# TRANSPORTATION ENGINEERING-I

## Unit 3:Design of Pavements

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# PAVEMENT

**Pavement: A layered structure supported by soil subgrade to form the carriageway of a road is called road pavement .**

- It is of two types
  - Flexible pavement or bituminous pavement or black top pavement
  - Rigid pavement or cement concrete pavement or white surface pavement

# Purpose of road pavement

- To carry heavy loads of vehicular traffic and to distribute the same over the larger area underlying subgrade soil.
- To prevent the subgrade soil from bad effect of weathering agencies.
- To provide a smooth riding surface.

# Types of road pavement

- Flexible pavement
- Rigid pavement

**Flexible pavement:** The road pavements which can change their shape to some extent without any rupture are known as flexible pavements.

Any change of shape occuring in the subgrade and subsequent layers over it,is reflected on the top surface of the pavement.

**Examples:** All bituminoud roads, gravel roads, water bound macadam roads, wet mix macadam roads etc.

# Rigid pavement

- The road pavement which can not change their shape without rupture are known as rigid pavements.
- Any change of shape occuring in the subgrade is not reflected by the surface of these pavements.

Examples; Cement Concrete pavements,Reinforced Cement Concrete pavements etc.

# Types of Rigid Pavements

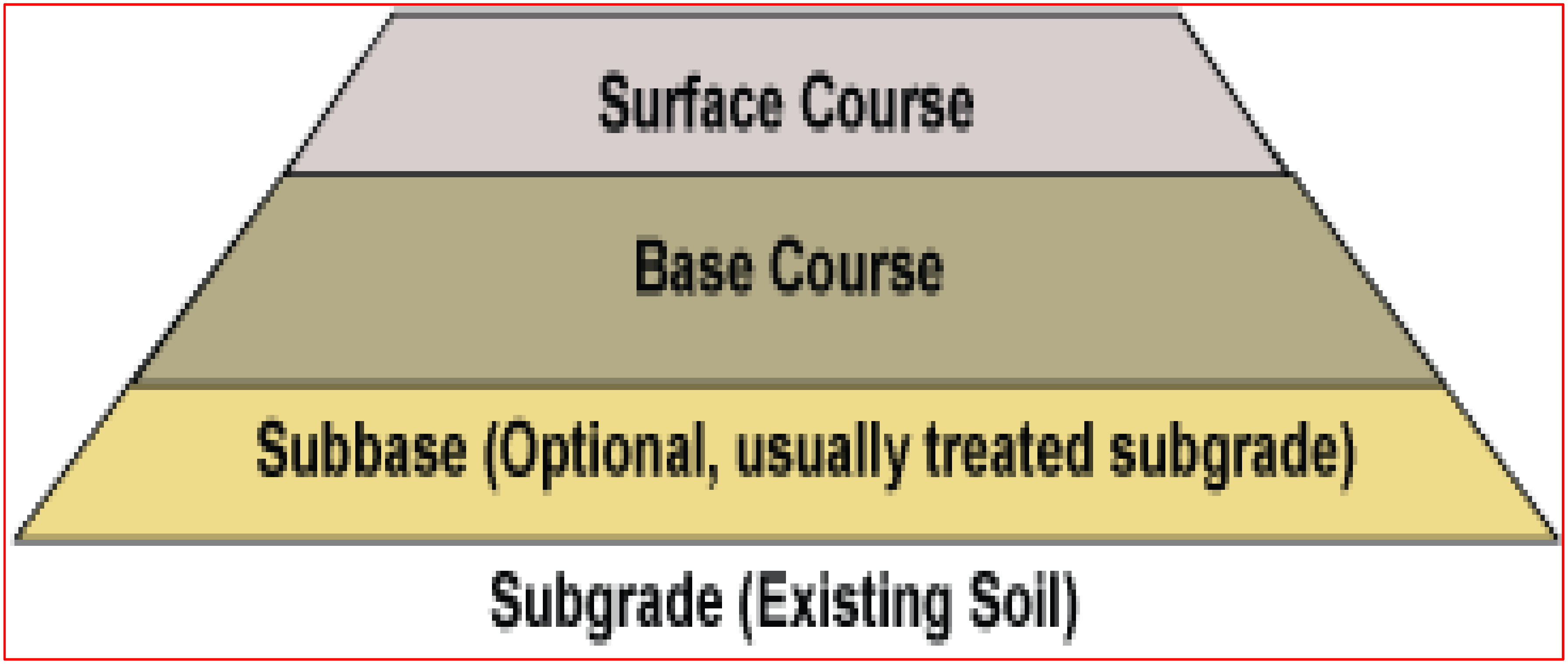
- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),
- Continuous reinforced concrete pavement (CRCP)
- Pre-stressed concrete pavement (PCP).


