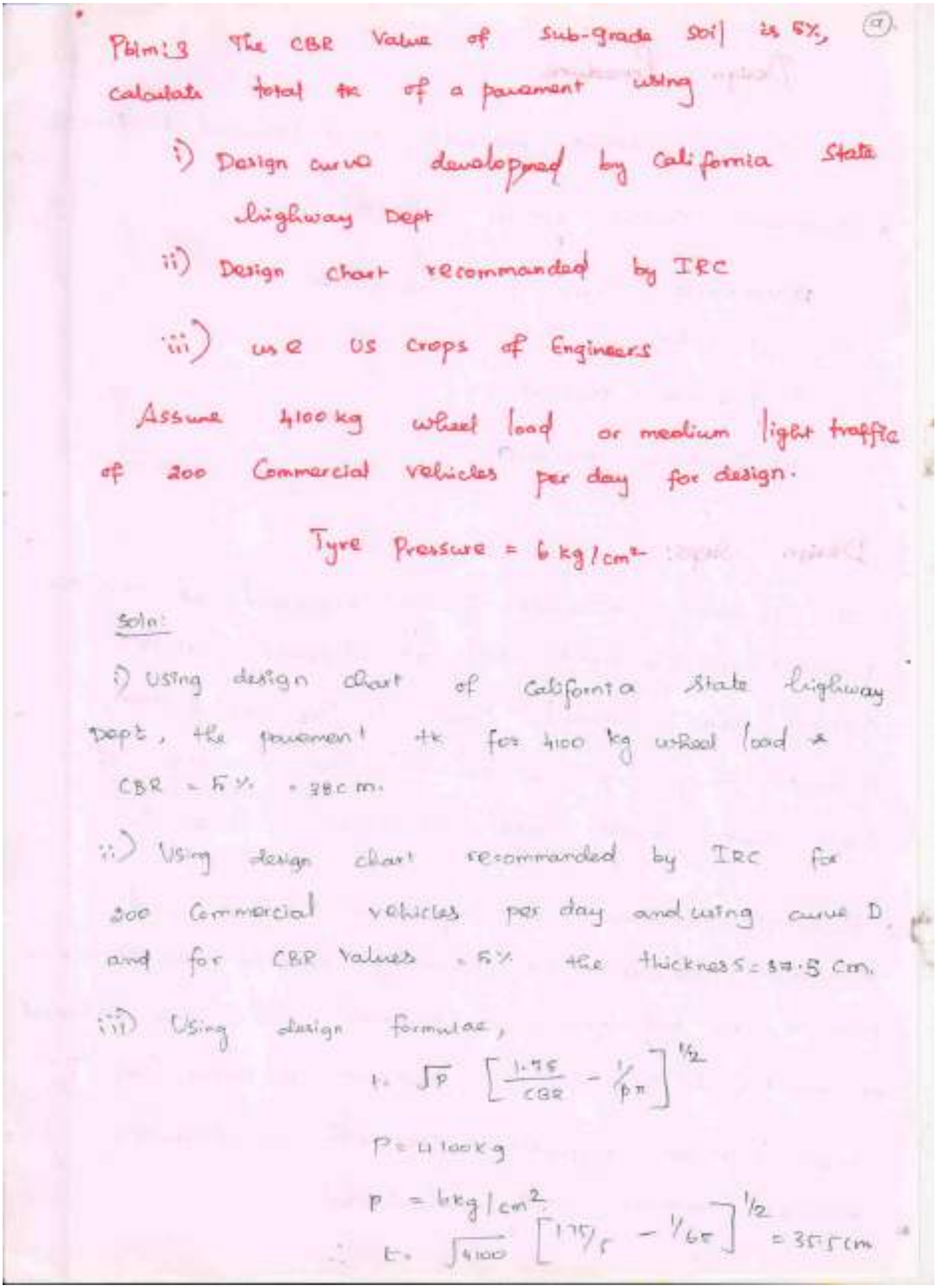
⇒ $A = P[1+r]^{(n+10)}$

where, A → no of heavy vehicles per day

P → no of heavy vehicles per day at least count.

r → Annual rate of increase of heavy vehicles

n → no of years b/w last count & Year of completion of construction



Pblm: 3 The CBR Value of Sub-grade soil is 5%, calculate total tk of a pavement using ⓐ

i) Design curve developed by California State highway Dept

ii) Design chart recommended by IRC

iii) use US crops of Engineers

Assume 4100 kg wheel load or medium light traffic of 200 Commercial vehicles per day for design.

Tyre Pressure = 6 kg/cm²

Soln:

i) Using design chart of California State highway Dept, the pavement tk for 4100 kg wheel load & CBR = 5% = 38 cm.

ii) Using design chart recommended by IRC for 200 Commercial vehicles per day and using curve D and for CBR Values = 5% the thickness = 37.5 cm.

iii) Using design formulae,

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

$P = 4100\,kg$

$p = 6\,kg/cm^2$

$$\therefore t = \sqrt{4100}\left[\frac{1.75}{5} - \frac{1}{6\pi}\right]^{1/2} = 35.5\,cm$$

Design Procedure

In this design method, it is required to provide a pavement section, which satisfies:

i) Resistance Value of Sub-Grade (R-value)

ii) Expansion pressure

iii) Exudation pressure.

Design Steps:

1. The pavement thickness values required as per the R-values of sub-Grade soil at different moisture contents are calculated (say T_{r_1}, T_{r_2} .....) Here, pavement may first be assumed to consists of single base course layer of known C-value, C_g.

2. Pavement thickness fulfilling both R-values and expansion pressure are found by dividing the expansion pressure by avg density of pavement which may assumed as about 2.1 g/cm³. the pavement tk value (say T_{e_1}, T_{e_2} ...) as per expansion pressure at different moisture contents are calculated.

iii) Pavement thickness fulfilling both R value & expansion pressure is found by plotting T_c values against Corresponding T_e values from (i) & ii) above, to the same scale, and by drawing 45° line.

iv) The exudation pressure of sub-grade soil found at various compacting moisture contents are plotted against pavement thickness found from (i) above based on corresponding R values. The pavement thickness corresponding to an exudation pressure of $28 kg/cm^2$ is obtained from this graph.

v) Pavement tk as per california design method is the higher the values determined in (iii) and (iv) above.

v:) The thickness of other pavement layers are decided & equivalent values of base course thickness replaced are Calculated using cohesiometer values of materials

Design of Rigid Pavements

Westergaard's Modulus of Sub-grade Reaction

$$K = \frac{P}{\Delta}$$

(i.e) $= \frac{P}{0.125}$ kg/cm³

Relative stiffness of slab to Sub-Grade

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

Here, l → radius of relative stiffness, cm.

E → modulus of elasticity of Cement Concrete, kg/cm².

μ → poisson's ratio for concrete

h → slab thickness, cm.

K → Sub Grade modulus, kg/cm³

Pblm: 4 Compute radius of Relative stiffness ⑪ of 15 cm thk, Cement Concrete slab from following data

Soln:

Given data:

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

$\mu \rightarrow 0{\cdot}15$

$E \Rightarrow 2{,}10{,}000\ \text{kg}/\text{cm}^2$

$k \Rightarrow 3\ \text{kg}/\text{cm}^3$

$7{\cdot}5\ \text{kg}/\text{cm}^3$

i) For $k = 3\ \text{kg}/\text{cm}^3$.

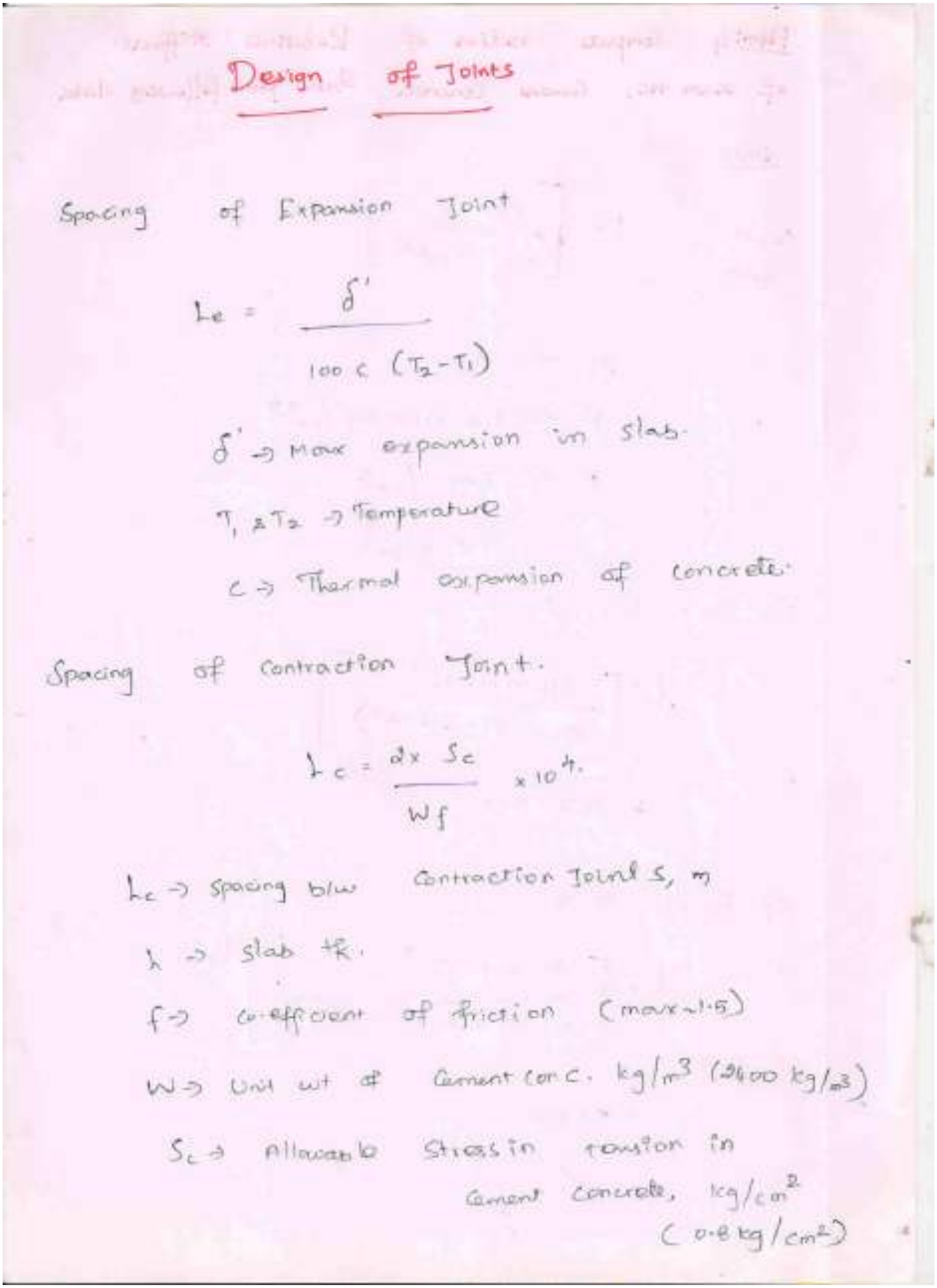
$$l = \left[\frac{210000 \times 15^3}{12 \times 3\,(1-0{\cdot}15^2)}\right]^{1/4}$$

$= 67{\cdot}0\ \text{cm}$

ii) For $k = 7{\cdot}5$.

$$l = \left[\frac{210\,000 \times 15^3}{12 \times (7{\cdot}5\,(1-0{\cdot}15^2))}\right]^{1/4}$$

$= 53{\cdot}3\ \text{cm}$



Design of Joints

Spacing of Expansion Joint

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

δ' → Max expansion in slab.

T_1 & T_2 → Temperature

c → Thermal expansion of concrete.

Spacing of contraction Joint.

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

L_c → spacing b/w contraction Joints, m

h → slab tk.

f → co-efficient of friction (max ~ 1.5)

W → Unit wt of Cement conc. kg/m³ (2400 kg/m³)

S_c → Allowable Stress in tension in cement concrete, kg/cm² (0.8 kg/cm²)

Spacing of Joints when reft provided,

$$L_c \rightarrow \frac{200\ S_s\ A_s}{b h\ w f}$$

where, A_s - Total area of steel, cm^2.

$b \rightarrow$ slab width

$h \Rightarrow$ slab thickness

$S_s \Rightarrow$ Allowable Tensile stress in steel, kg/cm^2 (1400).

Design of Dowel bar

$$L_d = 5d\left[\frac{F_f}{F_b} \times \frac{L_d + 1.5\,\delta}{L_d + 8.8\,\delta}\right]^{1/2}$$

$F_f \rightarrow$ Permissible flextural stress in dowel bar kg/cm^2

$F_b \rightarrow$ Permissible bearing stress in concrete, kg/cm^2

Pblm: 5. width of expansion Jt gap is 2.5 cm in a cement Conc. pavement. Laying temp 10°c, max slab temp in summer 54°c, calculate spacing b/w expansion Jt.

Assume $C - 10 \times 10^{-6}$ per °c.

Soln:

$$\delta' = \frac{2.5}{2}$$

$$= 1.25 \text{ cm}$$

$$T_2 - T_1 = 54 - 10$$

$$= 44°C$$

$$\therefore L_e = \frac{\delta'}{100\, C\, (T_2 - T_1)}$$

$$= \frac{1.25}{100 \times 10 \times 10^{-6} \times 44}$$

$$= 28.5 \text{ m}$$

<u>Pblm:6</u> Determine Spacing b/w Contraction Joints, for 3.5 m slab width having tk of 20 cm & f=1.5

i) for Plain Cement Conc, $S_c = 0.8 kg/cm^2$

ii) for R.C.C, 1.0 cm dia bar @ 0.3m spacing

<u>Soln:</u>

i) For P.C.C

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

$$= \frac{2 \times 0.8 \times 10^4}{2400 \times 1.5} = \underline{4.44\ m.}$$

ii) for R.C.C

$$A_s = \frac{3.5 \times \pi \times 1.0^2}{0.3 \times 4} = 9.16 cm^2.$$

$$L_c = \frac{200 \times S_s A_s}{b h w f}$$

$$= \frac{200 \times 1200 \times 9.16}{3.5 \times 20 \times 2400 \times 1.5}$$

$$= \underline{8.72 m}$$

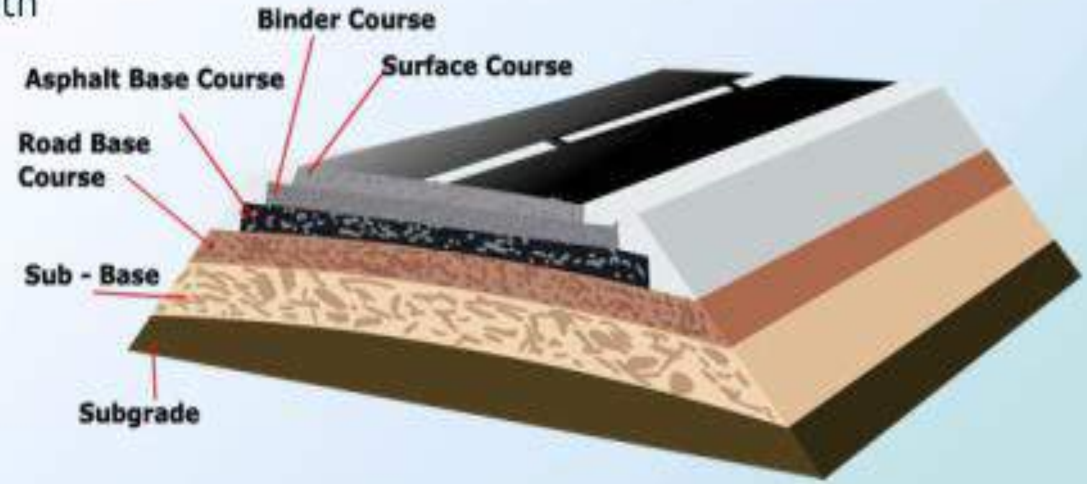
Pavement design

Introduction

- Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading
- A flexible pavement structure is typically composed of **several layers of material**
- Each layer receives the loads from the above layer, spreads them out, then passes on these loads to the next layer below
- Thus, the further down in the pavement structure a particular layer is, the less load (in terms of force per area) it must carry

Basic Structural Elements

- A typical flexible pavement structure consists of the surface course and the underlying base and subbase courses.
- Each of these layers contributes to structural support and drainage
- The surface course is the stiffest and contributes the most to pavement strength
- The underlying layers are less stiff but are still important to pavement strength as well as drainage and frost protection
- A typical structural design results in a series of layers that gradually decrease in material quality with depth



