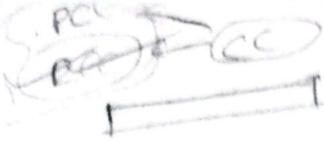
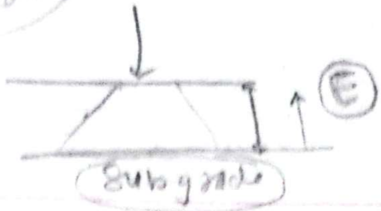


OMC & DD



Pavement

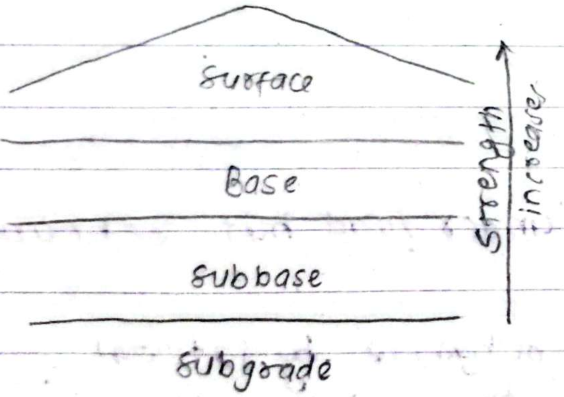
→ A relatively stable layer with even surface constructed over the natural soil for the movement of traffic.

→ Functions:-

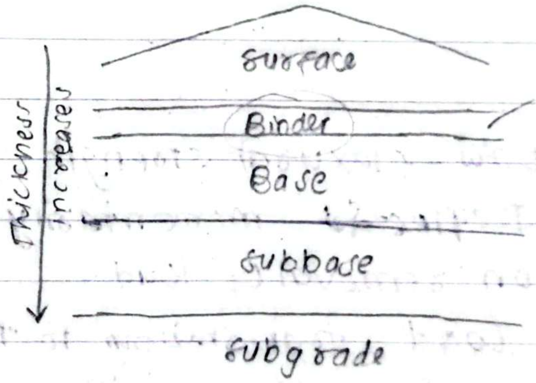
- To support and distribute wheel load of vehicle over a wide underlying area of subgrade soil.
- To keep the temporary deformation within the permissible range.

Pavement layers:-

Indian Practice



American Practice



less bitumen, large aggregate than surface

base/sub-base → made using aggregate/granular
↳ distribute wheel load evenly to underlying layer

→ Subgrade should have CBR value of 5% minimum. If not, it is increased by soil stabilization.

*Types of pavement:

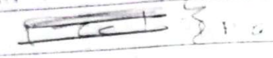
Depending on structural behaviour:

(i) Flexible pavement → grain to grain

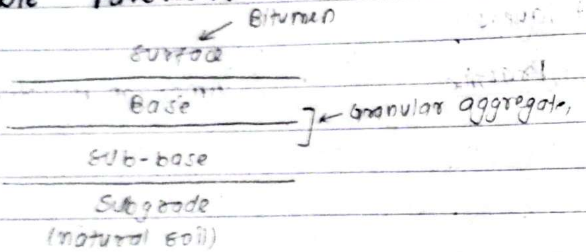
(ii) Rigid Pavement → slab

(iii) Semi-rigid Pavement → fly

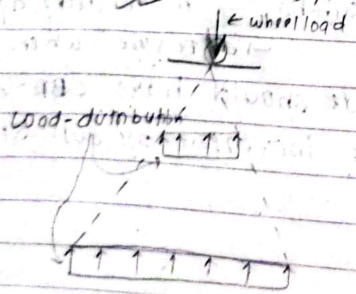
(iv) Composite Pavement



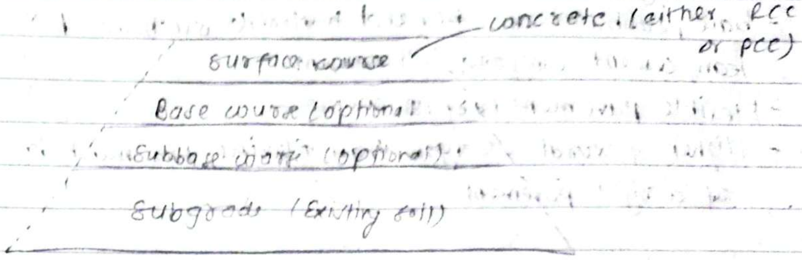
(i) Flexible Pavement



- Low-flexural strength
- Deflected momentarily under load but rebounds on removal of load
- Load transmission to the subgrade by lateral distribution with grain to grain point of contact.
- Designed in layers, empirical method

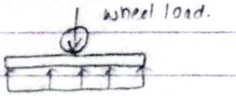


(ii) Rigid Pavement



- Joints are given & seen in plan in transverse & longitudinal direction to counteract the shrinkage properties of concrete.
- Mud pumping + frost action are seen due to poor joints ! so, to prevent them, a granular layer is preferred b/w surface & subgrade layer

[Mud pumping → Joint बाट Mud सहितको पानी निस्कने
[Frost action → पानी जम्ने २ वटा layer (surface & subgrade) बिचमा



→ cem. concrete slab

→ High flexural strength

→ Load distribution by slab action

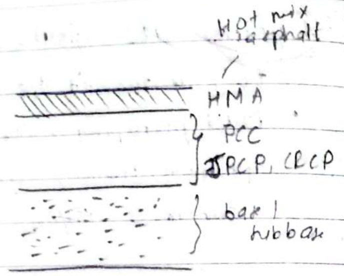
→ Permanent settlements

→ Design by structural analytical techniques

→ stage construction not possible as in flexible pavement.

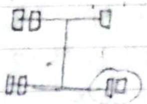
(iii) Semi-rigid Pavement
- base, subbase of bonded materials such as pozzolanic cement, lean cement concrete, soil cement.
- Flexible pavement surface course.
- Higher flexural strength than flexible but much lower than that of a rigid pavement

(iv) Composite Pavement
- Ideal pavement
- PCC bottom layer, HMA top layer.
- very expensive, rarely used in new construction
- Mostly rehabilitation of PCC using asphalt overlays.



☐ Loads and other factors controlling Pavement Design.
1. Traffic and loading factors
2. Material properties
3. Environment factors
4. Failure criteria

1. Traffic & loading factors.
- Axle Load
- Number of load repetitions.
- Contact area
- Vehicle speed.



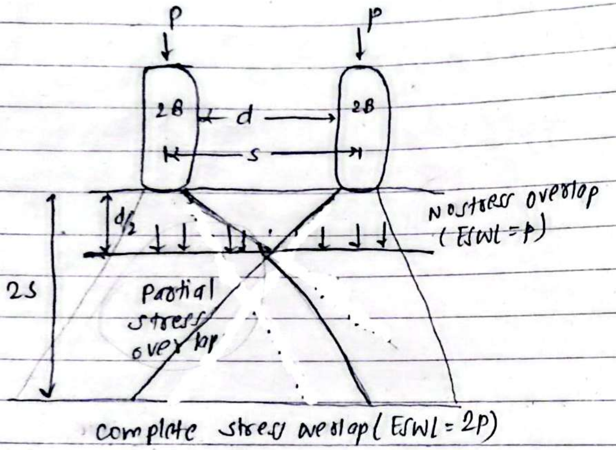
Axle load
→ Total wt. of the vehicle carried by its axles
→ Axle load → Wheel load → Pavement surface.

Wheel load:
→ Higher the wheel load, thicker is the pavement required.
→ Pavement design is governed by number and wheel loads of the commercial vehicles.

Wheel configuration:
→ Most commercial vehicles are provided with dual rear wheels
→ Affects the stress distribution and deflection
→ Design:
Flexible pavement: wheels on only one side is considered.
Rigid pavement: wheels on both sides are considered.

load → grain to grain laterally distribute

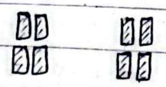
→ Dual wheel load is converted into equivalent single wheel load to simplify the analysis.



- Axle configuration:

→ commercial vehicles are provided with multiple axles to further enhance the load carrying capacity.

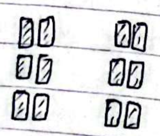
Single axle with Single wheel



Tandem Axle

Single axle with dual wheel

(हाम्रो मा त्यो use हुन्छ
र load 80kN



Tridem Axle

- In design standard axle load and Equivalency factor (F) are used

Equivalency factor for an axle load L (F)

$$= \frac{\text{Damage caused by passage of axle load } L \text{ on a pavement}}{\text{Damage caused by passage of}}$$

Axle load

→ Generalized ~~lo~~ 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 $(F) = \left(\frac{L}{L_s}\right)^4$

Empirical relation 4 varies for different failures malamaal weekly.

⊡ Number of Load Repetitions

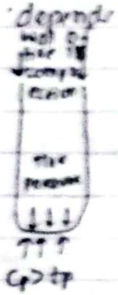
→ Repeated application of the wheel load → pavement distress → Pavement failures

→ Total number of repetitions of the axle loads is computed as cumulative Number of standard axle for design life.

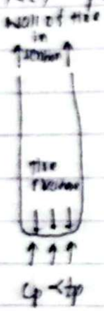
⊡ Contact area

→ wheel load is assumed to be uniformly distributed over the contact area

→ Size depends on the contact pressure.



Low pressure tire



High pressure tire

(Normally truck in high pressure)
(commercial)

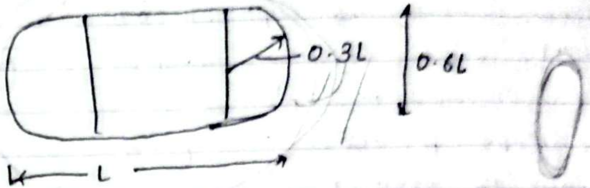
→ True shape is elliptical

Flexible pavement:

→ Each tire is assumed to have a circular contact area.

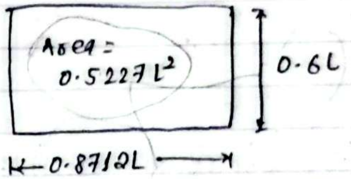
Rigid pavement.

→ Elliptical shape with a rectangular and two semicircles is assumed.



Actual area

→ For FEM analysis, an equivalent rectangular area is assumed.



Equivalent area.

⊡ Vehicle speed

- More speed less pressure.
- Low speed High pressure.

→ directly related to duration of loading

2. Material Properties:-

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

3. Environmental Factor :

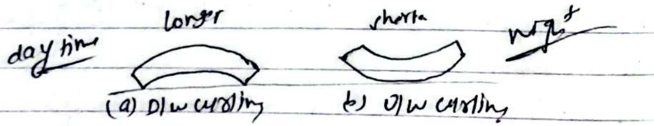
- → Temperature
- → Precipitation
- → Road geometry (small effects)

Temperature

Both temp & ppt. affect elastic modulii

Flexible pavement

Rigid pavement :



(a) D/w curling b) U/w curling

- → create curling stress and affect slab subgrade contact and the stress values.
- → Determine joint and crack openings and affect the efficien of load transfer

- Frost Penetration:-
  - Temp. effect
  -

Precipitation

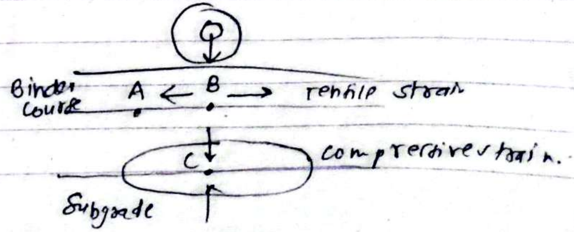
- → Quantity of surface water infiltration affects the moisture content of the subgrade and depth of GWT.
- → Poor drainage may bring lack of shear strength, pumping, loss of support etc.

4. Failure Criteria:-

→ Number of failure criterions is adopted considering different distress types.

Flexible pavement

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



- Rutting (धसिन्छो) ,
  → surface depression (rut depth) along the wheel path.
  → Failure criteria.
    ⓐ Limit veritical compression strain on

- Thermal cracking
  → Low temperature cracking
  → Thermal fatigue cracking.
  → Mix stiffness & fracture strength relationship to temperature, tensile strain due to daily temp. cycle.
  ~~→ pum~~

- Pumping, faulting / spalling / joint deterioring
  ↳ concrete टुक्रा गल्न सिट्कने
  → Difficult to analyse mechanistically

Class 3:

Chapter-2

2082/02/25

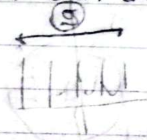
Design Methods for flexible pavements.
A. Mechanistic method
B. Semi-emperical method
C. Empirical Method
D. Mechanistic-empirical method.

- Mechanistic Method
  - Boussineq's theory
    → A layer theory first derived by Joseph Valentin Boussinesq.
    Assumptions:-
      ↳ Homogenous
      ↳ Isotropic
      ↳ Ideally elastic (constant elastic parameters E and μ - -)
      ↳ Semi-infinite

rtical stress(σ_z) = $p\left[1 - \dfrac{z^3}{(a^2+z^2)^{3/2}}\right]$

(due to UDL on circular area)

a → radius of circular loaded area
p → applied pressure per unit area
z → depth.

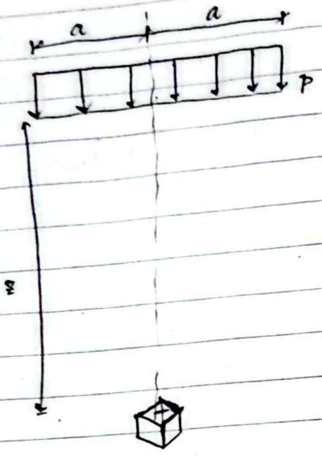


vertical displacement (Δ) = $\dfrac{pa}{E} \times \boxed{F}$

E → Modulus of elasticity of soil

F → Deflection factor for poisson's ratio of soil μ = 0.5

- vertical displacement due to u.d.l acting on a circular plate of radius a at depth z on another axis passing through center of plate



$$\Delta = \frac{pa}{E} F \text{ , } F = \text{deflection factor}$$

For flexible plate

$$F = \frac{3}{2} * \frac{1}{\left(1+\frac{z^2}{a^2}\right)^{1/2}} \quad (\mu = 0.5)$$

$$\left[\Delta_{max} = \frac{1.5pa}{E}\right] \quad \text{For } z=0$$

- Rigid plate,

$$\left[\Delta_{max} = \frac{1.18pa}{E}\right]$$

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

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

$$\left(p = \frac{\text{wheel load}}{\text{contact area}}\right)$$

p → ~~dial~~ tyre pressure

~~E=~~ P → wheel load

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

$$\therefore \left[z = \sqrt{\left(\frac{3P}{2\pi E \Delta}\right)^2 - a^2}\right]$$ ⇐ Boussinesq's displacement equation.

Drawbacks

↳ soils are not perfectly elastic and homogenous

↳

$p = \frac{P}{\pi a^2}$

Problem

Calculate the vertical deflection at the surface of a flexible pavement due to a wheel load of 30KN and a tire pressure of 0.75 MN/m². Take E pavement = E subgrade = 15 MN/m²

→ Solution,

Wheel load (P) = 30KN

Tire pressure (p) = 0.75 MN/m²

E = 15 MN/m²

$\Delta_{surf} = ?$

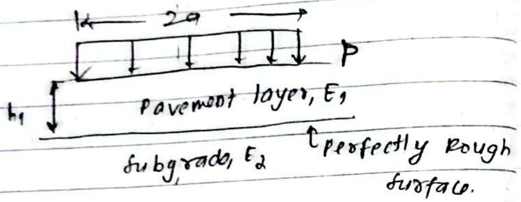
$$\Delta_{surf} = \frac{1.5pa}{E} = \frac{1.5 * 0.75 \times 1000 * 0.113}{15 \times 10^3} = 8.47 \text{ mm}$$

contact radius $a = \sqrt{\frac{P}{\pi p}} = \sqrt{\frac{30}{\pi * 0.75 * 1000}} = 0.113\text{m}$

$(P = p * \pi a^2)$

(B) Semi-empirical Method

- Burmister's Theory
  - ↳ By Donald M. Burmister, 1945
  - ↳ stresses and strain in two layered system(a pavement layer and a subgrade layer)



Assumptions:

↳ For large depth Burmister & Boussinesq's gives same depth
(interface might differ)

↳ Interface: perfectly rough ($f = 1$)
└coefficient of friction
↓
stress distribution uniform

↳ soil elastic, homogenous, isotropic, semi-infinite

↳ surface layer is free of shearing and normal stresses outside the loading area.

- Deflection at the surface (Δ)

For flexible circular plate:

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

For rigid circular plate

$\Delta =$

Displacement factor (F_w)

Depends. ↳ thickness ↑ (top layer) → F_w ↓
↳ strength ratio ($\frac{E_1}{E_2}$)

WASHO → Western Association of State Highway Officials.

AASHO

Burmister's Theory

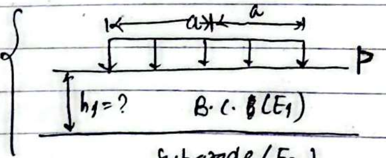
(8) Plate bearing tests were conducted with a 75cm dia plate on soil subgrade and a granular base. The stresses was 0.02MN/m² when the deflection on the subgrade soil was 0.25cm. The same plate yielded 0.25cm deflection on the base course of 15cm under a stress of 0.05MN/m². Design the pavement for an allowable deflection of 0.5 cm under a wheel load of 40KN and tire pressure of 0.5MN/m².