Rigid
Paveme
nt

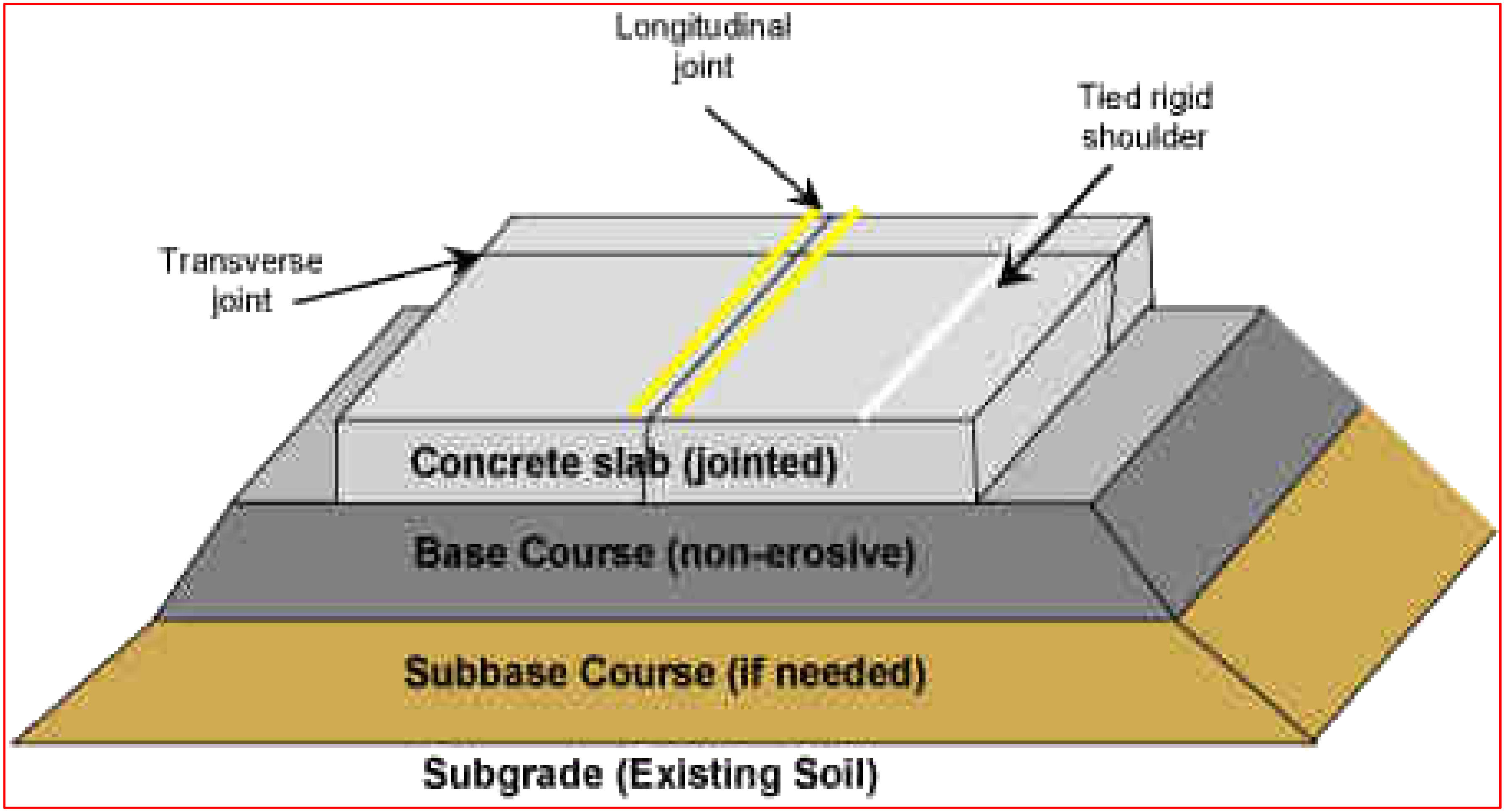

Flexible
pavement

# Cross section of Flexible and rigid pavements

# c/s of flexible pavement



# c/s of rigid pavement



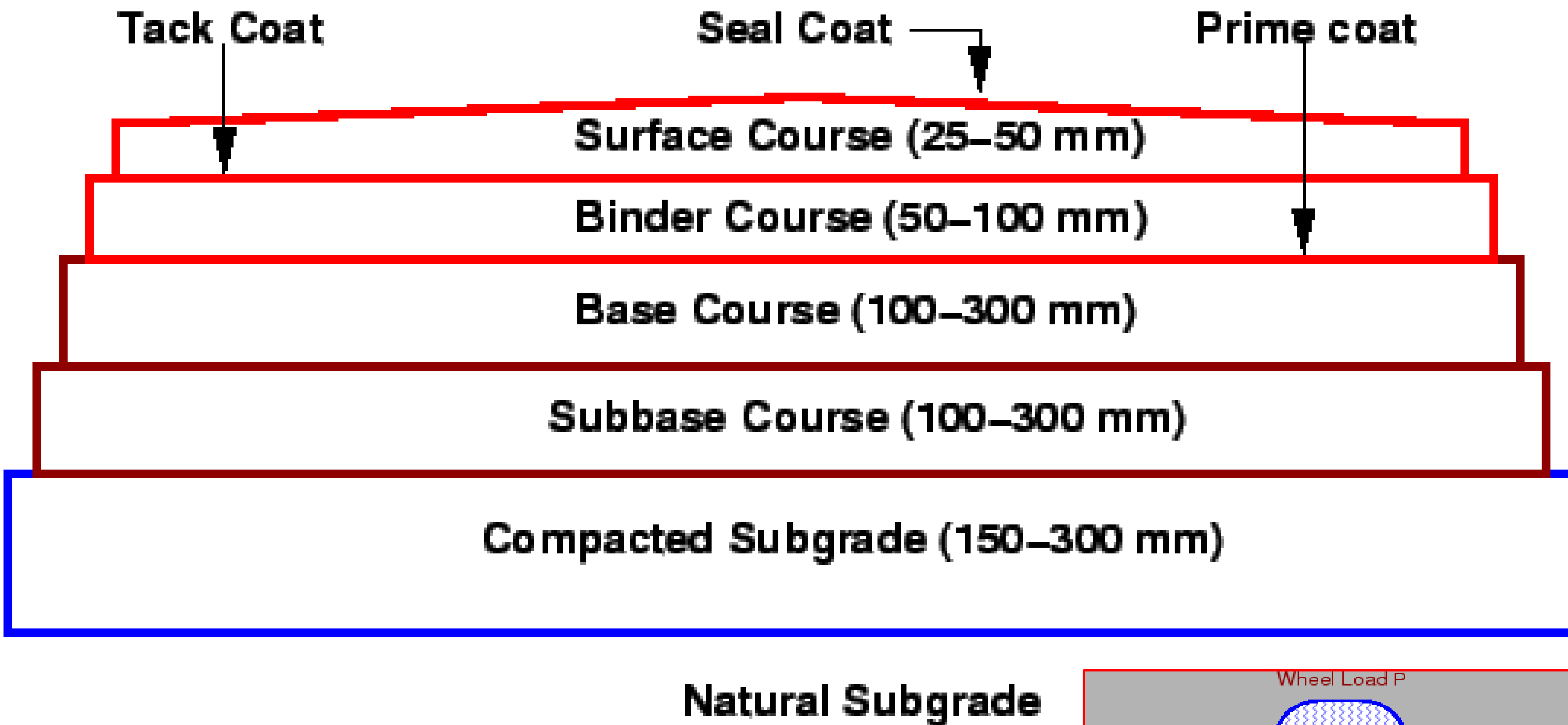
## COMPARISON OF FLEXIBLE PAVEMENT & RIGID PAVEMENT

### FLEXIBLE PAVEMENT

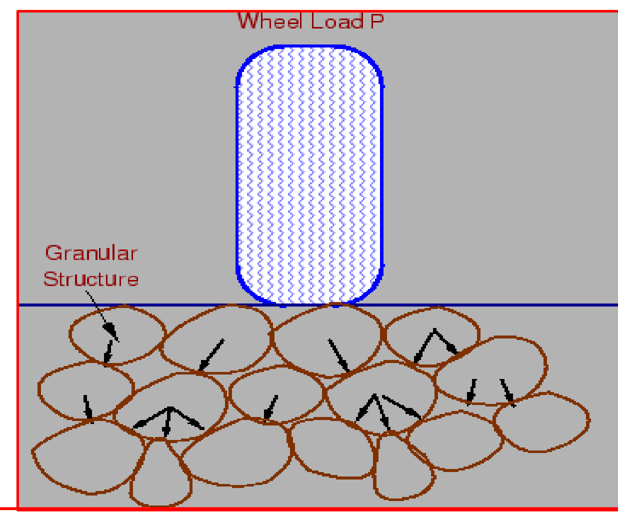
1. Have low flexural strength
2. Load is transferred by grain to grain contact
3. Surfacing cannot be laid directly on the sub grade but a sub base is needed
4. No thermal stresses are induced
5. expansion joints are not needed
6. Design life 10-15 years
7. Initial cost of construction is low
8. Maintenance cost is high
9. Road can be used for traffic within 24 hours
10. Damaged by Oils and Certain Chemicals

### RIGID PAVEMENT

1. Have more flexural strength
2. No such phenomenon of grain to grain load transfer exists
3. Surfacing can be directly laid on the sub grade
4. Thermal stresses are induced
5. expansion joints are needed
6. Design life 20-30 years
7. Initial cost of construction is high
8. Less maintenance cost
9. Road cannot be used until 14 days of curing
10. No Damage by Oils and other chemicals




c/s of flexible pavement




Load is transferred by grain to grain contact

# Typical layers of a flexible pavement

- **Sub-Base course:** The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage.
- It may WBM or WMM
- A sub-base course is not always needed or used. For example, a pavement constructed over a high quality.
- **Sub-grade:** The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed.
- It should be compacted to the desirable density, near the optimum moisture content.

# Typical layers of a flexible pavement

**Binder course:**

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

**Base course:**

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

# Typical layers of a flexible pavement

## Surface course:

- Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete(AC).
- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It provide a smooth and skid- resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

# Typical layers of a flexible pavement

**Seal Coat:** Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance and to seal the surfacing against the ingress of water.

**Tack Coat:** Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course.it is generally applied on impervious surface.

**Prime Coat:** Prime coat is an application of low viscous liquid bituminous material over an existing porous or absorbent pavement surface like WBM.

- Prime objective is to plug the capillary voids of the porous surface and to bond the loose materials on the existing surface like granular bases on which binder layer is placed. It provides bonding between two layers.

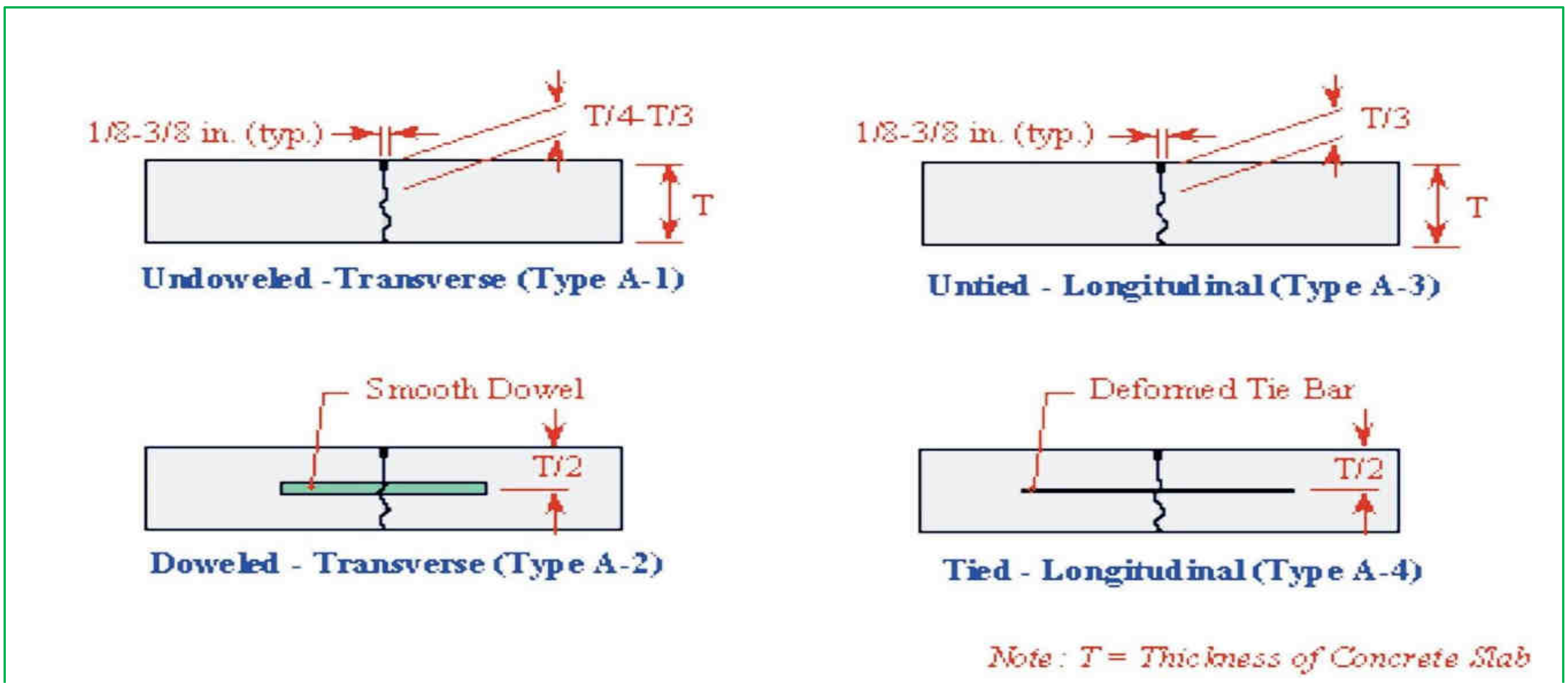

Prime coat
Seal coat

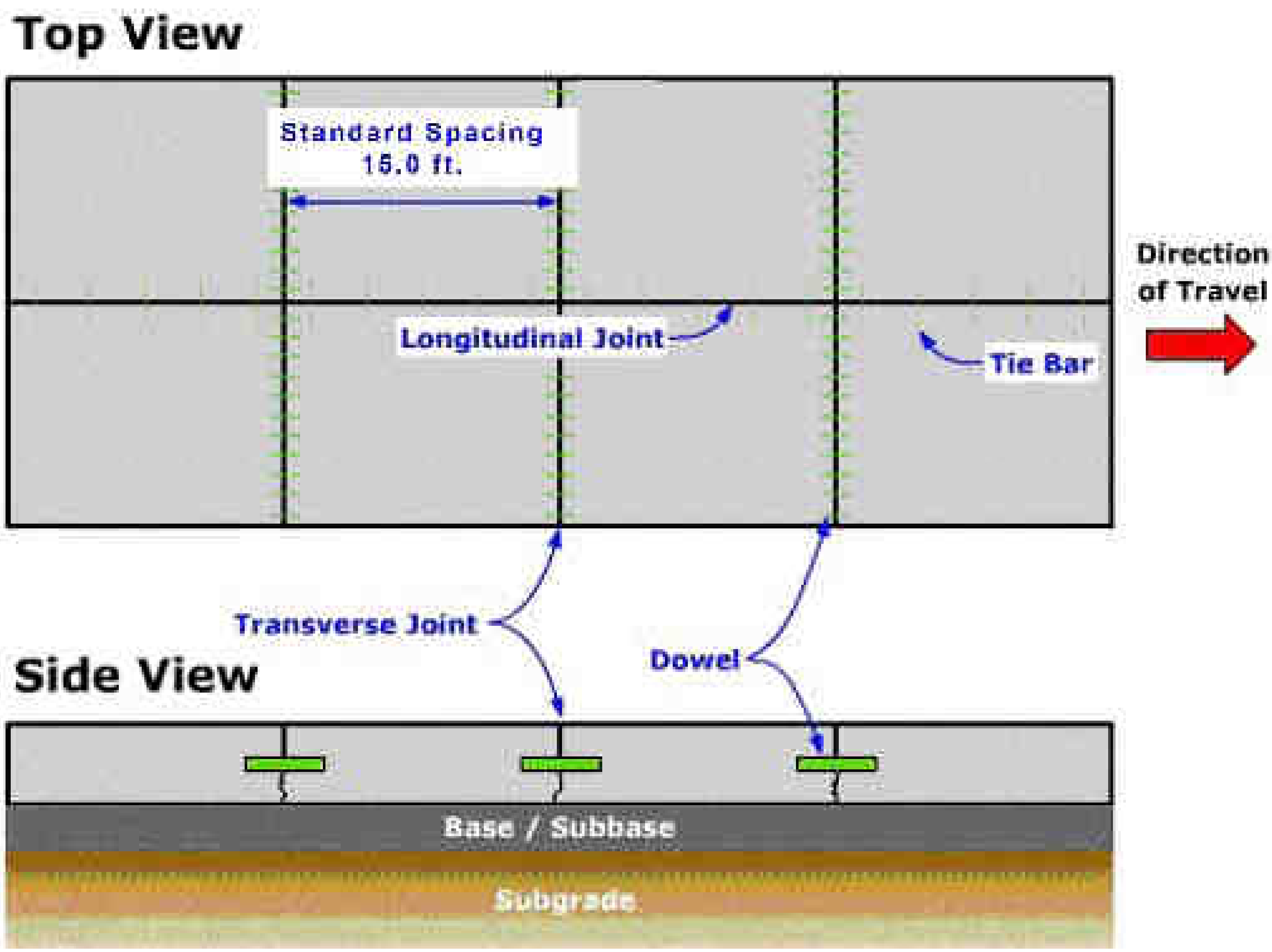
# Types of Rigid Pavements

- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),
- Continuous reinforced concrete pavement (CRCP)