Objectives and Requirements of Pavements

Sufficient Thickness

- To distribute the wheel load stresses to a safe value on the sub-grade soil

Structurally Strong

- To withstand all types of stresses imposed upon it

Adequate Coefficient of Friction

- To prevent skidding of vehicles

Smooth Surface

- To provide comfort to road users even at high speed

Produce least noise from moving vehicles

Dust Proof Surface

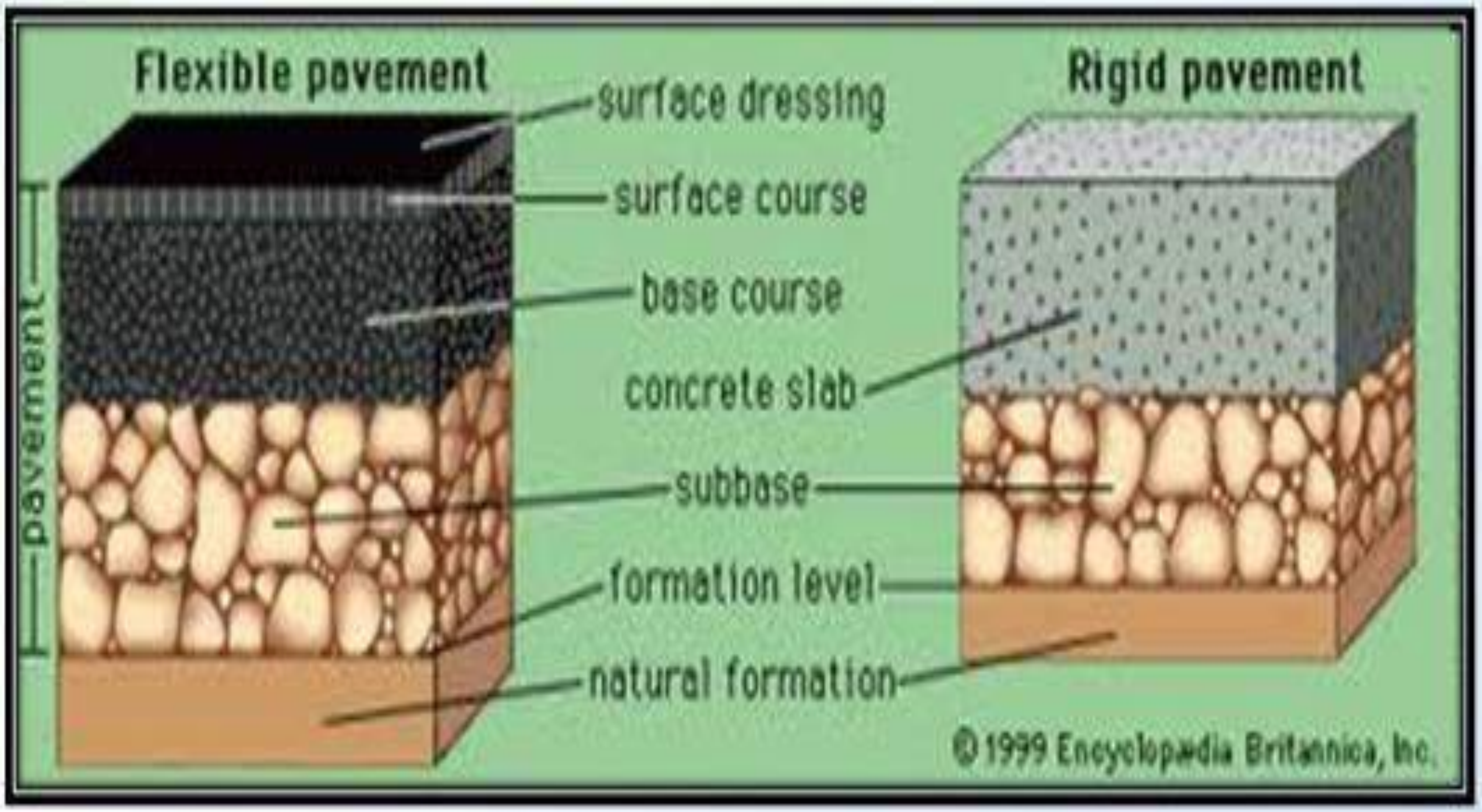
- So that traffic safety is not impaired by reducing visibility

Impervious Surface

- So that sub-grade soil is well protected, and

Long design life with low maintenance cost

Types of Pavement Structures



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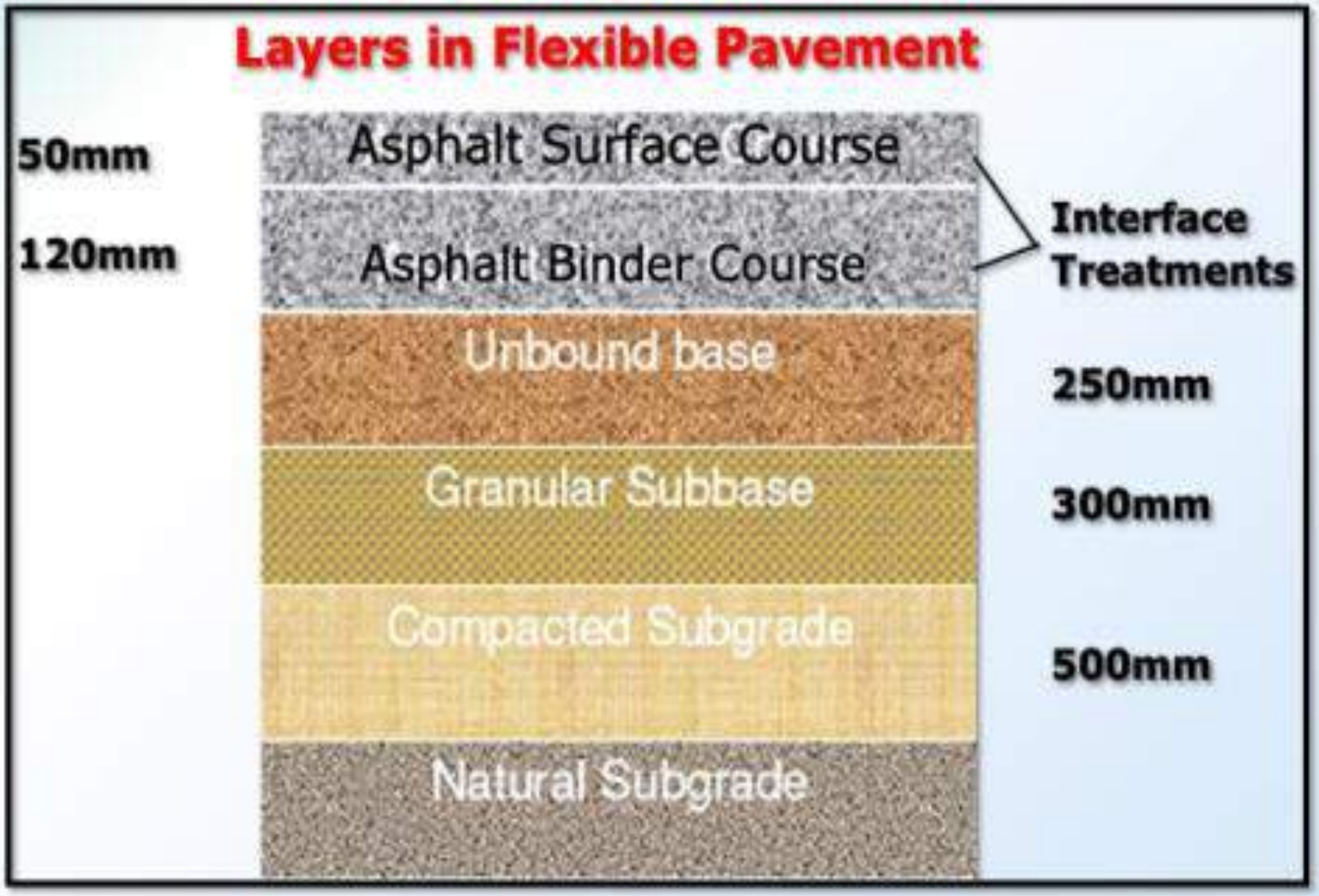
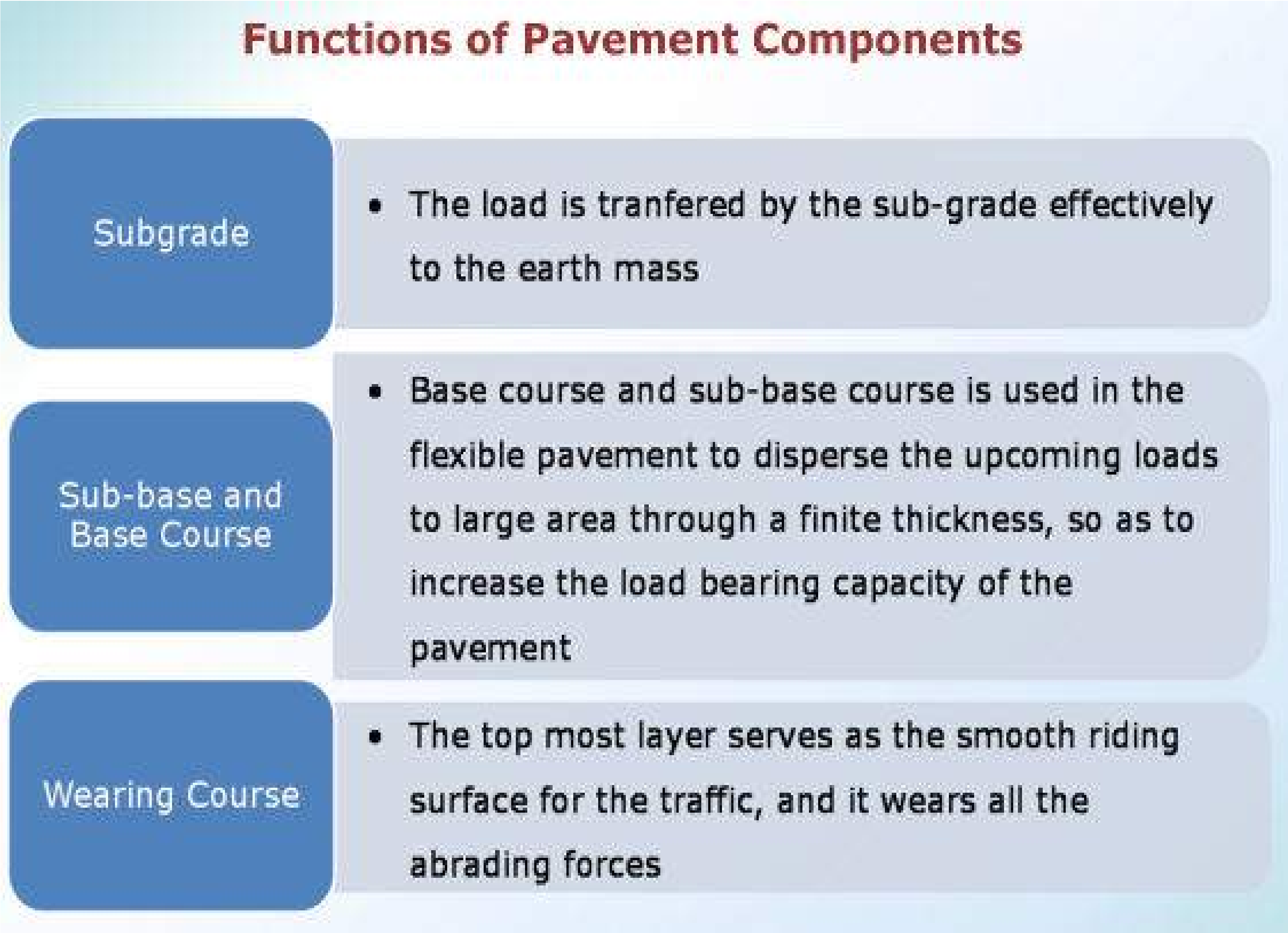
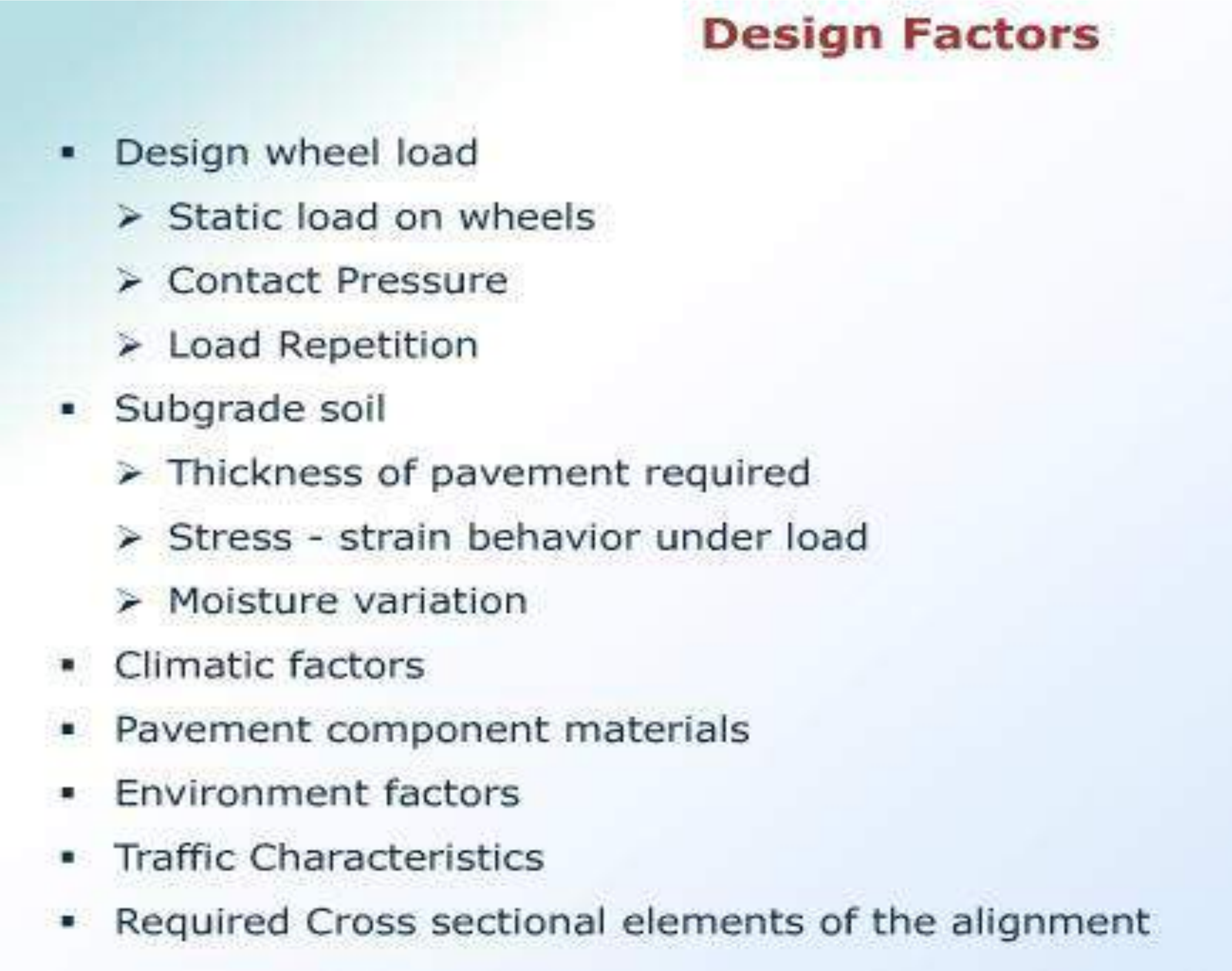
Flexible Pavements


Layers in Flexible Pavement



Functions of Pavement Components

Subgrade	• The load is tranfered by the sub-grade effectively to the earth mass
Sub-base and Base Course	• Base course and sub-base course is used in the flexible pavement to disperse the upcoming loads to large area through a finite thickness, so as to increase the load bearing capacity of the pavement
Wearing Course	• The top most layer serves as the smooth riding surface for the traffic, and it wears all the abrading forces

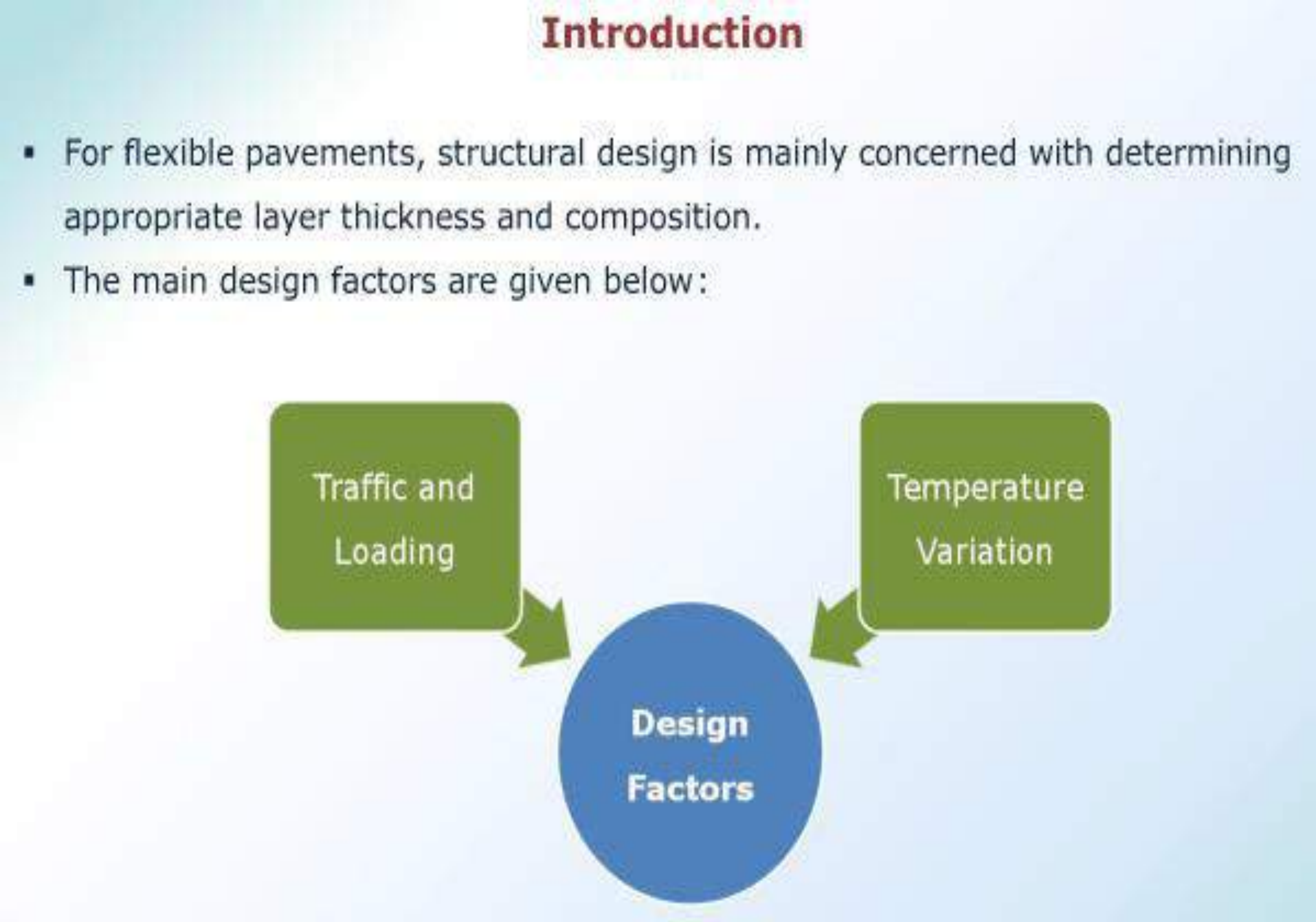


Design Factors

- Design wheel load
  - Static load on wheels
  - Contact Pressure
  - Load Repetition
- Subgrade soil
  - Thickness of pavement required
  - Stress - strain behavior under load
  - Moisture variation
- Climatic factors
- Pavement component materials
- Environment factors
- Traffic Characteristics
- Required Cross sectional elements of the alignment

