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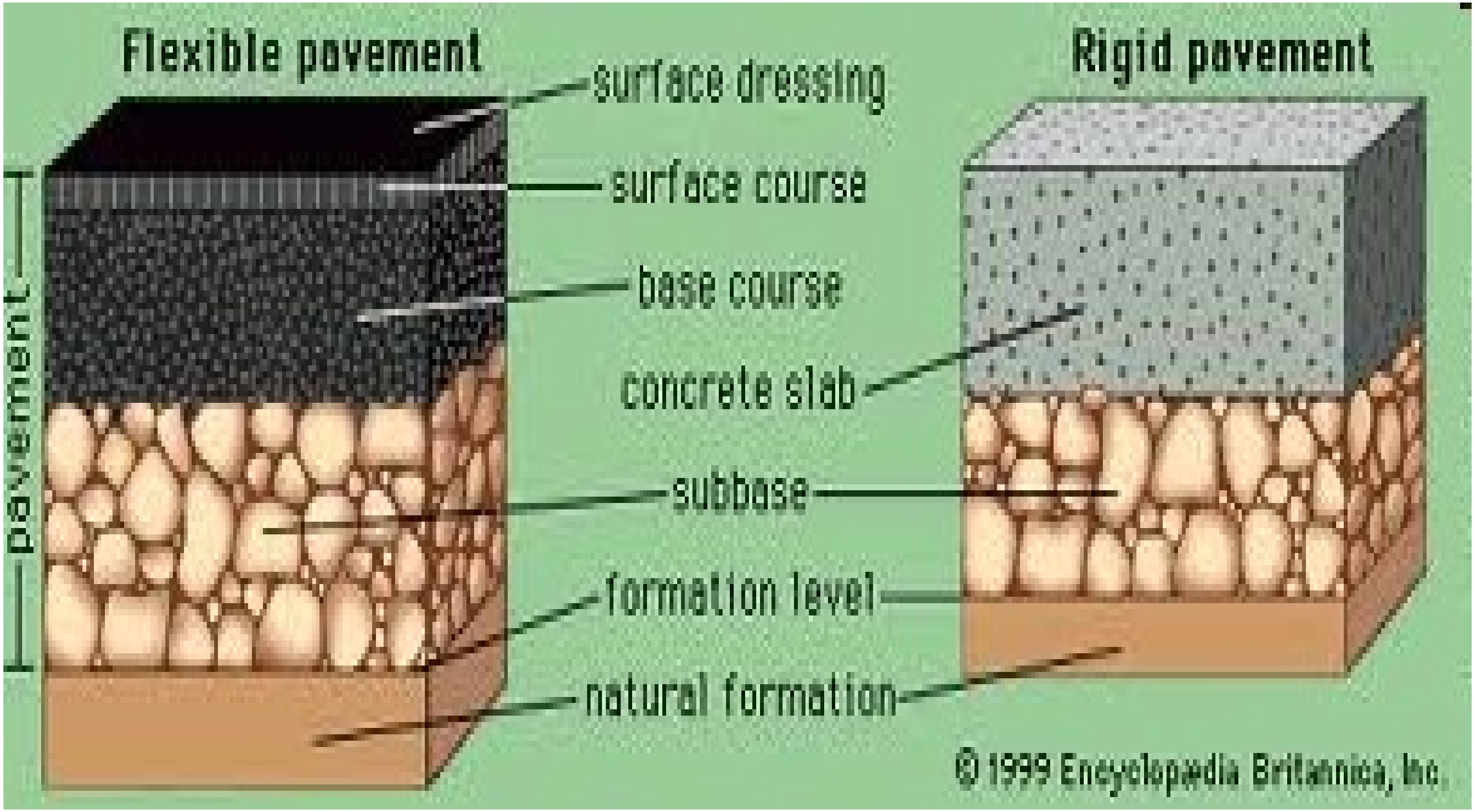
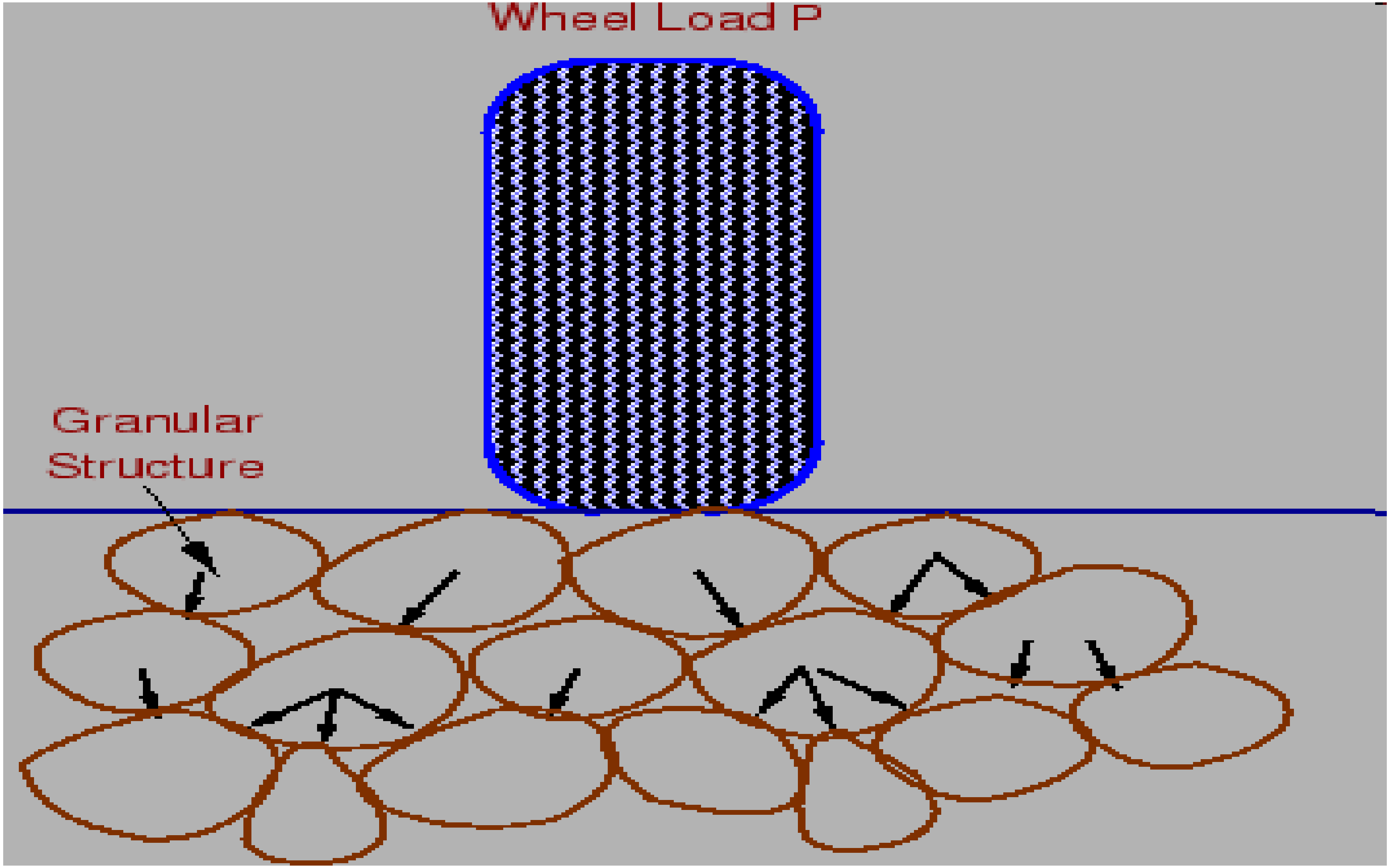
DESIGN FLEXIBLE AND RIGID PAVEMENTS

Design principles
pavement components and their role
Design practice for flexible and rigid pavements, (IRC methods only).

