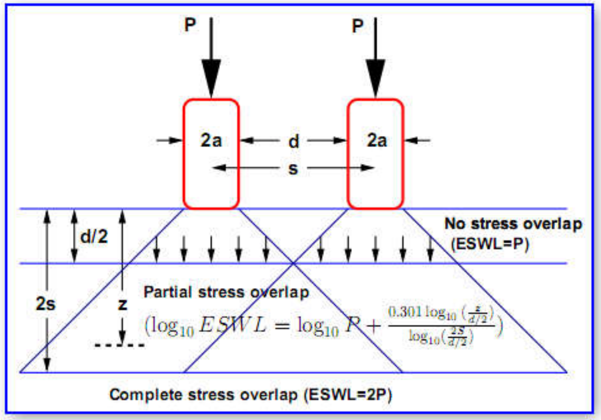
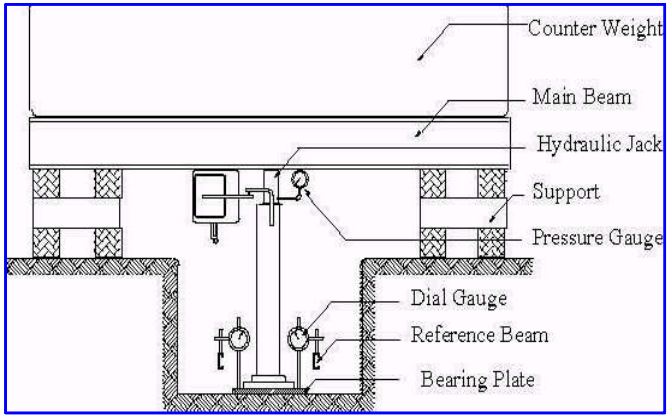
Pavement Analysis & Design

An Introduction





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Outline

- Pavement Types
- Design Factors
- IRC Guide lines for Design
  - Flexible Pavements
  - Rigid Pavements

Requirements

- Planning
- Design
- Construction
- Maintenance

Design Process

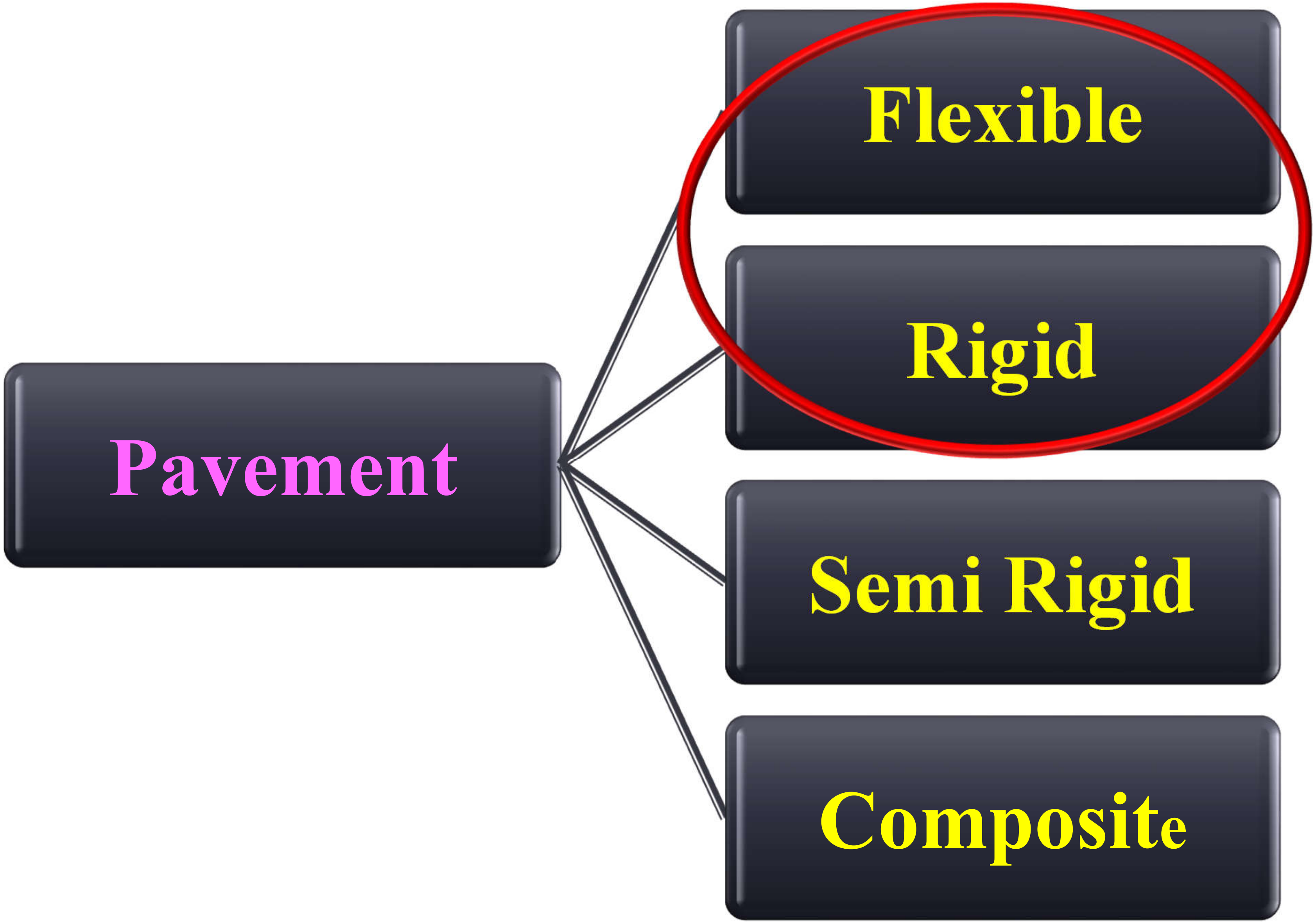
- Geometric Design
- Pavement Design
- Material Mix Design

Pavement Design

Pavement Purpose

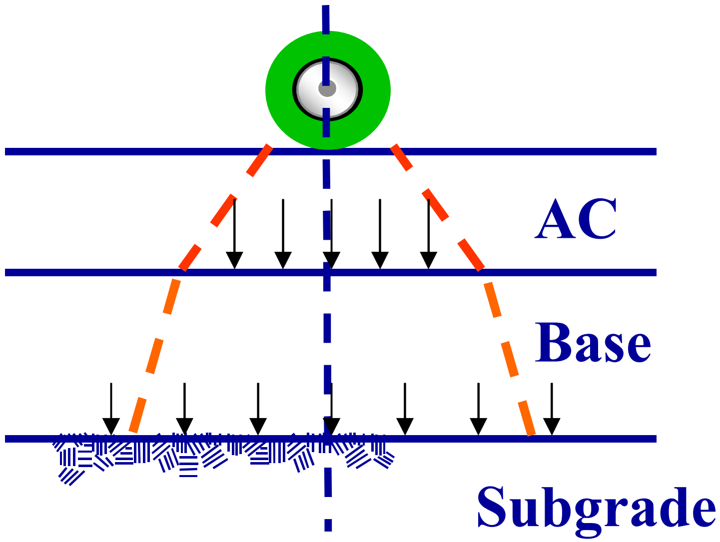
1. Load support
   - withstand and distribute stresses
   - hard wearing surface
2. Smoothness
   - riding quality
   - safety
   - low energy consumption
3. Drainage
   - impervious

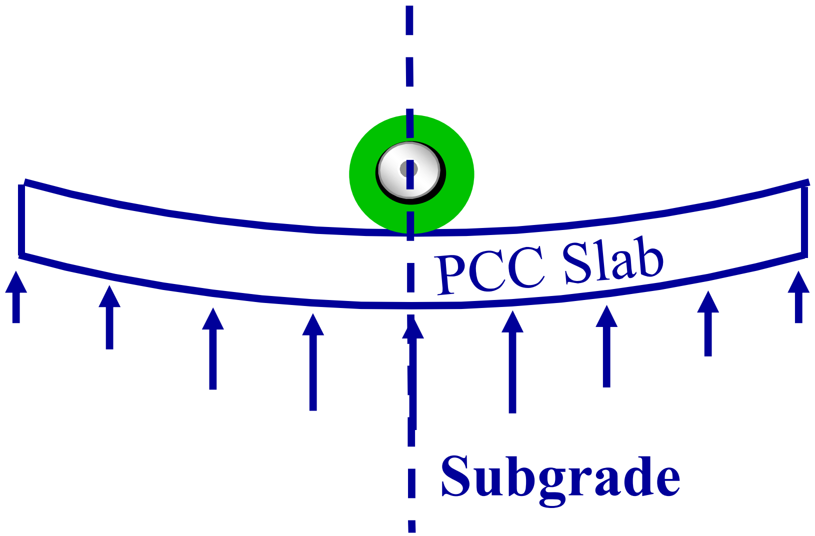
Pavement Types



Structural Response Models

Different analysis methods for AC and PCC





- Layered system behavior.
- All layers carry part of load.

- Slab action predominates.
- Slab carries most load.

Flexible Pavement

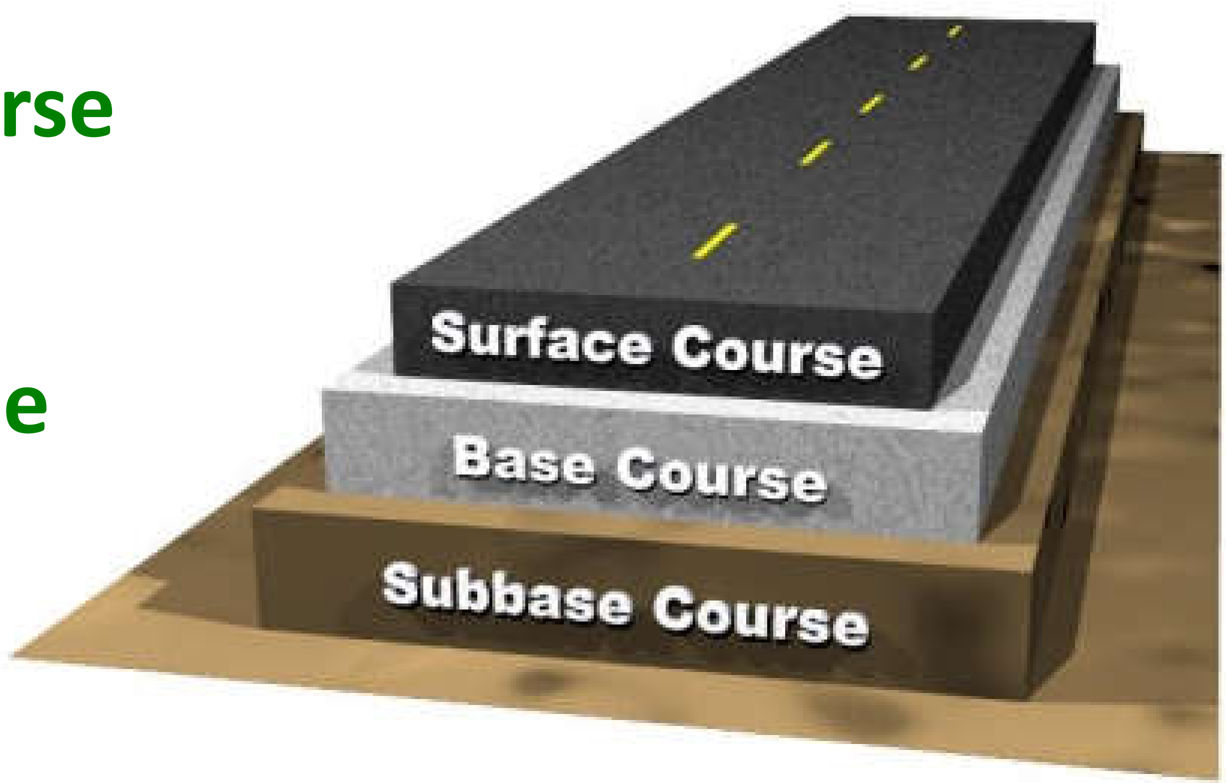
Typical Flexible Pavement Layers

Soil Subgrade

Sub-base course

Base course

Surface course



Design of Pavements

Pavement Design

- **Mix design**
- **Thickness design**

Thickness Design of Pavement

Design Factors

- Traffic
- Climatic Factors
- Road Geometry
- Subgrade
- Material Properties
- Environment

Design Parameters – Traffic

- Maximum Wheel load
- Contact Pressure
- Multiple Wheel Loads
- Repetition of Loads
- Position
- Impact of wheels
- Iron-tyred vehicles

Design Parameters – Climate

- Rainfall
- Frost
- Temperature

Design Parameters

Geometry

- Horizontal Curves
- Vertical Profile

Subgrade

- Strength
- Drainage

Design Parameters – Subgrade

- CBR and Resilient modulus
- Marshall stability values
- Modulus of subgrade reaction
- Modulus of rupture
- Elastic modulus etc..

Design Approaches

- Analytical methods
- Empirical methods
- Based on Pavement Performance

Pavement Design

- **Design of Flexible Pavements**

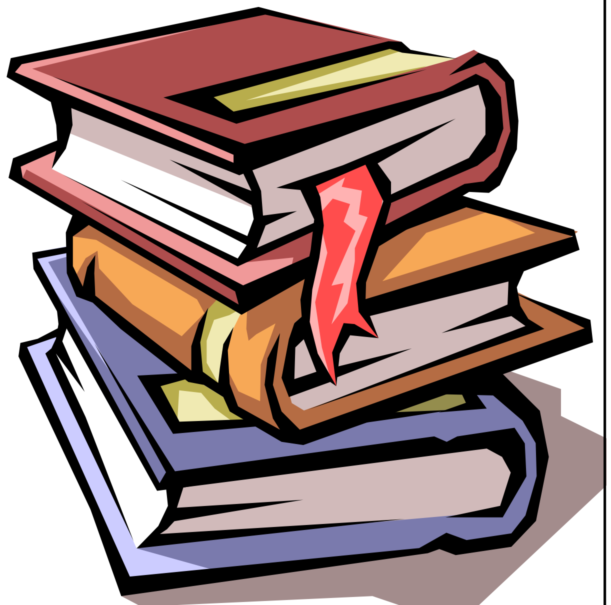
  HVR – IRC : 37 – 2001

  LVR – IRC SP : 72-2007

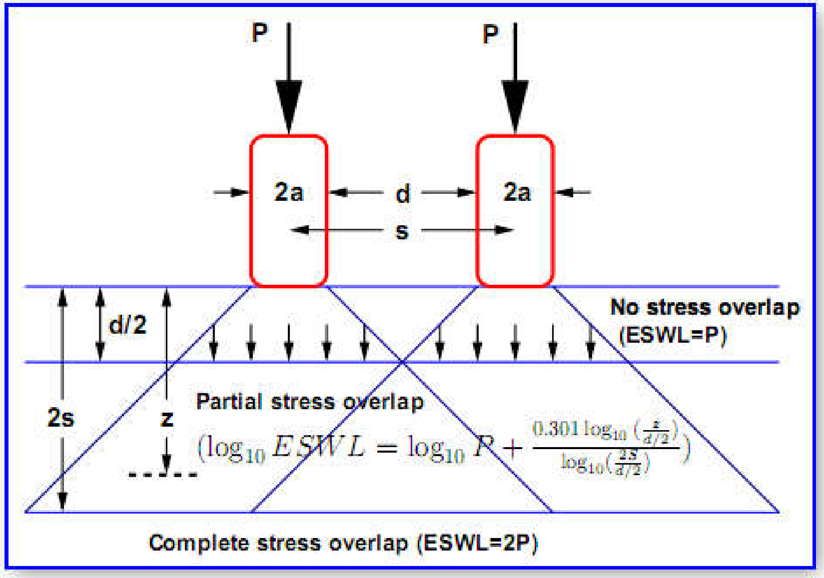
- **Design of Rigid Pavements**

  HVR – IRC : 58 – 2002

  LVR – IRC SP : 62-2004



Traffic Loading and Volume



Pavement Design Parameters

- Traffic
- Climatic Factors
- Road Geometry
- Subgrade
- Material Properties
- Environment

Design Parameters – Traffic

- Maximum Wheel load
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- Position
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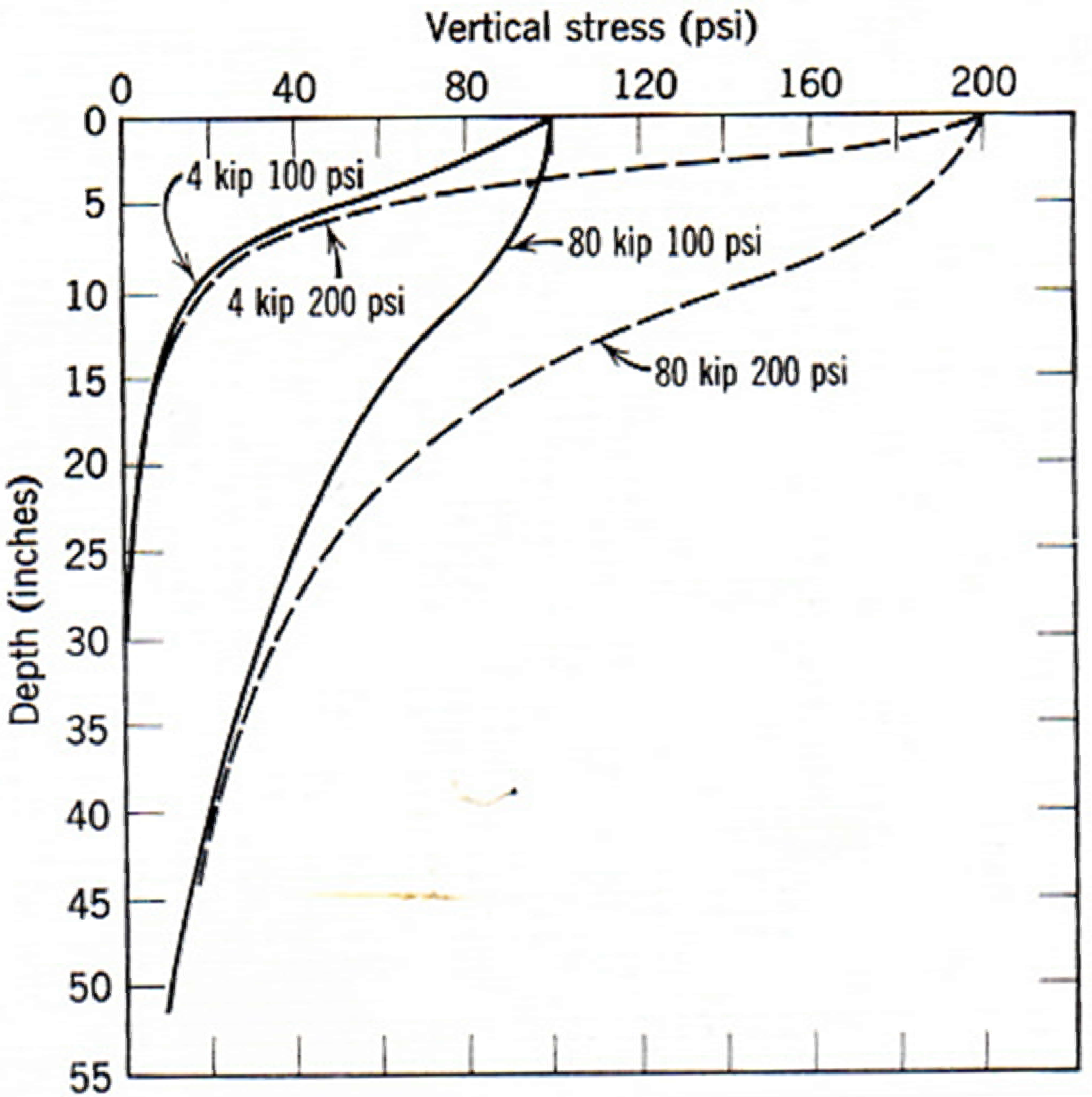
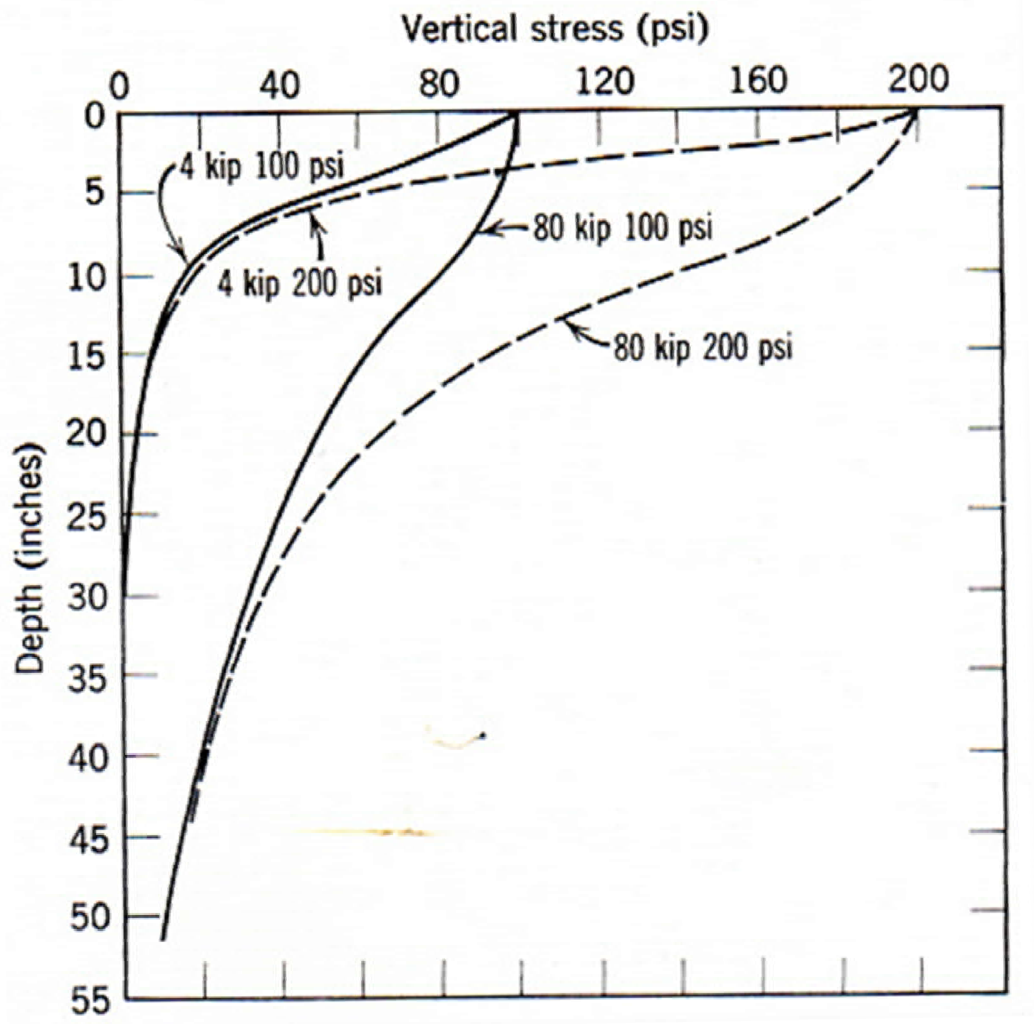
Wheel Load and Contact Pressure

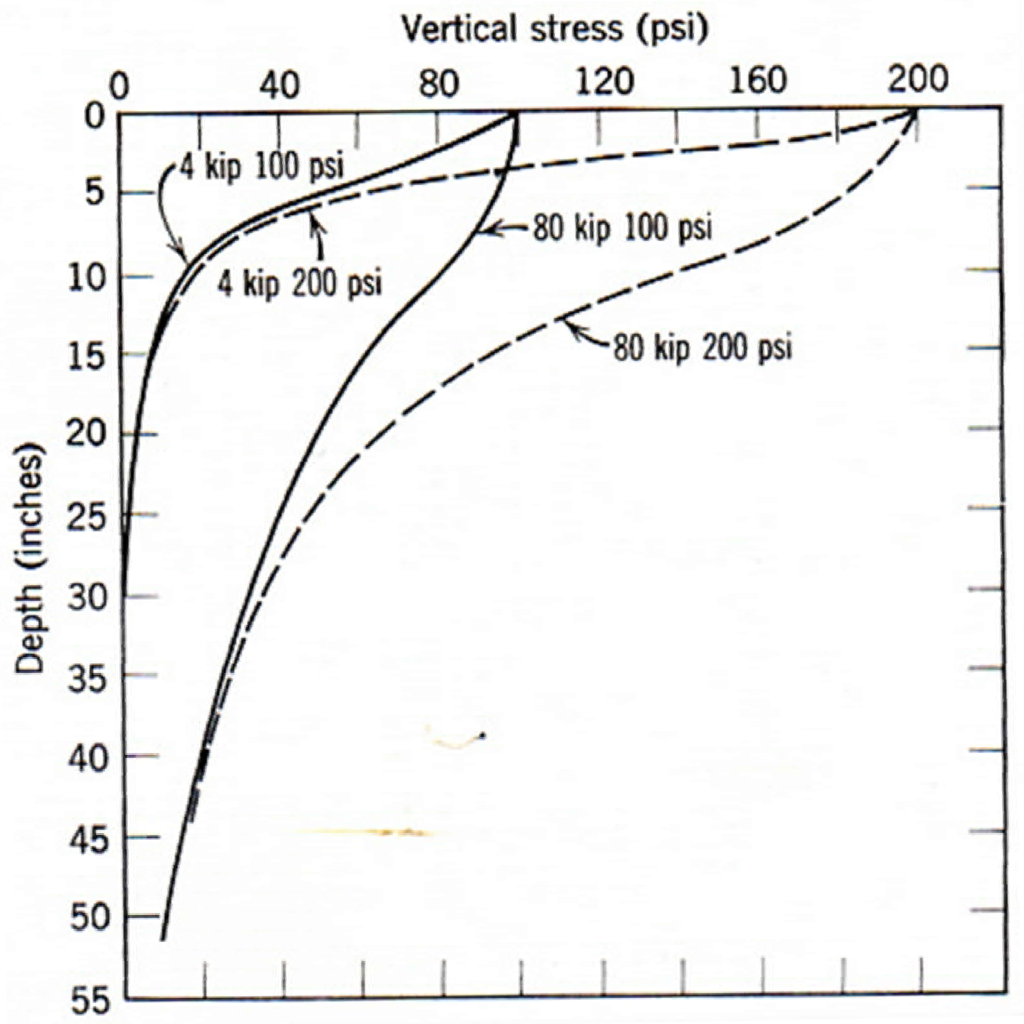


Contact Pressure



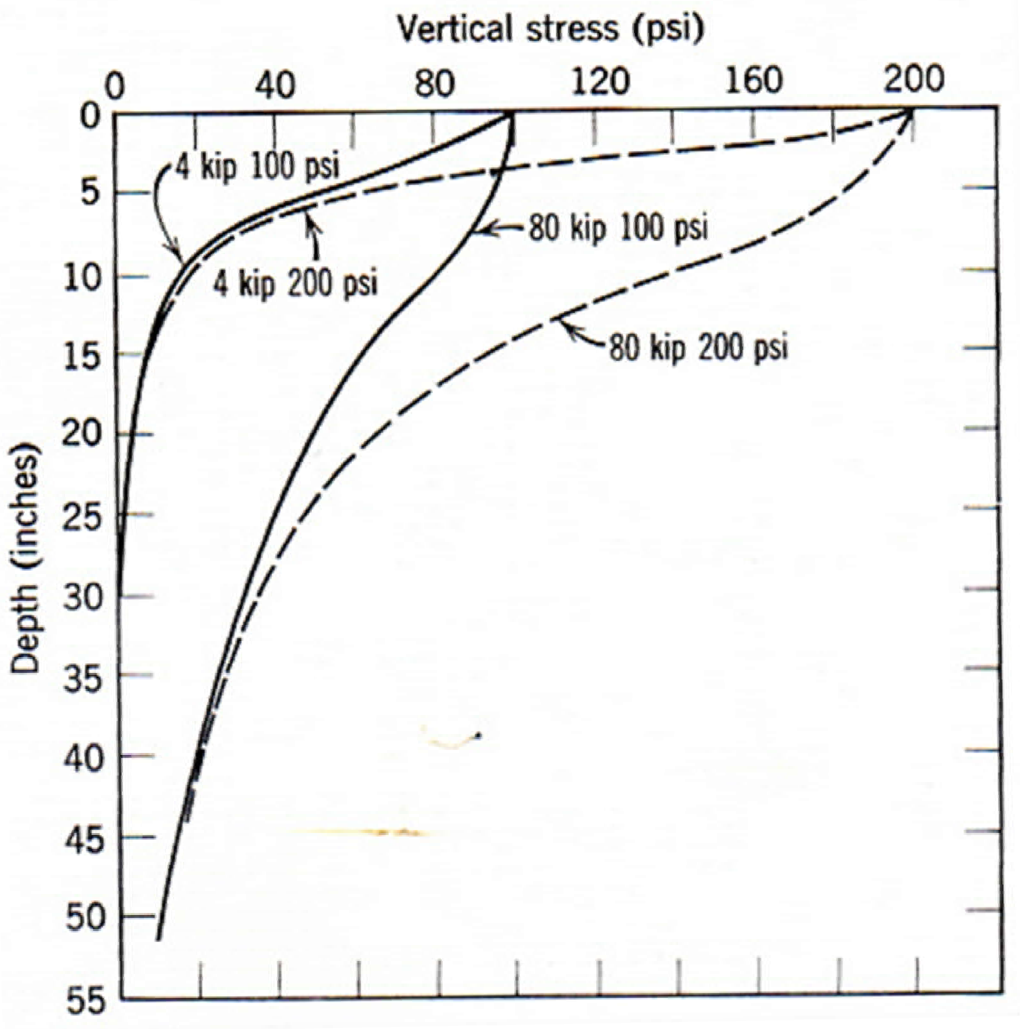
The influence of contact pressure on stress levels in base, subbase and subgrade layers are marginal

