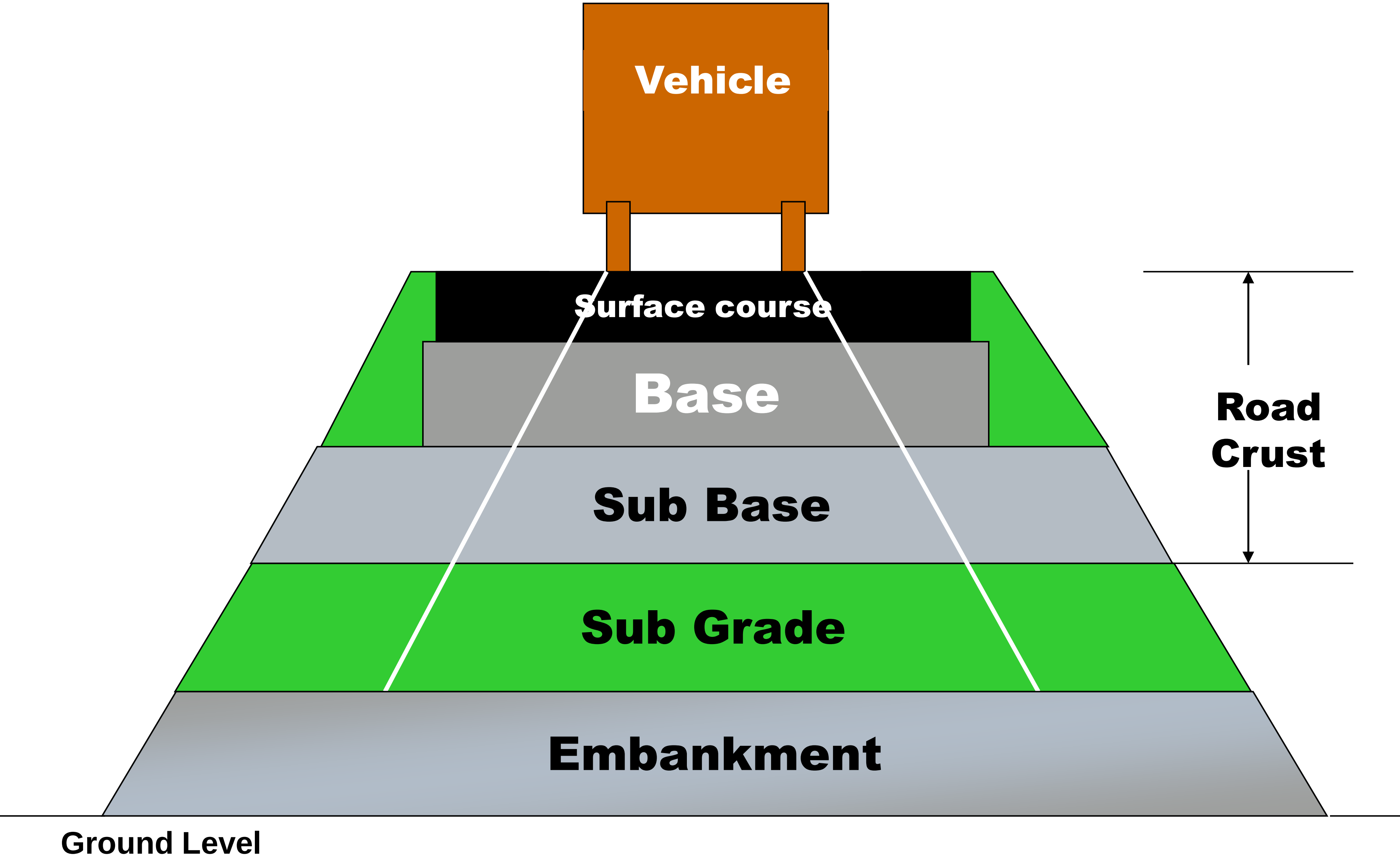
Pavement Design

Outline

- Requirements of Pavements
- Pavement types and their choice
- Design factors for flexible pavements
- Design of flexible pavements by CBR method

Pavement Composition



Requirements of pavements

- The surface of pavement should be stable and non yielding
- The surface of pavement should be even along longitudinal profile
- The uneven pavement surface causes increase in vehicle operation cost
- Unevenness also leads to discomfort and fatigue to passengers.
- Pavement design is to be done suitably to provide a stable and even surface
- Pavement consists of few layers of pavement materials, which are been laid over prepared subgrade to serve as a carriageway