# Types of Rigid Pavements

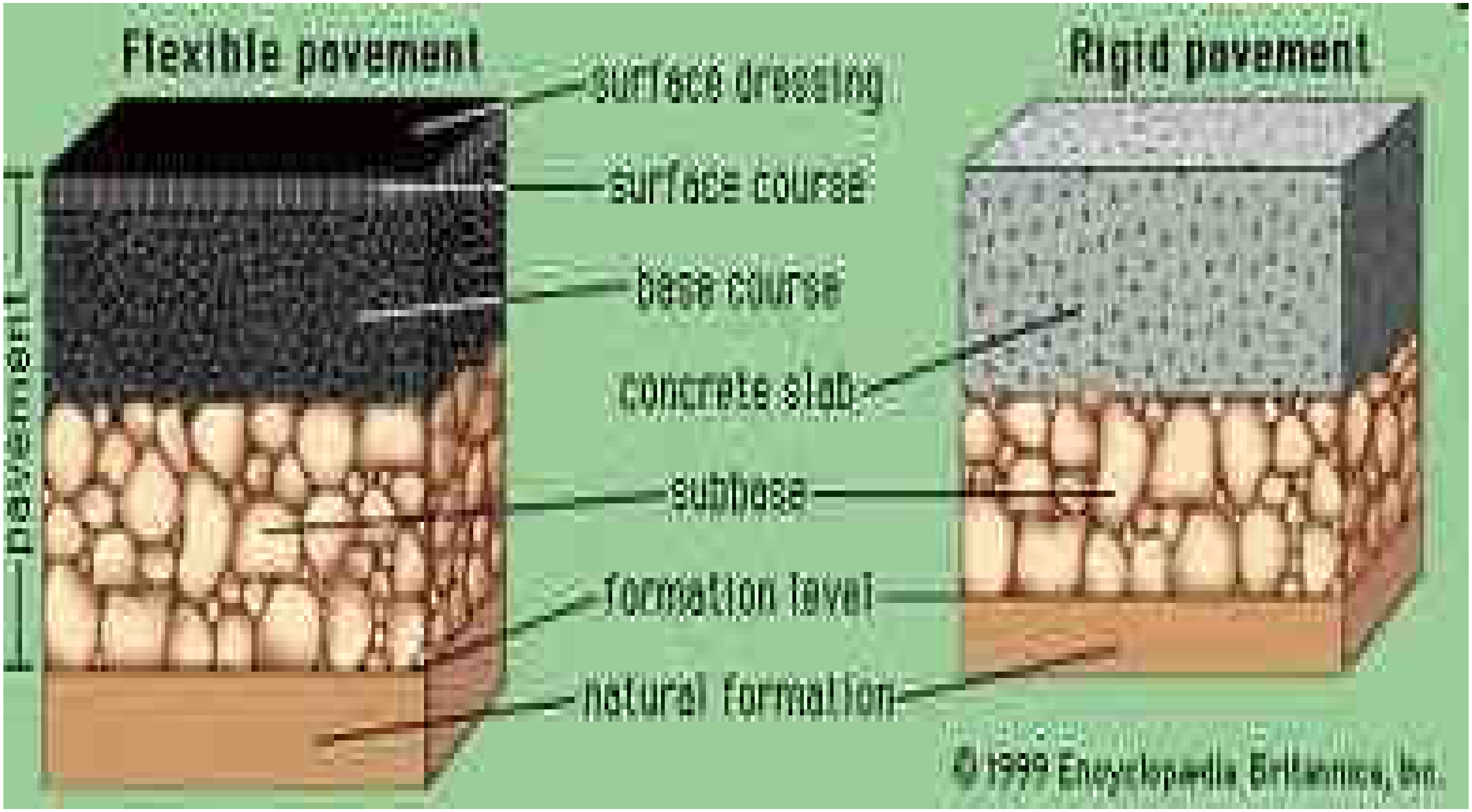
- **Jointed Plain Concrete Pavement:** constructed with closely spaced contraction joints. Dowelbars or aggregate interlocks are normally used for load transfer across joints. They normally has a joint spacing of 5 to 10m.
- **Jointed Reinforced Concrete Pavement:** reinforcements do not improve the structural capacity significantly but they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcements help to keep the slab together even after cracks.
- **Continuous Reinforced Concrete Pavement:** Complete elimination of joints are achieved by reinforcement.

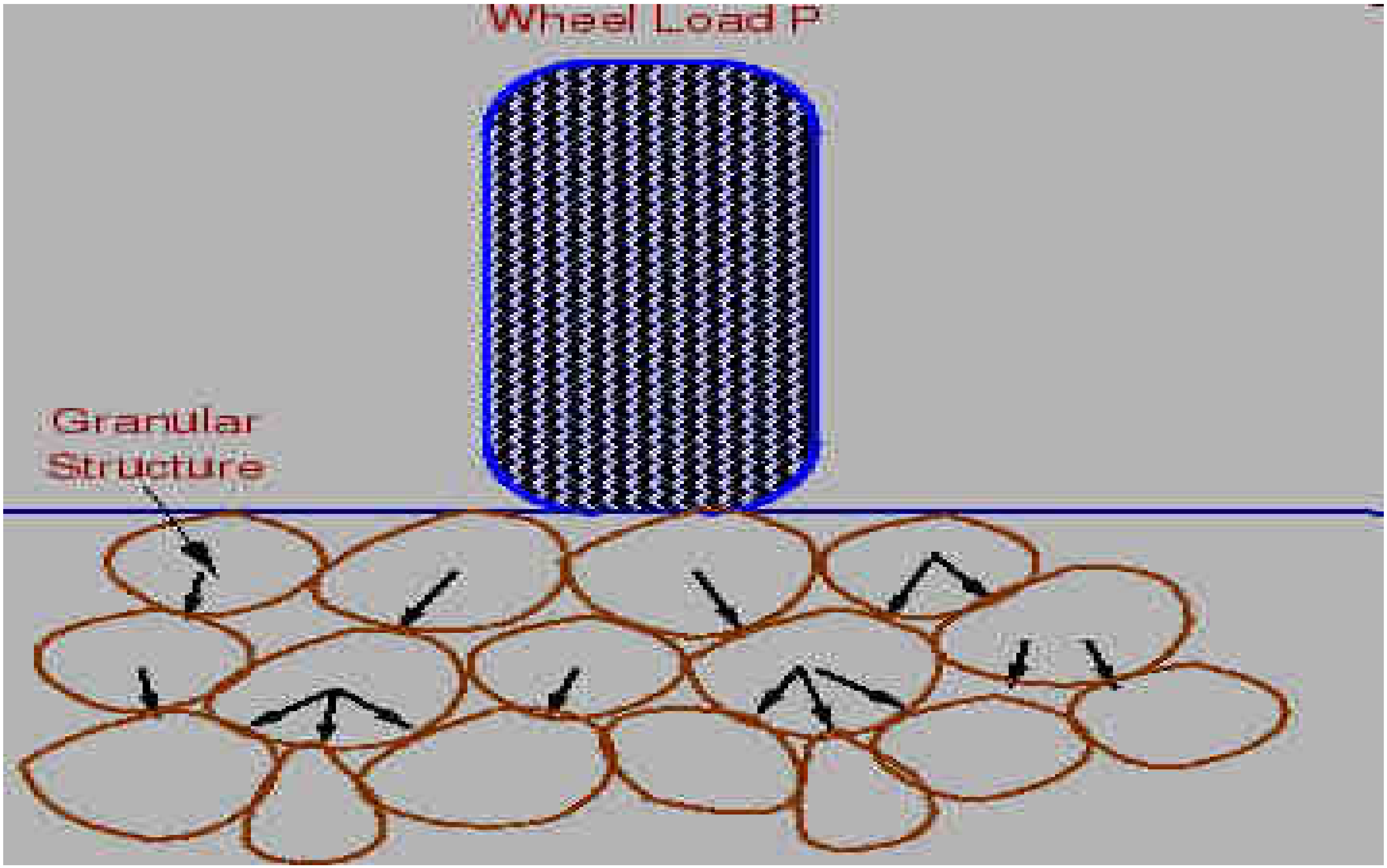

1/8-3/8 in. (typ.)
T/4-T/3
T
Undoweled -Transverse (Type A-1)
1/8-3/8 in. (typ.)
T/3
T
Untied - Longitudinal (Type A-3)
Smooth Dowel
T/2
Doweled - Transverse (Type A-2)
Deformed Tie Bar
T/2
Tied - Longitudinal (Type A-4)
Note : T = Thickness of Concrete Slab


Top View
Standard Spacing
15.0 ft.
Longitudinal Joint
Tie Bar
Direction
of Travel
Transverse Joint
Dowel
Side View
Base / Subbase
Subgrade