→ **Plate bearing test:**

Diameter of plate = 75cm , $a = 37.5cm$.

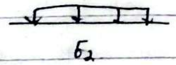
- On subgrade:
  - Deflection (Δ) = 0.25cm
  - Stress (p) = 0.02 MN/m²
- On base course:
  - Thickness of b.c. (h) = 15cm
  - Def. (Δ) = 0.25cm)
  - Stress (p) = 0.05MN/m².

Design: →



On sub-grade:-

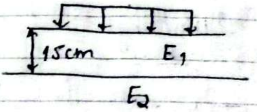
$\Delta = \frac{1.18pa}{E_2}$ (on single layer rigid pavement)



or $0.0025 = \frac{1.18 * 0.02 * 10^6 * 0.375}{E_2}$

or $[E_2 = 3.54MN/m^2]$

On base course



$\Delta = \frac{1.18pa}{E_2} * F_w$ ← two layered system

$0.0025 = \frac{1.18 * 0.05 * 10^6 * 0.375}{3.54 * 106} * F_w$

$\Rightarrow [F_w = 0.4]$.

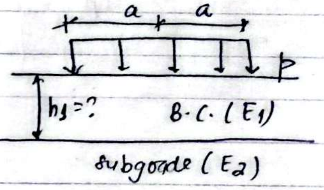
For $F_w = 0.4$, $\frac{h}{a} = \frac{15}{37.5} = 0.4$

from chart, $\frac{E_1}{E_2} = 200$ $[\overset{F_w}{0.4}, \overset{\text{Thickness of top layer}}{0.4a}\}$

$[E_1 = 200 * 3.54 = 708 MN/m^2]$

$p = \frac{P}{\pi a^2}$

Design:



$\Delta_{limiting} = 0.5cm$

$\Delta_{limit} = \frac{1.5pa}{E_2} * (F_w)_{limiting}$

~~$\pi a^2 * 40 = 0.5 * 10^3$~~ $(\pi a^2 * 0.5 * 10^3 = 40)$ $\boxed{p * A = P}$ 40kN, 0.5MN/m², πa²

$\Rightarrow [a = 0.16m = 160 cm]$.

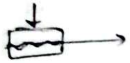
$p = 0.5 * 10^3$ kN/m²

$E_2 = 3.54 * 10^3$ kN/m²

$p = \frac{P}{\pi a^2}$ cont. (p) (P)

$\Delta_{limit} = 0.005 = \frac{1.5 * 0.5 * 10^3 * 0.16}{3.54 * 10^3} * (F_w)_{limiting}$

$(F_w)_{limiting} = 0.1475 \approx 0.14$ (round down)



For, $(F_w)_{limiting} = 0.14$, $\frac{E_1}{E_2} = 200$

~~$h = 1.3a = 1.3 * 16 = 20.8$ cm.~~

$h = 1.5a = 1.5 * 16 = \underline{24 \text{ cm}}$

(Give multiple of 5mm)

- Triaxial Method:-
  - ↳ developed by Kansas State Highway Department
  - ↳ based on Boussinesq's displacement eq^n.

Design thickness equation:

↳ Based on Boussinesq's.

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

↳ Final design thickness equation:

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

Triaxial Method

- Problem

Calculate the thickness of subbase, base and surface course using triaxial method with following data.

Wheel load (P) = 4080 kg

$E_{subgrade}$ $(E_s) = 90$ kg/cm²

$E_{sub\text{-}base}$ $(E_{sub}) = 270$ kg/cm²

E_{base} $[E_b] = 540$ kg/cm²

$E_{surface}$ $(E_{sur}] = 9000$ kg/cm²

Tire pressure (p) = 6 kg/cm²

Total traffic = 5000 vpd

Average annual rainfall = 80 cm.

Permissible deflection $(\Delta) = 2.5$ mm.

→ Solution:-

For ADT = 5000 vpd, X = 9/6

For rainfall = 80 cm, Y = 0.8

Contact radius (a) = $\sqrt{\frac{P}{\pi p}} = \sqrt{\frac{4080}{\pi * 6}} = 14.71$ cm

Thickness equation:

Taking $E_p = E_{surf} = 9000$ kg/cm²

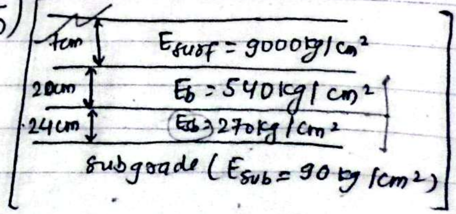
$$T_p = \sqrt{\left(\frac{3PXY}{2\pi E_{subg}.\Delta}\right)^2 - a^2} * \left(\frac{E_{subg}}{E_{surf}}\right)^{1/3}$$

$$= \sqrt{\left(\frac{3 * 4080 * \overset{1.5}{\cancel{6}} * 0.8}{2\pi * 90 * 0.25}\right)^2 - 14.71^2} * \left(\frac{90}{9000}\right)^{1/3}$$

$= \underline{22.16 \text{ cm}}$

(full depth bitumen design)

But we put 7cm (usually > 5cm) asphalt in surface



Taking thickness of surface layer (t_{surf}) = 7cm

converting remaining (22.16-7)cm to equivalent base material.

$$T_b = 15.16cm * \left(\frac{E_{surf}}{E_b}\right)^{1/3}$$

$$= (15.16) * \left(\frac{9000}{540}\right)^{1/3}$$

$$= 38.72cm.$$

→ Taking thickness of base layer (t_b) = $\boxed{22cm}$ ($\underline{\geq} 7cm$)

→ Converting remaining (38.7-22) cm to equivalent subbase material

$$T_{sb} = t_{sb} = (38.7-22) * \left(\frac{E_b}{E_{sb}}\right)^{1/3}$$

{ Must be >22cm else need to revise t_b s.t. t_{sb} >22cm }

$$= (38.72-22) * \left(\frac{540}{270}\right)^{1/3}$$

$$= 21.06 cm \ (< 22cm \text{ i.e. } t_b)$$

(NOT OK)

Again, Let, t_b = 20cm

$$T_{sb} = t_{sb} = (38.7-20) * \left(\frac{540}{270}\right)^{1/3}$$

$$= 23.56cm \ (> 22cm \text{ i.e. } t_b)$$

So okay.

Take, t_{sb} = 24cm (multiple of 5mm)

Empirical Method

- Based on soil classification
  (Ground Index Method)
- Based on Arbitrary soil strength Test
  (CBR Methods: IRC: 37-1970, Road Note 29, Road Note 31)
- Based on Pavement performance
  (AASTHO Method)

Group Index (GI)

↳ An arbitrary number used in AASHTO soil classification.

$$GI = \underline{0.2a + 0.005ac + 0.01bd}$$

GI: 0 to 20

0 → Excellent
0-1 → Good
2-4 → Fair
5-9 → Poor
10-20 → very por

$F = \underline{75\mu\text{ sie}}$ = %

$LL =$

$I_p = \underline{LL - PL}$

$a = F - 35$ (0-40)
$b = F - 15$ (0-40)
$c = LL - 40$ (0-20)
$d = I_p - 10$ (0-20)

→ Higher GI ⇒ lower strength ⇒ greater thickness of sub-base required

→ The thickness of base & surface is varied according to the volume of commercial traffic expected

- Traffic cateorgies

Light volume traffic	<50	comercial traffic/day
Medium	50-300	
Heavy	>300	

GI Method

(Q) A subgrade soil sample has following properties!
Soil passing 75 micron sieve = 60% = % fine (F)
Liquid limit (LL) = 65% .
Plastic limit = 35%

Design the pavement section by group index method for heavy traffic with over 400 commercial vehicles per day (cvpd)

→ Sol^n:-

% fine (F) = 60%
Liq. limit (LL) = 65%
Plas. limit (PL) = 35%

Plasticity Index (I_p) = 65-35 = 30%
Traffic = 400 cvpd (>300 ⇒ heavy traffic)

a = 60-35 = 25
b = 65-15 = 40   { as b: $\overset{\text{range}}{0-40}$ }
c = 60-40 = 20
d = 30-10 = 20

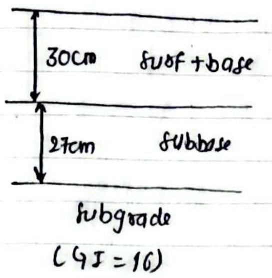
57 subbase

GI = 0.2a + 0.005ac + 0.01bd
= 0.2 * 25 + 0.005 * 25 * 20 + 0.01 * 40 * 20
= 15.5 ≈ 16 (round up → as जति बढी GI → thickness ↑)
(low strength) (safer side)

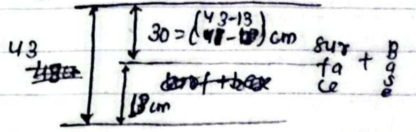
Thickness design!
GI = 16 , Traffic = heavy.

Thickness of sub-base = 27cm (selected material subbase only)

Thickness of surf + base + subbase = 57cm
Thickness of surface + base = (57-27) = 30cm.



'Or'



subgrade.

'Or'
Base only = ~~18cm~~ 13cm
surface + base = 43cm

⊡ CBR Method

↳ California Bearing Ratio of subgrade soil

(IRC Recommended CBR)

) Design a flexible pavement using CBR curves, given the following data:

Subgrade soil, CBR = 4 %.

Compacted sandy soil, CBR = 10 %

Poorly graded gravel, CBR = 25%.

Well-graded gravel, CBR = 90%.

Minimum thickness of bituminous concrete surfacing = 5cm

Number of heavy vehicle per day in Sept. 2021 = 1000

Design life = 10 yrs.

Annual growth rate of traffic = 6%.

{ If Design period not given → take 1.5-2 yrs]

The road is proposed to be completed in september 2024.

→ Design traffic

Traffic at last count / base yr. traffic (P) = 1000 cvpd

Design life (n) = 10 yrs.

NO. of yrs from last count to the completion of construction (y) = 3yrs.

Expected traffic at the end of design life (A)

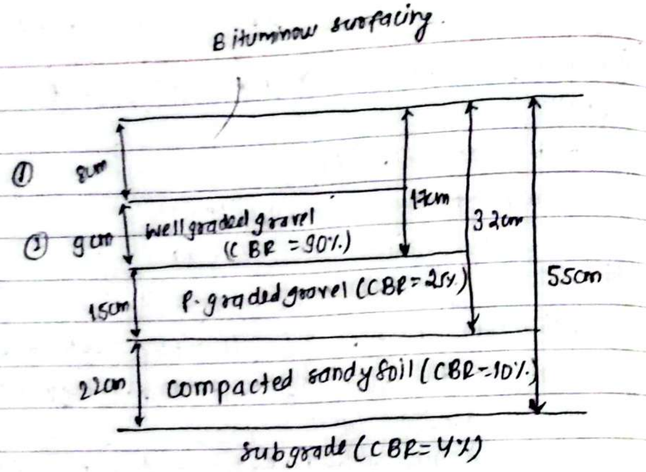
$$= P(1+r)^{n+y}$$

$$= 1000(1+0.06)^{10+3}$$

$$= 2132.93$$

$$\approx 2133$$

(Design curve F as range: 1500–4500)



(Generally ① मन्दा ② बढी)

Thickness design:

Total pavement thickness required to cover subgrade of CBR 4% for DT of F = 54cm (from curve)
↑
Daily Traffic

Total pavement thickness required to cover compacted sandy soil of CBR 10% for DT of F = 32cm
Actual pavement thickness ~~of~~ of compact sandy soil
= 54-32
= 22cm

Total pavement thickness required to cover Poorly graded gravel of CBR 25% for DT of F = 17cm
Actual pavement thickness of Poorly graded gravel = 32-17
= 15cm

Total pavement thickness reqd to cover Well graded gravel of CBR 90% for DT of F = 8cm
Actual pavement thickness of Well graded gravel = 17cm - 8cm
= 9cm

Drawbacks of IRC Recommended CBR
↳ Material specification of pavement not covered
↳ Load repetition not covered (covered in Road Note 29)

Road Note 29 (RN-29) – Major change in design traffic consideration

→ A revised methodology based on CBR value by Transport and Road Research Laboratory (TRRL) Britain
→ Introduced in 1960, revised in 1965, published as a manual in 1970.

Major features.

↳ Use of cumulative of standard axles in the design life of pavement over number of commercial vehicles per day.
↳ Different design thickness chart:
  ⓐ for sub-base (uses CBR values) and
  ⓑ for base and surfacing (with specified materials and considering varying cumulative number of standard axles) → enable planning of stage construction

[Full scale test → Real test]
[↳ based on axle loading consideration]
[↳ stage construction]. { overlay construction later for extra years if design traffic ↑ }.

- Design steps

① Estimate cumulative number of standard axles:

(a) Determine cvpd per lane (slow lane) from traffic survey and convert it to 80KN equivalent single axle load (esa) to find the present/base year traffic in number of axles per day. { Lane को लागी }

curve lane
↓
left lane
(slow lane)

ⓑ Determine the expected number of axles per day on the day it is opened using a suitable growth rate.

axle load → equivalency factor (if not given AASHTO 4th power formula)

① Determine number of axlar loads per day for each year during the design life. The number of axles per day mulltiplied by 365 for each year of life is summed to give the cumulative number of axle over the design life.

Design traffic:

Present or base yr traffic = P esal day

(esa/day)

(equivalent standard axle/day)

Expected traffic at the end of constructionperiod

$(A) = P(1+r)^y$ esal/day.

$y \rightarrow$ No. of construction year

(प्रक्षेपित [illegible] traffic [illegible])

Traffic!

Opening yr = $365 * A$

1st yr = $365 * A(1+r)$

2nd yr = $365 * A(1+r)(1+r)$

|

|

nth yr = $365 * A(1+r)^n$

n = design period

cumulative no. of std. axle over the design life in design lane $(N) = 365A\{1+(1+r)+\ldots+(1+r)^n\}$

S = ~~a(1+r)~~ $\frac{a(1-r^n)}{1-r}$

CBR test] → 12.5mm-20mm

↳ sub-base, base को लागि हुन्छ

$$S = \frac{1 * \{1-(1+r)^n\}}{(1-1-r)} = \left\{\frac{(1+r)^n - 1}{r}\right\}$$

$$\left\{N = \frac{365A\{(1+r)^n - 1\}}{r}\right\}$$

80kN बराबरको No. of axles.

② Determine thickness of sub-base based on on the cumulative number

- DT → subgrade CBR → sub-base thickness
- (1MSA) & (30%) → subgrade नै subbase जस्तै बनियो (no need to give subbase). } 30% or more छ भने subbase दिनु पर्दैन (subgrade नै बनियो)
- Min. req. of subgrade छ भने → no need to give subbase

> 0.5MSA & CBR < 30% → 150mm

< 0.5MSA & CBR < 20% → 80mm

~~[illegible]~~ & CBR < 2% → ($CBR_{2\%}$ thickness) + 150mm.

RN29 graph

③ Determine thickness of base course and surfacing using.

DT ⟶ CBR acc. to DT → thickness of layer

<u>RN-29</u>

Q) A double lane Highway is to be constructed for the present traffic load of 2200 cpvd. The estimated rate of growth of traffic is 7% and the period of construction is 2 years. The highway is to be designed for a life time of 20 years after construction and CBR value of subgrade is 5%. Design the flexible pavement as per Road Note 29. Adopt number of standard axles per commercial vehicle = 1.08.

→ **Design Traffic:**

Present or base year traffic (P) in design lane $= \frac{2200}{2}$ [Assuming direction distribution 50/50 percent]

$= 1100 \times 1.08$ esa/day ← converting factor

$= 1188$ esa/day.

Expected traffic at the end of construction period (A) (or before the road open to traffic)

$A = P(1+r)^y$ esa/day

$= 1188\,(1+0.07)^2$

$= 1360.14$ esa/day.

Cumulative no. of std. axles over the design life in design lane (N)

$N = \frac{365\,A\,\{(1+r)^n - 1\}}{r}$ esa

$= 20.4$ msa $\quad \{n = 20\}$

Thickness design:

Subgrade CBR = 5%
Design traffic = 20.4 msa.

Thickness of subbase = 280mm

Alt. I: (Alternative)
Thickness of base (DM) = 180mm (Dense Macadam)
" " surface = 100mm

Alt II
Thickness of. base (rolled asp.) = 150mm
" " surface = 100mm

Alt III: (chart 2)
Thickness of base (lean concrete ~~cement treated~~) = 210mm (traffic अनुसार (>4 msa – Lean concrete))
Thickness of surface = 130mm
{* को meaning → 30mm can be converted to composite base course
जसको 30mm मा bitumen कम भए नि हुन्छ}

Road Note 31/Catalogue Method

– considered local condition
– used in DPR
– sub-tropical countries

→ Based on research conducted in countries throughout the world by Transport Research Laboratory UK. (TRL, UK)
→ First published in 1962, Overseas Road Note 31 (Fourth Edition) in 1993
- Caters traffic up to 30 million ESAL
- considers variability in material properties, uncertainty in traffic and effect of climate and high axle loads.