Design Methods


Tack Coat
Seal Coat
Prime coat
Surface Course (25–50 mm)
Binder Course (50–100 mm)
Base Course (100–300 mm)
Subbase Course (100–300 mm)
Compacted Subgrade (150–300 mm)
Natural Subgrade



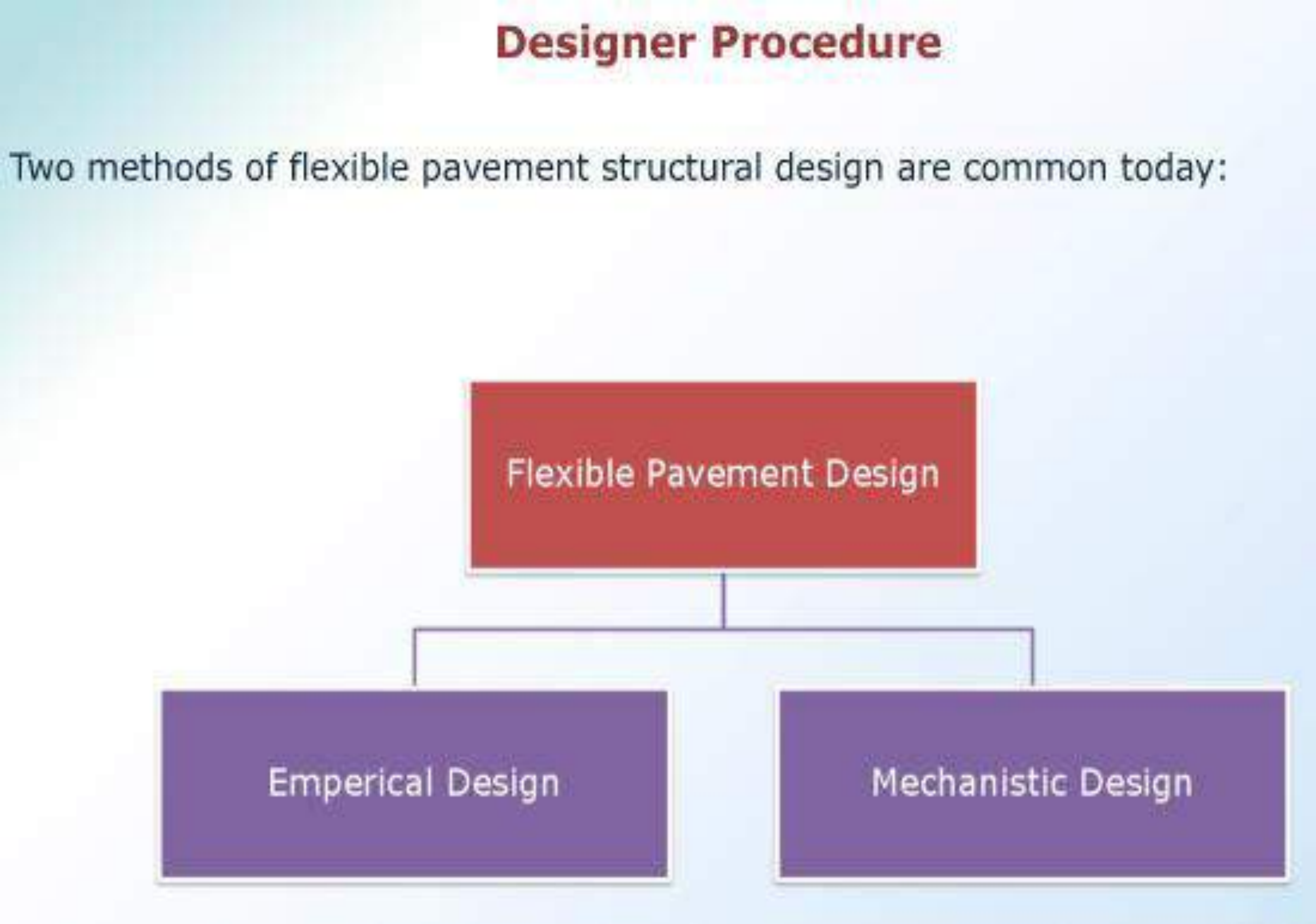
Introduction

- For flexible pavements, structural design is mainly concerned with determining appropriate layer thickness and composition.
- The main design factors are given below:

Traffic and Loading

Temperature Variation

Design Factors



Designer Procedure

Two methods of flexible pavement structural design are common today:

Flexible Pavement Design

Emperical Design

Mechanistic Design

Emperical Design

Emperical Design

Based on Experiments

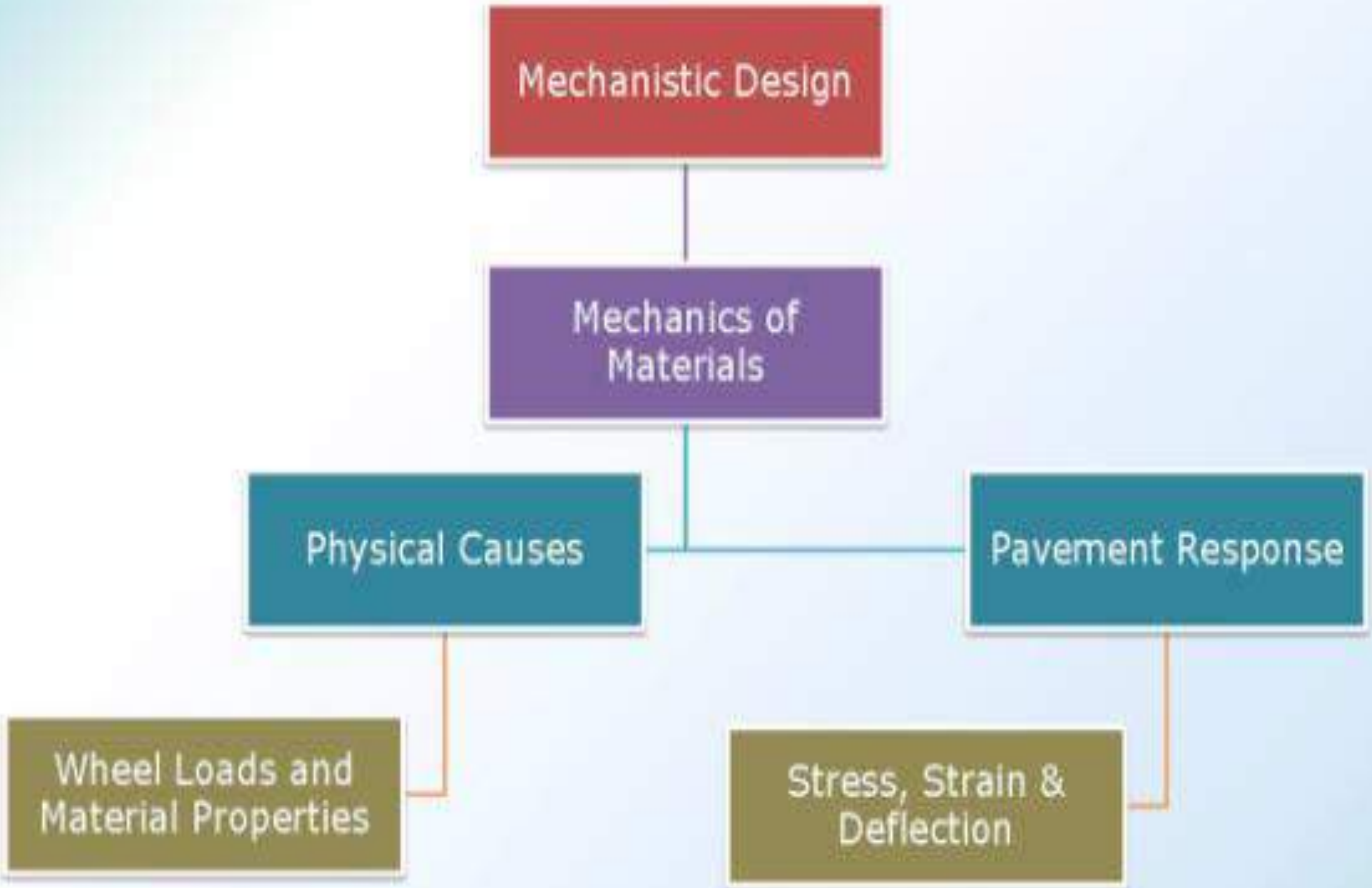
With Soil Strength thest

Without Soil Strength thest

McLeod, Stabilometer, California Bearing Ratio (CBR) test

HRB Classification

Mechanistic Design



Mechanistic Design

Mechanics of Materials

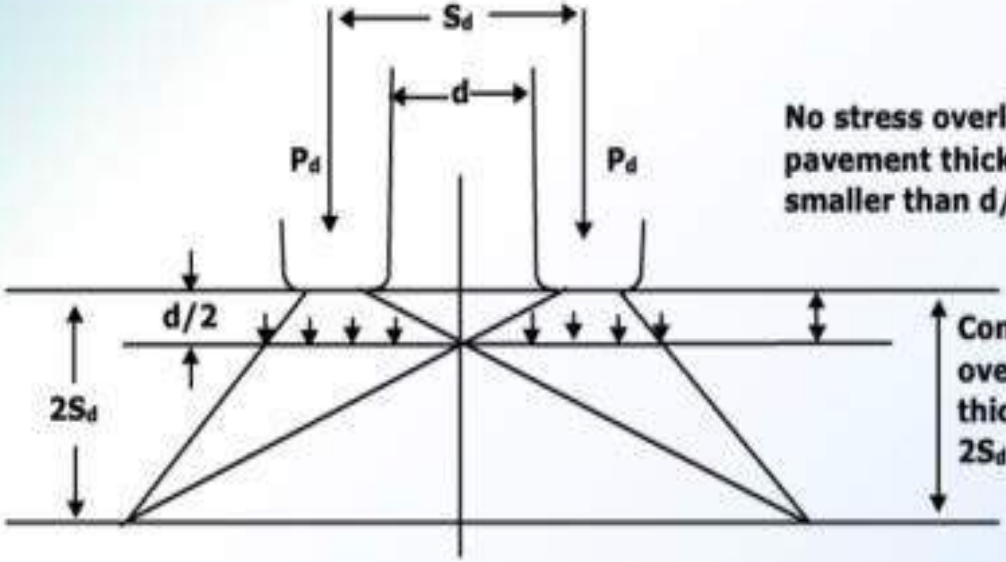
Physical Causes

Pavement Response

Wheel Loads and Material Properties

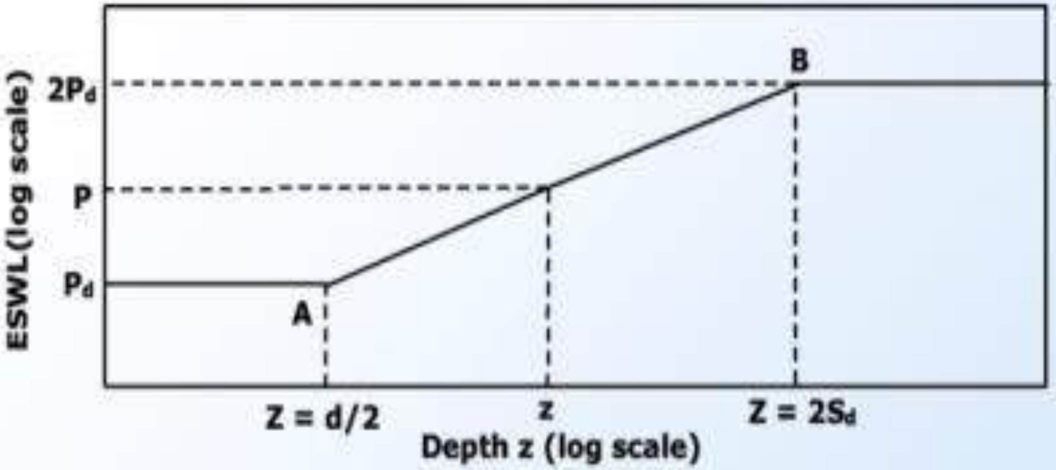
Stress, Strain & Deflection

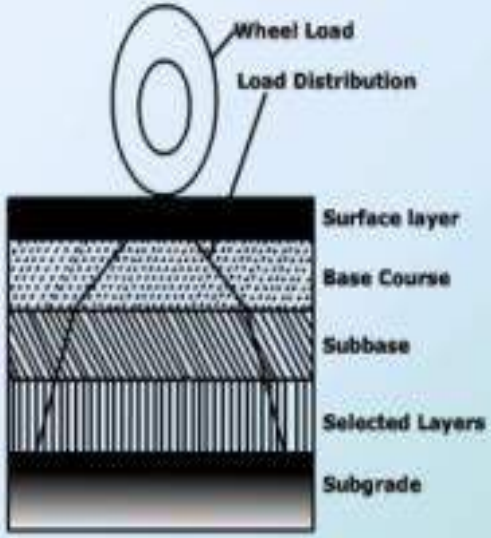
Equivalent Single Layer Theory

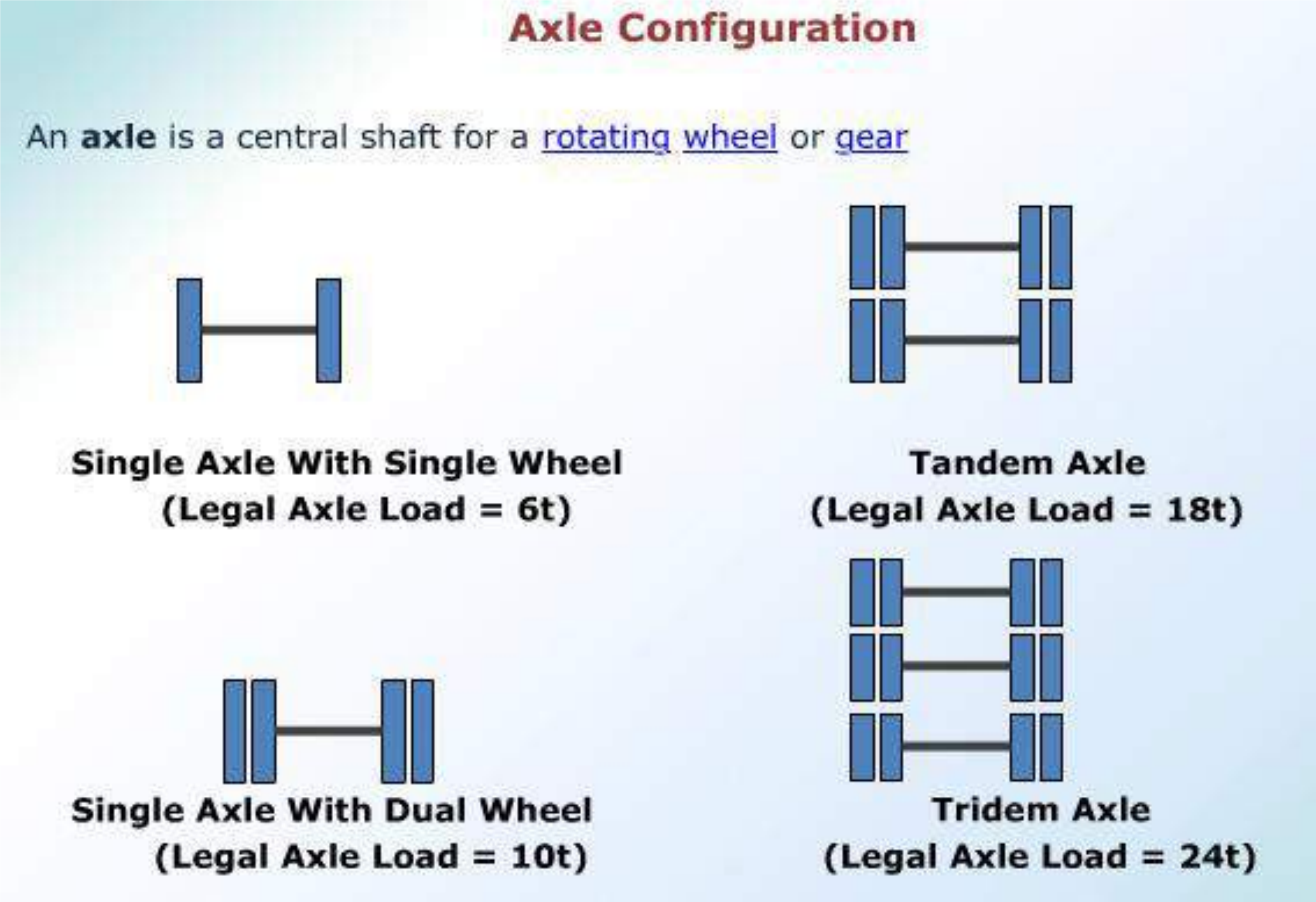


No stress overlap if pavement thickness is smaller than d/2

Complete Stress overlap if Pavement thickness is greatr than $2S_d$







Axle Configuration

An **axle** is a central shaft for a rotating wheel or gear

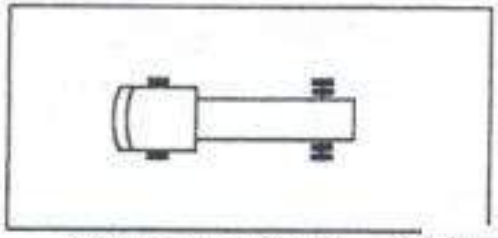
Single Axle With Single Wheel
(Legal Axle Load = 6t)

Tandem Axle
(Legal Axle Load = 18t)

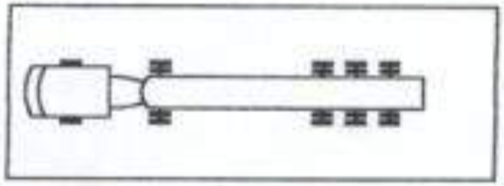
Single Axle With Dual Wheel
(Legal Axle Load = 10t)