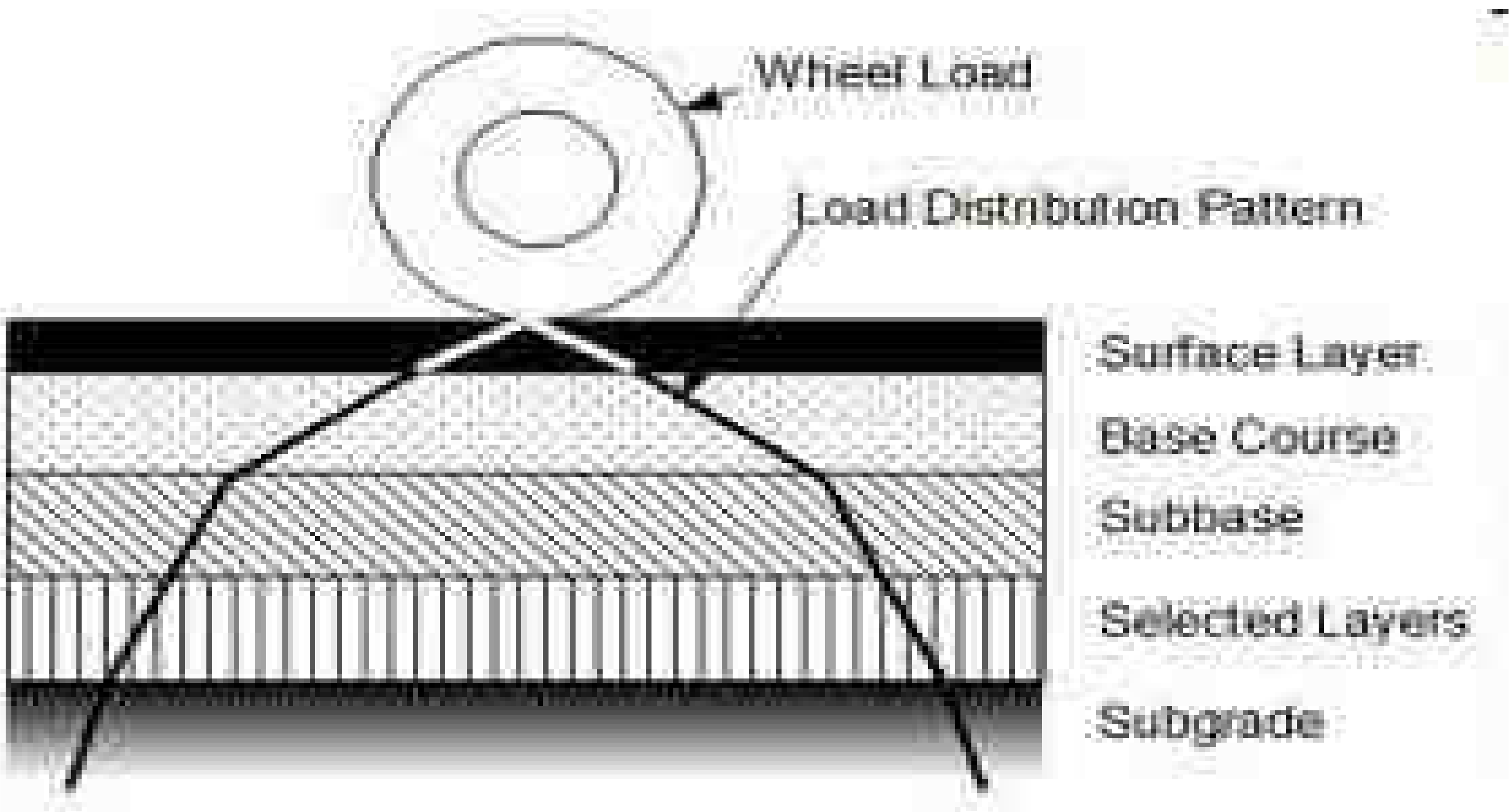

Rigid pavement
Longitudinal joint
Transverse joint

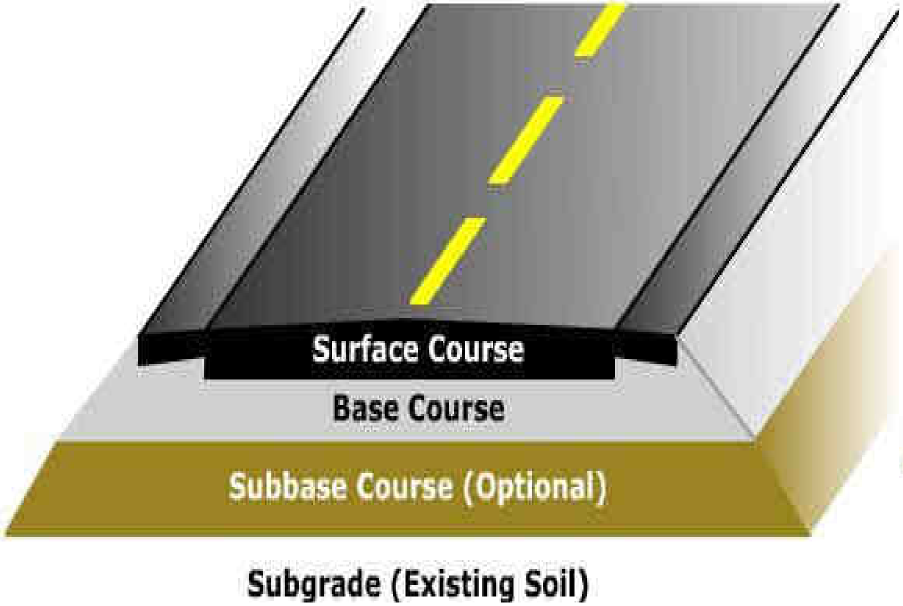
# Types of Pavements

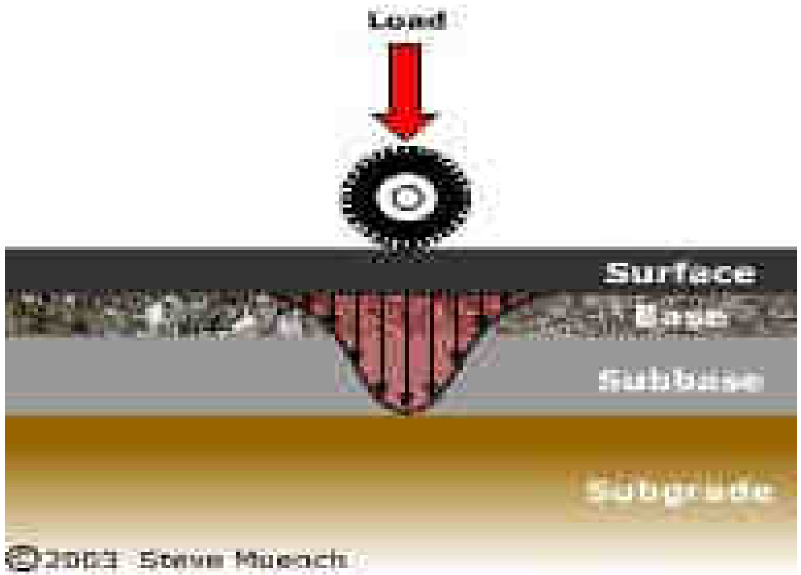


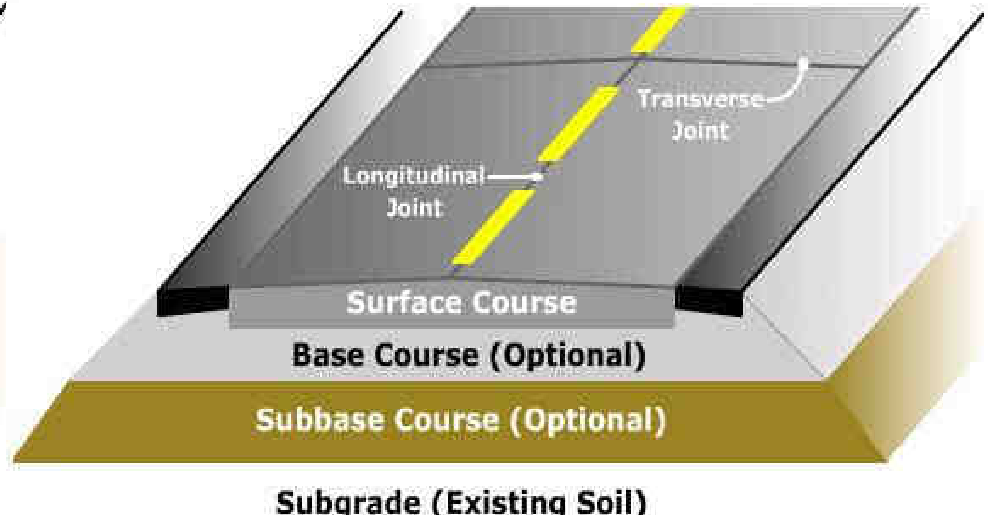

Wheel Load P
Granular
Structure

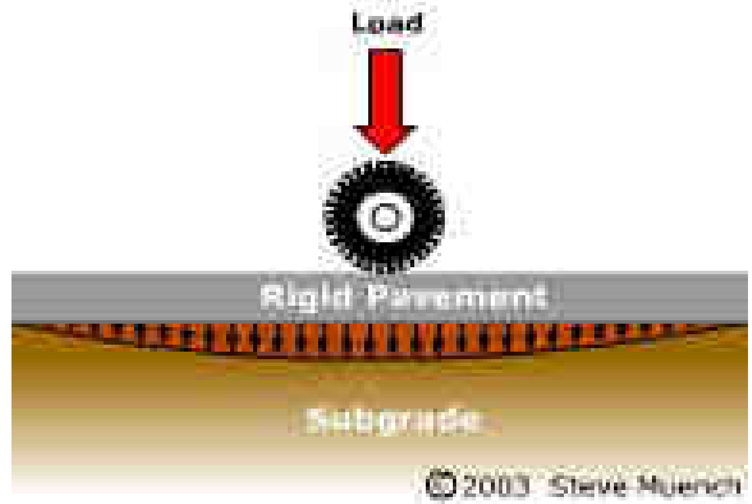
# Wheel Load Distribution





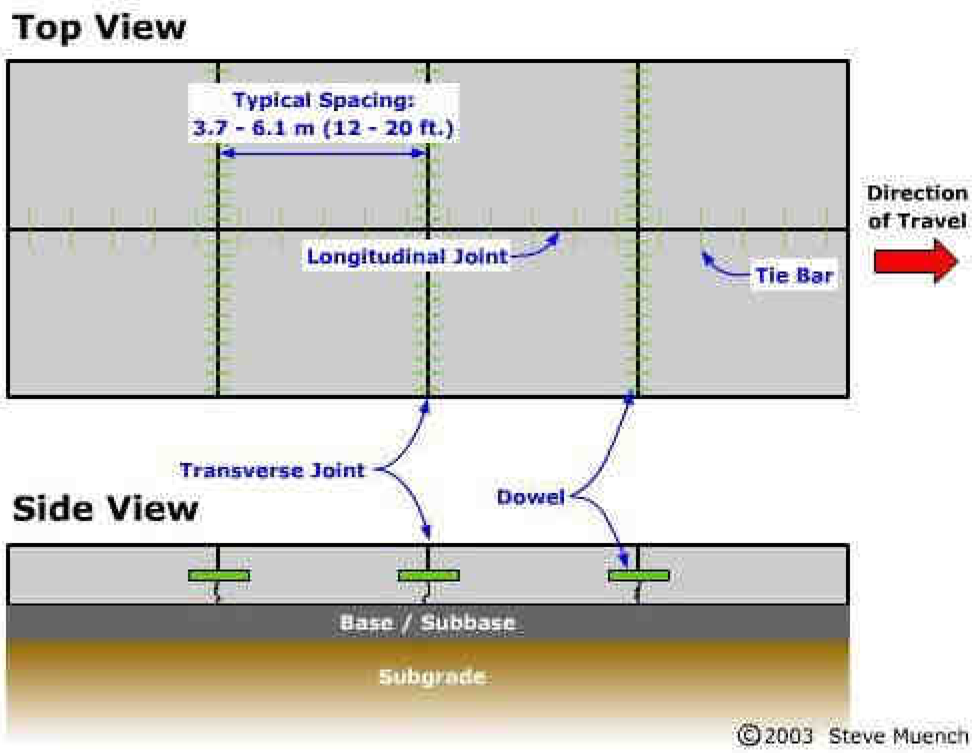



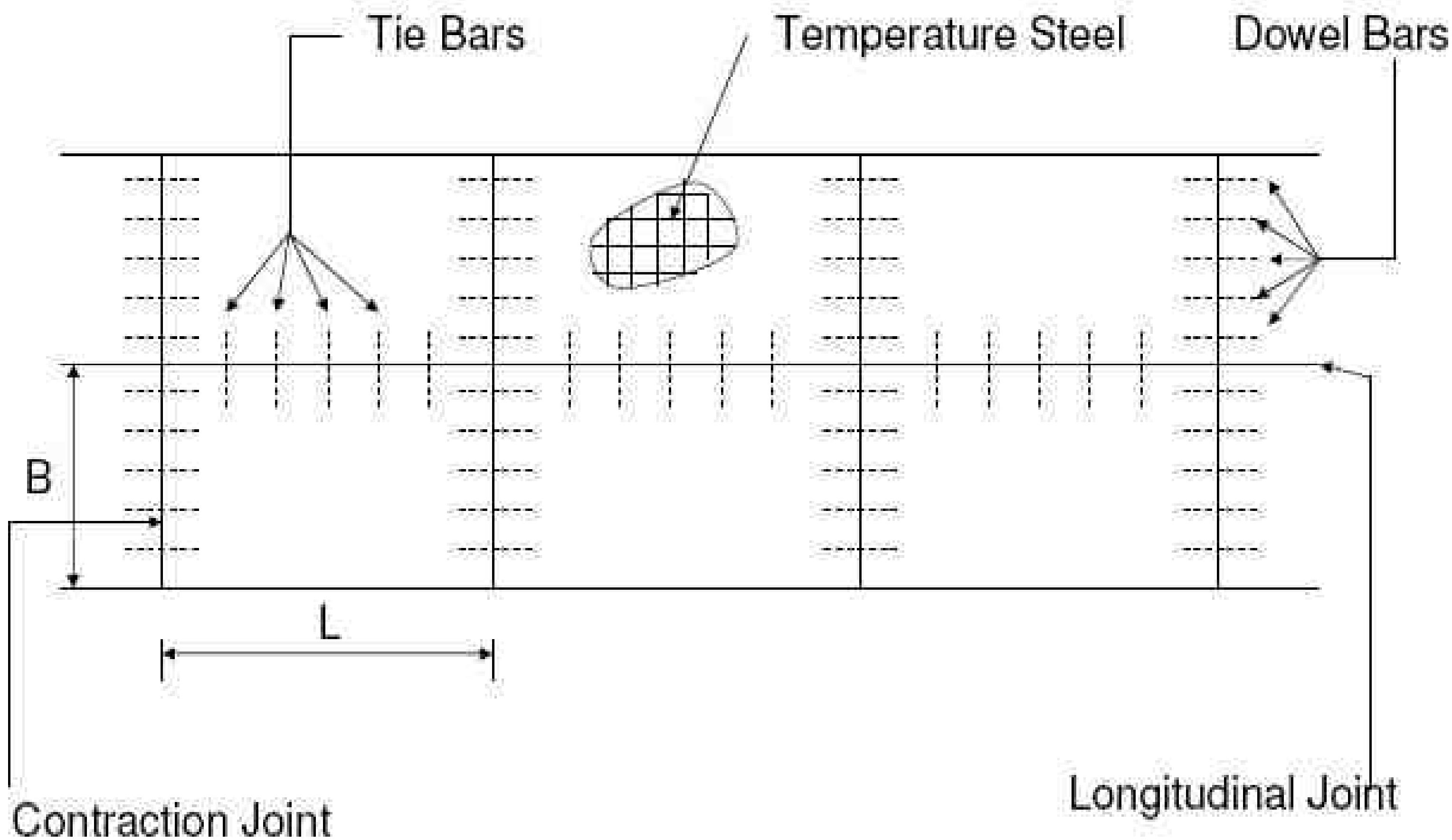