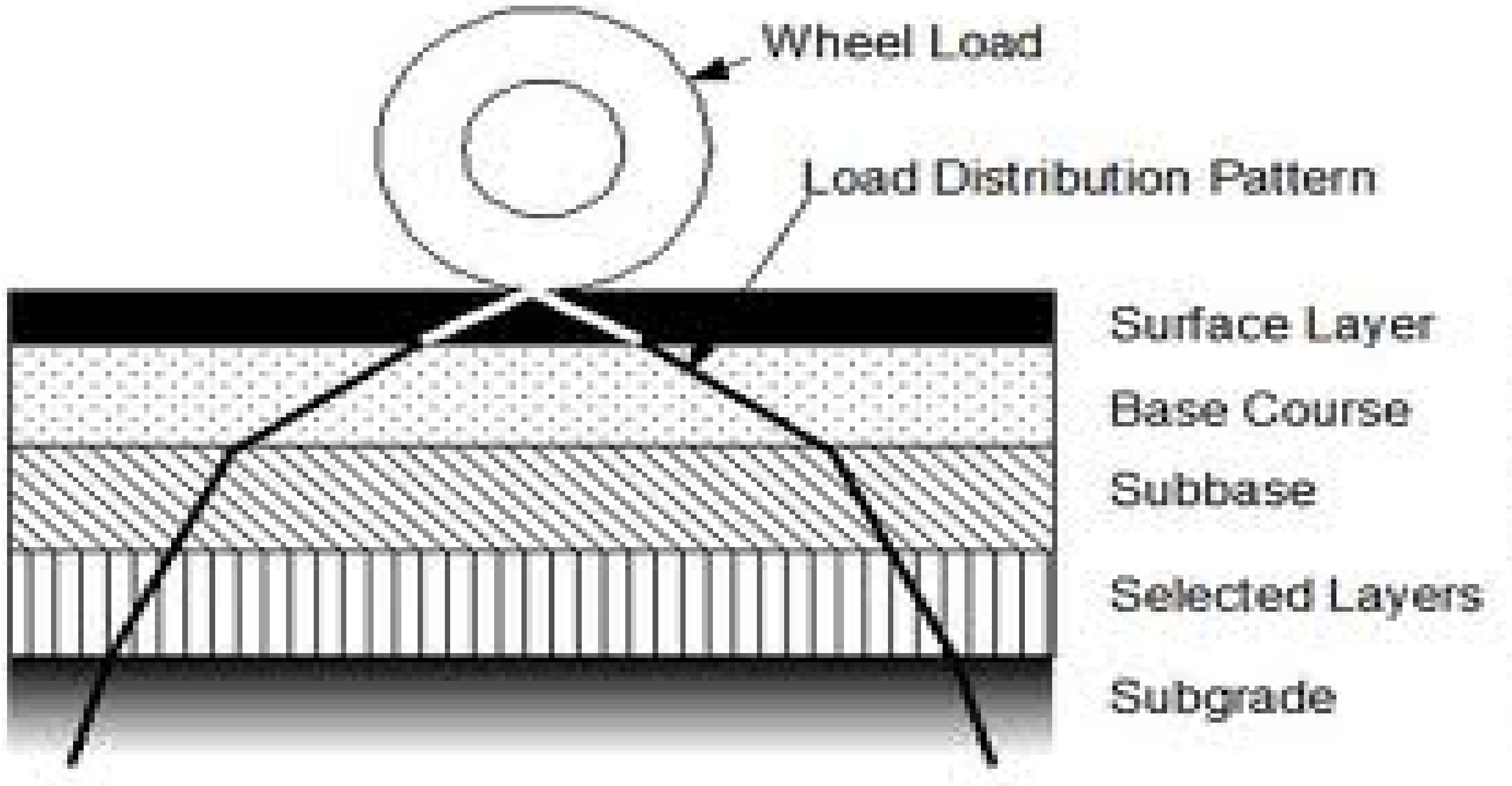
FLEXIBLE PAVEMENT **RIGID PAVEMENT**

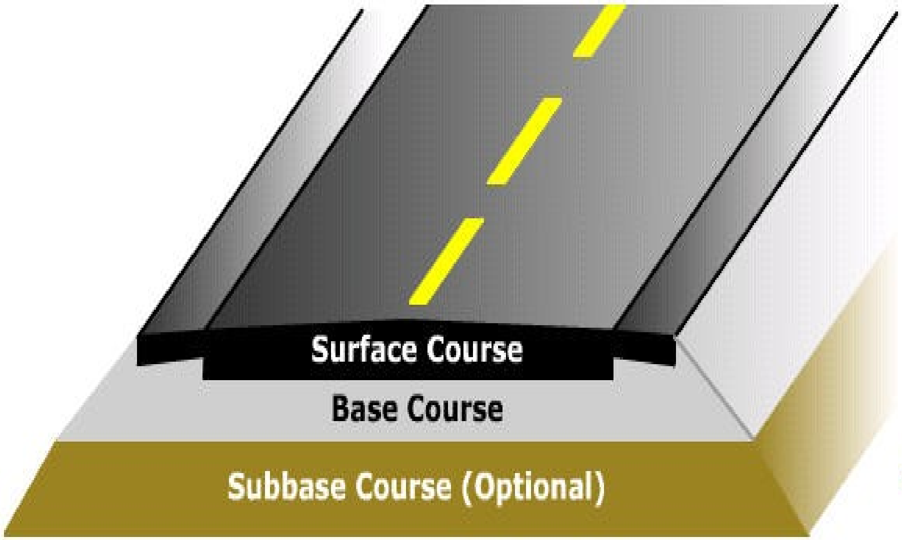
Types of Pavements

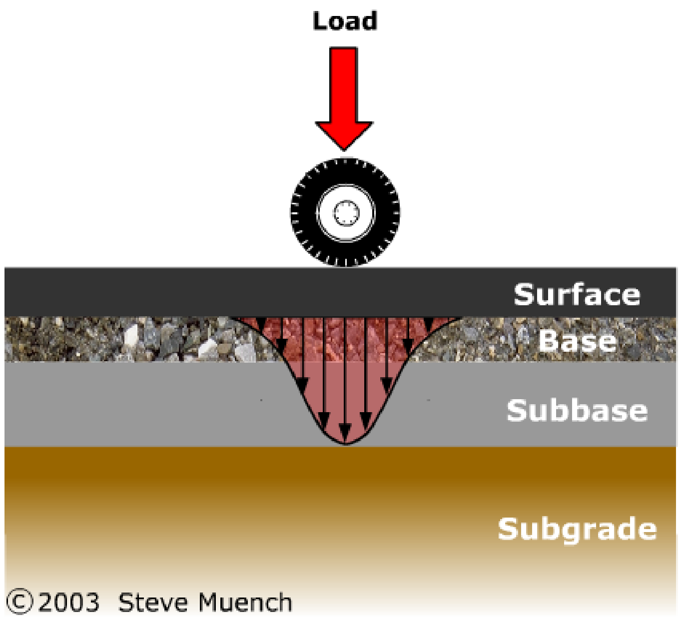



Wheel Load P
Granular
Structure

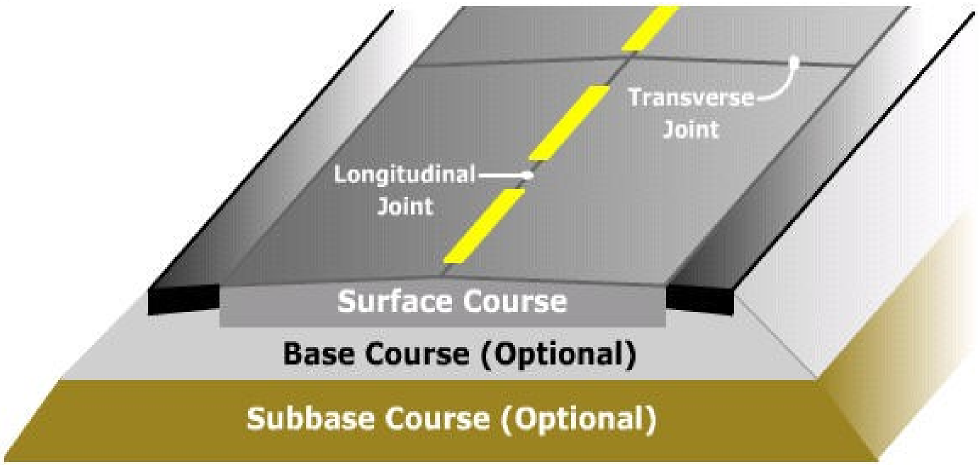
Wheel Load Distribution