Tridem Axle
(Legal Axle Load = 24t)

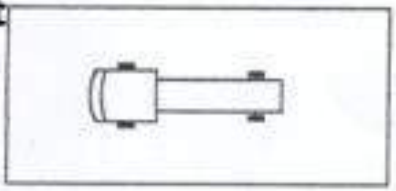
Truck Configuration



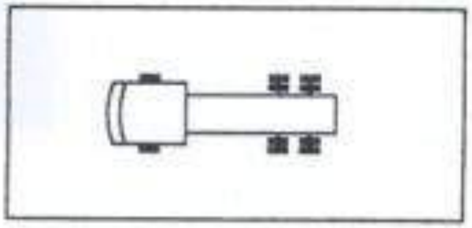
2 Axle Truck – 16t



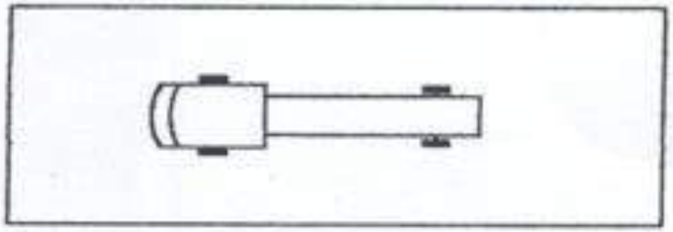
5 Axle Truck – 40t



LCV



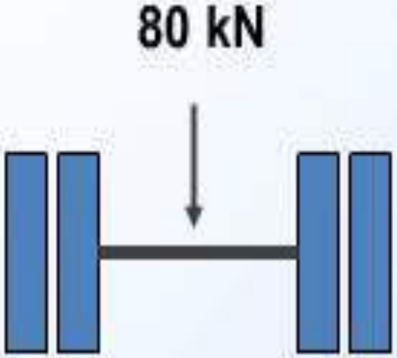
3 Axle Truck – 24t



4 Axle Semi Articulated – 34t

Standard Axle

Single axle with dual wheels carrying a load of 80 kN (8 tonnes) is defined as standard axle



Standard Axle

Equivalent Single Axle Load

- Vehicles can have many axles which will distribute the load into different axles, and in turn to the pavement through the wheels
- A standard truck has two axles, front axle with two wheels and rear axle with four wheels
- But to carry large loads multiple axles are provided
- Since the design of flexible pavements is by layered theory, only the wheels on one side needed to be considered
- On the other hand, the design of rigid pavement is by plate theory and hence the wheel load on both sides of axle need to be considered
- **Legal Axle Load:**
  - The maximum allowed axle load on the roads is called legal axle load
  - For highways the maximum legal axle load in India, specified by IRC, is 10 tonnes

Equivalent Single Axle Load

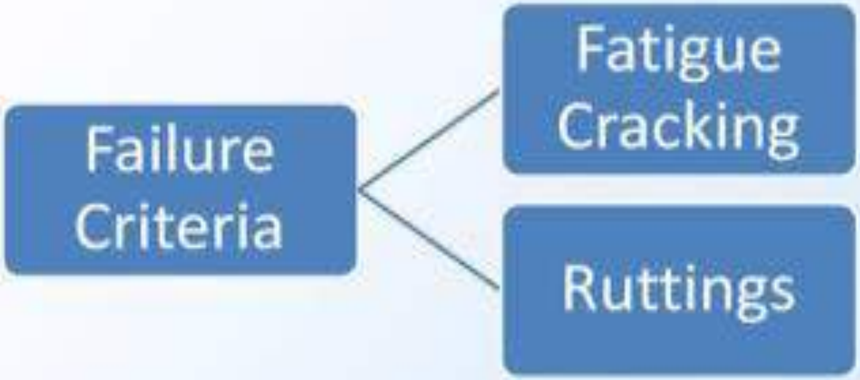
- **Standard Axle Load:**
  - It is a single axle load with dual wheel carrying 80 KN load and the design of pavement is based on the standard axle load

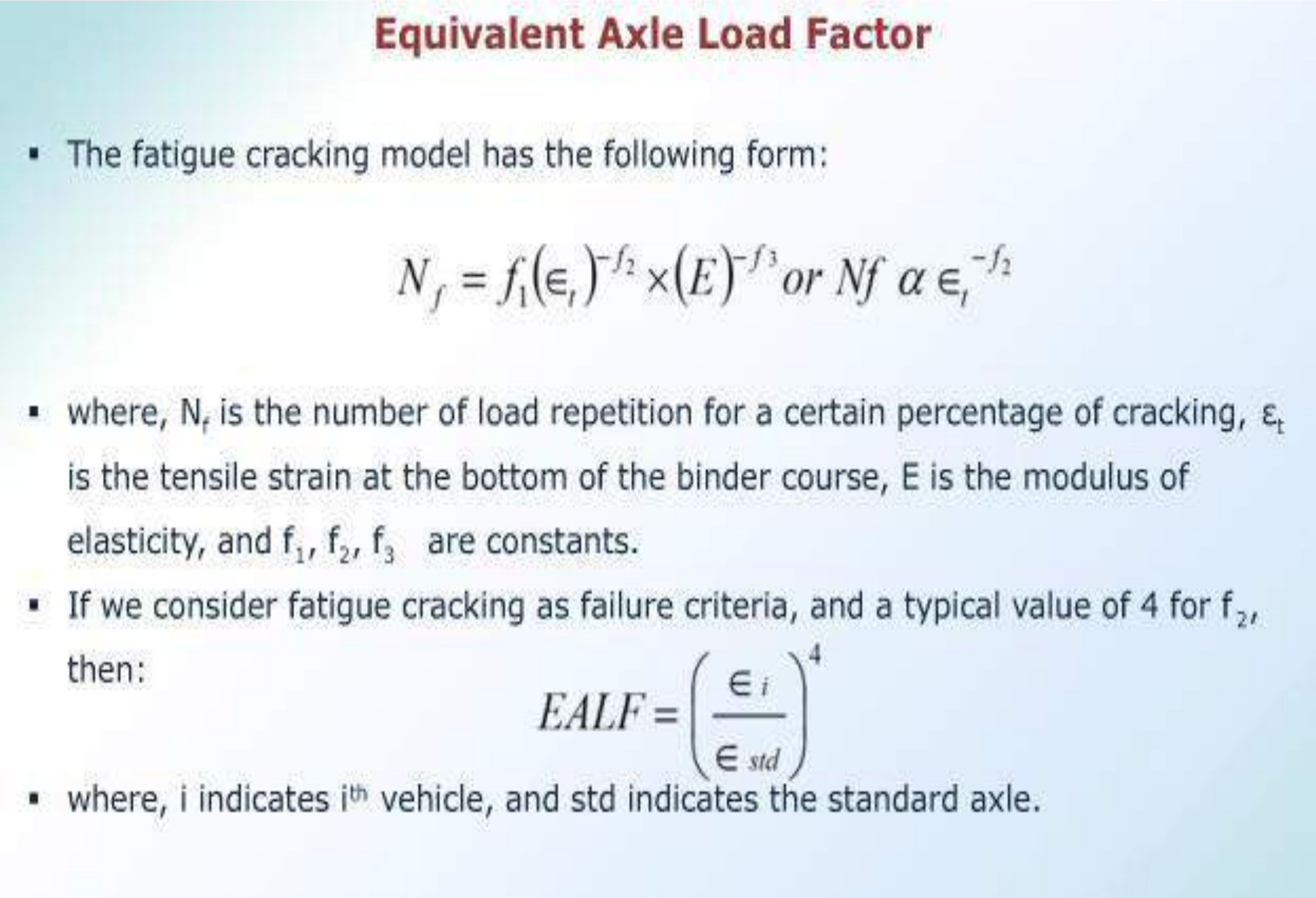
Repetition of Axle Loads

- The deformation of pavement due to a single application of axle load may be small but due to repeated application of load there would be accumulation of unrecovered or permanent deformation which results in failure of pavement.
- If the pavement structure fails with N_1 number of repetition of load W_1 and for the same failure criteria if it requires N_2 number of repetition of load W_2, then W_1N_1 and W_2N_2 are considered equivalent.
- Note that, W_1N_1 and W_2N_2 equivalency depends on the failure criterion employed

Equivalent Axle Load Factor

- An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the ith type of axle relative to the damage per pass of a standard axle load
- While finding the EALF, the failure criterion is important
- Two types of failure criterias are commonly adopted:





Equivalent Axle Load Factor

- The fatigue cracking model has the following form:

$$N_f = f_1(\in_t)^{-f_2} \times (E)^{-f_3} or\ Nf\ \alpha \in_t^{-f_2}$$

- where, N_f is the number of load repetition for a certain percentage of cracking, ε_t is the tensile strain at the bottom of the binder course, E is the modulus of elasticity, and f_1, f_2, f_3 are constants.
- If we consider fatigue cracking as failure criteria, and a typical value of 4 for f_2, then:

$$EALF = \left(\frac{\in i}{\in std} \right)^4$$

- where, i indicates i^{th} vehicle, and std indicates the standard axle.

Equivalent Axle Load Factor

- Now if we assume that the strain is proportional to the wheel load,

$$EALF = \left(\frac{W_i}{W_{std}} \right)^4$$

- Similar results can be obtained if rutting model is used, which is:

$$N_d = f_4 (\in_c)^{-f_5}$$

where N_d is the permissible design rut depth (say 20mm), E_c is the compressive strain at the top of the subgrade, and f_4 &f_5 are constants.

- Once we have the EALF, then we can get the ESAL as given below

  Equivalent single axle load, $$ESAL = \sum_{i=1}^{m} F_i n_i$$

where, m is the number of axle load groups, F_1 is the EALF for i^{th} axle load group,and n_i is the number of passes of i^{th} axle load group during the design period.

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, it is the same everywhere and will rebound to its original form once the load is removed

Assumptions in Layered Elastic Model

- The layered elastic approach works with relatively simple mathematical models and thus requires following assumptions

Assumption 1

Pavement layer extends infinitely in the horizontal direction

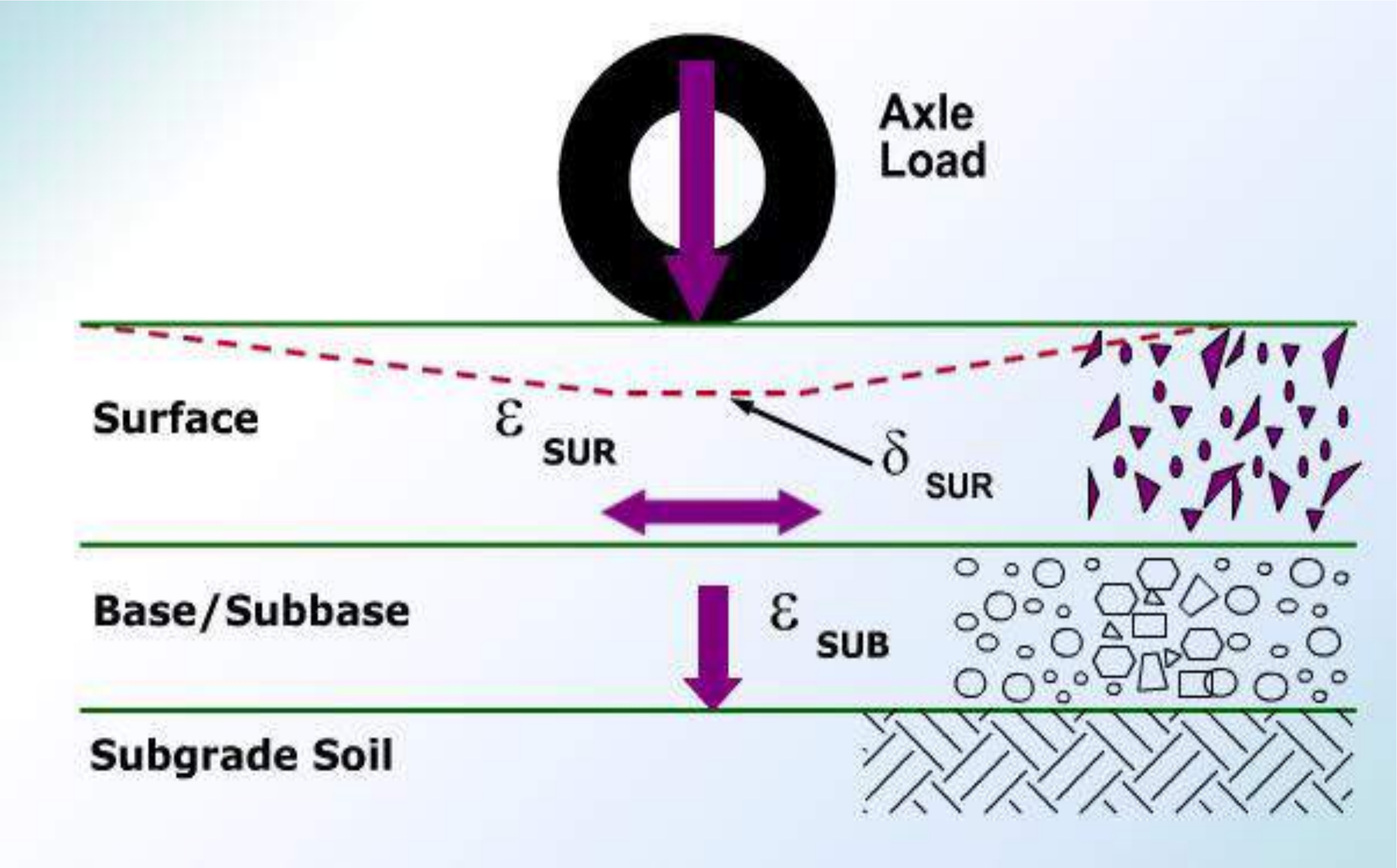
Assumption 2

The bottom layer (usually the subgrade) extends infinitely downwards

Assumption 3

Materials are not stressed beyond their elastic ranges

Pavement Design

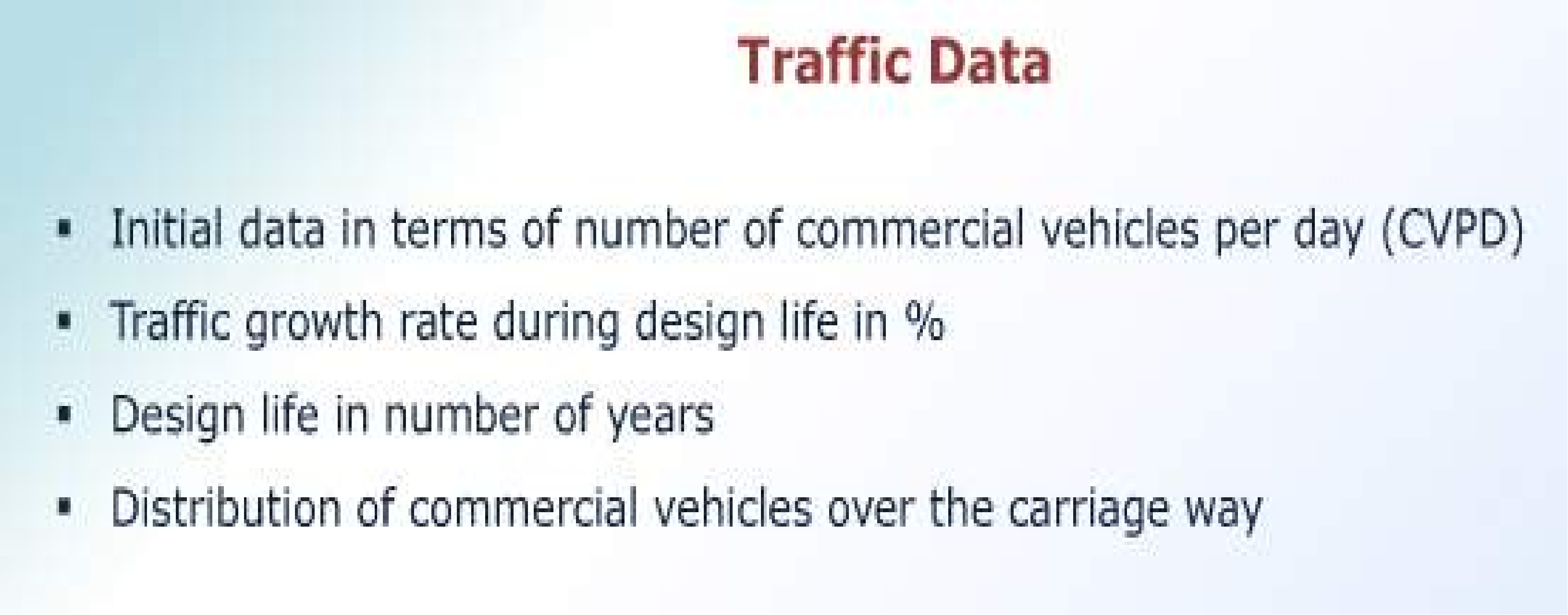

Axle Load
Surface
ε_{SUR}
δ_{SUR}
Base/Subbase
ε_{SUB}
Subgrade Soil

Introduction

- Indian roads congress has specified the design procedures for flexible pavements based on CBR values
- The Pavement designs given in the previous edition IRC: 37-1984 were applicable to design traffic up to only 30 million standard axles (msa)
- The earlier code is empirical in nature which has limitations regarding applicability and extrapolation
- This guidelines follows analytical designs and developed new set of designs up to 150 msa