# Flexible

# Rigid

- Jointed Plain Concrete Pavement (JPCP)




# Jointed CC Pavement



# LOAD DISTRIBUTION

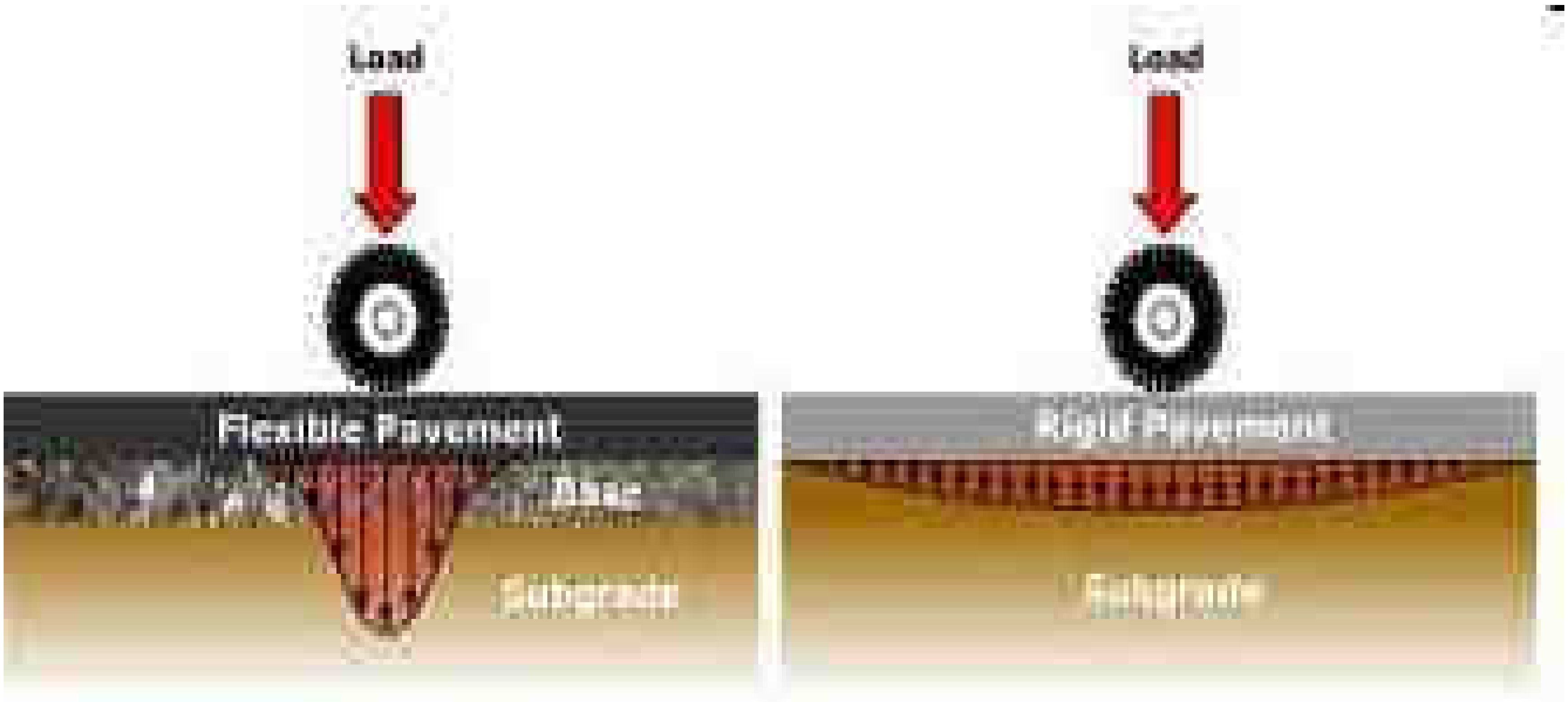
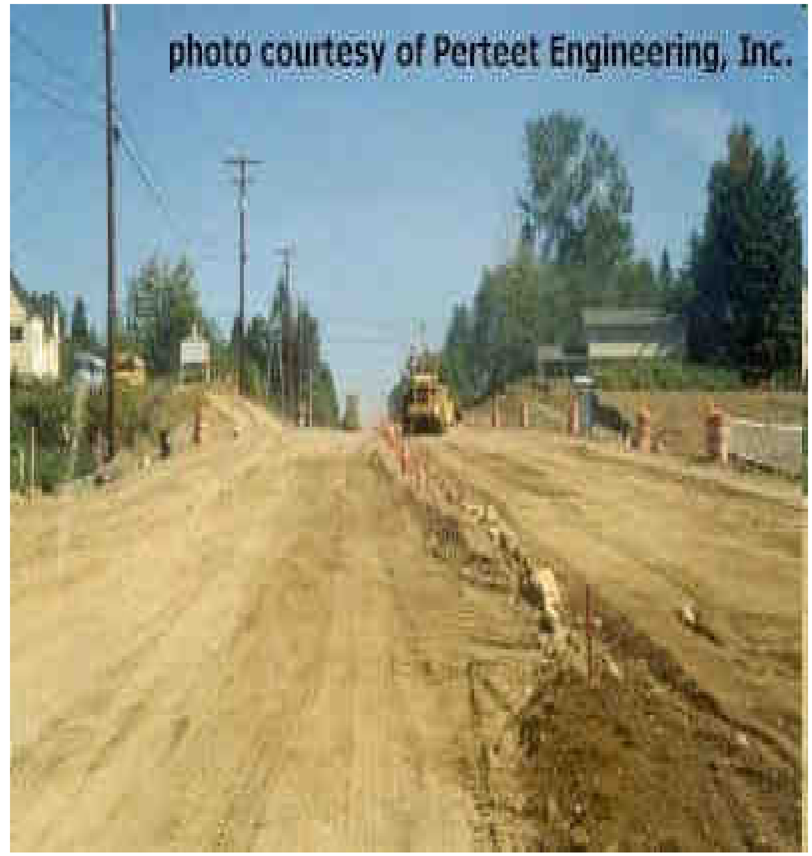



Figure 1: Rigid and Flexible Pavement Load Distribution

## Function and Significance of Subgrade Properties

- Basement soil of road bed.
- Important for structural and pavement life.
- Should not deflect excessively due to dynamic loading.
- May be in fill or embankment.