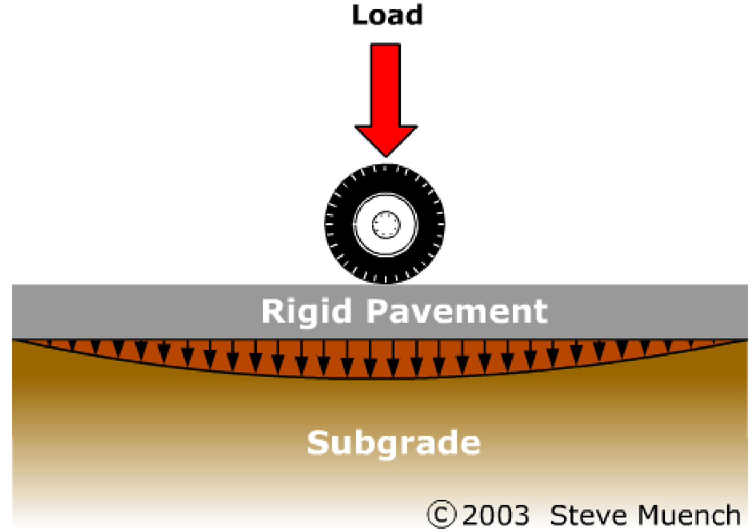






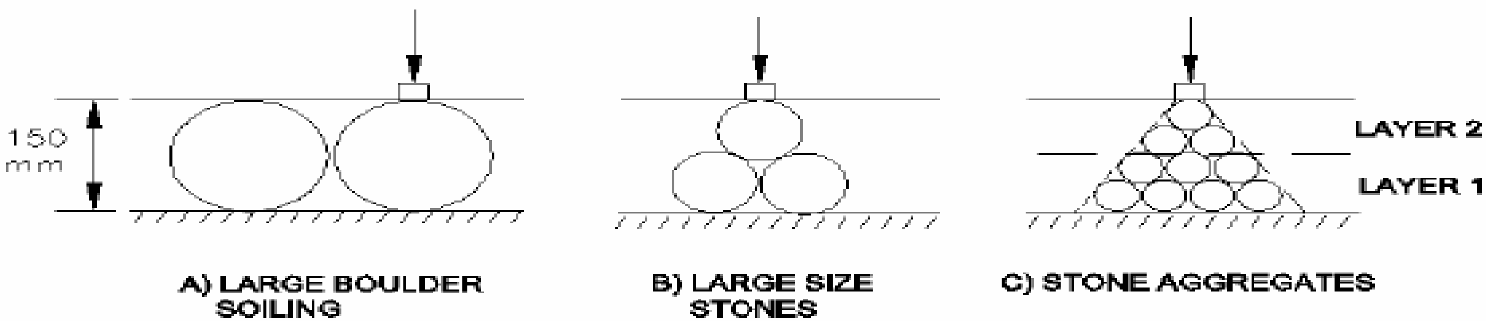
Flexible





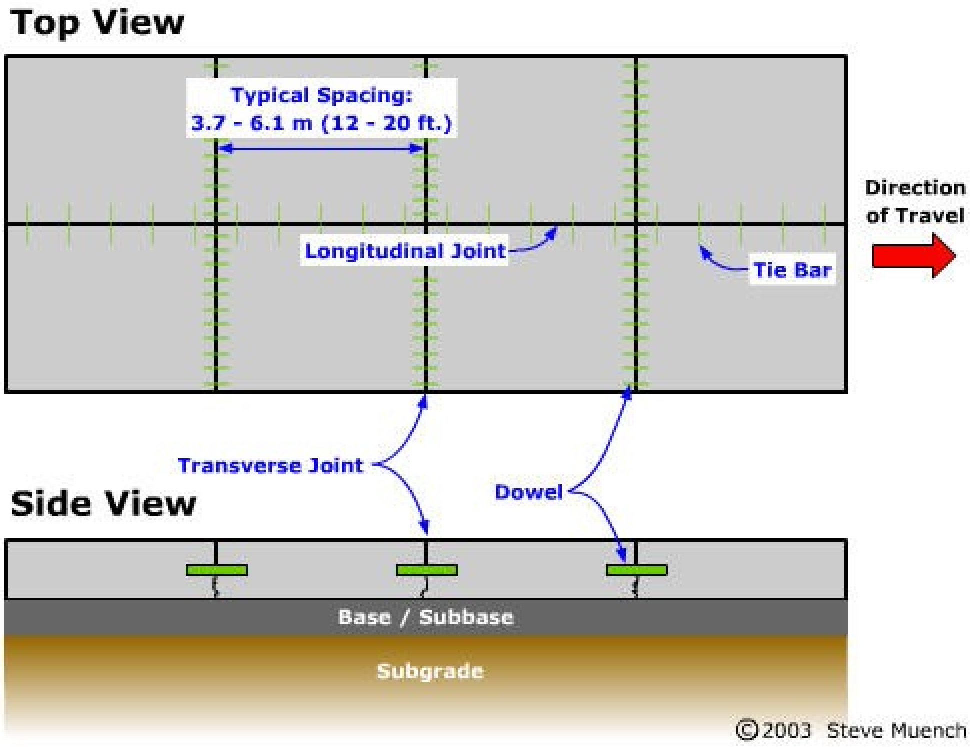
Rigid

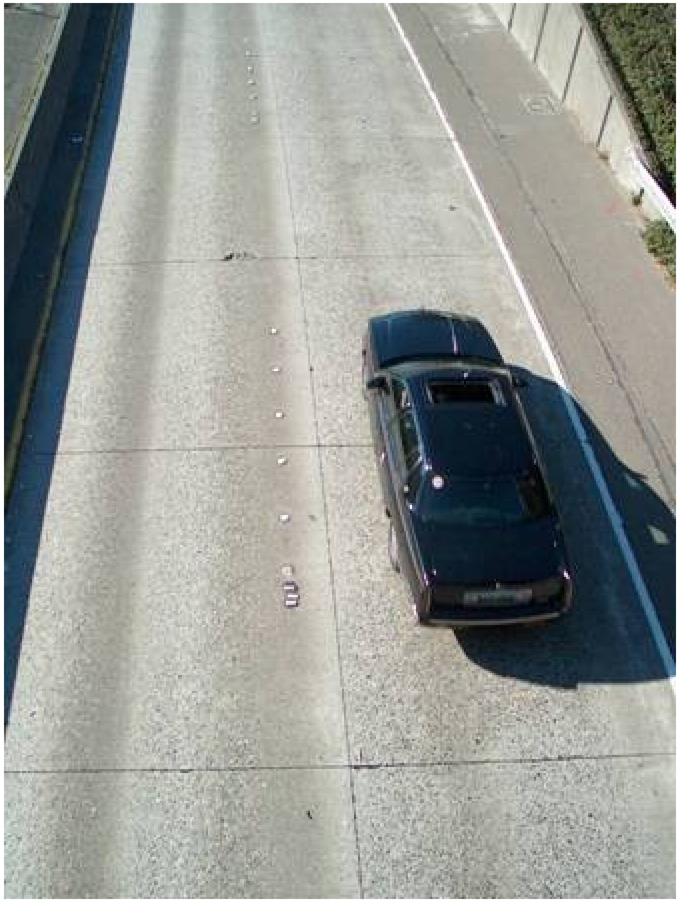
Layers in Flexible Pavement



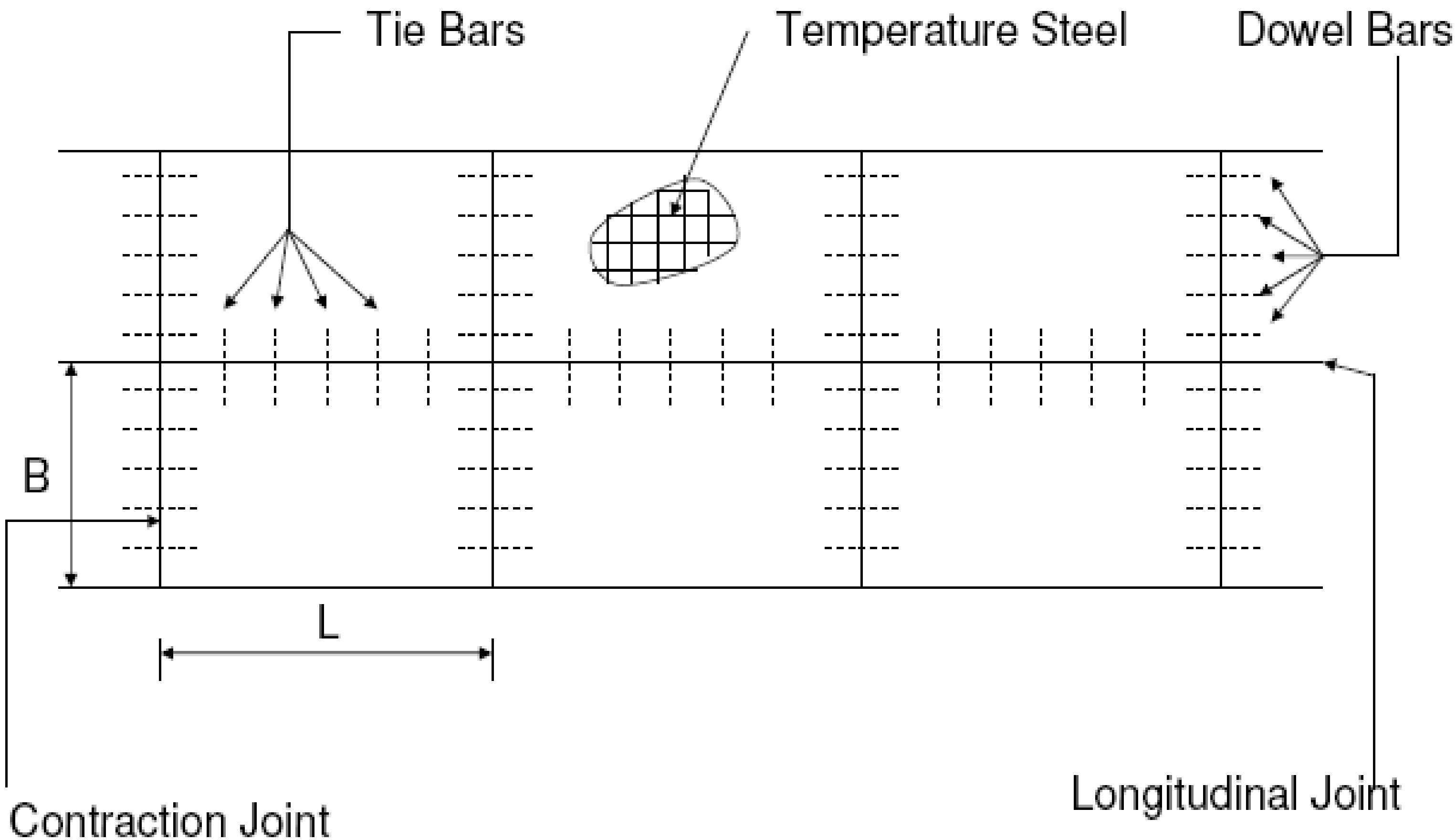
Stress Distribution Through Granular Layers