Design steps:

① Estimating amt. of traffic and cum. number of equivalent standard axles that will use the road over the selected design life;
- only the total number and the axle loading of the heavy vehicles (unladen wt. of 3000kg or more) need to be consi
  ↳ load को मात्र (self wt. excluded)

07.16

OD → origin Destination study.
Survey
Classify count → Minⁿ 3 days (usually 7 day

(Directional highest लाई नै design lane मानिन्छ)

RN31

Q. RN31) Catalogue Method

In a certain section of single Lane road, it is intended to construct the road pavement. The traffic survey shown that the road caters present ADT of 132 cv/day. The annual growth of traffic is 7%. The pavement is to be designed for 10 years period and expected completion period is 2 years from the last date of traffic count. CBR test values of subgrade soil:

Penetration mm	Load kg	Penetration mm	Load kg
0.0	0.0	3.0	56.5
0.5	5.0	4.0	67.5
1.0	16.2	5	75.2
1.5	28.1	7.5	89.0
2.0	40.0	10.0	99.5
2.5	48.5	12.5	106.5

Adopt equivalency factor for each commercial vehicle in 80KN single axle load = 1. Design pavement section as per RN 31 Guideline.

→ 1. Design traffic:

Present or base yr. traffic(P) = 132 × 1 esa/day ← equivalency factor
(single lane)

= 132 esa/day single lane.

Expected traffic at the end of construction period (A)

$$A = P(1+r)^N$$

$$= 132(1+0.07)^{10}$$

$$= 151.13 \text{ esa/day}$$

cumulative no. of std. axles over the design life in design lane (N) =

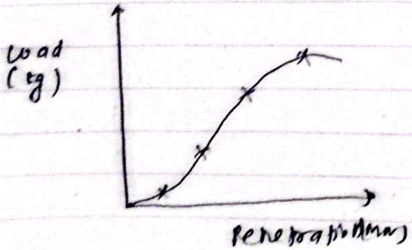
$$\frac{365 \times A \times [(1+r)^n - 1]}{r}$$

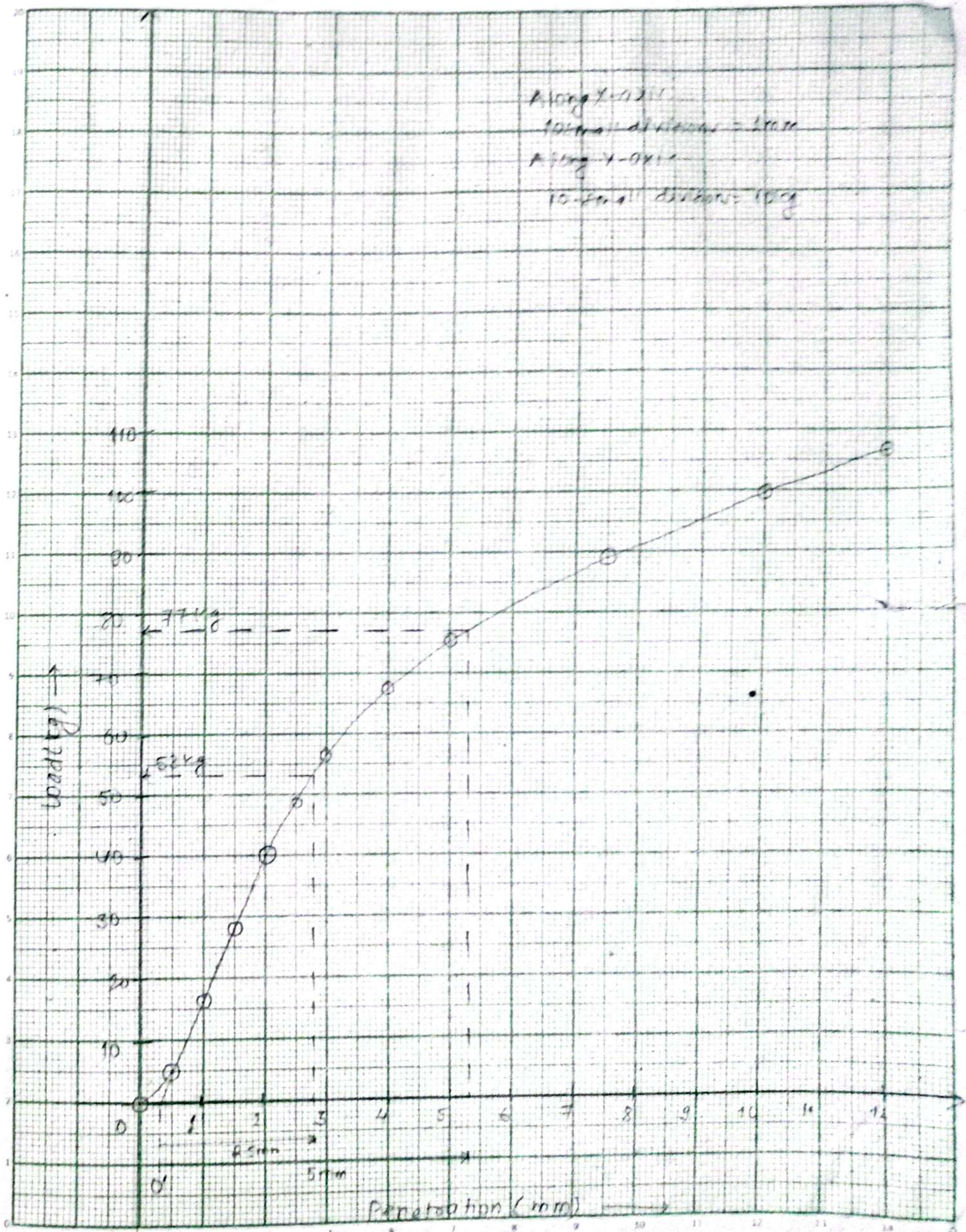
$$= \frac{365 \times 151.13 [(1+0.07)^{10} - 1]}{0.07}$$

= 0.76 msa
(million standard axles)

2. Design CBR

Load at 2.5 mm penetration = 58 kg
Load at 5 mm penetration = 77 kg





→ 1. Design traffic,

Present or base yr traffic (P) = 132 × 1 esa/day (single lane) ← equivalency fact.

= 132 esa/day single lane.

Expected traffic at the end of construction period (A)

$$A = P(1+r)^N$$

$$= 132(1+0.07)^{10}$$

$$= 151.13 \text{ esa/day}$$

Cumulative no. of std. axles over the design life in design lane (N) = $\frac{365 \times A \times [(1+r)^n - 1]}{r}$

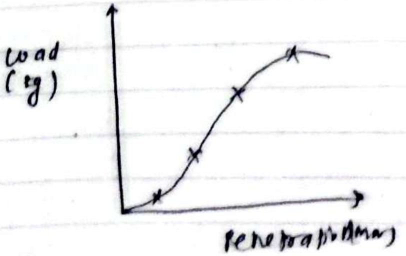
$$= \frac{365 \times 151.13 [(1+0.07)^{10} - 1]}{0.07}$$

= 0.76 msa (million standard axles)

2. Design CBR

Load at 2.5mm penetration = 53kg

Load at 5mm penetration = 77kg



CBR at 2.5mm penetration = $\frac{\text{Load sustained by specimen at 2.5mm penetration}}{\text{Load sustained by standard ~~axle load~~ crushed agg. at 2.5mm pen.}}$

$$= \frac{53 \text{ kg}}{1370 \text{ kg}} = 3.87\%$$

CBR at 5mm penetration = $\frac{\text{Load sustained by specimen at 5mm penetration}}{\text{Load sustained by standard crushed agg. at 5mm penetration}}$

$$= \frac{77 \text{ kg}}{2055 \text{ kg}} = 3.75\% < 3.87\%$$

(okay)

∴ Design CBR = 3.87%.

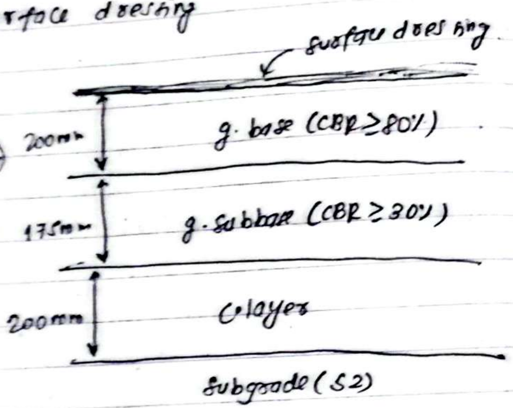
3. Thickness design

Traffic class = T3 (0.76 msa)

Subgrade class = S2 (3.87%)

(stay in lower class)

Thickness of capping layer = 200 mm (T3-S2)
Thickness of granular subbase = 175mm (T3-S2)
Thickness of granular base = 200mm (T3-S2)] chart 1.
Surface = surface dressing



(thk Gen. g. base < thk of g. subbase)
↓
but as it come from chart 1
(do as it is)

AASTHO Method
↳ US (AASTHO 1993)
↳ emperical method based on field performance data measured at AASTHO road test.
↳ ~~Design paremer~~

- Serviceability

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

where,

$\overline{SV}$ = Slope varience (measure of ~~rg~~ roughness)
$\overline{RD}$ = Average rut depth (inches)
$C+P$ = Area of cracking and patching per 1000 ft²

PSI	Objective rating
4-5	very good
3-4	Good
2-3	Fair
1-2	Poor
0-1	very Poor

✓ Design equation

$$\log_{10}(W_{18}) = Z_R S_0 + 9.36 \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \log_{10} M_R - 8.07$$

where,

W_{18} = Number of 18 kips ESALs.

Z_R = standard normal deviate.

Z_R [S_0] → Reliability parameter.

S_0 = ~~standard no~~ overall standard deviation

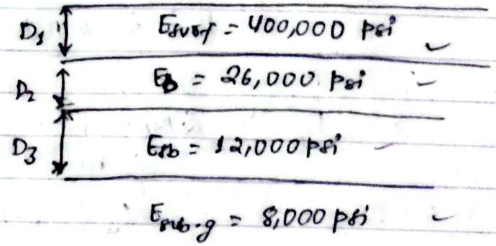
ΔPSI = Allowable serviceability loss at end of design life.

M_R = Resilient modulus of road bed (psi).

SN = structural number.

(Q) Design a pavement for a rural highway using AASTHO flexible design procedure. The expected ~~life~~ design ESAL is $13*10^6$. The pavement structure is to consist of asphalt concrete with an elastic modulus of 400,000 psi, a granular base with an elastic modulus of 26,000 psi and a granular subbase with an elastic modulus of 12,000 psi. The elastic modulus of the subgrade is 8,000 psi. The drainage conditions of base and sub-base are fair. It is estimated that the pavement will be saturated about 15% of the time. Assume that a reliability level of about 90% is required and that the initial serviceability index is 4.2 and final serviceability index is 2.5.

AASTHO Method



① W_{18} = 13msa = $13*10^6$

② Reliability, = 90%.

overall std. dev. S_0 = 0.45 (assume)

std. normal deviate Z_R = −1.28

③ Allowable serviceability loss,

$$(\Delta psi) = P_0 - P_t$$
$$= 4.2 - 2.5$$
$$= 1.7$$

④ M_R depends on SN:

SN_1 (surface), M_R = 26,000 psi — base

SN_2 (surface + base), M_R = 12,000 psi — sb

SN_3 (surface + base + sub base), M_R = 8000 psi — subgrade

⑤ [SN_1 = 3.3 SN_2 = 4.4 SN_3 = 5.04] calculator

chart (nomograph) [SN_1 = 3.3 SN_2 = 4.3 SN_3 = 5.0].

⑥ Layer's structural coefficients.

α_1 = 0.42 (chart) → for surface, E = 400,000 psi

$\alpha_2 = 0.249(\log_{10} E_b) - 0.977 = 0.122$

$\alpha_3 = 0.227(\log_{10} E_b) - 0.839 = 0.087$

⑦ Drainage coeffs:-

m_2 = 0.9
m_3 = 0.9] same drainage condition for both (fair & 15% moisture level)

(all in inches).

⑧ • $SN_1 \le \alpha_1 D_1$

$D_1 \ge \frac{SN_1}{\alpha_1} \ge \frac{3.3}{0.42}$.

$D_1 \ge 7.86$ inch. $\approx$ 7.9 inch (round up)

$(7.9) \Rightarrow D_2 \ge 8.94$
≈ 9 inch.

• $D_2 \ge \frac{SN_2 - \alpha_1 D_1}{\alpha_2 m_2} \ge \frac{4.3 - 0.42 * 7.86}{0.122 * 0.9}$

$D_2 \ge 9.108$ inch

• $D_3 \ge \frac{SN3 - \alpha_1 D_1 - \alpha_2 m_2 D_2}{\alpha_3 m_3}$

$D_3 \ge 8.86$
≈ 9 inc

(7.9) ⑨

$\ge \frac{5 - 0.42 * 7.86 - 0.122 * 0.9 * 9.108}{0.087 * 0.9}$

≥ 8.95 inch

Minimum check

$D_1 = 7.9$ inch > 4 inch OK

$D_2 = 9$ in > 6 in OK

$D_3 = 9$ in

Mechanistic - Emperical Methods

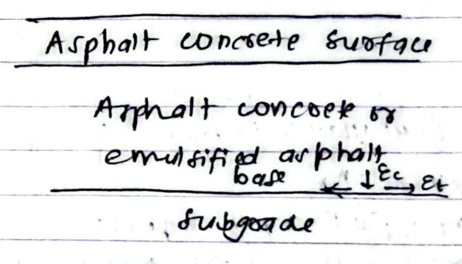
- → consider mechanics of materials together with observed performance.
- → pavement configuration, structural model (stress/strain), (distress modal/failure criteria)

Asphalt Institude Method

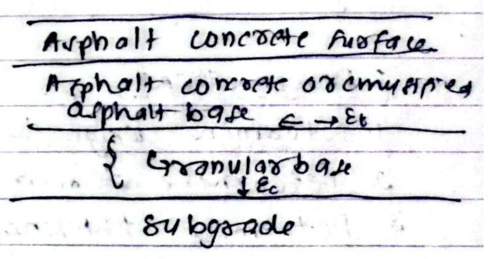
- ↳ earliest mechanistic-emperical method.
- ↳ A ~~de~~ series of thickness design manual (1981 & later edition)
- ↳ Based on theories and emperical observations.
- ↳ Can be used to design various combination of asphalt..

• Design principle:

↳ pavement regarded as a multi-layered elastic system.



Full depth asphalt pavements



Pavement with granular base

- Failure criteria
  - Fatigue cracking:

$$N_f = 1.365\,(\varepsilon_t)^{-0.3291}\,(E)^{-0.854}$$

where,

$N_f =$

  - Rutting failure

$$N_d = 1.365 * 10^{-9}\,(\varepsilon_c)^{-4.477}$$

- Design subgrade resilient Modulus (M_R):

→ Recommends triaxial tests for determining M_R, otherwise can

- 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 thk. of emulsified asphalt base and untreated aggregate bases using

8) Design a pavement for a certain length of existing single lane carriageway with the following data. CBR results of subgrade soil obtained from seven locations in the stretch are given in the table:

a) current traffic of 80kN equivalent single axle load = $0.26 * 10^3$ EAL/day
(b) Design period = 10 yrs.
(c) Construction period = 18 months from last traffic count
(d) Traffic growth rate = 8%.
(e) Elastic modulus of asphalt concrete for surface course, $E_{ac} = 2500$ MPa.
(f) " " " emulsified stabilized base, $E_b = 1200$ MPa.
(g) " " " granular sub base (CBR ≥ 30%), $E_{sb} = 150$ MPa.
(h) Draw the X-section of final pavement layers considering the thickness of asphalt concrete on the surface course not less than 75mm.

SN	1						
Chainage	0+50	0+350	0+500	0+650	0+800	0+950	1+500
Test. CBR results in %	11	9	7	8	6.5	5	4

→ Soln.:

Design traffic (N):

Current or base year traffic (P) = $0.26 * 10^3$ esal/day

[lane distribution & directional distribution is 1 as single lane].

Expected traffic at the end of construction period

$(A) = P(1+r)^x$ $\quad (y = 18 \text{ months} = 1.5 \text{ yrs.})$

$= 0.18 * (1+0.08)^{1.5}$

$= 0.29 \times 10^3$ sa

Cumulative no. of standard axles over the design life

in design lane $(N) = \dfrac{365 A \, [(1+r)^n - 1]}{r}$

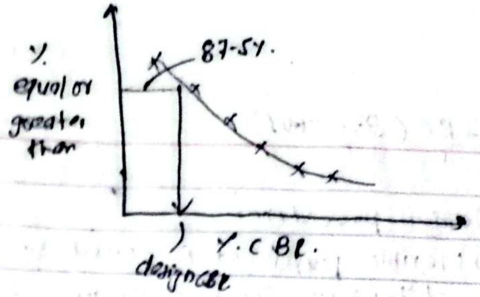
$= 365 * 0.29 \times 10^3 * \dfrac{[(1+0.08)^{10} - 1]}{0.08}$

$= 1.54$ msa.