Structural Requirements

- Traffic loads
- Load repetition
- Climatic variables
- Environmental factors

Functional Requirements

- Riding comfort
- Economic operation
- Safe operation

Pavement Types

Flexible pavements

Rigid pavements / Cement Concrete (CC) Pavements

Semi-rigid / Composite pavements

Flexible pavements

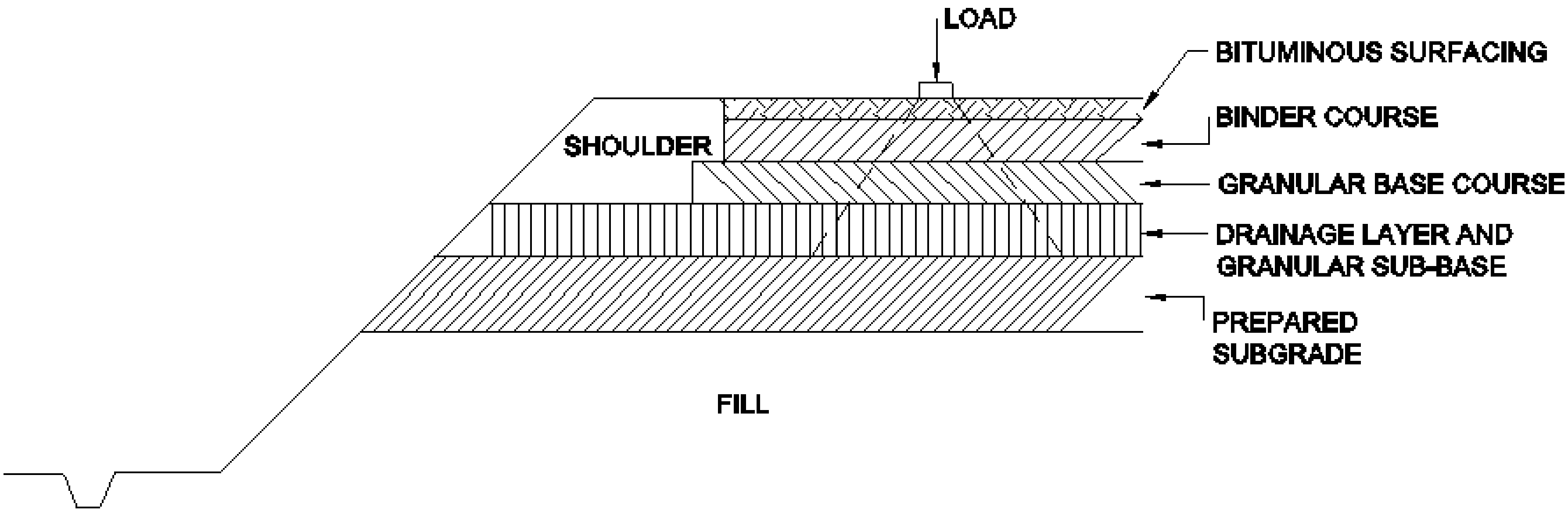


FIG. 2 TYPICAL CROSS SECTION OF
FLEXIBLE PAVEMENT

Stress distribution through granular layers

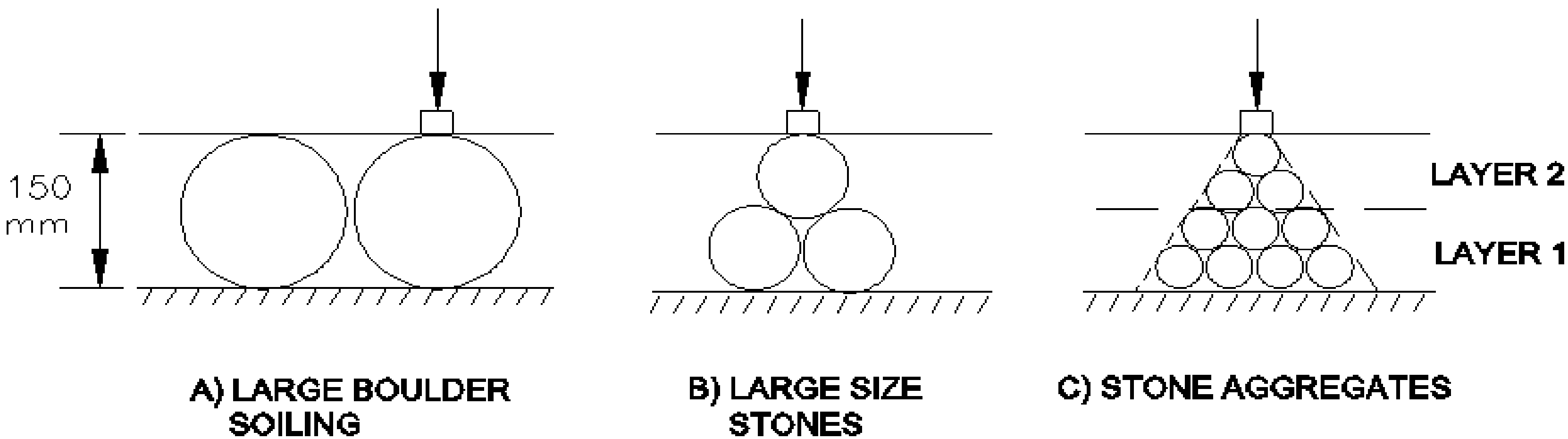


FIG. 1 PRESSURE DISTRIBUTION THROUGH TYPICAL GRANULAR MATERIALS

Rigid pavement

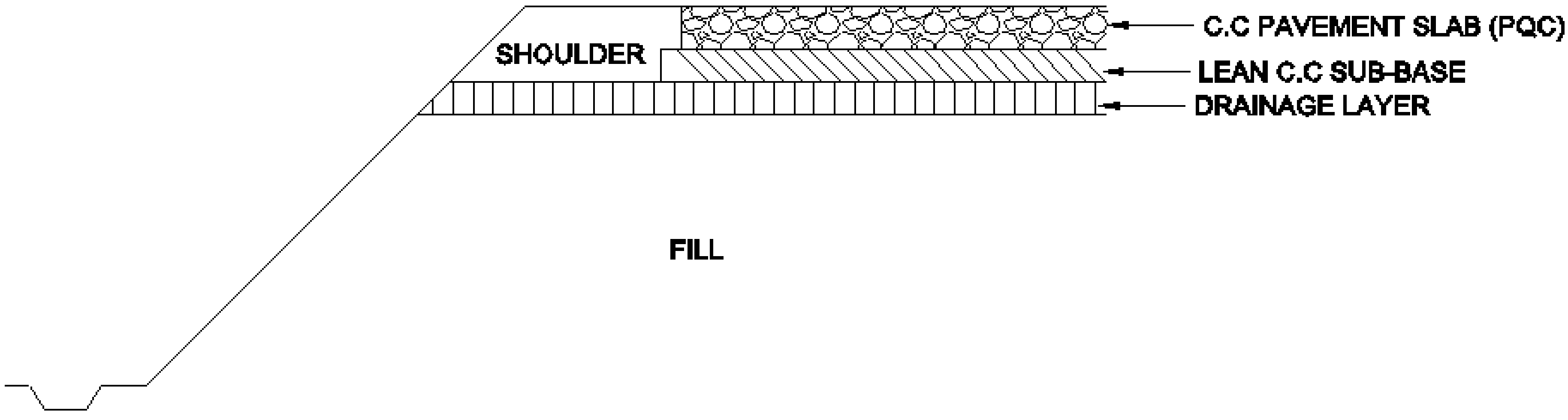


FIG. 3 TYPICAL CROSSSECTION OF
CEMENT CONCRETE PAVEMENT

Semi Rigid Pavements

- Intermediate class of materials used in base / sub base course
- The intermediate materials are – bonded materials like lime fly ash aggregate mix (puzzolanic concrete), lean cement concrete or soil cement
- They have slightly high flexural strength than the flexible pavements
- They do not possess as much flexural strength as cement concrete pavements
- These materials have low resistance to impact and abrasion

Choice Of Pavement Type

- **Initial cost**
- **Maintenance cost**
- **Total transportation cost**
- **Availability of funds**

Design Factors For Flexible Pavements

- **Design Wheel Load**
- **Sub-grade Support**
- **Materials in Pavement Component layers**
- **Climatic and Environmental Factors**
- **Drainage Characteristics**