# Flexible Pavement Design

## IRC (37-2001)

## Basic Principles

- **Vertical stress or strain on sub-grade**
- **Tensile stress or strain on surface course**

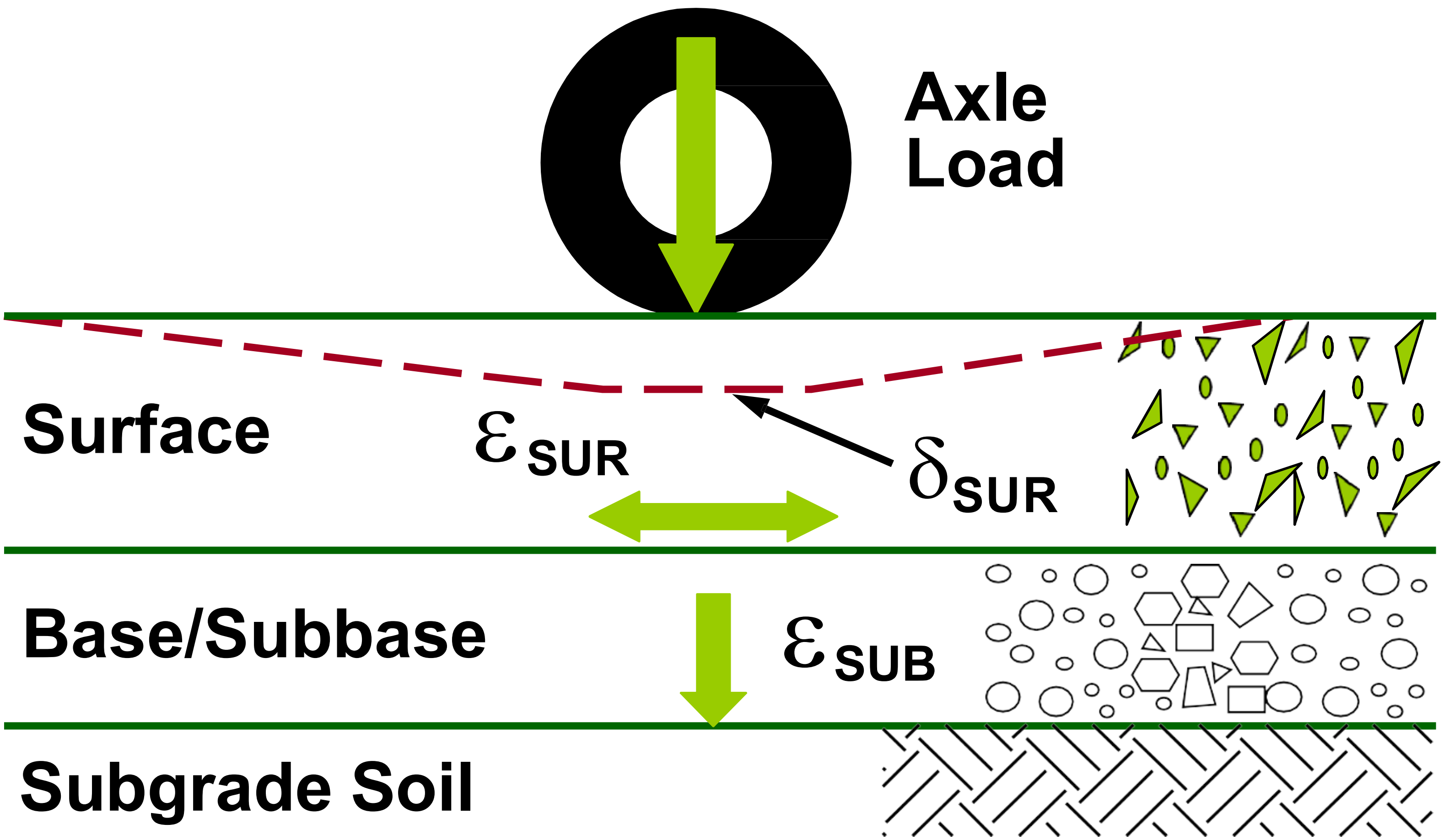
# Guidelines for Design by IRC: 37: 2012

- Design Traffic:
- The recommended method considers design traffic in terms of the cumulative number of standard axles (80 kN) to be carried by the pavement during the design life.
- Only the number of commercial vehicles having gross vehicle weight of 30 kN or more and their axle- loading is considered for the purpose of design of pavement.
- IITPAVE software is used to analyse the stresses and strains developed in the flexible pavements.

# Factors for design of pavements

- 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:(rain fall)
- Pavement component materials
- Environment factors:(height of embankment and its detailed)
- Traffic Characteristics
- Required Cross sectional elements of the alignment

# Pavement Responses Under Load

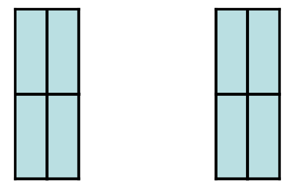


# Axle Configurations

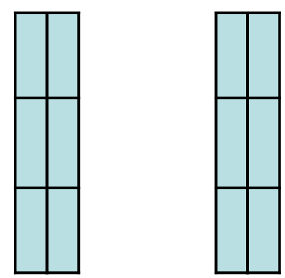
An **axle** is a central shaft for a rotating wheel or gear

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

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

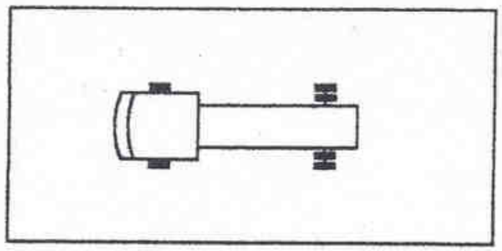


**Tandem Axle**
**(Legal Axle Load = 18t)**

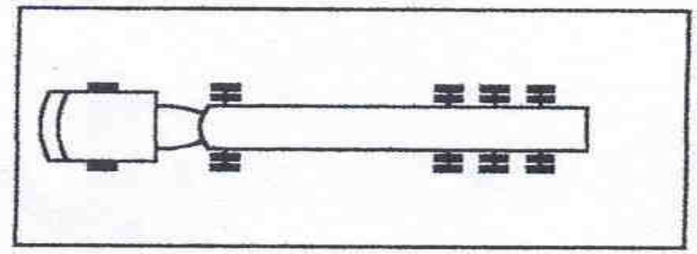


**Tridem Axle**
**(Legal Axle Load = 24t)**

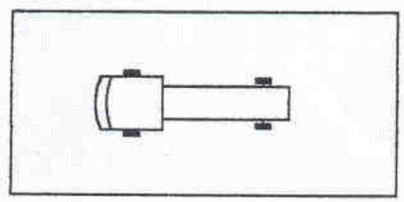
# Truck Configuration



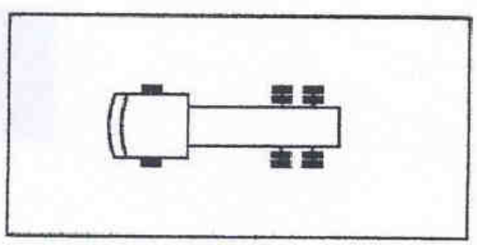
2 Axle Truck – 16t



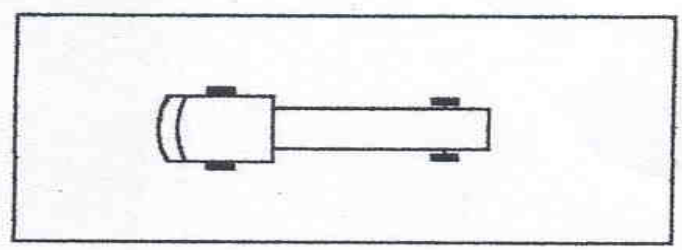
5 Axle Truck – 40t



LCV



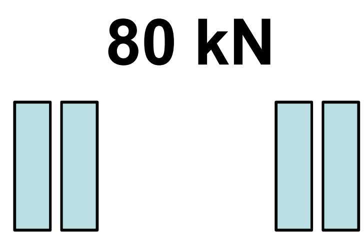
3 Axle Truck – 24t



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**

# Evaluation Of Pavement Component Layers

- **Sub-grade**
  - To Receive Layers of Pavement Materials Placed over it
  - Plate Bearing Test
  - CBR Test
  - Triaxial Compression

## 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 subgarde

# 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
  - 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**

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

  **$n = 4 - 5$**

# INDICATIVE VDF VALUES

| Initial Traffic in terms of CV/PD | Terrain | |
|---|---|---|
| | Plain/Rolling | Hilly |
| 0 – 150 | 1.5 | 0.5 |
| 150 – 1500 | 3.5 | 1.5 |
| > 1500 | 4.5 | 2.5 |

# 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:**

→ for two lane dual carriage way75% of the No. of Commercial Vehicles in each Direction

→For three lane-60%

→For four lane-45%

## Computation of Traffic for Use of Pavement Thickness Design

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

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

$=p(1-r)^x$

P=no. of commercial vehicle as per last count

X=no. of year between the last count and the year of completion of construction

F = Vehicle Damage Factor

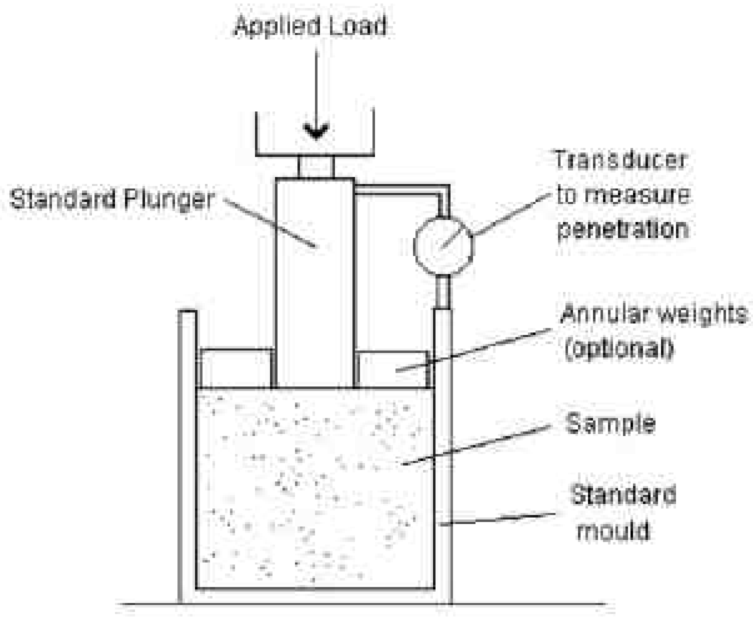
n = Design life in years

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.