② Design subgrade resilient modulus $(M_R) = 10.3 *$ DesignCBR

Design CBR = 87.5th percentile CBR (N>1msa) = $\underline{4.9\%}$

S.N.	(dec. order) % CBL	No. of reading equal or greater than	% Reading equal or greater than
1	11	1	14.28
2	9	2	28.57
3	8	3	42.86
4	7	4	57.14
5	6.5	5	71.43
6	5	6	85.71
7	4	7	100



Design $M_R = 10.3 * \overset{4.9}{\text{DesignCBR}}$

$= \underline{50.47}$ MPa

(3) Thickness design

Thickness of full depth asphalt concrete required for (N = 1.54 msa) ; M_R = 50.47 MPa) = 225mm.

(From chart $\underline{A-1}$)

(50.47MPa & 1.54msa).

→ Taking thickness of asphalt concrete surface layer = $\underline{75\text{mm}}$ &
(min)

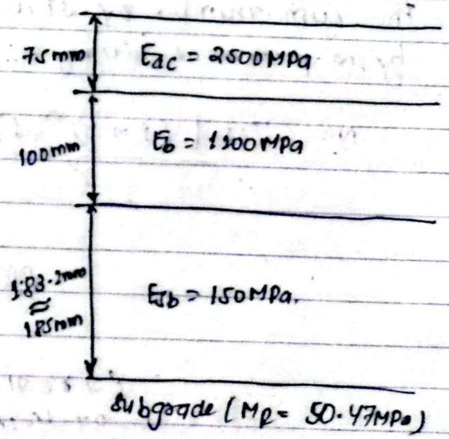
→ Converting remaining (225-75)mm to equivalent emulsified stabilized base T_b =

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

{Nb: ac > b > sb]

$$T_b = (225-75)\left(\frac{2500}{1200}\right)^{1/3}$$

= 191.58mm.



Taking thickness of emulsified stabilized base = 100mm &

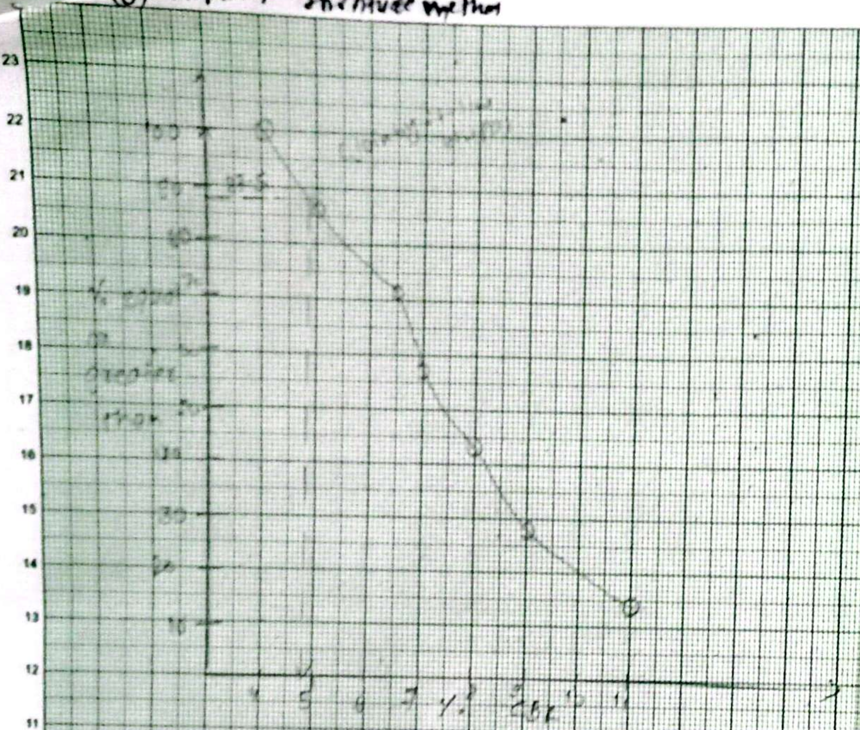
→ ~~Taking~~ converting remaining (191.6 − 100) mm to emulsified granular subbase

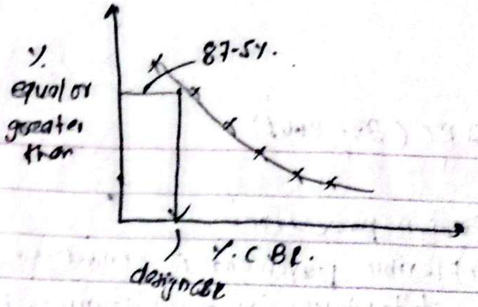
$$t_{sb} = (191.6-100) * \left(\frac{1200}{150}\right)^{1/3}$$

= 183.2mm.

≈ 185mm.

(4) Asphalt Institute method





$*\left\{ \text{Design } M_R = 10.3 \times \text{DesignCBR}^{4.9} \right.$

$= \underline{50.47}\,\text{MPa}$

(3) Thickness design

Thickness of full depth asphalt concrete required for ($N = 1.54$ msa) ; $M_R = 50.47$ MPa) = 225mm.

(From chart A-1)

(50.47MPa & 1.54msa).

→ Taking thickness of asphalt concrete surface layer = 75mm & (min)

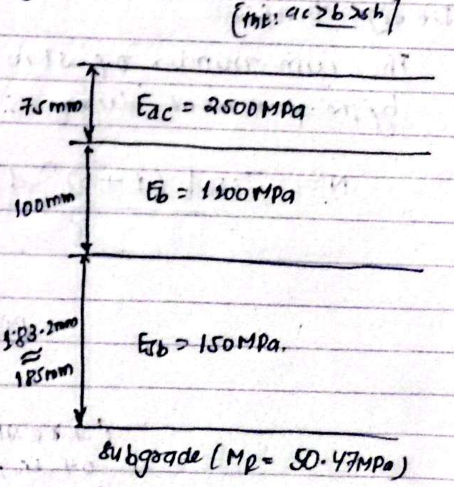
→ Converting remaining (225-75)mm to equivalent emulsified stabilized base T_b =

[thk: ac ≥ b > sb]

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

$T_b = (225-75)\left(\frac{2500}{1200}\right)^{1/3}$

$= 191.58$mm.



Taking thickness of emulsified stabilized base = 100mm &

→ ~~Taking~~ converting remaining (191.6 − 100) mm to emulsified granular subbase

$t_{sb} = (191.6-100) \times \left(\frac{1200}{150}\right)^{1/3}$

$= 183.2$ mm.

≈ 185mm.

IRC (37-2001)

- Design procedure:

→ Flexible pavement is considered to compose of 3 layers: bituminous surface, granular base and subbase course

→ Analytical approach based on multiple layer elastic theory

→ Critical stresses and strains are computed from software FPAVE which uses.

→ Fatigue and rutting failure criteria were consider

→ Simple design charts and catalogue

- Design traffic:

The cum. number of standard axles (N) to be carried by the pavement during the design life in design lane.

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

Lane Distribution factor (LDF)

(a real estimate of distribution of commercial traffic by direction and by lane)

Remember LDF values.

Problem 1

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

(a) 2-lane single carriageway is to be designed in plain area.

(b) Initial traffic in the year of completion := 310 cvpd (sum of both directions)

(c) Traffic growth rate = 7%

(d) Design life = 15 yrs.

(e) Design CBR of subgrade soil = 5.0%

→ Sol:

1. Design traffic:

Initial traffic in the year of completion of construction

(A) = 310 cvpd

(r) = 7%

(n) = 15 years

VDF (F) = 3.5 (from table)

LDF (D) = 0.75 of both direction.

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

= 7.46 msa

2. Design subgrade CBR = 5%.

3. Thickness design:

Total thickness of pav. required = 620 mm

(Interpolate to multiple of 5)

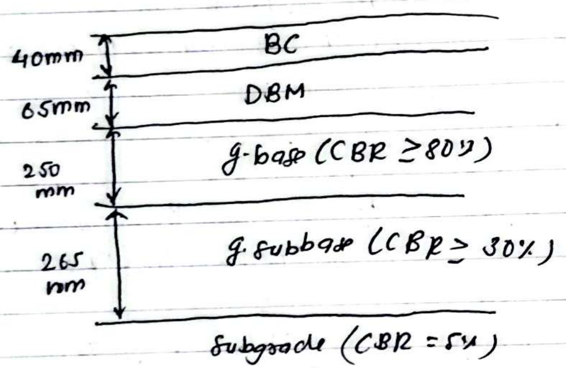
Pg. 24

ie [Different material → cannot interpolate]

Total thickness of WC (surface) = 40 mm BC
Total thickness of (Binding course surface) = 65mm (DBM)
" " " granular base = 250mm
" " " granular subbase = 620 − 40 − 65 − 250

= 265mm

(वही or = to interpolate values



(IRC 37-2001)

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

(a) 2-lane single carriageway is to be designed in plain area.
(b) Initial traffic in the year of completion of construction = 310 cvpd (sum of both directions) with axle load distribution as given below:

Heavy truck (12t)	10%
Light truck (10t)	20%
Mini truck (8t)	40%
Large Bus (6t)	20%
Bus (5t)	10%

(c) Traffic growth rate = 7%.
(d) Design life = 15yrs.
(e) Design CBR of subgrade soil = 5.0%

→ 1. Design traffic:

Initial traffic in the year of completion of construction

(A) = 310 cvpd

r = 7%

n = 15yrs.

LDF (D) = 0.75.

$(L/80)^4$ No of CV * Eq. factor

CV type	No. of CV	Axleload (KN)	Eq-factor	esal/day	
HT	31	120	5.0625	Eq. factor * 31	= 156.93
LT	62	100	2.4414	151.36	
MT	124	80	1	124	
LB	62	60	0.3164	19.62	
B	31	50	0.1526.	4.73	eqv. factor
				456.65 esal/day	← A*F

Assuming single axle dual wheels:

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

$$= \frac{365 * 456.65 * [(1+0.07)^{15} - 1] * 0.75}{0.07}$$

$= 314$ msa

2. Design subgrade CBR = 5%

3. Thickness design:

Total thickness of pavement required =

$$530 + \frac{580-530}{(5-3)} * (3.14-3)$$

$= 533.5 \approx 535$ mm
(Pg. 24)

Total thk. of WC (surface) = 20 (PC)

(20 mm or less भयो भने thickness मा contribute गर्दैन)

" " " Bind. course (surface) = 50 mm (BM)

" " " g. base = 250 mm

" " " g. sub-base = 535 − 50 − 250
= 235 mm
(not taking 20 mm WC surface)

(> 230 mm)
OK

DOR (2021)

Q. Design the flexible pavement for construction of new road with the following data for the flexible pavement design:

ⓐ 2-lane single carriageway is to be designed in plain area.

ⓑ Initial traffic in the year of completion of construction = 310 cvpd (sum of both directions as mentioned below

(i)	Heavy truck (3 axle)	= 30
(ii)	Heavy truck 2-axle	= 70
(iii)	Mini truck	= 120
(iv)	Large bus	= 60
(v)	Bus	= 30

ⓒ Traffic growth rate = 7%

ⓓ Design life = 15 yrs.

ⓔ Design CBR of subgrade soil = 5%

→ Soln:

1. Design traffic

Initial traffic in the year of completion of construction

(A) = 310 cvpd

(r) = 7%

n = 15 yrs.

LDF (D) = 0.75.

CV type	No. of CV	VDF	esal/day
HT	30	6.5	195
LT	70	4.75	332.5
MT	120	1	120
LB	60	0.5	30
B	30	0.35	10.5
			688 esal/day.

esal/day → VDF * No. of CV

Assuming single axle dual wheels

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

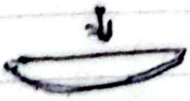
$$= \frac{365 * 688 \{(1+0.07)^{15} - 1\} * 0.75}{0.07}$$

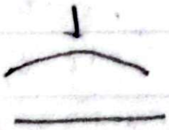
= 4.73 msa/day.

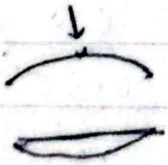
2. Design CBR = 5%.

3. Thickness design : N = 5msa, CBR = 5%]

Total thickness of pav. required = 490mm (AC)
" " " WC (surface) = 40mm
" " " Bind. course (surface) = 0 mm
" " " g. base = 250mm
" " " g. subbase = 200 mm.





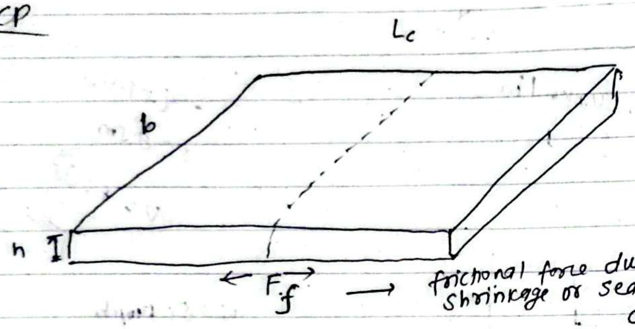


~~# Westg~~

Westergaard's Theory.

:- Wheel load stress

JPCP



→ frictional force due to concrete shrinkage or seasonal temperature change.

$$L_c = \frac{2 S_c \times 10^4}{W f} \text{ (for PCC parements)}$$

$$L_c = \frac{200 A_s \times S_s}{W b f h} \text{ (For RC parements)}$$

→ Frictional force developed $= W \times f \times \frac{L_c}{2} \times b \times h/100$

$\downarrow$ (under f): Coeff of friction.

→ Allowable tension in concrete $= S_c \times 10^4 \times b \times \frac{h}{100}$

$$W \times f \times \frac{L_c}{2} \times b \times \frac{h}{100} = S_c \times 10^4 \times b \times \frac{h}{100}$$

$$\left[L_c = \frac{2 S_c \times 10^4}{W f} \right]$$

For JRCP,

$$W \times f \times \frac{L_c}{2} \times b \times \frac{h}{100} = S_s \times A_s$$

$$\left[L_c = \frac{200 S_s \times A_s}{W f b h} \right]$$

*) Design of slab thickness

1. Width of slab (l_y) = 3.5m
2. Length of slab (l_x) = $\frac{2 \times \varepsilon_c \times 10^4}{W f}$

$= \frac{2 \times 0.8 \times 10^4}{2400 \times 1.5}$

= 4.45m < 4.5m (ok).

3. Assume : h = 20cm
4. Radius of relative stiffness:

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

$$l = \left[\frac{3 \times 10^5 \times 20^3}{12(1-0.15^2)} \right]^{1/4}$$

l = 71.1 cm

Warping stress of edge:- $\frac{l_x}{l} = \frac{4.45 \times 100}{71.1} = 6.26$

$C_x = 0.95$

$\frac{l_y}{l} = \frac{3.5 \times 100}{71.1} = 4.92$

C_y = ~~[illegible]~~ $\underline{0.698}$

Δt for 20cm thickness = 15.8°C

σ_{te} = 24 kg/cm²

(from chart)

5. Remaining strength = $40 - \sigma_{te}$ = 40 - 24 = $\underline{16 kg/cm^2}$

6. Load stress at edge (σ_e) from chart:

$\underline{\sigma_e}$ = 27 kg/cm².

7. Factor of safety = $\frac{\overset{16}{\text{Req. strength}}}{\sigma_e \to 27}$ = 0.5

(uns

d)

3. Assume, $h = 25\text{cm}$

4. $$l = \left[\frac{Eh^3}{12(1-\mu^2)k}\right]^{1/4} = 90.67\text{cm}$$

Warping stress at edge:

$$\frac{lx}{l} = \frac{4.45 \times 100}{90.67} = 4.91$$

$$C_x = 0.695$$

$$\frac{ly}{l} = 3.86$$

$$C_y = 0.403$$

At for 25cm thickness = ~~15.8°C~~ 16.3°C.
(table)

σ_{te} (from chart) = 17.5 kg/cm².

5. Remaining strength = 40 − 17.5 = 22.5 kg/cm².

6. Load stress at edge (σ_e) from chart

σ_e = 17.5 kg/cm².

7. Factor of safety = 1.29 > 1

safe

Now, corner

(8) Corner stress:

Warping stress at corner (σ_{te}) $= \dfrac{E\alpha t}{3(1-\mu)}\sqrt{\dfrac{a}{l}}$

$$= \frac{3\times10^5 \times 10 \times 16.3}{3(1-0.15)}\sqrt{\frac{15}{90.67}}$$

$$= 7.79\text{kg/cm}^2$$

Load stress at corner (σ_c) = 20kg/cm².
(chart)

$\sigma_{tc} + \sigma_c = 27.79 < 40\text{kg/cm}^2$ o.k

9. P = 950 cvpd

Assume

n = 20 years

r = 7.5%

$A = P(1+r)^n$

$= 950(1 + 7.5\%)^{20}$

$= 4035.46$

Adjusted thickness = 25 + 0 (No correction required)

= 25cm

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

$$P_s = 0.785d^2F_s$$

(9) Design spacing & dowel bars of expansion joint for a concrete pavement with following details:

[$\alpha = 10*10^{-6}/°C$]

Design wheel load = 5100kg.

Design load transfer = 40%.