Contact Pressure



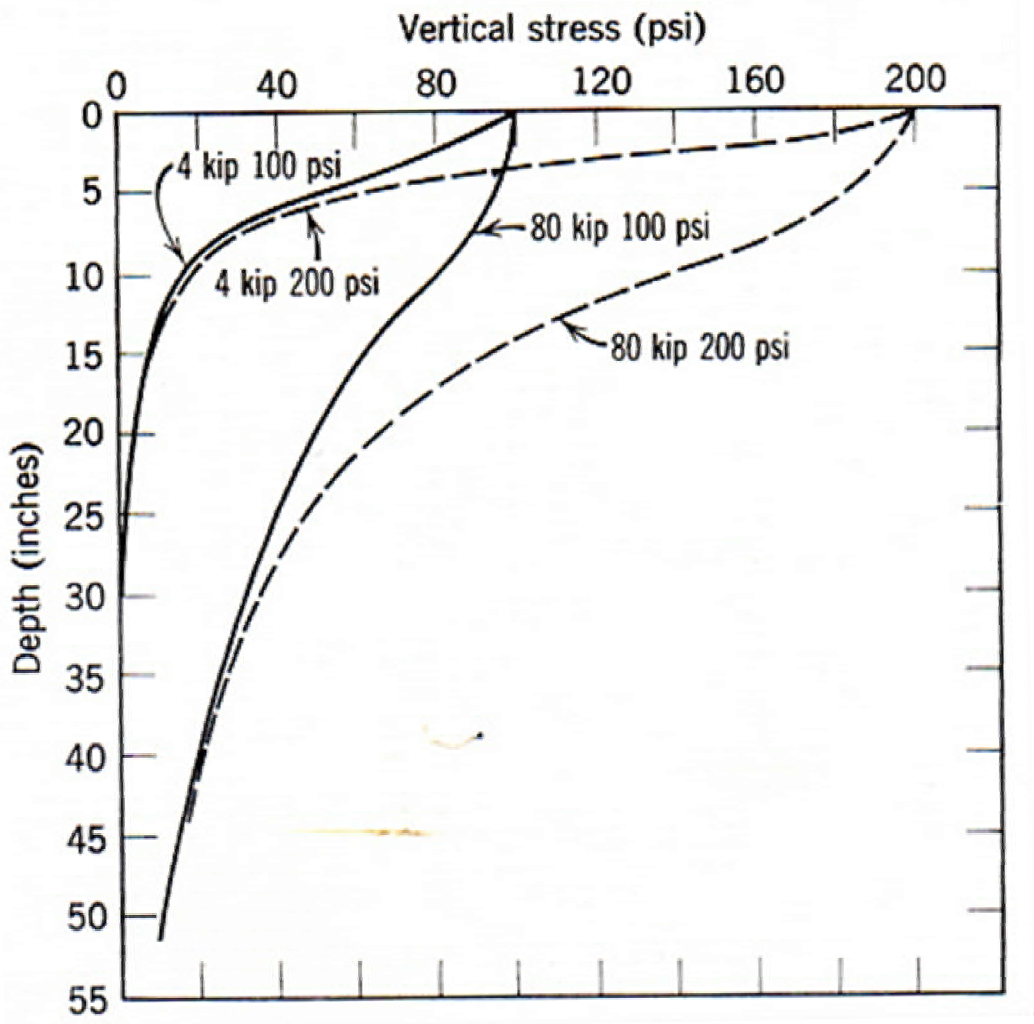
The magnitude of contact pressure determines the quality and thickness of wearing and binder course

Wheel Load



The influence of the magnitude of the wheel load on stress levels in base, sub-base and subgrade layers is significant

Wheel Load

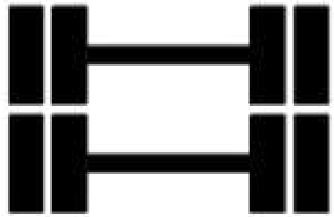


Total thickness of the pavement is mainly determined by the magnitude of the load and not the contact pressure

Axle Configurations and Loads

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

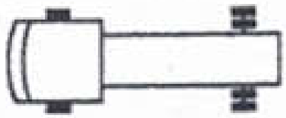
Single Axle With Dual Wheel
(Legal Axle Load = 10t)



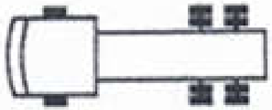
Tandem Axle
(Legal Axle Load = 19t)

Tridem Axle
(Legal Axle Load = 24t)

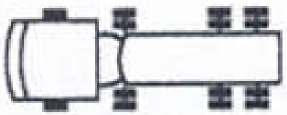
Axle Configurations



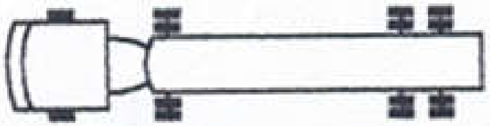
2 Axle Truck – 16t



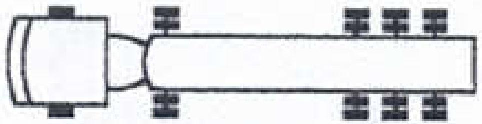
3 Axle Truck – 24t



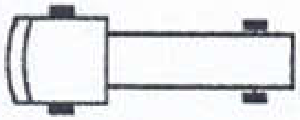
4 Axle Semi Articulated – 34t



4 Axle Articulated – 34t



5 Axle Truck – 40t



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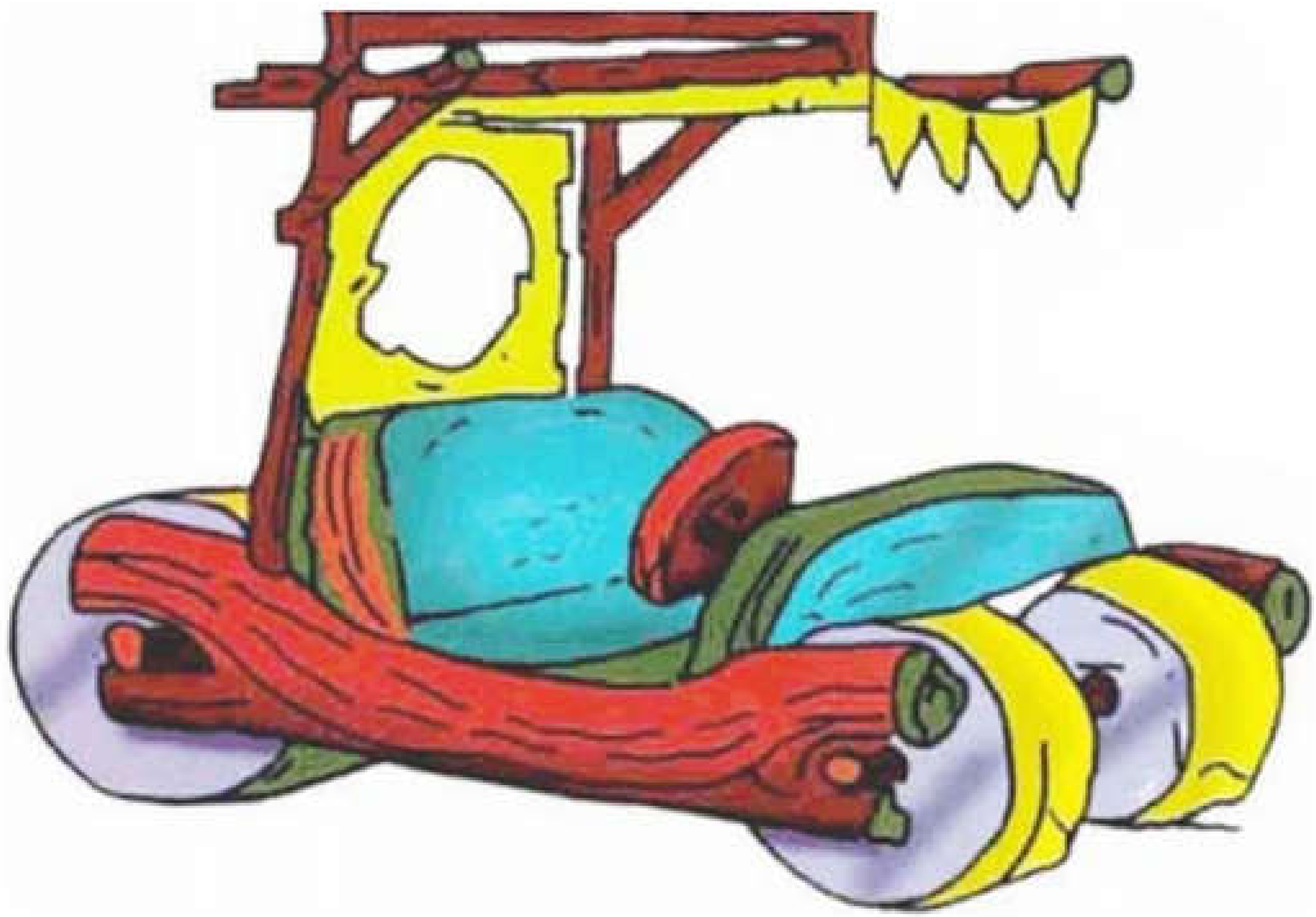
Axle Configurations

Axle Configurations

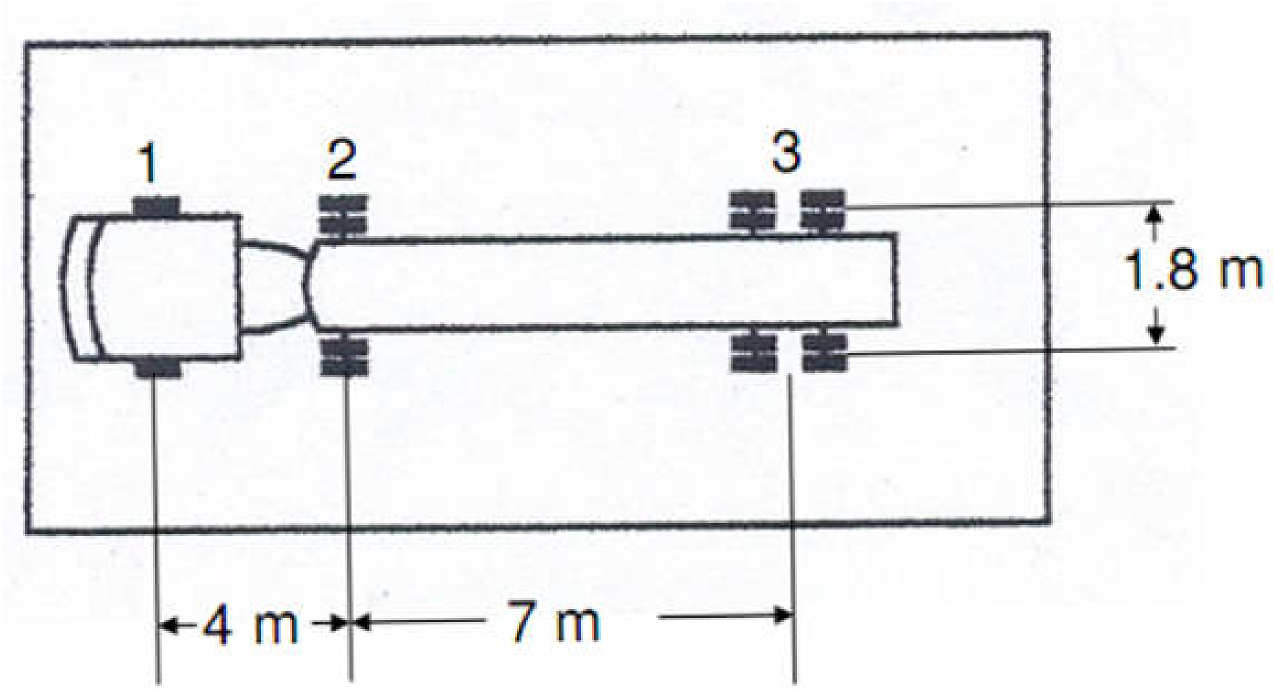
Axle Configurations

Axle Configurations

Design Vehicle ?

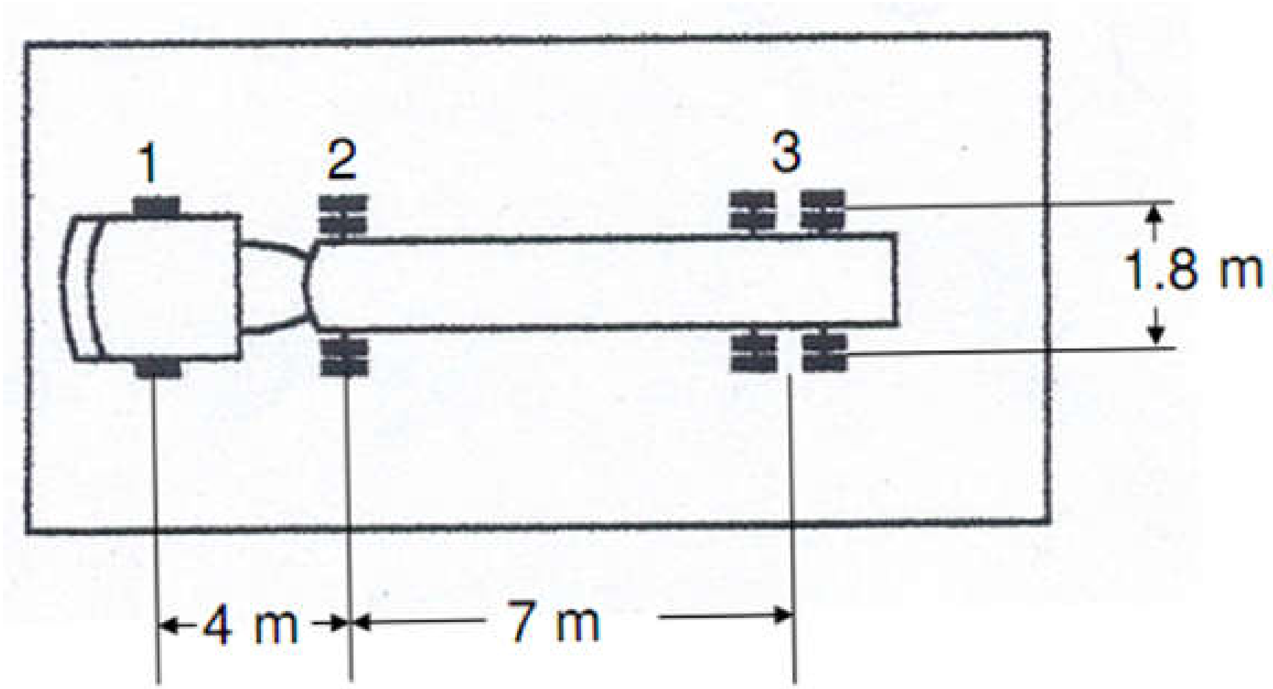


Effect of Wheel Configuration



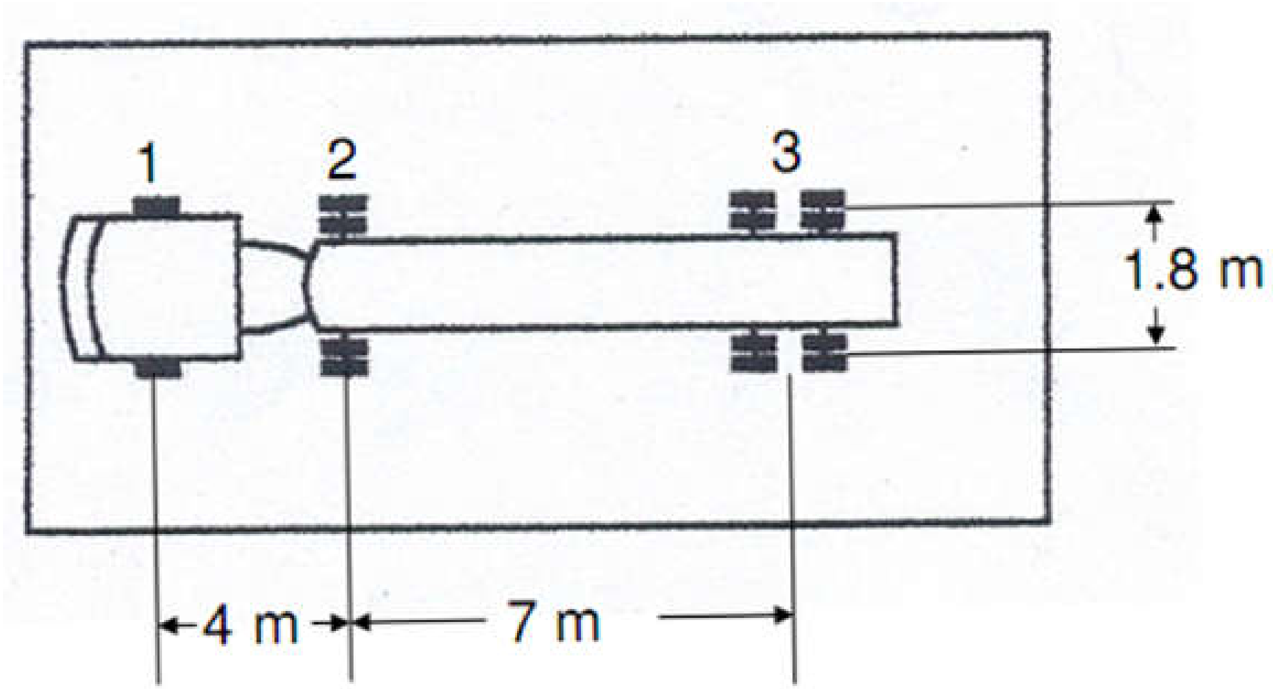
The effect of axles 1, 2 and 3 on stresses and strains within pavement layers are considered independently

Effect of Wheel Configuration



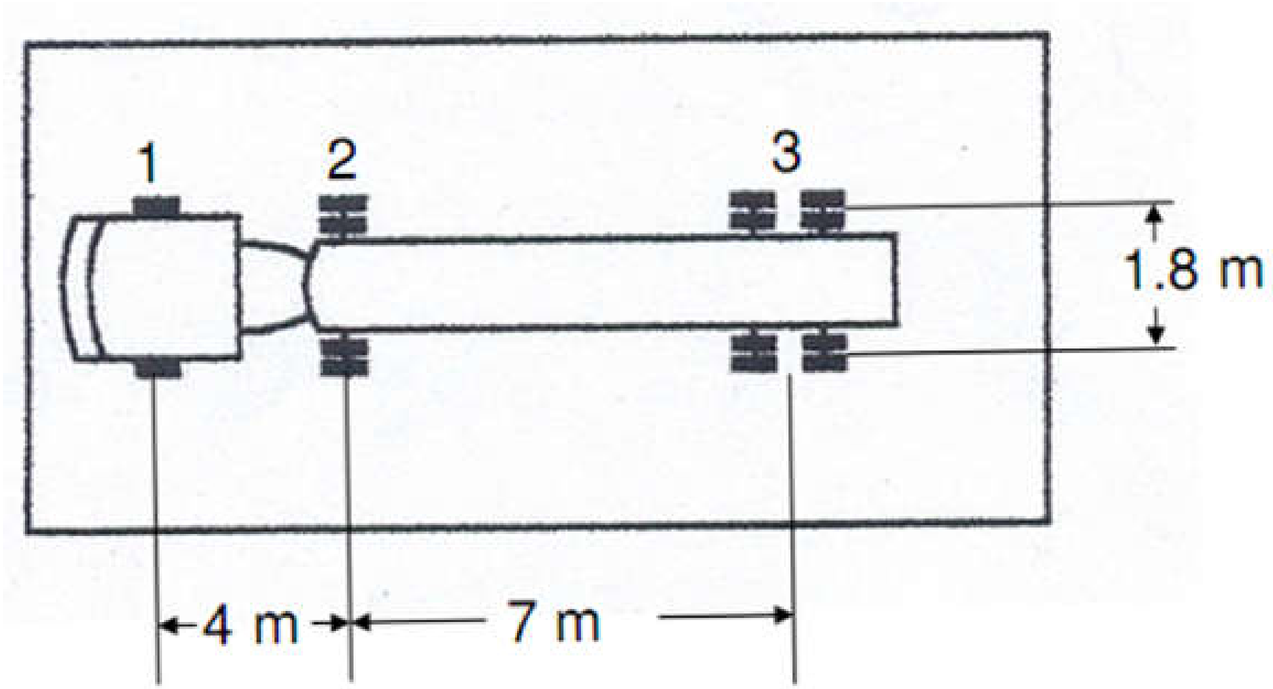
Within a group of axles, each axle is not considered as independent

Effect of Wheel Configuration

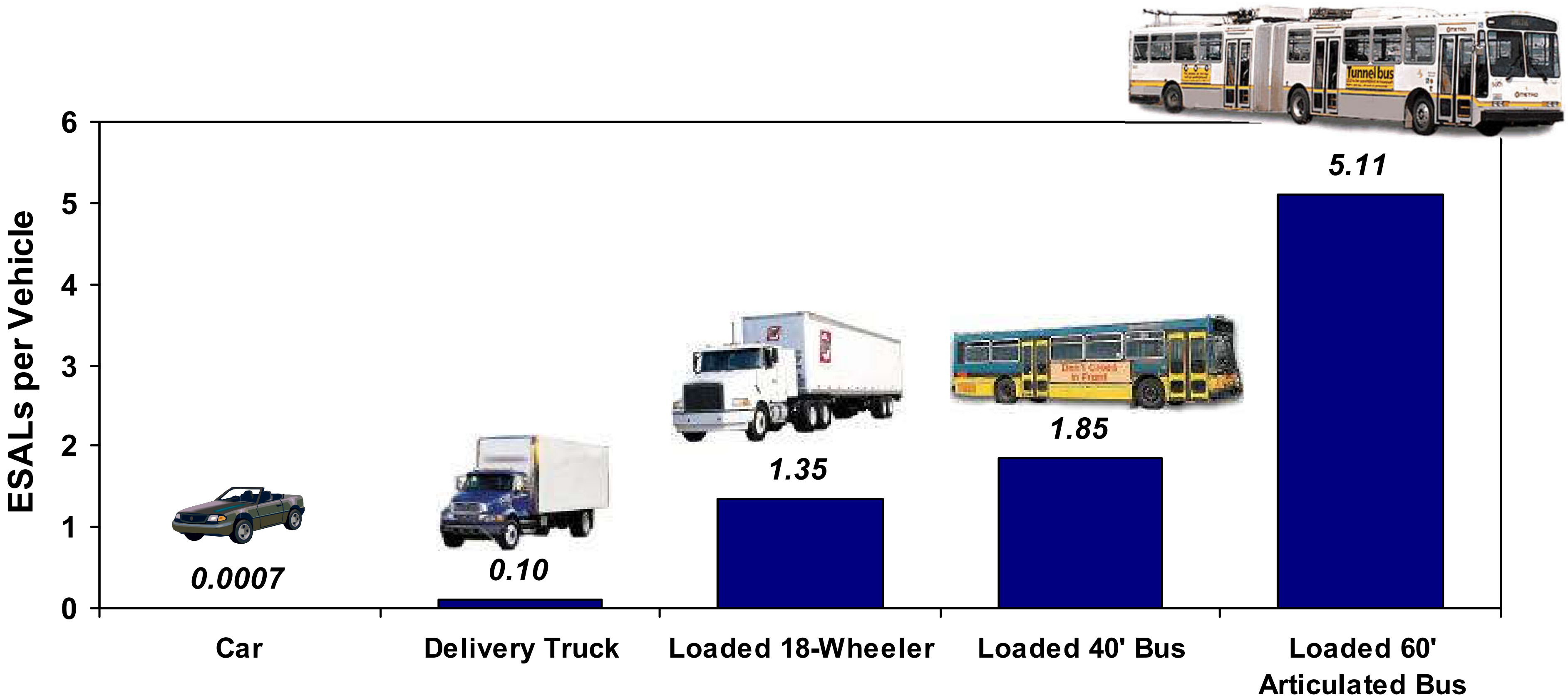


In flexible pavement design by layer theory, only the wheels on one side are considered

Effect of Wheel Configuration



In rigid pavement design by plate theory, the wheels on both sides are usually considered (even when distance > 1.8 m)



Notice that cars are insignificant and thus usually ignored in pavement design.