# Subgrade

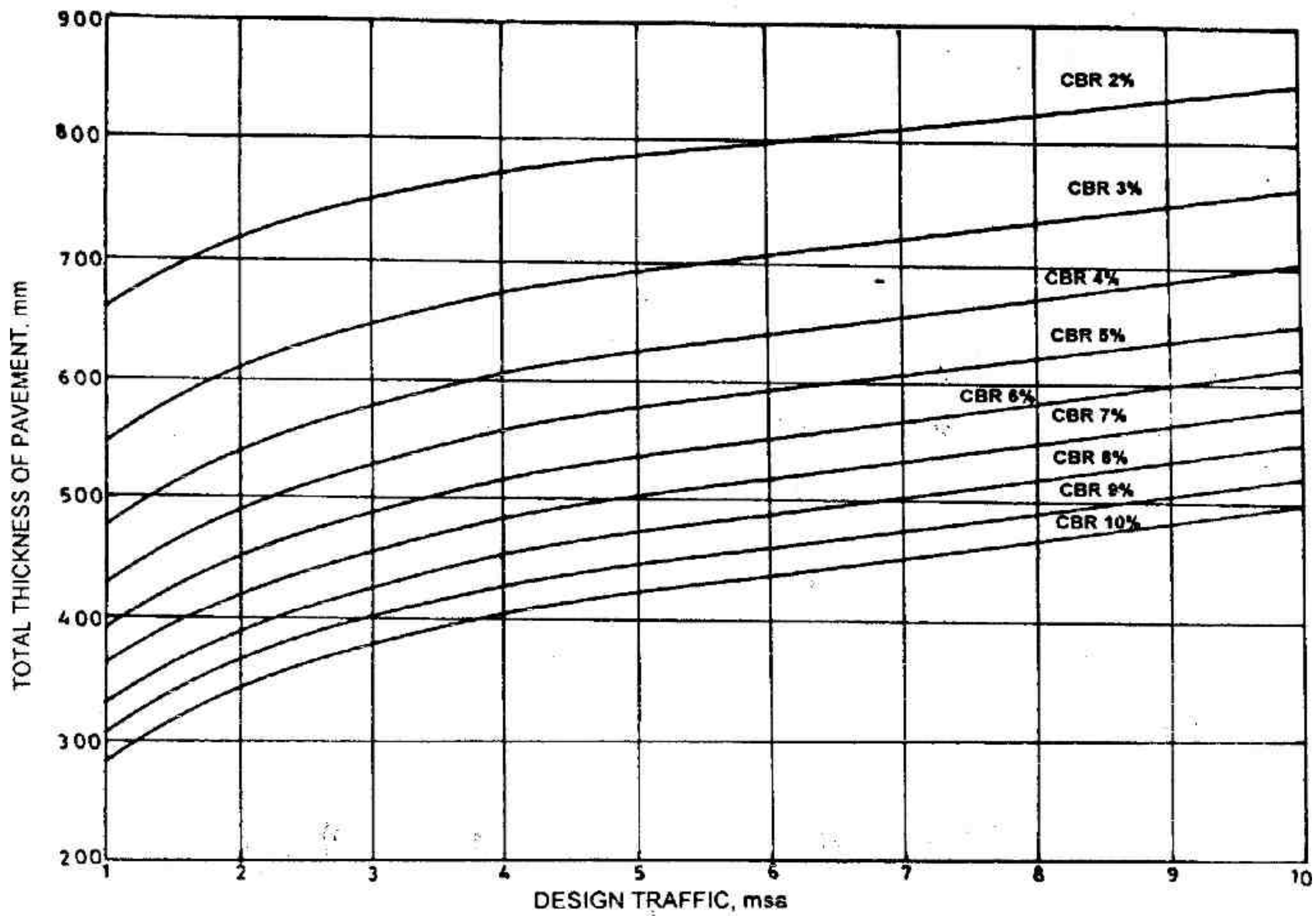
- **Soak the Specimen in Water for FOUR days and CBR to be Determined.**
- **Use of Expansive Clays NOT to be Used as Sub-grade**
- **Non-expansive Soil to be Preferred.**

# Subgrade

- **Subgrade to be Well Compacted to Utilize its Full Strength**

- **Top 500 mm to be Compacted to 97% of MDD (Modified Proctor).**

- **Material Should Have a Dry Density of 1.75 gm/cc.**




Pavement Thickness Design Chart for Traffic 1-10 msa

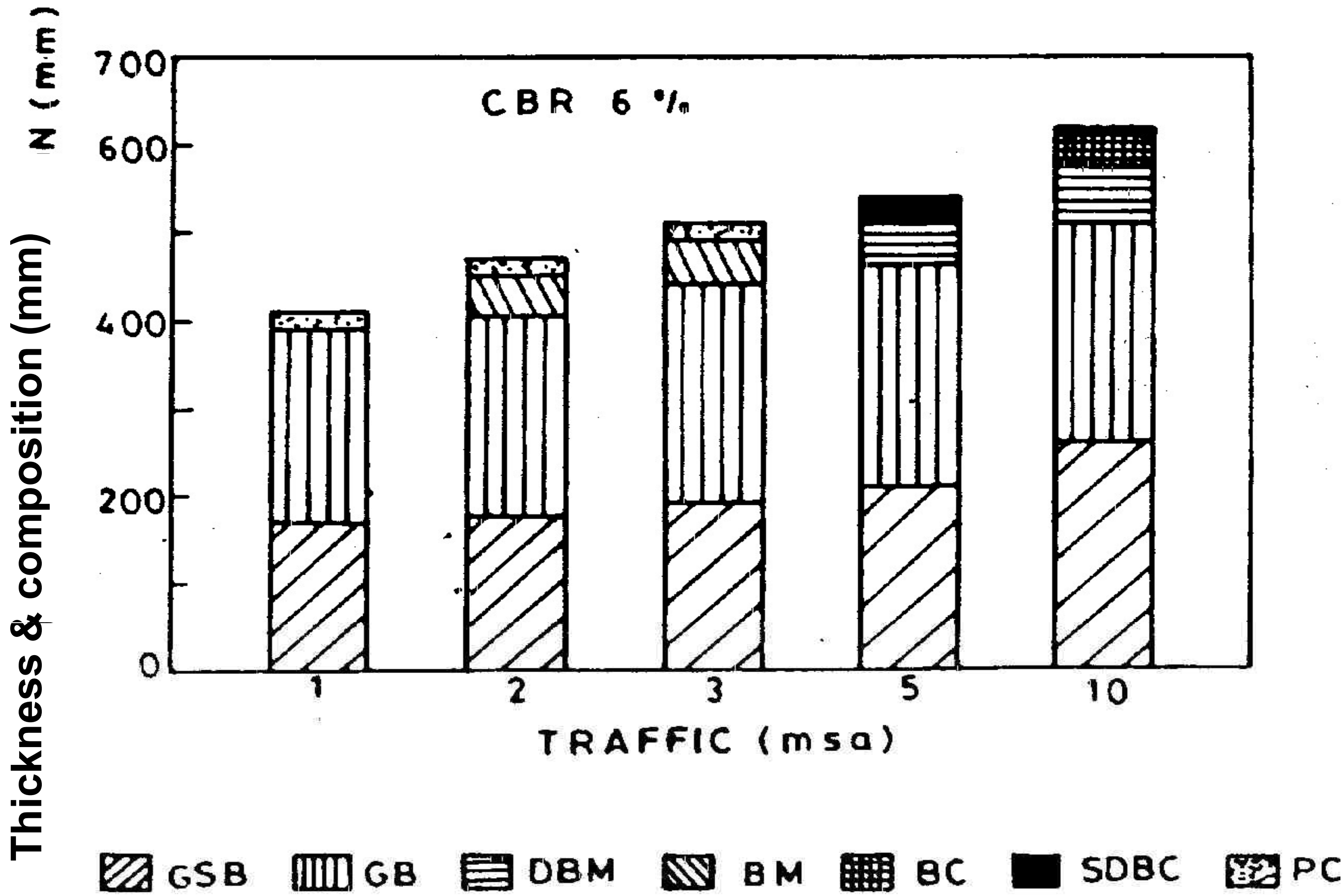
# Flexible pavement design chart (IRC) (for CSA< 10 msa)

## PAVEMENT DESIGN CATALOGUE

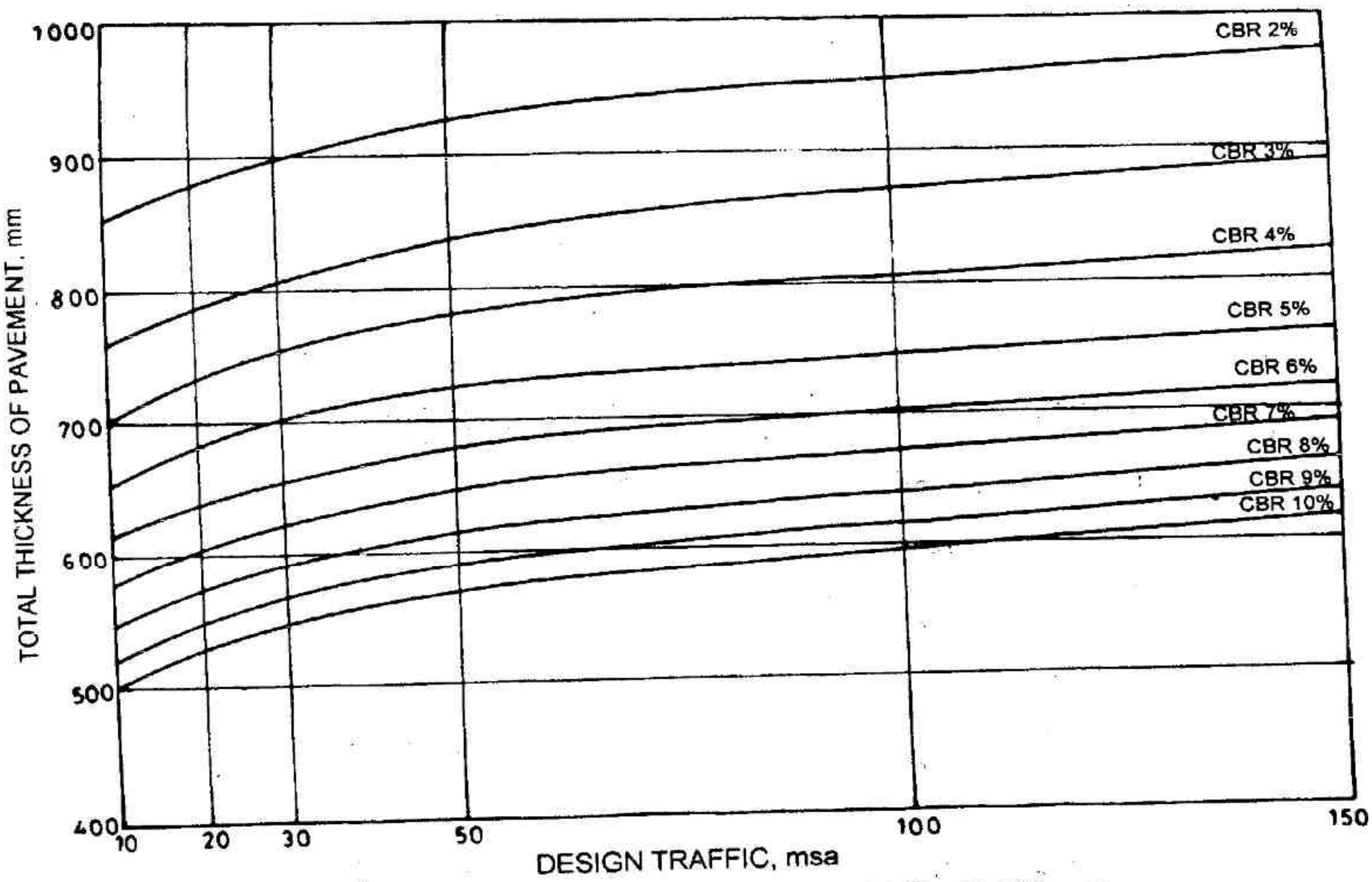
### RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

| CBR 6% | | | | | |
|---|---|---|---|---|---|
| Cumulative Traffic (msa) | Total Pavement Thickness (mm) | PAVEMENT COMPOSITION | | | |
| | | Bituminous Surfacing | | Granular Base (mm) | Granular Sub-base (mm) |
| | | Wearing 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 |
| 5 | 535 | 25 SDBC | 50 DBM | 250 | 210 |
| 10 | 615 | 40 BC | 65 DBM | 250 | 260 |