Slab thickness = 20cm

Expansion joint width (δ) = 2cm

Maximum variation of temp^r b/w summer and winter = 35°

Permissible flexural stress in dowel bar (F_f) = 1400kg/cm²

" shear " " " " (F_s) = 1000kg/cm²

" bearing " " " " (F_b) = 100kg/cm²

Modulus of subgrade reaction = 8kg/cm³

→ Sol^n:-

(i) <u>Spacing of expansion joints</u> $= \dfrac{\delta'}{100 \times \alpha * \Delta t}$

$$= \frac{\underset{(2cm)}{\text{Joint width}}/2}{100 * \underset{\uparrow 10\times10^{-6}/°C}{\alpha} * \underset{\uparrow 35°C}{\Delta t}}$$

= 28.57cm < 140cm (OK)

Design of Dowel Bar

(ii) <u>Dowel bar:</u>

Assume diameter of dowel bar (d) = 2cm (assume)

<u>1.</u> Length of embedment (L_d) for equal capacity in flexural & bearing

$$\frac{2d^3F_f}{(L_d+8.8\delta)} = \frac{L_d^2 d F_b}{12.5(L_d+1.5\delta)}$$

(δ = 2cm)

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

or $L_d = 5*0.02*\sqrt{\dfrac{1400\,(L_d+1.5\times0.02)}{100\,(L_d+8.8*0.02)}}$

⇒ L_d = ~~[illegible]~~ 0.313m ≈ 31.3cm.

$L = L_d + \delta$ = 33.3 cm ≈ 35cm

Act: L_d = 35−2 = 33cm.

<u>2.</u> Load transfer capacity of each dowel bar:

$P_s = 0.785d^2 F_s$

$= 0.785 * 2^2 * 1000$

= 3140 kg.

Fail in flexure

$P_f = \dfrac{2d^3 \cdot F_f}{(L_d+8.8\delta)} = \dfrac{2*2^3*1400}{(33+8.8*2)}$ = 442.7kg] min

$P_s = \dfrac{L_d^2 d F_b}{12.5(L_d+1.5\delta)} = \dfrac{33^2*2*100}{12.5(33+1.5*2)}$ = 484kg.

3. Required load transfer capacity of effective dowel system

$$= \max.\left(\frac{0.4P}{P_s}, \frac{0.4P}{P_f}, \frac{0.4P}{P_b}\right)$$

$$= \max.\left[\frac{0.4 \times 5100}{3140}, \frac{0.4 \times 5100}{442.6}, \frac{0.4 \times 5100}{484}\right]$$

=

= 4.61

(4) Assuming spacing of 20cm c/c

[15cm, 20cm, 25cm, 30cm)

↑Assume

Radius of relative stiffness (l)

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

$\mu = 0.5$

E =

$l = 71.1cm.$

h = slab thickness.

Length upto which dowel bars are effective = 1.8l

$= 1.8 \times 71.1$

$= 127cm.$

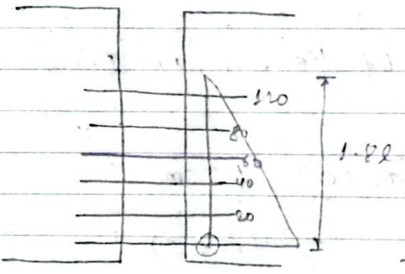
Load transfer capacity of eff. dowel bar system

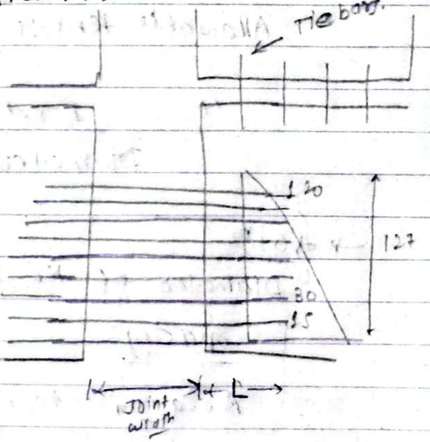
$$= 1 + \left(\frac{1207-40}{127}\right) + \left(\frac{127-40}{127}\right) +$$

$$\cdots\cdots + \left(\frac{127-120}{127}\right)$$

$= 3.69 < 4.61$

(not sufficient)





Again, Assuming spacing 15cm c/c.

Load t. capacity of eff. dowel bar system

$= 4.75 > 4.61$

OK

2cmϕ, 35cm length, 15cm c/c.

Design of Tie Bar

A cem. concrete pavement of 7.0m width has a thickness of 32cm and has a longitudinal joint. Design the dimension and spacing of the tie bar. Use the following data.

Unit wt. of concrete (w) = 2400kg/cm².

Allowable tensile stress in deformed tie bar (S_s) = 2000kg/cm²

" bond " " " " " (S_b) = 24.6kg/cm².

Diameter of tie bar (d) = 1.2cm.

→ Soln.

Diameter of tie bar (d) = 1.2 cm

Spacing: $(f = 1.5)$

Area of steel reqd per meter length of long joint (A_s)

$$A_s * S_s = W * f * 1 * b * \frac{h}{100}$$

↓

or $A_s * 2000 = 2400 * 1.5 * 1 * \frac{7.0}{2} * \frac{32}{100}$

$[A_s = 2.01 cm^2]$

Area of each tie bar (a_s) = $1.13 cm^2 = \frac{\pi * 2^2}{4}$

No of tie bar per m. length = $\frac{2.01}{1.13} \approx 2$.

Spacing = $\frac{100 cm}{2}$ = 50cm c/c

Length (L_t):-

$$L_t = \frac{2 a_s S_s}{p * S_b} = \frac{2 * \frac{\pi d^2}{4} * S_s}{\pi d * S_b} = d/2 * \frac{S_s}{S_b}$$

$$= \frac{1.2}{2} * \frac{2000}{24.61}$$

= ~~81.39cm~~ 48.78cm.

Length = L_t + (5-8cm)

↑ थप्नो

≈ ~~49.5cm~~ 55cm

(considering tolerance in placing)

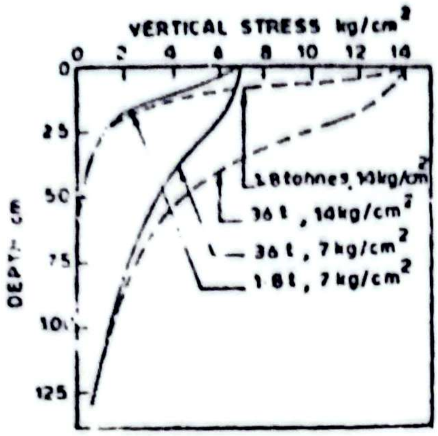
Soil stabilization

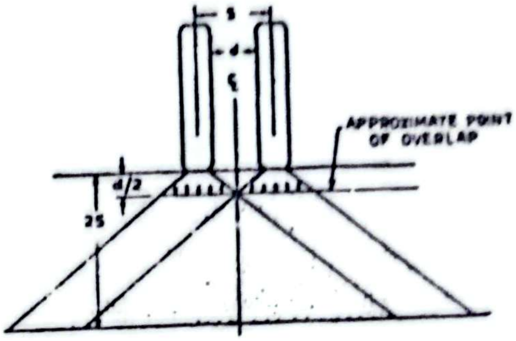
↳ Improving the strength of soil by proportioning and/or mixing with other materials & compaction.

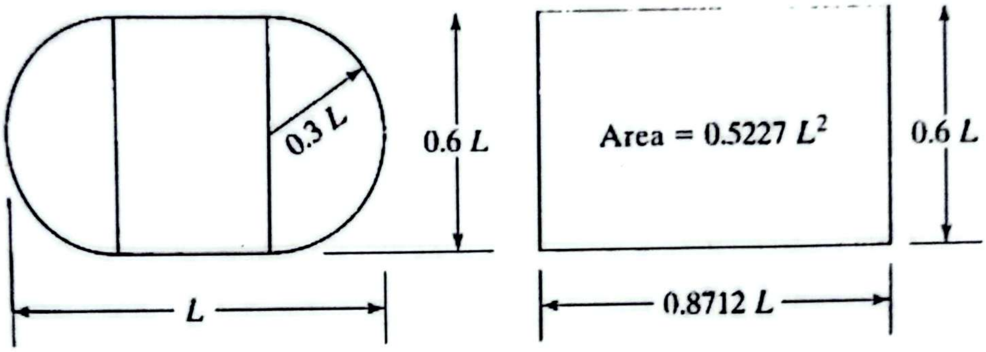
✓ Increase Bearing capacity; increase shear strength; prevent cracks in soil; good drainage; less frost susceptibility

Basic principle:
- → Evaluating properties of soil
- → Deciding effective & economical method of soil stabilization
- → Designing the mixes
- → compacting stabilized soil adequately

Mechanical SS	Soil-cement stab.	Soil-Lime	Soil-Bitumen
→ Blending of two different materials to meet required strength, grading & plasticity criteria. → Basic principle is proportioning & compaction **Factors affecting:** ↳ Mechanical strength of aggregate ↳ Gradation ↳ soil properties ↳ presence of salts & mica ↳ compaction. **Desirable properties of SSoil** ↳ strength ↳ Incompressibility ↳ stability with variation in moisture content ↳ Good drainage. ↳ Less frost susceptibility ↳ Ease of compaction. **Equipments** ↳ Laboratory facilities for mix design ↳ rotavator ↳ compaction eqp **Material selection** ↳ crushed stone <20% passing # 12 sieve & >85% passing # 40mm sieve. ↳ Max. size 60mm; CBR$_{min}$ = 25%. ρ_{max} = 95%. ↳ LL → 25% Base & 35% surface ↳ PI → 6 Base & (5-10) surface ↳ Fuller's formula.	→ Add^{n} of cem & water → Stabilization is due to bond b/w cem. & soil particle & Red^{n} in plasticity → curing for 7 days **Factors affecting** ↳ Nature of soil ↳ proportion of cem. ↳ compaction moisture content ↳ Dry density of mix (compacted) ↳ curing ↳ Additives. **Design of soil-cem mix** ↳ Based on fck of specimen cured for 7 days ↳ specimen: 5cm d & 10cm ht with diff cem content compacted upto OMC ↳ Design cem-content corr. to 17-51kg/cm^2 ⇒ Medium traffic 35kg/cm^2 ⇒ High traffic **Equipments** → Mix - rotavator or manually → or mixing plant or cem truck mixer → compacting eqp. **Material selection** ↳ # 4.75mm → > 50%. ↳ # 75μ ⇒ 50%. ↳ LL > 40%. ↳ PL → > 18% ↳ cem content: 5-14% by vol. **Field control** ↳ moisture content; °of pulverization; cem content; fck; ρ_{dry}; surface regularity	→ Add^{n} of lime → More effective option for plastic clay. → 4-8% by wt. is usually mixed on-site & then compacted at suitable moisture content and cured for about 14 days. **Factors affecting** similar as before exc. ↳ Lime content ↳ type of lime (quick lime, CaO, Hydrated lime) **Design of mix** ↳ No standard method ↳ lime content is based on lime fixation limit or amount req^{d} to reduce PI or swelling value to desired level. **Equipments** → For scarifying, pulverizing, mixing & compacting **Material selection** → lime of consistent quality. → Fresh water for compaction moisture control & curing	→ Modification of sub-standard locally available materials through addition of bitumen → Bitumen emulsion is an effective option for strengthening non plastic sandy materials. → Normally 4-8% residual bitumen is usually mixed. **Factors affecting** ↳ Bitumen content ↳ type of bitumen ↳ Additives (anti-stripping & reactive chemical additives) **Design of mix** ↳ No standard method ↳ Specimen prepared with various bitumen contents and are tested for stability and water absorption. → **Equipments** ~ **Material selection** → local sandy soil compatible with emulsion modification → slow setting emulsion → soil [# 4.75 → 90%, # 0.425 → 35 to 100%, # 0.075 → 10-50%, LL - 40%, PL - 18%.) **Field control** → checking pulverization → Moisture & bitumen content → ρ_{dry} after compaction

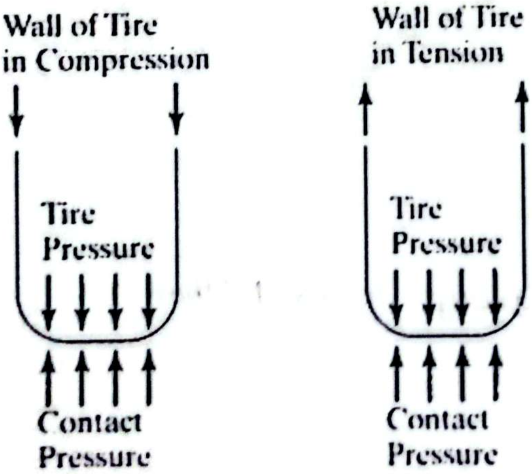




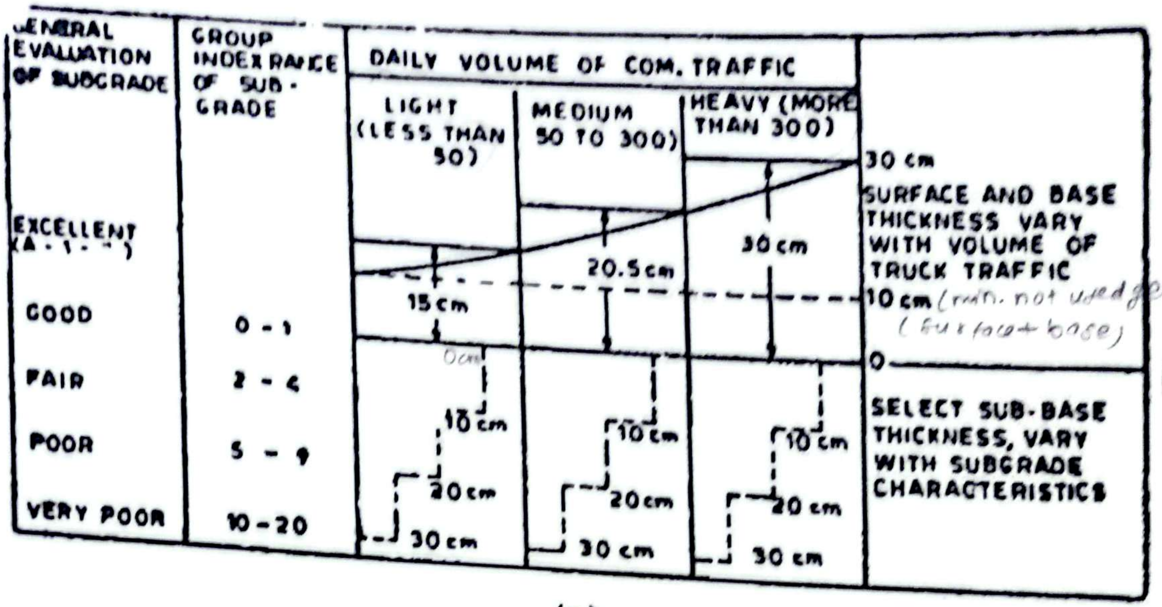


(a) ActuaL Area

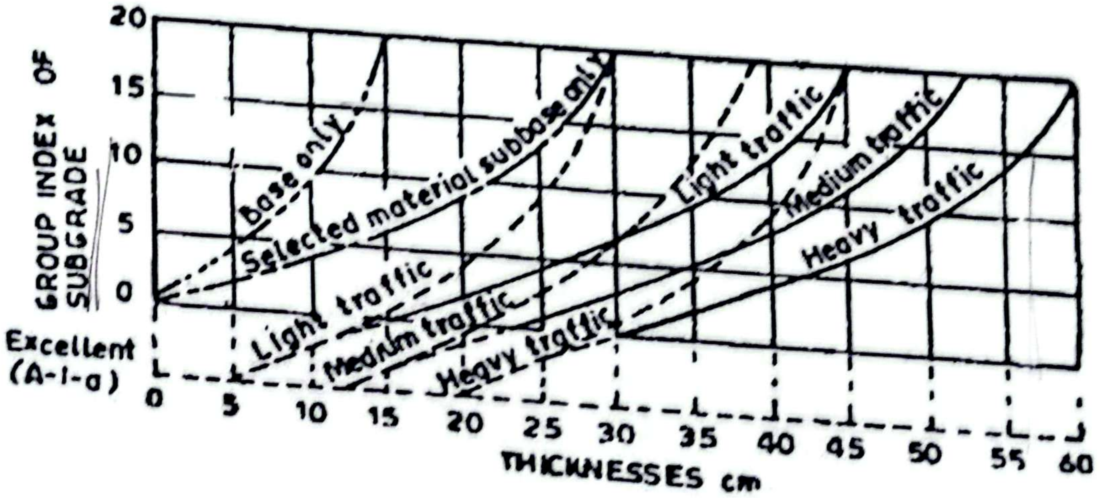
(b) Equivalent Area



(a) Low Pressure Tire (b) High Pressure Tire



(a)



(b)

Group Index Method

- - - - - Surface + base system

———— Surface + base + subbase system

Surface + base
Subgrade

Surface + base
Subbase
Subgrade

eg: (GI = 10)

Subbase = 22 cm

Light traffic : Surf + base + Sb = 37cm (——)

Surf + base = 37 - 22 = 15cm.