Load

- **Gross load, ‘P’**
- **Tyre and Contact pressure, ‘p’ or the area of contact, A**
- **Multiple wheel load and ESWL**
- **Repeated application of wheel loads and EWL factors**

  - $P_1 N_1 = P_2 N_2$
- **Cumulative standard axles, CSA in msa**
- **Other factors - pavement width and coverage or lane distribution factor, speed etc.**

Subgrade

- **Soil type and index properties**
- **Strength properties (CBR, K - value or E-value)**
- **Drainage characteristics**

Pavement Materials

- **Materials characteristics in different layers**
- **(Stress distribution, drainage, strength factor etc)**
- **Durability**
- **Fatigue effects**

Climatic And Environmental Factors

- **Rain fall**
- **Depth of water table and relative height of formation**
- **Sub-grade moisture content for design**
- **Temperature variations - daily and seasonal**
- **Frost action**

Drainage characteristics

effective functioning of :

- **surface drainage system**
- **subsurface drainage system**

Flexible Pavement Design

Basic Principles

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

Solutions

- **Better Load Dispersing Materials**
- **Limit Elastic Deformation**
- **Construction Above Maximum Water Level**

Evaluation Of Pavement Component Layers

- Sub-grade
  - To Receive Layers of Pavement Materials Placed over it
  - Plate Bearing Test
  - CBR Test
  - California Resistance Value test
  - Triaxial Compression

Evaluation Of Pavement Component Layers

- **Sub-base And Base Course**
  - To Provide Stress Transmitting Medium
  - To Spread Wheel Loads
  - To Prevent Shear and Consolidation Deformation

    - Plate Bearing Test
    - CBR Test
    - Stabilometer 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**
- **Predictable Performance**

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 Commercial Vehicles/day**
  - **Based on 7 days 24 hours Classified Traffic**
- **Traffic Growth Rate**
- **Establishing Models Based on Anticipated Future Development**
  - **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

VEHICLE DAMAGE FACTOR (VDF)

AXLE LOAD, t	No. of Axles		Total Axles	Eq. FACTOR	Damage Factor
10-12	8	795	803	3.5	2810.5
12-14	0	804	804	7.16	5756.64
14-16	2	274	276	13.35	3684.6
16-18	2	56	56	23.17	1297.52
18-20	2	17	19	36.5	693.5

Vehicle Damage Factor (VDF)

AXLE LOAD, t	No. of Axles		Total Axles	Eq. FACTOR	Damage Factor
20-22	0	5	5	53	265
Total Damage Factor					16255

Vehicle Damage Factor = 16225 / 3280 (No. of Veh. Weighed)

$$\text{Vehicle Damage Factor} = \frac{16225}{3280} \quad \text{(No. of Veh. Weighed)}$$

= 4.95 (Sample size = 86 %)

Vehicle Damage Factors

- LCV - 0.259
- 2-Axle Trucks - 4.95
- 3- Axle Trucks - 7.587
- BUS - 1.027
- MULTI-AXLE TRUCKS - 9.535

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

Computation Of CSA For Different Vehicle Classes

Veh.	N	GF,%	DF	VDF	CSA
LCV	500	7	0.75	0.259	0.89
BUS	200	5	0.75	1.03	16.64
2-axle	3000	6	0.75	4.95	94.62
3-axle	500	4	0.75	7.58	20.7
M-axle	200	3	0.75	9.54	0.29
CSA for design life of 15 Yrs.					133.14