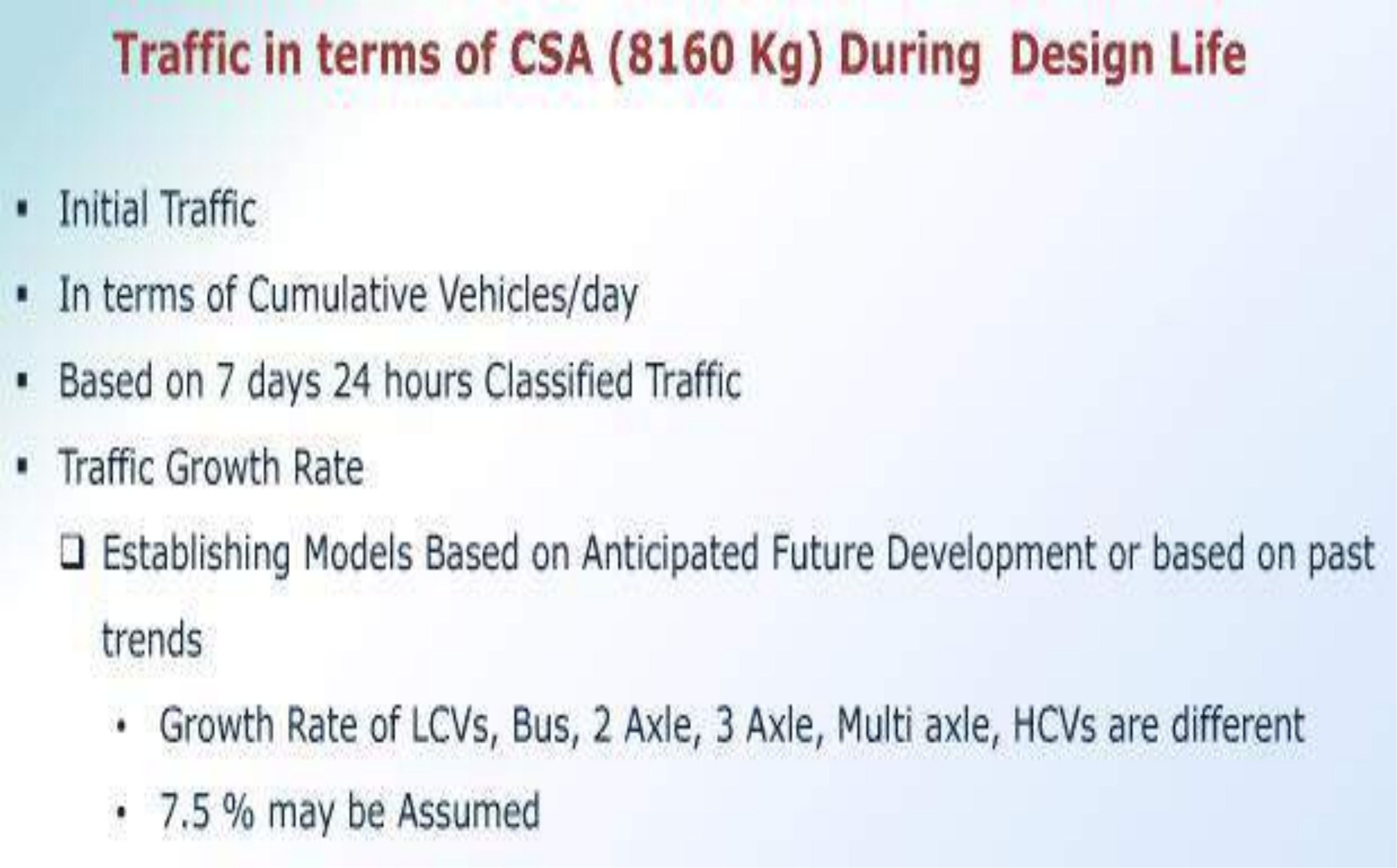
Flexible Pavement Design Using CBR Value Of Sub-grade Soil

- California State Highways Department Method
  - ❑ Required data
    - Design Traffic in terms of cumulative number of standard axles(CSA)
    - CBR value of subgrade



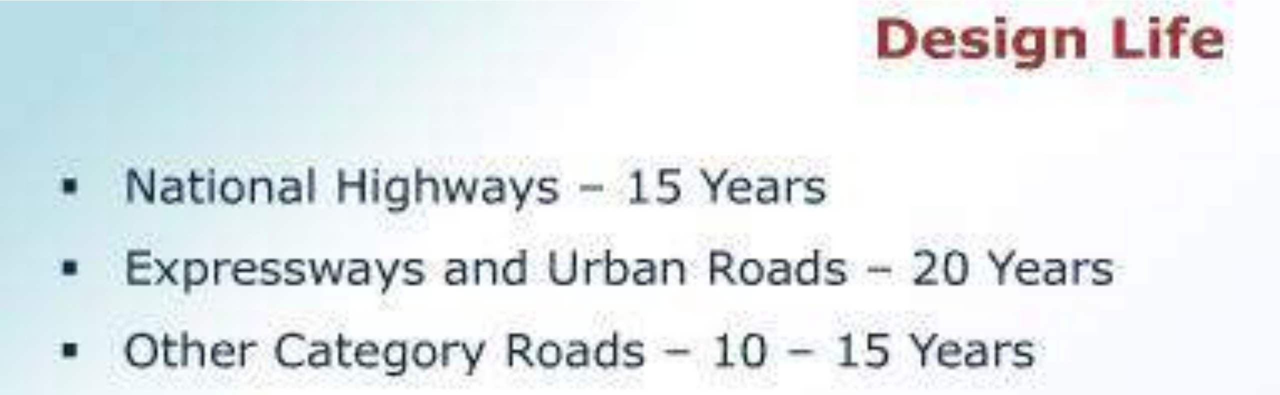
Traffic Data

- Initial data in terms of number of commercial vehicles per day (CVPD)
- Traffic growth rate during design life in %
- Design life in number of years
- Distribution of commercial vehicles over the carriage way



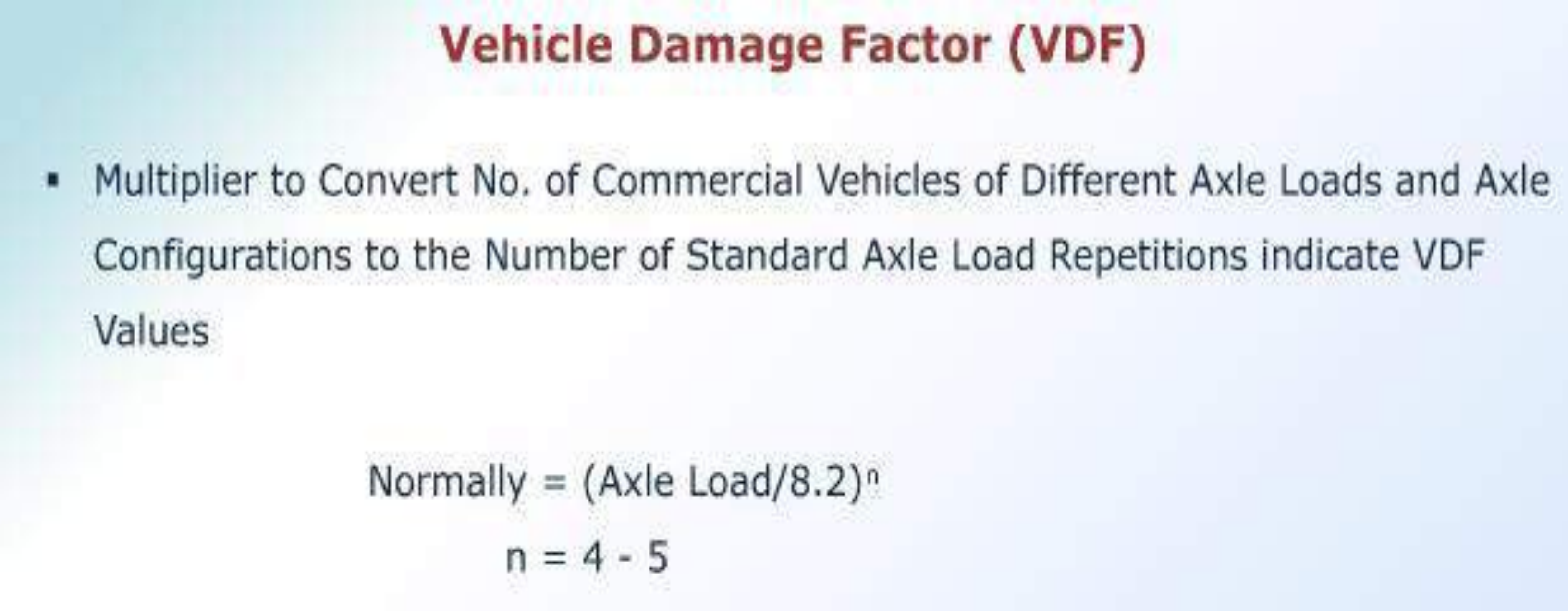
Traffic in terms of CSA (8160 Kg) During Design Life

- Initial Traffic
- In terms of Cumulative Vehicles/day
- Based on 7 days 24 hours Classified Traffic
- Traffic Growth Rate
  - ❑ Establishing Models Based on Anticipated Future Development or based on past trends
    - Growth Rate of LCVs, Bus, 2 Axle, 3 Axle, Multi axle, HCVs are different
    - 7.5 % may be Assumed



Design Life

- National Highways – 15 Years
- Expressways and Urban Roads – 20 Years
- Other Category Roads – 10 – 15 Years



Vehicle Damage Factor (VDF)

- Multiplier to Convert No. of Commercial Vehicles of Different Axle Loads and Axle Configurations to the Number of Standard Axle Load Repetitions indicate VDF Values

$$\text{Normally} = (\text{Axle Load}/8.2)^n$$

$$n = 4 - 5$$

Distribution Of Traffic

- Single Lane Roads
  - Total No. of Commercial Vehicles in both Directions
- Two-lane Single Carriageway Roads
  - 75% of total No. of Commercial Vehicles in both Directions
- Four-lane Single Carriageway Roads
  - 40% of the total No. of Commercial Vehicles in both Directions
- Dual Carriageway Roads
  - 75% of the No. of Commercial Vehicles in each Direction

Computation of Traffic for Use of Pavement Thickness Design Chart

$$N = \frac{365 \times A[(1+r)n - 1]}{r} \times D \times F$$

N = Cumulative No. of standard axles to be catered for the design in terms of msa

D = Lane distribution factor

A = Initial traffic, in the year of completion of construction, in terms of number of commercial vehicles per day

F = Vehicle Damage Factor

n = Design life in years

r = Annual growth rate of commercial vehicles

CBR Testing Machine

- **Definition:**

  It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

CBR

Basis of Design chart:

- A material with a given CBR value requires certain thickness of pavement

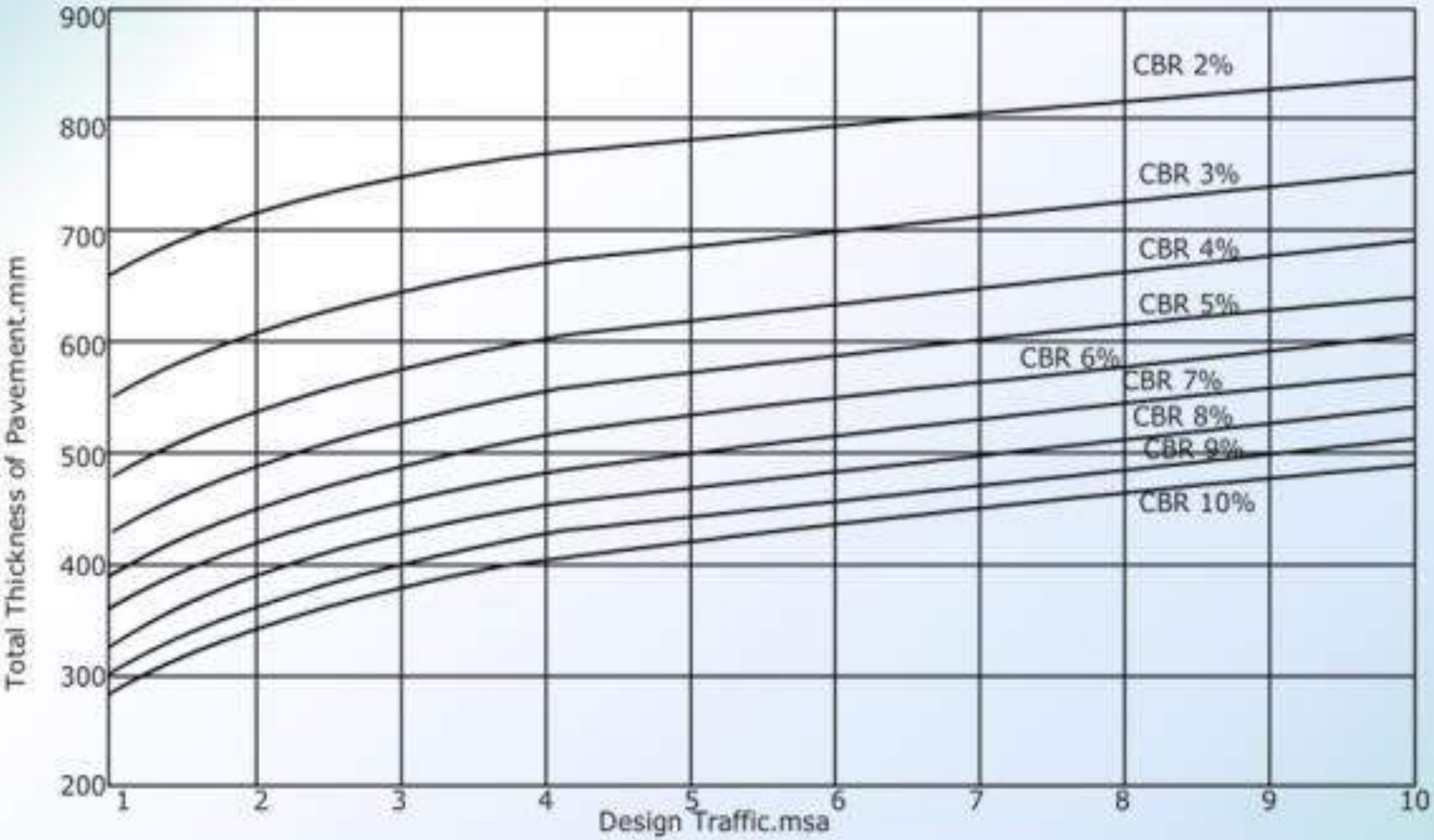
Chart developed for traffic wheel loads:

- Light Traffic - 3175 kg
- Heavy traffic – 5443 kg
- Medium traffic – 4082 kg

Permissible Variation in CBR Value

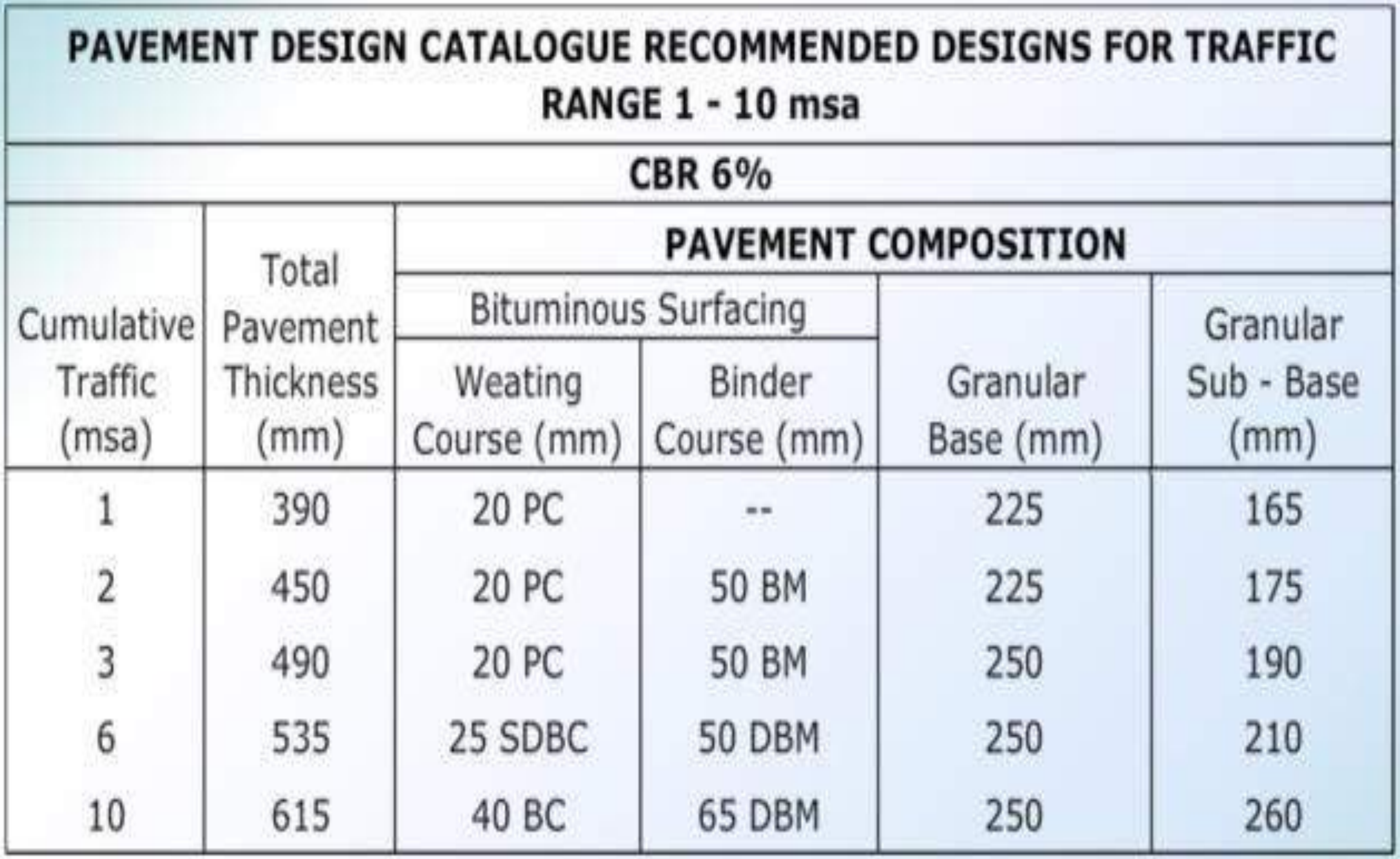
CBR (%)A	Maximum Variation in CBR Value
5	+_ 1
5-10	+_ 2
11-30	+_ 3
31 and above	+_ 4

Flexible Pavement Design Chart (IRC) (for CSA< 10 msa)



Pavement Thickness Design Chart for Traffic 1-10 msa

Flexible Pavement Layers (IRC) (CSA< 10 msa)