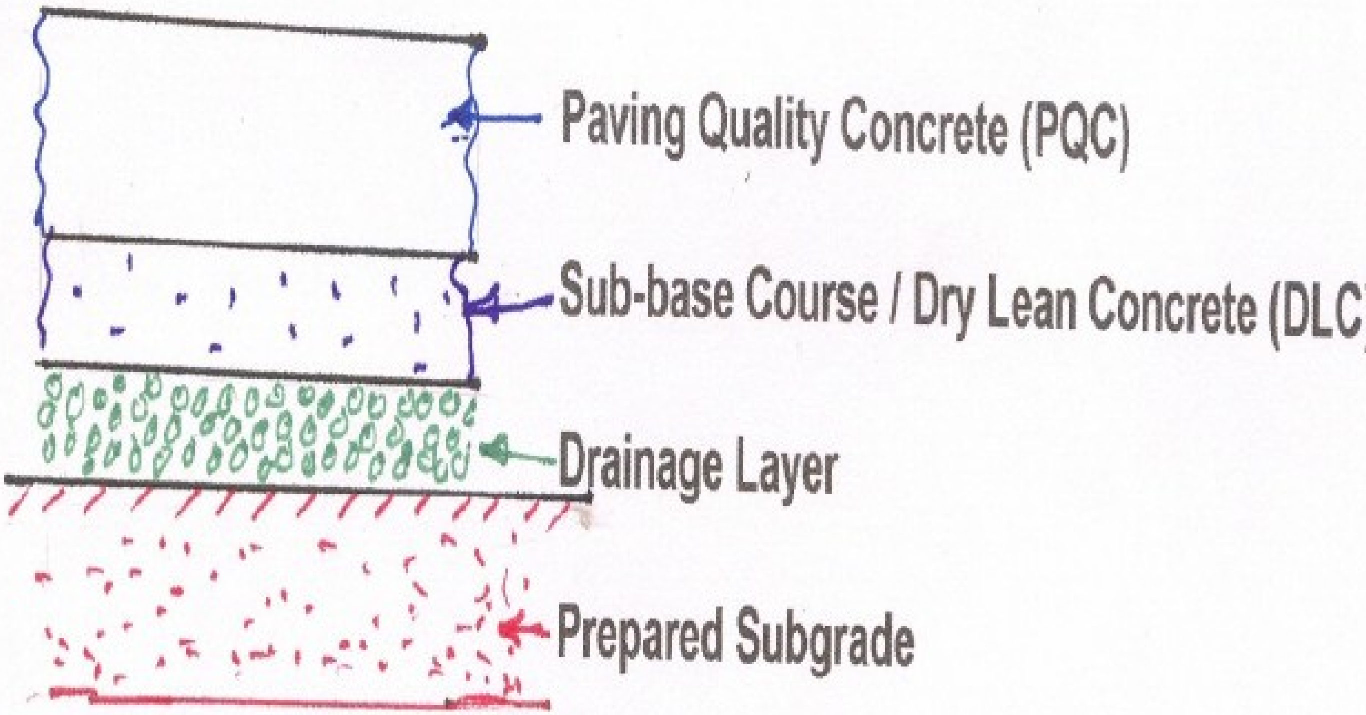
- Jointed Plain Concrete Pavement (JPCP)





Jointed CC Pavement





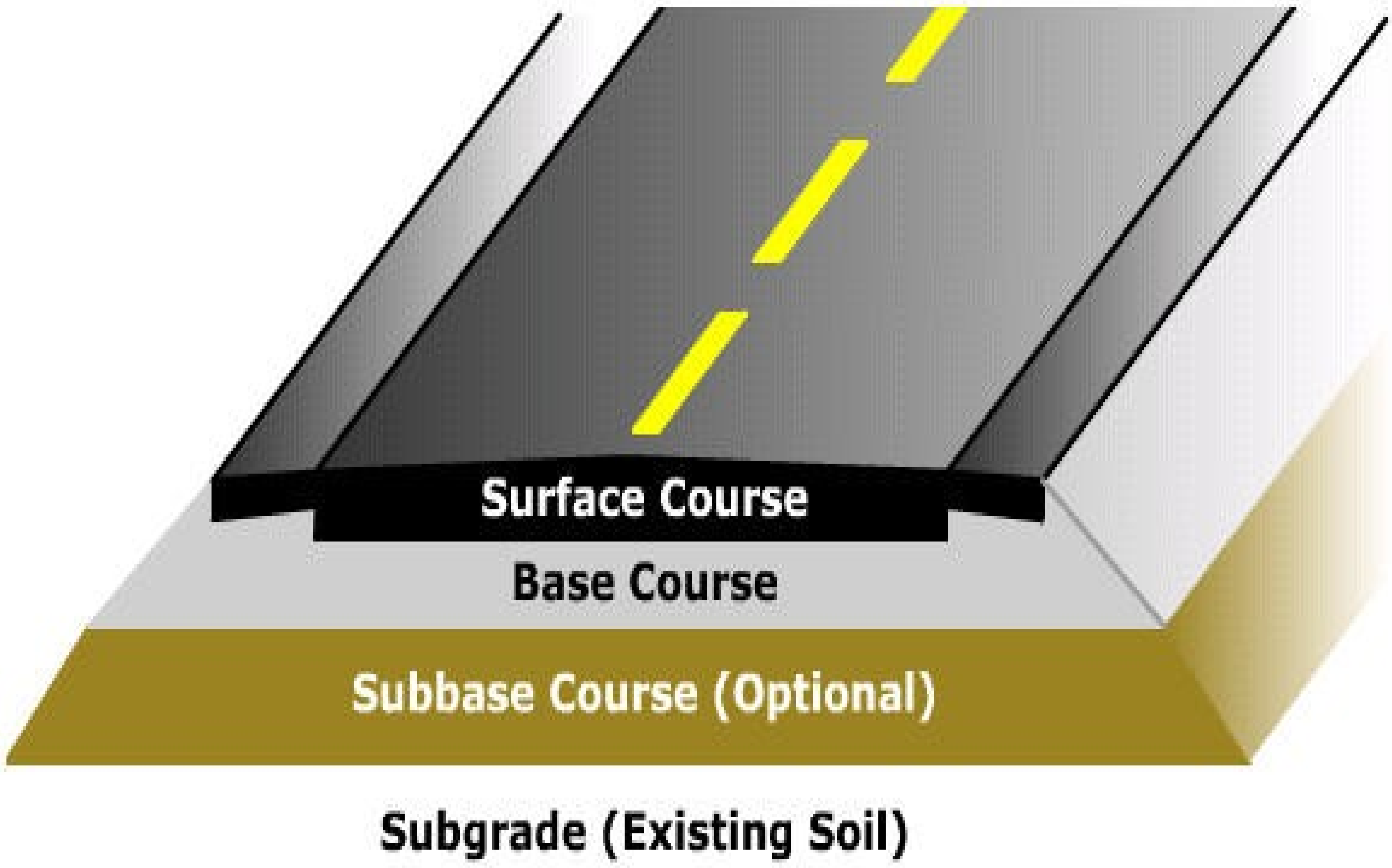
Components of Cement Concrete Pavement

Properties	Flexible	Rigid
Design Principle	Empirical method Based on load distribution characteristics of the components	Designed and analyzed by using the elastic theory
Material	Granular material	Made of Cement Concrete either plan, reinforced or prestressed concrete
Flexural Strength	Low or negligible flexible strength	Associated with rigidity or flexural strength or slab action so the load is distributed over a wide area of subgrade soil.
Normal Loading	Elastic deformation	Acts as beam or cantilever
Excessive Loading	Local depression	Causes Cracks
Stress	Transmits vertical and compressive stresses to the lower layers	Tensile Stress and Temperature Increases
Design Practice	Constructed in number of layers.	Laid in slabs with steel reinforcement.
Temperature	No stress is produced	Stress is produced
Force of Friction	Less. Deformation in the sub grade is not transferred to the upper layers.	Friction force is High
Opening to Traffic	Road can be used for traffic within 24 hours	Road cannot be used until 14 days of curing
Surfacing	Rolling of the surfacing is needed	Rolling of the surfacing in not needed.