Subgrade

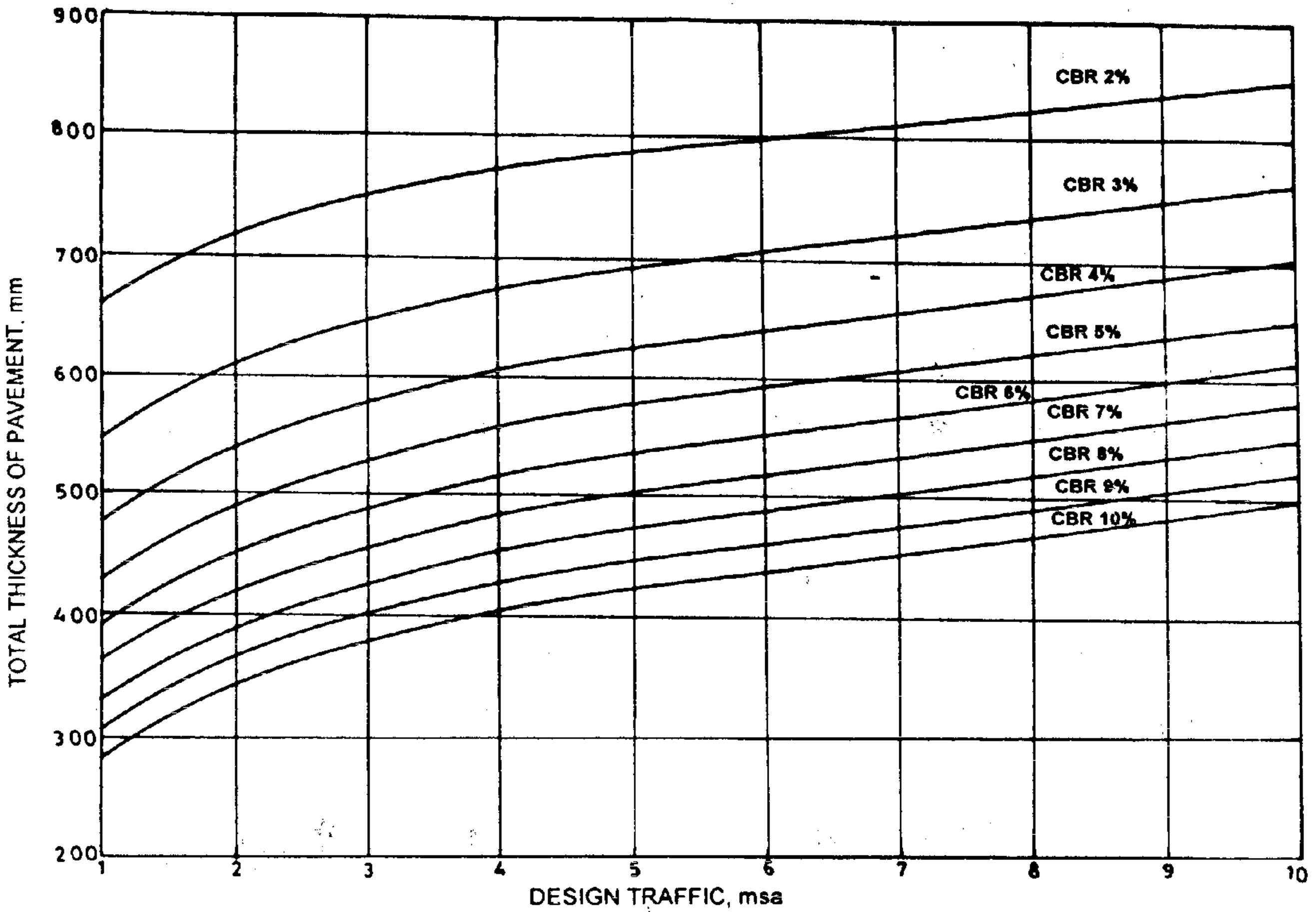
- ★ Subgrade to be Well Compacted to Utilize its Full Strength
- ★ Top 500 mm to be Compacted to 97% of MDD (Modified Proctor)
- ★ Material Should Have a Dry Density of 1.75 gm/cc
- ★ CBR to be at Critical Moisture Content and Field Density
- ★ Strength – Lab. CBR on Remoulded Specimens and NOT Field CBR

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**
- → **If ARF < 500 mm, Soaking is NOT required**