Equivalent Axle Load Factor (EALF)

Defines the damage per pass to a pavement by an axle relative to the damage per pass of a standard axle

Exact EALF can be worked out only by using distress models

Approximate EALF can be worked out using the fourth power rule

$$EALF = \left(\frac{Axle\ Load}{Standard\ Axle\ Load}\right)^4$$

Standard Axle Load

Single axle : 8160 kg

Tandam axle : 14968 kg

Vehicle Damage Factor (VDF)

Instead of converting each axle pass into equivalent standard axle passes, it will be convenient to convert one truck pass into equivalent standard axle passes

The factor that converts – VDF

VDF is the number of standard axles per truck

Vehicle Damage Factor (VDF)

$$VDF = \frac{V_1\left(\frac{W_1}{W_s}\right)^4 + V_2\left(\frac{W_2}{W_s}\right)^4 + V_3\left(\frac{W_3}{W_s}\right)^4 + \dots\dots}{V_1 + V_2 + V_3 + \dots\dots}$$

$$VDF = \frac{V_1 EALF_1 + V_2 EALF_2 + V_3 EALF_3 \dots\dots}{V_1 + V_2 + V_3 + \dots\dots}$$

Indicative VDF Values as per IRC : 37 - 2001

Initial Traffic Volume (CVPD)	Rolling/Plain	Hilly
0 – 150	1.5	0.5
150 – 1500	3.5	1.5
> 1500	4.5	2.5

Traffic on Design Lane

Design Lane - Lane carrying maximum truck volume

One direction may carry more traffic than the other

Within high traffic direction, each lane may carry different portion of the loading

The outermost lane often carries most trucks and is usually subjected to heaviest loading

The distribution of truck traffic across the width of carriage is considered for traffic on design lane

Need for Distribution Factors

Traffic on Design Lane

Worked out by finding the

Directional Distribution Factor (0.5 to 0.6)

Proportion of ADT of trucks occurring in the maximum direction

Lane Distribution Factor

Proportion of trucks occurring on the design lane which depends on

Number of lanes and

Traffic volume

Factors Suggested by IRC

Undivided Roads (Single Carriageway)

No. of Traffic lanes in two directions	Percentage of trucks in Design Lane
1	100
2	75
4	40

Factors Suggested by IRC

Divided Roads (Dual Carriageway)

No. of Traffic lanes in two directions	Percentage of trucks in Design Lane
1	100
2	75
3	60
4	45

Design Period

- **Depends on**
  - traffic volume
  - growth rate
  - capacity of road and
  - possibility of augmentation
- **Flexible Pavement**

  15 years – NH, 20 years – Express ways & Urban Roads, 10 to 15 years – Other Roads
- **Rigid Pavement**

  30 years. When Accurate prediction not possible – 20 years

Design Traffic

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

N = Cumulative std. axle repetitions during design period (expressed in msa)

A = Initial traffic intensity (CVPD)

D = Lane distribution factor

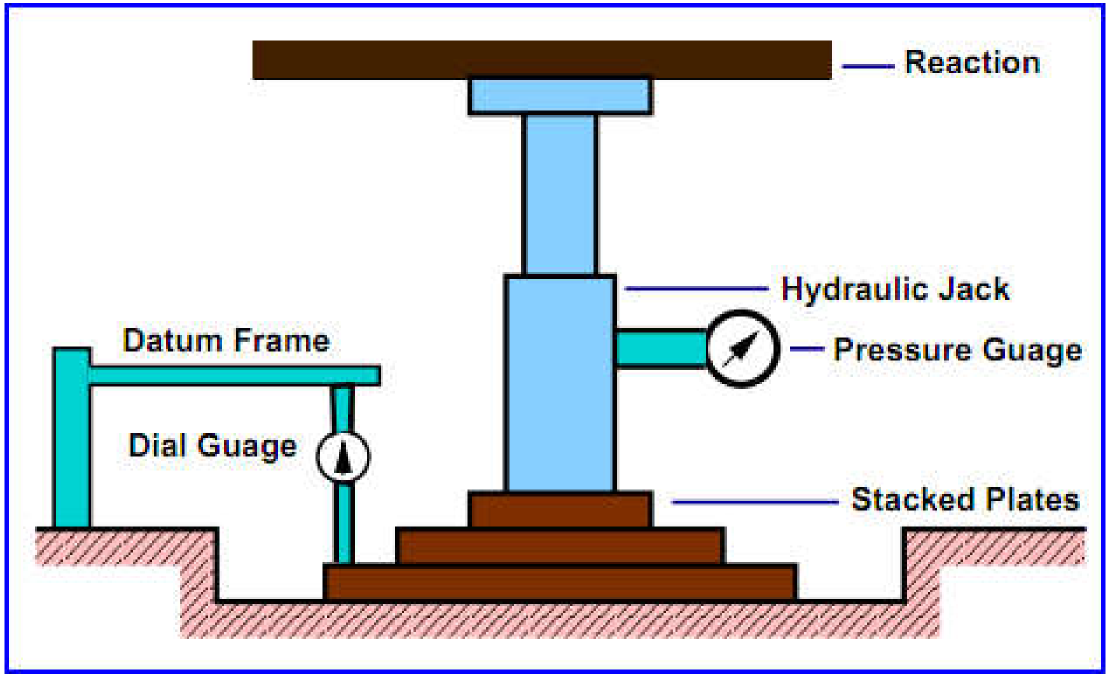
F = Vehicle damage factor

n = Design life (years)

r = Annual rate of growth for commercial vehicles

- Average annual growth rate – 7.5%

Material Characterisation



In this Presentation

Definition, Test setup, procedure and typical results of

- ❖ **California Bearing Ratio**
- ❖ **Modulus of Subgrade Reaction**

California Bearing Ratio (CBR)

A penetration test developed by California Division of Highways

To evaluate the stability of soil subgrade and other flexible pavement materials

An empirical test and results have been correlated with flexible pavement thickness

California Bearing Ratio (CBR)

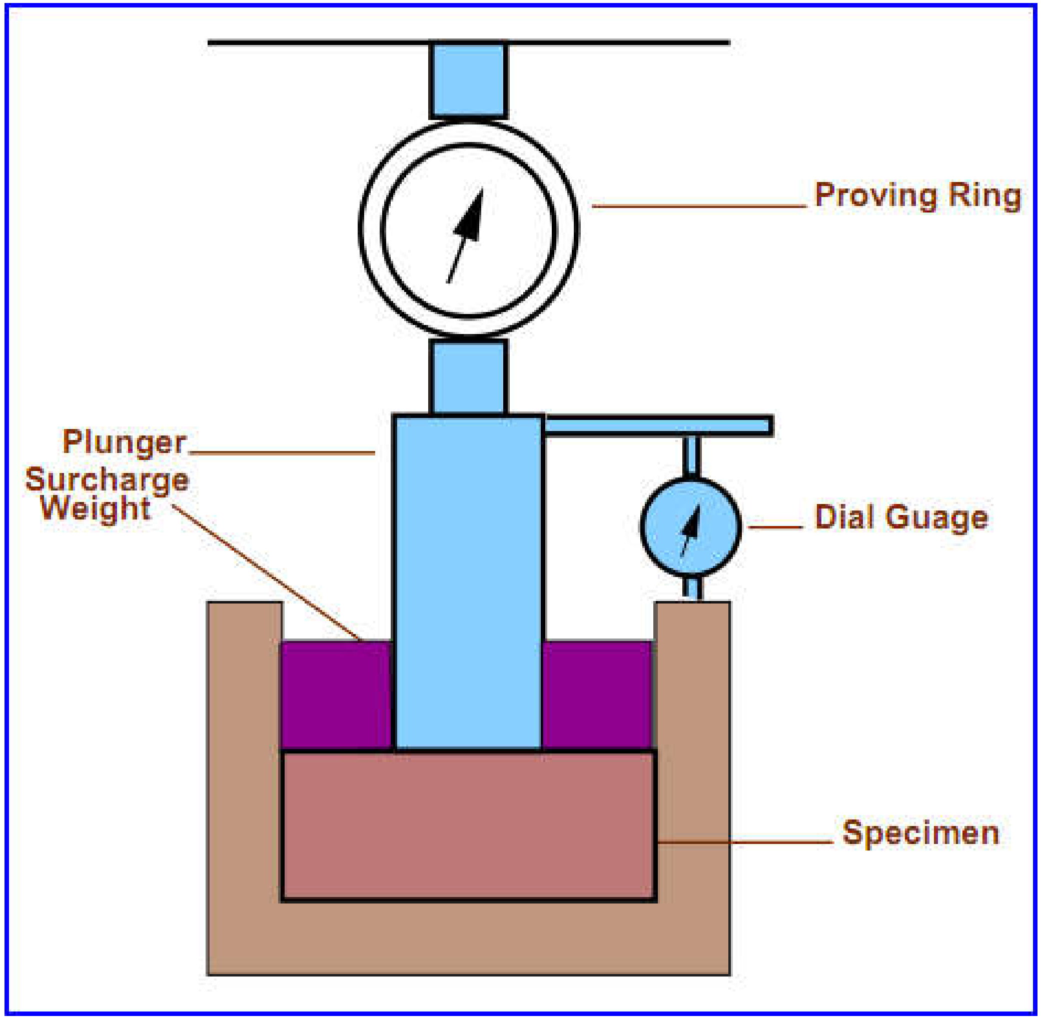
Procedure as per IS: 2720 part 16

Generally, re-moulded specimen is prepared at MDD & OMC

A standard piston of diameter 50 mm is used to penetrate soil at a standard rate of 1.25 mm/minute

The load or pressure values up to a penetration of 12.5 mm is recorded

California Bearing Ratio (CBR)



Test Setup

Test Setup

Test Setup

Test Setup

Field CBR

California Bearing Ratio (CBR)

Penetration (mm)	Standard Load (kg)	Unit Std. Load (kg/cm^2)
2.5	1370	70
5.0	2055	105
7.5	2630	134
10.0	3180	162
12.5	3600	183

$$CBR,\% = \frac{\left[\begin{array}{c}\text{Load sustained by the specimen}\\ \text{at 2.5 or 5.0 mm penetration}\end{array}\right]}{\left[\begin{array}{c}\text{Load sustained by the standard aggregates}\\ \text{at the corresponding penetration}\end{array}\right]} X\ 100$$

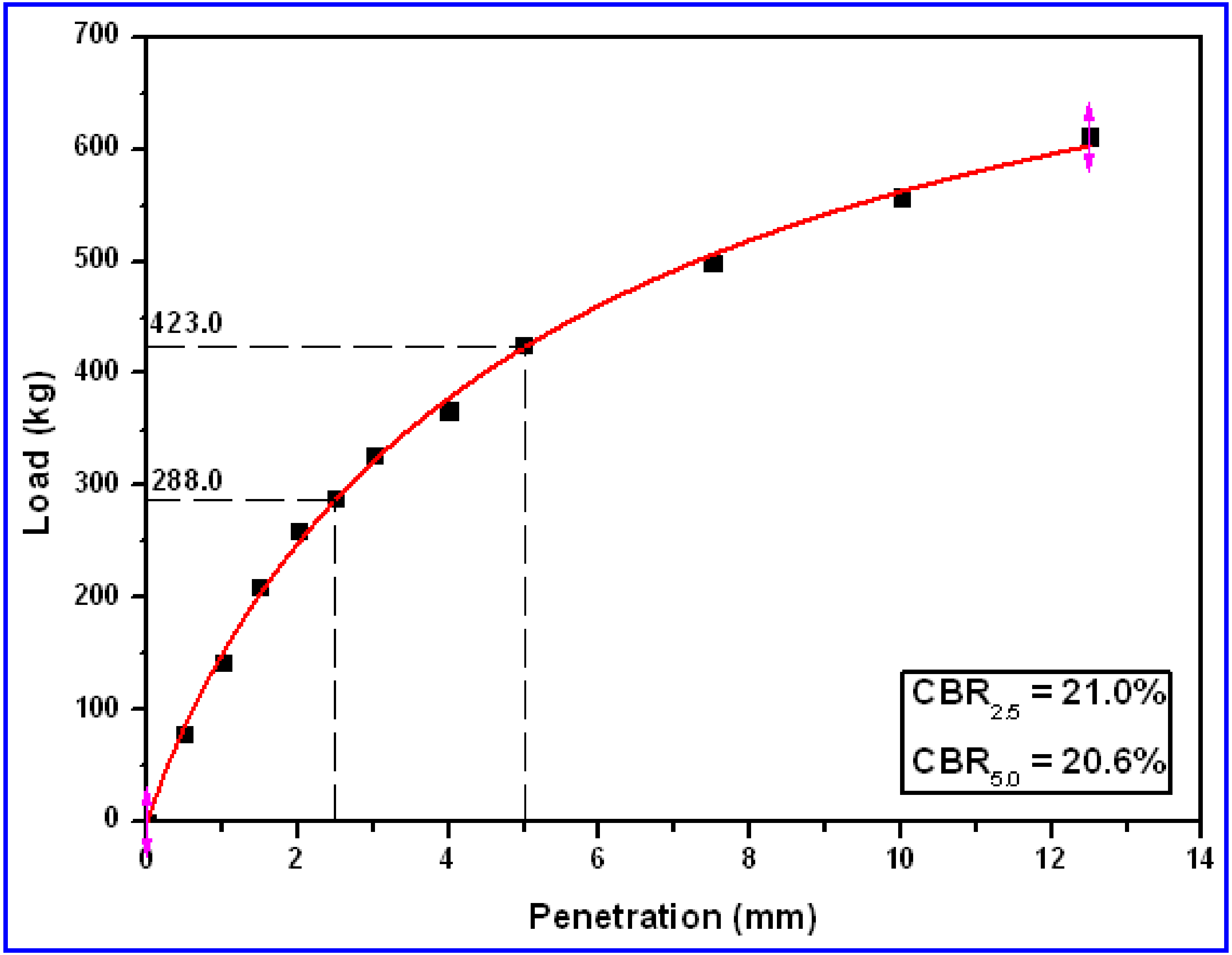
Test Setup

Para 3.4.4 of IRC: 37-2001

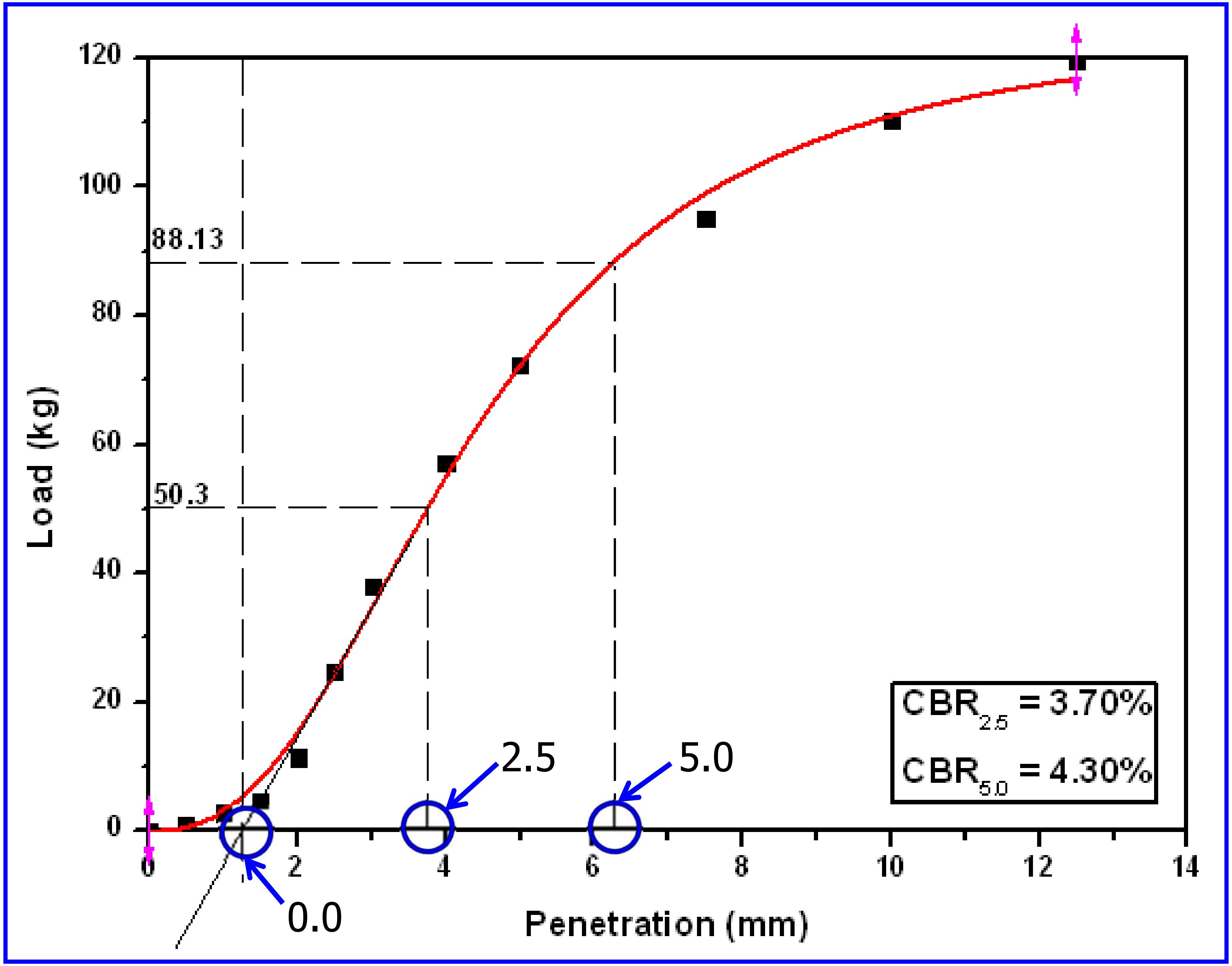
The test must always be performed on remoulded samples of soils in the laboratory. Wherever possible the test specimens should be prepared by static compaction but if not so possible dynamic method may be used as an alternative.

In-situ tests are not recommended for design purposes as it is not possible to satisfactorily simulate the critical conditions of dry density and moisture content in the field

Results from Test



Results from Test



Results from Test

Permissible variations in CBR values for 3 specimens as per IRC: 37-2001	
CBR (per cent)	Maximum variation in CBR value
5	±1
5 – 10	±2
11 - 30	±3
31 and above	±5

Note: when variation is more than the above, the design CBR value should be the average of test results from at least six samples and not three

Sub Grade CBR Value – Other Methods

1. Based on soil classification tests and using table-1 of IRC:SP:72-2007
2. Based on wet sieve analysis data and using the nomograph given in APPENDIX-C of IRC:SP:72-2007
3. Based on 2 sets of equations for plastic and non plastic soils given in APPENDIX-D of IRC:SP:72-2007
4. Conducting actual CBR test in the laboratory

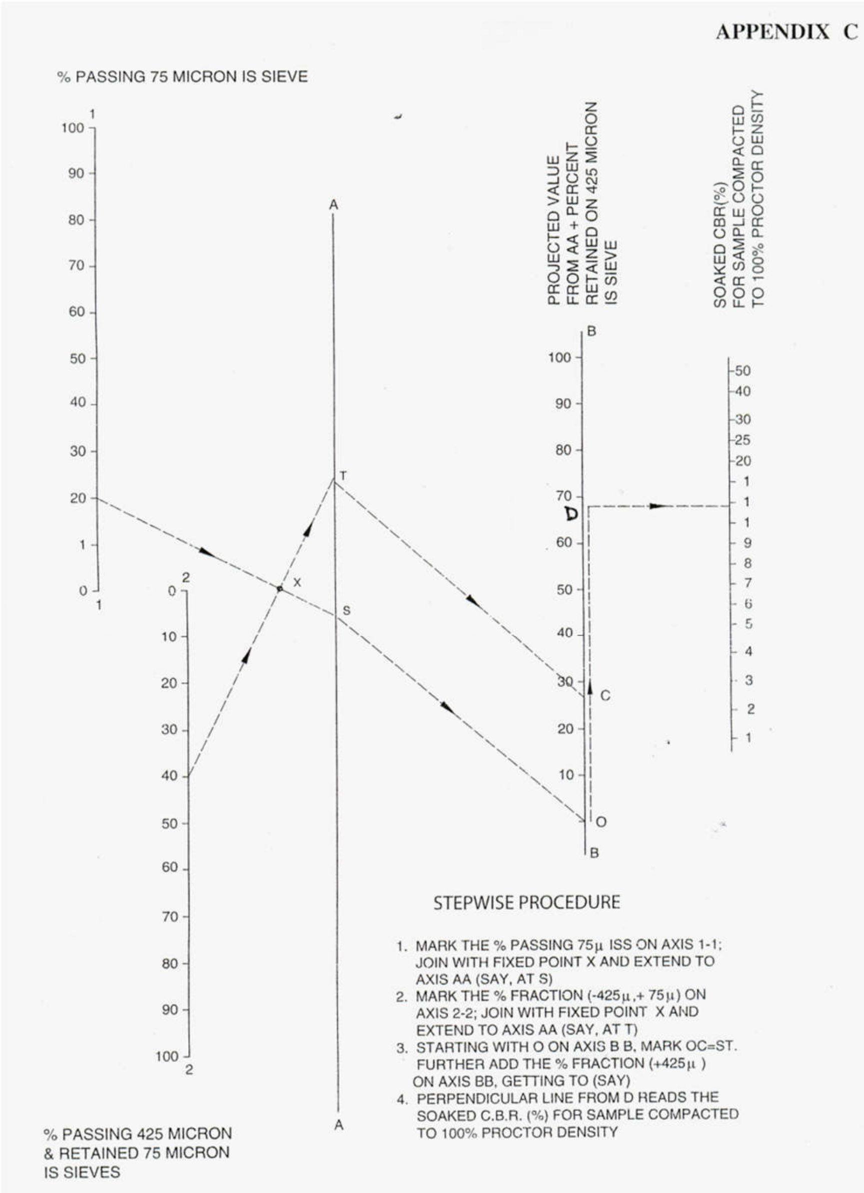
Typical Presumptive Design CBR Values

Description of Subgrade Soil	IS Soil classification	Typical Soaked CBR Value(%)
Highly Plastic Clays and Silts	CH,MH	*2-3
Silty Clays and Sandy Clays	ML,MI CL,CI	4-5
Clayey Sands and Silty Sands	SC,SM	6-10

*Expensive clays like BC soil may have a soaked CBR of less than 2%

- A sample free swelling index test (IS 2720-Part 40) should be determined on expensive clays

Nomograph



Nomograph for Computing Soaked CBR Value from Sieve Analysis Data (Ref. 6)

Nomograph for computing soaked CBR value from Sieve Analysis Data

- % Passing 75 µ
- % Passing 425 µ and retained on 75 µ

Quick Estimation of CBR

Plastic Soil

$CBR = 75(1+0.728\ WPI)$, $R^2 = 0.67$

WPI = Weighted Plasticity Index = $P_{0.075}$ x PI

$P_{0.075}$ = % Passing 75 µ sieve in decimal

PI = Plasticity Index of soil, %.

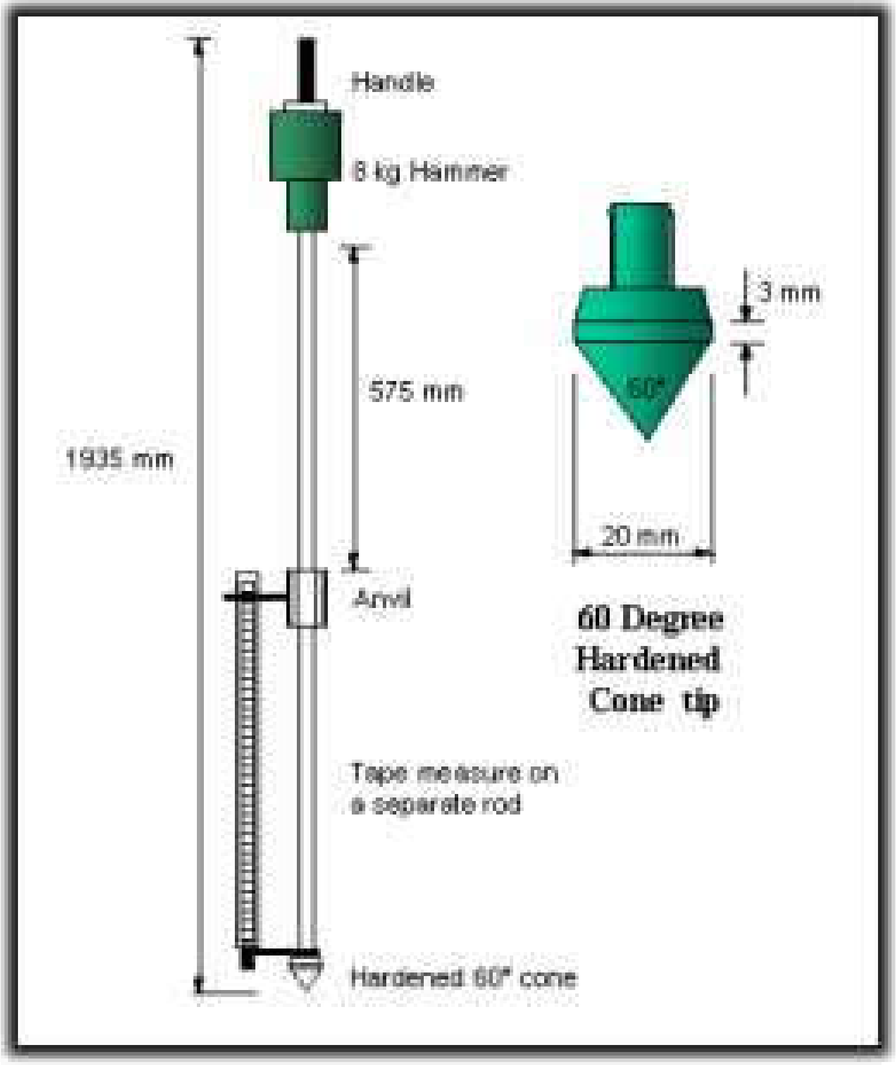
Non-Plastic Soil

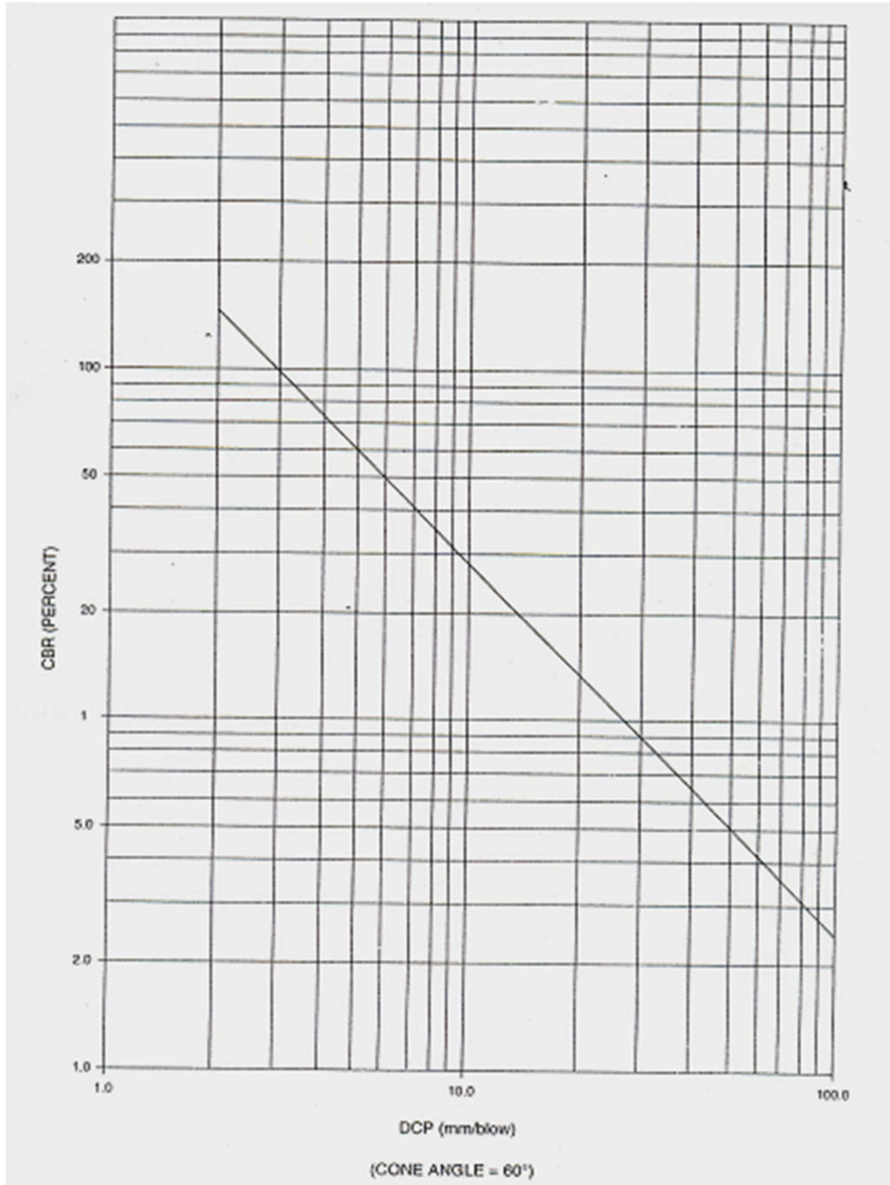
$CBR = 28.091(D_{60})^{0.3581}$, $R^2 = 0.84$

D_{60} = Diameter(mm) of the size corresponding to 60% finer.