LOAD DISTRIBUTION

Figure 1: Rigid and Flexible Pavement Load Distribution

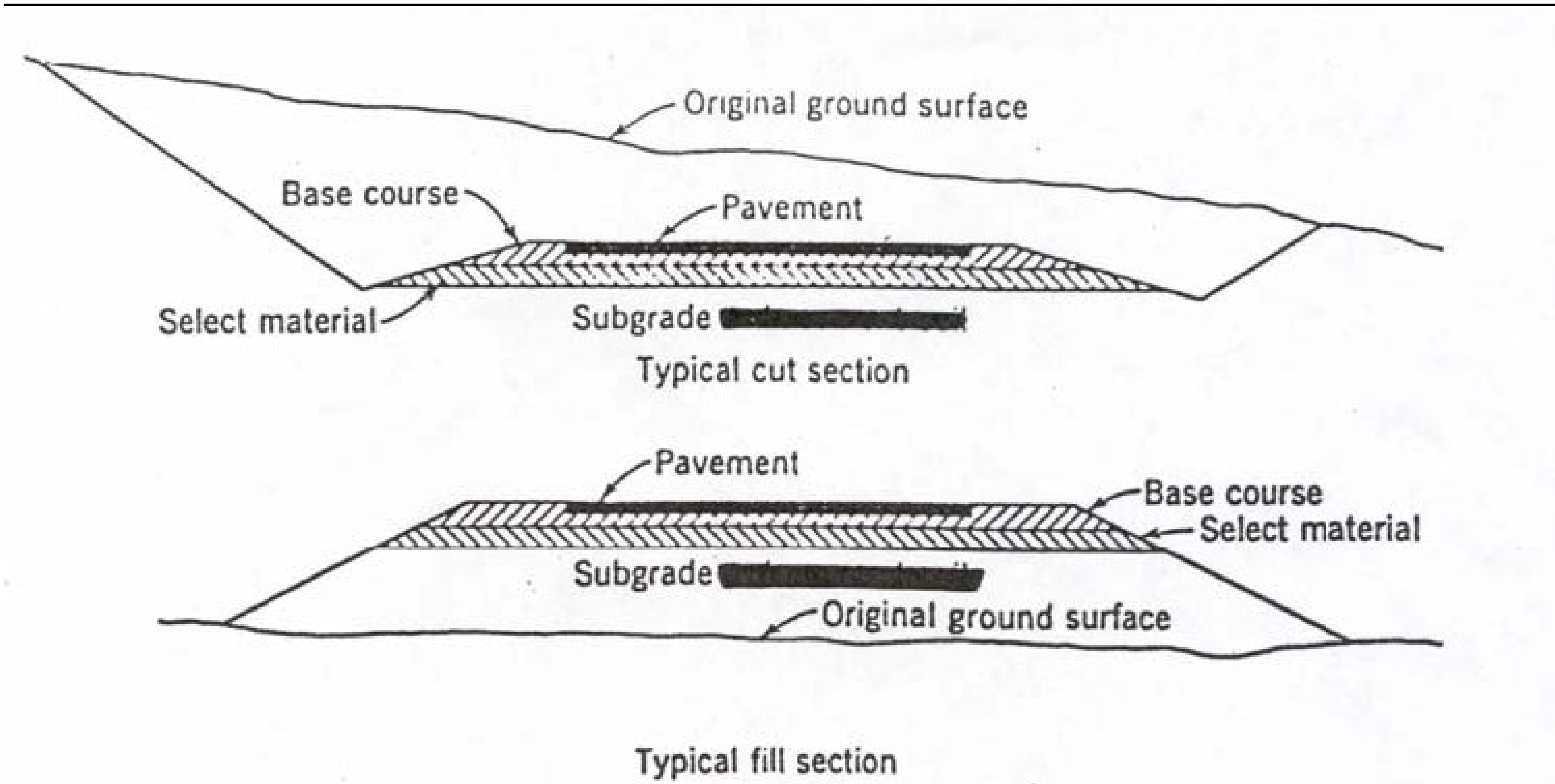
Components of Flexible Pavement



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.

Cut and Fill Sections



Typical cut section

Typical fill section

Desirable Properties of Soil as Subgrade Material

- Stability
- Incompressibility
- Permanency of strength
- Minimum changes in volume and stability under adverse condition of weather and ground water
- Good drainage
- Ease of compaction

Subgrade Performance

- **Load bearing capacity:**

  Affected by degree of compaction, moisture content, and soil type.

- **Moisture content:**

  Affects subgrade properties like load bearing capacity, shrinkage and swelling.

  Influenced by drainage, groundwater table elevation, infiltration, or pavement porosity (which can be assisted by cracks in the pavement).

- **Shrinkage and/or swelling:**

  Shrinkage, swelling and frost heave will tend to deform and crack any pavement type constructed over them.

Subgrade Soil Strength

Assessed in terms of CBR of subgrade soil for most critical moisture conditions.

- Soil type
- Moisture Content
- Dry Density
- Internal Structure of the soil
- Type and Mode of Stress Application.

} IS 2720 Part 8 (Moisture Content, Dry Density)

Flexible Pavement Design

IRC (37-2001)

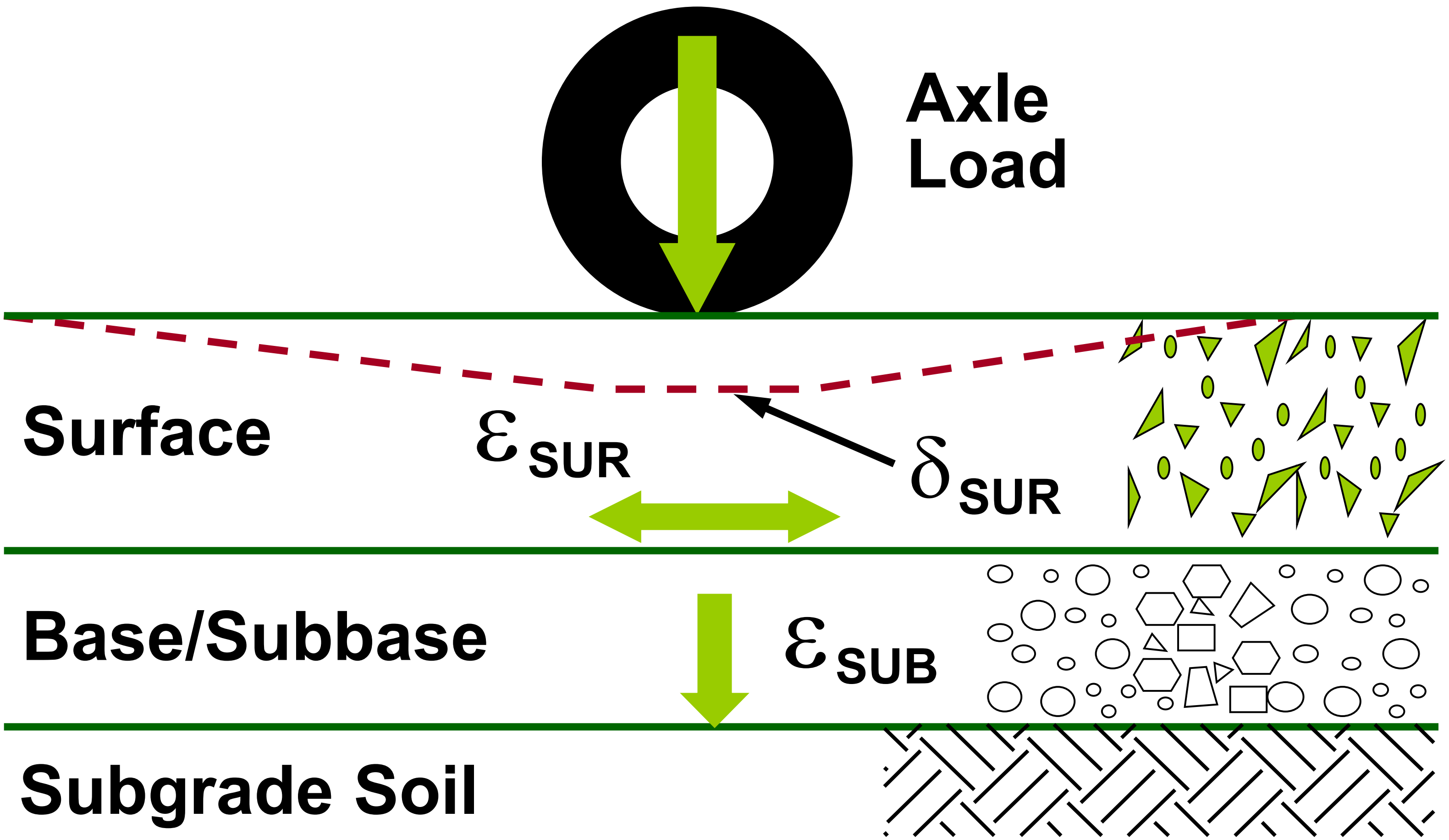
Basic Principles

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

Factors for design of pavements

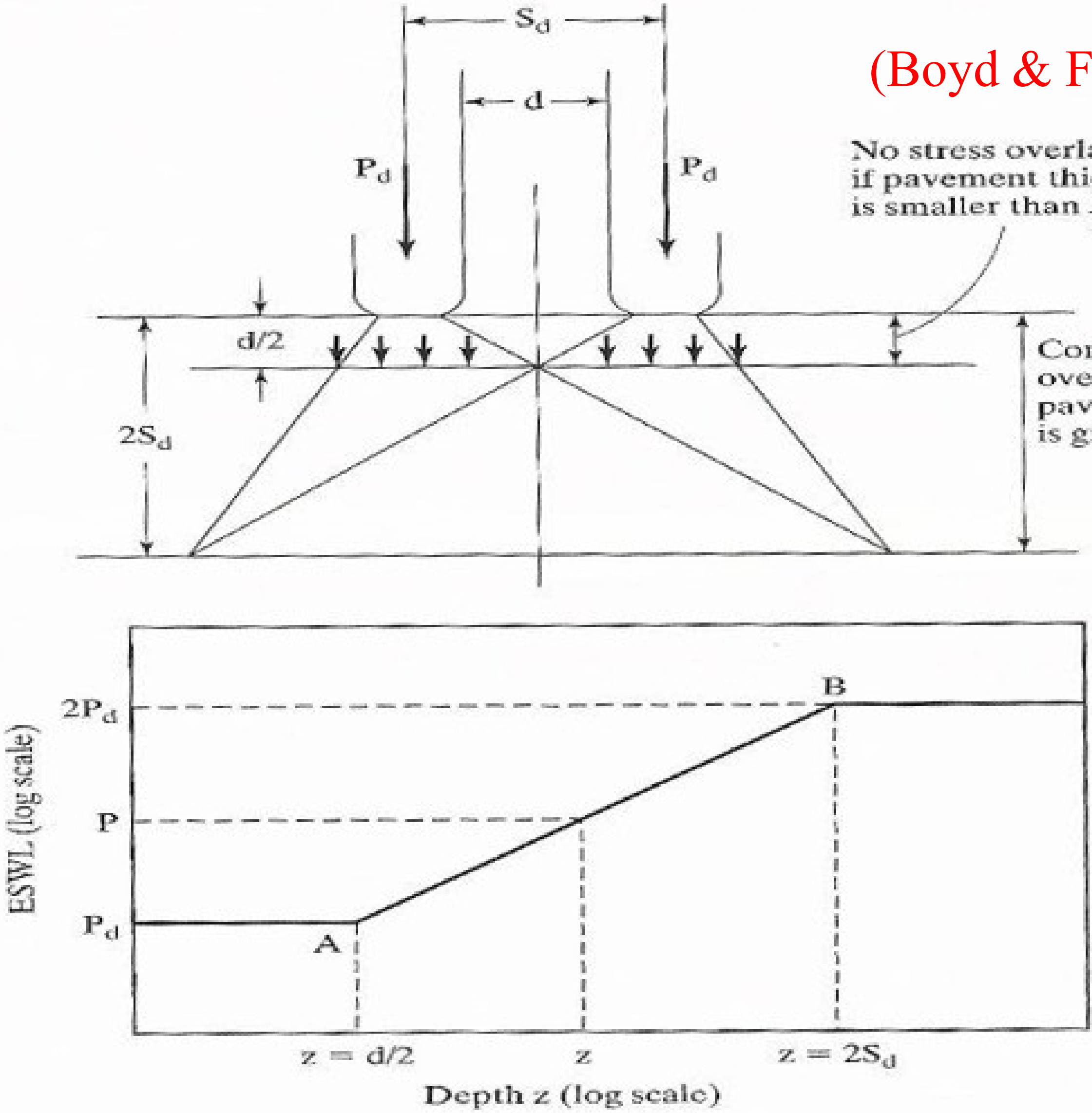
- Design wheel load
  - Static load on wheels
  - Contact Pressure
  - Load Repetition
- Subgrade soil
  - Thickness of pavement required
  - Stress- strain behaviour under load
  - Moisture variation
- Climatic factors
- Pavement component materials
- Environment factors
- Traffic Characteristics
-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

