ROAD PAVEMENT

ABHASH ACHARYA

M.SC. IN TRANSPORTATION ENGINEERING

1

CONTENTS

- Definition and types of pavements
- Differences between flexible and rigid pavement structure
- Loads and other factors controlling pavement design
- Design methods for flexible pavements – Road notes 29, 31, CBR, AASHTO
- Details of Asphalt Institute Method of Design of Flexible Pavements
- Design Methods for Rigid Pavements and Westargard's Theory
- Stress due to load, temperature differential and sub-grade friction
- Details of the IRC method of design of rigid pavements for highways

2

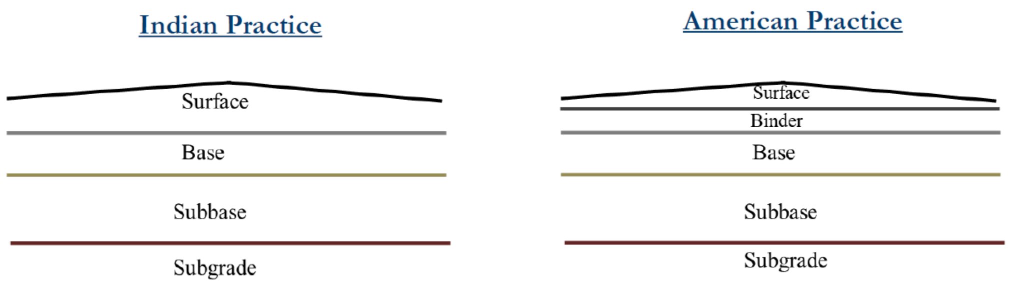
DEFINITION

- A relatively stable layer constructed over the natural soil for the purpose of **supporting and distributing the wheel loads and providing an adequate surface for the movement of the vehicles** is defined as road pavement.
  - Designed to support the wheel loads imposed on it from moving traffic over it.
  - Designed to keep the temporary deformation within the permissible range.
- Should be **strong enough to resist the stresses on it and should be thick enough to distribute the external loads on the earthen sub-grade**, so that the sub-grade itself can safely withstand it.

QUALITY OF GOOD PAVEMENT

- Structurally **sound** to withstand the stresses
- **Sufficient thickness** to distribute the loads
- Should be **dust proof**
- **Smooth** enough for comfort driving
- Should **develop low friction** for traffic movement
- Should have a texture and adequate roughness **to prevent skidding**
- It **should be impermeable**

LAYERS OF PAVEMENT



5

LAYERS OF PAVEMENT

- **Surface Course/Wearing Course**
  - Topmost layer that provides smooth, abrasion resistant, dust proof and strong layer that facilitate the movement of traffic
- **Base Course**
  - Medium through which the stresses imposed are distributed uniformly
- **Sub-base Course**
  - Helps in distribution of loads.
  - Has good drainage property
  - Protects the base course from capillary rise.
- Base course and sub-base course are made up of granular materials.
- **Subgrade** is a natural soil that is well-compacted or provided with suitable treatment.

6

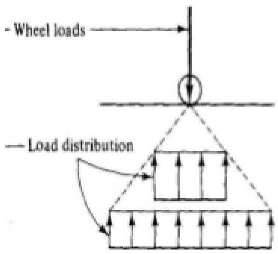
TYPES OF PAVEMENT

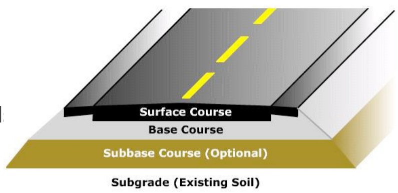
- Flexible pavement
- Rigid pavement
- Semi-rigid pavement
- Composite pavement

7

TYPES OF PAVEMENT

- **Flexible pavement**
  - Pavement deflects momentarily under load but rebounds to its original level on removal of load
  - Load transmission to the subgrade by lateral distribution with grain to grain point of contacts
  - Low flexural strength
  - Designed in layers using empirical method

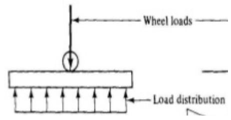


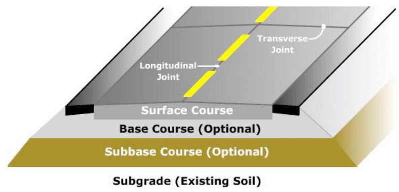


8

TYPES OF PAVEMENT

- **Rigid pavement**
  - Permanent settlements
  - Concrete slab acts as the wearing surface and distributes the load
  - Slab may be directly placed on the subgrade or in case of weak soils, a base or sub-base may be provided between slab and the subgrade
  - Load distribution by slab action
  - Design by structural analytical techniques





9

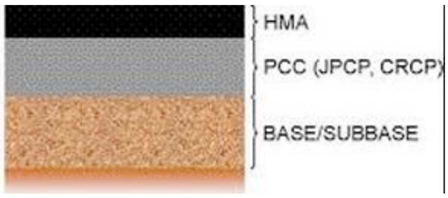
TYPES OF PAVEMENT

- **Semi-rigid pavement**
  - Base, subbase of bonded materials like lean cement concrete or soil cement are used in the base course or sub-base course
  - Flexible pavement surface course
  - Flexural strength lies in between of flexible pavement and rigid pavement

10

TYPES OF PAVEMENT

- **Composite pavement**
  - Comprises of multiple, structurally significant layers of different composition
  - Bottom layer – PCC, top layer – HMA
  - Ideal pavement
  - Expensive and rarely used in new construction



DIFFERENCES BETWEEN FLEXIBLE AND RIGID PAVEMENT

Properties	Flexible Pavement	Rigid Pavement
	Structural Characteristics	
Strength	Less flexural strength, result of load transmission via lateral distribution over the layers	High flexural strength, result of slab's bending action
Self healing	Has self healing property	No self healing property
Excessive load	Yields resulting in local depression of the surface	Ruptures resulting crack of the surface
Weak subgrade	Pavement reflects the deformation of the subgrade due to excessive stress exceeding its bearing capacity	Pavement is able to bridge the small weakness and depression of the subgrade
Irregularities in subgrade	Pavement will adjust due to differential settlement	Pavement will not adjust but covers acting as a beam
Temperature variation	Relatively less effect	Heavy stress is produced

DIFFERENCES BETWEEN FLEXIBLE AND RIGID PAVEMENT

Properties	Flexible Pavement	Rigid Pavement
Design, Construction, Maintenance and Economy		
Design Method	Empirical method	Structural analysis techniques
Design Life	10-20 years	20-40 years
Economy	Low initial construction cost	High initial investment
Maintenance	Requires frequent maintenance	Requires less maintenance (mainly maintenance of joints)
Stage construction	Possible	Not possible
Opening to traffic	Within 24 hours	14 to 28 days
Environmental considerations	Hazardous	Has emission issues but is comparatively less hazardous

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- Traffic and loading factors
- Material properties
- Environmental factors
- Failure criteria

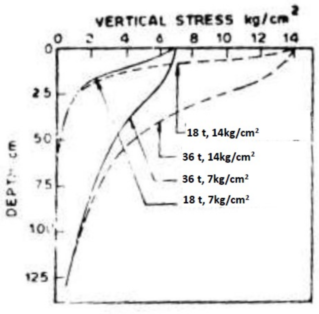
LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - Axle load
  - Number of load repetitions
  - Contact area
  - Vehicle speed

15

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Axle load**
    - Total weight of the vehicle carried by its axles
    - The wheel transmits the axle loads to the pavement surfaces
    - Wheel load
      - Higher the wheel load, thicker is the pavement required
      - **Pavement design is governed by number and wheel loads of the commercial vehicles**



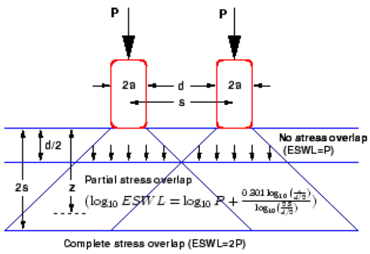
16

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Axle load**
    - **Wheel configuration**
      - Most commercial vehicles are provided with dual rear wheels
      - **Affects the stress distribution and deflection**
      - Design of flexible pavement considers wheels on only one side
      - Design of rigid pavement considers wheels on both sides

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Axle load**
    - Dual wheel load is converted into equivalent single wheel load to simplify the analysis



Equivalent single wheel load (ESWL) is the **single wheel load having the same contact pressure**, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth.

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Axle load**
    - **Axle configuration**
      - Commercial vehicles are provided with multiple axles to further enhance the load carrying capacity
      - In design **Standard Axle Load** and **Equivalency Factor (F)** are used

Equivalency factor for an axle load L (F) = $\frac{Damage\ caused\ by\ passage\ of\ axle\ load\ L\ on\ a\ pavement}{Damage\ caused\ by\ passage\ of\ a\ standard\ axle\ load\ (L_s) on\ the\ same\ pavement}$

- **Standard Axle Load: 80KN rear single axle with dual wheels** (varying depending on country's design standard)

ABHASH ACHARYA | HIGHWAY PAVEMENT 19

19

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Axle load**
    - **Axle configuration**
      - Generalized version of AASHTO's fourth power damage formula
        - Structural damage caused by an axle load varies as fourth power of its ratio to the standard axle load

Equivalency factor for an axle load L (F) = $(\frac{L}{L_s})^4$

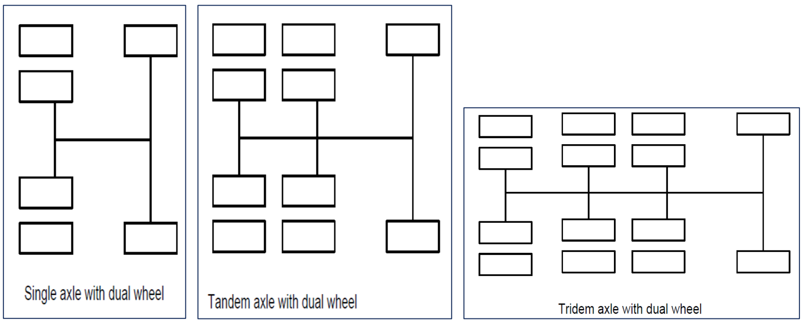
Empirical relation and varies for different failure criterion.

ABHASH ACHARYA | HIGHWAY PAVEMENT 20

20

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

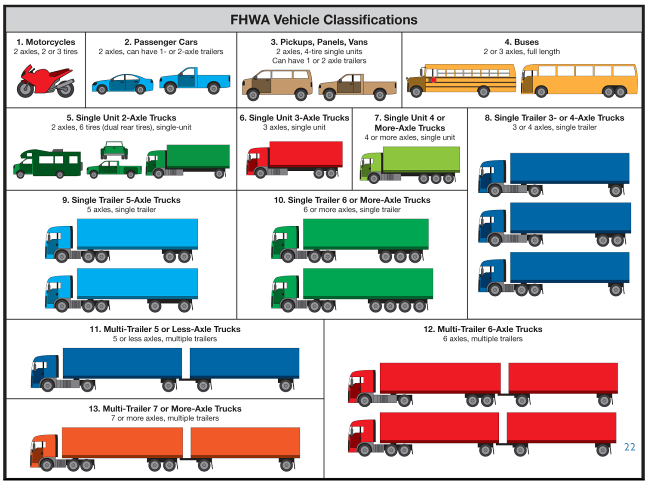
- **Traffic and loading factors**
  - **Axle load**
    - Axle configuration



21

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Axle load**
    - Axle configuration



22

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

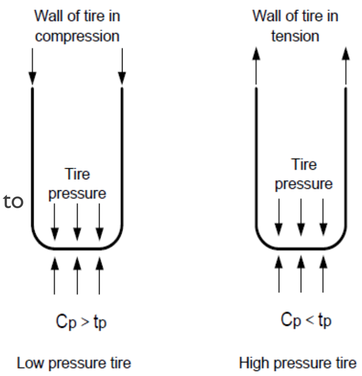
- **Traffic and loading factors**
  - **Number of load repetitions**
    - Repeated application of the wheel load leads to distress in pavement thereby causing pavement failure
    - Total number of repetitions of the axle loads is computed as **Cumulative Number of Standard Axles** for the design life

23

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Contact area**
    - Wheel load is assumed to be uniformly distributed over the contact area
    - Size depends on the contact pressure
    - In pavement design, the contact pressure is generally assumed to be equal to the tire pressure

$$\text{Contact area } (A_c) = \frac{Load}{Tire\ Pressure\ (t_p)}$$



    - True shape is elliptical

24

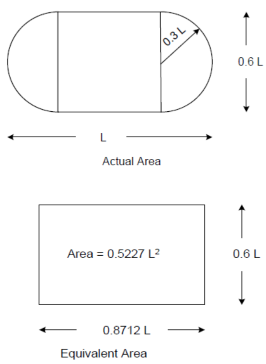
LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Contact area**
    - **Flexible pavement**
      - Each tire is assumed to have a circular contact area since it is axisymmetric and suitable for layered theory
      - For dual tire, a single circle with the same contact area as of the dual is used

Radius of contact area $a = \sqrt{\dfrac{Load}{\pi\, t_p}}$

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Contact area**
    - **Rigid pavement**
      - Elliptical shape with a rectangle and two semicircle is assumed
      - For FEM analysis, an equivalent rectangular area is assumed



LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Traffic and loading factors**
  - **Vehicle Speed**
    - Directly related to duration of loading
    - Damage to the pavement is much higher if the **vehicle is moving at creep speed**
    - The resilient modulus of the pavement layers should be selected carefully considering the combination of loading and vehicle speed

27

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Material Properties**
  - Must be specified to determine pavement responses (stresses, strains and displacements)
  - **Linearly elastic: Elastic modulus and Poisson's ratio**
  - For consideration of **moving load/repetition of load, resilient modulus** is better representative
  - Nonlinear property of material can e characterized by a stress dependent resilient modulus

28

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Environment factor**
  - Temperature
  - Precipitation
  - Road geometry

29

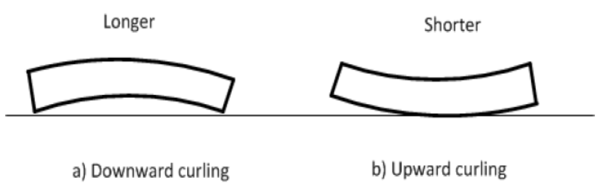
LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Environment factor**
  - **Temperature**
    - **Affects the elastic modulus** of pavement layers
    - Flexible pavement
      - Affects elastic modulus of asphalt layer
      - Low temperature can cause asphalt pavement to crack

30

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Environment factor**
  - **Temperature**
    - **Rigid pavement**
      - **Create curling stress** and affect slab subgrade contact and the stress values
      - Determines joint and crack openings and affects the efficiency of load transfer
    - **Frost penetration** affects the subgrade strength in cold climate



31

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Environment factor**
  - **Precipitation**
    - Quantity of surface water infiltration affects the moisture content of the subgrade and the depth of Ground Water Table (GWT)
    - **Poor drainage may reduce shear strength**
    - May cause pumping, loss of support, etc.

32

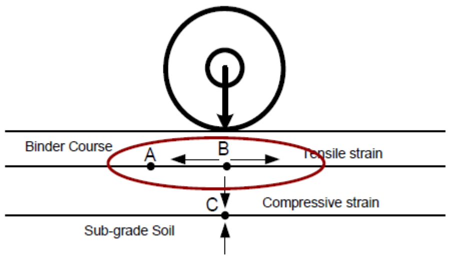
LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Failure criteria**
  - Number of failure criterion is adopted considering different distress types
  - Flexible pavement
    - Fatigue cracking
    - Rutting criteria
    - Thermal cracking
  - Rigid pavement
    - Fatigue cracking
    - Pumping faulting./spalling/joint deterioration

33

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

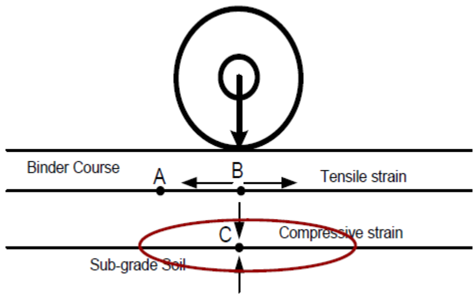
- **Failure criteria**
  - **Flexible pavement**
    - Fatigue cracking
      - Under repeated traffic loading, bituminous surfacing pavement displays flexural fatigue cracking
      - Relates allowable number of load repetitions to the tensile strain at the bottom of the bituminous layer based on laboratory fatigue test



34

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Failure criteria**
  - **Flexible pavement**
    - Rutting criteria
      - Surface depression (rut depth) along the wheel path
      - Failure criteria: a) Limit vertical compressive strain on the top of the sub grade or b) Limit the rut depth to tolerable limit using empirical relation from road test



35

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Failure criteria**
  - **Flexible pavement**
    - Thermal cracking
      - Low temperature cracking
      - Thermal fatigue cracking
      - Tensile strain due to daily temperature cycle

36

LOADS AND OTHER FACTORS CONTROLLING PAVEMENT DESIGN

- **Failure criteria**
  - **Rigid pavement**
    - **Fatigue cracking**
      - Major failure criteria in rigid pavement design
      - Due to load and temperature stresses
      - Allowable number of load repetitions depends on ratio of flexural tensile stress and concrete modulus of rupture
    - **Pumping, faulting**
      - Difficult to analyze mechanistically

37

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic Method
- Semi-empirical Method
- Empirical Method
- Mechanistic-empirical Method

38

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

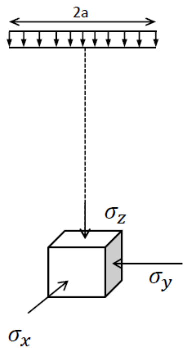
- **Mechanistic Method**
  - Materials forming the flexible pavement layers and the soils supporting the pavement are not materials exhibiting uniform properties.
  - Completely satisfactory method of design, wholly based on theoretical considerations has not yet emerged.
    - Boussinesq's Theory
    - Burmister's Theory

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method - Boussinesq's Theory**
    - First attempt towards analytical solution.
    - **Stresses, strains and deflections** at any point in the layered system can be determined by using the layer theory.
    - Single layered system
    - **Assumptions**
      - Semi-infinite, ideally elastic, isotropic and homogenous soil mass.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method - Boussinesq's Theory**
  - **Vertical Stress (σ_z)**
    - The vertical stress at any point below the surface located on the vertical axis passing through the center of the circle due to a uniformly distributed load on a circular area is given by

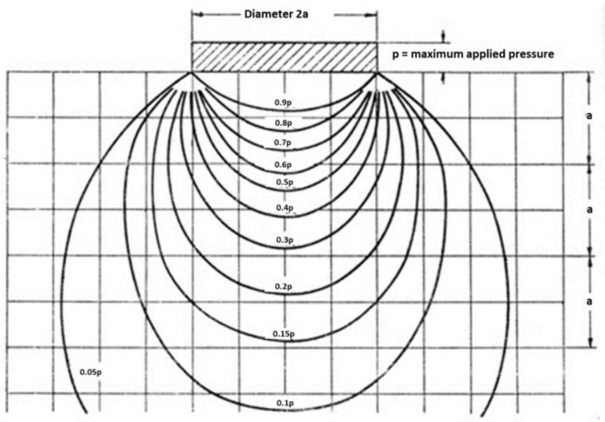


$$\sigma_z = p\left[1 - \frac{z^3}{(a^2 + z^2)^{\frac{3}{2}}}\right]$$

Where,
p : Applied pressure per unit area
a : Radius of circular loaded area
z : Depth

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic Method - Boussinesq's Theory - Vertical Stress (σ_z)



DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method - Boussinesq's Theory - Vertical Displacement (Δ)**
  - The vertical displacement at depth z below the surface under the center of loaded area is given by

$$\Delta = \frac{pa}{E} F$$

Where, E is the modulus of elasticity of soil

F is the deflection factor for Poisson's ratio of soil μ = 0.50

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method - Boussinesq's Theory - Vertical Displacement (Δ)**
  - For flexible circular plate

Deflection factor: $F = \frac{3}{2} \frac{1}{\left(1+\frac{z^2}{a^2}\right)^{\frac{1}{2}}}$

Maximum deflection at surface (z=0): $\Delta = \frac{\mathbf{1.5}\, pa}{E}$

  - For rigid circular plate

Maximum deflection: $\Delta = \frac{1.18\, pa}{E}$

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method - Boussinesq's Theory - Vertical Displacement (Δ)**
  - Deflection Δ is the function of contact pressure, radius, elastic modulus and pavement thickness

$\Delta = f(p, a, E, z)$

$$\Delta = \frac{pa}{E} F = \frac{pa}{E} * \frac{3}{2} \frac{1}{\left(1+\frac{z^2}{a^2}\right)^{\frac{1}{2}}}$$

For wheel load P

$$\Delta = \frac{3P}{2\pi E} \frac{1}{(a^2 + z^2)^{1/2}}$$

$z = \sqrt{\left(\frac{3P}{2\pi E\Delta}\right)^2 - a^2}$ known as Boussinesq's displacement equation

ABHASH ACHARYA | HIGHWAY PAVEMENT 45

45

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method - Boussinesq's Theory - Limitations**
  - Assumptions that **soils are perfectly elastic and homogeneous** is not true.
  - Pavement consist number of layers with their own elastic modulus.
  - Assumption that **load is uniformly distributed** is not true.