(3 layer system)

2

15cm Surf + base
22cm Sb
subgrade

Two layer system

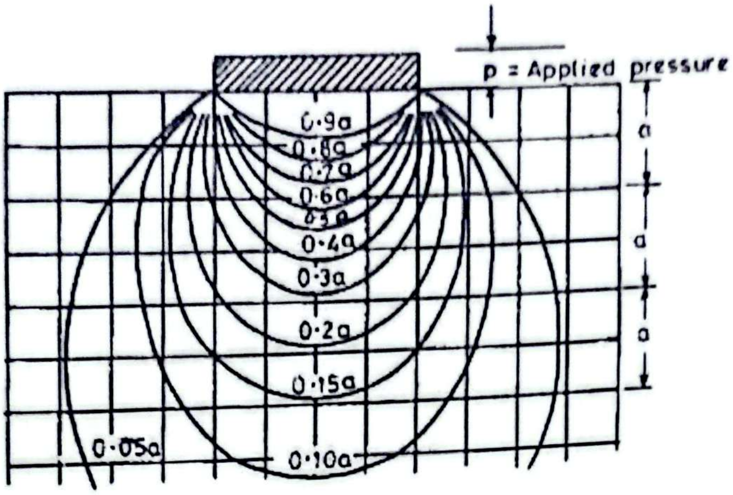
Surface + base = 28cm (- - -)

(Base only ⇒ subbase लाई replace गर्दा उति thickness of base चाहिन्छ)

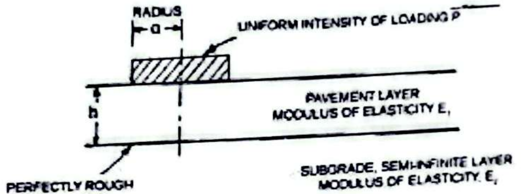
Equ. thickness of 22 cm of subbase = 13cm (- - - base only)

{ 15cm ✓ / 22 ⇒ 13cm) 28 - 13 = 15cm

28cm 15cm surf + base
13cm



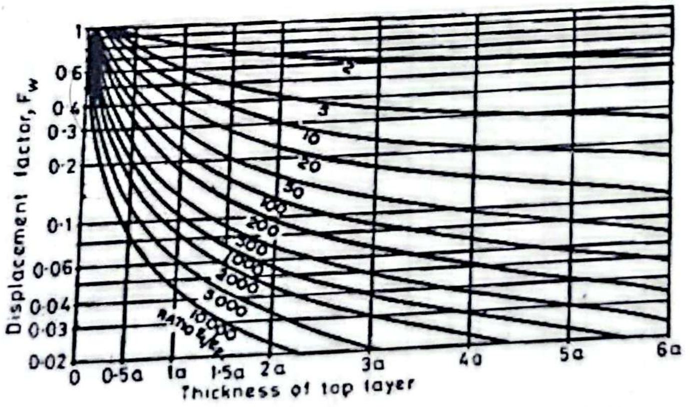
Boussineq's theory pressure bulb shows, $\sigma_z \propto \frac{1}{z}$



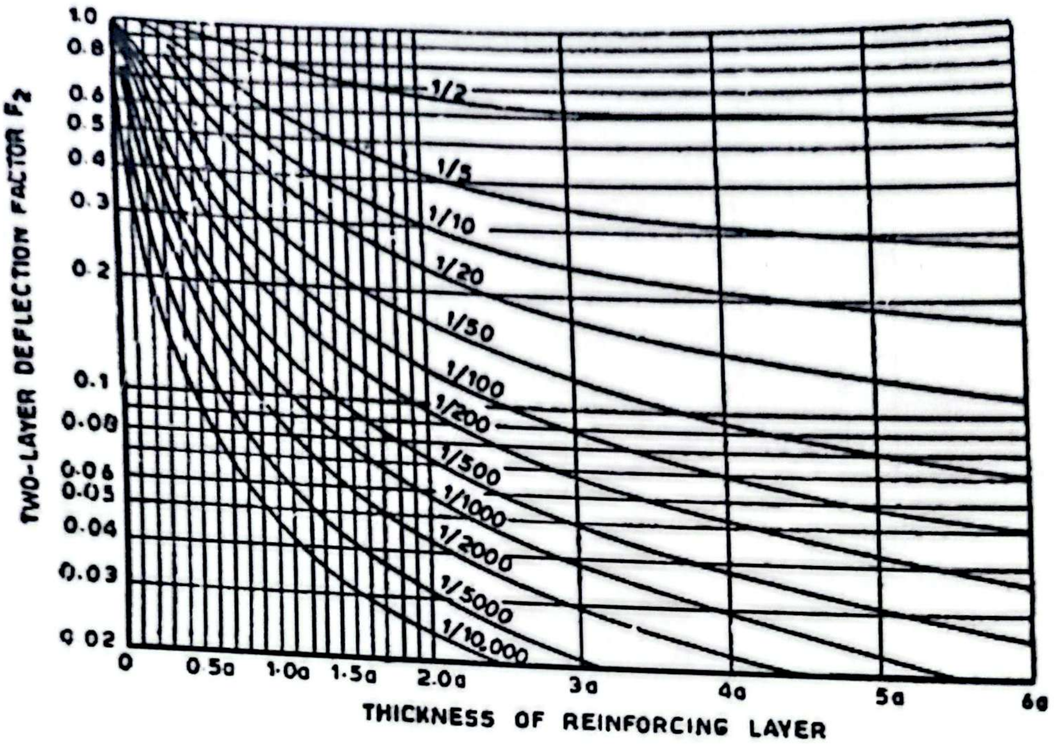
POISSON'S RATIO = 1/2 IN BOTH LAYERS

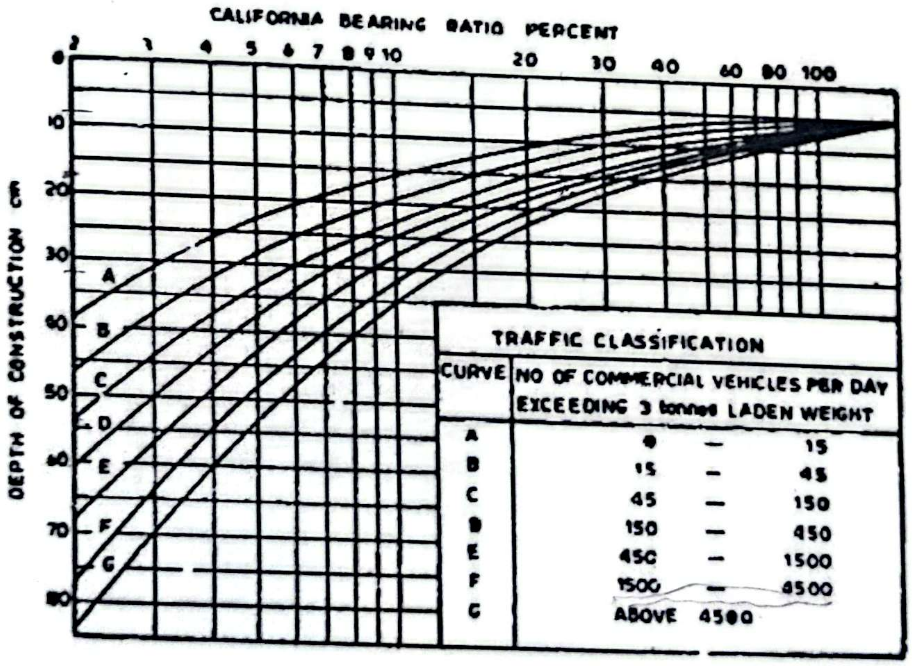
DISPLACEMENT UNDER CENTRE OF LOADED AREA

$= \frac{1.5 pa}{E_2} F_w$, WHERE F_w = DISPLACEMENT FACTOR



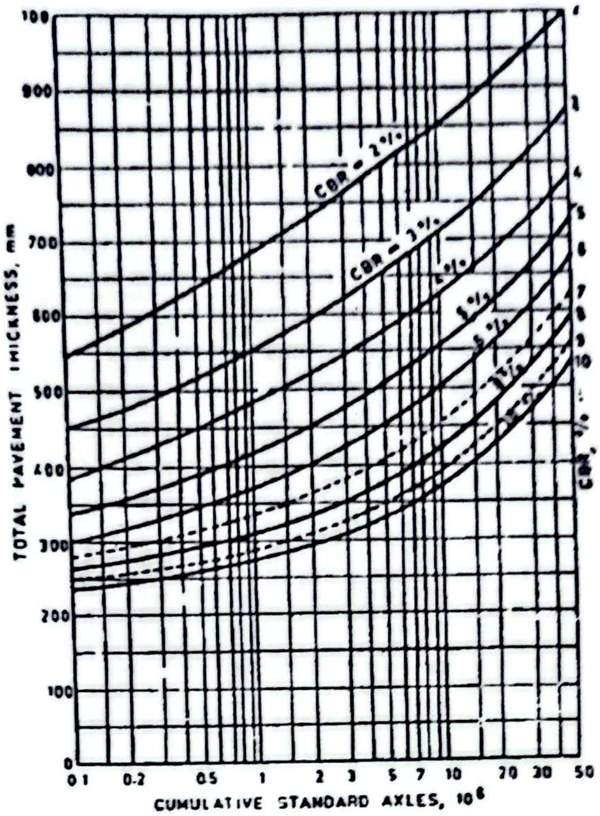
Displacement factor (Fw): Burmister's theory.





TRAFFIC CLASSIFICATION			
CURVE	NO OF COMMERCIAL VEHICLES PER DAY EXCEEDING 3 tonnes LADEN WEIGHT		
A	0	—	15
B	15	—	45
C	45	—	150
D	150	—	450
E	450	—	1500
F	1500	—	4500
G	ABOVE 4500		

IRC Recommended CBR



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

Material Definitions

▭	Double surface dressing
▥	Flexible bituminous surface
▩	Bituminous surface (Usually a wearing course, WC, and a basecourse, BC)
▩	Bituminous roadbase, RB
■	Granular roadbase, GB1 - GB3
▦	Granular sub-base, GS
□	Granular capping layer or selected subgrade fill, GC
▨	Cement or lime-stabilised roadbase 1, CB1
▤	Cement or lime-stabilised roadbase 2, CB2
▧	Cement or lime-stabilised sub-base, CS

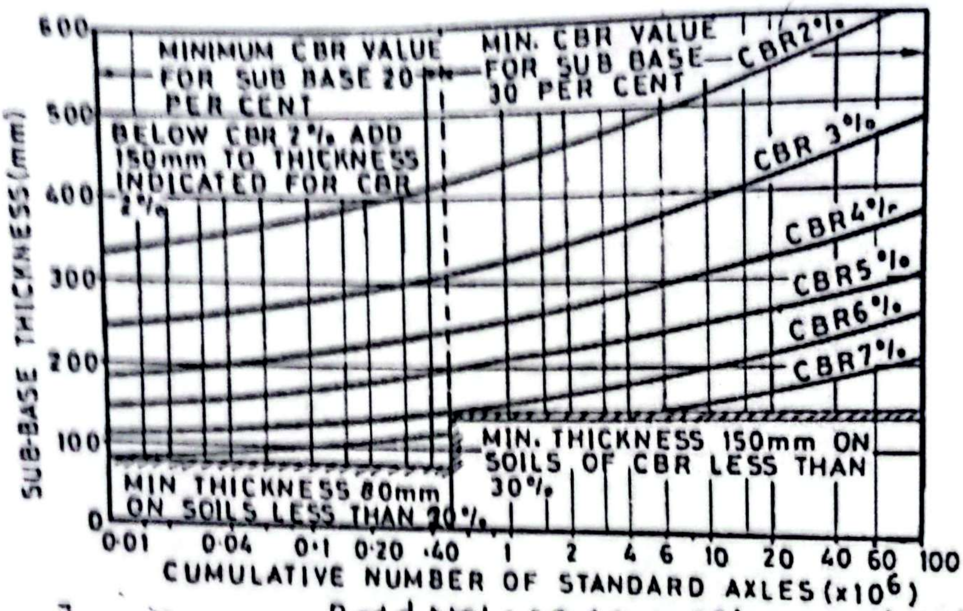
KEY TO STRUCTURAL CATALOGUE

Traffic classes
(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

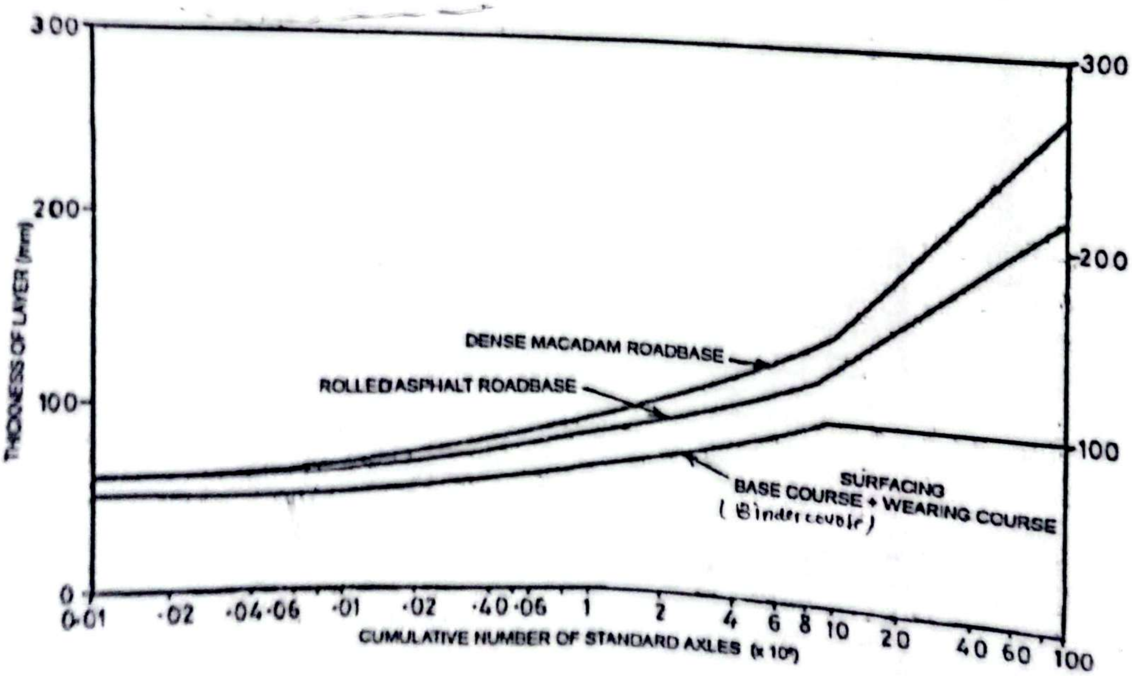
Subgrade strength classes
(CBR%)

S1 = 2
S2 = 3 - 4
S3 = 5 - 7
S4 = 8 - 14
S5 = 15 - 29
S6 = 30+



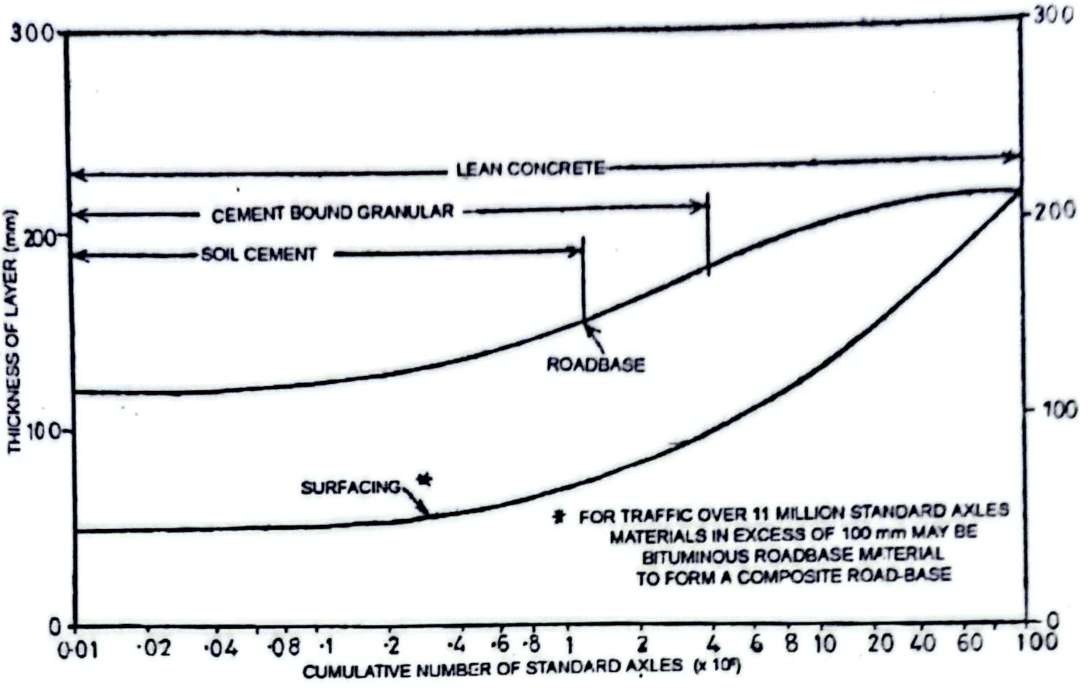
[ ]

Road Note 29 (RN-29) L Million standard axle

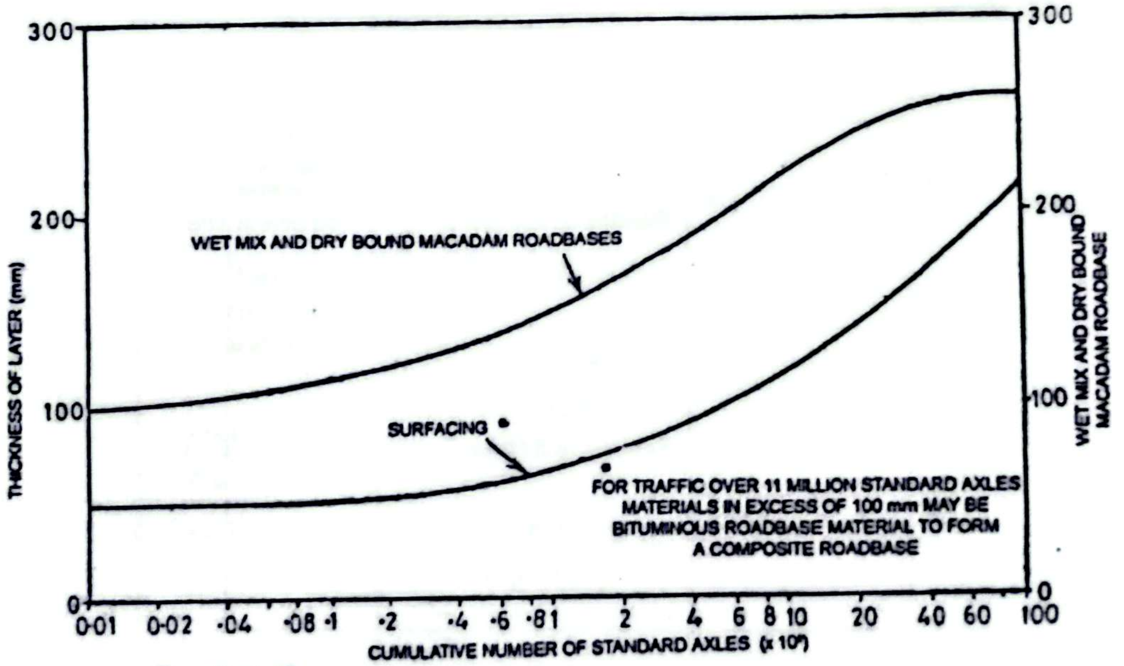


• Rolled Asphalt base, dense Macadam base

(chart 1)



Lean concrete base, cement bound granular base, soil cement base



wet mix and dry bound Macadam base.