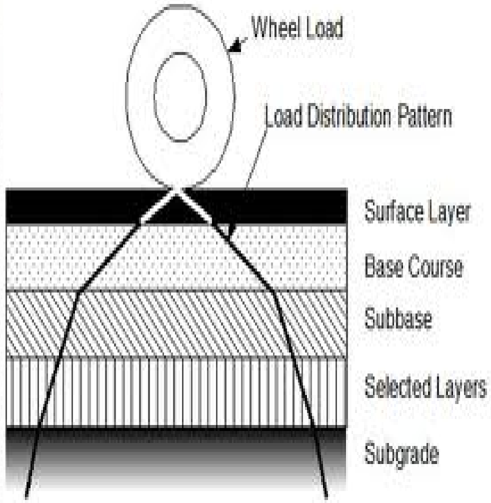
Pavement Responses Under Load



Equal Single Wheel Load (ESWL)

(Boyd & Foster - 1950)



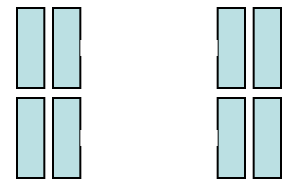


Axle Configurations

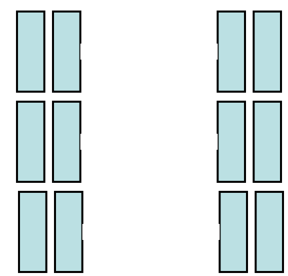
An **axle** is a central shaft for a rotating wheel or gear

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

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

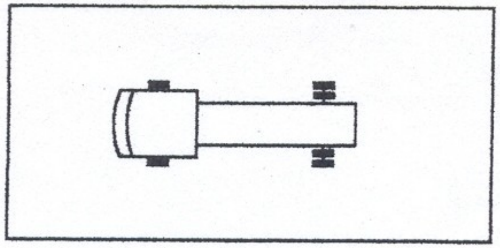


Tandem Axle
(Legal Axle Load = 18t)

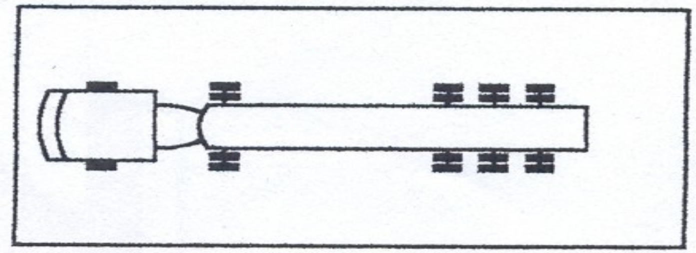


Tridem Axle
(Legal Axle Load = 24t)

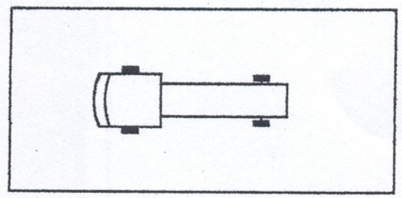
Truck Configuration



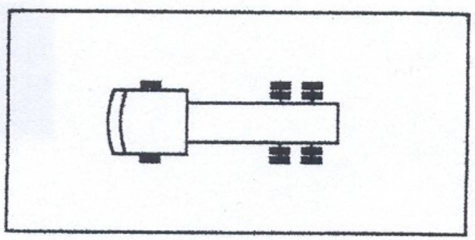
2 Axle Truck – 16t



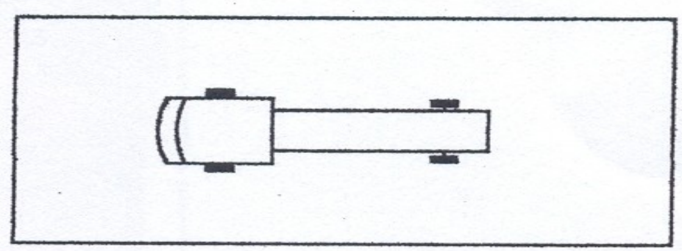
5 Axle Truck – 40t



LCV



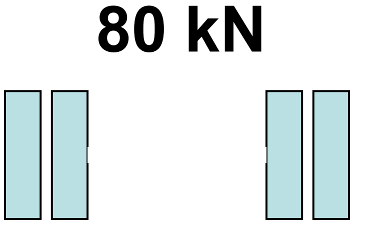
3 Axle Truck – 24t



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**

Evaluation Of Pavement Component Layers

- Sub-base And Base Course

- To Provide Stress Transmitting Medium
- To distribute Wheel Loads
- To Prevent Shear and Consolidation Deformation

In case of rigid pavements to

- Prevent pumping
- Protect the subgrade against frost action
  - Plate Bearing Test
  - **CBR Test**

Wearing Course

- **High Resistance to Deformation**
- **High Resistance to Fatigue; ability to withstand high strains - flexible**
- **Sufficient Stiffness to Reduce Stresses in the Underlying Layers**
- **High Resistance to Environmental Degradation; durable**
- **Low Permeability - Water Tight Layer against Ingress of Surface Water**
- **Good Workability – Allow Adequate Compaction**
- **Sufficient Surface Texture – Good Skid Resistance in Wet Weather**

- bituminous materials used in wearing course tested by Marshall test

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**

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

  $n = 4 - 5$

VEHICLE DAMAGE FACTOR (VDF)

AXLE LOAD, t	No. of Axles		Total Axles	Eq. FACTOR	Damage Factor
0-2	30	34	64	0.0002	0.0128
2-4	366	291	657	0.014	9.198
4-6	1412	204	1616	1616	213.312
6-8	1362	287	1649	1649	857.48
8-10	98	513	611	1.044	637.884

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

→ 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

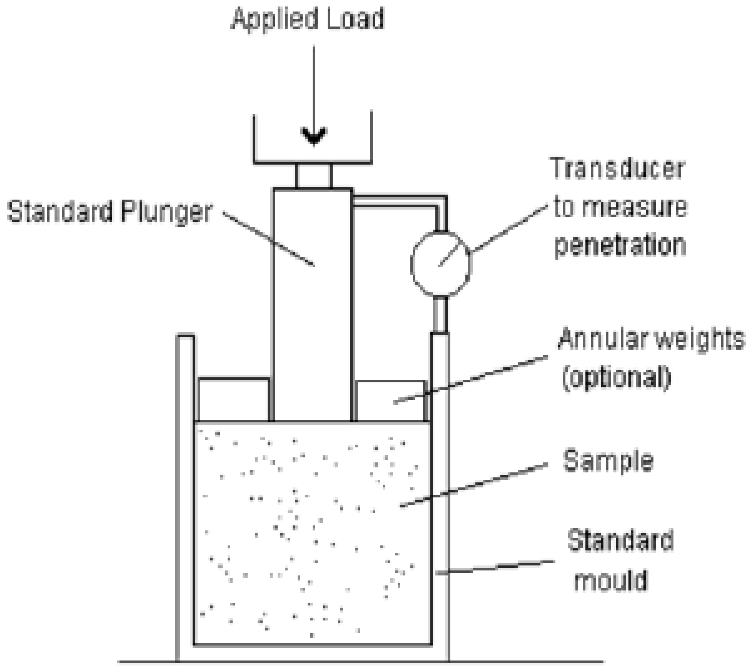
n = Design life in years

r = Annual growth rate of commercial vehicles

CBR Testing Mach

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

Equipments For CBR Test

Cylindrical mould :

Inside dia 150 mm , height 175 mm,

detachable extension collar 50 mm height

detachable perforated base plate 10 mm thick.

Spacer disc 148 mm in dia and 47.7 mm in height along with handle.

Metal rammers. Weight 2.6 kg with a drop of 310 mm (or) weight 4.89 kg a drop 450 mm.

Weights. One annular metal weight and several slotted weights weighing 2.5 kg each, 147 mm in dia, with a central hole 53 mm in diameter.

Loading machine.

capacity of atleast 5000 kg , movable head or base that travels at an uniform rate of 1.25 mm/min.

Metal penetration piston 50 mm dia and minimum of 100 mm in length.