ABHASH ACHARYA | HIGHWAY PAVEMENT 46

46

NUMERICAL

Calculate the deflection at the surface of a pavement due to wheel load of 40 KN and a tire pressure of $0.5 MN/m^2$. The value of E of the pavement and subgrade may be assumed to be uniformly equal to $20 MN/m^2$.

Given,

P = 40 KN

Tire pressure = $0.5 MN/m^2$

Tire pressure = $500 KN/m^2$

E = $20 MN/m^2$

Deflection at surface:

$\Delta = \frac{1.5\,pa}{E}$

Calculation of a

Tire pressure = Wheel load/Area

$0.50*10^3 = \frac{40}{\pi a^2}$

a = 0.1595 m

Calculation of deflection

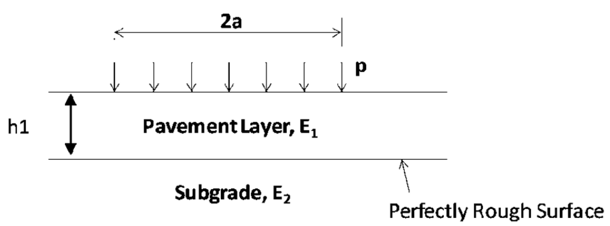
$\Delta = \frac{1.5\,pa}{E}$

$\Delta = \frac{1.5*500*0.1595}{20*10^3}$

Δ = 0.005986 m

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method – Burmister's Theory**
  - Two layered system
  - Top layer of finite thickness (surfacing, base course, sub-base course) and bottom layer of semi-infinite thickness (subgrade)



DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method – Burmister's Theory - Assumptions**
  - Homogeneous, isotropic and elastic properties of materials in each layer.
  - Surface layer (infinite in lateral direction, finite in vertical direction).
  - Underlying layer (infinite in both lateral and vertical direction)
  - There exist perfectly rough interface (full friction is developed)
  - Stress solutions are characterized by two material properties **E and μ**

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method – Burmister's Theory – Deflection at the surface (Δ)**
  - Stress and deflection values depend on the depth and the strength ratio E_1 / E_2
    - $E_1/E_2 = 1$ → Stress on interface (base-subgrade) is 70% of the total applied stress
    - $E_1/E_2 = 100$ → Stress on interface (base-subgrade) is 10% of the total applied stress
  - WASHO – 10 to 30cm reduction in total pavement thickness if 10cm bituminous concrete surface is used of 5cm surface.
  - AASHO road test – Flexible pavement bases treated with bituminous materials or cement are superior to untreated crushed limestone or gravel base in resisting loss of serviceability under load.
  - Typical flexible pavements are composed of layers so that the moduli of elasticity, E decrease with depth

$$E_s > E_b > E_{sb} > E_{sub}$$

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method – Burmister's Theory – Deflection at the surface (Δ)**
  - **For flexible circular plate**

$$\Delta = \frac{1.5\,pa}{E_2} F_w$$

  - **For rigid circular plate**

$$\Delta = \frac{1.18\,pa}{E_2} F_w$$

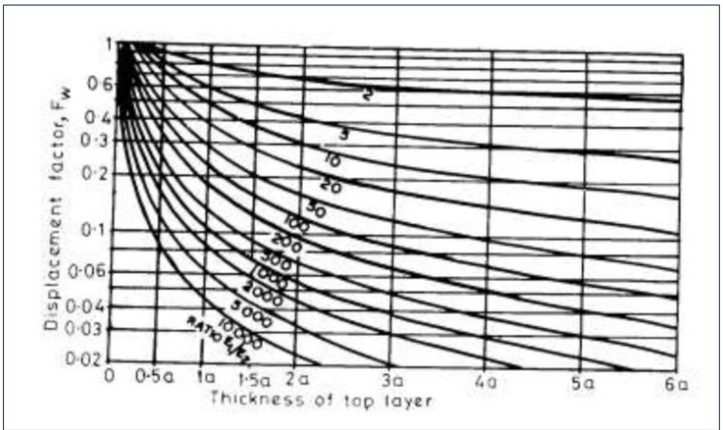
Where, p is load intensity on the circular plate

a is the radius of circular plate

E_2 is the modulus of elasticity of the lower layer, F_w is the displacement factor

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Mechanistic Method – Burmister's Theory – Displacement Factor (F_w)**
  - Dimensionless factor depending on the ratio of moduli of elasticity of the pavement and the subgrade (E_1/E_2) as well as the depth to radius ratio (h_1/a)
  - The displacement under the wheel load is suggested to be limited to 5.0mm for the flexible pavement.



NUMERICAL

Design the thickness of a flexible pavement by Burmister's two layer analysis for a wheel load of 40 KN and a tire pressure of 0.5 KN/m². The modulus of elasticity of the pavement material is 150 MN/m² and that of the subgrade is 30 MN/m². The value of F_w can be taken from the graph.

Given,

P = 40 KN

Tire pressure = 0.5 MN/m²

Tire pressure = 500KN/m²

E_1 = 150 MN/m²

E_2 = 30 MN/m²

Deflection:

$\Delta = \frac{1.5\,pa}{E_2} F_w$

Calculation of a

Tire pressure = Wheel load/Area

$0.50*10^3 = \frac{40}{\pi a^2}$

a = 0.1595 m

2a = 32cm

E_1/E_2 = 150/30 = 5

From chart, F_w = 0.43

Therefore, deflection $\Delta = \frac{1.5\,pa}{E_2} F_w$

$\Delta = \frac{1.5 * 500 * 0.1595}{30*10^3} * 0.43$

Δ = 0.001716 m = 1.716 mm < 5 mm

(OK)

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Semi-empirical Method – Triaxial Method**
  - Based on Boussinesq's displacement equation for homogeneous elastic single layer
  - Stiffness factor $\left(\frac{E_s}{E_p}\right)^{1/3}$ to account for stress distributing qualities of pavement layer compared to that of subgrade soil
  - Uses empirical modifications as Traffic coefficient (X) and Saturation coefficient (Y)
  - X is based on the ADT of design traffic
  - Y is based on annual rainfall

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Semi-empirical Method – Triaxial Method – Design thickness equation**

Based on Boussinesq's displacement equation:

$$T = \sqrt{\left(\frac{3P}{2\pi E_s \Delta}\right)^2 - a^2}$$

Final design thickness equation:

$$T_p = \left\{\sqrt{\left(\frac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2}\right\}\left(\frac{E_s}{E_p}\right)^{1/3}$$

Where,

T_p : Pavement thickness, cm
P : Wheel load, kg
E_s: Modulus of elasticity of subgrade from triaxial test results, kg/cm²
X: Traffic coefficient
a: Radius of contact area, cm²
Δ : Design deflection (assumed 0.25 cm)
E_p : Modulus of elasticity of pavement material, kg/cm²
Y : Rainfall coefficient

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Semi-empirical Method – Triaxial Method – Design thickness equation**

Traffic coefficient (X)	ADT (number)
½	40-400
2/3	401-800
5/6	801-1200
1	1201-1800
7/6	1801-2700
8/6	2701-4000
9/6	4001-6000
10/6	6001-9000
11/6	900-13500
12/6	13501-20000

Rainfall coefficient (Y)	Average annual rainfall (cm)
0.5	38-50
0.6	51-64
0.7	65-76
0.8	77-90
0.9	91-100
1.0	101-127

For pavement layers of thickness t_1 and t_2 of elastic moduli E_1 and E_2 respectively, we have

$$\frac{t_1}{t_2} = \left(\frac{E_2}{E_1}\right)^{1/3}$$

NUMERICAL

Design the pavement section by triaxial method using the given data: Wheel load = 4100 kg, radius of contact area = 15cm, design ADT = 5000, average annual rainfall = 96 cm, modulus of elasticity of subgrade = 100kg/cm² (E_s), modulus of elasticity of base = 400kg/cm², modulus of elasticity for 7.5cm thick bituminous concrete surface course = 1000kg/cm²

P = 4100kg

a = 15cm

For ADT = 5000, X = 9/6

For 96cm annual rainfall, Y = 0.9

$$T_p = \left\{\sqrt{\left(\frac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2}\right\}\left(\frac{E_s}{E_p}\right)^{1/3}$$

T_p = 65.91 cm (Taking E_p = 400kg/cm²)

Let 7.5cm bituminous concrete surface be equivalent to the thickness t_b of base course.

Then,

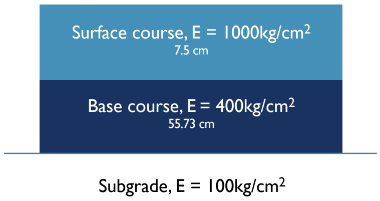
$\frac{t_1}{t_b} = \left(\frac{E_b}{E_1}\right)^{1/3}$ Taking t_1 = 7.5cm, E_1 = 1000kg/cm²

and E_b = 400kg/cm²

t_b = 10.179 cm

Thickness of base course required

= 65.91 – 10.179 = 55.73cm



57

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method**
  - Group Index Method – Based on soil classification
  - CBR Methods: IRC:37-1970, Road Note 29, Road Note 31 – Based on arbitrary soil strength test
  - AASHTO Method – Based on pavement performance

58

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method - Group Index Method – Based on soil classification**
  - Used in AASHTO soil classification system for grading of soil
  - GI is the function of particle size distribution, liquid limit and plasticity index
  - Higher the value of GI, lower the quality of soil to carry traffic and hence pavement of greater thickness is required
  - The thickness of base and surface course is varied according to the volume of commercial traffic expected

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method - Group Index Method – Based on soil classification**

GI = 0.2a + 0.005ac + 0.01bd (GI value ranges from 0 to 20)

where, a: that portion of percentage of subgrade soil passing 75 micron sieve greater than 35 and not exceeding 75, expressed as a positive whole number (0 to 40)

b: that portion of percentage of subgrade soil passing 75 micron sieve greater than 15 and not exceeding 55, expressed as a positive whole number (0 to 40)

c: that portion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number (0 to 20)

d: that portion of the numerical plasticity index greater than 10 and not exceeding 30, expressed as a positive whole number (0 to 20)

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method - Group Index Method – Based on soil classification**

Subgrade rating

Quality	GI value
Excellent	0
Good	0-1
Fair	2-4
Poor	5-9
Very Poor	10-20

Traffic categories

Traffic categories	Commercials vehicles/day
Light volume traffic	Less than 50
Medium volume traffic	50 to 300
Heavy volume traffic	Over 300

61

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method - Group Index Method – Based on soil classification**
  - Limitations
    - The actual strength characteristics of the subgrade soil is not considered.
    - The quality of surface, base and sub-base material is not specified.

62

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method - Group Index Method – Based on soil classification**
  - Design steps
    - Determine GI
    - Determine the anticipated commercial vehicle traffic
    - Determine the thickness of sub-base if needed from the design curve
    - Use the appropriate design curve according to the GI and traffic and determine the total thickness of the pavement (surfacing, base and subbase)

63

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method - Group Index Method – Based on soil classification**

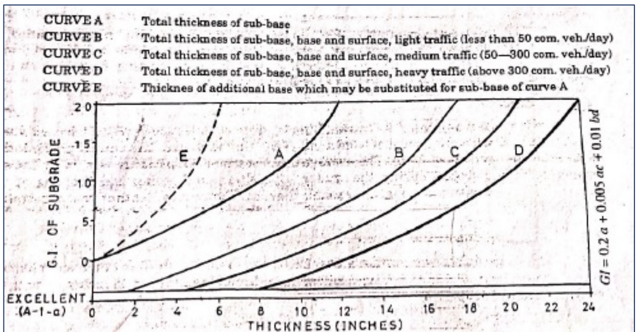


Fig. 16.16. Pavement thickness design based on Group Index.

64

NUMERICAL

Soil subgrade sample collected from the site was analyzed and the result obtained are as given: soil portion passing 75 micron sieve = 60%, liquid limit = 65, plastic limit = 35%. Design the pavement section by GI method for road carrying design traffic of 500 commercial vehicles per day.

F = 60%

LL = 65%

PL = 35%

I_P = LL – PL = 65 – 35 = 30%

a = F – 35 = 60 – 35 = 25

b = F – 15 = 55 – 15 = 40

c = LL – 40 = 60 – 40 = 20

d = I_P – 10 = 30 – 10 = 20

GI = 0.2a + 0.005ac + 0.01bd

GI = 0.2*25 + 0.005*25*20 + 0.01*40*20

GI = 15.5 Take, GI = 16

From chart, Curve D

Total thickness = 23 inch

Thickness of subbase = 11 inch (Curve A)

Thickness of base and surface course

= 23 -11 inch = 12 inch

Taking thickness of surface course = 2 in

Thickness of base = 12 – 2 = 10 inch

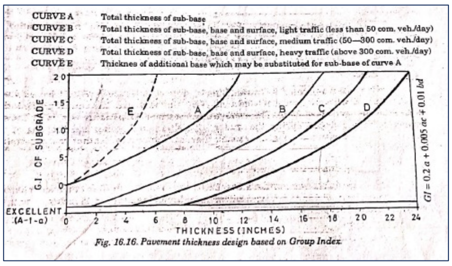
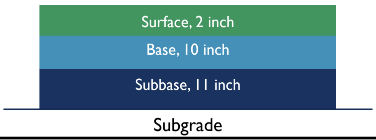


Fig. 16.16. Pavement thickness design based on Group Index



65

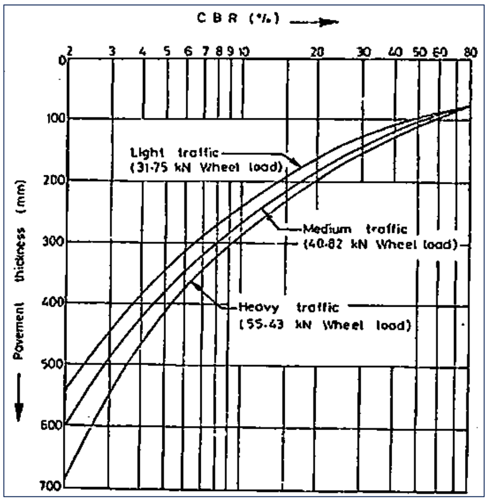
DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – CBR Methods**
  - Based on California Bearing Ratio (CBR) of subgrade soil and subsequent pavement layers
  - Developed by California State Highway Department
  - Modified by various organizations for different conditions and wheel loads

66

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – CBR Methods**
  - Design chart with curves correlating the soaked CBR value and the total pavement thickness has been provided based on extensive CBR test data collected on pavement
  - Three classes of traffic with different loads are considered. **Light – 31.75 KN, Medium – 40.82 KN, Heavy – 54.43 KN**
  - Higher the load, greater thickness of the pavement required



67

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – CBR Methods [IRC 37-1970]**
  - Adopts UK based traffic classification based on the number of heavy vehicles
  - Design chart include correlation between soaked CBR values and pavement thickness for 7 curves for different number of commercial vehicles per day
    - CBR test should be performed in the laboratory following standard test procedure
    - Subgrade soil sample should be compacted at OMC to Proctor density whenever possible or to dry density achievable in the field
    - CBR test samples may be soaked in water for four days period before testing
    - At least three samples should be tested for each type of soil at the same density and moisture content

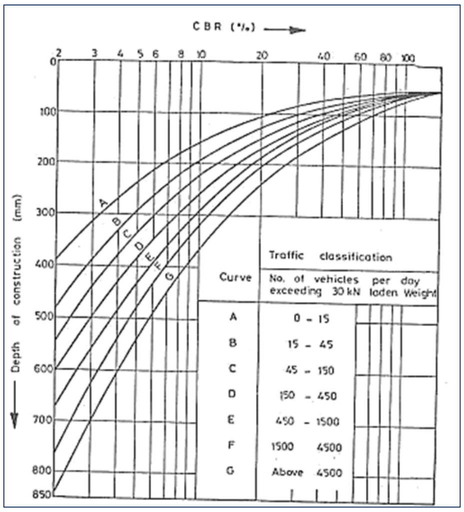
68

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC 37-1970**
- **Design traffic** should be calculated as an estimate of the traffic carried by the pavement at the end of the expected life in both direction

$$A = P\,(1+r)^{n+y}$$

  - P – Present heavy vehicles per day (last count)
  - r – Traffic growth rate (Take 7.5% if data is not available)
  - Design life = y years
  - Construction period = n years
  - A is heavy vehicles per day (laden weight > 3 tones)

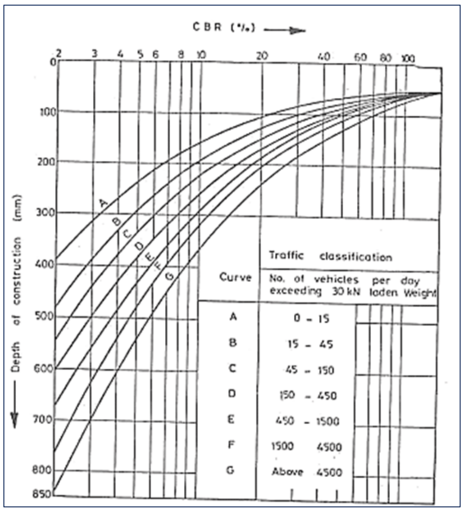


ABHASH ACHARYA | HIGHWAY PAVEMENT 69

69

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC 37-1970**
- **Design Steps**
  - Evaluate the soak CBR value of the subgrade
  - Choose appropriate curve considering design traffic
  - Determine the pavement thickness for the CBR value of the subgrade
  - To determine thickness of sub-base, base and surface course, use the curve repeatedly with suitable CBR values



ABHASH ACHARYA | HIGHWAY PAVEMENT 70

70

NUMERICAL

Design a flexible pavement using CBR method for the data given: CBR of subgrade soil = 5%, CBR of laterite subbase = 15%, CBR of WBM base = 95%, No. of heavy vehicles per day in November 2018 = 150, design life = 15 years, annual traffic growth rate = 5%, road is proposed to be completed in November 2023.