(2T) 3. Road construction Technology } Principles of Highway
(1T or 1N) 4. Road Maintenance } Eng. L.R. Kadiyali,
(1T) 5. Introduction to Bridge & Tunnel Highway Engg. Khanna & Justo

↳ transportation Engineering II - Vazirani

6. some portion from traffic Engineering
(2N + 2T) ↳ transport planning & Traffic Engineering - Kadiyali: Khanna & Justo

- Transportation Engg. II Shrestha & Marasini
- Handouts

* Standard specification for Road & Bridge.

ch.3

Road construction Technology

- Branch of engineering that deals with:
  - → All activities for changing existing ground to the desired shape and slope
  - → Providing all necessary facilities for traffic operation
  - → Reconstruction/ Maintenance of existing roads

- Activities in road construction

1. Earthwork
2. Drainage
3. Pavement
4. Miscellaneous
   - · median
   - · Road markings
   - · Traffic sign
   - · Footpath.
5. Slope stabilization

(1) Earthwork & site clearance

- → site clearance
- → Earthwork in filling for embankment
- → ~~EW~~ Excavation for cutting
- → Excavation for borrow pit.
- → Excavation for structure foundation

(2) Drainage works

- – Minor bridges
- – Culverts
- – Causeways
- – Side drains
- – Catch drain

(3) Protection work

- → site clearance
- → River training works
- → Gully control works
- → Landsline stabilization works
- → Bridge protection works.

(4) Pavement works

- → Sub-grade works
- → Sub-base works
- → Base works
- → Surface works.

(5) Miscellaneous works

- → Road ancillaries (Beautify road)
- → Traffic sign/ signal/ marking etc.
- → Bioengineering works.

Green roads → purely
↳ environmentally friendly and
↳ no use of equipments
↳ w/o disturbing environment.

3.2 Tools, Equipments & plants used in construction

(a). Tools

→ simple piece of equipment that use to do a particular kind of work in construction, usually holding in hand.

→ Important for labor based construction.

* Excavating tools
- Shovel
- Spade
- Pick axe
- Crowbar
- Trowel
- Hoe
- Chisel & hammer

* Compaction
- Hammer
- Rammer (धुर्मुस)

* Levelling
- Plumb bob
- Rope/String
- Level pipe
- Spirit level
- Trowel

* Transport
- Wheel barrow
- Dokol Thunche
- Shovel
- Trowel

(b) Equipments

All appliances for the execution, completion, operation or maintenance of the road work; but which will not become a permanent part.

→ Used for executing complex tasks in even the most unfavourable topography.

→ 15% to 40% of total project costs

(1) - Earth moving (Excavating) equipment covers a broad range of machines that can excavate soil and rock.

- Earth moves help to speed not only earthwork but also

- Dozer (used for excavating at shallow depths.

- Scrapper (used to scrap surfaces. scraps old pavement during reconstruction)
  ↳ generally with blades & buckets

- Loader (for excavating as well as loading materials to other devices)
  ↳ with bucket that can be raised.

- Excavator (hoe is attached to boom
  ↳ for excavating trench, cleaning drains, etc.
  ↳ for excavating at different levels, below own level

- Backhoe (hoe at backward & loader at front operator.)
- Dragline (used for excavation in soft soil and sands at greater depth)

dredging works
↑
- Clamshell (excavation in underwater as it has clamp)
(excavation at very different excavations)

(ii) Compacting equipments
- Refers to machinery used to compact soils, to increase the density of soil & reducing voids.

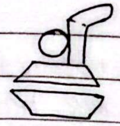
a. Smooth wheel roller
- used when the crushing action (breaking down) action is required
- roller with steel drum. Drum ~~be~~ may be in one or two in number.

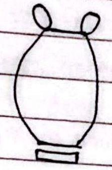
b. Sheep's foot roller
- used in compaction of cohesive soil i.e. clay & silt
- steel drum with projection outward of diameter.

c. Pneumatic tyred roller
- work in kneading action (push मात्र गरेर compaction)
- May be 4wheel - 3wheel or 5wheel - 4 wheel)

d. Vibrating roller
- Steel drum with motor to generate vibration action which impose extra compaction/compression

e. Rammer





Monkey Jumper
↳used where heavy equipments cannot be used i.e. in side drains.

(iii) Levelling equipments
First levelling - Dozer

a. Grader
→ Precise levelling - Grader
→ has blades that can be tilted or adjusted at angles.
→ Used in forming camber, superelevation.

(iv) Lifting equipments → used ~~in~~ when pre-cast elements has to be lifted.
(e.g. hume pipes)

a. Crane

b. Hoist - to move people /·material at different levels.

c. Forklift truck

(v) Paving equipments

(a) Bitumen spreader (distributor)
- spread bitumen at desired ~~to~~ rate
- provided with bitumen storage tanks, nozzles & heating devices.
- to apply different coats i.e. prime coats, tack coats.
- rate of spreading of bitumen depends on size of nozzles opening & speed

(b) Aggregate spreader
- to spread aggregate at desired rate & thickness.
- rate of spreading depends on size of opening & speed of vehicles.

(c) Bituminous paver
- to pave required thickness of bitumenous concrete & bituminous mat.

(d) Cement concrete mixer
- only for small volume work.
- RMC for large volume work (Ready Mix concrete)

(e) Cement concrete paver
- to pave req^d thickness of cement concrete

(f) Concrete vibrator
- Needle vibrator
- Plate vibrator

(vi) Transport Equipment

(a) Haul truck
- for transport of hot mix asphalt

(b) Tipper
- bucket can be hydraulically lifted up & down

(c) Dump truck
- high capacity large volume.
- used in quarry site

(d) Trailer
- Power driven unit is coupled with non-power driven unit. to transport equipment.

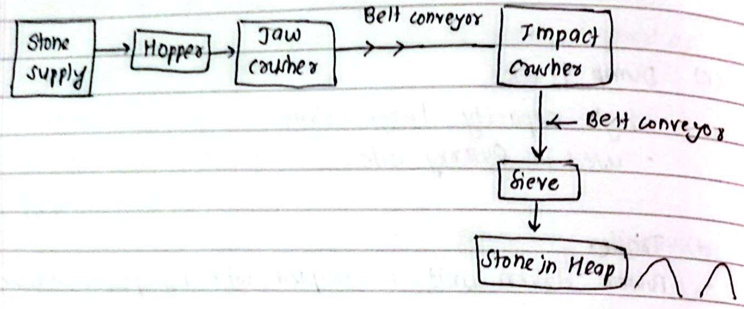
(e) Mini Dumper
- to transport small volume of work in site

(f) Concrete transport truck
(RMC को गाडी)

(c) Plants

- are fixed in site ∴ unless dismantled.
- combination of different equipments performing different action & fixed in a space.
- for complex, voluminous mass production work.

i. Stone crusher



ii. Asphalt Mixing Plant

iii. Cement concrete Mixing Plant.

3 Preparation of Road Bed

- All operation before the pavement would be laid:

This includes:

(i) Site clearance

→ clearing bushes and shrubs at least covering toe width

→ Removal of existing trees, stumps and roots along the alignment

→ Removal of existing structures along the alignment

→ a minimum of 1 to 3m from the top of the cut or toe of the fill.

(ii) Earthworks in Excavation (cut)

→ cutting and removing the earth, rocks from its original position, transporting & dumping

→ Required when the natural ground is higher than the designed level.

→ Also construction of side drain requires excavation

∴ Design:-

- Depth
- stability of foundation
- stability of slope
- Requirements of side drains.

(iii) Earth works in embankment (Fill)

→ The filling of earth/soil to achieve the desired formation level

→ Required when the natural ground is below the formation level, high water table & prevent capillary rise

Design elements:

→ Height of fill

→ Fill materials (PI ≯ 45)

(swelling index 50%)

→ settlement of embankment

→ stability of foundation

→ stability of slopes

℄ → site clearance → materials dumped along alignment → If MC<OMC add moisture,

If MC>OMC,

↳ add petrol & burn

↳ leave in air it will dry up

(s.t. MC≈OMC)

↓

Compaction ← Spreading

(one layer compacted thickness not more than 15cm)

For embankment depth	compacted density
<3m	15kN/m3
>3m	17kN/m3

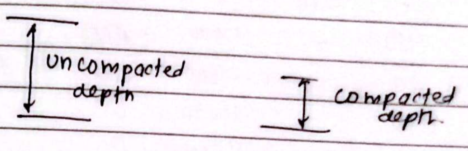
Mass-Haul Density Diagram

↳ Diagrametric representation of earthwork volume involved in road construction along a linear profile.

↳ Horizontal stationing is plotted along the X-axis

↳ Net cut values are plotted above the X-axis (positive Y-value) & Net fill values are plotted below X-axis (-ve Y-value)

Steps: ↳(i) compute the net earthwork value for each station, applying the appropriate shrink factor.



Defns:

Shrinkage

↳ volume of the compacted embankment is less than the borrow area volume, called shrinkage

↳ Shrinkage factor depends on soil types & vary between 10-20%.

Swell:

↳ Excavated soil/rock occupy a larger volume, called swell.

↳ swell may vary from 20-40%.

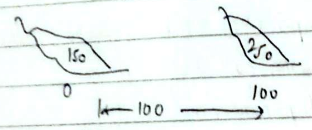
(II) Net cuts have a positive value, net fills have a negative value.

(iii) The value at the first station (origin) = 0

(iv) Plot the value of each succeeding station. which equals the cumulative value to the point.

Plot the mass haul diagram for the earthwork quantities contained in table.

Station	Area cut	Area Fill	Volume cut	Volume Fill	cumulative Earthwork
			0	0	0
0	150	-			
			20000	0	20000
100	250	-			
			18000	0	38000
200	110	-			
			2750	-12500	28250
300	-	500			
			0	-33500	-5250
400	-	170			
			0	-26000	-31250
500	-	350			
			12000	-8750	-28000
600	480	-			
			25000	0	-3000
700	20	-			
			12000	0	9000
800	220	-			
			11500	0	20500
900	10				

→ 

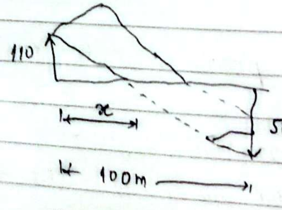
$\frac{150+250}{2} * 100$

(avg area) * length

→ 300 → cut & fill दुवै हुन्छ

at some pt. it will be zero

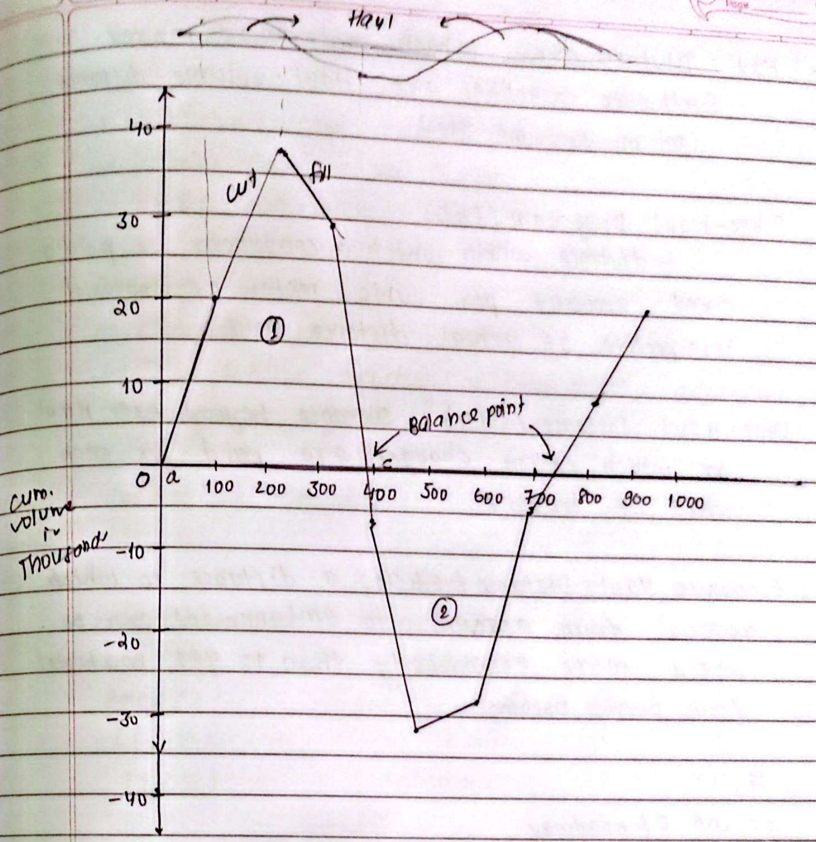
कहाँ हुन्छ ? ⇒ interpolation.



say (assume) → कतिमा zero हुन्छ

say, x = 50m. (x according to ground condition) but, not give exact value)

(Slide no55)



① convex

② concave

ac → zero balance line

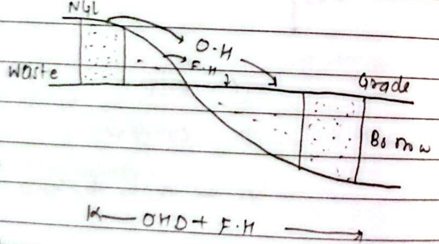
- Haul: Distance over which material is moved.
  Earthwork quantities are Haul · volume - distance
  ($m^3 . m$ or m^3. Sta.)

- Free-Haul Diagram (FHD)
  ↳ distance within which a contractor is paid a fixed amount per cubic meter of material irrespective of actual distance price.

- Over-Haul Distance (OHD): Distance beyond free-Haul for which extra charges are paid for each unit of haulage.

- Economic Haul Distance (EHD): a distance to which material from excavation to embankment can be moved more economically than to get material from borrow opening.

If,



a = cost of roadway excavation per m^3

b = cost of overhaul & tipping per m^3/m

c = cost of borrow material per m^3

L = economic overhaul distance in m

Cost of overhaul = cost of borrow

$$a + b * L = a + c$$

$$\Rightarrow \left[L = \frac{c}{b} \right]$$

3.4 construction of low cost roads

→ Low construction cost & maintainence cost
→ Suitable for low vol. traffic.
→ WBC earthen road.

Earthen roads:
→ cheapest road
→ It utilize existing or immediately adjacent materials along an alignment.

section of Materials:

	Base course	Wearing course
clay(%)	< 5	10-18
silt (%)	9 - 32	5-15
sand (%)	60-80	65-80
LL (%)	< 35%	< 35%
PL (%)	< 6%	4 to 10%

☐ 3.4.3] Water Bound Macadam Roads

→ pioneered by scottish Engineer John Loudon Macadam around 1820

→ Made of crushed gravel, hard stones, etc.

→ The broken stones are mechanically interlocked by rolling

→ the voids filled with screening & binding material with the assistance of water.