Two dial gauges reading to 0.01 mm.

Sieves. 4.75 mm and 20 mm I.S. Sieves.

Load vs Penetration

The standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%

Penetration of plunger (mm)	Standard load (kg)
2.5	1370
5.0	2055
7.5	2630
10.0	3180
12.5	3600

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**

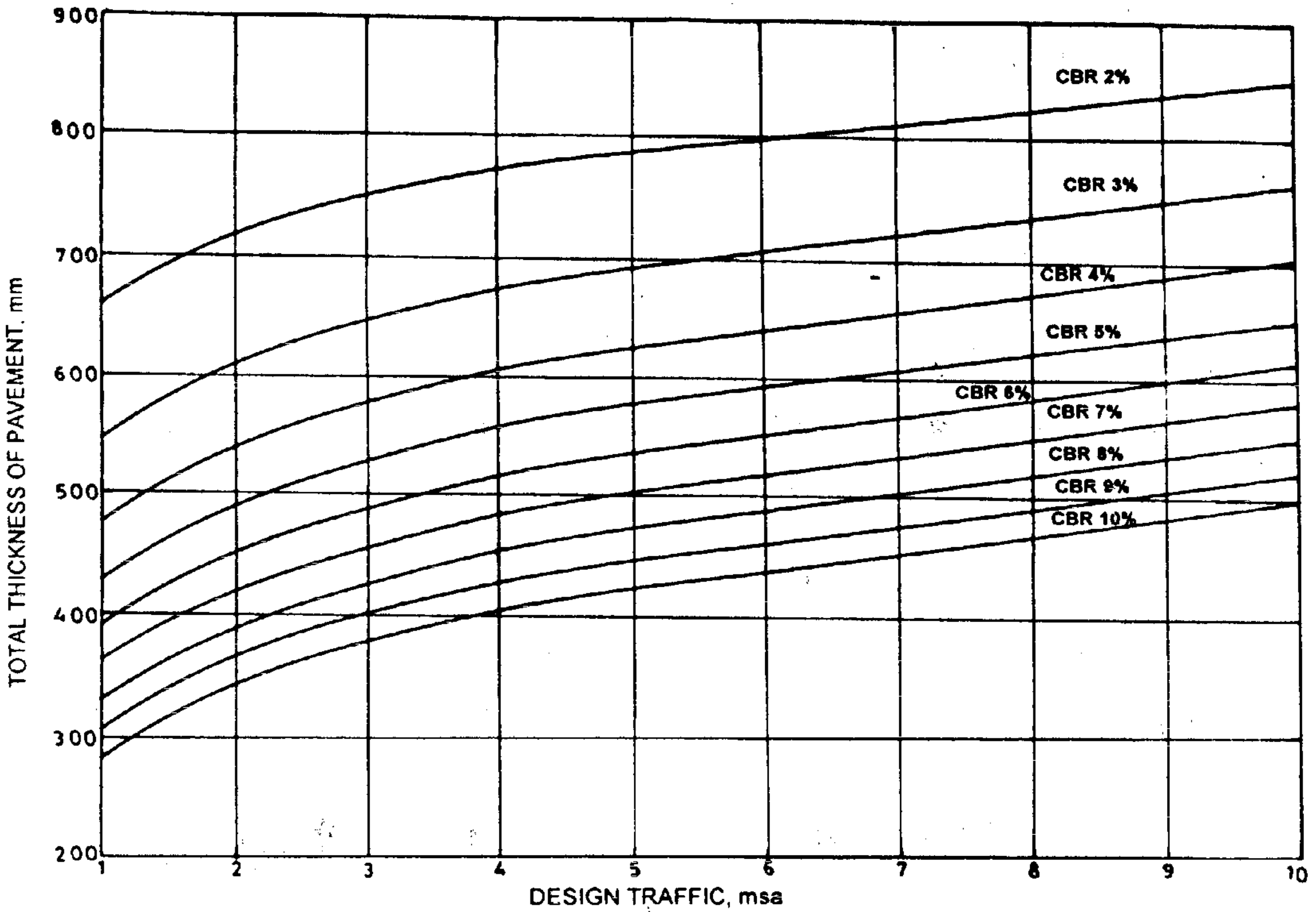
- **Non-expansive Soil to be Preferred.**

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.**
- **CBR to be at Critical Moisture Content and Field Density.**
- **Strength – Lab. CBR on Remoulded Specimens and NOT Field CBR**

Permissible Variation in CBR Value

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



Pavement Thickness Design Chart for Traffic 1-10 msa

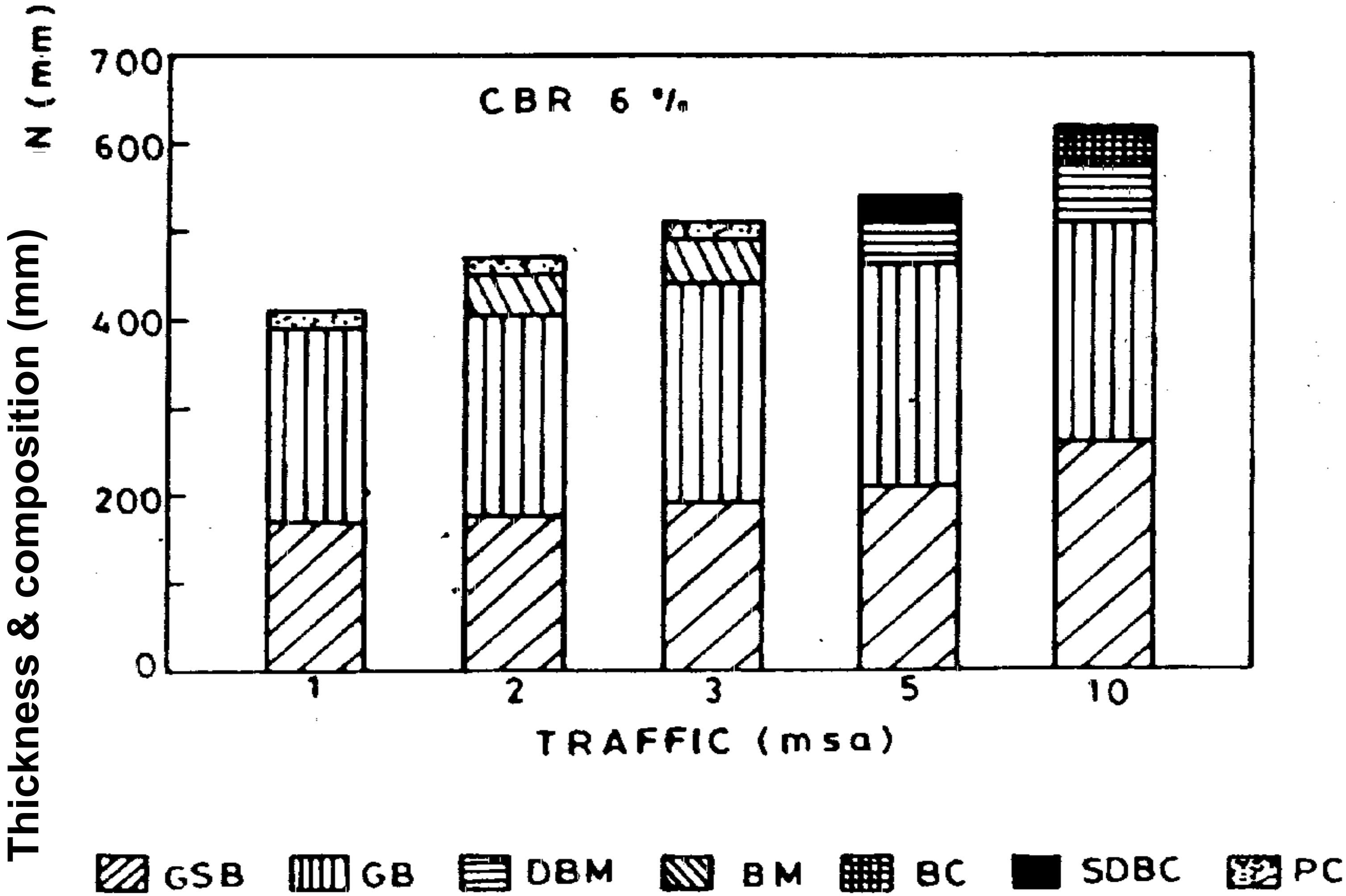
Flexible pavement design chart (IRC) (for CSA< 10 msa)