P = 150

r = 5% = 0.05

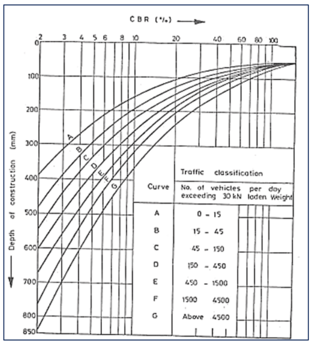
n = 5 years

y = 15 years

$A = P (1+r)^{n+y}$

$A = 150 (1+0.05)^{5+15}$

A = 398 cvpd



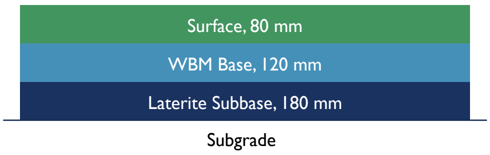
Total thickness above subgrade = 380 mm

Total thickness above subbase = 200 mm

Thickness of subbase = 380 – 200 = 180 mm

Total thickness above base = 80 mm

Thickness of base = 200 – 80 = 120 mm



DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - Indian Road Congress has specified the design procedures for flexible pavements based on CBR values.
  - This guidelines follows analytical designs and developed new set of designs upto 150 msa (million standard axle).
- **Design procedure**
  - Based on the performance of existing designs and using **analytical approach, simple design charts and a catalogue of pavement designs** are added in the code.
  - Pavement designs are given for subgrade CBR values ranging from 2% to 10% and design traffic ranging from 1 msa to 150 msa for an average annual pavement temperature of 35°C.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - **Design Procedure**
    - Using the following simple input parameters, appropriate designs (thickness of pavement, mm) could be chosen for the given traffic and soil strength.
      - Design traffic in terms of cumulative number of standard axles and
      - CBR value of subgrade

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - **Design Procedure**
    - Design traffic
      - Method considers traffic in terms of the cumulative number of standard axles (80KN) to be carried by the pavement during the design life. Information required are:
        - Initial traffic in terms of CVPD
        - Traffic growth rate during the design life
        - Design life in number of years
        - Vehicle Damage Factor (VDF)
        - Distribution of commercial traffic over the carriage way

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - **Design Procedure - Design traffic - Cumulative number of standard axles**
    - Design traffic is considered in terms of the cumulative number of standard axles in the lane carrying maximum traffic during the design life of the road.

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

where, N is the cumulative number of standard axles to be catered for the design in terms of million standard axles (msa),

A is the initial traffic in year of completion of construction in terms of the number of commercial vehicles per day.

D is the land distribution factors

F is the Vehicle damage factor

n is design life in years and r is the annual growth rate of commercial vehicles

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - Design Procedure - Design traffic - Cumulative number of standard axles
    - Initial Traffic is determined in terms of commercial vehicles per day. Vehicles with laden weight of 3 tonnes or more are only considered.
    - The traffic in the year of completion is estimated using the formula

$$A = P\,(1+r)^x$$

where, P is the number of commercial vehicles as per last count

x is the number of years between the last count and the year of completion of construction

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - Design Procedure - Design traffic - Cumulative number of standard axles
    - Traffic growth rate (r) can be estimated by studying the past trends of traffic growths.
    - If adequate data is not available, **7.5 percent may be adopted.**
    - Design life (n) is defined in terms of the cumulative number of standard axles that can be carried before strengthening of the pavement is necessary.
    - For NH, SH – 15 years, express highway and urban roads – 20 years and other categories – 10 to 15 years

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - Design Procedure - Design traffic - Cumulative number of standard axles
    - Vehicle Damage Factor (F) is a multiplier for converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle load repetitions.
    - It is defined as equivalent number of standard axles per commercial vehicle.
    - VDF varies with the axle configuration, axle loading, terrain type, type of road, and from region to region.
    - The axle load equivalency factors are used to convert different axle load repetitions into equivalent standard axle load repetitions.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - Design Procedure - Design traffic - Cumulative number of standard axles
    - Lane Distribution Factor (D)
      - Realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load application used in the design.
      - Until reliable data is available, following distribution may be assumed.
        - **Single lane roads – Design based on total number of commercial vehicles in both direction.**
        - **Two-lane single carriageway roads – Design based on 75% of the commercial vehicles in both directions.**
        - **Four-lane single carriageway roads – Design based on 40% of the total number of commercial vehicles in both directions**

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - Design Procedure - Design traffic - Cumulative number of standard axles
    - Lane Distribution Factor (D)
      - Realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load application used in the design.
      - Until reliable data is available, following distribution may be assumed.
        - Dual carriageway roads
          - Design based on 75% of the number of commercial vehicles in each direction
          - For dual three-lane carriageway and dual four-lane carriageway the distribution factor will be 60% and 45% respectively. 150% is taken for intermediate lane carriageway.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**
  - Design Procedure - Design traffic - Cumulative number of standard axles
    - VDF

Initial traffic volume in terms of cvpd	Terrain	
	Rolling/Plain	Hilly
0-150	1.5	0.5
150-1500	3.5	1.5
More than 1500	4.5	2.5

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**

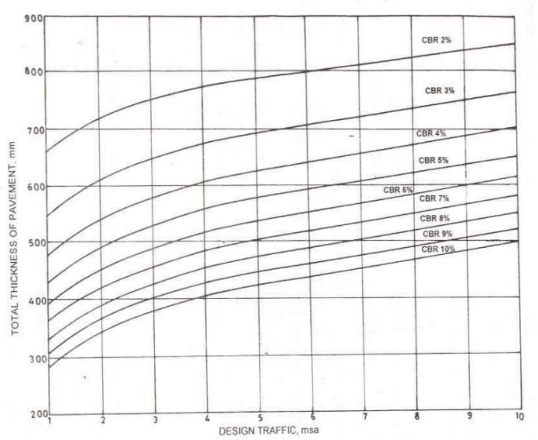


Fig. 1. Pavement Thickness Design Chart for Traffic 1-10 msa

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – IRC Method 37 – 2001**

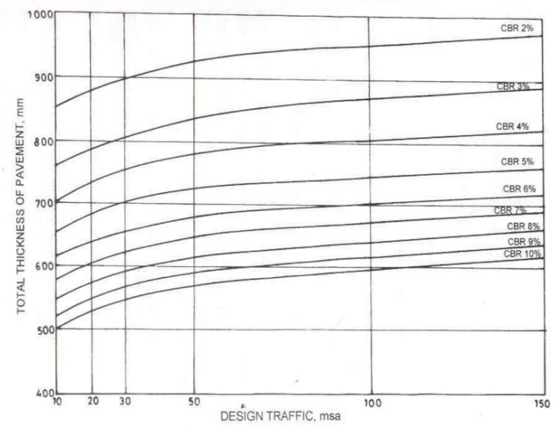


Fig. 2. Pavement Thickness Design Chart for Traffic 10-150 msa

NUMERICAL

Design the pavement for a new road in plain terrain with a two lane single carriageway using the given data: initial traffic in the year of completion of construction in both direction = 500 cvpd, design life = 12 years, design CBR of subgrade soil = 4%

A = 500 cvpd

n = 12 years

CBR = 4%

F = 3.5

r = 7.5%

D = 0.75

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

N = 8.826 msa

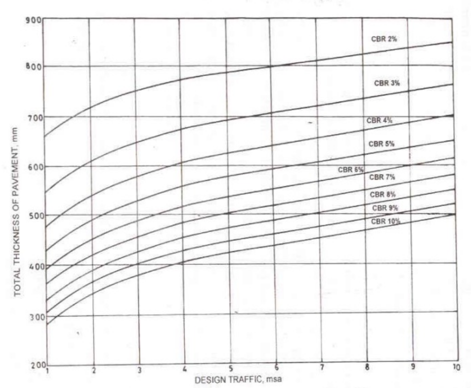


Fig. 1. Pavement Thickness Design Chart for Traffic 1-10 msa

Total thickness of the pavement = 680 mm

NUMERICAL

Design the pavement for a new road in plain terrain with a two lane single carriageway using the given data: initial traffic in the year of completion of construction in both direction = 500 cvpd, design life = 12 years, design CBR of subgrade soil = 4%

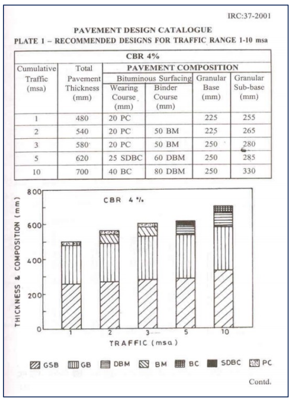
Total thickness of the pavement = 680 mm

Wearing course = 40 mm BC

Binder course = 75 mm

Granular base = 250 mm

Granular subbase = 315 mm



IRC:37-2001

PAVEMENT DESIGN CATALOGUE

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

CBR 4%					
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	480	20 PC		225	255
2	540	20 PC	50 BM	225	265
3	580	20 PC	50 BM	250	280
5	620	25 SDBC	60 DBM	250	285
10	700	40 BC	80 DBM	250	330

NUMERICAL

Design the flexible pavement for construction of new road with the given data: 2 lane single carriageway is to be designed in plain area. Initial traffic in the year of completion of construction = 310 cvpd which is sum of both directions as mentioned below.

Heavy truck three axle – 30 (VDF – 6.5)

Heavy truck two axle – 70 (VDF – 4.75)

Mini truck – 120 (VDF – 1.0)

Large bus – 60 (VDF – 0.5)

Normal bus – 30 (VDF – 0.35)

Traffic growth rate = 7%, Design life = 15 years, CBR = 5%

NUMERICAL

Design the flexible pavement for construction of new road with the given data: 2 lane single carriageway is to be designed in plain area. Initial traffic in the year of completion of construction = 310 cvpd which is sum of both directions as mentioned below.

Heavy truck three axle – 30 (VDF – 6.5)

Heavy truck two axle – 70 (VDF – 4.75)

Mini truck – 120 (VDF – 1.0)

Large bus – 60 (VDF – 0.5)

Normal bus – 30 (VDF – 0.35)

Traffic growth rate = 7%, Design life = 15 years, CBR = 5%

n = 15 years

CBR = 5%

r = 7%

D = 0.75

A*F = 30*6.5 + 70*4.75 + 120*1 + 60*0.5 + 30*0.35 = 688 cvpd

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

N = 4.732 msa

NUMERICAL

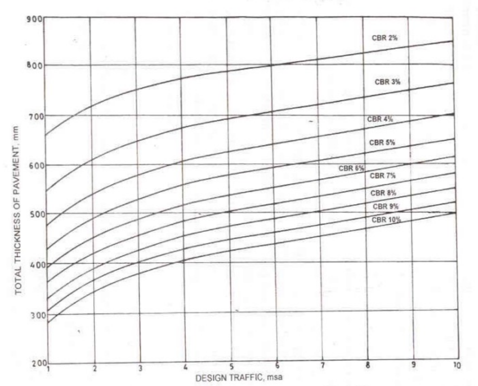


Fig. 1. Pavement Thickness Design Chart for Traffic 1-10 msa

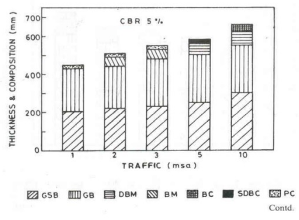
Total thickness of the pavement = 580 mm

IRC:37-2001

PAVEMENT DESIGN CATALOGUE

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



<u>Adopted for 5 msa, However, interpolation would have been better.</u>

Wearing course = 25 mm SDBC

Binder course = 55 mm DBM

Granular base = 250 mm

Granular subbase = 250 mm

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

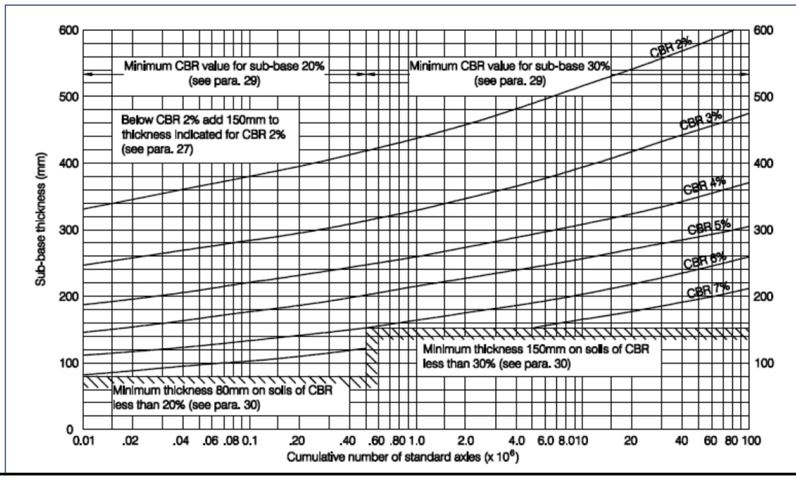
- **Empirical Method – Road Note 29**
  - Based on CBR by Transport and Road Research Laboratory (TRRL) Britain
  - Major features
    - Use of cumulative number of standard axles in the design life of the pavement over the number of commercial vehicles per day
    - Different design thickness charts
      - For sub-base (use CBR values) and
      - For base and surfacing (with specified materials and considering varying cumulative number of standard axles

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – Road Note 29**
  - Design Steps
    - Estimate cumulative number of standard axles
      - Determine the commercial vehicles per day (cvpd) per lane (slow lane) from traffic survey and convert it to 80KN equivalent single axle load (esal) to find the present/base year traffic in number of axles per day
      - Determine the expected number of axles per day on the day it is opened using a suitable growth rate
      - Determine the number of axles load per day for each year during the design life. The number of axles per day multiplied by 365 for each year of life is summed to give cumulative number of axles over the design life.
    - Determine the thickness of sub-base based on the cumulative number of standard axles and the CBR of the subgrade using design chart. If CBR of subgrade is greater than the minimum requirement of the sub-base, no sub-base need to be provided.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – Road Note 29**
  - Design Steps



91

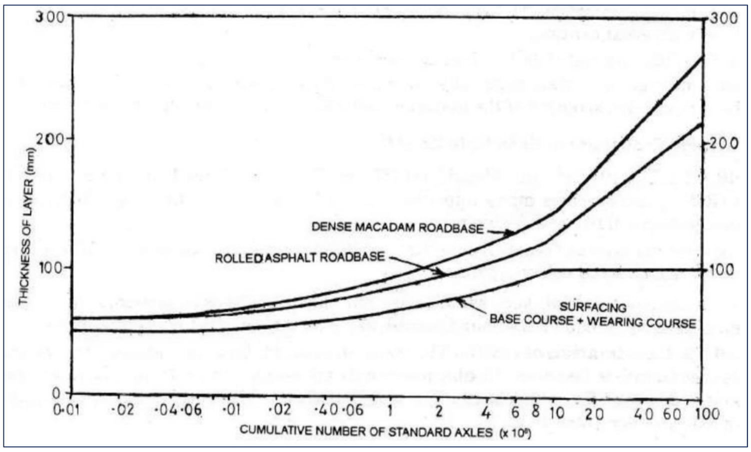
DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 29
  - Design Steps
    - Determine the thickness of base course and surfacing using the design charts for the specific materials based on cumulative number of standard axles to be carried. RN-29 also provides a table with recommendations on surfacing.

92

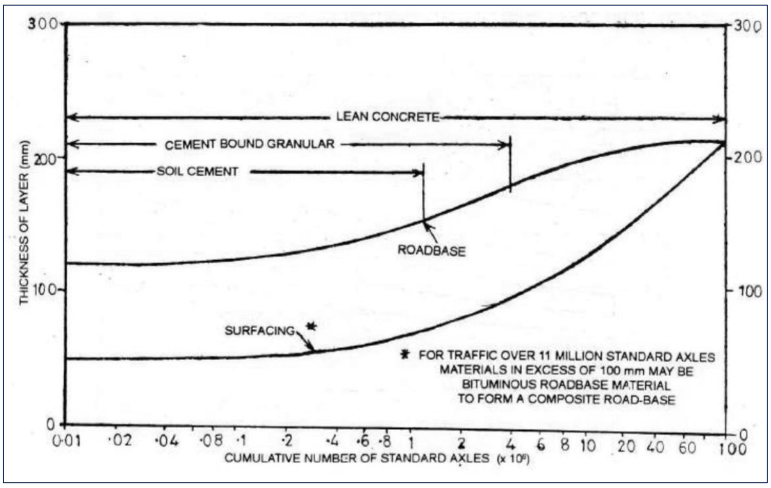
DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 29
  - Design Steps



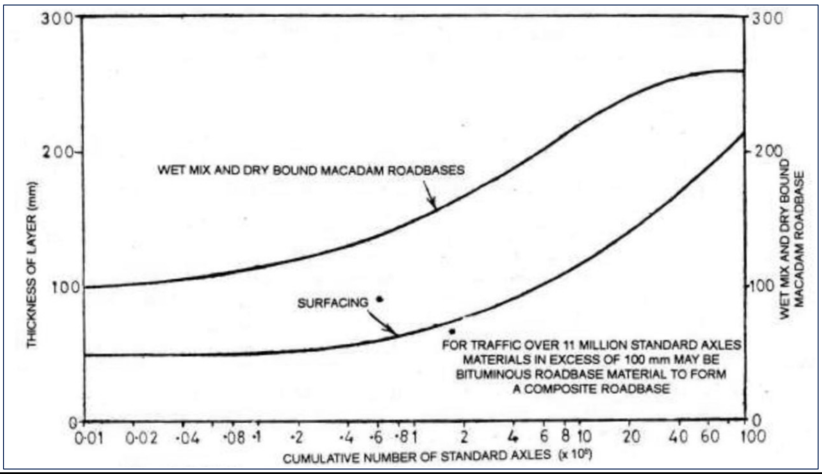
DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 29
  - Design Steps



DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 29
  - Design Steps



95

NUMERICAL

Design a flexible pavement for a two-lane carriageway in rural area to carry 1500 commercial vehicles per day in each direction at the end of construction. The traffic growth rate may be assumed as 5%. The design life is 20 years and CBR value of subgrade is 3%.

A = 1500 cvpd

r = 5%

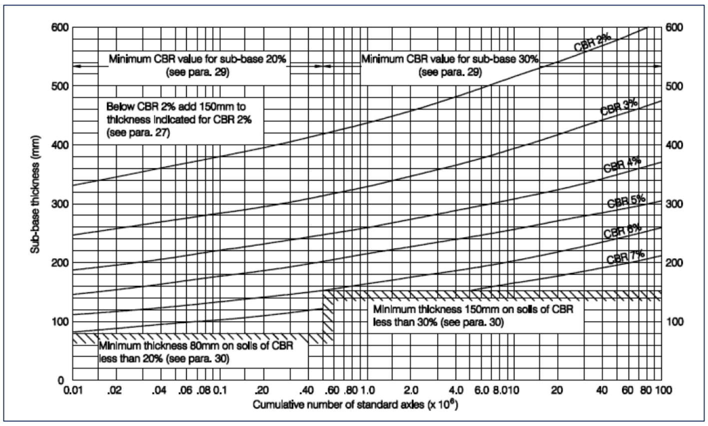
n = 20 years

CBR = 3%

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

N = 18103609.87 esa

N = 18.10 msa



Thickness of subbase = 410 mm

96

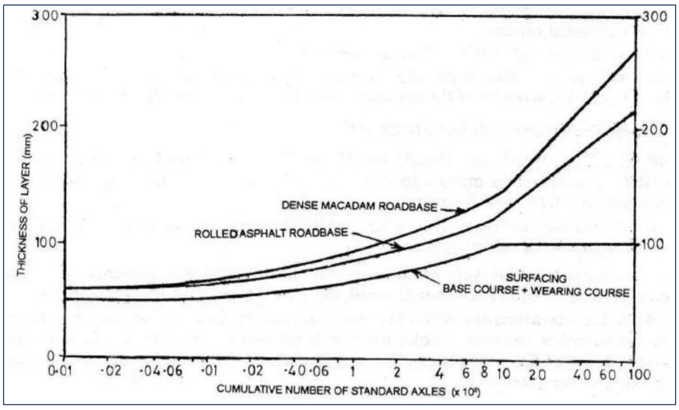
NUMERICAL

Design a flexible pavement for a two lane carriageway in rural area to carry 1500 commercial vehicles per day in each direction at the end of construction.The traffic growth rate may be assumed as 5%.The design life is 20 years and CBR value of subgrade is 3%.

Dense macadam roadbase = 160mm

Rolled asphalt roadbase = 145mm

Surfacing = 100mm



ABHASH ACHARYA | HIGHWAY PAVEMENT 97

97

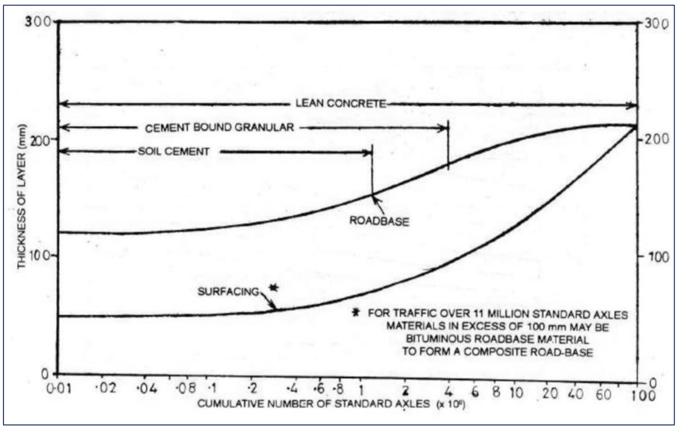
NUMERICAL

Design a flexible pavement for a two lane carriageway in rural area to carry 1500 commercial vehicles per day in each direction at the end of construction.The traffic growth rate may be assumed as 5%.The design life is 20 years and CBR value of subgrade is 3%.