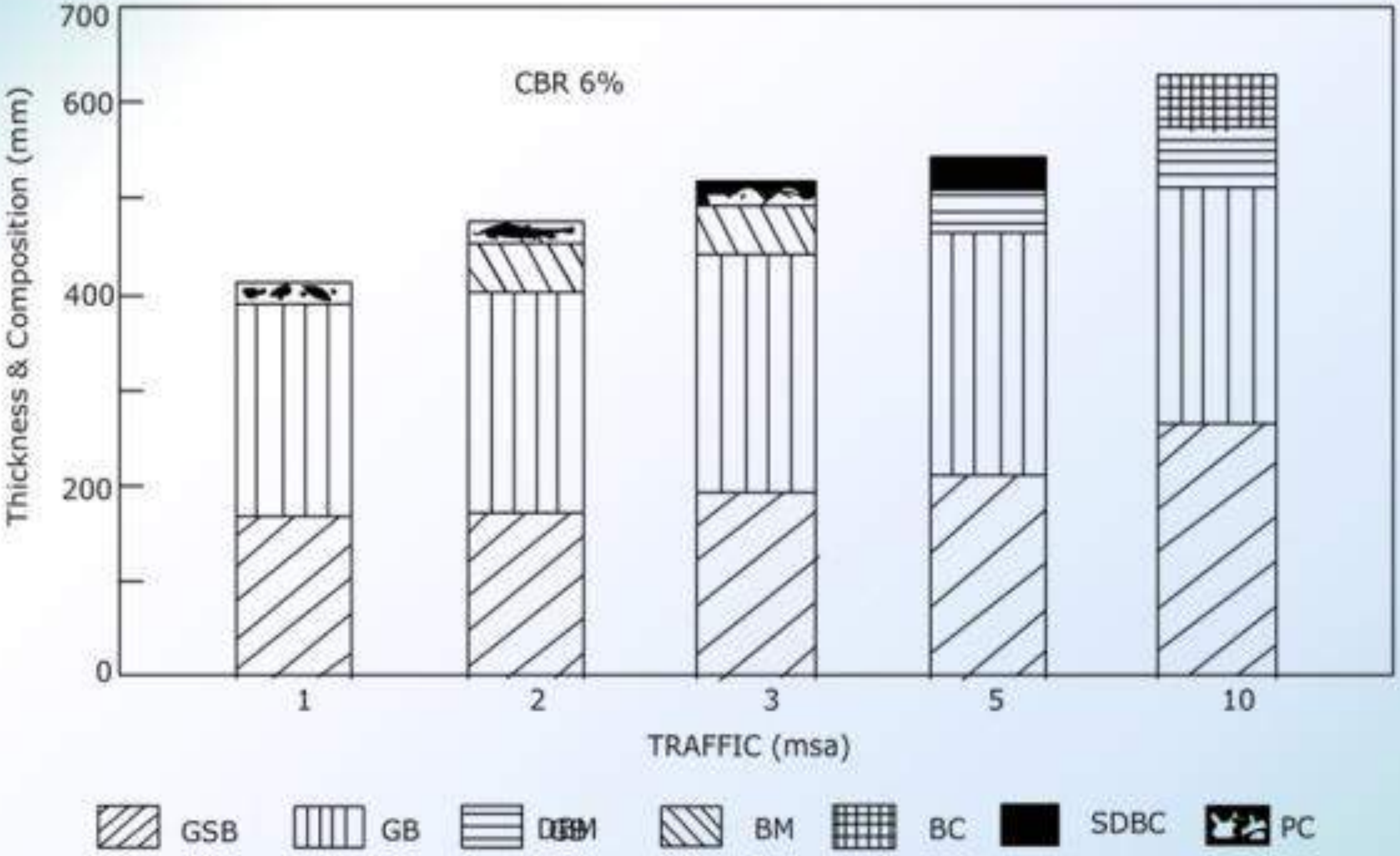


PAVEMENT DESIGN CATALOGUE RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1 - 10 msa

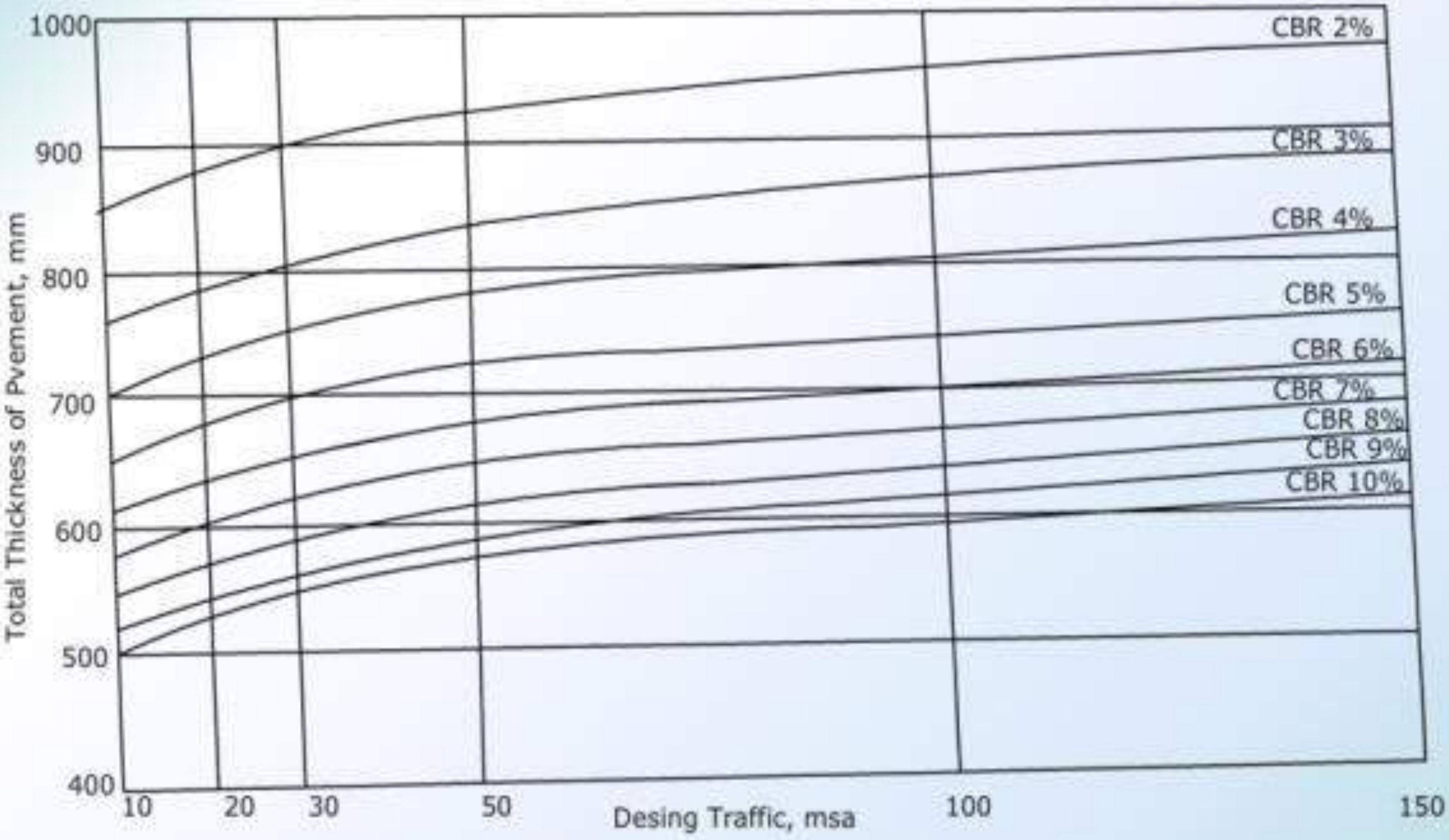
CBR 6%

Cumulative Traffic (msa)	Total Pavement Thickness (mm)	**PAVEMENT COMPOSITION**			
		Bituminous Surfacing		Granular Base (mm)	Granular Sub - Base (mm)
		Weating Course (mm)	Binder Course (mm)		
1	390	20 PC	--	225	165
2	450	20 PC	50 BM	225	175
3	490	20 PC	50 BM	250	190
6	535	25 SDBC	50 DBM	250	210
10	615	40 BC	65 DBM	250	260

Flexible Pavement Layers (IRC) (CSA< 10 msa)



Flexible Pavement Design Chart (IRC)



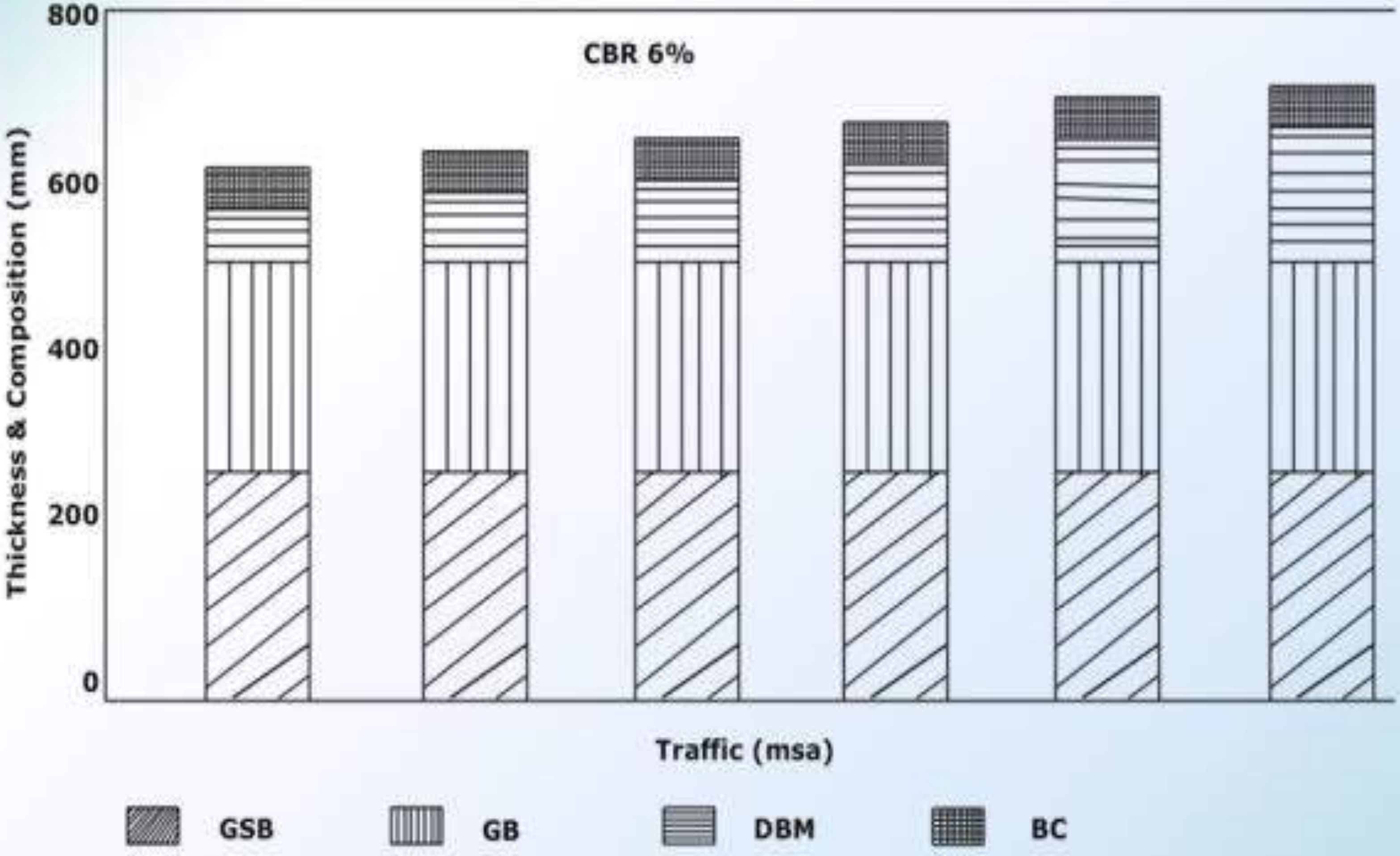
Pavement Thickness Design Chart for Traffic 10-150 msa

Flexible Pavement Layers (IRC)

PAVEMENT DESIGN CATALOGUE
RECOMMENDED DESIGNS FOR TRAFFIC RANGE 10-150 msa

CBR 6%				
Cumulative. Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION		
		Bituminous Surfacing		Granular Base & Sub-base (mm)
		BC (mm)	DBM (mm)	
10	615	40	65	Base = 250 Sub-base = 260
20	640	40	90	
30	655	40	105	
50	675	40	125	
100	700	50	140	
150	720	50	160	

Flexible Pavement Layers (IRC)



Sub - Base

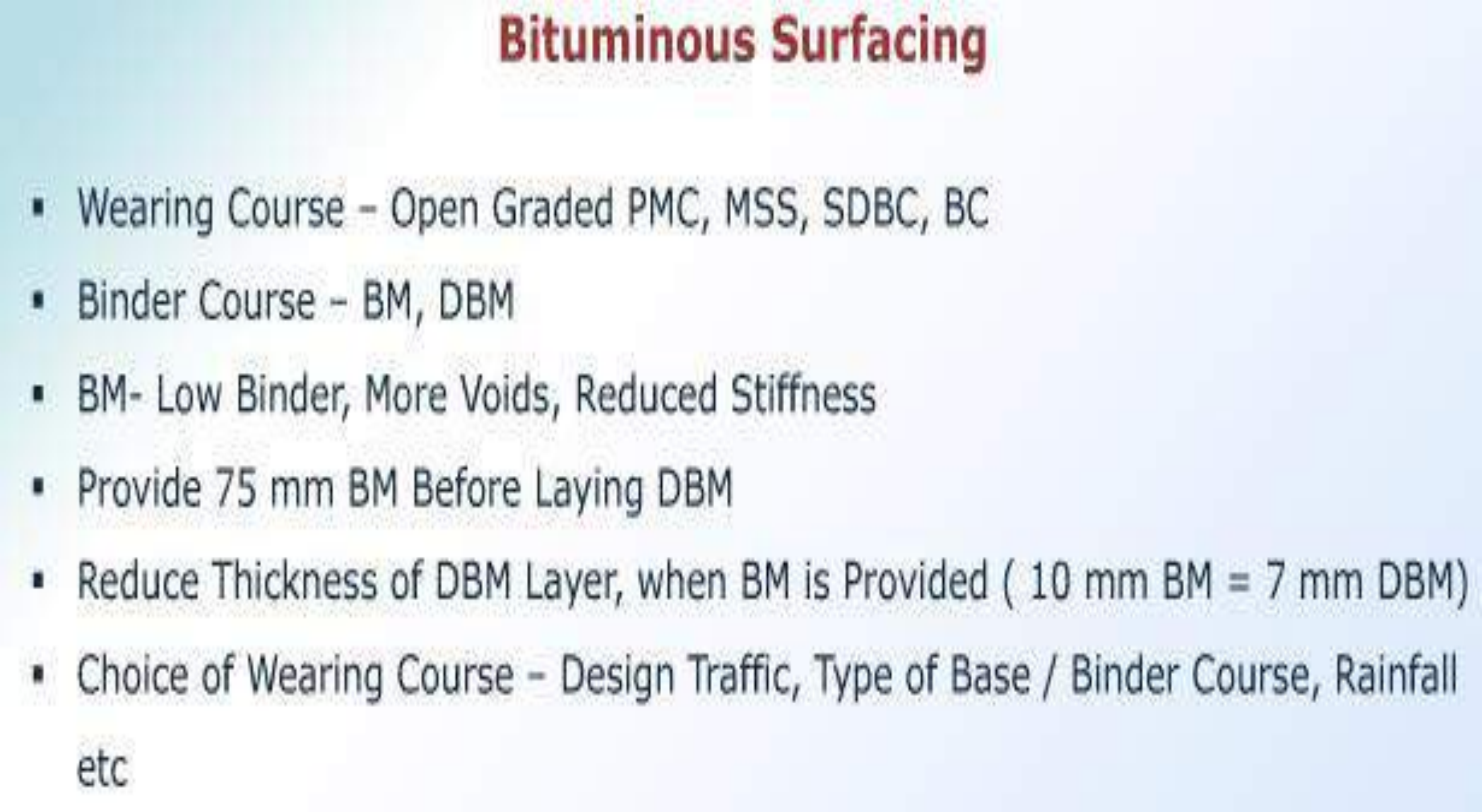
- Material – Natural Sand, Moorum, Gravel, Laterite, Kankar, Brick Metal, Crushed Stone, Crushed Slag, Crushed Concrete
- GSB - Close Graded / Coarse Graded
- Parameters – Gradation, LL, PI, CBR
- Stability and Drainage Requirements

Base Course

- Unbound Granular Bases – WBM / WMM or any other Granular Construction
- Min. Thickness – 225 mm – < 2 msa
- Min. Thickness – 250 mm - > 2 msa
- WBM – Min. 300 mm (4 layers – 75mm each)

Sub - Base

- Min. CBR 20 % - Traffic up-to 2 msa
- Min. CBR 30 %- Traffic > 2 msa
- If GSB is Costly, Adopt WBM, WMM
- Should Extend for the FULL Width of the Formation
- Min. Thickness – 150 mm - <10 msa
- Min. Thickness – 200 mm - >10 msa
- Min. CBR – 2 %
- If CBR < 2% - Pavement Thickness for 2 % CBR + Capping layer of 150 mm with Min. CBR 10% (in addition to the Sub-Base)
- In case of Stage Construction – Thickness of GSB for Full Design Life



Bituminous Surfacing

- Wearing Course – Open Graded PMC, MSS, SDBC, BC
- Binder Course – BM, DBM
- BM- Low Binder, More Voids, Reduced Stiffness
- Provide 75 mm BM Before Laying DBM
- Reduce Thickness of DBM Layer, when BM is Provided (10 mm BM = 7 mm DBM)
- Choice of Wearing Course – Design Traffic, Type of Base / Binder Course, Rainfall etc

Choice of Wearing Course

BASE/ BINDER	WEARING COURSE	ARF	TRAFFIC
WBM, WMM, CRM, BUSG	PMC+SC (B)	L and M	< 10
	PMC + SC (A)	L,M,H	
	MSS	L,M,H	
BM	SDBC	L,M,H	<10
	PMC (A)		
	MSS		
DBM	BC 25 mm	L,M,H	>5<10
	BC 40 mm		>10
	BC 50 mm		>100