APPENDIX- D, IRC:SP:72-2007

Dynamic Cone Penetrometer (DCP)





DCP-CBR Relationship (Ref. 5)

DCP

DCP

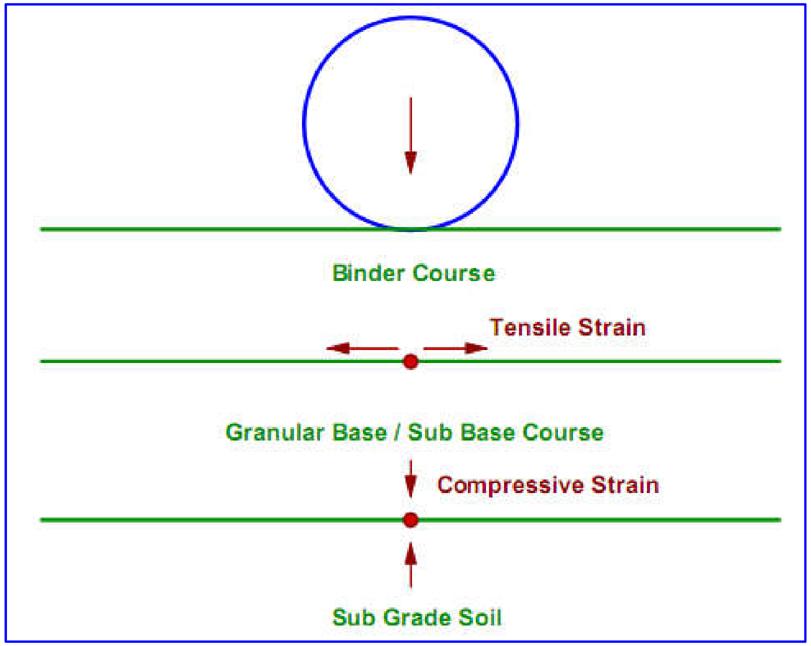
Pavement Dynamic Cone Penetrometer

Geo-Gauge

H-4140

Flexible Pavement Design

(As per IRC : 37 - 2001)



In this Presentation

- Introduction
- Design Criteria
- Failure Criteria
- Design Procedure
- Pavement Thickness Design Charts
- Pavement Composition

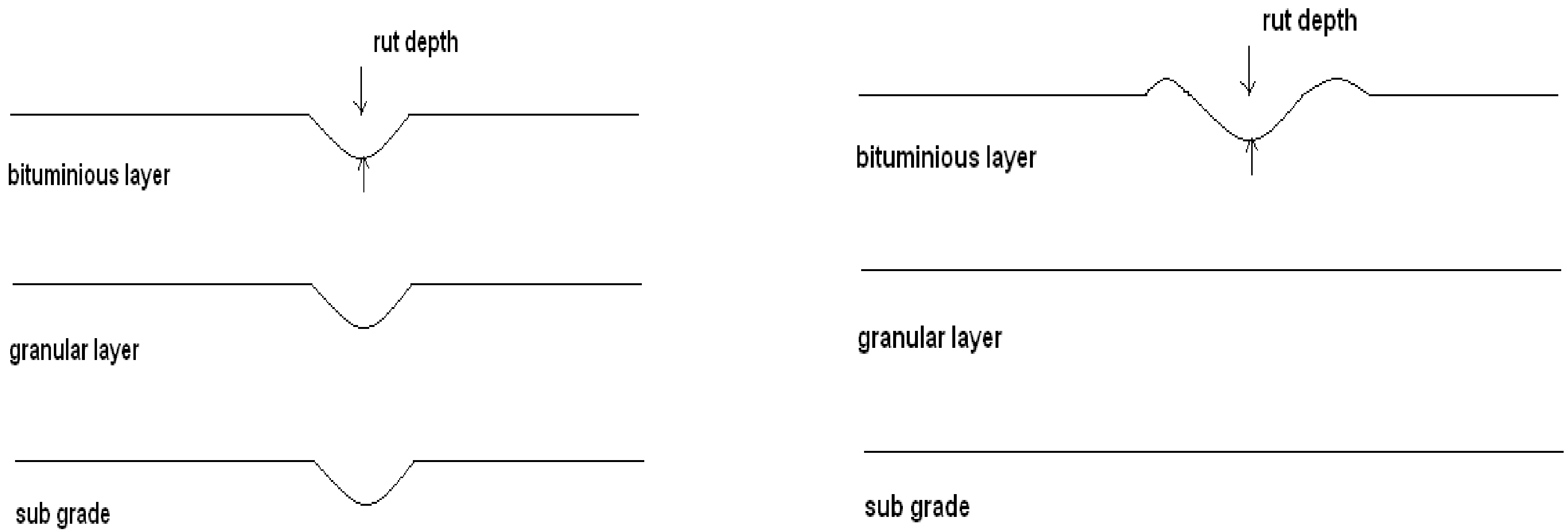
Introduction

- Flexible pavement design given in the previous edition (IRC : 37-1984) were applicable to design traffic up to only 30 msa
- The earlier code was empirical in nature which has limitations regarding applicability and extrapolation
- The present guidelines follows mechanistic empirical approach and developed new set of designs up to 150 msa

Introduction

- It is applicable to Expressways, NH, SH, MDR and other categories of roads predominantly carrying motorised vehicles
- It is apply to new pavements
- Pavements are considered to include bituminous surfacing and granular base and sub-base courses confirming to IRC/MOST standards

Design Criteria



Three main types of critical distresses

Rutting failure due to permanent deformation in sub grade

Rutting due to permanent deformation in bituminous layer

Fatigue cracking in bituminous (top surface) layer.

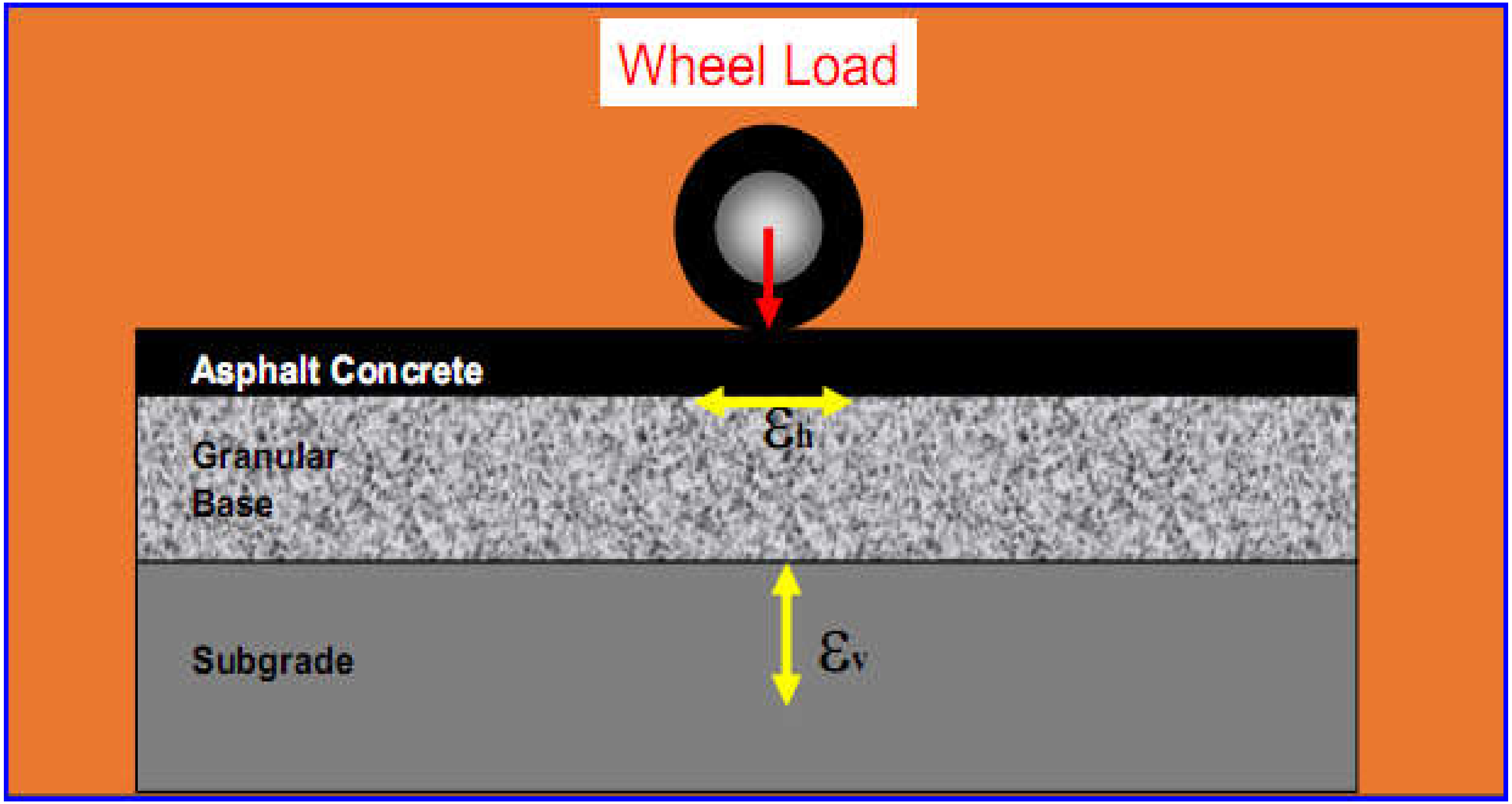
Design Criteria . . . .

Rutting Failure

Design Criteria . . . .

Fatigue Cracks

Design Criteria . . . .



Failure Criteria

Fatigue criteria

$$N_f = 2.21 \text{ x } 10^{-4} \left(\frac{1}{\varepsilon_t}\right)^{3.89} \left(\frac{1}{E}\right)^{0.854}$$

N_f= Cumulative std. axle load repetitions before the pavement develop 20% Cracking

ε_t= Initial horizontal tensile strain at the bottom of bituminous layer

E= Elastic modulus of bituminous layer in Mpa

Failure Criteria . . . .

Rutting criteria

$$N_r = 4.1656 \times 10^{-8} \left(\frac{1}{\varepsilon_z}\right)^{4.5337}$$

N_r= Cumulative std. axle load repetitions before the pavement develop 20 mm rut depth

ε_z= Initial vertical strain at the top of subgrade

Design Approach

Selection of appropriate inputs for

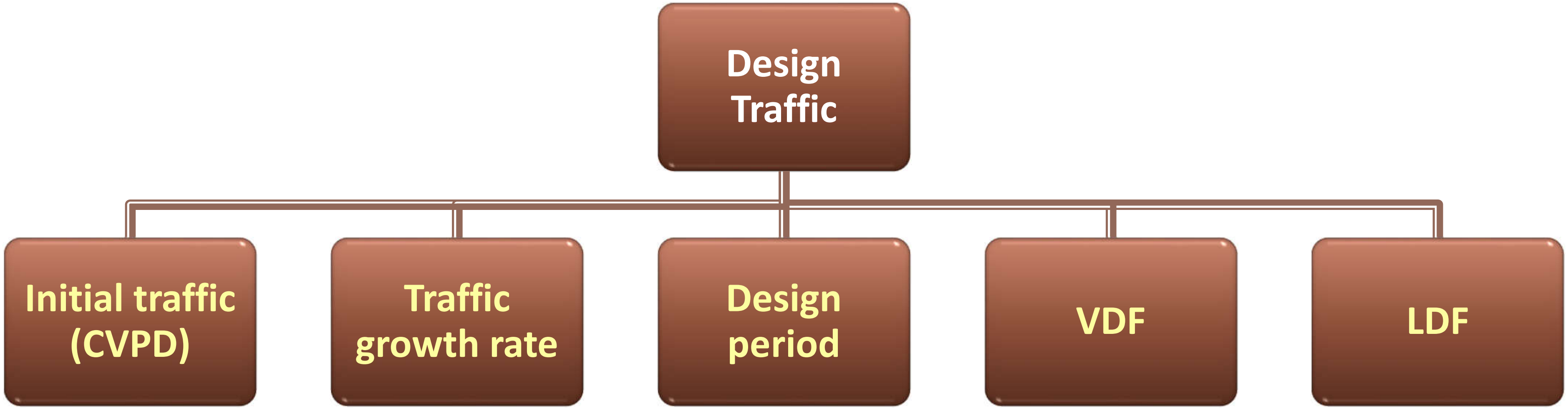
- **Climatic condition**
- **Pavement layers – no & composition**
- **Material characterisation**
- **Traffic characterisation**

Design Approach

Based on the inputs perform trial design

- Assign material properties (E & μ)
- Consider standard loading
- Use linear elastic layered theory
- Compute critical response
- Compare with failure criteria
- Revise the thickness if needed

Estimation of Design Traffic



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

Traffic in the year of completion $A = P(1+r)^x$

P = no of commercial vehicles as per last count

x = no of years between year of last count and year of completion of construction

Design Tables & Charts

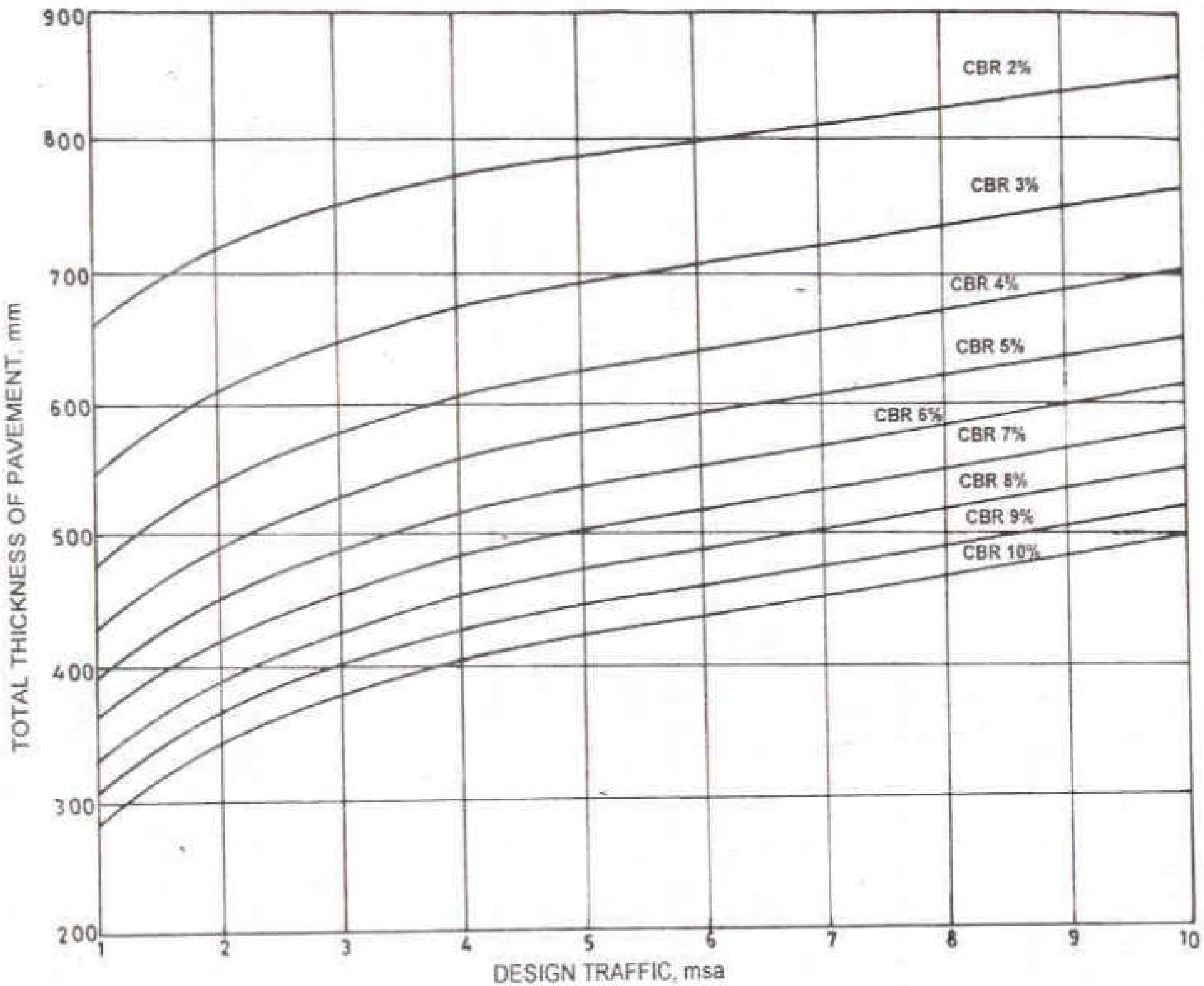
Designs are given for

- Sub-grade CBR values : 2% to 10%
- Design traffic : 1 msa to 150 msa
- Pavement temperature 35° C

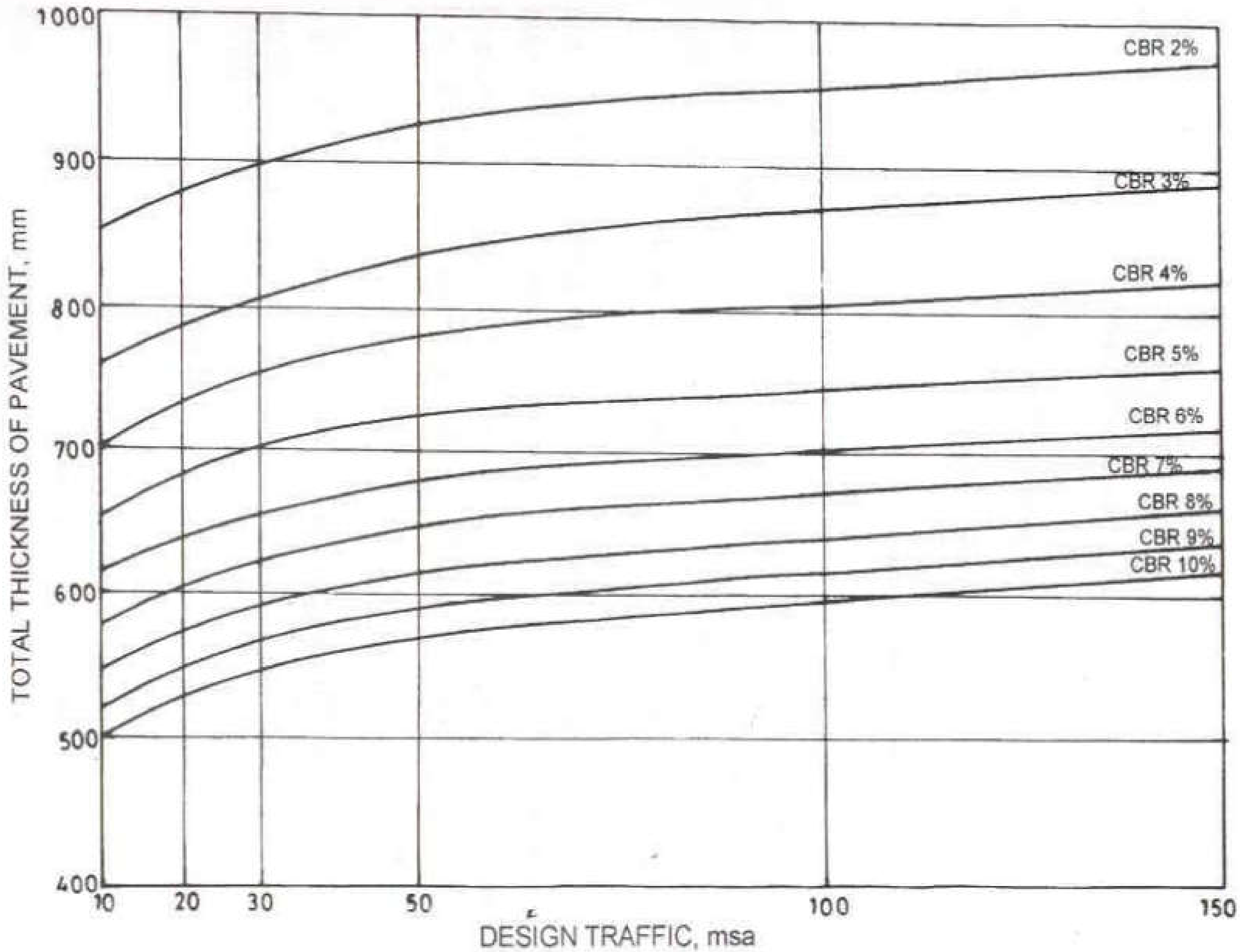
Input parameters

- Design traffic in terms of cumulative number of standard axles
- CBR value of Sub-grade

Design Charts



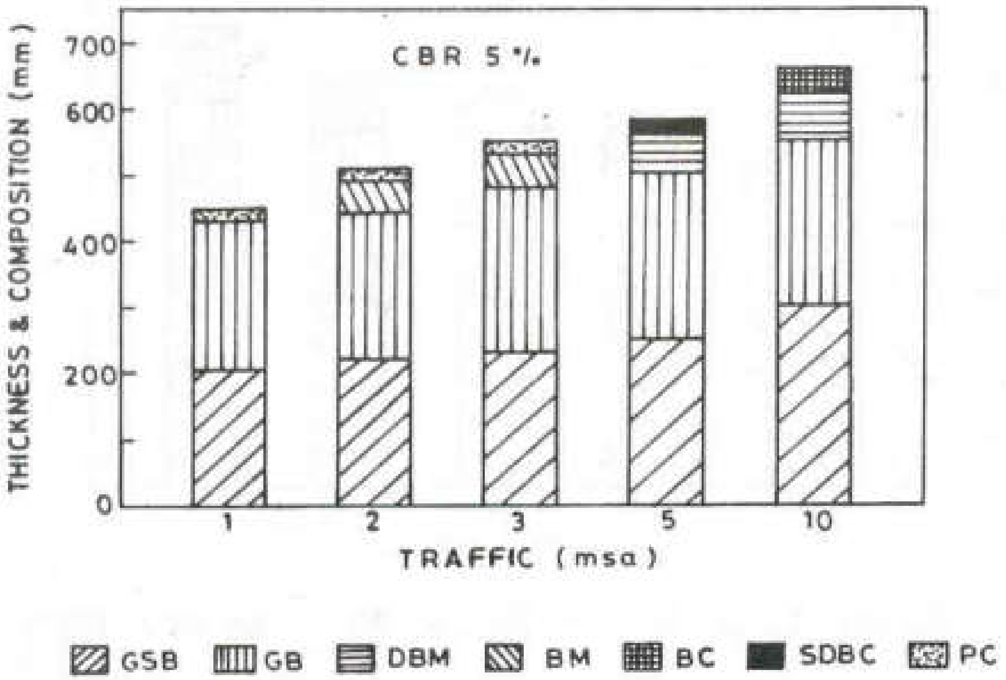
Design Charts



Design Tables & Charts

PLATE 1 – RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

CBR 5%					
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	430	20 PC		225	205
2	490	20 PC	50 BM	225	215
3	530	20 PC	50 BM	250	230
5	580	25 SDBC	55 DBM	250	250
10	660	40 BC	70 DBM	250	300



Pavement Composition

- Pavement Composition
  - Sub-base
  - Base
  - Surface

Pavement Composition

Sub-base Course

- Natural sand, gravel, laterite, brick metal, crushed stone or combinations thereof
- Minimum CBR :

  20% upto 2 msa traffic
  30% exceeding 2 msa
- Minimum Thickness

  150 mm for traffic < 10 msa
  200 mm for traffic ≥ 10 msa
- If subgrade CBR < 2%, design for subgrade CBR of 2% and provide a 150 mm thick capping layer of minimum CBR 10%

Pavement Composition

Base Course

- Unbound granular material – WBM, WMM, …
- Minimum CBR :

  20% upto 2 msa traffic

  30% exceeding 2 msa
- Minimum Thickness

  225 mm for traffic ≤ 2 msa

  250 mm for traffic > 2 msa
- If WBM is used and traffic > 10 msa, minimum thickness is 300 mm (4 layers of 75 mm each)

Pavement Composition

Bituminous Surfacing

- Wearing course or Binder course+wearing course
- Wearing course : Surface dressing, open-graded premix carpet, mix seal surfacing, SDBC and BC
- Binder course : BM, DBM, mix seal surfacing, SDBC and BC
- Wearing surface used is open-graded premix carpet of thickness upto 25 mm, it should not be counted towards the total thickness

Final Remarks

- The present guidelines follows mechanistic empirical approach and developed new set of designs up to 150 msa
- Thickness charts are still available for CBR values of up to 10% only
- Design charts are available for only a pavement temperature of 35^{o} C
- The contribution of individual component layers is still not realized fully with the system of catalogue thicknesses. The same can be done with the analytical tool for design.