Lean concrete

Roadbase = 210 mm

Surfacing = 140 mm



ABHASH ACHARYA | HIGHWAY PAVEMENT 98

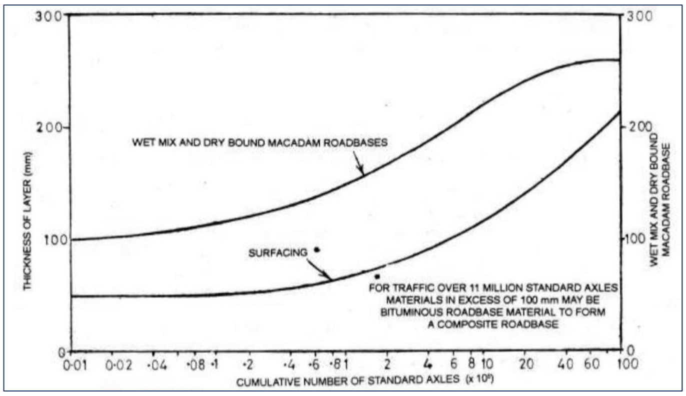
98

NUMERICAL

Design a flexible pavement for a two lane carriageway in rural area to carry 1500 commercial vehicles per day in each direction at the end of construction. The traffic growth rate may be assumed as 5%. The design life is 20 years and CBR value of subgrade is 3%.

Wet mix and dry bound macadam roadbase = 235 mm

Surfacing = 135 mm



NUMERICAL

Design a two lane flexible pavement for a road expected to carry 1100 commercial vehicles per day at the time of construction with an expected growth rate of 3%. Assume each commercial vehicle to contribute 0.72 standard 80KN axles. The design life is 20 years and the subgrade CBR is 5. Design the flexible pavement as per road note 29.

A = 1100 cvpd

r = 3%

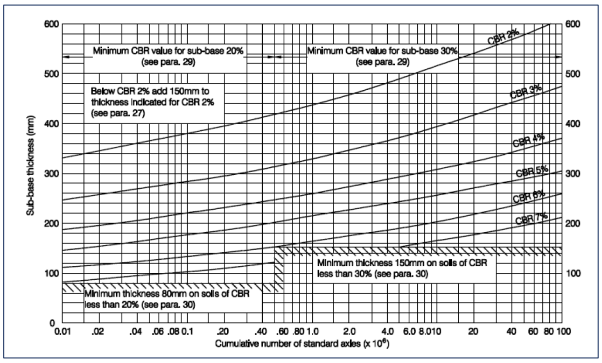
n = 20 years, F = 0.72, D = 0.50

(Better to use 0.75)

CBR = 5%

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

N = 3.89 msa



Thickness of subbase = 215 mm

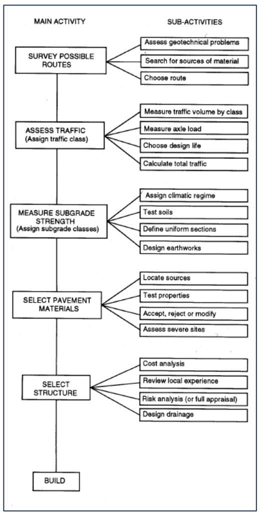
DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- **Empirical Method – Road Note 31**
  - Gives recommendations for the structural design of bituminous surfaced roads in tropical and subtropical climates.
  - Aimed at highway engineers responsible for the design and construction of new road pavements and is appropriate for roads which are required to carry upto 30 million cumulative equivalent standard axles in one direction.

101

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 31
  - Design process
    - Estimating the amount of traffic and the cumulative number of equivalent standard axles that will use the road over the selected design life.
    - Assessing the strength of the subgrade soil over which the road is to be built.
    - Selecting the most economical combination of pavement materials and layer thickness that will provide satisfactory service over the design life of the pavement using structural catalogues.



102

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 31
  - Traffic
    - Deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied.
    - For pavement design purpose, it is necessary to consider not only the total number of vehicles that will use the road but also the wheel loads of these vehicles.
    - The loads imposed by private cars do not contribute significantly to the structural damage.
    - For the purpose of structural design, cars and similar sized vehicles can be ignored and only the total number and the axle loading of the heavy vehicles that will use the road during its design life need to be considered. In this context, heavy vehicles are defined as those vehicles having a laden weight of 3000kg or more.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 31
  - Design life
    - For most road projects – 10 to 20 years
    - Design life does not mean that at the end of the period, the pavement will be completely worn out and in need of reconstruction.
    - It means that towards the end of the period, the pavement will need to be restrengthened so that it can continue to carry traffic satisfactorily for a further period of time.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 31
  - Estimating traffic flows
    - In order to determine the total traffic over the design life of the road, the first step is to estimate baseline traffic flows.
    - The estimate should be the (Annual) Average Daily Traffic (AADT) currently using the route.
    - The AADT is defined as the total annual traffic summed for both directions and divided by 365.
    - For long projects, large differences in traffic along the road may make it necessary to estimate the flow at several locations. It should be noted that for structural design purposes, the traffic loading in one direction is required and for this reason care is always required when interpreting ADT figures.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 31
  - Determination of cumulative equivalent standard axles

Equivalence factors for different axle loads

Wheel load (single & dual) (10^3 kg)	Axle load (10^3 kg)	Equivalence factor
1.5	3.0	0.01
2.0	4.0	0.04
2.5	5.0	0.11
3.0	6.0	0.25
3.5	7.0	0.50
4.0	8.0	0.91
4.5	9.0	1.55
5.0	10.0	2.50
5.5	11.0	3.83
6.0	12.0	5.67
6.5	13.0	8.13
7.0	14.0	11.3
7.5	15.0	15.5
8.0	16.0	20.7
8.5	17.0	27.2
9.0	18.0	35.2
9.5	19.0	44.9
10.0	20.0	56.5

$$\text{Equivalence factor} = \left(\frac{\text{Axle load (kg)}}{8160}\right)^{4.5}$$

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 31
  - Determination of traffic classes and subgrade strength class

Traffic classes

Traffic classes	Range (10^6 esa)
T1	< 0.3
T2	0.3 - 0.7
T3	0.7 - 1.5
T4	1.5 - 3.0
T5	3.0 - 6.0
T6	6.0 - 10
T7	10 - 17
T8	17 - 30

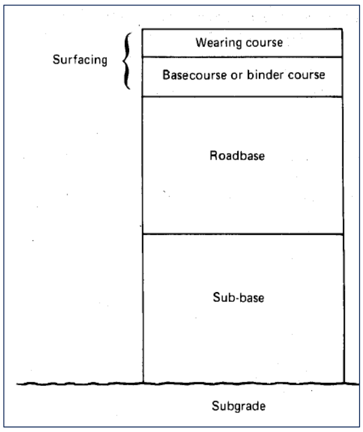
Subgrade strength classes

Class	Range (CBR %)
S1	2
S2	3 - 4
S3	5 - 7
S4	8 - 14
S5	15 - 29
S6	30

107

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

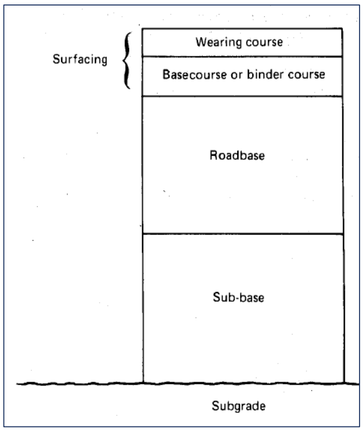
- Empirical Method – Road Note 31
  - Pavement layers
    - Surfacing – Uppermost layer of the pavement and will normally consist of a bituminous surface dressing or a layer of premixed bituminous materials. Where premixed materials are laid in two layers, these are known as the wearing course and the base course.
    - Roadbase – Main load-spreading layer of the pavement. Consist of crushed stone or gravel or gravelly soils, decomposed rock, sands and sand-clays stabilized with cement, lime and bitumen.
    - Sub-base – Secondary load-spreading layer underlying the roadbase. Consist of a material of lower quality than used in the roadbase as unprocessed natural gravel, gravel-sand, or gravel-sand-clay. Important role in protecting the subgrade.



108

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

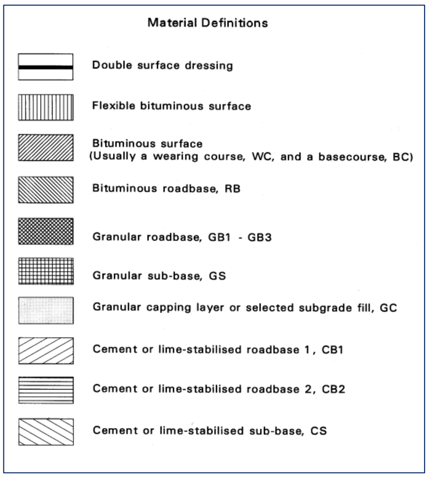
- Empirical Method – Road Note 31
  - Pavement layers
    - Capping layer (selected or improved subgrade) – Where very weak soils are encountered, a capping layer is sometimes necessary. This may consist of better quality subgrade material imported from elsewhere or existing subgrade material improved by mechanical or chemical stabilization.
    - Subgrade – This is the upper layer of the natural soil which may be undisturbed local material or may be soil excavated elsewhere and placed as fill. In either case, it is compacted during construction to give added strength.

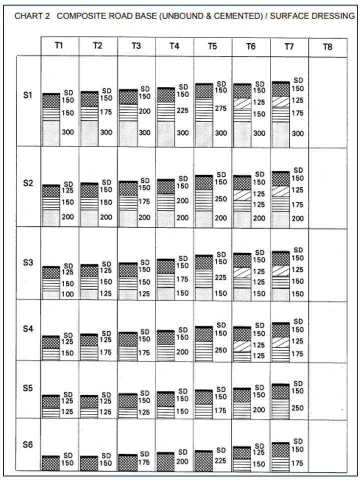


109

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method – Road Note 31
  - Pavement layers





110

NUMERICAL

A single lane carriageway carries total traffic of 800 commercial vehicles per day at the end of construction. The traffic growth rate is 8% per annum, design life is 15 years. The vehicle damage factor is 1.5. The subgrade soil sample was obtained from the site and CBR test was conducted giving the following data. Design the pavement section by Road Note 31 method.

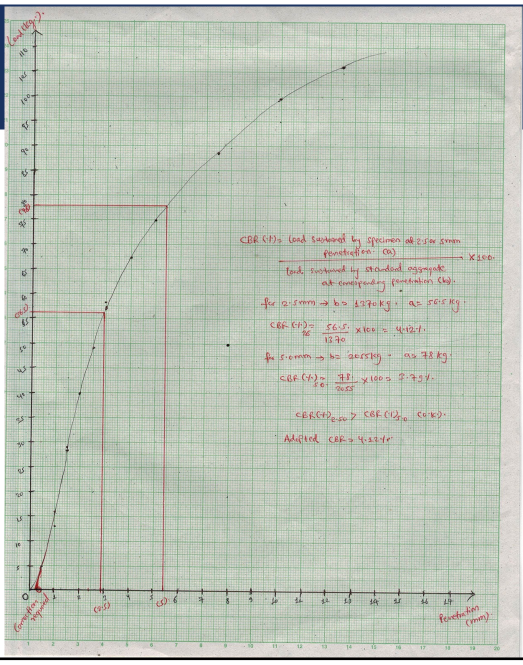
Penetration	Load (kg)
0	0
0.5	5
1.0	16.2
1.5	28.1
2.0	40
2.5	48.5
3.0	56.5

Penetration	Load (kg)
4.0	67.5
5	75.2
7.5	89
10	99.5
12.5	106.5

111

NUMERICAL

Penetration	Load (kg)
0	0
0.5	5
1.0	16.2
1.5	28.1
2.0	40
2.5	48.5
3.0	56.5
4.0	67.5
5	75.2
7.5	89
10	99.5
12.5	106.5



Penetration of Plunger (mm)	Standard Load (kg)
2.5	1370
5.0	2055

If the initial portion of the curve is concave upwards, apply correction by drawing a tangent to the curve at the point of greatest slope and shift the origin. Find and record the correct load reading corresponding to each penetration.

112

NUMERICAL

A single lane carriageway carries total traffic of 800 commercial vehicles per day at the end of construction. The traffic growth rate is 8% per annum, design life is 15 years. The vehicle damage factor is 1.5. The subgrade soil sample was obtained from the site and CBR test was conducted giving the following data. Design the pavement section by Road Note 31 method.

If the initial portion of the curve is concave upwards, apply correction by drawing a tangent to the curve at the point of greatest slope and shift the origin. Find and record the correct load reading corresponding to each penetration.

The C.B.R. values are usually calculated for penetration of 2.5 mm and 5 mm. Generally the C.B.R. value at 2.5 mm will be greater than at 5 mm and in such a case/the former shall be taken as C.B.R. for design purpose. If C.B.R. for 5 mm exceeds that for 2.5 mm, the test should be repeated.

NUMERICAL

A single lane carriageway carries total traffic of 800 commercial vehicles per day at the end of construction. The traffic growth rate is 8% per annum, design life is 15 years. The vehicle damage factor is 1.5. The subgrade soil sample was obtained from the site and CBR test was conducted giving the following data. Design the pavement section by Road Note 31 method.

A = 800cvpd

r = 8% = 0.08

n = 15 years, F = 1.5

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

$$N = 365 * \frac{[(1+0.08)^{15} - 1]}{0.08} * 800 * 1 * 1.50$$

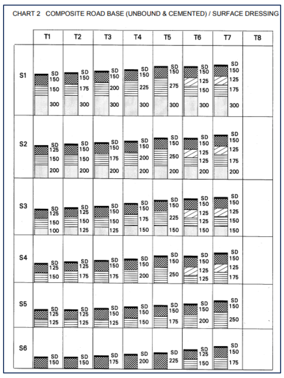
N = 11.89 msa

Traffic classes

Traffic classes	Range (10^6 esa)
T1	< 0.3
T2	0.3 - 0.7
T3	0.7 - 1.5
T4	1.5 - 3.0
T5	3.0 - 6.0
T6	6.0 - 10
T7	10 - 17
T8	17 - 30

Subgrade strength classes

Class	Range (CBR %)
S1	2
S2	3 - 4
S3	5 - 7
S4	8 - 14
S5	15 - 29
S6	30



T7, S2

Granular road base = 150mm

Cement or lime-stabilized roadbase 1 = 125mm

Cement or lime stabilized roadbase 2 = 175mm

Granular capping layer or selected subgrade fill = 200mm

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- DOR Method (2014)
  - Similar to IRC: 37-2001

Vehicle type	VDF	Remarks
Heavy truck (three axle or more)	6.50	
Heavy two axle	4.75	hilly terrain 3.5
Mini truck/tractor	1.0	
Large bus	0.50	
Bus	0.35	

NUMERICAL

Design the flexible pavement for construction of a new road with the following data:

- Two lane single carriageway is to be designed in plain area
- Initial traffic in the year of completion of construction = 3150 CVPD (sum of both directions) as mentioned below:
  - Heavy truck three axle: 30
  - Heavy truck two axle: 70
  - Mini truck: 120
  - Large bus: 60
  - Bus: 30
- Traffic growth rate = 7%, Design life = 15 years, CBR = 5%

r = 7%

D = 0.75

A * F = (30*6.50) + (70*4.75) + (120*1.0) + (60*0.50) + (30*0.35)

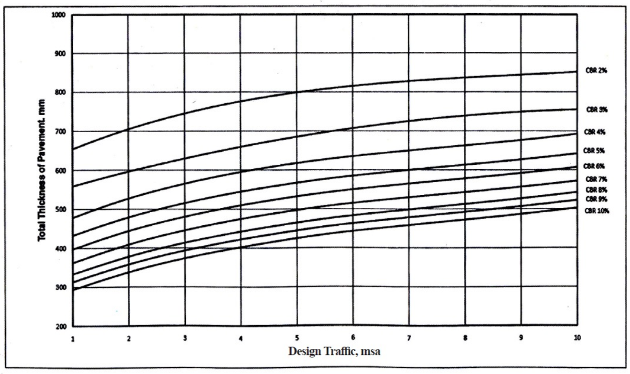
A * F = 689

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

N = 4.73 msa

NUMERICAL

Annex-II: Pavement Design Chart



Total pavement thickness from chart = 575 mm

117

NUMERICAL

Total pavement thickness from chart = 575 mm

Pavement composition can be taken as:

Bituminous wearing course = 50 mm AC

Bituminous binder course = 50 mm DBM

Base course = 150 mm WBM

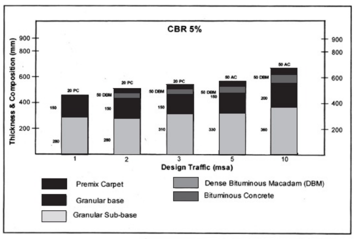
Subbase course = 325 mm Granular subbase

Wearing course, 50 mm
Binder course, 50 mm
Granular base, 150 mm
Granular subbase, 325 mm

Subgrade (5% CBR)

Pavement Design Catalogue
Plate I - Recommended Design 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		150	280
2	480	20 PC	50 DBM	150	280
3	510	20 PC	50 DBM	150	310
5	580	50 AC	50 DBM	150	330
10	660	50 AC	50 DBM	200	360



118

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method
  - Empirical method based on field performance data measured at AASHO road test.
  - Based on specific total traffic volume and a minimum level of serviceability desired at the end of the performance period.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method
  - Serviceability
    - Measure reflecting the ability of a pavement to serve the traffic. Expressed in terms of Present Serviceability Index (PSI).

$$PSI = 5.03 - 1.91\log(1 + \overline{SV}) - 1.38\,\overline{RD}^2 - 0.01\sqrt{C + P}$$

- where, $\overline{SV}$ = Slope variance (measure of roughness)

  $\overline{RD}$ = Average rut depth (inches)

  C + P = Area of cracking and patching per 1000 sq,ft.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method
  - Serviceability

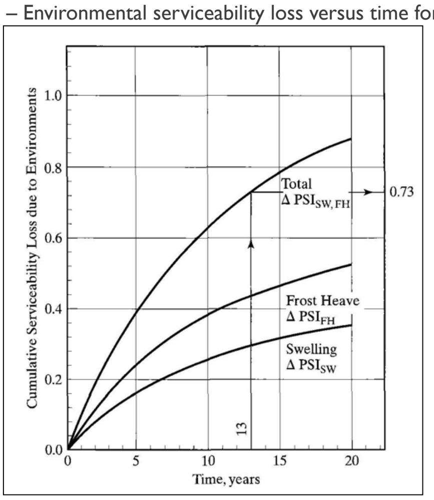
PSI	Objective Rating
4-5	Very good
3-4	Good
2-3	Fair
1-2	Poor
0-1	Very Poor

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method
  - Serviceability
    - Initial and terminal serviceability indexes must be established to compute the change in serviceability ΔPSI, to be used in the design equations.
    - The initial serviceability index is a function of pavement type and construction quality. Typical values from the AASHO Road Test were 4.2 for flexible pavements and 4.5 for rigid pavements.
    - The terminal serviceability index is the lowest index that will be tolerated before rehabilitation, resurfacing, and reconstruction become necessary. An index of 2.5 or higher is suggested for design of major highways and 2.0 for highways with lower traffic. For relatively minor highways where economics dictate a minimum initial capital outlay, it is suggested that this be accomplished by reducing the design period or total traffic volume, rather than by designing a terminal serviceability index less than 2.0.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Environmental serviceability loss versus time for a specific location



123

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - Design (performance) equations - Modified equation

$$\log W_{t18} = 9.36 \log(SN + 1) - 0.20 + \frac{\log[(4.2 - p_t)/(4.2 - 1.5)]}{0.4 + 1094/(SN + 1)^{5.19}} + 2.32 \log M_R - 8.07$$

  - W_t: axle load application at end of time, t
  - P_t: serviceability at end of time, t
  - SN: structural number
  - M_r: the effective roadbed soil resilient modulus

124

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - Design (performance) equations - Modified equation

$$SN = a_1D_1 + a_2D_2 + a_3D_3$$

in which a_1, a_2, and a_3 *are layer coefficients for the surface, base, and sub* - base, respectively, and D_1, D_2, *and* D_3 *are the thicknesses of the surface,* base, and sub-base, respectively.