Design Considerations

Introduction

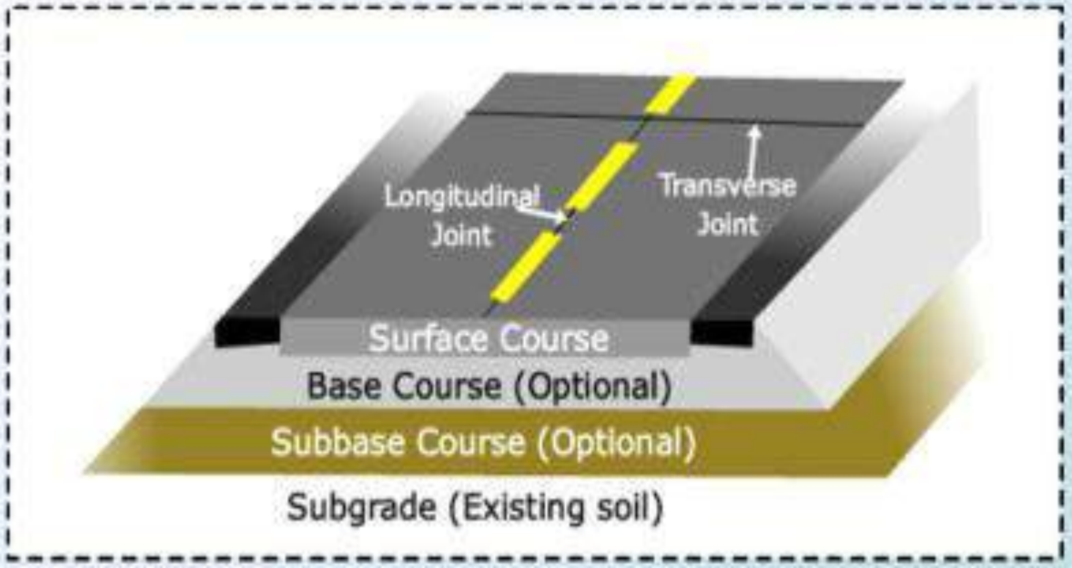
- Rigid pavements are so named because the pavement structure deflects very little under loading due to the high modulus of elasticity of their surface course
- A rigid pavement structure is typically composed of a PCC surface course built on top of either

  (1) the subgrade or

  (2) an underlying base course
- Because of its relative rigidity, the pavement structure distributes loads over a wide area with only one, or at most two, structural layers

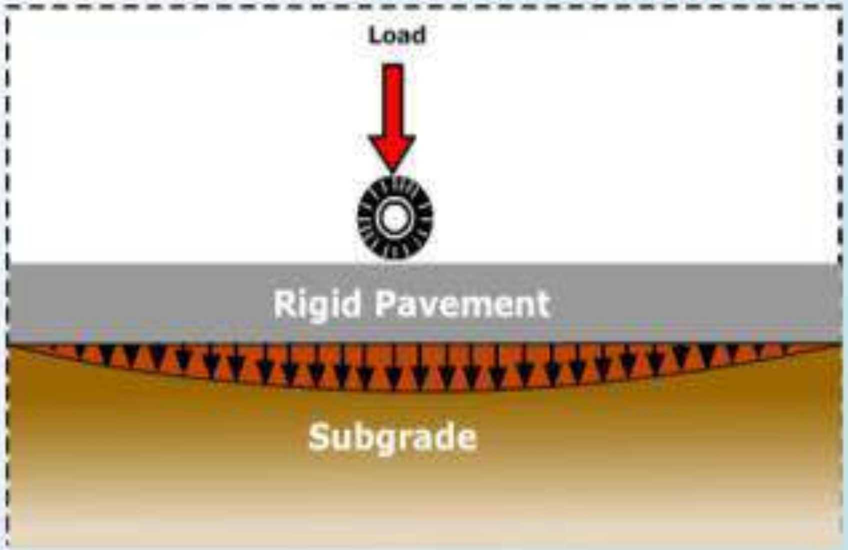
Basic Structural Elements

- A typical rigid pavement structure consists of the surface course and the underlying base and subbase courses (if used)
- The surface course (made of PCC) is the stiffest and provides the majority of strength
- The underlying layers are orders of magnitude less stiff but still make important contributions to pavement strength as well as drainage and frost protection



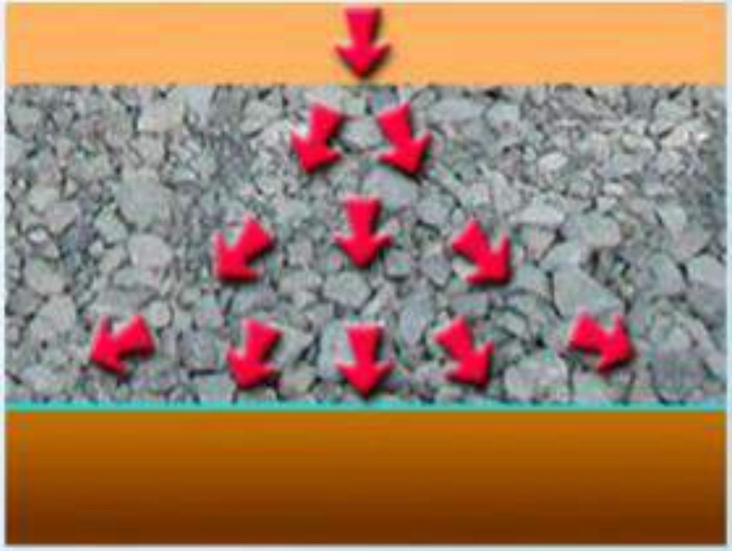
Surface Course

- The surface course is the layer in contact with traffic loads and is made of PCC
- It provides characteristics such as friction, smoothness, noise control and drainage
- In addition, it serves as a waterproofing layer to the underlying base, subbase and subgrade
- The surface course can vary in thickness but is usually between 150 mm (for light loading) and 300 mm (for heavy loads and high traffic)



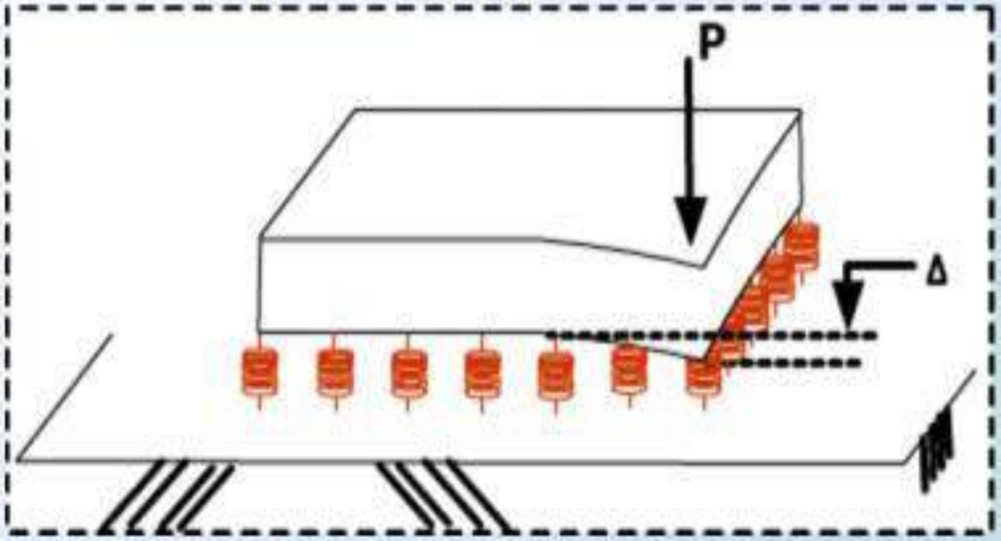
Base Course

- The base course is immediately beneath the surface course
- It provides
    - Additional load distribution,
    - Contributes to drainage and frost resistance,
    - Uniform support to the pavement and
    - A stable platform for construction equipment



Modulus of Subgrade Reaction

- Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed as a dense liquid.
- The upward reaction is assumed to be proportional to the deflection
- Based on this assumption, Westergaard defined a modulus of sub-grade reaction K in kg/cm^3 given by $K = p/\Delta$ where Δ is the displacement level taken as 0.125 cm and p is the pressure sustained by the rigid plate of 75 cm diameter at a deflection of 0.125 cm



Relative Stiffness of Slab to Sub - Grade

- A certain degree of resistance to slab deflection 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

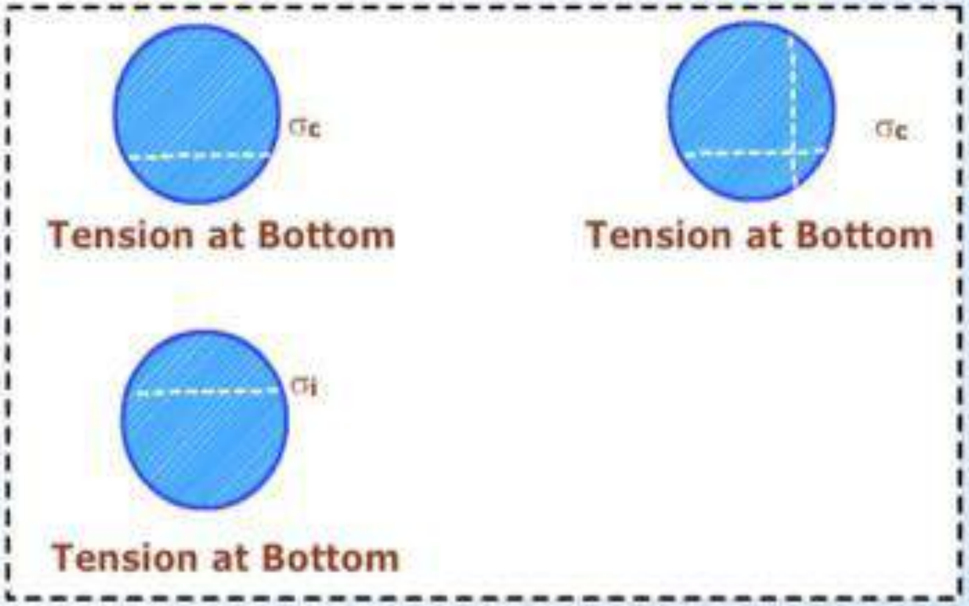
$$l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}}$$

where E is the modulus of elasticity of cement concrete in kg/cm^2

m is the Poisson's ratio of concrete (0.15), h is the slab thickness in cm and

Critical Load Positions

- The intensity of maximum stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface
- There are three typical locations namely the interior, edge and corner, where differing conditions of slab continuity exist
- These locations are termed as critical load positions



Equivalent Radius of Resisting Section

- Westergaard's gives a relation for equivalent radius of the resisting section in cm in the equation

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

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

Westergaard's Stress Equation

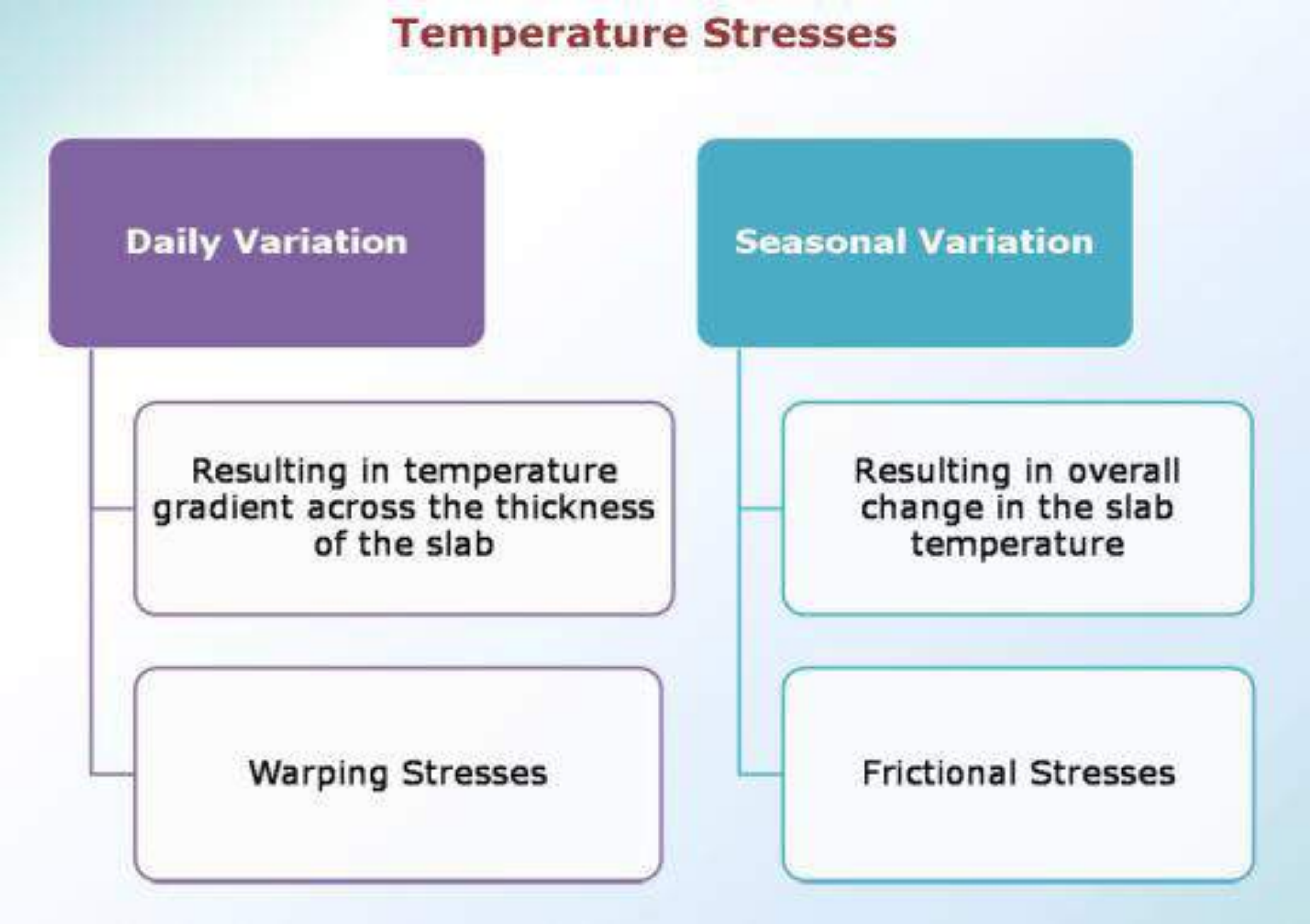
- Westergaard developed relationships for the stress at interior, edge and corner regions, denoted as σ_i; σ_e; σ_c in kg/cm^2 respectively and given by the equation

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

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

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

where h is the slab thickness in cm, P is the wheel load in kg, a is the radius of the wheel load distribution in cm, l the radius of the relative stiffness in cm and b is the radius of the resisting section in cm.



Temperature Stresses

- **Daily Variation**
  - Resulting in temperature gradient across the thickness of the slab
  - Warping Stresses
- **Seasonal Variation**
  - Resulting in overall change in the slab temperature
  - Frictional Stresses

Warping Stresses

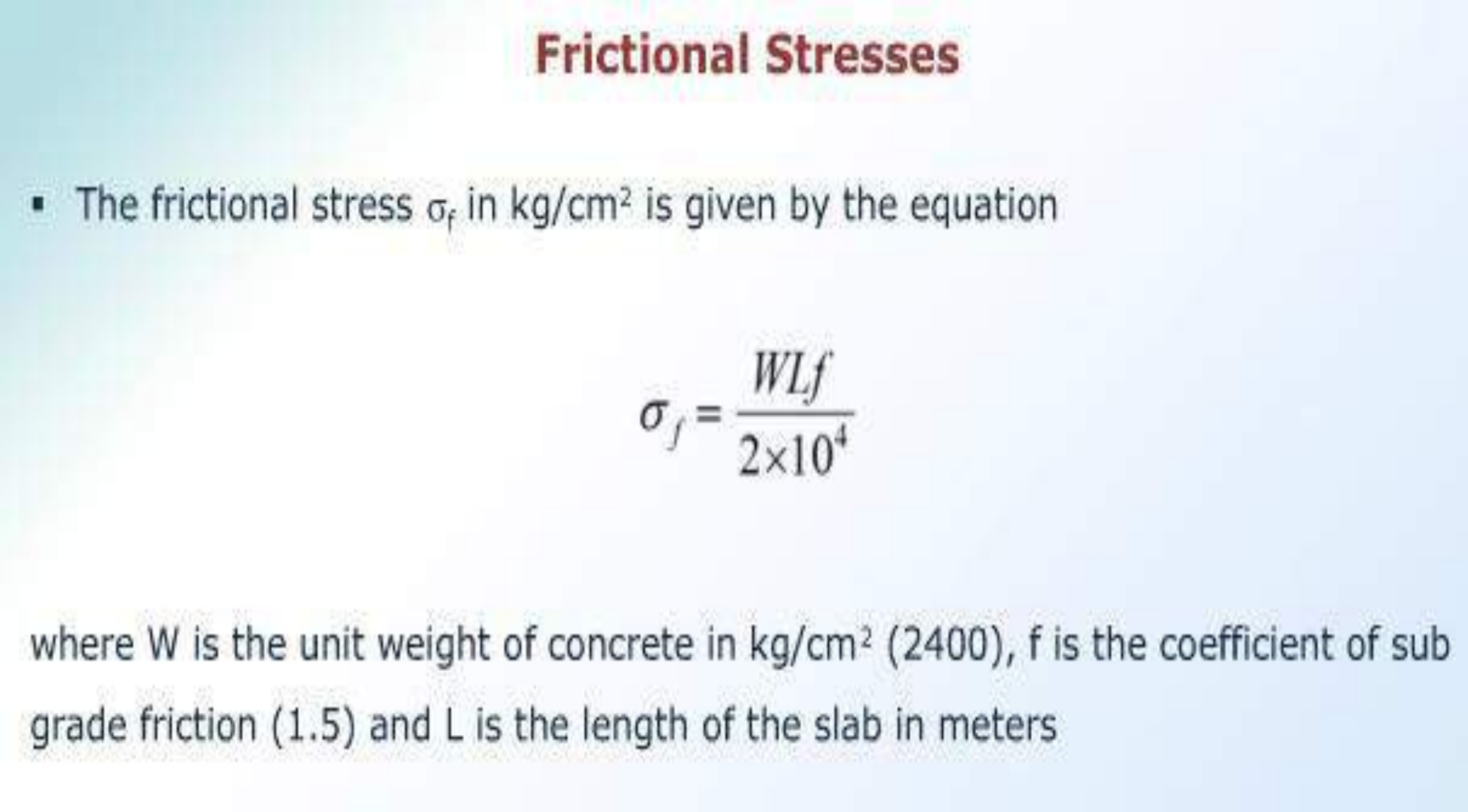
- The warping stress at the interior, edge and corner regions, denoted as σ_{ti}; σ_{te}; σ_{tc} in kg/cm^2 respectively and given by the equation

$$\sigma_{t_i} = \frac{E \in t}{2}\left(\frac{C_x + \mu C_y}{1-\mu^2}\right)$$

$$\sigma_{t_e} = Max\left(\frac{C_x E \in t}{2}, \frac{C_y E \in t}{2}\right)$$

$$\sigma_{t_c} = \frac{E \in t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

where E is the modulus of elasticity of concrete in kg/cm^2 (3×10^5), ε is the thermal coefficient of concrete per °C (1×10^{-7}) t is the temperature difference between the top and bottom of the slab, C_x and C_y are the coefficient based on L_x/l in the desired direction and L_y/l right angle to the desired direction, m is the Poisson's ration (0.15), a is the radius of the contact area and l is the radius of the relative stiffness.