Example

- Two-lane road with single carriageway
- Initial traffic in the year of completion of construction = 660 CVPD
- Traffic growth rate per annum = 7.5%
- Design life = 15 years
- Design CBR of subgrade soil = 5%

Example - Axle Load Spectrum

Axle Loads	
Axle Load range	% of axle loads
05-07	04
07-09	12
09-11	37
11-13	24
13-15	19
15-17	04
Total	100.0

Example – Design Calculations

$$VDF = \frac{V_1\left(\frac{W_1}{W_s}\right)^4 + V_2\left(\frac{W_2}{W_s}\right)^4 + V_3\left(\frac{W_3}{W_s}\right)^4 + \ldots\ldots}{V_1 + V_2 + V_3 + \ldots\ldots}$$

$$VDF = \frac{4\left(\frac{6}{8.2}\right)^4 + 12\left(\frac{8}{8.2}\right)^4 + 37\left(\frac{10}{8.2}\right)^4 + 24\left(\frac{12}{8.2}\right)^4 + 19\left(\frac{14}{8.2}\right)^4 + 4\left(\frac{16}{8.2}\right)^4}{100}$$

$$VDF = 4.23$$

For Two-lane road with single carriageway

$$Lane\ Distribution\ factor = 0.75$$

Example – Design Calculations

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

$$N = \frac{365\left[(1+0.075)^{15} - 1\right]}{0.075} * 660 * 0.75 * 4.23$$

$$N = 19961097 \text{ std axles}$$

$$N \approx 20 \text{ msa}$$

Example – Design Calculations

$N = 20\ \text{msa}$

$CBR = 5\%$

CBR 5%				
Cumulative Traffic (msa)	Total Pavement Thickness (mm)	PAVEMENT COMPOSITION		
		Bituminous Surfacing		Granular Base & Sub-base (mm)
		BC (mm)	DBM (mm)	
10	660	40	70	
20	690	40	100	
30	710	40	120	Base = 250
50	730	40	140	
100	750	50	150	Sub-base = 300
150	770	50	170	

Total Pavement Thickness		=	690 mm
Bituminous Surfacing			
	BC	=	40 mm
	DBM	=	100 mm
Granular Base		=	250 mm
Granular Sub-base		=	300 mm

Example – Design Calculations

For Stage Constuction

n = 5 years

$$N = \frac{365\left[(1+0.075)^{5}-1\right]}{0.075} * 660 * 0.75 * 4.23$$

$$N = 4439093 \text{ std axles}$$

$$N \approx 4.5 \text{ msa}$$

Example – Design Calculations

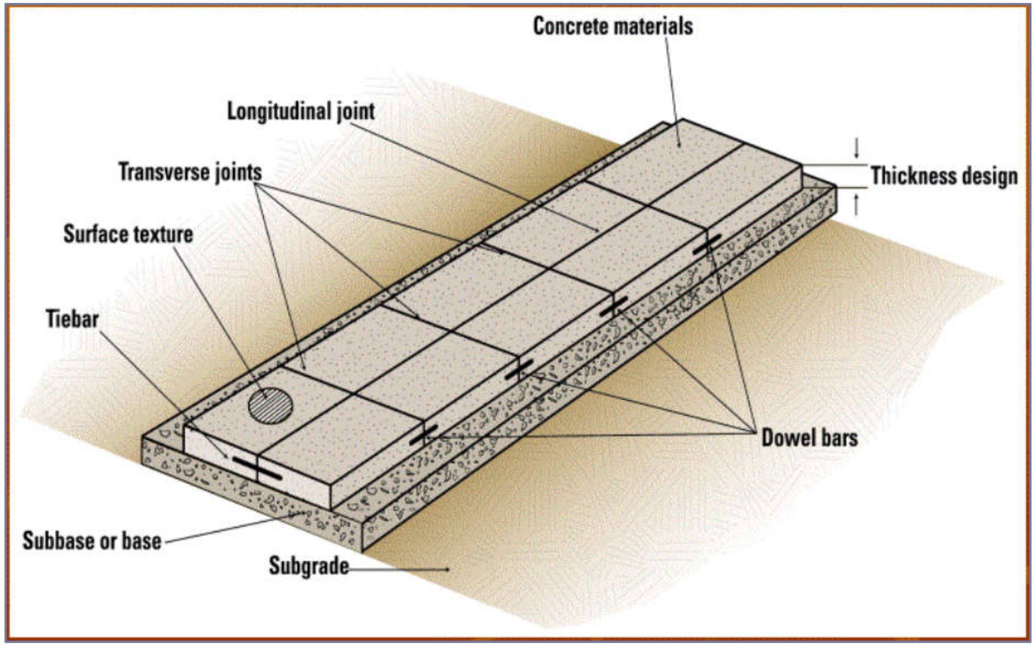
$$N = 4.5 \text{ msa}$$

$$CBR = 5\%$$

CBR 5%						
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	430	20 PC		225	205	
2	490	20 PC	50 BM	225	215	
3	530	20 PC	50 BM	250	230	
5	580	25 SDBC	55 DBM	250	250	
10	660	40 BC	70 DBM	250	300	

Total Pavement Thickness		=	690 mm	580+50 mm
Bituminous Surfacing				
	BC/SDBC	=	40 mm	25 mm
	DBM	=	100 mm	55 mm
Granular Base		=	250 mm	250 mm
Granular Sub-base		=	300 mm	250+50 mm

Rigid Pavement Design

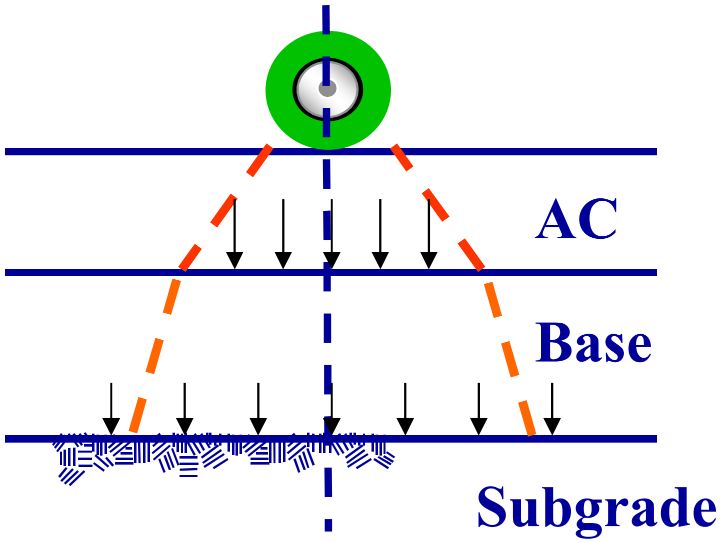


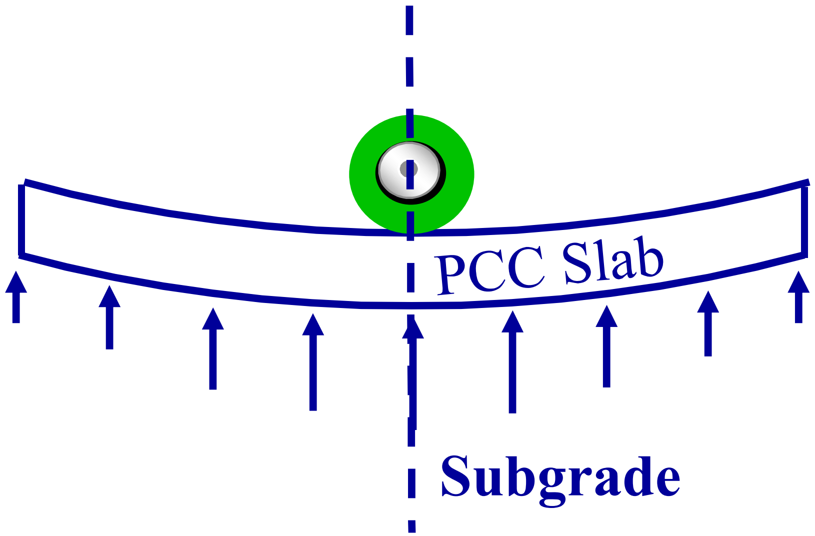
In this presentation

- Rigid pavement design considerstions
- Wheel load and temperature stresses
- Design considerations as per IRC
- Design of Slab
- Design of Joints
- Dowel bar design
- Tie bar design

Structural Response Models

Different analysis methods for AC and PCC





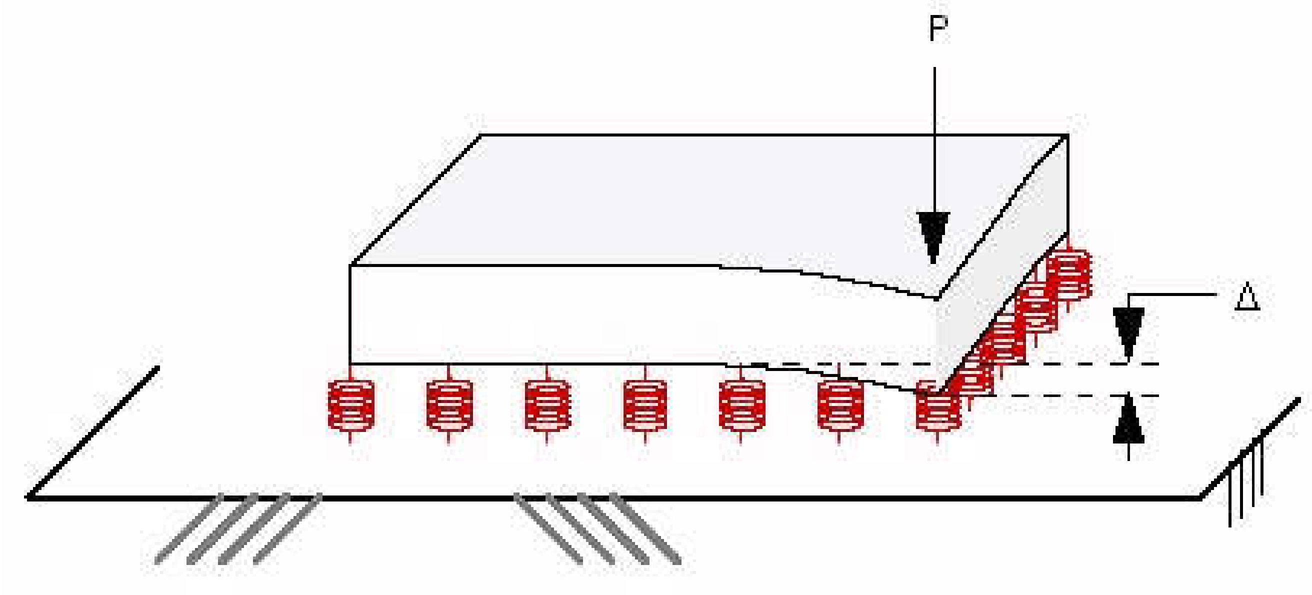
- Layered system behavior.
- All layers carry part of load.

- Slab action predominates.
- Slab carries most load.

General Design Considerations

- Modulus of Subgrade Reaction
- Relative Stiffness of Slab to Subgrade
- Equivalent Radius of Resting Section
- Critical Load Position
- Wheel Load Stresses
- Temperature Stresses
- Critical Combination of Stresses

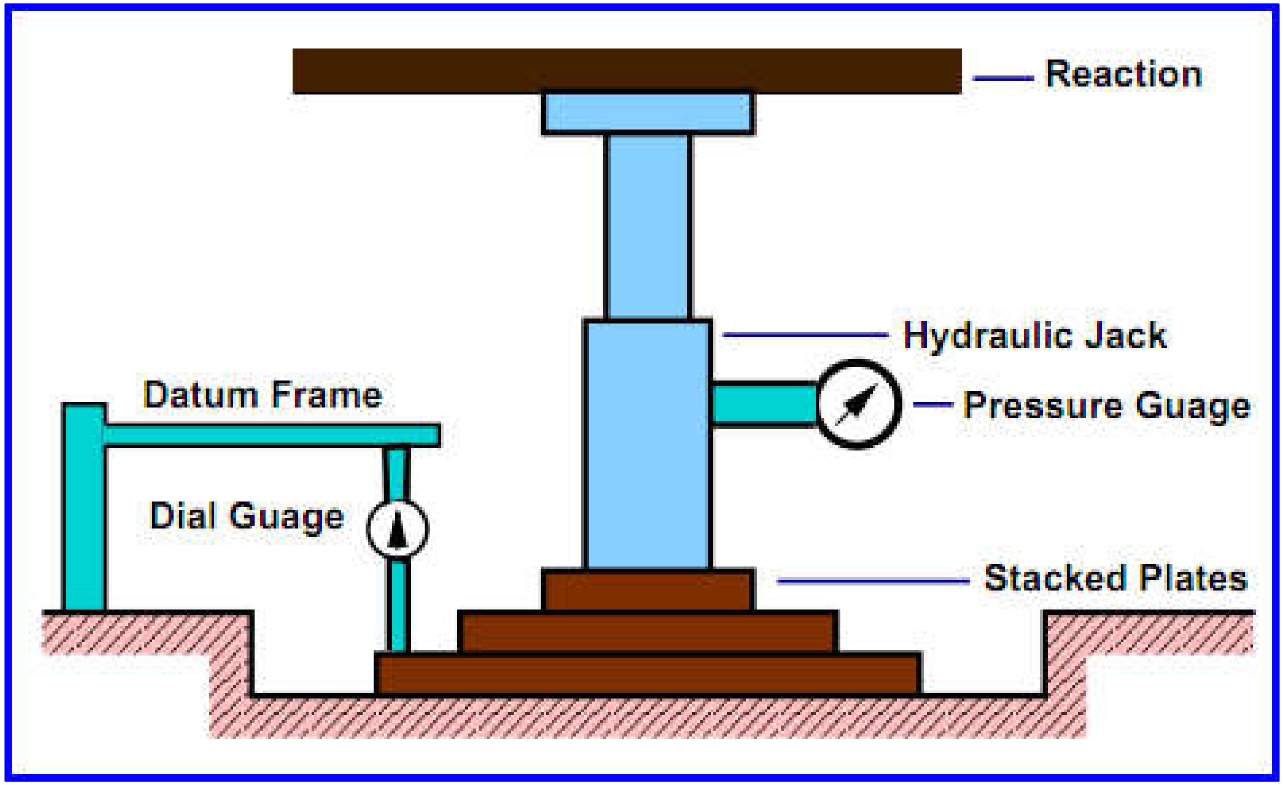
Modulus of Subgrade Reaction



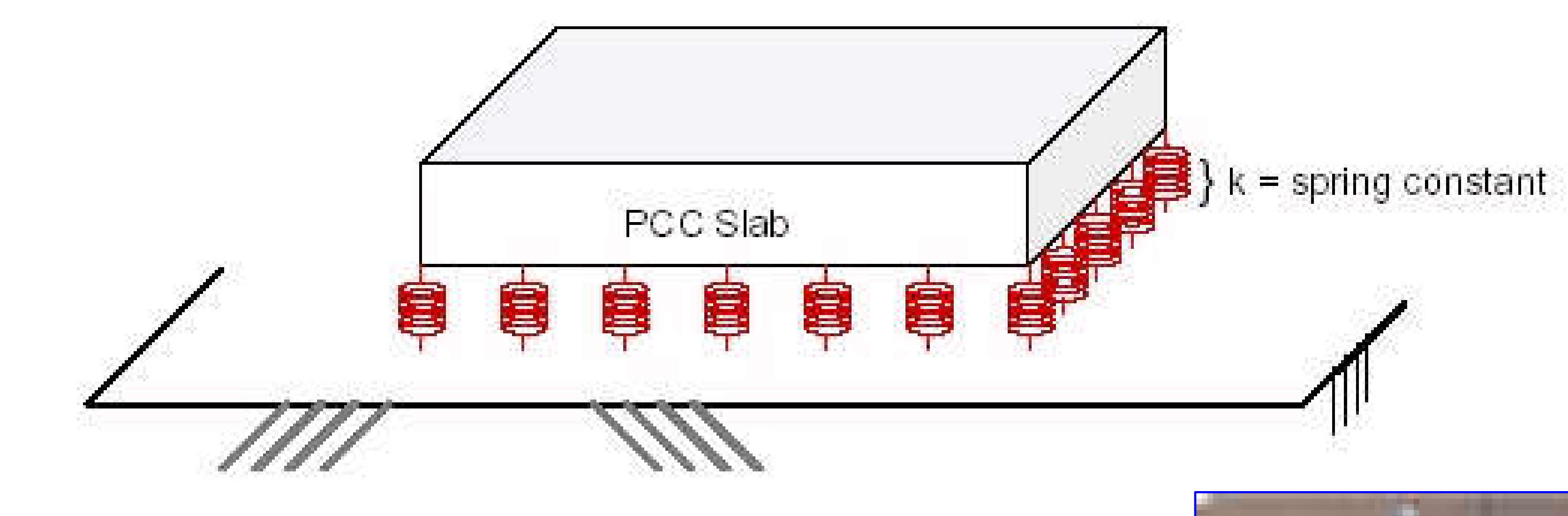
$$K = \frac{P}{\Delta}$$

- P = pressure sustained in kg/cm² by a rigid plate of diameter 75 cm
- Δ = design deflection = 0.125 cm

Plate Bearing Test

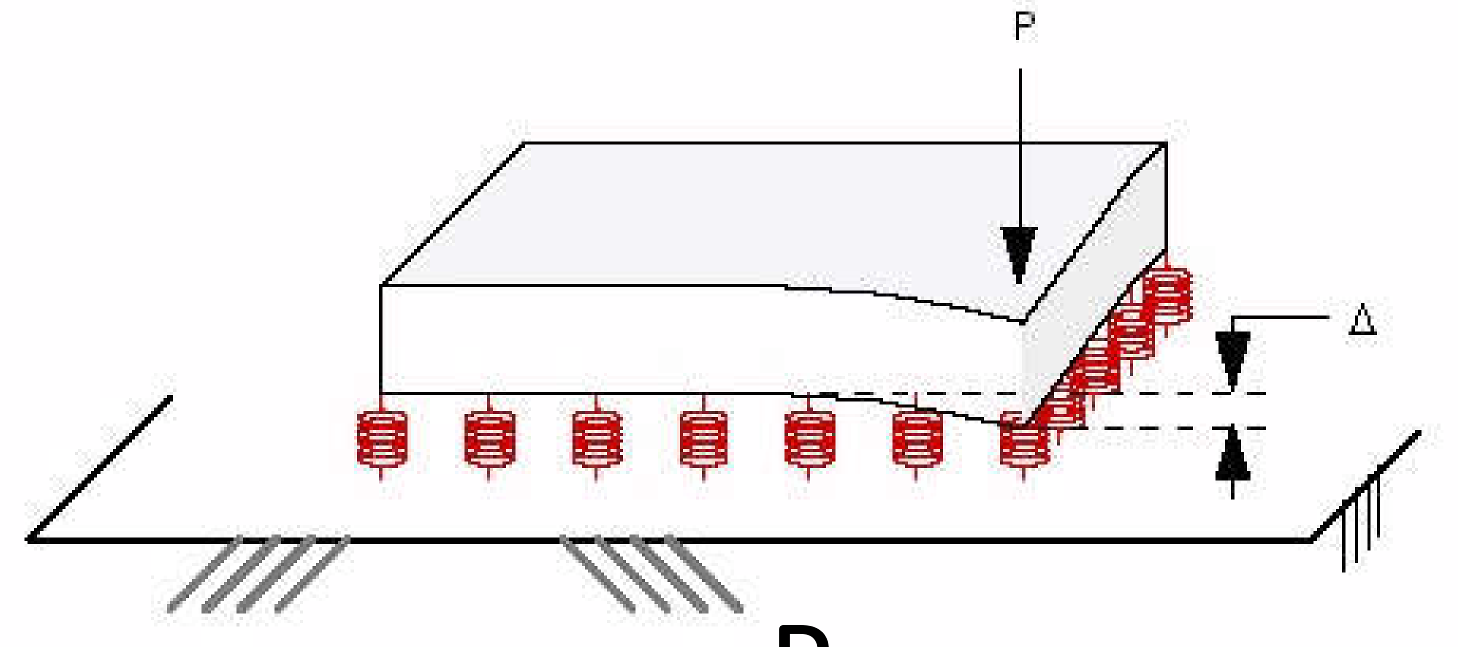


Modulus of Subgrade Reaction



- Pressure sustained per unit deflection
- Plate bearing test
- Limiting design deflection = 1.25mm

Modulus of Subgrade Reaction



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

- P = pressure sustained in kg/cm^2 by a rigid plate of diameter 75 cm
- Δ = design deflection = 0.125 cm

Plate Bearing Test

Plate Bearing Test

Plate Bearing Test Results

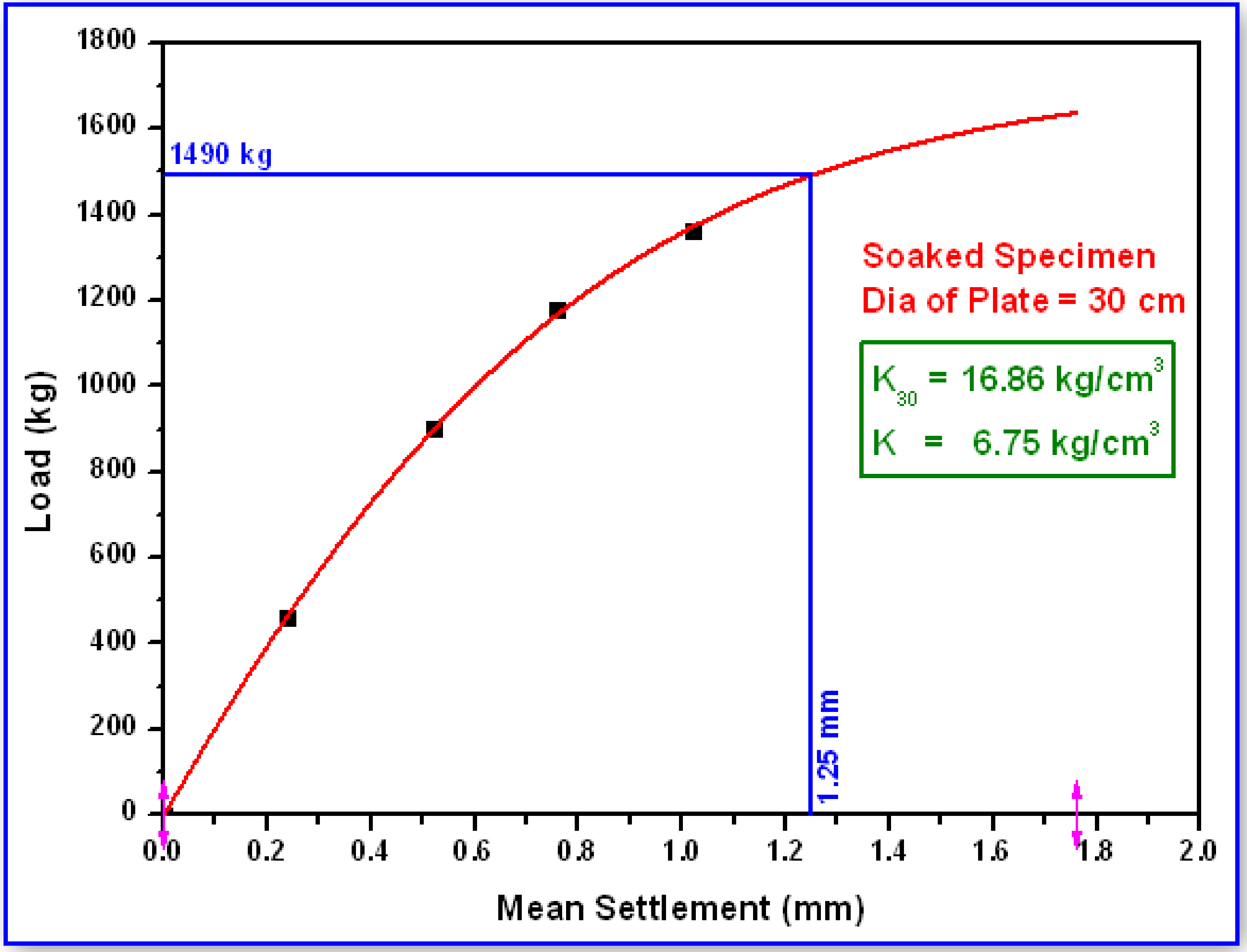


Plate Bearing Test – Corrections

❖ **Allowance for Worst Subgrade Moisture**

$$K_S = K_{US} \frac{P_S}{P_{US}}$$

❖ **Correction for Small Plate Size**

$$K = K_1 \frac{r_1}{r}$$

Approximate k-value

Approximate k-value corresponding to CBR values for homogeneous soil subgrade										
Soaked CBR (%)	2	3	4	5	7	10	15	20	50	100
k-Value (kg/cm^3)	2.1	2.8	3.5	4.2	4.8	5.5	6.2	6.9	14.0	22.2

Approximate k-value

k-values over Granular and Cemented Sub-bases						
k-Value of subgrade (kg/cm^3)	Effective k (kg/cm^3)					
	Untreated granular sub-base of thickness in cm			Cement treated sub-base of thickness in cm		
	15	22.5	30	10	15	20
2.8	3.9	4.4	5.3	7.6	10.8	14.1
5.6	6.3	7.5	8.8	12.7	17.3	22.5
8.4	9.2	10.2	11.9	-	-	-

Approximate k-value

k-value over Dry Lean Concrete Sub-base						
k-Value of subgrade (kg/cm^3)	2.1	2.8	4.2	4.8	5.5	6.2
Effective k over 100 mm DLC (kg/cm^3)	5.6	9.7	16.6	20.8	27.8	38.9
Effective k over 150 mm DLC (kg/cm3)	9.7	13.8	20.8	27.7	41.7	-

Radius of relative stiffness

Pressure deformation characteristics of rigid pavement is a function of relative stiffness of slab to that of subgrade