PAVEMENT DESIGN CATALOGUE

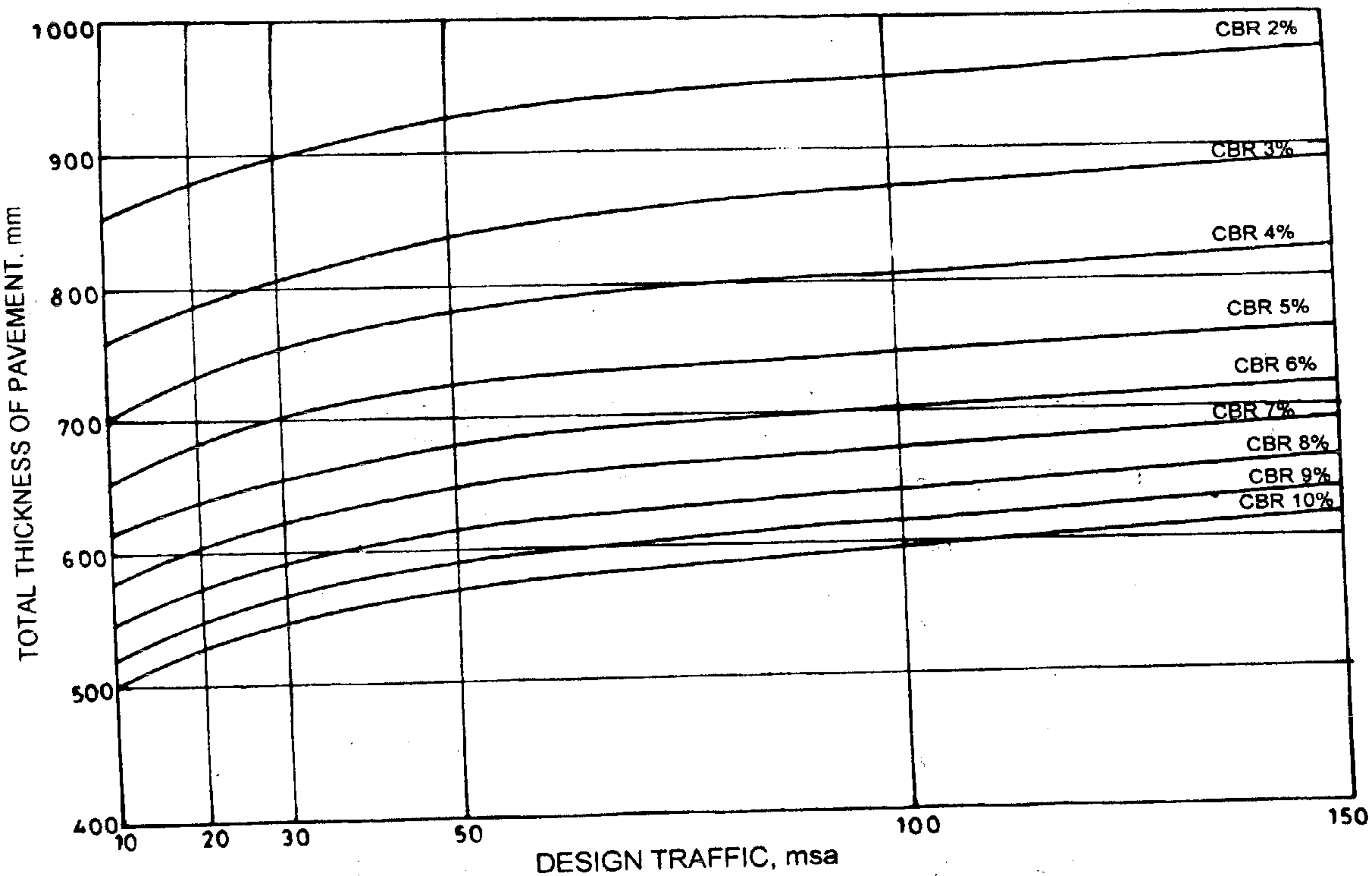
RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

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)



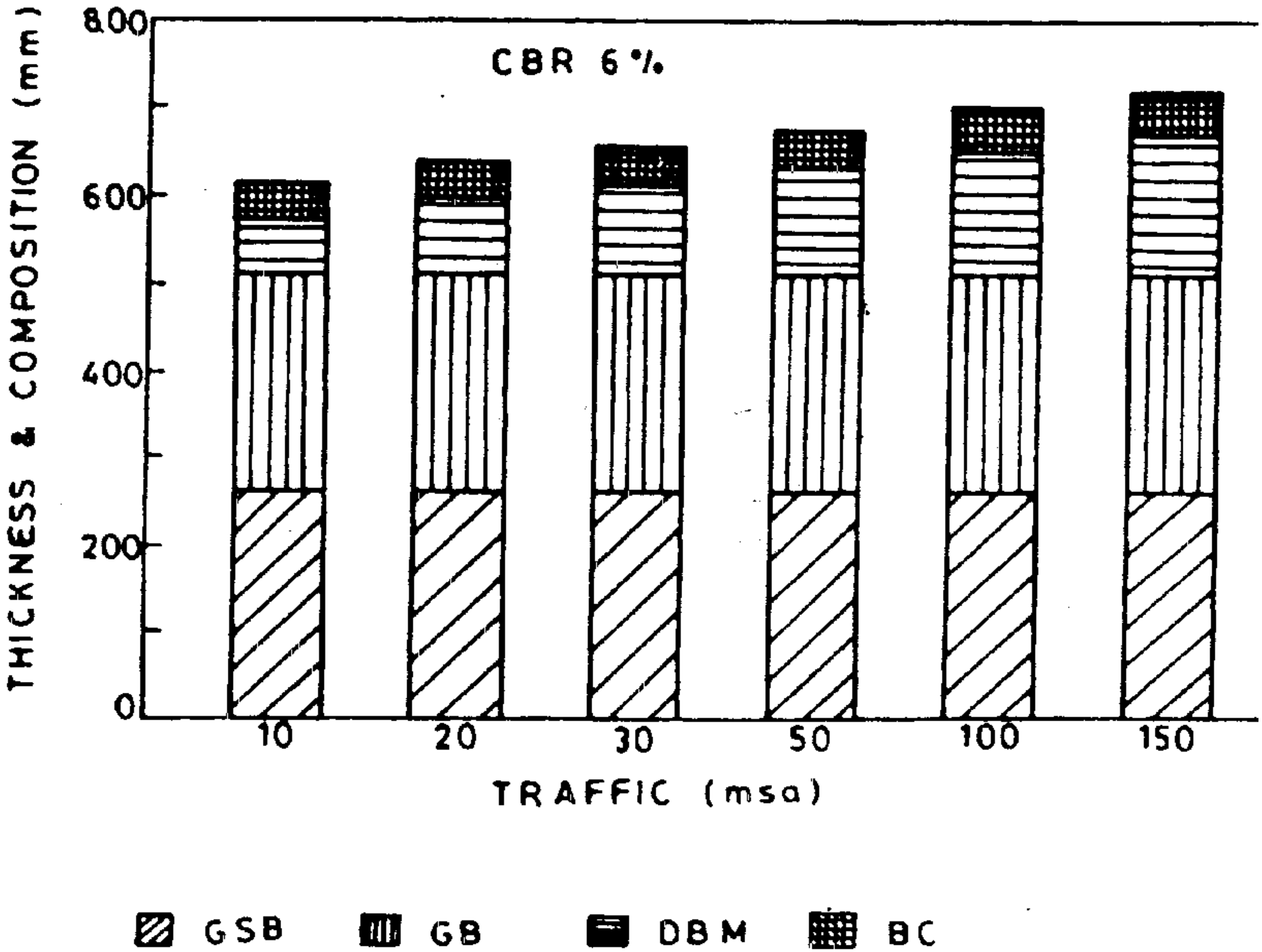
Pavement Thickness Design Chart for Traffic 10-150 msa

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 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**
- **Should Extend for the FULL Width of the Formation**
- **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)**

Bituminous Surfacing

- **Wearing Course – Open Graded PMC, MSS, SDBC, BC**
- **Binder Course – BM, DBM**
- **BM- Low Binder, More Voids, Reduced Stiffness,**

Bituminous Surfacing

- 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 Courses

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

Appraisal Of CBR Test And Design

- **Strength Number and Cannot be Related Fundamental Properties**
- **Material Should Pass Through 20 mm Sieve**
- **Surcharge Weights to Simulate Field Condition**
- **Soaking for Four Days- Unrealistic**
- **CBR Depends on Density and Moisture Content of Sub-grade Soil**
- **Design Based on Weakest Sub-grade Soil Encountered**

Example Of Pavement Design For A New Bypass

DATA:

Two-lane single carriageway = 400 CV/day
(sum of both directions)

Initial traffic in a year of completion of construction

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 %

Distribution factor = 0.75

Cumulative number of standard axles to to be catered for in the design

$$N = \frac{365 \times [(1+0.075)^{15} - 1]}{0.075} \times 400 \times 0.75 \times 2.5$$

$$= 7200000 = 7.2 \text{ msa}$$

Total pavement thickness for CBR 4% and Traffic 7.2 msa = 660 mm

Pavement Composition interpolated From Plate 1, CBR 4% (IRC37-2001)

Bituminous surfacing = 25 mm SDBC + 70 mm DBM

Road base, WBM = 250 mm

Sub-base = 315 mm

Example Of Pavement Design For Widening An Existing 2-lane NH To 4-lane Divided Road

Data:

i) 4-lane divided carriageway

Initial traffic in each directions in the year of = 5600cv / day

Completion of construction

iii) Design life = 10/15yrs

iv) Design CBR of sub-grade soil = 5 %

v) Traffic growth rate = 8 %

vi) Vehicle damage factor = 4.5

(Found out from axle road survey axles per CV on existing road)

Distribution factor = 0.75

VDF = 4.5

CSA for 10 Years = 100 msa

CSA for 15 years = 185 msa

Pavement thickness for CBR 5% and

100 msa for 10 Years = 745 mm

For 185 msa for 15 years = 760 mm

Provide 300 mm GSB + 250 mm WMM + 150 mm DBM + 50 mm BC (10 years)

Provide 300 mm GSB + 250 mm WMM + 170 mm DBM + 50 mm BC (15 years)

References

1.Yoder and Witczak “Principles of Pavement Design”

John Wiley and Sons , second edition

2.IRC :37-2001, Guidelines of Design of

Flexible Pavements”

3.IRC:81 - 1997 “Tentative Guidelines for Strengthening

of Flexible Road Pavements Using Benkelman Beam
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