Considering the local precipitation and drainages conditions:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

m_2 is the drainage coefficient of base course and m_3 is the drainage coefficient of sub-base course.

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - Design (performance) equations - Modified equation

The performance equation that gives the allowable number of 18-kip (80-kN) single-axle load applications W_{t18} to cause the reduction of PSI to p_t.

If the predicted number of applications W_{18} is equal to W_{t18}, the reliability of the design is only 50%, because all variables in the equation are based on mean values

To achieve a higher level of reliability, W_{18} must be smaller than W_{t18} by a normal deviate *ZR* , *as* shown in

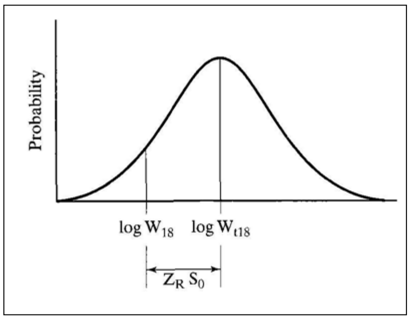
$$Z_R = \frac{\log W_{18} - \log W_{t18}}{S_0}$$

Z_R *is the normal deviate for a given reliability R, and So is the standard deviation.*

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

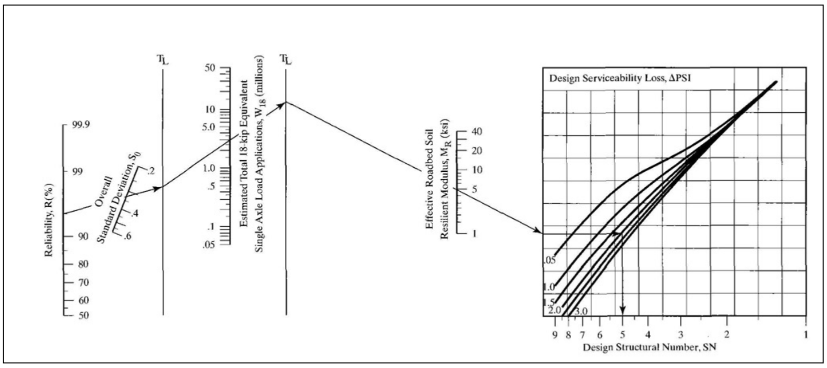
- Empirical Method - AASHTO Method - Design (performance) equations - Modified equation

$$\log W_{18} = Z_R S_0 + 9.36 \log(\text{SN} + 1) - 0.20 + \frac{\log[\Delta \text{PSI}/(4.2 - 1.5)]}{0.4 + 1094/(\text{SN} + 1)^{5.19}} + 2.32 \log M_R - 8.07$$



DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - Design (performance) equations - Modified equation



DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - Design (performance) equations – Structural Number
  - Structural number is a function of layer thickness, layer coefficients, and drainage coefficients and can be computer from the equation

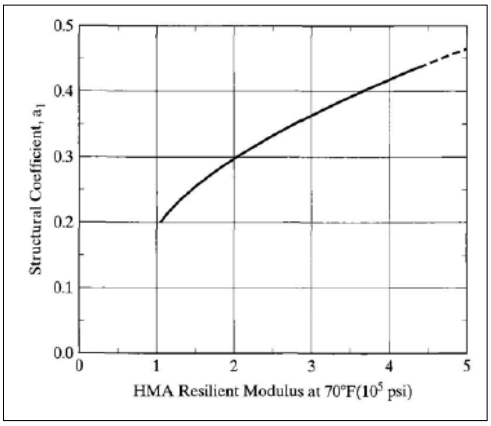
$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

  - Layer coefficients (a_i) is a measure of the relative ability of a unit thickness of a given material to function as a structural component of the pavement.
  - Layer coefficients can be determined based on the resilient modulus (material property)
  - Drainage coefficient: Depending on the quality of drainage and the availability of moisture, drainage coefficients m_2 and m_3 should be applied to granular bases and sub-bases to modify the layer coefficients.

129

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - Design (performance) equations – Chart for estimating layer coefficient of dense-graded asphalt concrete based on elastic modulus



130

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Design traffic (W_{18})
    - Analysis period/Design life

Highway condition	Analysis period (years)
High-volume urban	30-50
High-volume rural	20-50
Low-volume paved	15-25
Low-volume aggregate surface	10-20

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Design traffic (W_{18})
    - Determine the cumulative ESAL for the design life in the design lane considering the growth factor (r), equivalent factor (truck factor), directional distribution factor (50% for most roadways) and lane distribution factor.
    - The guideline provides truck factor tables for flexible pavement for varying SN of pavement, terminal serviceability index and axle configuration.

No. of lanes in each direction	% of 18-kip ESAL in the design lane
1	100
2	80-100
3	60-80
4	50-70

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of reliability factors (S_0, Z_R)
    - Reliability (R) is the probability that the pavement section designed will perform satisfactorily over the traffic and environmental conditions for the design period.
    - Reliability: Reliability is a means of incorporating some degree of certainty into the design process to ensure that the various design alternatives will last the analysis period.
    - The level of reliability to be used for design should increase as the volume of traffic, difficulty of diverting traffic, and public expectation of availability increase.

133

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of reliability factors (S_0, Z_R)

TABLE 11.14 Suggested Levels of Reliability for Various Functional Classifications

Functional classification	Recommended level of reliability: Urban	Rural
Interstate and other freeways	85–99.9	80–99.9
Principal arterials	80–99	75–95
Collectors	80–95	75–95
Local	50–80	50–80

134

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of reliability factors (S_0, Z_R)
    - Application of the reliability concept requires the selection of a standard deviation that is representative of local conditions. It is suggested that standard deviations of 0.49 be used for flexible pavements and 0.39 for rigid pavements. These correspond to variances of 0.2401 and 0.1521.
    - When stage construction is considered, the reliability of each stage must be computed to achieve the overall reliability, i.e.

$$R_{stage} = (R_{overall})^{1/n}$$

    - n is the number of stages being considered. For example, if two stages are contemplated and the desired level of overall reliability is 95%, the reliability of each stage must be $(0.95)^{1/2}$ or 97.5%

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of reliability factors (S_0, Z_R)

Reliability (%)	Standard normal deviate (Z_R)	Reliability (%)	Standard normal deviate (Z_R)
50	0.000	93	−1.476
60	−0.253	94	−1.555
70	−0.524	95	−1.645
75	−0.674	96	−1.751
80	−0.841	97	−1.881
85	−1.037	98	−2.054
90	−1.282	99	−2.327
91	−1.340	99.9	−3.090
92	−1.405	99.99	−3.750

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of allowable serviceability loss due to traffic (ΔPSI)

$$\Delta PSI = p_0 - p_t$$

Where, p_0 is the initial serviceability index (4.2 for flexible pavement design)

p_t is the terminal serviceability index (taken as 2.5)

137

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

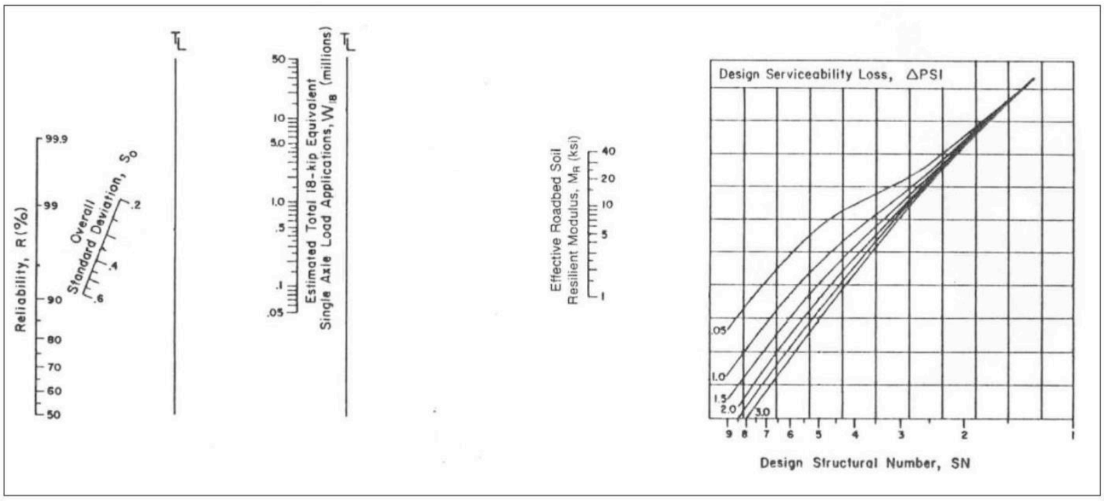
- Empirical Method - AASHTO Method – Design Steps
  - Evaluation of resilient modulus (M_R)
    - M_R use for material characterization

$$M_R \text{ (psi)} = 1500 * \text{CBR (\%)}$$

  - Determination of overall structural number (SN)
    - Equation or nomograph can be used.

138

DESIGN METHODS FOR FLEXIBLE PAVEMENTS



139

139

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of structural layer coefficients (a_1, a_2, a_3)
    - Depends on material properties (Resilient modulus and CBR values)
    - For asphalt concrete surface courses

Resilient modulus (psi)	a_1
450000	0.44
400000	0.42
300000	0.36
200000	0.30
100000	0.20

140

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of structural layer coefficients (a_1, a_2, a_3)
    - For granular base and subbase courses

$$a_2 = 0.249(\log_{10}E_{BS}) - 0.977$$

$$a_3 = 0.227(\log_{10}E_{SB}) - 0.839$$

where, E_{BS} is the resilient modulus of base material

E_{SB} is the resilient modulus of subbase material

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of structural layer coefficients (a_1, a_2, a_3)
    - For granular base and subbase courses

CBR	a_2
100	0.14
55	0.12
45	0.11
30	0.09
20	0.07

CBR	a_3
100	0.14
40	0.12
30	0.11
25	0.10
15	0.09
10	0.08

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method – Design Steps
  - Determination of drainage coefficients (m_2, m_3)
    - For considering local drainage characteristics

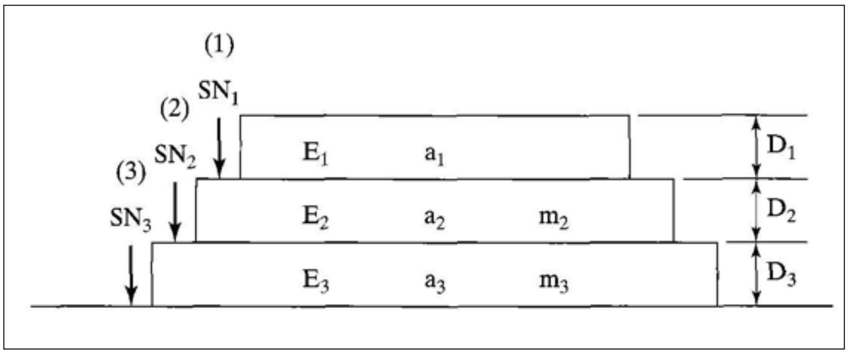
Quality of drainage		Percentage of time pavement structure is exposed to moisture levels approaching saturation			
Rating	Water removed within	Less than 1%	1–5%	5–25%	Greater than 25%
Excellent	2 hours	1.40–1.35	1.35–1.30	1.30–1.20	1.20
Good	1 day	1.35–1.25	1.25–1.15	1.15–1.00	1.00
Fair	1 week	1.25–1.15	1.15–1.05	1.00–0.80	0.80
Poor	1 month	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very poor	Never drain	1.05–0.95	0.95–0.75	0.75–0.40	0.40

Source. After AASHTO (1986).

143

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - General Procedure



144

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - General Procedure
  - Using E_2 as M_R, determine from design chart the structural number SN_1 required to protect the base, and compute the thickness of layer 1 from equation $D_1 \geq \frac{SN_1}{a_1}$
  - Using E_3 as M_R, determine from design chart the structural number SN_2 required to protect the sub-base, and compute the thickness of layer 2 from equation $D_2 \geq \frac{SN_2 - a_1 D_1}{a_2 m_2}$
  - Based on the roadbed soil resilient modulus M_R, determine from design chart the total structural number S_3 required and compute the thickness of layer 3 from equation $D_3 \geq \frac{SN_3 - a_1 D_1 - a_2 D_2 m_2}{a_3 m_3}$

145

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Empirical Method - AASHTO Method - Selection of layer thickness

TABLE 11.21 Minimum Thickness for Asphalt Surface and Aggregate Base

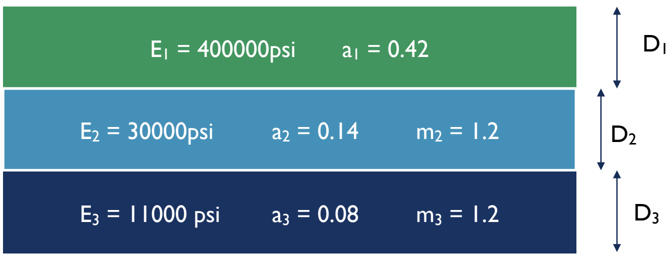
Traffic (ESAL)	Asphalt concrete	Aggregate base
Less than 50,000	1.0	4
50,001–150,000	2.0	4
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

Note. Minimum thickness is in in.; 1 in. = 25.4 mm.
Source. After AASHTO (1986).

146

NUMERICAL

ESAL = 18.6*10⁶, R = 95%, S_0 = 0.35 and ΔPSI = 2.10. Design the pavement using AASHTO method.



M_R = 5700 psi

NUMERICAL

ESAL = 18.6*10⁶, R = 95%, S_0 = 0.35 and ΔPSI = 2.10. Design the pavement using AASHTO method.

$$\log W_{18} = Z_R S_0 + 9.36 \log(\text{SN} + 1) - 0.20 + \frac{\log[\Delta \text{PSI}/(4.2 - 1.5)]}{0.4 + 1094/(\text{SN} + 1)^{5.19}} + 2.32 \log M_R - 8.07$$

Take W_{18} = $18.6*10^6$

Z_R = -1.645 for 95% reliability

S_0 = 0.35

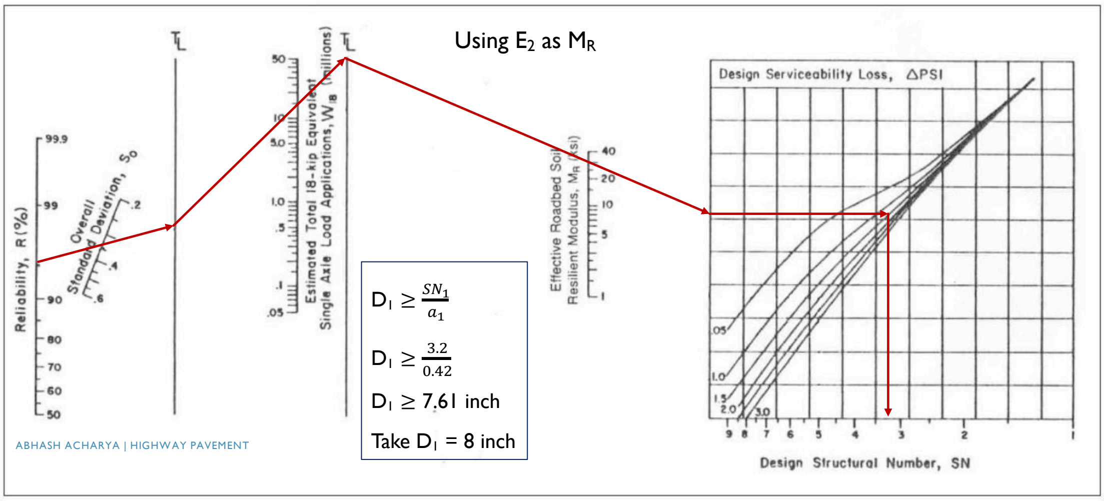
ΔPSI = 2.10

M_R = E_2 = 30000 psi

We get, SN = 3.199

NUMERICAL

Using E_2 as M_R



$D_1 \geq \frac{SN_1}{a_1}$

$D_1 \geq \frac{3.2}{0.42}$

$D_1 \geq 7.61$ inch

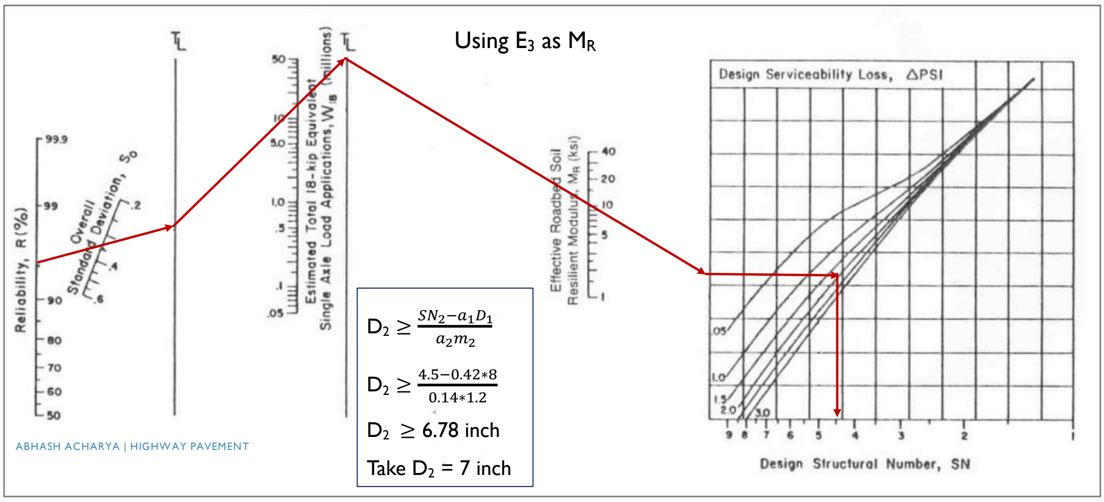
Take D_1 = 8 inch

ABHASH ACHARYA | HIGHWAY PAVEMENT 149

149

NUMERICAL

Using E_3 as M_R



$D_2 \geq \frac{SN_2 - a_1 D_1}{a_2 m_2}$

$D_2 \geq \frac{4.5 - 0.42*8}{0.14*1.2}$

$D_2 \geq 6.78$ inch

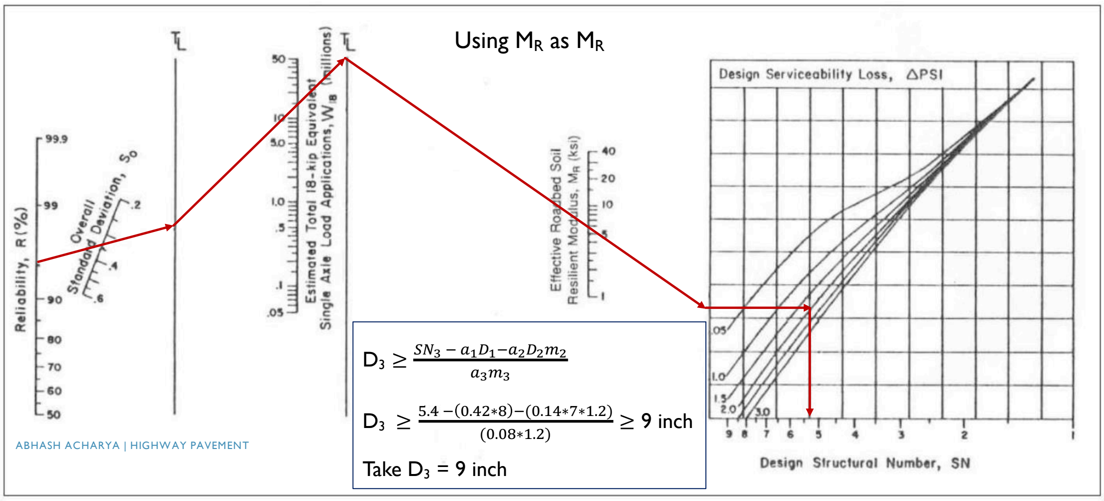
Take D_2 = 7 inch

ABHASH ACHARYA | HIGHWAY PAVEMENT 150

150

NUMERICAL

Using M_R as M_R



$$D_3 \geq \frac{SN_3 - a_1D_1 - a_2D_2m_2}{a_3m_3}$$

$$D_3 \geq \frac{5.4 - (0.42*8) - (0.14*7*1.2)}{(0.08*1.2)} \geq 9 \text{ inch}$$

Take D_3 = 9 inch

NUMERICAL

ESAL = 18.6*10^6, R = 95%, S_0 = 0.35 and ΔPSI = 2.10. Design the pavement using AASHTO method.