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

Equivalent Radius of Resisting Section

❖**When a < 1.724 h**

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

❖**When a ≥ 1.724 h**

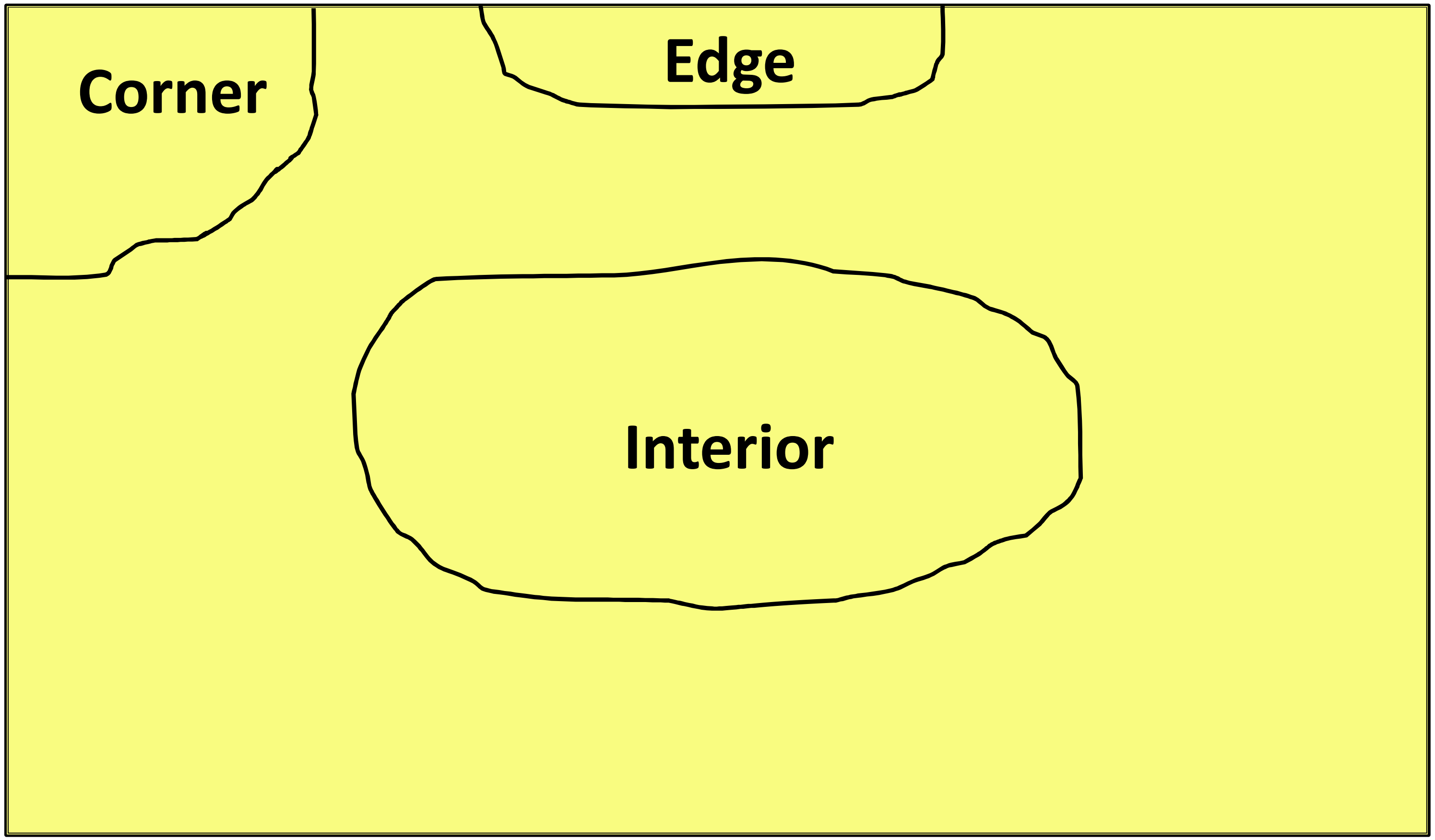
$$b=a$$

a = radius of wheel load distribution, cm

h = slab thickness, cm

Critical Load Position

PCC SLAB

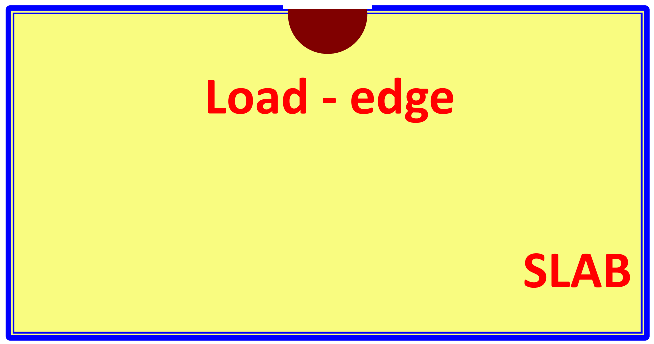


Wheel Load Stresses for Design

IRC : 58 - 1988

Westergaard's edge load stress equation, modified by Teller and Sutherland

$$\sigma_e = \frac{0.529\,P}{h^2}(1 + 0.54\,\mu)\left[4\,log_{10}\left(\frac{l}{b}\right) + log_{10}(b) - 0.4048\right]$$

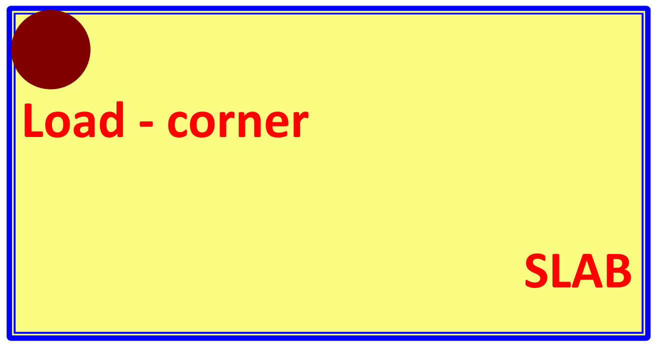


Wheel Load Stresses for Design

IRC : 58 - 1988

Westergaard's corner load stress equation, modified by Kelley

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



Temperature Stresses

Westergaard's concept of Temperature Stresses

- Warping Stresses
- Frictional Stresses

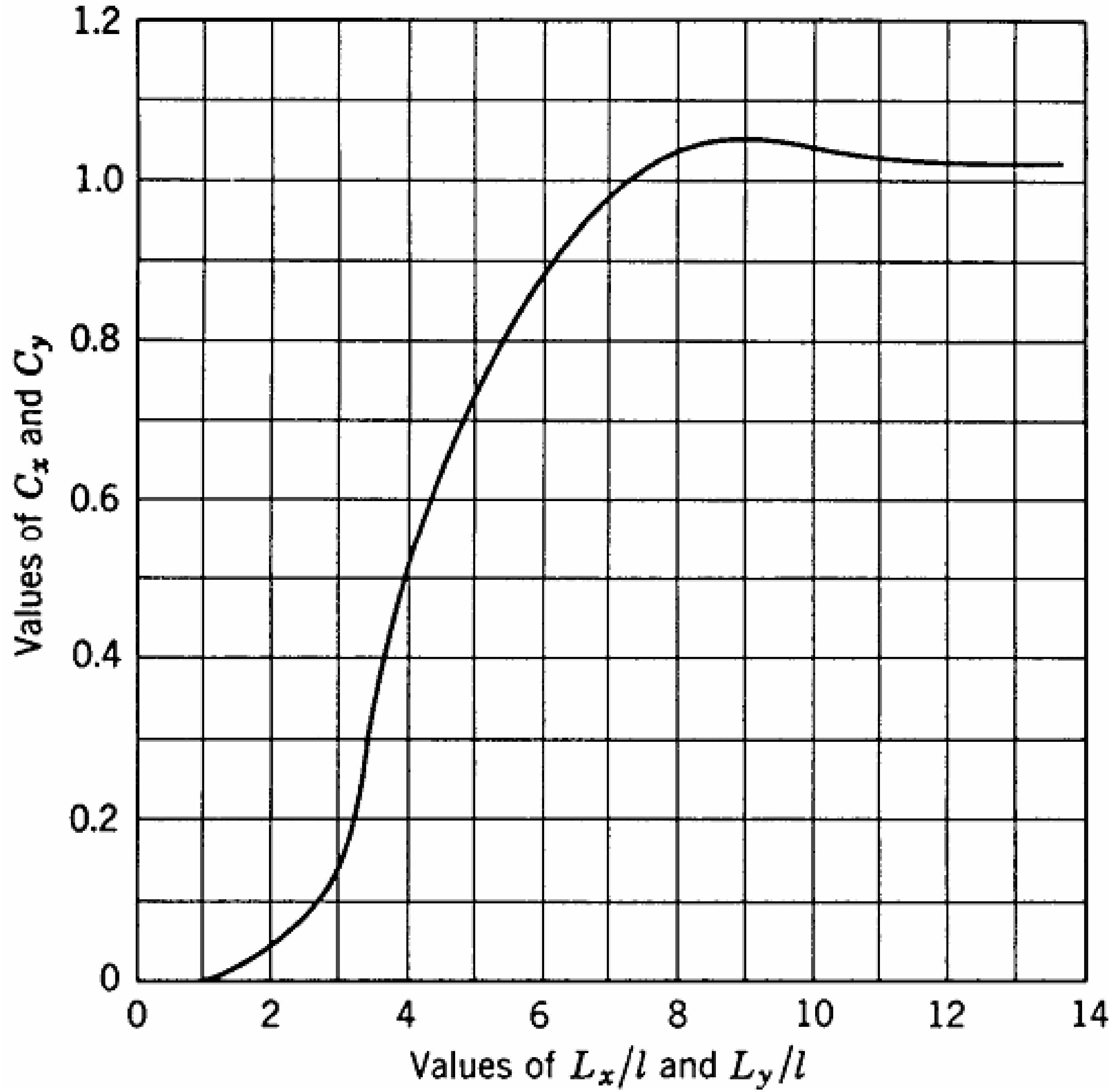
Warping Stresses

$$\sigma_{ti} = \frac{E\,\alpha\,t}{2}\left[\frac{C_x + \mu\,C_y}{1-\mu^2}\right]$$

$$\sigma_{te} = \frac{C_x E\,\alpha\,t}{2} \;\; or \;\; \sigma_{te} = \frac{C_y E\,\alpha\,t}{2}$$

$$\sigma_{tc} = \frac{E\,\alpha\,t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

Bradbury's Warping Stress Coefficients



Bradbury's Warping Stress Coefficients

Guide line as per IRC 58-2002

L/l	C	L/l	C
1	0.000	7	1.030
2	0.040	8	1.077
3	0.175	9	1.080
4	0.440	10	1.075
5	0.720	11	1.050
6	0.920	12	1.000

Frictional Stresses

$$\sigma_{tf}\, h\, B = B\,\frac{L}{2}\,h\,\gamma_c\,f$$

B = Slab width

L = Slab length

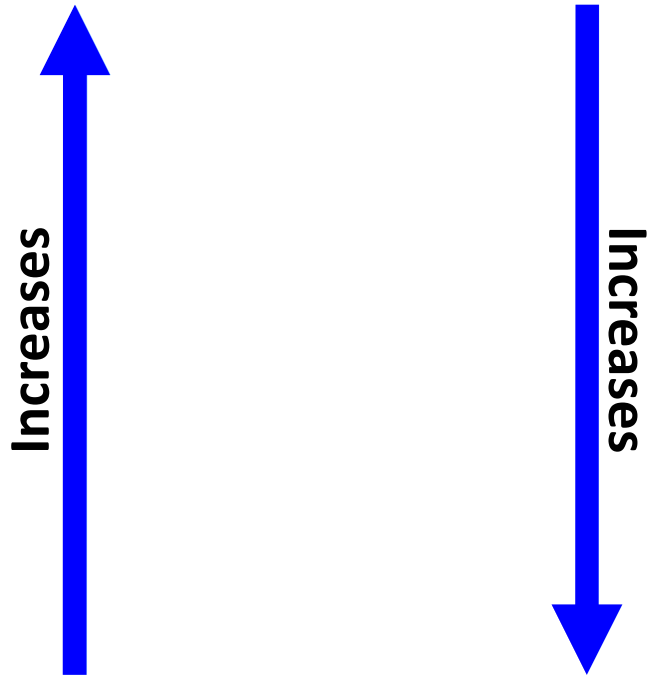
H = Slab thickness

γ_c = Unit weight of concrete

f = Coefficient of subgrade restraint (max 1.5)

Stress levels – load and temperature

	Due to Load	Due to Temperature
Corner Stress		
Edge Stress		
Interior Stress		



Plain Jointed Rigid Pavement Design

(IRC : 58 – 2002)

Wheel Loads

- **Axle loads**
  - Single : 10.2 tonnes
  - Tandem : 19.0 tonnes
  - Tridem : 24.0 tonnes

- **Sample survey**
  - Min sample size 10% in both directions

Wheel Loads

❖ **Tyre pressure**

- Range 0.7 to 1.0 MPa
- No significant effect on pavements ≥ 20cm thick
- 0.8 MPa is adopted

❖ **Load safety factor**

- Expressway/NH/SH/MDR – 1.2
- Lesser importance with lower truck traffic – 1.1
- Residential and other streets – 1.0

Design Period

- Depends on
  - traffic volume
  - growth rate
  - capacity of road and
  - possibility of augmentation

- Normal – 30 years
- Accurate prediction not possible – 20 years

Design Traffic

- Average annual growth rate – 7.5%

- Design traffic
  - 2-lane 2-way road – 25% of total for fatigue design
  - 4-lane or multi-lane divided traffic – 25% of total traffic in the direction of predominant traffic.
  - New highway links where no traffic data is available - data from roads similar classification and importance

Design Traffic

Cumulative Number of Repetitions of Axles

$$C = \frac{365[(1+r)^n - 1]}{r} A$$

A = Initial number of axles per day in the year when the road is operational

r = Annual rate of growth of commercial traffic

n = Design period in years

Temperature Differential

Guide line as per Table 1 of IRC 58-2002

Zone	States	Temperature Differential, °C in slab of thickness			
		15 cm	20 cm	25 cm	30 cm
I	Punjab, U.P., Uttaranchal, Gujarat, Rajasthan, Haryana and North M.P. Excluding hilly regions.	12.5	13.1	14.3	15.8
II	Bihar, Jharkhand, West Bengal, Assam and Eastern Orissa excluding hilly regions and coastal areas	15.6	16.4	16.6	16.8
III	Maharashtra, Karnataka, South M.P., Chattisgarh, Andhra Pradesh, Western Orissa and North Tamil Nadu, excluding hilly regions and coastal areas	17.3	19.0	20.3	21.0
IV	Kerala and South Tamilnadu excluding hilly regions and coastal areas	15.0	16.4	17.6	18.1
V	Coastal areas bounded by hills	14.6	15.8	16.2	17.0
VI	Coastal areas unbounded by hills	15.5	17.0	19.0	19.2

Characteristics of Sub-grade

❖ Modulus of sub-grade reaction (k)

- Pressure sustained per unit deflection
- Plate bearing test (IS : 9214 – 1974)
- Limiting design deflection = 1.25mm
- $K_{75} = 0.5\ k_{30}$
- One test/km/lane

Characteristics of Concrete

- **Modulus of Elasticity**
  - Experimentally determined value
  - 3.0×10^5 kg/cm^2
- **Poisson's ratio**

  $\mu = 0.15$
- **Coefficient of thermal expansion**

  $\alpha = 10 \times 10^{-6}$ per °C

Fatigue behaviour of cement concrete

Fatigue Life (N)

$$N = Unlimited$$

for SR < 0.45

$$N = \left[\frac{4.2577}{SR - 0.4325}\right]^{3.268}$$

when 0.45 ≤ SR ≤ 0.55

$$\log_{10} N = \left[\frac{0.9718 - SR}{0.0828}\right]$$

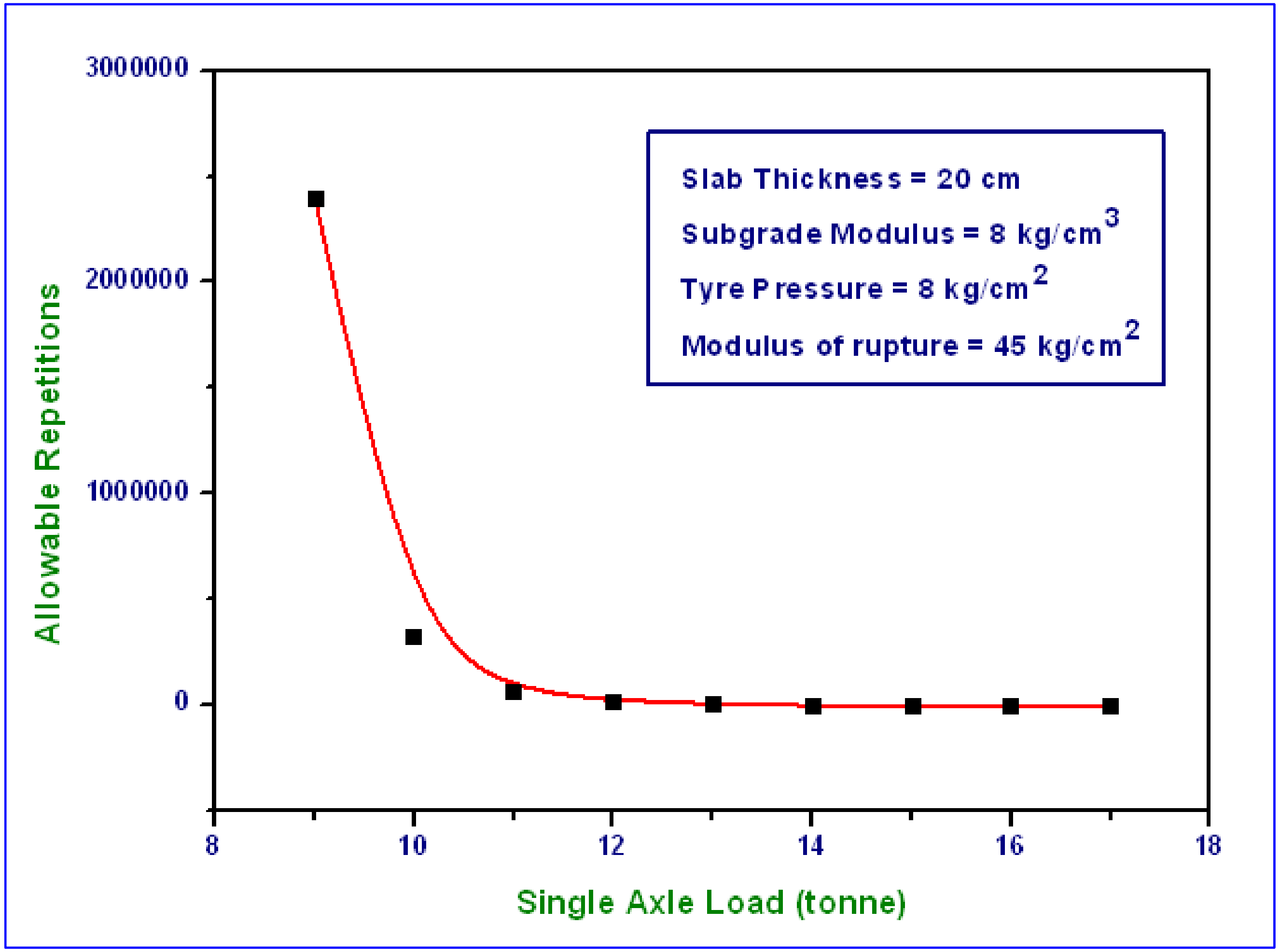
for SR > 0.55

where SR – Stress Ratio

Fatigue behaviour of cement concrete

Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions	Stress Ratio	Allowable Repetitions
0.45	62,790,761	0.59	40,842	0.73	832
0.46	14,335,236	0.60	30,927	0.74	630
0.47	5,202,474	0.61	23,419	0.75	477
0.48	2,402,754	0.62	17,733	0.76	361
0.49	1,286,914	0.63	13,428	0.77	274
0.50	762,043	0.64	10,168	0.78	207
0.51	485,184	0.65	7,700	0.79	157
0.52	326,334	0.66	5,830	0.80	119
0.53	229,127	0.67	4,415	0.81	90
0.54	166,533	0.68	3,343	0.82	68
0.55	124,526	0.69	2,532	0.83	52
0.56	94,065	0.70	1,917	0.84	39
0.57	71,229	0.71	1,452	0.85	30
0.58	53,937	0.72	1,099		

Fatigue behaviour of cement concrete



Single Axle Load tonne	Allowable Repetitions
9	2,402,754
10	326,334
11	71,229
12	23,419
13	7,700
14	1,917
15	630
16	207
17	68

Calculation of Stresses

Edge Stress

- ❖ Due to Load – Picket & Ray's chart

- ❖ Due to Temperature

$$\sigma_{te} = \frac{E \alpha t C}{2}$$

Calculation of Stresses

Corner Stress

- **Due to Load**

$$\sigma_c = \frac{3P}{h^2} \quad 1 \qquad \frac{a\sqrt{2}}{l} \quad ^{1.2}$$

- **Due to temperature**

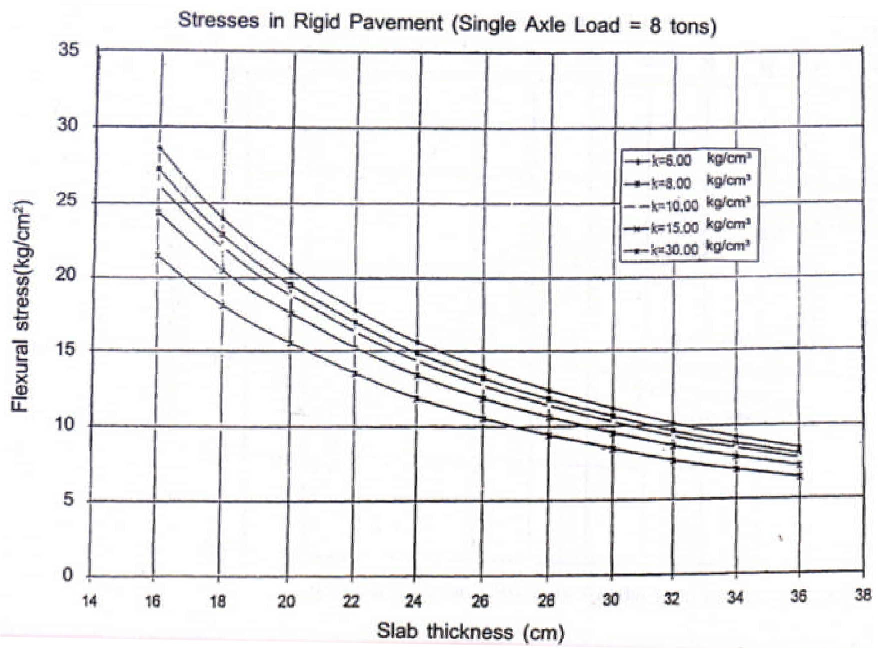
  negligible and hence ignored

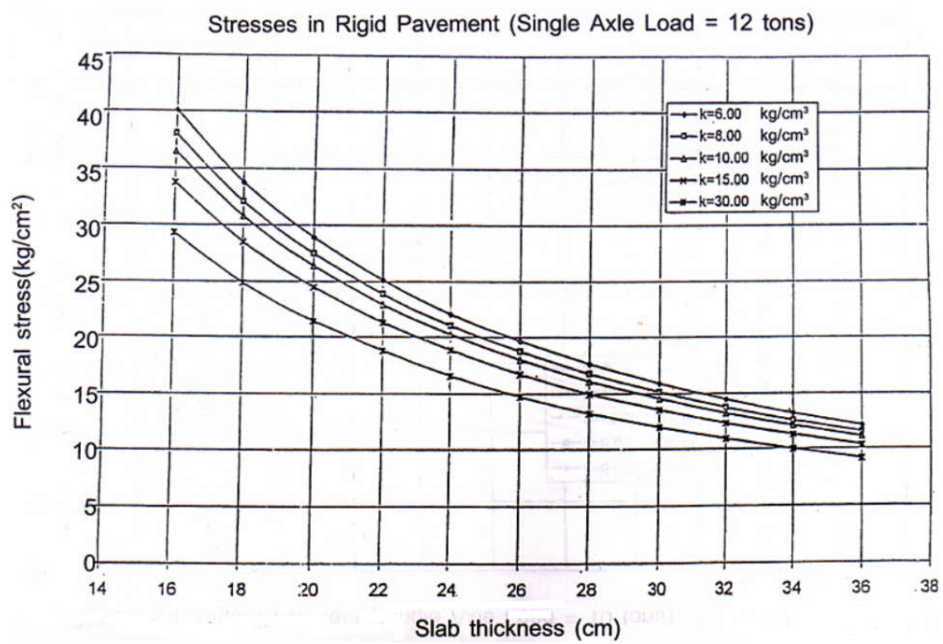
Calculation of Stresses

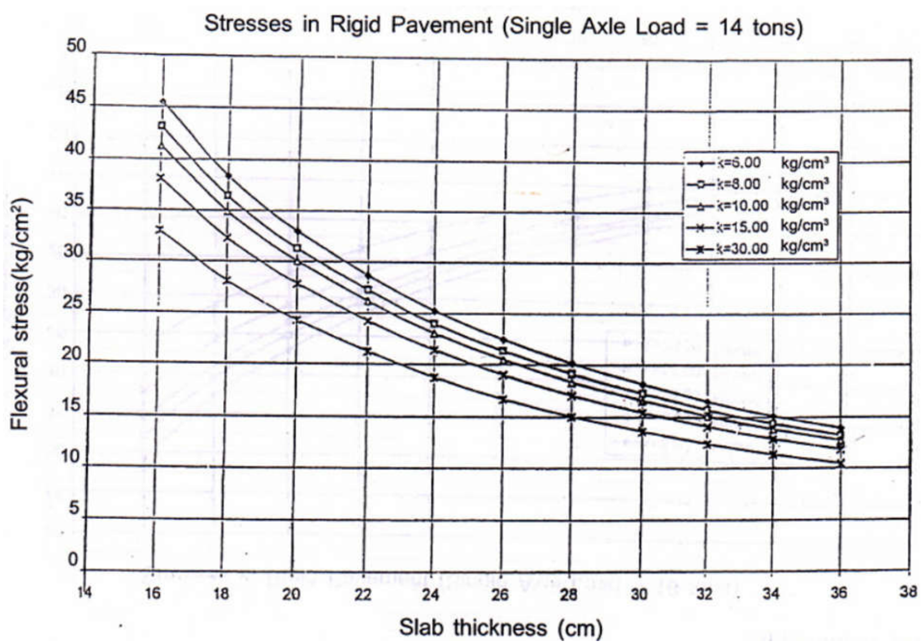
Radius of relative stiffness is given by

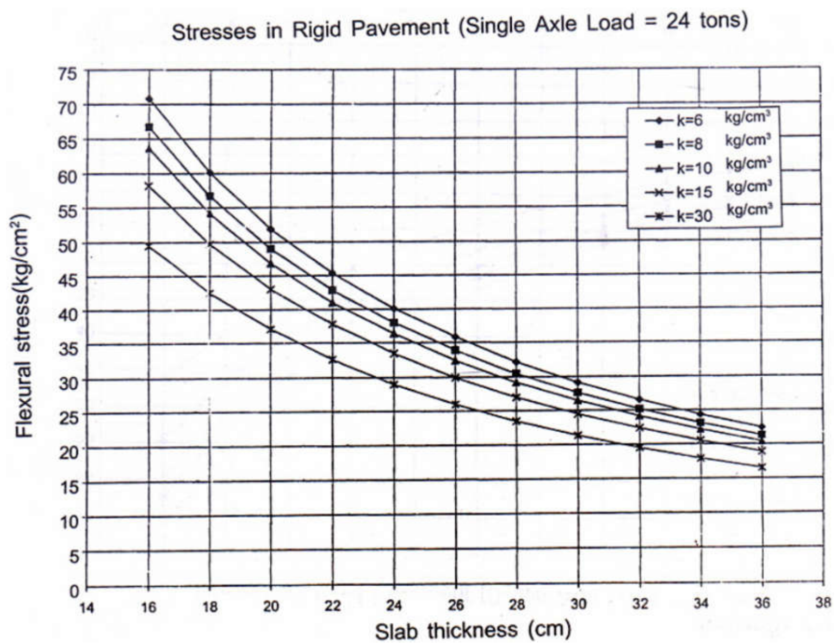
$$\sqrt[4]{\frac{Eh^3}{12(1 \quad \mu^2)k}}$$