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




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



Pavement Thickness Design Chart for Traffic 10-150 msa

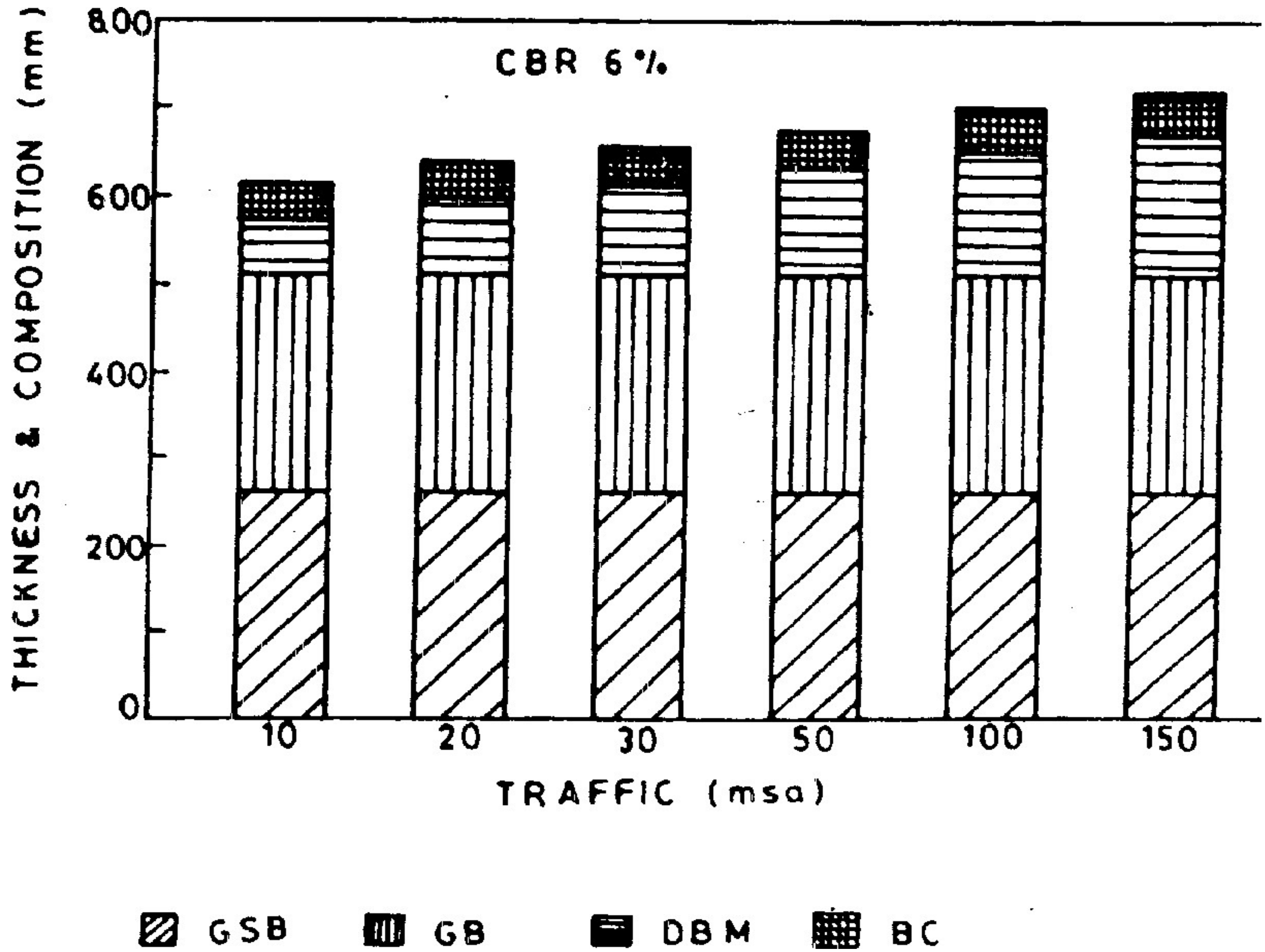
# Flexible pavement design chart (IRC)

**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<br>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)




# 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

# Sub-base

- **Min. CBR 20 % - Traffic up-to 2 msa**
- **Min. CBR 30 %- Traffic > 2 msa**
- **If GSB is Costly, Adopt WBM, WMM**
- **Min. Thickness – 150 mm - <10 msa**
- **Min. Thickness – 200 mm - >10 msa**

# Sub-base

- 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

# 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)

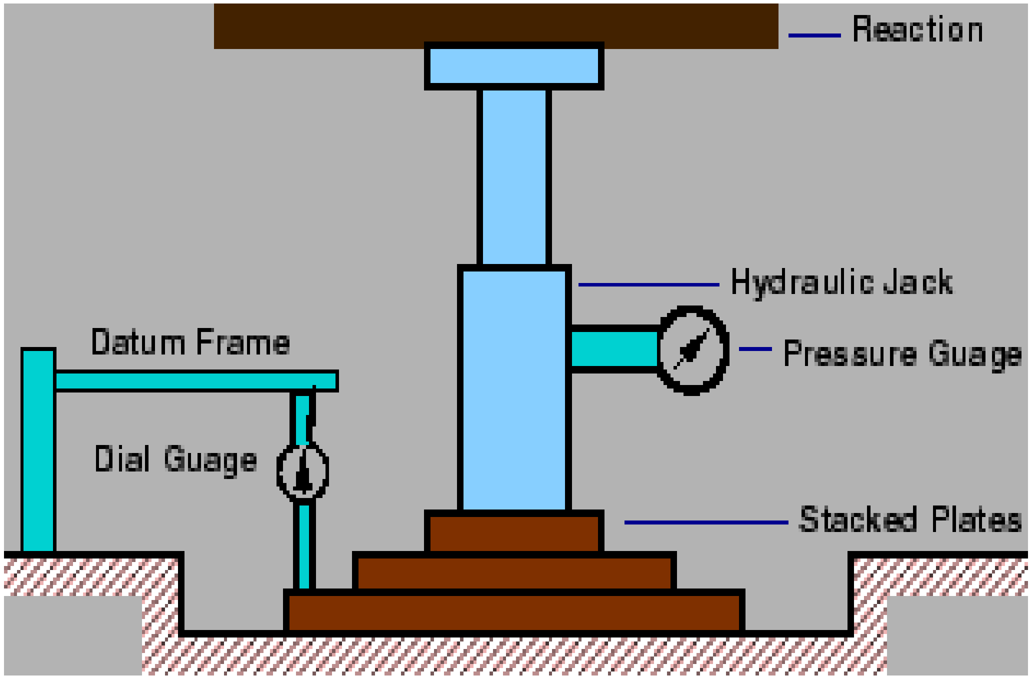
# Example-1

- Design the pavement for construction of a new bypass with the fallowing data:

  - ✓ **Two lane single carriage way**
  - ✓ **Initial traffic in a year of completion of construction work (sum of both directions) = 400 CVPD**
  - ✓ **Traffic growth rate per annum = 7.5 percent**
  - ✓ **Design life = 15 years**
  - ✓ **Vehicle damage factor = 2.5 (standard axles per commercial vehicle)**
  - ✓ **Design CBR value of sub-grade soil = 4%**

# Design of rigid pavement as per IRC-58:2002

- Stress acting on the rigid pavement are:
- Wheel load stress
  - ✓Interior loading
  - ✓Edge loading
  - ✓Corner loading
- Temperature stress
  - ✓Warping stress
  - ✓Frictional stress


Reaction
Hydraulic Jack
Pressure Guage
Datum Frame
Dial Guage
Stacked Plates

# Radius of relative stiffness:

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

- Where
- l= Radius of relative stiffness
- E= modulus of elasticity of cement concrete , $kg/cm^2$
- μ= poisson’s ratio for concrete= 0.15
- h= slab thickness, cm
- K= modulus of subgrade reaction, $kg/cm^3$

# Westergaard's stress equation for wheel load

- Stress at the interior($s_i$)

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

- Stress at the edge ($s_e$)

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

- Stress at the corner ($s_c$)

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

# Where

- P= design wheel load, kg
- l= Radius of relative stiffness
- E= modulus of elasticity of cement concrete , $kg/cm^2$
- μ= poisson's ratio for concrete= 0.15
- h= slab thickness, cm
- K= modulus of subgrade reaction, $kg/cm^3$
- b= radius of equivalent distribution of pressure, cm
  - b=a , if $a/h \geq 1.724$
  - $b = \sqrt{1.6\, a^2 + h^2} - 0.675\, h$, when $a/h < 1.724$
- a= radius of load contact, cm

# Modified Westergaard's stress equation for wheel load

- Modified by '*Teller*'

$$s_e = \frac{0.572P}{h^2}(1+0.54\mu)\times\left(4\log_{10}\left(\frac{l}{b}\right)+\log_{10} b - 0.4048\right)$$

- Modified by '*Kelley*'

$$s_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right]$$

# Warping stress(given by '*Bradbury*')

- Stress at the interior($st_i$)

$$st_i = \frac{Eet}{2}\left[\frac{c_x + \mu c_y}{1-\mu^2}\right]$$

- Stress at the edge ($st_e$)

$$st_e = \frac{C_x\, Eet}{2}$$

**Or**

$$st_e = \frac{C_y\, Eet}{2}$$

Whichever is higher

- Stress at the corner ($st_c$)

$$st_c = \frac{Eet}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

# Where

- E= modulus of elasticity of cement concrete , kg/cm²
- e= thermal coefficient of concrete per ºC
- t= temperature difference between the top and bottom of the slab in degree C
- μ= poisson's ratio for concrete= 0.15
- Cx = Bradbury coefficient based on L/l in desire direction (IRC-58:2002)
- Cy = Bradbury coefficient based on B/l in right angle to the desire direction (IRC-58:2002)
- L = length of slab, m
- B= width of slab, m

# Frictional stress

- Frictional stress($s_f$)

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

- Where,
- $s_f$ = unit stress developed in CC pavement, kg/cm²
- W= unit wt. of concrete, (about 2400 kg/cm²)
- L= length of slab, m
- B= width of slab, m

## Example-1

- Calculate the stress at interior, edge and corner regions of a cement concrete pavement using westergaard's equation. Use the fallowing data
  - ✓ Wheel load, P=5100kg
  - ✓ Modulus of elasticity of concrete, E=3.0x10^5 kg/cm²
  - ✓ Pavement thickness, h=18cm
  - ✓ Poisson's ratio=0.15
  - ✓ Modulus of subgrade reaction=6.0 kg/cm3
  - ✓ Radius of contact area=15 cm

## Example-2

- Compute the radius of relative stiffness of 15 cm thick cement concrete slab from the fallowing data
  - E=21000kg/cm2
  - Poisson's ratio=0.13
  - K=3KG/cm2 or 7.5 kg/cm2

# Example-3

- Determine the warping stress at interior, edge and corner regions in a 25 cm thick cement concrete pavement with transverse joint at 9 m interval and longitudinal joint at 3.6 m intervals. The modulus of subgrade reaction is 6.9 $kg/cm^2$ . Assume temperature difference for day condition to be 0.6ºc per cm of the slab thickness. Assume radius of loded area as 15 cm for computing warping stress at the corner.
- E= 3 x 10^5kg/cm²
- e= 10 x 10^-6 per ºc
- μ= 0.15

# Bibliography


- Khanna, S. K., & Justo, C. E. G. "*Highway engineering*". *Nem Chand & Bros.*
- *IRC Codes.*