Frictional Stresses

- The frictional stress σ_f in kg/cm² is given by the equation

$$\sigma_f = \frac{WLf}{2\times10^4}$$

where W is the unit weight of concrete in kg/cm² (2400), f is the coefficient of sub grade friction (1.5) and L is the length of the slab in meters

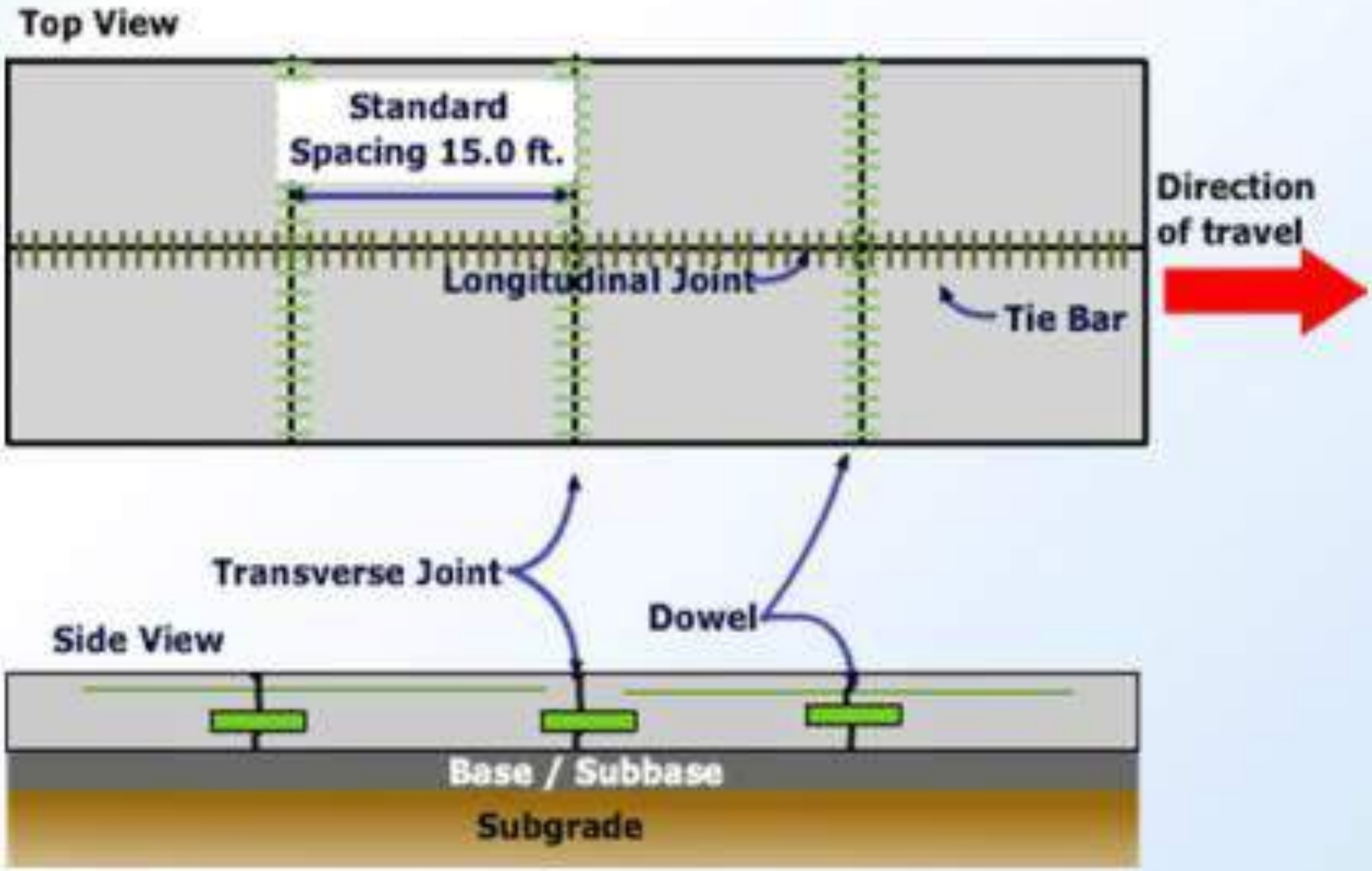
Combination of Stresses

The cumulative effect of the different stress give rise to the following thee critical cases:

Summar, Mid Day	• **The critical stress is for edge region given by** $\sigma_{critical} = \sigma_e + \sigma_{te} - \sigma_f$
Winter, Mid Day	• **The critical combination of stress is for the edge region given by** $\sigma_{critical} = \sigma_e + \sigma_{te} + \sigma_f$
Mid Nights	• **The critical combination of stress is for the corner region given by** $\sigma_{critical} = \sigma_e + \sigma_{tc}$

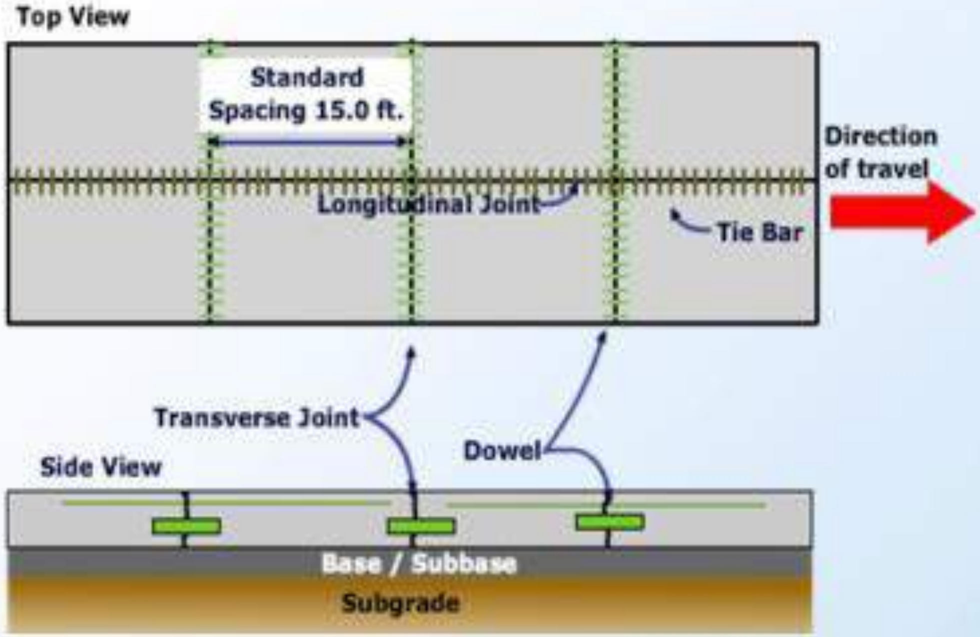
Design of Joints

Design of Joints



Introduction

- Joints in cement concrete pavements are provided in order to reduce temperature stresses
- Transverse joints in cement concrete pavements are constructed using Dowel bars and longitudinal joints with suitable Tie bars



Design of Joints in Cement Concrete Pavements

Various types of joints provided in cement concrete pavements to reduce temperature stresses are

- Expansion Joint
- Contraction Joint
- Warping Joint

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)

Spacing of Expansion Joints

- The gap in Expansion joint depends upon the length of Slab
- Greater the distance between the expansion joints,the greater is the width required of the gap for expansion
- If δ is the maximum expansion in a slab of length L_e with a temperature rise from T_1 to T_2

$$\delta' = L_e C\,(T_2 - T_1)$$

where,

C = The thermal Expansion of concrete per degree rise in temperature

- The joint filler may be assumed to be compressed upto 50 percent of its thickness and therefore, the expansion joint gap should be twice the allowable expansion in concrete, i.e.,2 δ'.
- From the relation given above, if δ is half the joint width, the spacing of expansion joint L_e, is given by equation

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

Contraction Joints

- The purpose of the contraction joint is to allow the contraction of the slab due to fall in slab temperature below the construction temperature. The design considerations are:
- The movement is restricted by the sub-grade friction
- Design involves the length of the slab given by:

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

where,

S_c = The allowable stress in tension in cement concrete and is taken as 0.8 kg/cm^2,

W = The unit weight of the concrete which can be taken as 2400 kg/cm^3 and

f = The coefficient of sub-grade friction which can be taken as 1.5

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

Spacing of Construction Joints

- The slab contracts due to the fall in slab temperature below the construction temperature
- This movement is resisted by the subgrade drag or friction between the bottom fibre of the slab and the subgrade
- When reinforcement is provided it is assumed that the reinforcement takes the entire tensile force in the slab, caused by the frictional resistance of subgrade and hair cracks are allowed, then

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

$$L_c = \frac{200 * S_s * A_s}{b * h * W * f}$$

where,

A_s = Total area of steel, cm^2 across the slab width

L_c = Spacing between contraction joints, m

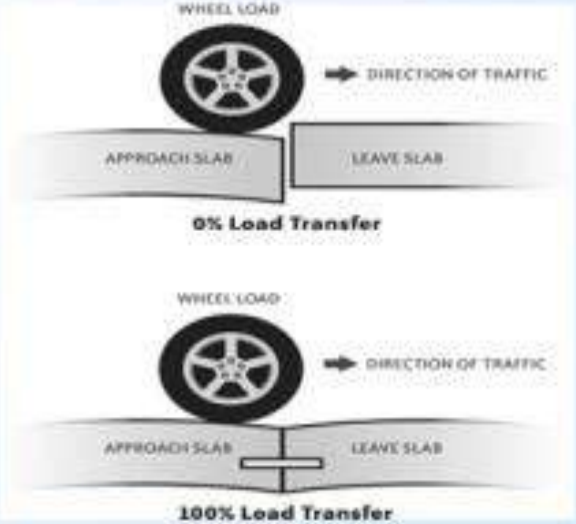
b = Slab width, m

h = Slab thickness, cm

W = Unit weight of cement concrete, kg/m^3

Bradbury's Analysis

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



$$P_s = 0.785 * d^2 * F_s$$

$$P_f = \frac{2 * d^3 * F_f}{L_d + 8.8 * \delta}$$

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

where,

P = The load transfer capacity of a single dowel bar in shear s, bending f and bearing b,

d = The diameter of the bar in cm,

L_d = The length of the embedment of dowel bar in cm,

δ' = The joint width in cm, F_s, F_f, F_b are the permissible stress in shear, bending and bearing for the dowel bar in kg/cm^2

Design Procedure

Step 1:- Find the length of the dowel bar embedded in slab L_d

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

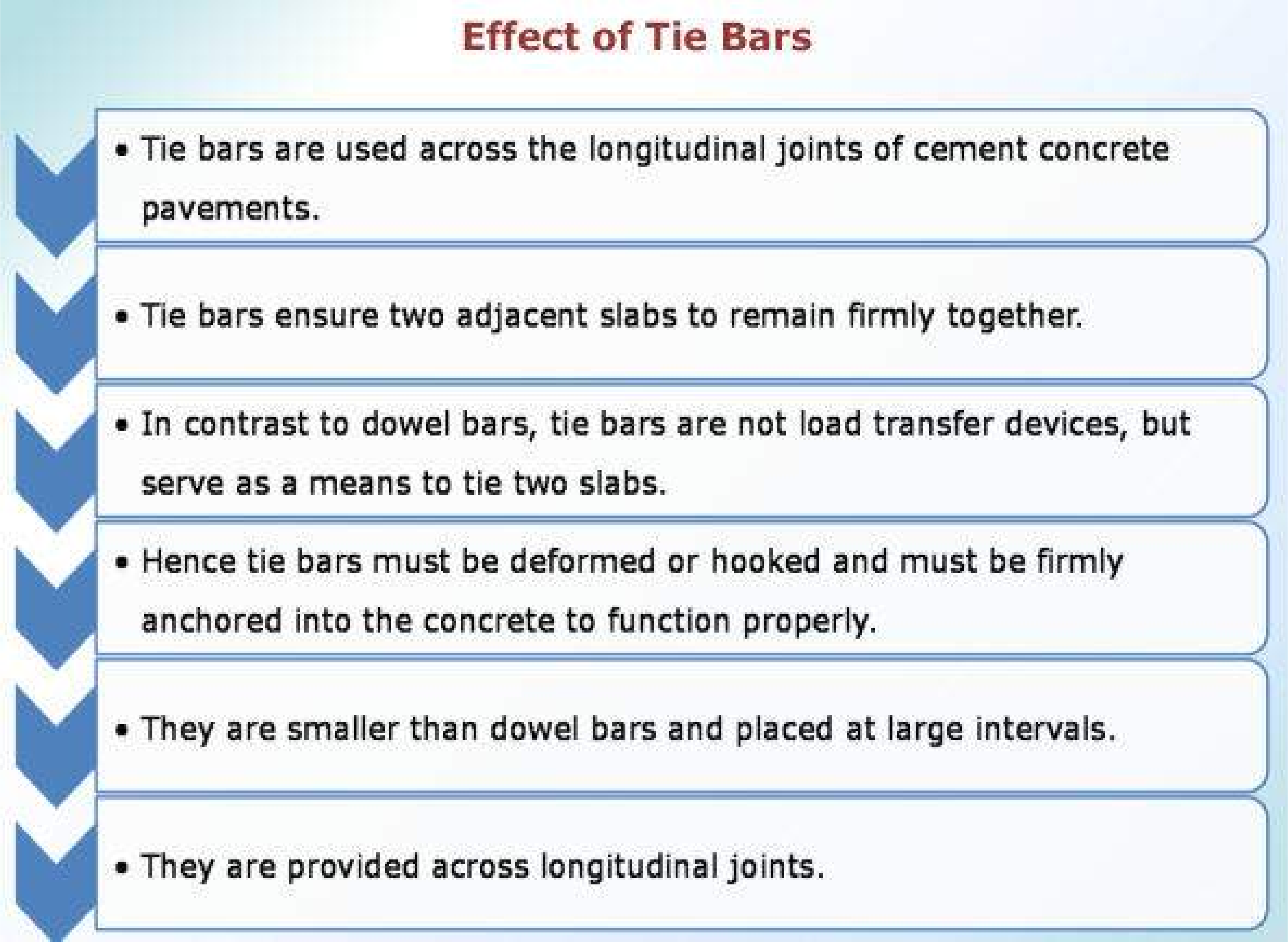
Step-3:- Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor f as

$$\max\left\{\frac{0.4P}{P_s}, \frac{0.4P}{P_f}, \frac{0.4P}{P_b}\right\}$$

Design Procedure

Step 4:- Spacing of the dowel bars

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



Effect of Tie Bars

- Tie bars are used across the longitudinal joints of cement concrete pavements.
- Tie bars ensure two adjacent slabs to remain firmly together.
- In contrast to dowel bars, tie bars are not load transfer devices, but serve as a means to tie two slabs.
- Hence tie bars must be deformed or hooked and must be firmly anchored into the concrete to function properly.
- They are smaller than dowel bars and placed at large intervals.
- They are provided across longitudinal joints.

Diamater & Spacing

- The diameter and the spacing is first found out by equating the total sub-grade friction to the total tensile stress for a unit length (one meter).
- Hence the area of steel per one meter in cm² is given by:

$$A_s * S_s = b * \frac{h}{100} * W * f$$

$$A_s = \frac{b * h * W * f}{100 * S_s}$$

where,

A_s = Area of steel per metre length of joint, cm²

b = Distance between the joint and nearest free edge, m

h = Thickness of pavement, cm

f = Coefficient of friction between pavement and subgrade

W = Unit weight of cement concrete, kg/m³

S_s = Allowable working stress in tension for steel, kg/cm²

Length of Tie Bars

- Length of the tie bar is twice the length needed to develop bond stress equal to the working tensile stress and is given by

$$a_s * S_s = \frac{L_t}{2} * P * S_b$$

$$L_t = \frac{2 * a_s * S_s}{P * S_b}$$

Substituting a, = n $d^2/4$ and P = nd,

$$L_t = \frac{d * S_s}{2 * S_b}$$

Hence total length of tie bar

$$L_t = \frac{2 * a_s * S_s}{P * S_b} = \frac{d * S_s}{2 * S_b}$$

Length of Tie Bars

where,

$L_t/2$ = Length of tie bar on one side of slab, cm or half length of tie bar

S_s = Allowable stress in tension, kg/cm^2

S_b = Allowable bond stress in concrete, kg/cm^2 (taken as 24.6 kg/cm^2 for deformed bars and 17.5 kg/cm^2 in plain tie bars)

a_s = Cross sectional area of one tie bar, cm^2

P = Perimeter of tie bar, cm

d = Diameter of tie bar, cm