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

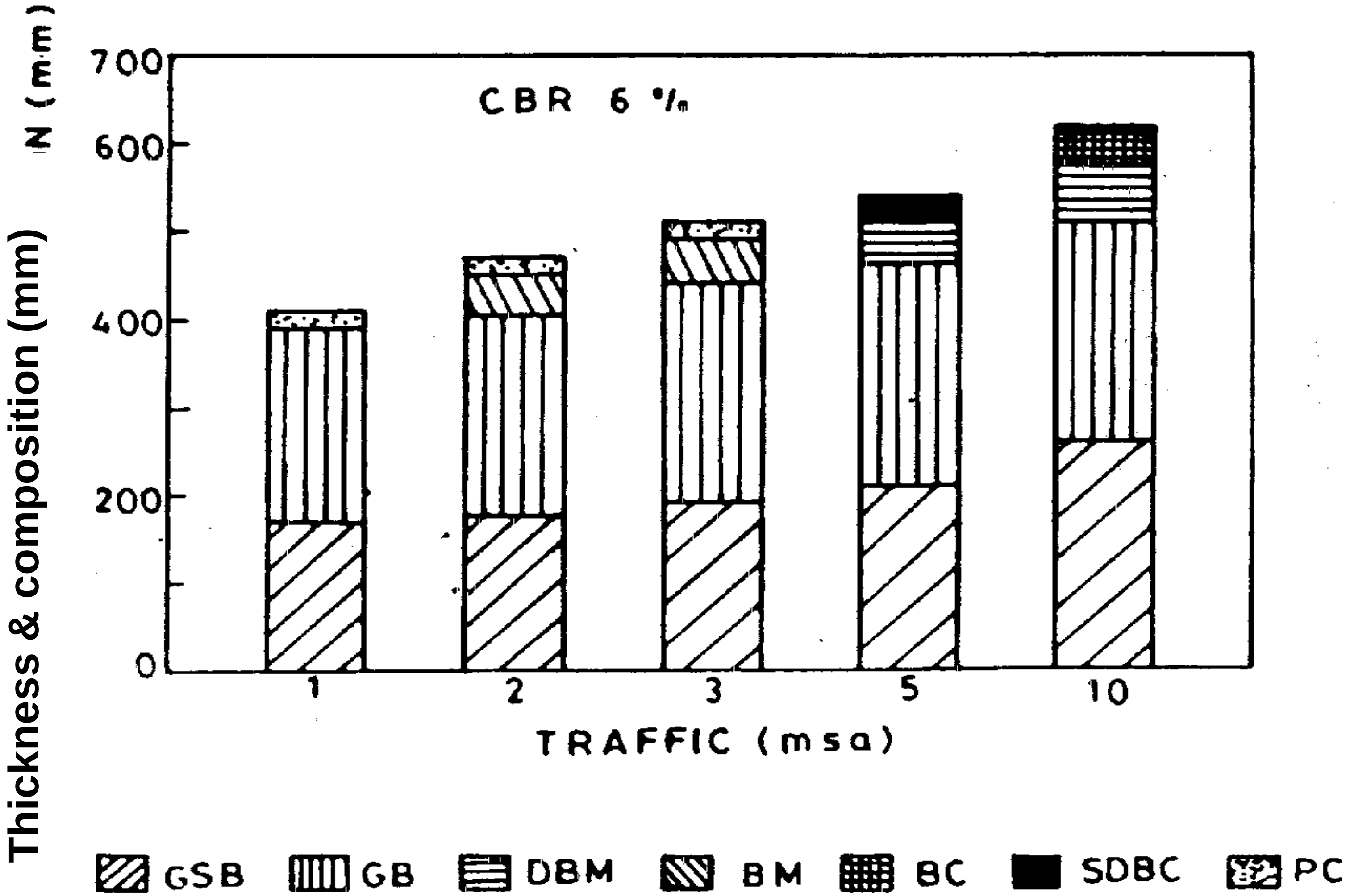
Flexible pavement design chart (IRC) (for CSA< 10 msa)