Typical Design Charts

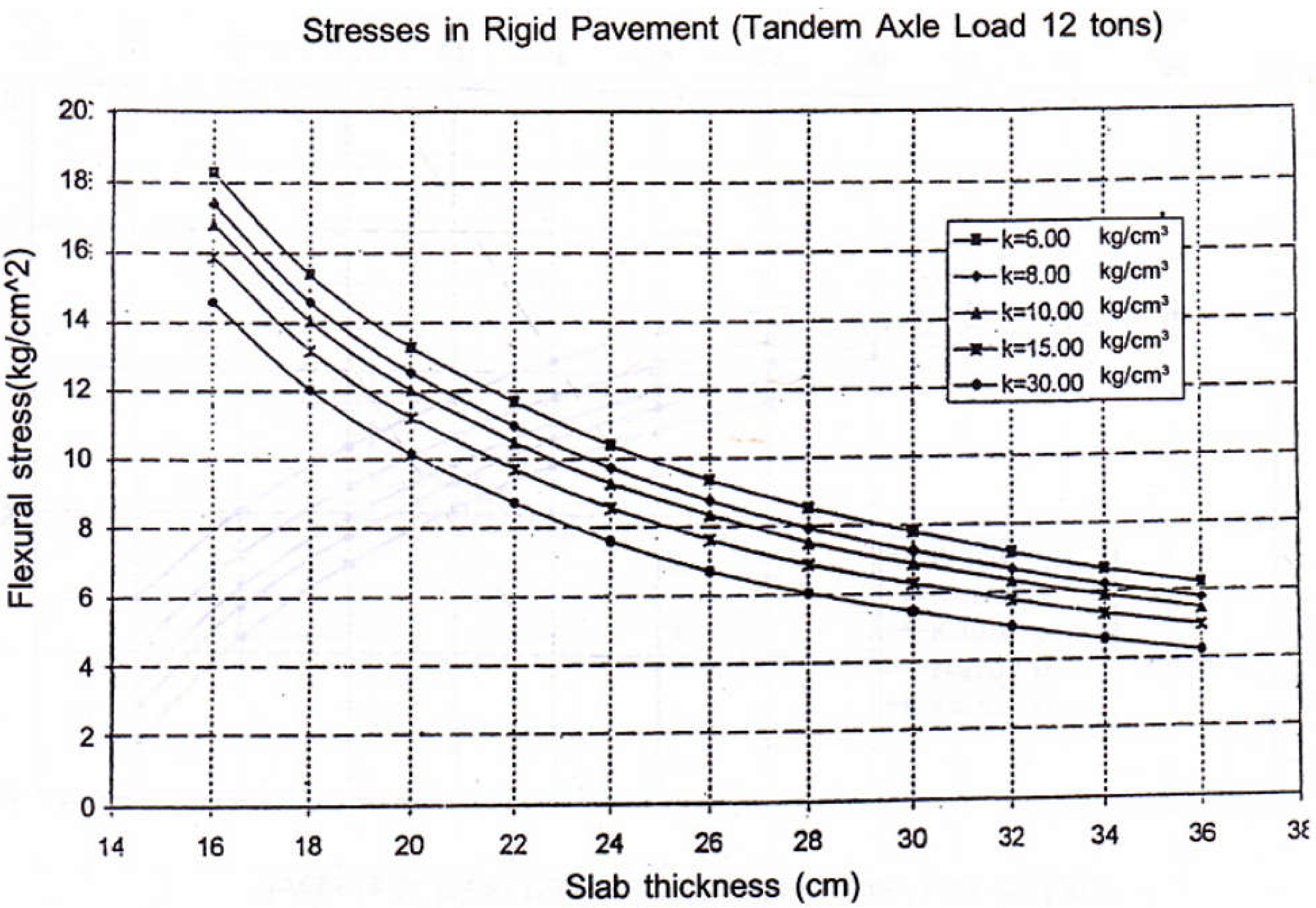




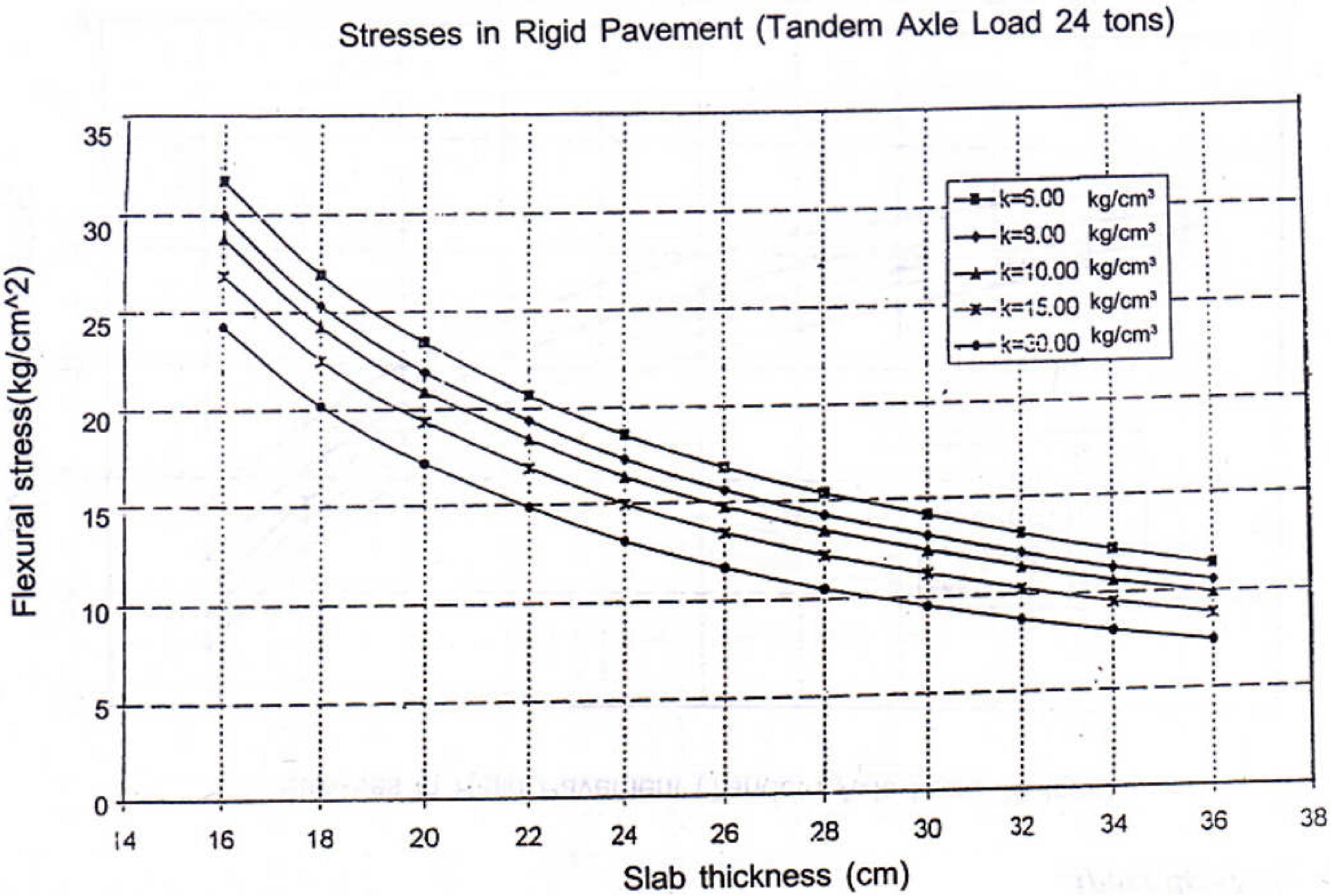




Typical Design Chart



Typical Design Chart



Design Procedure

- Stipulate design values for the various parameters
- Decide types and spacing between joints
- Select a trial design thickness of pavement
- Compute the repetitions of axle loads of different magnitudes during design period
- Calculate cumulative fatigue damage (CFD)
- If CFD is more than 1.0 revise the thickness
- Check for temp+load stress at edge with modulus of rupture
- Check for corner stress

Example

Total two-way traffic = 3000 CVPD at the end of construction period

Flexural strength of concrete = 45kg/cm^2

Modulus of subgrade reaction = 8 kg/cm^3

Slab dimension 4.5 m x 3.5 m

Example - Axle Load Spectrum

Single Axle Loads		Tandem Axle Loads	
Axle Load	% of axle loads	Axle Load	% of axle loads
19-21	0.6	34-38	0.3
17-19	1.5	30-34	0.3
15-17	4.8	26-30	0.6
13-15	10.8	22-26	1.8
11-13	22.0	18-22	1.5
9-11	23.3	14-18	0.5
< 9	30.0	< 14	2.0
Total	93.0	Total	7.0

Example – Design traffic

Cumulative repetition in 20 years is

$$C = \frac{365 * A\{(1+r)^{n} \quad 1\}}{r}$$

= 47,418,626 commercial vehicles

Design traffic = 25 % of above

= 11,854,657

Example – Fatigue analysis

AL	1.2AL	Stress	SR	ER	N	ER/N
Single axle						
20	24	25.19	0.56	71127	941000	0.76
18	21.6	22.98	0.51	177820	485000	0.37
16	19.2	20.73	0.46	569023	14330000	0.04
14	16.8	18.45	0.41	128030	∞	0.00
Tandem axle						
36	43.2	20.07	0.45	35564	62.8x10e6	0.0006
32	38.4	18.40	0.40	35564	∞	0.00

Example – Fatigue analysis

Cumulative fatigue life consumed = 1.1706

Hence revise the depth to 33 cm

Example – Fatigue analysis

AL	1.2AL	Stress	SR	ER	N	ER/N
Single axle						
20	24	24.10	0.53	71127	216000	0.33
18	21.6	21.98	0.49	177820	1290000	0.14
16	19.2	19.98	0.44	569023	∞	0.00
Tandem axle						
36	43.2	20.07	0.45	35564	∞	0.00

Cumulative fatigue life consumed = 0.47

Example – Check for Stresses

❖ **Edge**

warping stress = 17.30 kg/cm²

Load stress = 24.10 kg/cm²

Total = 41.10 kg/cm²

❖ **Corner**

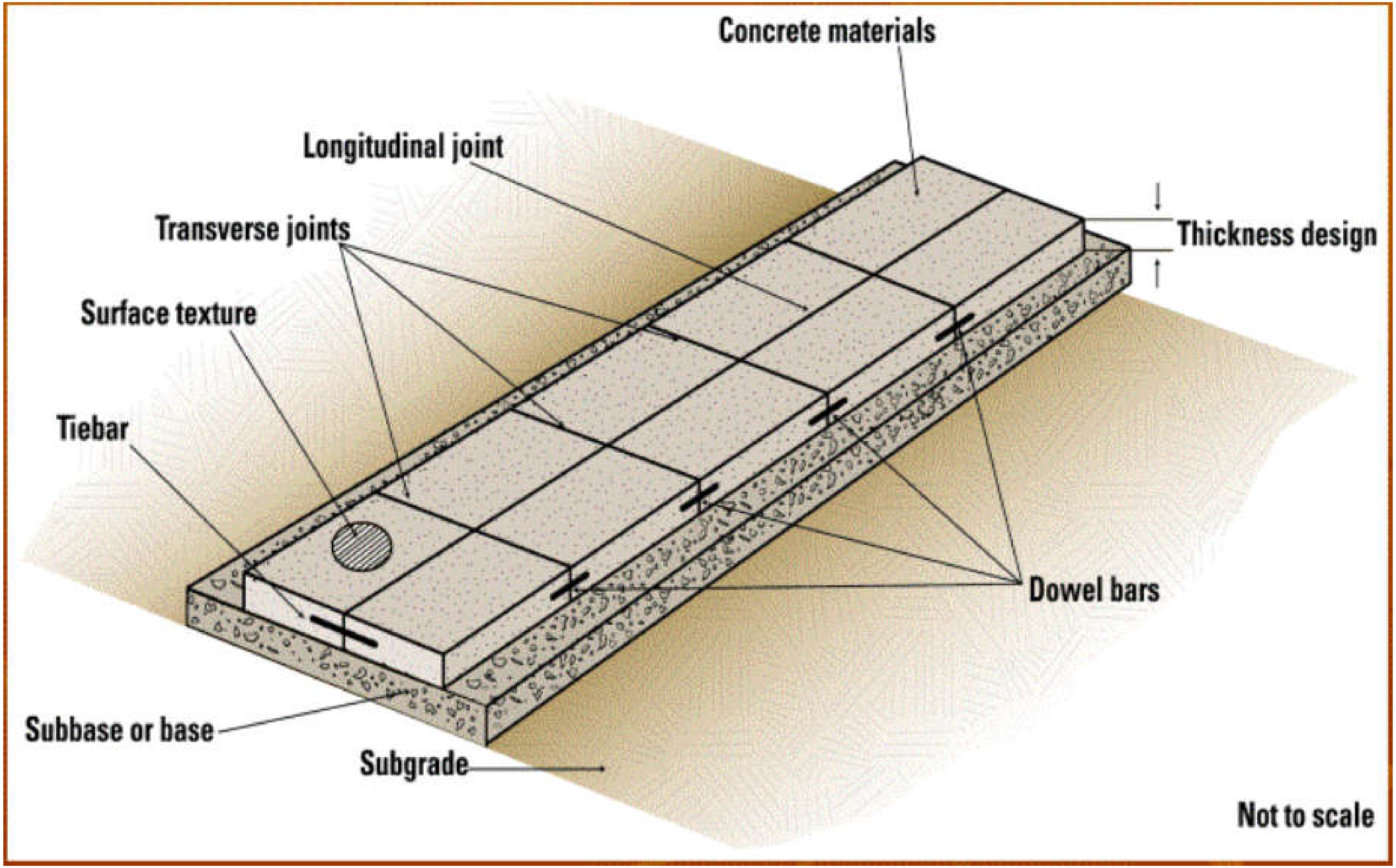
Load stress = 15.52 kg/cm²

Both are Less than

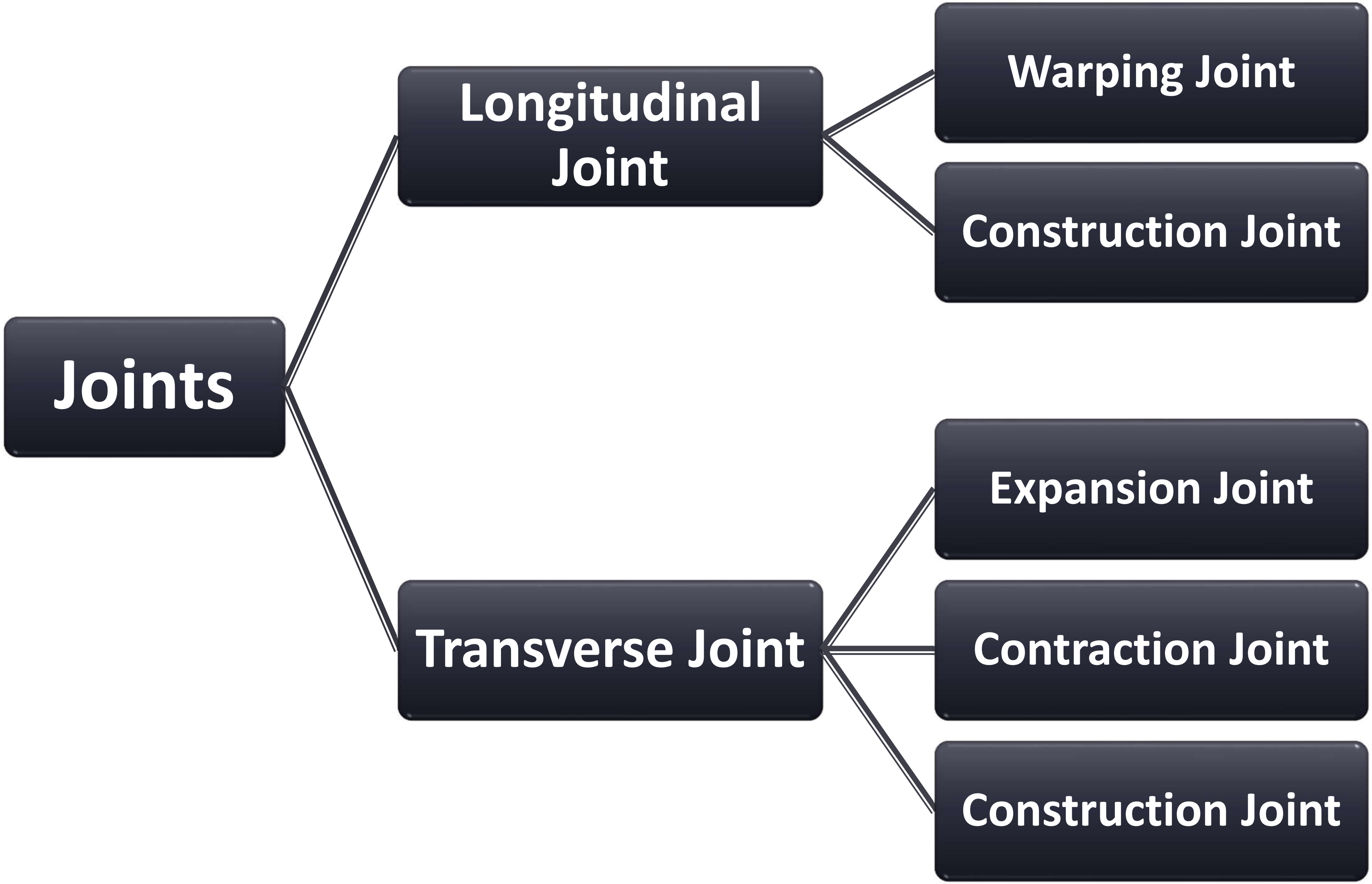
45 kg/cm² The Flexural strength

Design of Joints

Joints in Concrete Pavement



Types of Joints



Spacing of Joints

Spacing of Expansion Joint

If δ' is the maximum expansion in a slab of length L_e with a temperature rise from T_1 to T_2, then

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

α is the thermal expansion of concrete

Expansion joint gap $\delta = 2\,\delta'$

Spacing of Joints

Spacing of Expansion Joint

Recommended (by IRC)

Maximum expansion joint gap = 25 mm

Maximum Spacing between expansion joints

for rough interface layer

140 m – all slab thicknesses

for smooth interface layer

when pavement is constructed in summer

90 m – upto 200 mm thick slab

120 m – upto 250 mm thick slab

when pavement is constructed in winter

50 m – upto 200 mm thick slab

60 m – upto 250 mm thick slab

Spacing of Joints

Spacing of Contraction Joint

$$\sigma_{tc}\, h\, B = B\, \frac{L_c}{2}\, h\, \gamma_c\, f$$

σ_{tc} = Allowable tensile stress in concrete

h = Slab thickness

B = Slab width

L_c = Slab length or spacing b/w contraction joints

γ_c = Unit weight of concrete

f = Coefficient of subgrade restraint (max 1.5)

If Reinforcement is provided, replace LHS by $\sigma_{ts}\, A_s$

Spacing of Joints

Spacing of Contraction Joint

Recommended (by IRC)

Maximum Spacing between contraction joints

for unreinforced slabs

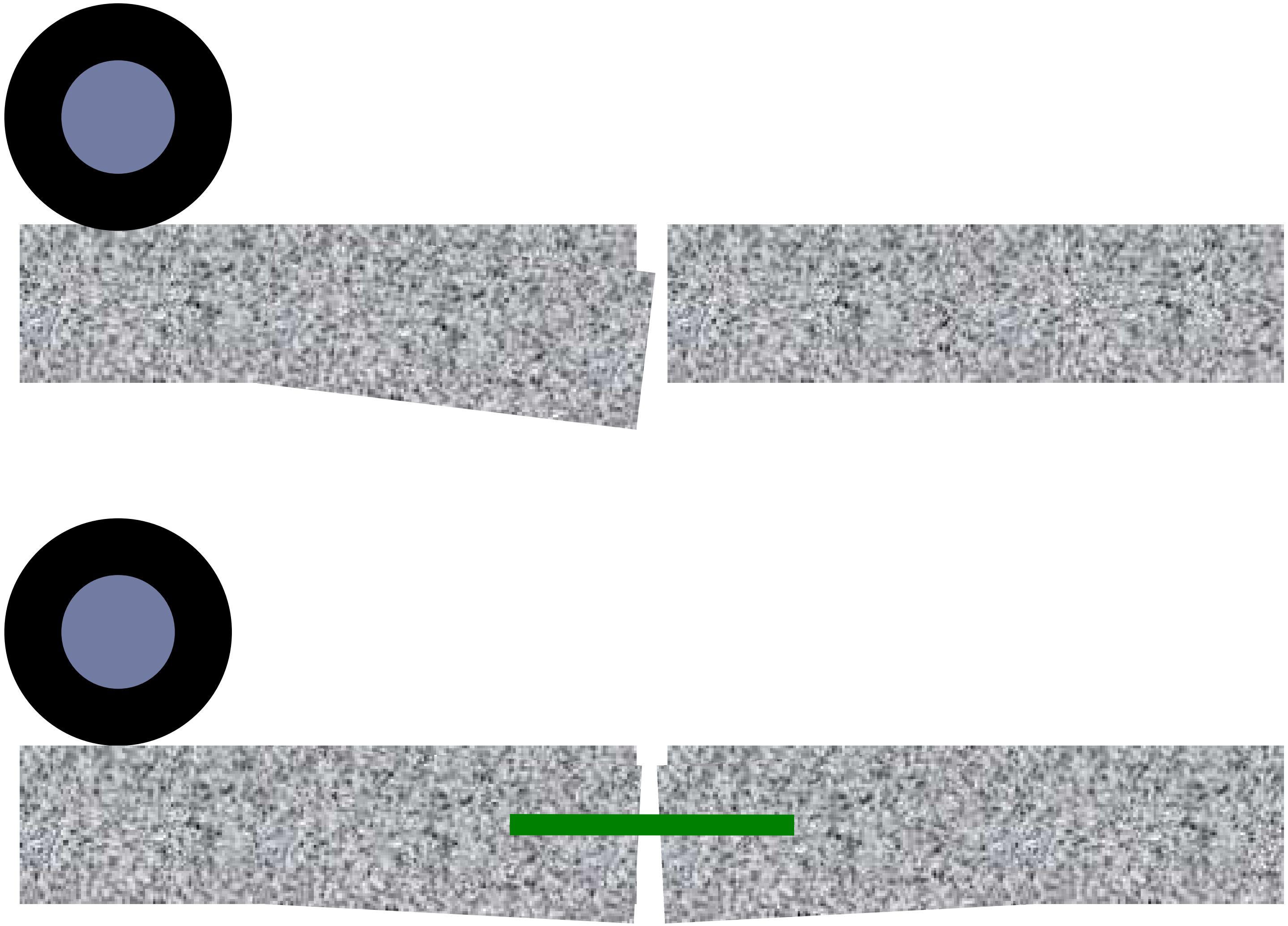
4.5 m – all slab thicknesses

for reinforced slabs

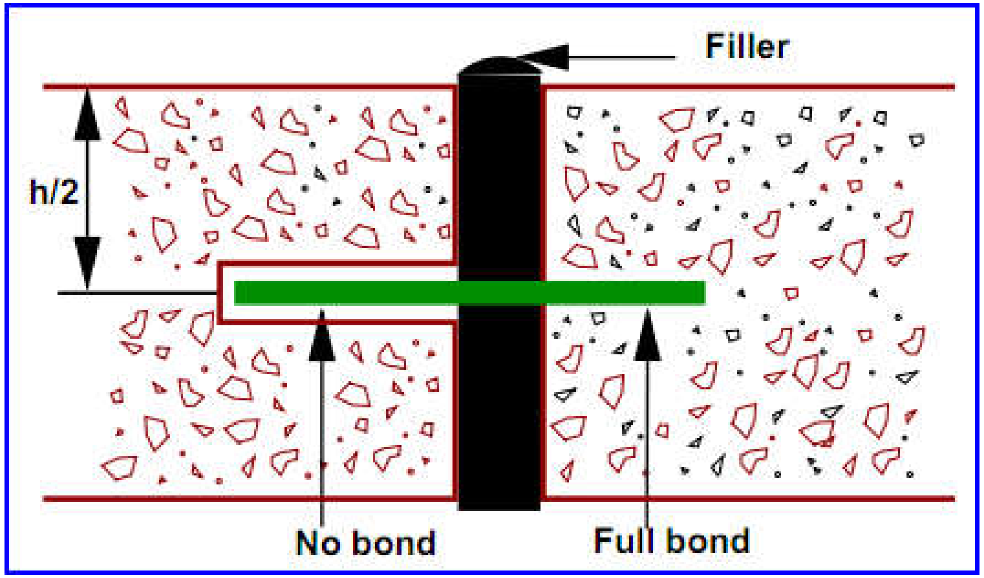
13 m – for 150 mm thick slab

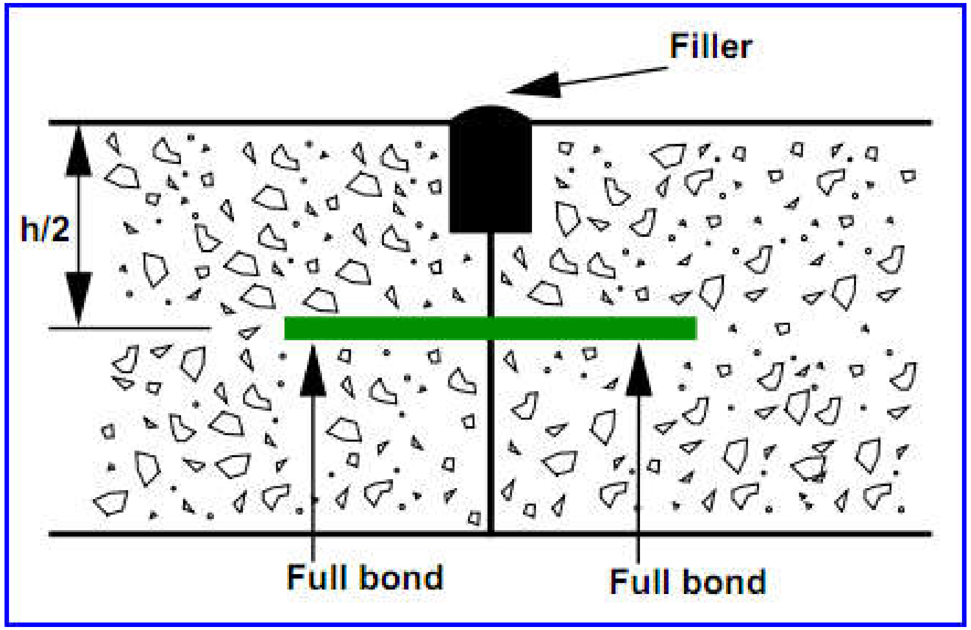
14 m – for 200 mm thick slab

Load Transfer – Dowel Bars



Dowel Bars and Tie Bars





Dowel Bars

Tie Bars

Tie bars are either deformed steel bars or connectors used to hold the faces of abutting slabs in contact.