E_1 = 400000psi	a_1 = 0.42		8 inch
E_2 = 30000psi	a_2 = 0.14	m_2 = 1.2	7 inch
E_3 = 11000 psi	a_3 = 0.08	m_3 = 1.2	9 inch

M_R = 5700 psi

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

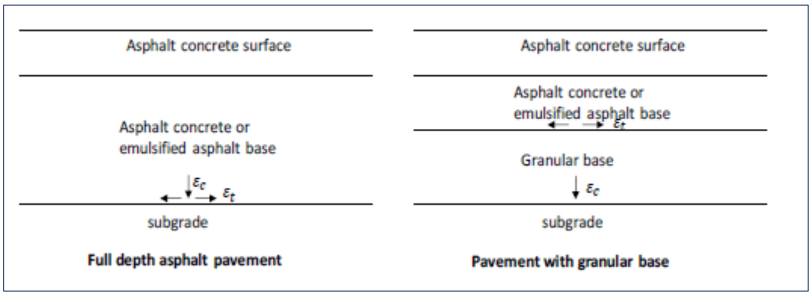
- Mechanistic-Empirical Method
  - Considers mechanics of materials together with observed performance
  - Pavement configuration, structural model (stress/strain), distress model/failure criteria

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic-Empirical Method – Asphalt Institute Method
  - Full depth asphalt concrete thickness
  - Emulsified asphalt base course
  - Granular subbase course
    - Instead of VDF, truck factor is used
    - Instead of CBR, Resilient Modulus (M_R) – M_R = 10.3 CBR (Mpa)

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

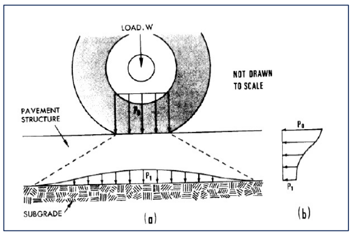
- Mechanistic-Empirical Method – Asphalt Institute Method
  - Design Principle
    - Pavement is regarded as a multi-layered elastic system.

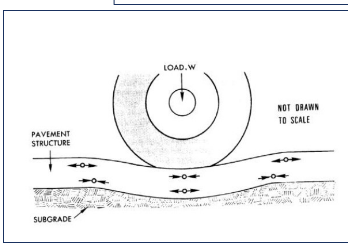


155

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic-Empirical Method – Asphalt Institute Method
  - Design Principle
    - Traffic is expressed in terms of repetitions of 80 KN ESAL on the design lane anticipated over the design life.
    - Wheel load causes tensile and compressive strains.
    - Critical strains: Horizontal tensile strain ϵ_t at the bottom of asphalt layer that results fatigue failure and vertical compressive strain ϵ_c at the surface of the subgrade that results rutting or permanent deformation.





156

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic-Empirical Method – Asphalt Institute Method
  - Failure Criteria
    - Fatigue cracking

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

where,

N_f is the allowable number of repetitions of standard axle load to control fatigue cracking

ϵ_t is the horizontal tensile strain at the bottom of asphalt layer

E is the dynamic modulus of asphalt concrete

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic-Empirical Method – Asphalt Institute Method
  - Failure Criteria
    - Rutting failure

$$N_f = 0.0796(\varepsilon_t)^{-3.291}(E)^{-0.854}$$

where,

N_d is the allowable number of repetitions of axle load to limit rutting to 12.7 mm

ϵ_c is the vertical compressive strain on the surface of the subgrade

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic-Empirical Method – Asphalt Institute Method
  - Design subgrade resilient modulus (M_R)
    - Recommends triaxial tests for determining M_R, otherwise can be determined from CBR values.
    - For fine grained soils with CBR $\leq$ 10
      - M_R (psi) = 1500 CBR
      - M_R (Mpa) = 10.3 CBR

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic-Empirical Method – Asphalt Institute Method
  - Design subgrade resilient modulus (M_R)
    - Defined conducting tests (6-8) and ranking them for percentage of test equal to or greater than

Traffic Level (EAL)	Design subgrade value, percent
10^4 or less	60
Between 10^4 and 10^6	75
10^6 or more	87.5

DESIGN METHODS FOR FLEXIBLE PAVEMENTS

- Mechanistic-Empirical Method – Asphalt Institute Method
  - Design Steps
    1. Determine design traffic (cumulative ESAL)
    2. Determine design subgrade M_R
    3. Determine thickness of full depth asphalt concrete using design corresponding chart. Assume 50mm surface course and calculate the thickness of base course.
    4. Determine thickness of emulsified asphalt base and untreated aggregate bases using corresponding charts.
    5. Determine substitution factors for emulsified asphalt mix and untreated aggregate using thickness obtained in steps 3 and 4.
    6. Select a thickness of asphalt concrete surface layer, use substitutions ratio to determine the thickness of emulsified asphalt mix and untreated aggregate.

NUMERICAL

Results of 7 tests produced the following subgrade resilient modulus values as: 44.8, 68.3, 67.3, 106.3, 80, 68.3, 58.6 Mpa. The traffic classification at the end of construction is projected as below:

No of vehicles	Truck factor
4000	0.003
2050	0.28
1000	1.06
1100	0.62
1200	1.05

Design the flexible pavement using AI method for two lane single carriageway road to cater the above traffic with the following details.

i) Minimum depth of Asphalt Concrete wearing course with Modulus of elasticity 2500 Mpa = 50 mm
ii) Emulsified Asphalt base course with modulus of elasticity 1250 Mpa
iii) Granular subbase course with modulus of elasticity 150 Mpa
iv) Annual traffic growth rate = 6.5%
v) Design period = 12 years

NUMERICAL

r = 6.5% = 0.065

n = 12 years

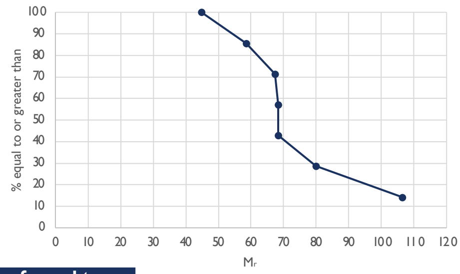
$N = 365 * \frac{[(1+r)^n - 1]}{r} * A * D * TF$

A*TF = (4000*0.003) + (2050*0.28) + (1000*1.06) + (1100*0.62) + (1200*1.05)

A*TF = 3588

N = 17.061 msa

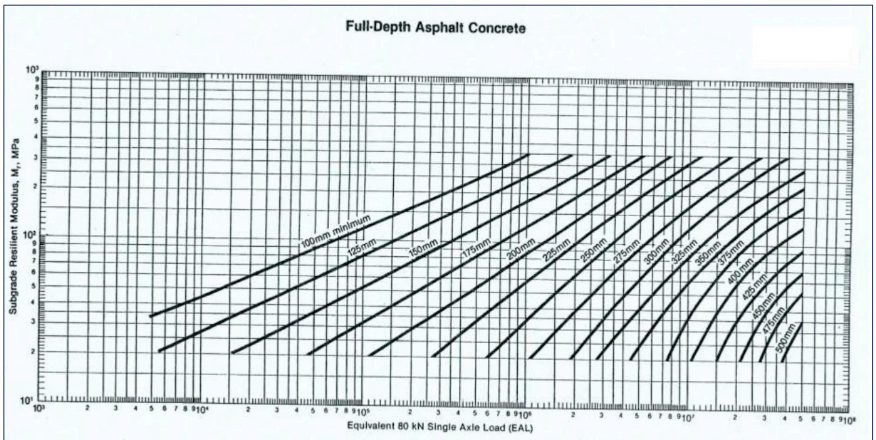
M_r	Probability of equal to or greater than
106.3	(1/7)*100
80	(2/7)*100
68.3	(3/7)*100
68.3	(4/7)*100
67.3	(5/7)*100
58.6	(6/7)*100
44.8	(7/7)*100



M_r	Probability of equal to or greater than
106.3	14.286
80	28.57
68.3	42.857
68.3	57.143
67.3	71.43
58.6	85.714
44.8	100

M_r = 56 Mpa

NUMERICAL

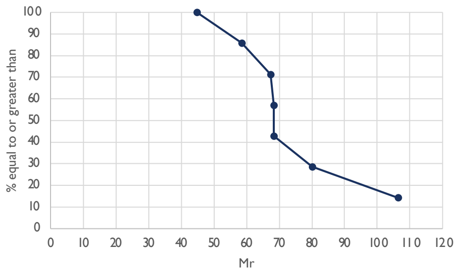


Design Chart A-7

From graph, full depth = 390mm

NUMERICAL

M_r	Probability of equal to or greater than
106.3	14.286
80	28.57
68.3	42.857
68.3	57.143
67.3	71.43
58.6	85.714
44.8	100



Thickness except wearing course =

390 – 50 = 340 mm

Equivalent thickness of emulsified

asphalt = $(\frac{2500}{1250})^{1/3}$ * 340

Thickness = 428.37mm

Thickness = 428.37 mm

Let thickness of base be 200 mm

Thickness of subbase = 428.37 – 200 = 228.37 mm of emulsified asphalt base course

Corresponding granular subbase thickness = $(\frac{1250}{150})^{1/3}$ * 228.37 = 463 mm.

NUMERICAL

r = 6.5% = 0.065

n = 12 years

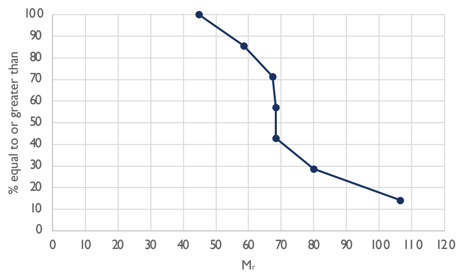
N = 365 * $\frac{[(1+r)^n-1]}{r}$ * A * D * TF

A*TF = (4000*0.003) + (2050*0.28) + (1000*1.06) + (1100*0.62) + (1200*1.05)

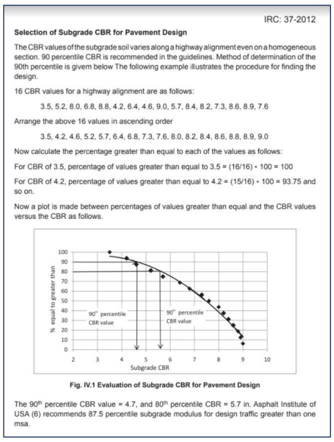
A*TF = 3588

N = 17.061 msa

M_r	Probability of equal to or greater than
106.3	14.286
80	28.57
68.3	42.857
68.3	57.143
67.3	71.43
58.6	85.714
44.8	100



NUMERICAL


IRC: 37-2012

Selection of Subgrade CBR for Pavement Design

The CBR values of the subgrade soil varies along a highway alignment even on a homogeneous section. 90 percentile CBR is recommended in the guidelines. Method of determination of the 90th percentile is givem below The following example illustrates the procedure for finding the design.

16 CBR values for a highway alignment are as follows:

3.5, 5.2, 8.0, 6.8, 8.8, 4.2, 6.4, 4.6, 9.0, 5.7, 8.4, 8.2, 7.3, 8.6, 8.9, 7.6

Arrange the above 16 values in ascending order

3.5, 4.2, 4.6, 5.2, 5.7, 6.4, 6.8, 7.3, 7.6, 8.0, 8.2, 8.4, 8.6, 8.8, 8.9, 9.0

Now calculate the percentage greater than equal to each of the values as follows:

For CBR of 3.5, percentage of values greater than equal to 3.5 = (16/16) • 100 = 100

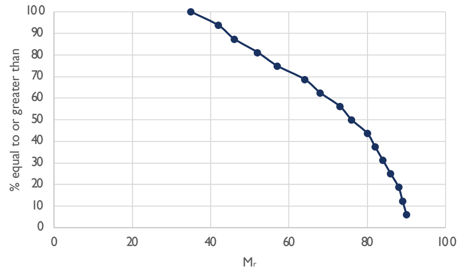
For CBR of 4.2, percentage of values greater than equal to 4.2 = (15/16) • 100 = 93.75 and so on.

Now a plot is made between percentages of values greater than equal and the CBR values versus the CBR as follows.

Fig. IV.1 Evaluation of Subgrade CBR for Pavement Design

The 90th percentile CBR value = 4.7, and 80th percentile CBR = 5.7 in. Asphalt Institute of USA (6) recommends 87.5 percentile subgrade modulus for design traffic greater than one msa.

Mr	% equal to or greater than	
90	(1/16)*100	6.25
89	(2/16)*100	12.5
88	(3/16)*100	18.75
86	(4/16)*100	25
84	(5/16)*100	31.25
82	(6/16)*100	37.5
80	(7/16)*100	43.75
76	(8/16)*100	50
73	(9/16)*100	56.25
68	(10/16)*100	62.5
64	(11/16)*100	68.75
57	(12/16)*100	75
52	(13/16)*100	81.25
46	(14/16)*100	87.5
42	(15/16)*100	93.75
35	(16/16)*100	100

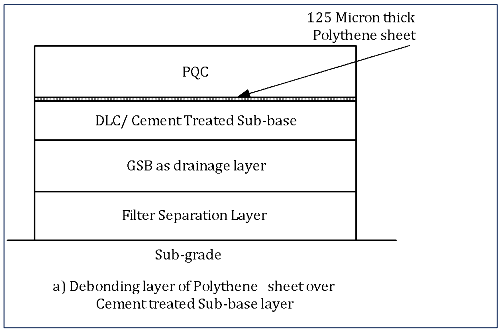


RIGID PAVEMENT

- Has sufficient beam strength to be able to bridge over localized sub grade failures and areas of inadequate support.
- Analyzed by plate theory.
- Plate theory is simplified version of the layered theory that assumes the concrete slab to a medium thick plate with a plane before bending and to remain a plane after bending.
- Plate or layered theory valid – if the wheel load is applied in the interior of the slab.
- Plate theory – if the wheel load is applied near to the slab edge (less than 610mm from the edge)
  - PCC is much different than HMA and distributes the load over a much wider area.
  - 610 mm from the edge is considered quite far in a flexible pavement but nor far enough in a rigid pavement.
  - Existence of joints in rigid pavements also makes the layered theory inapplicable.

RIGID PAVEMENT

- **Types of Concrete Pavements**
  - **Joint Plain Cement Concrete Pavement (JPCP)**
  - JPCP is the most common type of rigid pavement.
  - JPCP is engineered with longitudinal and transverse joints to control where cracking occurs in the slabs.
  - JPCPs do not contain steel reinforcement, other than tie bars and dowel bars.
  - JPCP layers can be arranged in various ways depending on the climatic conditions, availability of materials, soil types, and traffic intensity.

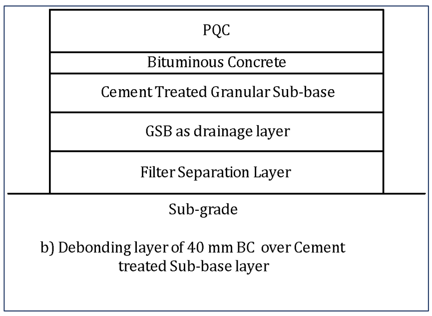


PQC-Pavement Quality Concrete
DLC- Dry Lean Concrete
BC- Bituminous Concrete

169

RIGID PAVEMENT

- **Types of Concrete Pavements**
  - **Joint Plain Cement Concrete Pavement (JPCP)**
  - Joint spacing between 4.6 m to 9.1 m has been used.
  - However, as the joint spacing increases, the aggregate interlock decreases and there is also an increased risk of cracking.
  - Maximum joint spacing of 6.1m for doweled joints and 4.6m for joints without dowel bars are recommended.



170

RIGID PAVEMENT

- **Types of Concrete Pavements**
  - **Joint Reinforced Concrete Pavement (JRCP)**
  - Steel reinforcement in the form of wire mesh or deformed bars do not increase the structural capacity of pavements but allow the use of longer joint spacings.
  - Joint spacings vary from 9.1 m to 30 m.
  - Because of longer panel length, dowels are required for load transfer across the joints.
  - The amount of distributed steel in JRCP increases with the increase in joint spacing and is designed to hold the slab together after cracking.

RIGID PAVEMENT

- **Types of Concrete Pavements**
  - **Continuous Reinforced Concrete Pavement (CRCP)**
  - This type of pavement is limited in construction.
  - CRCP is still a relatively new concept and preferred for construction in High Mountain and High Desert climate regions.
  - The continuous reinforcement in the pavement holds the cracks tightly together.
  - CRCP typically costs more initially than JPCP due to the added cost of the reinforcement.
  - However, CRCP is typically more cost-effective over the life of the pavement on high volume routes due to improved long-term performance and reduced maintenance.
  - Because there are no sawn transverse joints, properly built CRCP should have better ride quality and less maintenance than JPCP.

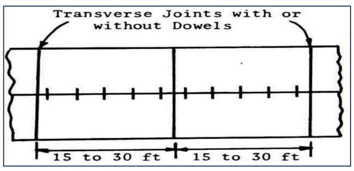
RIGID PAVEMENT

- **Types of Concrete Pavements**
  - **Precast Panel Concrete Pavement (PPCP)**
  - PPCPs use panels that are precast off-site instead of cast-in-place.
  - The precast panels can be linked together with dowel bars and tie bars or can be post-tensioned after placement.
  - PPCP offers the advantages of:
    - Improved concrete mixing and curing in a precast yard
    - Reduced pavement thicknesses, which is beneficial when there are profile grade restrictions such as vertical clearances
    - Shorter lane closure times, which is beneficial when there are short construction duration.

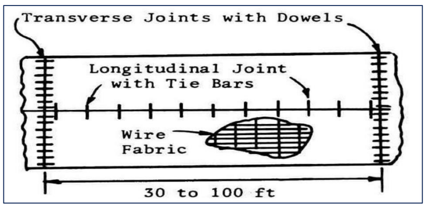
173

RIGID PAVEMENT

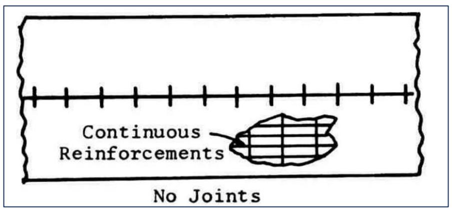
- **Types of Concrete Pavements**



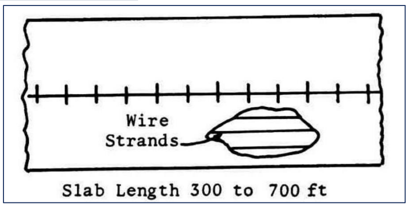
JPCP



JRCP



CRCP



PCP

174

RIGID PAVEMENT

- Factors affecting design

- Loading
  - Wheel load and its repetition
  - Design period = 20 years
  - Growth rate = 7.5%
  - Area of contact of wheel - circular

- Properties of sub-grade
  - Sub-grade strength and properties
  - Sub-base provision or omission
    - Provides a uniform and reasonably firm support
    - Prevents mud pumping on clays and silts
    - Acts as capillary cut off

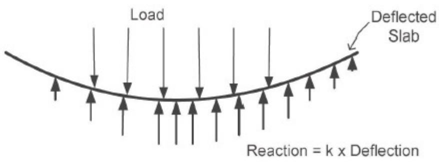
- Properties of concrete
  - Strength, modulus of elasticity, Poisson's ratio, shrinkage properties, fatigue behaviour
- External conditions
  - Temperature changes, friction between slab and sub-grade
- Joints arrangement
- Reinforcement quantity

RIGID PAVEMENT

- Westergaard's Analysis
  - Cement concrete with or without reinforcement.
  - Failure of rigid pavements usually occurs by overstressing of the concrete and not by overstressing of the subgrade and the thickness determination is generally based on the calculation of stress in the concrete.