PAVEMENT DESIGN CATALOGUE

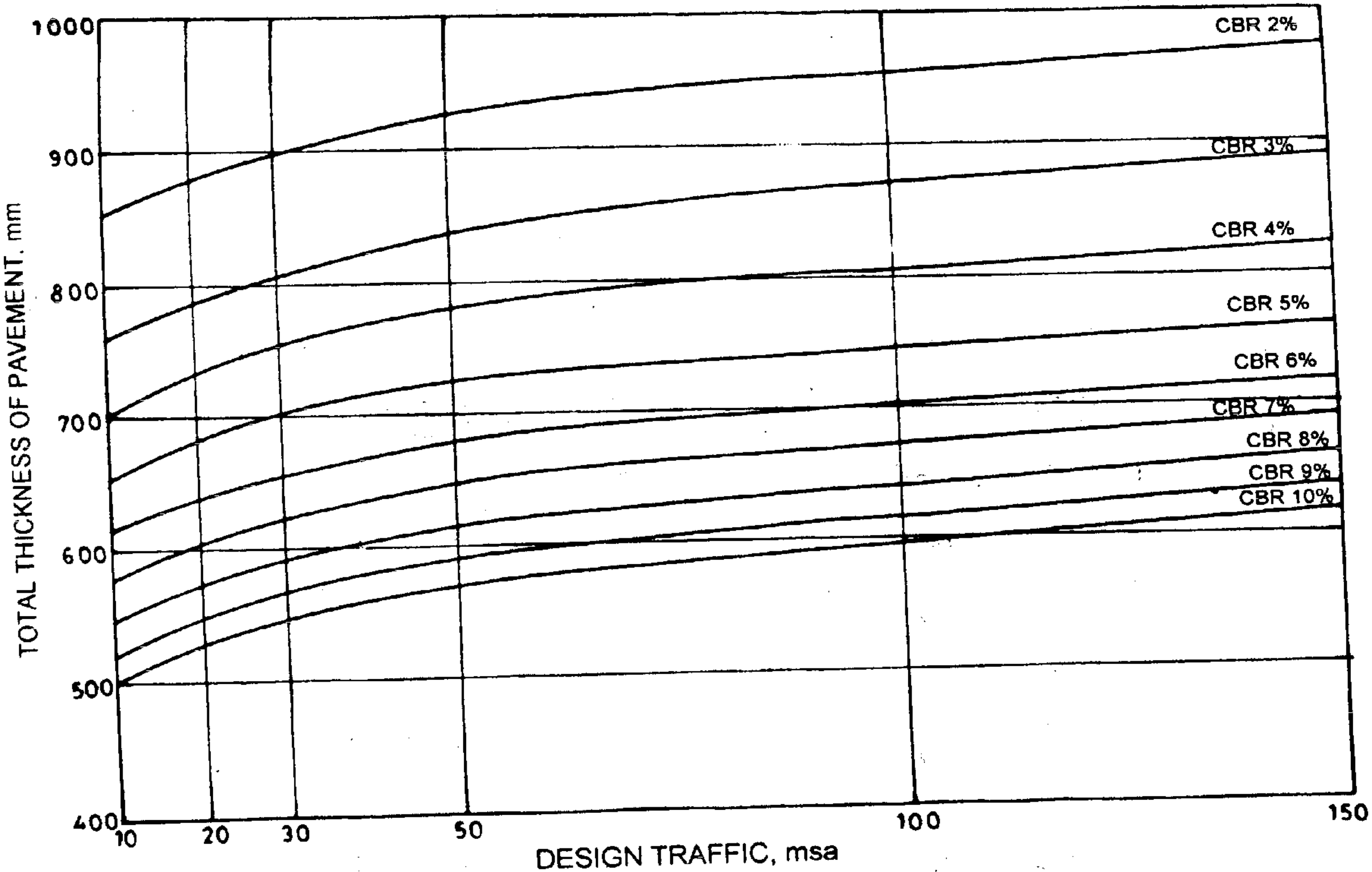
RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

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)