Typically, tie bars are about 12 mm in diameter and between 0.6 and 1.0 m long

Dowel Bars – Bradbury's analysis

Load transfer capacity of a single dowel bar

- shear

$$P' = 0.785\, d^2 F_s$$

- Bending

$$P' = \frac{2\, d^3 F_f}{L_d + 8.8\, \delta}$$

- Bearing

$$P' = \frac{L_d^2 d F_b}{12.5\,(L_d + 1.5\, \delta)}$$

Bradbury's analysis

P' = Load transfer capacity of a single dowel bar, kg

d = Diameter of dowel bar, cm

L_d = Total length of embedment of dowel bar, cm

δ = Joint width, cm

F_s = Permissible shear stress in dowel bar, kg/cm^2

F_f = Permissible flexural stress in dowel bar, kg/cm^2

F_b = Permissible bearing stress in concrete, kg/cm^2

Dowel bar design - Length

The load capacity of the dowel bar in bending and bearing depend on the total embedded length L_d on both the slabs

Balanced design for equal capacity in bending and bearing, the value of Ld is obtained for the assumed joint width and dowel diameter using

$$L_d = 5d\left[\sqrt{\frac{F_f}{F_b}\left(\frac{L_d + 1.5\,\delta}{L_d + 8.8\,\delta}\right)}\right]$$

Minimum dowel length $L = L_d + \delta$

Dowel design - Spacing

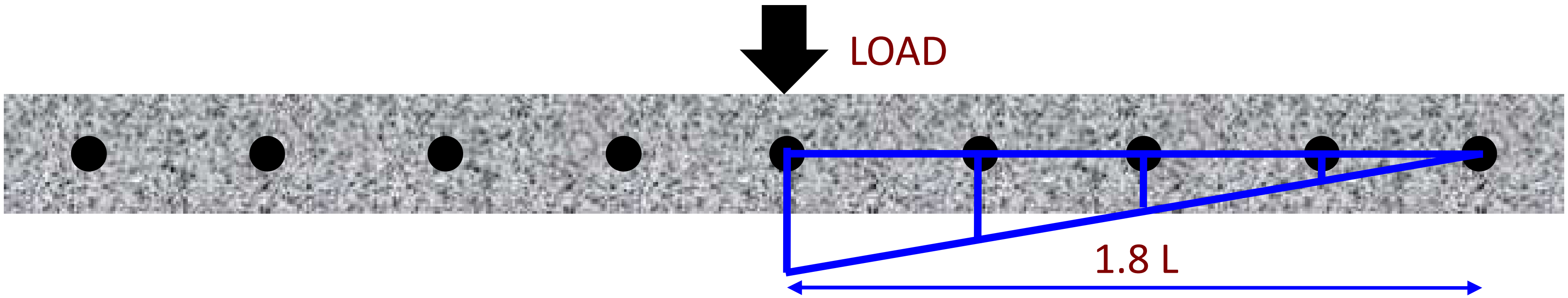
Load capacity of dowel system = 40% of wheel load

Required load capacity factor = $\dfrac{40\%\ of\ wheel\ load}{(P')_{min}}$

Effective distance upto which there is load transfer

= 1.8 *(radius of relative stiffness)*

Variation of capacity factor linear from 1.0 under the load to 0.0 at effective distance



Design spacing = The spacing which conforms to required capacity factor

Dowel bars design details

Design details of dowel bars (MS Rounds) for rigid Highway pavements as per IRC:58-2002				
Design loading, Kg	Slab thickness cm	Dowel bar details		
		Diameter, mm	Length, mm	Spacing, mm
Axle Load 10.2 T	20	25	500	250
	25	25	500	300
	30	32	500	300
	35	32	500	300

Note: Dowel bars shall not be provided for slabs of less than 15cm thick

Tie bar design – Diameter & Spacing

Area of steel per unit length of joint is obtained by equating the total friction to the total tension developed in the tie bars

$$\sigma_{ts} A_s = B \ h \gamma_c f$$

σ_{ts} = Allowable tensile stress in steel

A_s = Area of steel per unit length of joint

B = distance b/w the joint and nearest free edge

h = Slab thickness

γ_c = Unit weight of concrete

f = Coefficient of subgrade restraint (max 1.5)

Tie bar design – Length

Length of embedment required to develop a bond strength equal to working stress of the steel

$$\sigma_{ts} A_s = \frac{L_t}{2} P \, \sigma_{bc}$$

or

$$L_t = \frac{d}{2} \frac{\sigma_{ts}}{\sigma_{bc}}$$

σ_{ts} = Allowable tensile stress in steel

σ_{bc} = Allowable bond stress in concrete

A_s = Area of tie bar

L_t = Length of tie bar

P = Perimeter of tie bar

d = Diameter of tie bar

Tie bars design details

σ_{ts} = Allowable tensile stress in steel = 1400 kg/cm^2

σ_{bc} = Allowable bond stress in concrete

= 24.6 kg/cm^2 for deformed tie bars

= 17.5 kg/cm^2 for plain tie bars

Slab Thickness cm	Tie bar details, cm			
	Diameter	Max. spacing	Plain bars	Deformed bars
15	0.8	38	40	30
	1.0	60	45	35
20	1.0	45	45	35
	1.2	64	55	40
25	1.0	30	45	35
	1.2	55	55	40
	1.4	62	65	46

Flexible Pavement Design
For Low Volume Rural Roads

(As per IRC : SP : 72 - 2007)

In this Presentation

- Introduction
- Design Criteria
- Design Procedure
- Pavement Thickness Design Charts
- Pavement Composition

Introduction – Need for Revision

Revision of IRC:SP: 20-2002

Only chapter-5 (Pavement Design) of Rural Roads Manual has been revised

- **To economise rural road construction**
- **To benefit from recent international experiences on rural road design**
- **To evolve performance based designs**
- **To thrust the use of locally available materials**
- **To emphasise the design and construction of gravel roads**

Existing Design Approach IRC:SP:20-2002

- Traffic Survey
  - Present CVPD (>3 tonne axle load)
  - Projected CVPD = $P(1+r)^{n+D}$ (D = 10,n= 1, r= 6%)
- Sub grade Strength
  - Determine 4 days soaked CBR
- Select suitable design curve (A,B,C & D)
- Find crust thickness from design curves
- Take base thickness
  - 150mm (for A & B) 225mm (for C & D)
- Compute thickness of Sub base (Drainage Layer)

  For weak soils provide a well compacted subgrade of 300mm thick using gravelly soils

Recommended Design Approach

IRC:SP:72-2007

Classification of Roads

- **Unpaved roads**
  - **Gravel roads**
    - ≤ 1 lakh ESAL per performance year
  - **Earthen roads**
    - ≤ 10,000 ESAL per performance year
- **Paved roads**
  - **Flexible Pavements**
    - ≥ 50,000 ESAL per performance year
  - **Rigid Pavements**

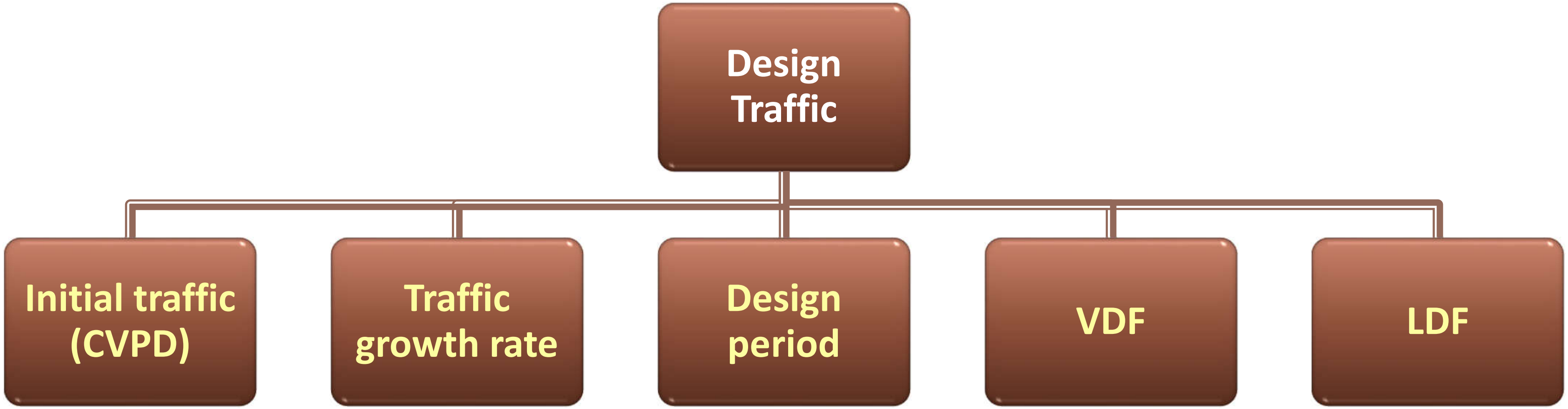
Salient Features

- Pavement designs for new roads and upgradation of existing roads-included
- Procedure has been detailed for computing ADT and ESAL for design life
- Categorizing

  Subgrade strengths : 5 classes

  Traffic : 7 ranges
- The warrants for BT surface - spelt out
- Importance for condition survey and data collection

Estimation of Design Traffic



Design Traffic

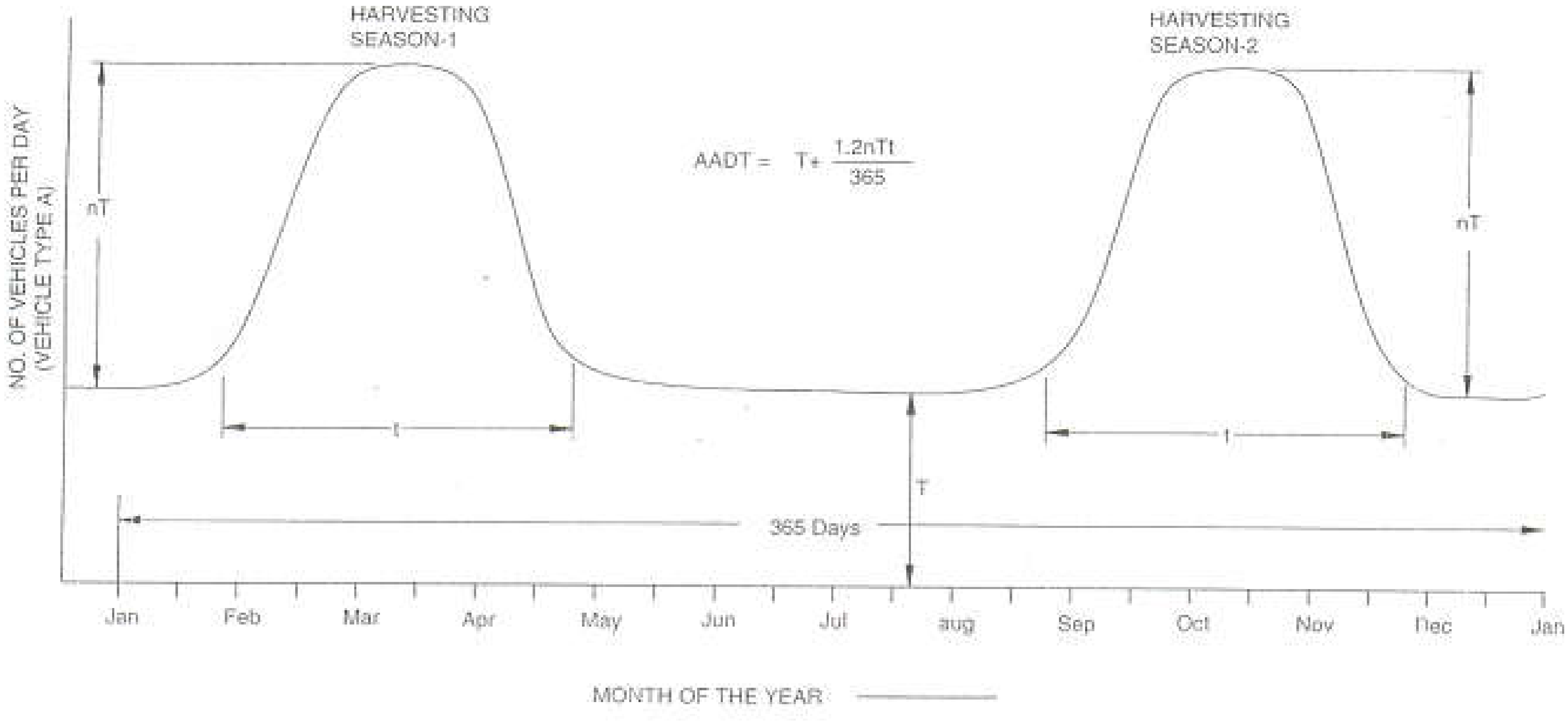


Fig. 1. Seasonal Variations in Rural Traffic

Design Traffic

The total no of repetitions (N) of a given vehicle type during the course of a year

$$N = T(365) + 2nT(0.6t)$$

$$AADT = T + (1.2\ nTt\ /365)$$

Determination of ESAL Application

- Vehicles with axle load > 3 tonnes considered
- Axle equivalency factor = $(W/W_s)^4$
- Standard axle load = W_s = 80 kN
- W = Single axle load (kN) of given vehicle

Equivalency Factors

Axle Load		Equivalency Factor
Tonnes	kN	
3.0	29.4	0.02
4.0	39.2	0.06
5.0	49.1	0.14
6.0	58.8	0.29
7.0	68.7	0.54
8.0	78.5	0.92
9.0	88.3	1.48
10.0	98.1	2.25
11.0	107.9	3.30
12.0	117.7	4.70
13.0	127.5	6.40
14.0	137.3	8.66
15.0	147.1	11.42

Vehicle Damage Factor (VDF)

Axle load survey has to be carried out
In absence the following table can be referred

Sl. No.	Vehicle category	Load (tonnes)		VDF
		Rear	Front	
1	Fully loaded HCV	10.2	5.0	2.44+0.14 = 2.58
2	Unladen / partially loaded HCV	6.0	3.0	0.29+0.02 = 0.31
3	Over loaded HCV (+20% extra)	12.3	6.0	5.06+0.29 = 5.35
4	Fully loaded MCV (Tractor- Trailer)	6.0	3.0	0.29+0.02 = 0.31
5	Unladen / partially loaded MCV	3.0	1.5	0.018+0.001= 0.019
6	Over loaded MCV (+20% extra)	3.6	1.8	0.61+0.04 = 0.65

Indicative VDF Values

In absence of detailed traffic survey, it is assumed that 10% of HCVs and MCVs are over loaded to the extent of 20%

VDF values can be taken as given below

Vehicle Type	Laden	Partially loaded/ Unladen
HCV	2.86	0.31
MCV	0.34	0.02

ESAL Application Over The Design Life

$$N = T_o \times L \times 365 \{(1+r)^n - 1\}/r$$

n = Design Life = 10 years

r = Rate of growth = 6 %

L = Lane distribution factor

= 1 for single lane road

= 0.75 for 2 lane road

T_o = CVPD x VDF

$$N = T_o \times 4811 \times L$$

ESAL for 10-year Design Life

In absence of traffic data regarding, HCVs and MCVs, design may be made based on the following table

ADT*	CVPD	Break up of commercial vehicles		Cumulative ESAL
		HCV	MCV	
100	25	0	25	19,380
150	35	5	30	60,969
200	50	10	40	96,482
300	75	15	60	1,49,952
400	100	20	80	1,92,961
500	125	25	100	2,57,225
1000	300	60	240	6,63,120

*ADT includes both motorised and non-motorised vehicles

(APPENDIX-A,IRC:SP:72-2007)

Correction Factor for Solid-Wheeled Carts

- SWC causes deep rutting
- SWC is twice as damaging as 6-8 tonne MCV
- Percentage of SWC decreases with increase in CVPD

AADT	Correction Factor for SWC Traffic
100	1.7
150	1.25
200	1.20
300	1.15
400	1.10
500	1.07

APPENDIX-B,IRC:SP:72-2007

Traffic Categories

For pavement design, the traffic has been categoriesed into 7 categories as under

Traffic category	Cumulative ESAL Applications
T_1	10,000-30,000
T_2	30,000-60,000
T_3	60,000-1,00,000
T_4	1,00,000-2,00,000
T_5	2,00,000-3,00,000
T_6	3,00,000-6,00,000
T_7	6,00,000-10,00,000

Sub Grade Strength

Sub grade

- 300mm thick , compacted soil layer beneath the pavement crust
- Compaction: 100% standard proctor density
- Minimum dry density 16.5 kN/m^3 (1.65 g/cc)

Soil Investigations

- Three samples/km for simple soil classification
- One CBR test for each identified soil group

Sub Grade CBR Value

CBR - any one of the following four methods

1. Based on soil classification tests and using table-1 of IRC:SP:72-2007
2. Based on wet sieve analysis data and using the nomograph given in **APPENDIX-C of IRC:SP:72-2007**
3. Based on 2 sets of equations for plastic and non plastic soils given in **APPENDIX-D of IRC:SP:72-2007**
4. Conducting actual CBR test in the laboratory

Subgrade Strength Classes

Quality of Subgrade	Class	Range (CBR%)
Very poor	S_1	2
Poor	S_2	3-4
Fair	S_3	5-6
Good	S_4	7-9
Very Good	S_5	10-15

* where the CBR of subgrade soil is less than 2, the economic feasibility of replacing 300mm subgrade with suitable soil needs to be explored and, if found feasible, the pavement should then be designed based on the CBR value of the improved subgrade. Alternatively , a capping layer of thickness not less than 100mm of modified soil (with CBR not lees than 10) should be provided.

Pavement composition

Subbase course (minimum 100mm)

Use of any locally available material, such as natural sand, moorum, gravel, brick metal etc or combination there of, satisfying grading requirements as per MORD specifications for Rural roads

Base course

ESAL > 1Lakh,the options are WBM,WMM & CRMB

ESAL < 1Lakh, the option is gravel base

Except for soil with CBR <2, ESAL 30,000 to 60,000 and for soil CBR <4,ESAL 60,000 to 1 Lakh

Surface course

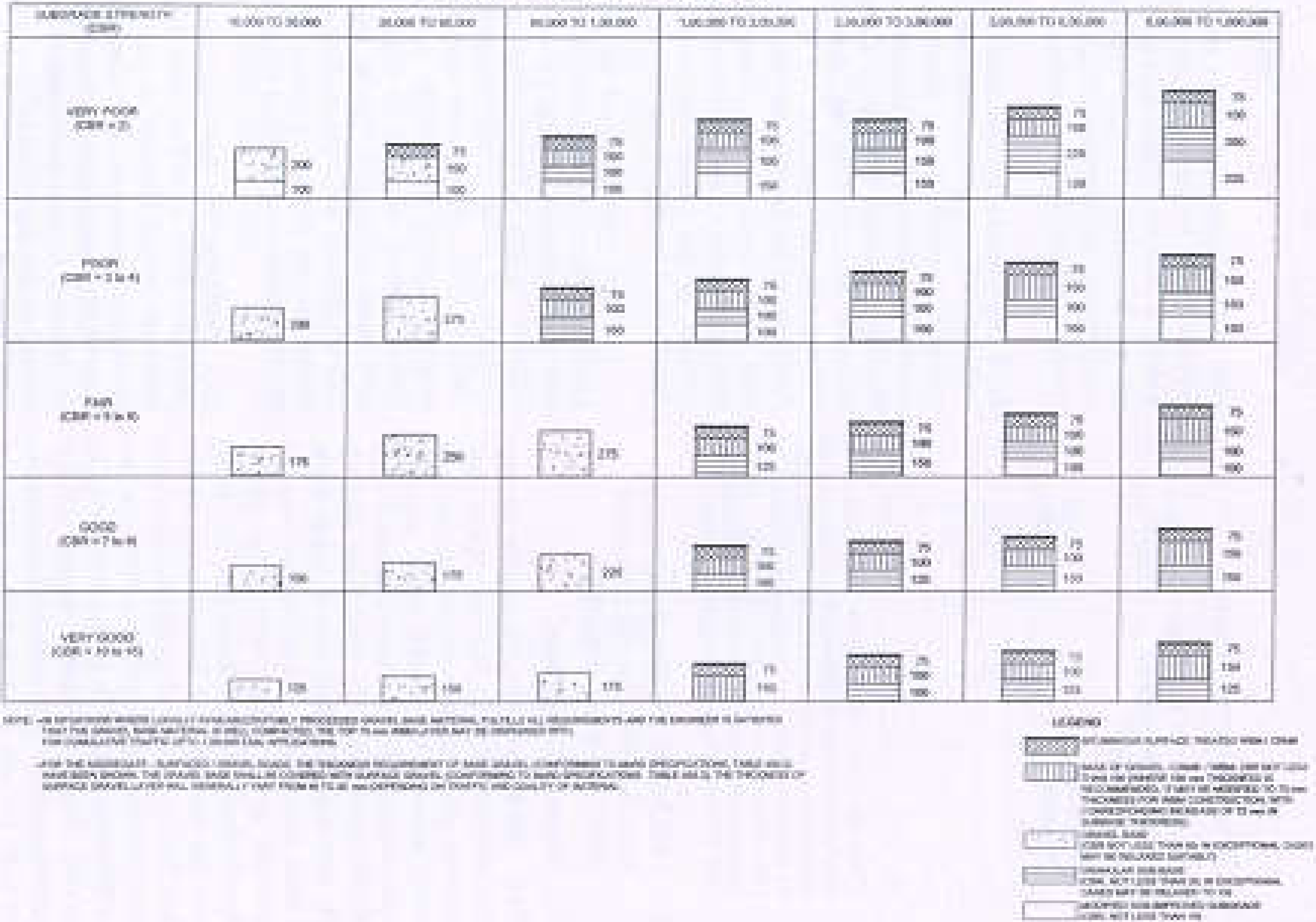
ESAL > 1Lakh; 2 coats of SD or 20 mm PMC

ESAL < 1Lakh; non-bituminous gravel surface is recommended

Bituminous Surface treatment

Annual Rainfall (mm/year)	Type of Surfacing			
	Traffic Category			
	T_1 (ADT< 100)	T_2 (ADT= 100 -150)	T_3 (ADT= 150 -200)	T_4 (ADT> 200)
> 1500	Gravel	BT	BT	BT
1000 – 1500	Gravel	Gravel	BT	BT
<1000	Gravel	Gravel	Gravel	BT

CUMULATIVE ESAL APPLICATIONS



LEGEND

Replacing a Part of Gravel Base with Subbase

To economise rural road construction, it is desirable to convert a portion of the aggregate base layer thickness to an equivalent thickness of subbase with an intermediate CBR value between the base and subgrade

* In such cases, a minimum 100mm thickness of gravel base is to be retained

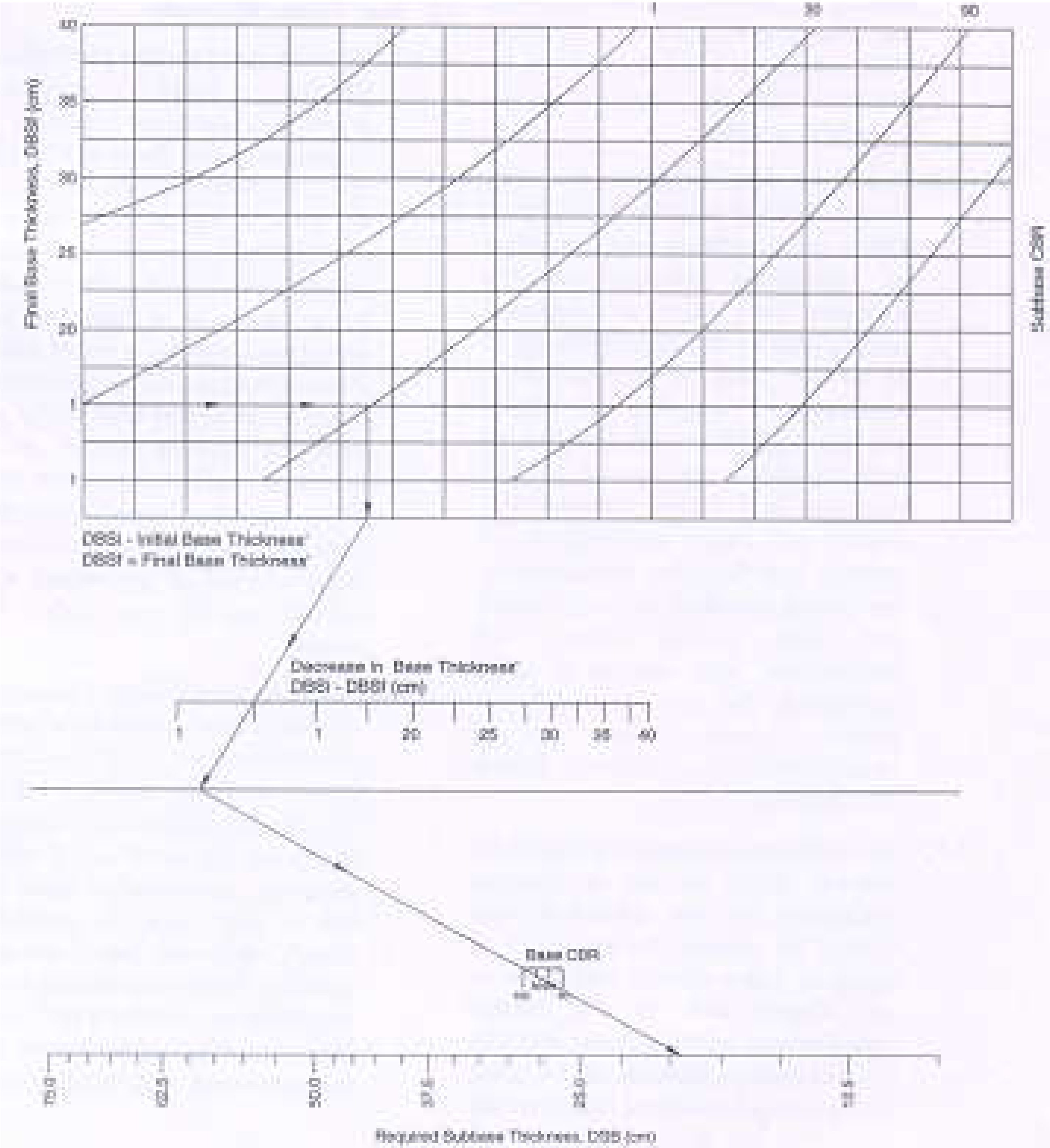


Fig. 5. Chart to Convert a Portion of the Gravel/Soil-Aggregate Base Layer Thickness to an Equivalent Thickness of Subbase (Ref. 2)

Design Problem

- Soil CBR =3%
- 3-day traffic survey has been carried out in lean season.
- The traffic details are as follows.

Traffic Details (ADT)

1. HCV	Trucks	unladen 4, laden 4
	Buses	unladen 3, laden 3
2. MCV	Tractors	unladen 5, laden 5
	other MCVs	unladen 6, laden 6

3. LCVs + 2wheelers + Bullock carts etc. 50

Total 86 ADT

To find AADT

- AADT $= T + \dfrac{1.2.n.T.t}{365}$

$= 86 + 1.2 \times 1 \times 86 \times 75 / 365$

$= 107.205$

Projected AADT

- Before opening to traffic,

$$\begin{aligned} AADT &= 107.205\,(1 + r)^2 \\ &= 107.205\,(1 + 0.06)^2 \\ &= 120.456 \end{aligned}$$

AADT/ADT Ratio

- The ratio of projected AADT / ADT

  = 120.456/ 86

  = 1.401

(40% increase in vehicular traffic)

Vehicles considered for Design

- At the time of Survey,

HCV (unladen) = 7

HCV (laden + overladen) = 7

MCV (unladen) = 11

MCV (laden + overladen) = 11

Predicted Traffic

- Just before opening to traffic,

HCV (unladen) = 7 x 1.401 = 10

HCV (laden + overladen) = 7 x 1.401 = 10

MCV (unladen) = 11 x 1.401 = 15

MCV (laden + overladen) = 11 x 1.401 = 15

ESAL Calculations

- ESAL / day = vehicles / day x VDF

  = 10 x 2.86 + 10 x 0.31 + 15 x 0.34 + 15 x 0.02

  = 37.1

Cumulative ESAL applications over 10 years period at 6% growth rate = 37.1 x 4881

= 178488.

Pavement cross section

- Traffic category T_4
- Soil CBR = 3%

From Nomogram,

20 mm chip carpet
75 mm WBM Grade - III
75 mm WBM Grade - II
125 mm GSB for full width
100 mm modified soil
200 mm compacted sub grade

Thank you