RIGID PAVEMENT

- Westergaard's Analysis - Assumptions
  - Concrete slab acts as a homogeneous isotropic elastic solid in equilibrium.
  - Reactions of the subgrade are vertical only and are proportional to the deflections of the slab.



RIGID PAVEMENT

- Westergaard's Analysis - Assumptions
  - The reaction of the subgrade per unit of area at any given point is equal to a constant K multiplied by the deflection at the point. The constant K is termed 'the modulus of subgrade reaction' and is assumed to be constant at each point, independent of the deflection and to be the same at all points within the area of consideration.
  - The thickness of slab is uniform.
  - The load at the interior and at the corner of the slab is distributed over a circular area of contact. For corner loading, the circumference of this circular area is tangential to the edge of the slab.
  - The load at the edge off the slab is distributed uniformly over a semi-circular area of contact, diameter of the semi circle being at the edge of the slab.

RIGID PAVEMENT

- Modulus of subgrade reaction
  - Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed as a dense liquid.
  - The upward reaction is assumed to be proportional to the deflection.
  - The modulus of subgrade reaction 'k' is proportional to the displacement.
  - The displacement level Δ is taken as 0.125 cm in calculating k.
  - If p is the pressure sustained in N/mm^2 by the rigid plate of diameter 750mm at a deflection Δ = 0.125cm, the modulus of subgrade reaction k is given by:

$$k = \frac{p}{\Delta} = \frac{p}{1.25}\ N/mm^3$$

179

RIGID PAVEMENT

- Relative Stiffness
  - A certain degree of resistance to slab deflection is offered by the sub-grade.
  - The sub-grade deformation is same as the slab deflection.
  - Hence, the slab deflection is direct measurement of the magnitude of the sub-grade pressure.
  - Thus, the pressure deformation characteristics of a rigid pavement lead Westergaard to define the term radius of relative stiffness l in cm.

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

where, l = radius of relative stiffness (mm), E = modulus of elasticity of cement concrete (N/mm^2), μ = Poisson's ratio of cement concrete (0.15), h = cement concrete slab thickness (mm), k = modulus of subgrade reaction (N/mm^3)

180

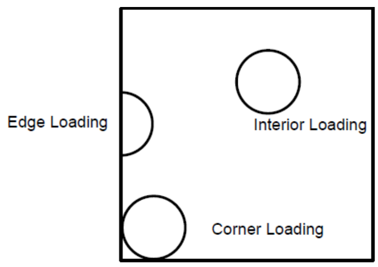
RIGID PAVEMENT

- Stress Consideration
  - Sources of stress in rigid pavement
    - Applied wheel loads
    - Change in temperature (warping and frictional stresses)
    - Volumetric changes in the sub-grade soil (heave and shrinkage including frost action)
    - Lack of continuity of subgrade support (mud pumping)
    - Stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface.
    - Critical loading positions are interior, edge and corner.

181

RIGID PAVEMENT

- Critical load positions
  - Three critical locations as interior, edge and corner.
  - These critical locations are known as critical load positions.
- Equivalent radius of resisting section
  - When interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate.



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

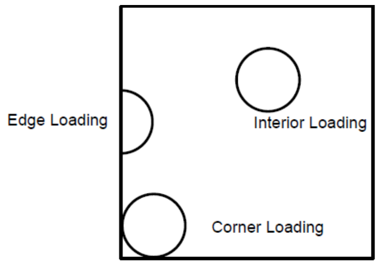
182

RIGID PAVEMENT

- Interior Loading

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

$\Delta_i = \frac{P}{8kl^2}\left\{1 + \frac{1}{2\pi}\left[\ln\left(\frac{a}{2l}\right) - 0.673\right]\left(\frac{a}{l}\right)^2\right\}$



where, l is the radius of relative stiffness

a is the radius of equivalent distribution of pressure at the bottom of the slab

b = a when $a \geq 1.724\,h$

b = $\sqrt{1.6a^2 + h^2}$ - 0.675h when a < 1.724 h

183

RIGID PAVEMENT

- Corner Loading

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

$\Delta_c = \frac{P}{kl^2}\left[1.1 - 0.88\left(\frac{a\sqrt{2}}{l}\right)\right]$

where, P is the concentrated load

h is the thickness of the slab

l is the radius of relative stiffness

a is the contact radius and k is the modulus of subgrade reaction

- Corner Loading

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

$\Delta_c = \frac{P}{kl^2}\left[1.1 - 0.88\left(\frac{a\sqrt{2}}{l}\right)\right]$

where, P is the concentrated load

h is the thickness of the slab

l is the radius of relative stiffness

a is the contact radius and k is the modulus of subgrade reaction

184

RIGID PAVEMENT

- Edge Loading

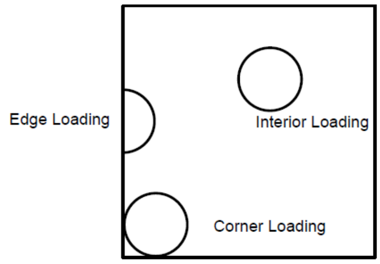
$\sigma_{e(circle)} = \frac{0.803P}{h^2}[4\log_{10}(\frac{l}{a}) + 0.666(\frac{a}{l}) - 0.034]$

$\sigma_e \text{ (semicircle)} = \frac{0.803P}{h^2}[4\log_{10}(\frac{l}{a}) + 0.282(\frac{a}{l}) + 0.650]$

$\Delta_e \text{ (circle)} = \frac{0.431P}{kl^2}[1 - 0.82(\frac{a}{l})]$

$\Delta_e \text{ (semicircle)} = \frac{0.431P}{kl^2}[1 - 0.349(\frac{a}{l})]$

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



ABHASH ACHARYA | HIGHWAY PAVEMENT 185

185

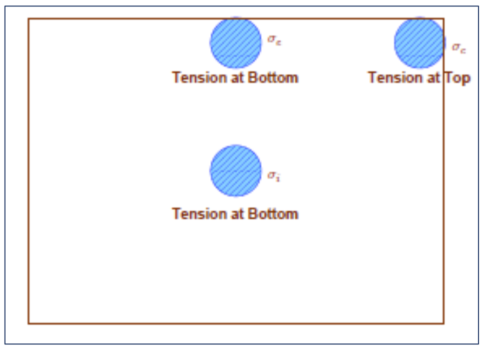
RIGID PAVEMENT

- Wheel load stresses – Westergaard's stress equation

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

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

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



ABHASH ACHARYA | HIGHWAY PAVEMENT 186

186

RIGID PAVEMENT

- Temperature Stresses
  - Developed in cement concrete pavement due to variation in slab temperature.
  - Caused by: daily variation resulting in temperature gradient across the thickness of the slab and seasonal variation resulting in overall change in the slab temperature.
  - Daily variation results in warping stresses and seasonal variation results in frictional stresses.
  - During the day, when the temperature on the top of the slab is greater than that at the bottom, the top tends to expand with respect to the neutral axis, while the bottom tends to contract. However, the weight of the slab restrains it from expansion and contraction, thus compressive stresses are induced at the top, tensile stresses at the bottom.
  - At night, when the temperature on the top of the slab is lower than that at the bottom, the top tends to contract with respect to the bottom, thus tensile stresses are induced at the top and compressive stresses at the bottom.

187

RIGID PAVEMENT

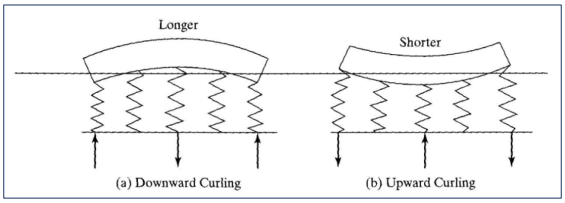
- Warping Stress

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

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

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

$$\sigma_t = \frac{E\alpha_t \Delta t}{2(1-\mu^2)}(C_x + \mu C_y)$$



- Frictional Stress

$$\sigma_f = \frac{WLf}{2 \times 10^4}$$

where, W is the unit weight of concrete in kg/cm^2 (2400), f is the coefficient of sub grade friction (1.5) and L is the length of the slab in meters

188

RIGID PAVEMENT

- Bending of Infinite Plate
  - Beam – stressed in only one direction
  - Plate – stressed in two directions
  - For stresses in two directions, the strain ϵ_x in the x direction can be determined by the generalized Hooke's law,

$$\epsilon_x = \frac{\sigma_x}{E} - \vartheta\frac{\sigma_y}{E}$$

where, E is the elastic modulus of concrete

First term indicates the strain in the x direction caused by stress in the x direction

Second term indicates the strain in the x direction caused by stress in the y direction

$$\epsilon_y = \frac{\sigma_y}{E} - \vartheta\frac{\sigma_x}{E}$$

RIGID PAVEMENT

- Bending of Infinite Plate
  - When the plate is bent in the x direction, ϵ_y should be equal to 0 because the plate is so wide and well restrained that no strain should ever occur unless near the very edge.

$\sigma_y = \mu\sigma_x$ → indicates the stress in the direction perpendicular to bending

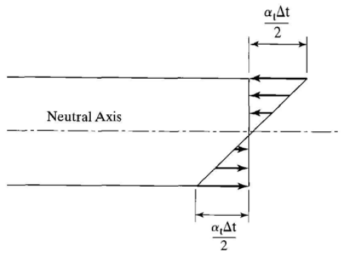
$\sigma_x = \frac{E\epsilon_x}{1-\mu^2}$ ……………….a) → indicates the stress in the bending direction

When bending occurs in both the x and y directions, as in the case for temperature curling, the stresses in both directions must be superimposed to obtain the total stress.

The maximum stress in an infinite slab due to temperature curling can be combined by assuming that the slab is completely restrained in both x and y directions.

RIGID PAVEMENT

- Bending of Infinite Plate
  - Let Δt be the temperature differential between the top and the bottom of the slab and α_t be the coefficient of thermal expansion of concrete. If the slab is free to move and the temperature at the top is greater than that at the bottom, the top will expand by a strain of $\alpha_t \Delta t$ / 2 and the bottom will contract by the same strain as shown in figure.
  - If the slab is completely restrained and prevented from moving, a compressive strain will result at the top and a tensile strain at the bottom. The maximum strain is



$$\epsilon_x = \epsilon_y = \frac{\alpha_t \Delta t}{2} \text{ ....b)}$$

From a) and b) $\sigma_x = \frac{E\alpha_t \Delta t}{2\,(1-\mu^2)}$ ....c) is also the stress in the y direction due to bending in y direction.

RIGID PAVEMENT

- Bending of Infinite Plate
  - The stress in the x direction due to bending in the y direction is

$$\sigma_x = \frac{\mu E \sigma_t \Delta t}{2(1-\mu^2}) \text{ ....d)}$$

The total stress is the sum of c) and d)

$$\sigma_x = = \frac{E\alpha_t \Delta t}{2\,(1-\mu^2)} + \frac{\mu E \sigma_t \Delta t}{2(1-\mu^2}) = \frac{E\alpha_t \Delta t}{2\,(1-\mu^2)}\,(1+\mu) = \frac{E\alpha_t \Delta t}{2\,(1-\mu)} \text{ ....i)}$$

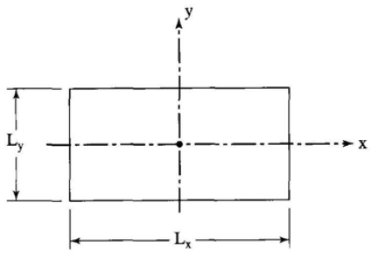
RIGID PAVEMENT

- Curling Stresses in Finite Slab
  - The total stress in he x direction can be expressed as

$$\sigma_x = \frac{C_x E \alpha_t \Delta t}{2(1-\mu^2)} + \frac{C_y \mu E \alpha_t \Delta t}{2(1-\mu^2)} = \frac{E \alpha_t \Delta t}{2(1-\mu^2)} (C_x + \mu C_y) \quad \text{............ii)}$$

where, C_x and C_y are correction factors for a finite slab. The first term is the stress due to bending in the x direction and the second term is the stress due to bending in the y direction. Similarly, the stress in the y direction is

$$\sigma_y = \frac{E \alpha_t \Delta t}{2(1-\mu^2)} (C_y + \mu C_x) \quad \text{..................e)}$$



The equation e) gives the maximum interior stress at the center o a slab. The edge stress at the midspan of the slab can be determined by $\sigma = \frac{C E \alpha_t \Delta t}{2}$ ....f)

where, σ be σ_x or σ_y depending on whether C is C_x or C_y.

Equation f) is same as equation i) and ii) when the Poisson ratio at the edge is taken as 0.

NUMERICAL

Compute the radius of relative stiffness of 15 cm thick cement concrete slab using the following data.

Modulus of elasticity of cement concrete (E) = 2.1 * 10^5 kg/cm^2

Poisson ratio for concrete (μ) = 0.15

Modulus of subgrade reaction (k) – a) = 3.0 kg/cm^3 b) = 7.5 kg/cm^3

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

$l = [\frac{2.1 * 10^5 * 15^3}{12k\ (1-0.15^2)}]^{1/4}$

for k = 3.0 kg/cm^3

l = 67cm

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

$l = [\frac{2.1 * 10^5 * 15^3}{12k\ (1-0.15^2)}]^{1/4}$

for k = 7.5 kg/cm^2

l = 53.27cm

NUMERICAL

Using the data given below, calculate the wheel load stress at a) Interior b) Edge and c) Corner of a cement concrete pavement using Westergaard's stress equation. Also, determine the probable location where the crack is likely to develop due to corner loading.

Wheel load (P) = 5100 kg, Modulus of elasticity of concrete (E) = 3.0*10^5 kg/cm^2, Pavement thickness (h) = 18cm, Poisson's ratio of concrete (μ) = 0.15, Modulus of subgrade reaction (k) = 6.0 kg/cm^3, Radius of contact area (a) = 15 cm

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

$l = [\frac{3*10^5*18^3}{12*6*(1-0.15^2)}]^{1/4}$

l = 70.61 cm

b = a when a $\geq 1.724\,h$

b = $\sqrt{1.6a^2 + h^2}$ - 0.675h when a < 1.724 h

Check

1.724 h = 1.724*18 = 31.032 → a < 31.032

b = $\sqrt{1.6 * 15^2 + 18^2}$ - 0.675*18

b = 14cm

Interior Loading

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

$\sigma_i = \frac{0.316*5100}{18^2}$ [4 $\log_{10}(\frac{70.61}{14})$ + 1.069]

σ_i = 19.29 kg/cm^2

Edge Loading

$\sigma_e = \frac{0.572P}{h^2}$ [4 $\log_{10}$ (l/b) + 0.359] = 28.54 kg/cm^2

NUMERICAL

Using the data given below, calculate the wheel load stress at a) Interior b) Edge and c) Corner of a cement concrete pavement using Westergaard's stress equation. Also, determine the probable location where the crack is likely to develop due to corner loading.

Wheel load (P) = 5100 kg, Modulus of elasticity of concrete (E) = 3.0*10^5 kg/cm^2, Pavement thickness (h) = 18cm, Poisson's ratio of concrete (μ) = 0.15, Modulus of subgrade reaction (k) = 6.0 kg/cm^3, Radius of contact area (a) = 15 cm

Corner loading

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

$\sigma_c = \frac{3*5100}{18^2}[1 - (\frac{15\sqrt{2}}{70.61})^{0.60}]$

σ_c = 24.27 kg/cm^2

Location where corner load crack develops

X = 2.58 $\sqrt{al}$

X = 2.58 $\sqrt{15 * 70.60}$

X = 83.95 cm

NUMERICAL

Determine the warping stress at interior, edge and corner of a 25cm thick cement concrete pavement with transverse joints at 5.0m interval and longitudinal joints at 3.6m interval. The modulus of sub-grade reaction (K) is 6.9kg/cm^3 and radius of contact area is 15 cm. Assume maximum temperature differential during day to be 0.6°C per cm slab thickness (for warping stresses at interior and edge) and maximum temperature differential of 0.4°C per cm slab thickness during the night (for warping stress at the corner), additional data are given as: α = 10*10^{-6} per °C, E = 3*10^5 kg/cm^2 and μ = 0.15.

h = 25 cm

l_x = 5m = 500 cm

l_y = 3.6m = 360 cm

a = 15 cm

k = 6.9 kg/cm^3

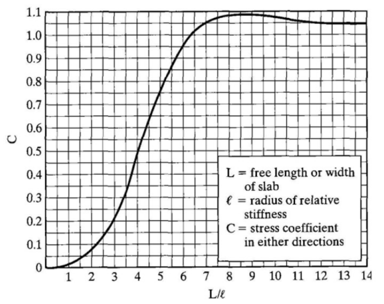
Temperature differential during day = 0.6 * 25 = 15°C

Temperature differential at night = 0.4 * 25 = 10°C

l = 87.20 cm (Calculated using formula)

Calculation of $\frac{l_x}{l}$ and $\frac{l_y}{l}$

$\frac{l_x}{l}$ = 5.73 and $\frac{l_y}{l}$ = 4.13



C_x = 0.87

C_y = 0.51

ABHASH ACHARYA | HIGHWAY PAVEMENT

197

197

NUMERICAL

Determine the warping stress at interior, edge and corner of a 25cm thick cement concrete pavement with transverse joints at 5.0m interval and longitudinal joints at 3.6m interval. The modulus of sub-grade reaction (K) is 6.9kg/cm^3 and radius of contact area is 15 cm. Assume maximum temperature differential during day to be 0.6°C per cm slab thickness (for warping stresses at interior and edge) and maximum temperature differential of 0.4°C per cm slab thickness during the night (for warping stress at the corner), additional data are given as: α = 10*10^{-6} per °C, E = 3*10^5 kg/cm^2 and μ = 0.15.