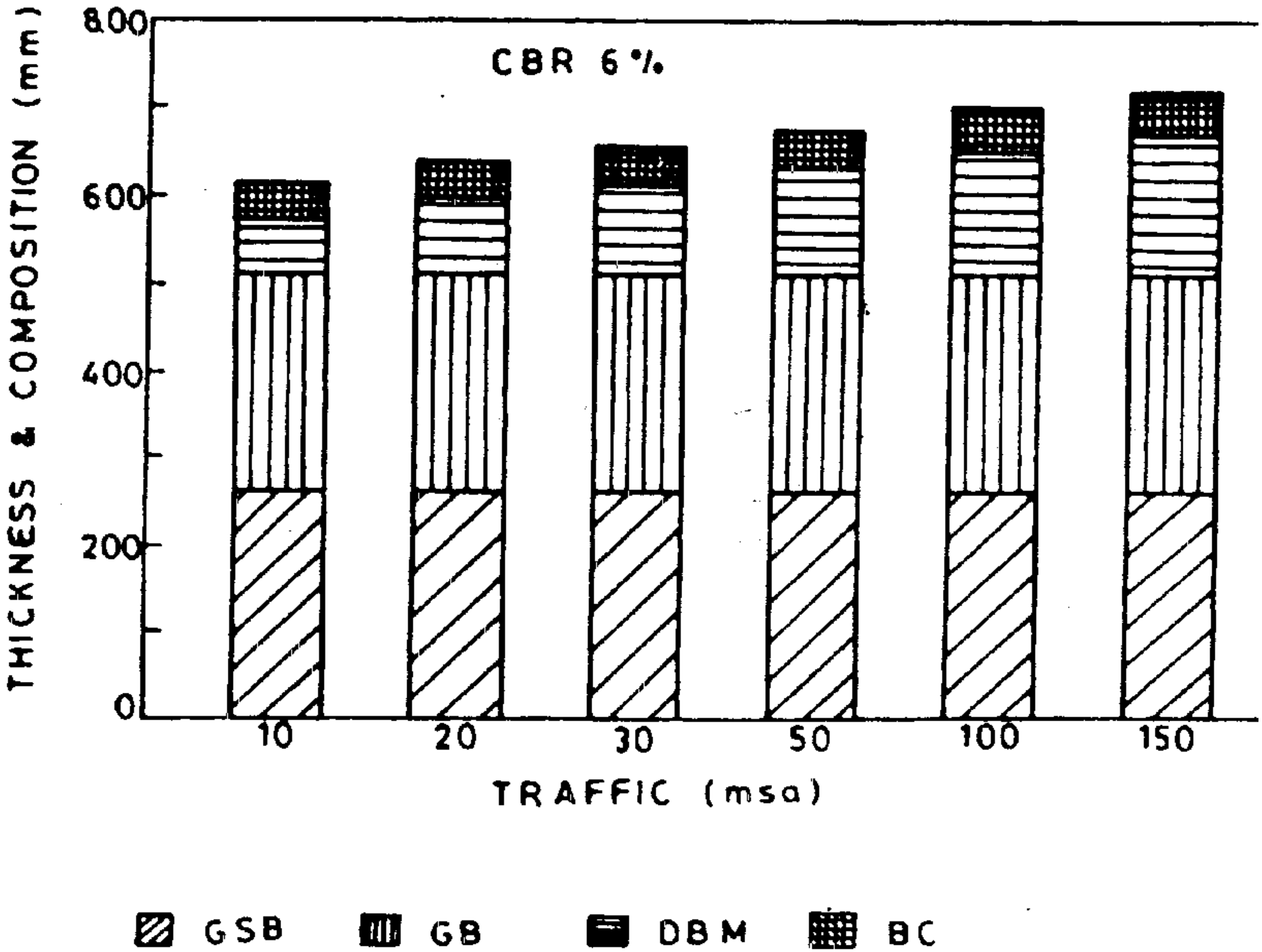
Pavement Thickness Design Chart for Traffic 10-150 msa

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, Increased Stress Concentrations – Desirable for Traffic < 5 msa**

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**

Criteria For The Selection Of Grade Of Bitumen For Bituminous Courses

Climate	Traffic	BC	Grade
Hot	Any	BM, BMP, BUSG	60/70
Mod/Cold	Any	BM, BMP, BUSG	80/100
Any	Heavy/ Urban	DBM, SDBC, BC	60/70
Hot/Mod	Any	PMC	50/60 or 60/70
Cold	Any	PMC	80/100
Hot/Mod	Any	Mastic	15± 5
Cold	Any	Mastic	30/40

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 msa

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

Pavement Composition interpolated

From Plate 1, CBR 4%

Bituminous surfacing	**=**	**25 mm SDBC + 70 mm DBM**
Road base, WBM	**=**	**250 mm**
Sub-base	**=**	**315 mm**

(Granular material of CBR not less than 30 percent)

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)

Design Factors for Rigid (CC) Pavements

Load

- ☜ **Wheel load : magnitude and repetitions**
- ☜ **Multiple wheel loads and ESWL for CC pavement**
- ☜ **Design wheel load based on cumulative distribution of loads**
- ☜ **Fatigue life due to loads in excess of design load during design life**

Subgrade support - K value of subgrade and sub-base course

Maximum temperature variations in the location

- ☞ **maximum temperature differential during the daily cycle**
- ☞ **maximum seasonal variation during annual cycle**

Properties of CC / PQC used in pavement slab : specified compressive / flexural strength

Design of joints in CC pavement

- ☞ **spacing of different contraction and longitudinal of joints**
- ☞ **dowel bars and tie bars / reinforcements at joints**

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
Deflection Technique

Thank you....