At interior

$\sigma_i = \frac{E\alpha_t \Delta t}{2(1-\mu^2)}(C_x + \mu C_y)$

$\sigma_i = \frac{3*10^5*10*10^{-6}*15}{2(1-0.15^2)}(0.87 + (0.15*0.51))$

σ_i = 21.78 kg/cm^2

At edge

$\sigma_e = \text{Max}\left(\frac{C_x E\alpha_t\,\Delta t}{2}, \frac{C_y E\alpha_t\,\Delta t}{2}\right)$

$\sigma_e = \frac{0.87*3*10^5*10*10^{-6}*15}{2}$

σ_e = 19.85 kg/cm^2

At corner

$\sigma_c = \frac{E\alpha_t \Delta t}{3(1-\mu)}\sqrt{\frac{a}{l}}$

$\sigma_c = \frac{3*10^5*10*10^{-6}*10}{3(1-0.15)}\sqrt{\frac{15}{87.2}}$

σ_c = 4.879 kg/cm^2

ABHASH ACHARYA | HIGHWAY PAVEMENT

198

198

RIGID PAVEMENT

- **Design of Slab Thickness – Design Steps**

  1. Decide the width of slab based on joint spacing and lane width

  2. Length of cement concrete slab = spacing of contraction joints (L_c)

  $L_c = \frac{2 s_c * 10^4}{W f}$ for plain cement concrete pavements and $L_c = \frac{200 * A_s * S_s}{W b f h}$ for reinforced concrete pavements

  where, L_c is the spacing of contraction joints (m), f is the coefficient of friction (1.5), W is the unit weight of concrete (2400 kg/m^3), S_c is the allowable stress (tension) in cement concrete (0.8 kg/cm^2), A_s is the area of steel across the width of the slab (cm^2), S_s is the allowable tensile stress in steel (1400 kg/cm^2), b is the width of the slab (m) and h is the thickness of the slab (cm)

  Recommended maximum spacing of contraction joints

  4.5 m for unreinforced slab of all thickness, 13 m for reinforced slab of 15 cm thick with steel reinforcement 2.7 kg/cm^2, 14 m for reinforced slab of 20 cm thick with steel reinforcement of 3.8 kg/cm^2

199

RIGID PAVEMENT

- **Design of Slab Thickness – Design Steps**

  3. Assume trial thickness of slab

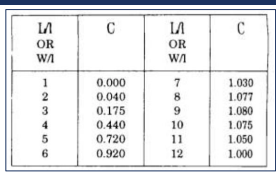
  4. Calculation of warping stress at edge

  σ_e = Max $\left(\frac{C_x E \alpha_t \Delta t}{2}, \frac{C_y E \alpha_t \Delta t}{2}\right)$ or from the chart provided

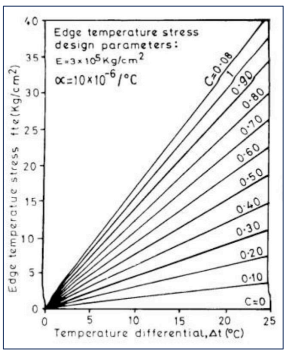
  5. Subtract the value from step 4 from the allowable flexural stress of concrete to find the residual strength

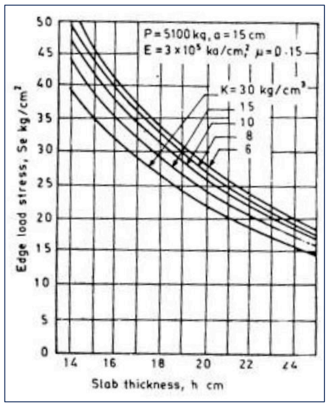
  6. Find the total load stress at edge

  $\sigma_e = \frac{0.529P(1+0.54\mu)}{h^2}$ [4log$_{10}$(l/b) + log$_{10}$b – 0.4048] or from the chart provided



l/l OR W/l	C	l/l OR W/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





200

RIGID PAVEMENT

- **Design of Slab Thickness – Design Steps**

  7. Calculate the Factor of Safety (F)

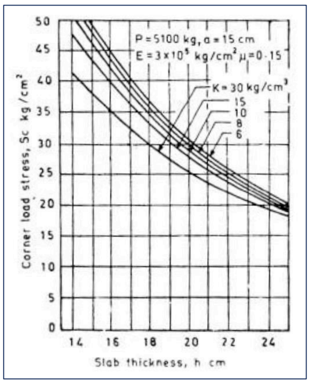
  $F = \frac{Residual\ Strength}{Load\ stress\ at\ edge}$

  If F<1.0 or >>1.0, repeat process 3-7 for further check

  8. Calculate the stress at the corner due to wheel load and warping

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

  $\sigma_c = \frac{E\alpha_t \Delta t}{3(1-\mu)}\sqrt{\frac{a}{l}}$



  If this stress is less than allowable flexural stress in concrete, the slab thickness (h cm) is adequate or else revision is needed.

RIGID PAVEMENT

- **Design of Slab Thickness – Design Steps**

  9. The designed thickness is adjusted for traffic intensity at the end of the design life to obtain the final adjusted slab thickness.

Traffic classification	Design traffic intensity (No. of vehicles of weight greater than 3 tonnes per day a the end of design life)	Adjustment in design thickness of pavement slab (cm)
A	0-15	-5
B	15-45	-5
C	45-150	-2
D	150-450	-2
E	450-1500	0
F	1500-4500	0
G	>4500	+2

NUMERICAL

Design the thickness of plain cement concrete pavement for a two lane highway for the following data.

a) Coefficient of thermal expansion = $10*10^{-6}/°C$
b) Allowable stress in concrete in tension = 0.8 kg/cm^2
c) Coefficient of friction = 1.5
d) Unit weight of concrete = 2400 kg/m^3
e) Design of wheel load = 5100 kg
f) Radius of contact area = 15cm
g) Present traffic intensity = 950 CVPD
h) Design life = 20 years
i) Traffic growth rate = 7.5%
j) Temperature variation (seasonal) = 35°C
k) Modulus of subgrade reaction = 8kg/cm^3
l) Flexural strength (allowable flexural stress) of concrete = 40kg/cm^2

Temperature differential values in the region

Slab thickness (cm)	15	20	25
Temperature differential in slab in the region (°C)	14.6	15.8	16.3

203

NUMERICAL

1. Decide the width of slab based on joint spacing and lane width

2. Spacing of contraction joints (L_c)

$$L_c = \frac{2S_c*10^4}{Wf}$$

$$L_c = \frac{2*0.80*10^4}{2400*1.5} = 4.45 < 4.5.$$

Therefore, L_c = 4.5m

3. Assume trial thickness of slab as 20cm

4. Calculation of warping stress at edge

$$\sigma_e = \text{Max}\left(\frac{C_x E\alpha_t\,\Delta t}{2}, \frac{C_y E\alpha_t\,\Delta t}{2}\right)$$

Calculation of radius of relative stiffness

$$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4} = 71.1 \text{ cm}$$

$$\frac{l_x}{l} = \frac{4.5}{0.711} = 6.33 \text{ and } \frac{l_y}{l} = \frac{3.5}{0.711} = 4.92$$

C_x = 0.92, C_y = 0.72

$$\sigma_e = \frac{C_x E\alpha_t\,\Delta t}{2} = 21.8 \text{ kg/cm}^2$$

5. Subtract the value from step 4 from the allowable flexural stress of concrete to find the residual strength

Residual strength in cement concrete = 40 – 21.8 = 18.2 kg/cm^2

6. Find the total load stress at edge

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

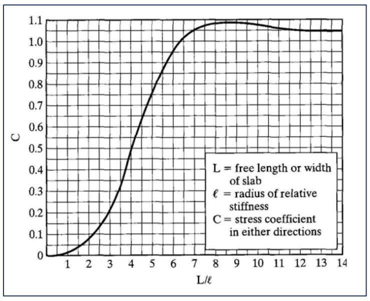
σ_e = 25.94 kg/cm^2

7. Calculate the Factor of Safety (F)

$$F = \frac{\textit{Residual Strength}}{\textit{Load stress at edge}} = \frac{18.2}{25.94} = 0.7016 < 1$$

Repeat process 3 to 7

Assume trial thickness of slab as 24 cm.



204

NUMERICAL

Assume trial thickness of slab as 24 cm.

l = 81.53 cm (Determined using formula)

$\frac{l_x}{l} = \frac{4.5}{0.8153} = 5.46$ and $\frac{l_y}{l} = \frac{3.5}{0.8153} = 4.29$

$C_x = 0.80$, $C_y = 0.60$

$\sigma_e = \frac{C_x E \alpha_t \Delta t}{2} = 19.44$ kg/cm^2

Subtract the value from step 4 from the allowable flexural stress of concrete to find the residual strength

Residual strength in cement concrete = 40 – 19.44 = 20.56 kg/cm^2

Find the total load stress at edge

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

$\sigma_e = 19.22$ kg/cm^2

Calculate the Factor of Safety (F)

$F = \frac{Residual\ Strength}{Load\ stress\ at\ edge} = \frac{20.56}{19.22} = 1.07 > 1$ (OK)

Calculate the stress at the corner due to wheel load and warping

$\sigma_c = \frac{3P}{h^2}[1 - (\frac{a\sqrt{2}}{l})^{0.6}] = 14.72$ kg/cm^2 < 40 kg/cm^2

$\sigma_c = \frac{E\alpha_t\Delta t}{3(1-\mu)}\sqrt{\frac{a}{l}} = 8.22$ kg/cm^2 < 40 kg/cm^2

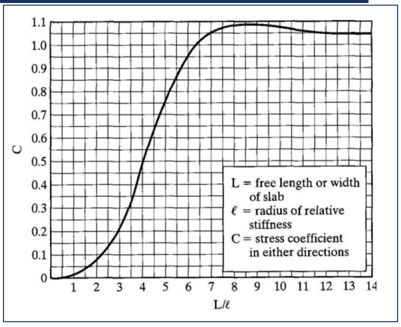
Furthermore, 14.72 + 8.22 = 22.94 kg/cm^2 < 40 kg/cm^2

The designed thickness is adjusted for traffic intensity at the end of the design life to obtain the final adjusted slab thickness.

$A = P(1+r)^n = 950(1+0.075)^{3+20} = 5013$ CVPD (Category G)

Adjustment = +2

Therefore, the thickness of slab to be provided is 24+2 = 26 cm.



RIGID PAVEMENT

- **Dowel Bars**
  - The purpose of the dowel bar is to effectively transfer the load between two concrete slabs and to keep the two slabs in same height.
  - Provided in the direction of the traffic (longitudinal).
  - Bradbury's Analysis
    - Gives load transfer capacity of single dowel bar in shear, bending and bearing as follows:

$P_s = 0.785\, d^2 F_s$ ……………a)

$P_f = \frac{2d^3F_f}{L_d + 8.8\delta}$ ………………..b)

$P_b = \frac{F_b L_d^2 d}{12.5\,(L_d + 1.5\delta)}$ ………....c)

where, P is the load transfer capacity of a single dowel bar in shear s, bending f and bearing b, d is the diameter of the bar in cm, L_d is the length of the embedment of dowel bar in cm, δ is the joint width in cm, F_s, F_f, F_b are the permissible stress in shear, bending and bearing for the dowel bar in kg/cm^2.

RIGID PAVEMENT

- **Design of Dowel Bars – Design Steps**
  - Step 1: Find the length of the dowel bar embedded in slab L_d by equating equation b) and c) as $L_d = 5d\sqrt{\frac{F_f(L_d+1.5\delta)}{F_b(L_d+8.8\delta)}}$
  - Step 2: Find the load transfer capacities P_s, P_f, and P_b of single dowel bar with the L_d
  - Step 3: Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor f as Max $\{\frac{0.4P}{P_s}, \frac{0.4P}{P_f}, \frac{0.4P}{P_b}\}$
  - Step 4: Spacing of the dowel bars
    - Effective distance upto which effective load transfer takes place is given by 1.8l, where l is the radius of relative stiffness.
    - Assume a linear variation of capacity factor of 1.0 under load to 0 at 1.8l.
    - Assume a dowel spacing and find the capacity factor of the above spacing.
    - Actual capacity factor should be greater than the required capacity factor.
    - If not, do one more iteration with new spacing.

NUMERICAL

Design size and spacing of dowel bars at an expansion joint of concrete pavement of thickness 25cm. Given the radius of relative stiffness of 80cm, design wheel load 5000kg. Load capacity of the dowel system is 40 percent of design wheel load. Joint width is 2.0 cm and the permissible stress in shear, bending and bearing stress in dowel bars are 1000, 1400 and 100 kg/cm^2 respectively.

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

$L_d = 5d\sqrt{\frac{F_f(L_d+1.5\delta)}{F_b(L_d+8.8\delta)}}$

L_d = 40.50

Minimum length of the dowel bar is

$L_d + \delta$ = 40.50 + 2 = 42.50 cm.

Take Length = 45 cm

L_d = 45 – 2 = 43 cm

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

P_s = 0.785 d^2 F_s = 0.785*2.5^2*1000 = 4906 kg

$P_f = \frac{2d^3F_f}{L_d+8.8\delta}$ = 722 kg

$P_b = \frac{F_bL_d^2d}{12.5\,(L_d+1.5\delta)}$ = 804 kg

Required load transfer capacity

Max $\{\frac{0.4P}{P_s}, \frac{0.4P}{P_f}, \frac{0.4P}{P_b}\}$ = 2.77

Find the required spacing

Effective distance of load transfer = 1.8l = 1.8*80 = 144 cm (l)

Assuming 35cm spacing

Number of dowels participating in load transfer = 1 + l/spacing = 1 + 144/35 = 5 dowels

Assuming the load transferred by first dowel is full and that on the dowel at a distance of l is 0, then Actual capacity is

$1 + \frac{144-35}{144} + \frac{144-70}{144} + \frac{144-105}{144} + \frac{144-140}{144} = 2.56 < 2.77$

Assume 30 cm spacing, No of dowels participating = 5 dowels, Actual capacity is

$1 + \frac{144-30}{144} + \frac{144-60}{144} + \frac{144-90}{144} + \frac{144-120}{144} = 2.92 > 2.77$

Provide 2.5 cm ϕ dowel bars of length 45 cm at 30 cm center to center.

RIGID PAVEMENT

- **Tie Bars**
  - Not load transfer devices as dowel bars but serve as a means to tie two slabs.
  - Smaller than dowel bars and are placed at large intervals.
  - Provided across longitudinal joints.

RIGID PAVEMENT

- **Tie Bars – Design Steps**
  - **Step 1:** Diameter and Spacing: The diameter and spacing is first found out by equating the total sub-grade friction to the total tensile stress for a unit length (one meter). Hence, the area of steel per one meter in cm^2 is given by: $A_s * S_s = b * h * W * f$

$$A_s = \frac{bhWf}{100S_S}$$

where, b is the width of the pavement panel in m, h is the depth of the pavement in cm, W is the unit weight of the concrete (assume 2400 kg/cm^2), f is the coefficient of friction (1.5), and S_s is the allowable working tensile stress in steel (assume 1750 kg/cm^2). Assume 0.8 to 1.5 cm ϕ bars for the design.

  - **Step2:** Length of the tie bar: Length of the tie bar is twice the length needed to develop bond stress equal to the working tensile stress and is given by:

$$L_t = \frac{dS_S}{2S_b}$$

where, d is the diameter of the bar, S_s is the allowable tensile stress in kg/cm^2 and S_b is the allowable bond stress and can be assumed for plain and deformed bars respectively as 17.5 and 24.6 kg/cm^2.

NUMERICAL

A cement concrete pavement of thickness 18cm, has two lanes of 7.2m with a joint. Design the tie bars.

h = 18 cm

b = 7.2/2 = 3.6 m

S_s = 1750 kg/cm^2

W = 2400 kg/cm^2

f = 1.5

S_b = 24.6 kg/cm^2

Step 1: Diameter and spacing

$A_s = \frac{bhWf}{100S_s}$

A_s = 1.33 cm^2/m

Assume ϕ = 1cm, a = 0.785 cm^2

Number of bars = A/a = 1.697

Spacing = 100/Number of bars = 100/1.697 = 59 cm

Take Spacing = 55 cm.

Step 2: Length of bar

$L_t = \frac{dS_s}{2S_b}$

$L_t = \frac{1*1750}{2*24.6}$ = 35.56 cm

Provide 36cm, 1ϕ bars at 55cm spacing.

211

RIGID PAVEMENT

- **Design of Joints**
  - Great care is needed in the design and construction of joints in cement concrete pavements, as these are critical locations having significant effect on the pavement performance.
  - Cement concrete pavements have different types of joints
    - Contraction joints
    - Construction joints
    - Expansion joints
    - Longitudinal joints

212

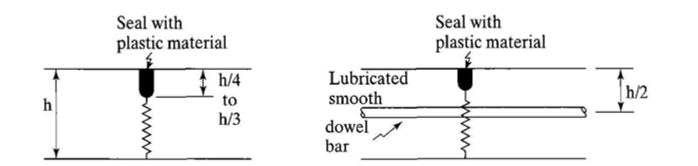
RIGID PAVEMENT

- **Design of Joints**
  - Contraction Joints
    - Purpose is to allow the contraction of the slab due to fall in slab temperature below the construction temperature.
    - Spacing of contraction joints should be limited to 4.5m to prevent top-down cracking during the night hours.
      - A groove is formed by placing a metal strip on the fresh concrete, which is later removed.
      - The groove is then sealed with a plastic material.
      - Dowels are needed if the joint spacing is large.
      - Joints can be formed by placing a felt, asphalt ribbon, or asphalt board strip in the fresh concrete and leaving it there permanently.

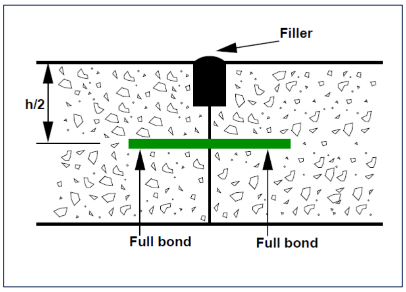
213

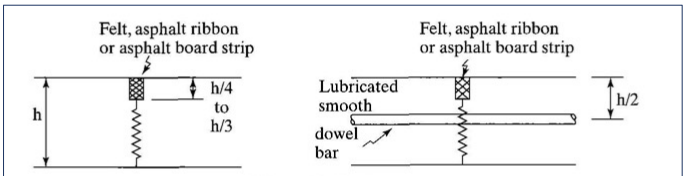
RIGID PAVEMENT

- **Design of Joints**
  - Contraction Joints



(a) Dummy Groove





(b) Premolded Strip

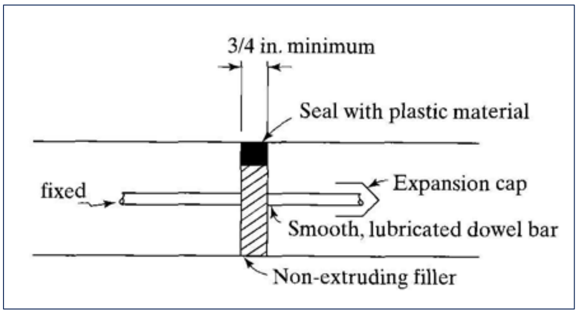
214

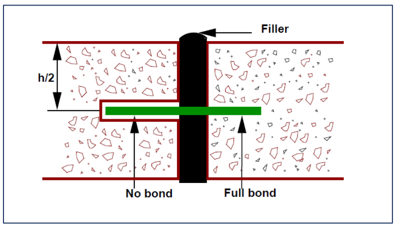
RIGID PAVEMENT

- **Design of Joints**
  - Expansion Joints
    - Purpose is to allow the expansion of the pavement due to rise in temperature with respect to construction temperature.
    - Difficult to maintain and they get filled up with dirt and other incompressible materials causing locking of the joints and preventing expansion of concrete slabs.
    - Minimum width of joint is ¾ inch (19 mm)
    - Smooth dowel bars lubricated at least on one side must be used for load transfer
    - Expansion cap must be installed at the free end to provide space for dowel movements
    - Non-extruding fillers, including fibrous and bituminous materials or cork, must be placed in the joint and the top sealed with a plastic material.

RIGID PAVEMENT

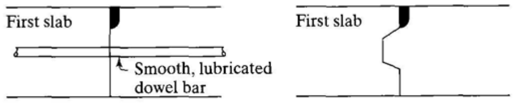
- **Design of Joints**
  - Expansion Joints





RIGID PAVEMENT

- **Design of Joints**
  - Construction Joints
    - To stop the work by the end of the day
    - Should be as far as possible, be placed at the location of contraction joints except in case of emergency

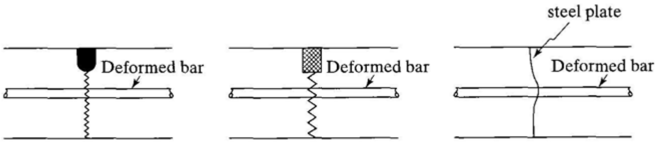


(a) Butt Joint at Contraction Joint.
(b) Key Joint for Emergency.

217

RIGID PAVEMENT

- **Design of Joints**
  - Longitudinal Joints
    - Required in pavements of width greater than 4.5m to allow for transverse contraction and warping.
    - Allow for warping and uneven settlement of the subgrade
    - Necessary to provide some form of load transferring devices like tie bars



(a) Dummy Groove.
(b) Ribbon or Premolded Strip.
(c) Deformed Plate.

218

RIGID PAVEMENT

- **Design of Joints**
  - Warping Joints
    - Known as hinge joints and are provided to relieve warping stresses
    - Can be either longitudinal or transverse joints
    - To minimize the effect of daily temperature

219

THANK YOU!

Abhash Acharya
M.Sc. In Transportation Engineering
acharyaabhash@gmail.com
abhashacharya.com.np

220