- Selection of materials:
- Angular and cubical shape, nominal size Grading 1 (63mm), Grading 2 (53mm), LA value upto 40% (base) & 45% (subbase), AIV upto 30% (base), & 40% (subbase) and combined flakiness & elongation index less than max. 35%.

- screening materials (Grading 1 - 13.2 mm, & Grading 2 - 11.2 mm) of LL < 20%, PL < 9%.

- Filler (Binding) materials fine grained material, Plasticity index less than 6%.

- Equipments:
  Water tanker, dump truck, grader compaction equipments.

- Construction process:

→ Material with 20% extra broken stones are stocked along the road.

→ Preparation of subgrade to required grade & camber

→ Provision of lateral confinement.

→ spreading of CA.

→ Dry rolling - roller 8 to 10 tonnes (compacted thickness <7.5cm) three wheeled power rollers or tandem or vibratory roller.

→ Dry screening is applied gradually over the surface to fill the voids

→ The surface is sprinkled with water and wet rolling to fill about 50% of total voids.

→ Application of binding material at a uniform and slow rate of two and more thin layers.

→ opening of traffic after few days of construction.

- Quality control:

→ Material specification

→ LAA, AIV, Flakiness and Elongation Index

→ 90-105% of OMC.

→ Dry density = 98% of MDD, 95% for subbase and shoulder.

→ Platicity Index 6 for base course and 5 to 10 for surface course.

3.4.4 Soil Stabilization

↳ process of improving the strength of the soil by proportioning and/or mixing with other materials & compaction.

- Advantages

→ Increase bearing capacity of soil

→ Increase shear strength of soil

→ Avoid changes in soil characteristics due to changes in moisture content

→ Prevent cracks in soil.

→ Good drainage, less frost susceptibility

- Basic principle in soil stabilization

(i) → Evaluating the properties of soil

- gradation, soil type (clay, sand), PI

(ii) → Deciding the effective and economical method of soil stabilization.

- gradation → Rich in finer + add coarse } compaction → Mechanical stabilization.

  ↳ Rich in coarse (A) + add (B) finer

  proportioning

  {A? + B? = P ← desired gradation}.

- gradation + cement → when soil has sufficient granular materials (but PI & plasticity property is weak)

- gradation + lime → when soil has sufficient clay. (PI of clay ↓ + stabilization)

sand (cohesionless) → Bitumen.

(iii) → Designing mixes

[Mix % कति add गर्ने ??]

(i) Proportioning Method

Proportion of A & B to find required gradation.

(ii) Mixing

ⓐ If cement.

↳ decide from compressive strength

(Reqd value 17.5 kg/cm² → light traffic

35 kg/cm² → Medium/heavy traffic)

How?

5cm ϕ & 10cm height cylinder
+ compaction
+ curing (7 days)
+ (trial cement %) → ↑ UCS with st. req^d compressive strength or not

ⓑ CBR Test

add cement → compact → test.

- sample for different cement %.
- cement % that give required CBR → adopt.

If lime

ⓐ PI value
ⓑ lime fixation limit
ⓒ CBR.

+ curing + 14 day.

ⓐ PI value → % lime that gives PI value within upper limit.

ⓑ (Lime add, PL↑ upto a limit then PL↓ in further ↑ in lime, at that point which is called fixation limit and lime at that level taken as % lime.

% lime that doesn't increase PL value (plastic limit)

ⓒ % lime that gives required CBR

If Bitumen

(used in sandy (cohesionless soil))

- CBR.

(iv) → compacting the stabilized soil adequate

Surface Dressing (Surface Treatment)

→ The application of bituminous emulsion over the prepared road base followed immediately by covering with single sized stone aggregate chippings that are lightly rolled.

(first lay bitumen followed by aggregate)

eg. Surface Dressing

- Single bituminous surface treatment (SBST)
- Double bituminous surface treatment (DBST)

- Equipment

- Construction Procedure (SBST)
  - → Surface cleaning by sweeping with mechanical brooms

Ch.4 Highway Maintenance, Repair and Rehabilitation

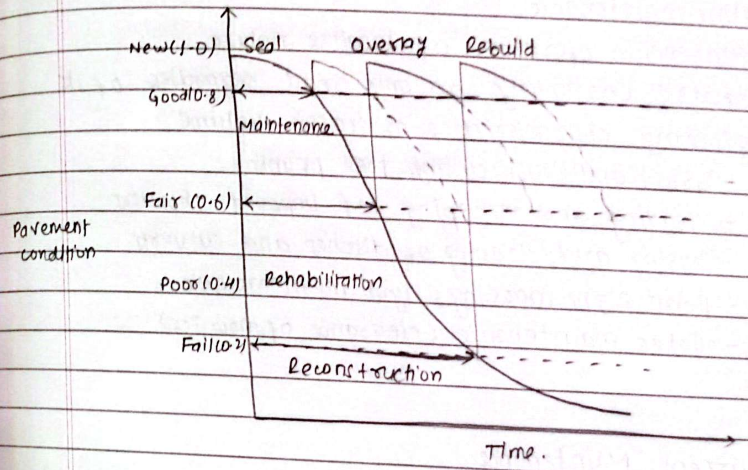
→ Highway maintenance is preserving and keeping the serviceable conditions of highway as normal as possible and as best as practicable.

→ eg. sealing of cracks, filling pot holes, etc.

→ Highway Rehabilitation is improving the structural strength of pavement.

→ eg. Overlay of greater thickness, replacement of surfacing, etc.

* concept of Pavement maintenance



* Classification of Maintenance activities :
- ↳ Road maintenance
- ↳ Roadside Maintenance.

- Road Maintenance
  - → All maintenance works on the road way
  - → Maintenance of all structures within road way (eg. side ditches, culverts, causeways, bridges, etc.)
  - → Types:
    - Routine Maintenance
    - Recurrent Maintenance
    - Periodic Maintenance
    - Emergency Maintenance

-Routine maintenance

↳ Maintenance operations of localize nature

↳ Require continually on any road regardless of its engineering characteristics or traffic volume.

- Grass and bush cutting, tree pruning
- Grading and reshaping of unpaved shoulders.
- Clearing and cleaning of ditches and culverts
- Road sign, marking, light maintenance, etc.
- Winter maintenance (clearance of snow, ice)

-Recurrent Maintenance

↳ Maintenance operation of localized nature carried out at more or less regular interval of six months to two year with a frequency that depends on the traffic volume.

↳ to be done by using minor equipment

- Sealing cracks
- Local surface treatment
- Repair of depressions, holes and ruts, pot hole patching, etc

- Periodic Maintenance

→ Maintenance operations of large extent required only at intervals of several years

→ Frequency and type depend on original surfacing, traffic, rainfall and climatic conditions

- Resealing (surface treatment, slurry seal, thin overlap
- Re-gravelling of unpaved road
- Restoration of road marking, drainage items, etc.

- Emergency Maintenance

↳ Urgent Emergency maintenance works needed for reopening of road after slides, road wash outs, etc.

↳ Removal of debris or any other obstacles.

↳ Reinstatement of the pavement structures and drainage after rainy season.

↳ Strengthening/reconstruction of pavement.

↳ Protect road against falls of rock, flooding, etc.

- Road side maintenance
  - concerns all maintenance works on structures and surface above and below the road having direct active and/or passive influence on the road.
  - E.g. culverts protection works, retaining walls, cut slopes, fill slopes, unstable natural slopes, river protection works and vegetation structures.

Inspection, prioritization and planning of maintenance operations

- Type and extent of maintenance depends on.
  - Serviceability standard
  - Maintenance fund available
  - Priorities for the maintenance operation.

* Inspection and Assessment of maintenance need.

→ Find out road inventory (soil type, terrain, climate, etc)

→ Nature and volume of traffic.

→ Identify defects likely to be hazardous or cause serious inconvenience to users of the highway.

→ Identify defects ~~to~~ requiring urgent attention.

→ Priorities are determined through regular inspection of each road usually the six months.

* Prioritization of maintenance ~~of~~ operations

→ Urgent repairs (eg. Removal of debris)

→ Routine drainage work (Ditch cleaning, cleaning of culvert bridges, filling scour areas, etc.)

→ Routine pavement work (grading of unpaved road, patching, sealing of paved roads)

→ Shoulder maintenance, grass cutting, cleaning and repairing road furniture.

→ Periodic work like grading, re-graveling of unpaved road, surface dressing, etc

→ Overlay and reconstructions.

* Planning of Maintenance operations

→ Minimum acceptable service standard

→ Field survey for finding maintenance requirement.

→ Factors influencing maintenance need such as sub grade, drainage, traffic, environment.

→ Estimate extent of pavement deterioration.

→ Development of alternatives of maintenances.

→ Check availability of funds, materials, manpower and equipment

→ Maintenance costs.

Types of Road Failure and its causes

1. Failures in flexible pavements
2. " " Rigid "

1. Failure in flexible pavements

- Flexible pavement failure
  - ↳ Excessive deformation/settlements of any layer
  - ↳ Excessive undulation or waves and corrugation.
  - ↳ Lateral shoving of the pavement near the edge along the wheel path

(i) Failures of sub grade

Causes
- Inadequate stability or strength
- Excessive stress application.

(ii) Failures of sub-base or Base

Causes
- Inadequate stability or strengths
- Loss of binding action
- Loss of base course materials
- Inadequate wearing course
- Use of Inferior materials
- Lack of lateral confinement for the granular base course.

(iii) Failures of wearing course

- Causes:-
  - Improper mix design
  - Inadequate quality control during construction
  - Volatilization and oxidation of bitumen.

* Typical Flexible pavement failures

(a) Alligator (map) cracking:
- Due to fatigue, localize weakness in base course would also cause such cracking.
- Because a structural failure is taking place, the only possible solution is a full-depth patch.

(b) Rutting:
- channellized depressions along the wheel-path
- Due to consolidation, lateral movement of any pavement layer.
- Insufficient pavement thickness and compaction.

(c) Longitudinal cracking
- Parallel to pavements centerline
- Due to frost action, differential volume change, and/or poor joint construction.
- crack < $1/2$ inch can be sealed

Severe cracks- ~~fo~~ remove the cracked pavement layer and replace it with an overlay.

(d) Reflection cracking
- observed in a flexible pavement over a rigid pavement
- occur directly over the underlying rigid pavement joints or over cracks in rigid pavement
- crack sealing for cracks less than 1/2 inch, and removal of the cracked pavement layer followed by an overlay for severe one.

ⓔ Pot holes
- small, bowl-shaped depressions in the pavement surface that penetrate upto the base course.
- Due to moisture infiltration and usually the end result of untreated alligator cracking.
- Full depth - replacement patch.

(f) Ripples (corrugations) and wave (shoving):
→ Ripples or an abrupt wave across the pavement surface.
→ usually occurs at points where traffic starts and stops.
→ Caused by excess asphalt; too much fine aggregate; rounded aggregate; too soft an asphalt; or a weak granular base.
→ small distortion - patching, For large - overlay.

(g) Slippage cracking
- slipping occurs when the surface is not bound with the underlying layers or low strength surface mix.
- slowly, it forms pot holes
- Fix: Removal and replacement of affected area.

(h) Shear failure
- Excessive loads that cause a shear failure in the subgrade, base course, or the surface.
- characterized by upheaval of pavement followed with depressions
- Fix: Removal & replacement of affected area.

(i) Raveling
- The separation of aggregate particles in a pavement
- usually, the fine aggregate wears away first. Soon larger and larger particles are broken free.
- Due to loss of bond between aggregate and bitumen.
- Fix: small raveling - patching,
  for large raveled area a thin hot-mix overlay.

(j) Frost Heaving
- Localized heaving up of portion of pavement due to action of frost.
- small distortion - patching
  For large - overlay.

(k) Polished aggregate

- Areas of pavement where there are no rough or angular aggregate particles, loss of skid resistance
- Due to abrasion of soft aggregates
- Fix:- abrasion free overlay.

2. Failures in Rigid Pavements

- Formation of cracks is the main cause of failure.
- They fail mainly due to two factors:
  - Deficiency of pavement material:
    - Soft aggregate
    - Poor workmanship in joints
    - Poor joint filter and sealar material
    - Poor surface finish
    - Improper and insufficient curing.
  - Structural inadequacy of pavement:
    - Inadequate pavement thickness
    - Inadequate sub grade supports and poor sub grade soil
    - Incorrect spacing of joints

* Typical Rigid Pavement Failures:

(i) Scaling of cement concrete:

- The deterioration of the upper concrete slab surface
- Deficiency in mix or presence of chemical impurities excessive vibration makes mortar on top of the layer which get abraded exposing aggregate.
- Repair with bituminous patch or cement mortar

(ii) Shrinkage crack

- Hairline cracks formed during concrete setting and curing that are not located at joints.
- Due to poor reinforcement, improper curing technique, high early strength.
- For moderate, cracks are sealed; for severe slab replacement

(iii) Spalling of joints

- loose debris on the pavement, roughness, generally an indicator of advanced joint/crack deterioration.
- Excessive stresses at the joint/crack, low quality concrete, disintegration of the PCC from freeze-thaw.
- Repair: Partial or full depth patch.

(iv) Warping crack

- For improper design of joint, irregular cracks are developed at joints due to excessive warping stress.
- Hinge joints are provided with adequate reinforcement.

(v) Corner crack

- A crack that intersects the PCC slab joints near the corner
- Severe corner stresses caused by load repetitions combined with a lack of support, poor load transfer across the joint, curling stresses and warping stresses
- Repair: Full depth patch

(vi) Mud pumping

- Movement of material underneath the slab or ejection of material from underneath the slab.
- Due to repeated ocurrence, slab losses subgrade support
- Water accumulation due to a high water table, poor drainage, and cracks or poor joint seals that allow water to infiltrate.
- full depth patch to remove any deteriorated slab area & stabilize sub grade.

(vii) Pop-out

- small pieces of pavement broken loose from the surface.
- Causes: use of non-durable aggregates, Improper curing, internal pressure.

(viii) Blow out

- A localized upward slab movement and shattering at a joint or crack.
- the result of insufficient room for slab expansion during hot weather.
- Full depth patch.

(ix) Polished aggregates

- Surface mortar and texturing worn away to expose coarse aggregate resulting skidding surface.
- Due to abrasion of soft aggregates.
- Fix: abrasion free overlay.

Types and methods of pavement repair

1. Maintenance of Earthen/Gravel Roads
2. " " WBM "
3. " " Bituminous "
4. " " Cement concrete "

1. Maintenance of Earthen/Gravel Roads

- Common problems
  - Formation of dust
  - Formation of longitudinal/cross ruts along the surface.

- Maintenance
  - Maintained by sprinkling water, treatment with calcium chloride, applying oiled earth to prevent dust
  - Periodic maintenance by spreading moist soil (gravel) along rut and reshaping of the camber or suitable stabilizing treatment is provided on surface.

2. Maintenance of WBM roads

- Problems
  - Dust formed in dry weather, mud in rain
  - Pot holes and ruts.

- Repair
  - Dust is reduced by sprinkling dust palliatives, moist soil or bitumen spreading.
  - spreading of a thin layer of moist soil binder on the surface periodically to prevent aggregate disintegration.
  - Pot holes and ruts are remedied by patch repair.
    - cut defective area in a rectangular shape up to defective depth.
    - Coarse aggregate of same size as old is filled up and compacted up to 1 cm.
    - Wet soil binder is applied on the surface of the patched area and surface rammed again.
  - Resurfacing after its useful life.

3. Maintenance of Bituminous surfaces

- Repair works mainly consists of:
  - Patching
  - Surface treatments
  - Repair of depression and settlement of pavement and shoulder.
  - Repair of pavement edge and shoulder distress
  - Resurfacing

* **Patch Repair**

- patching
  - Pot hole or other defects in the road surface shall be cut to rectangular shape.
  - Excavate the area until sound materials encountered.
  - clean area by removing dust and loose materials.
  - Apply prime/tack coat at side and bottom of area.
  - Premix material is placed in layer of 6cm quickly.
  - compaction is carried out.
  - Patch repair should be slightly higher than old pavement

* **Surface treatment**

- Surface treatment
  - Bleeding
    ↳ corrected by application of blotting materials such as chips (10mm), sand, etc. and rolling
  - cracks
    ↳ Bituminous surface treatment renewal coat.
    ↳ More than one layer of surface treatment may be necessary if surface is severely damaged.
  - skidding surface
    ↳ skidding occurs as a result of polishing of aggregate by wheel
    ↳ Bituminous surface treatment renewal coat

- sweeping the surface area clean by broom/ Mechanical broom sweeper
- Mark out the area to be repaired in box shape
- For small area of the cracks, compacted with vibrating plate. And, for large area use hand roller compactor.

* **Resurfacing**

- If pavement surface is totally worn out and develops poor riding surface, additional surface course is provided on the existing surface.
- If thickness is inadequate, overlay of adequate thickness should be designed and constructed.

* **Rut, corrugation and wave Repair**

- Necessary to correct the defect such as excessive moisture, poor compaction, etc in any pavement layers.
- If instability due to excessive moisture, suitable sub surface drainage if necessary.
- If failure is due to improper compaction, it need complete reconstruction

→ Marking out the area to be repaired
→ clean area to be repaired by using mechanical broom or hand broom
→ spray tack coat (0.5 to $1 L/m^2$) and spread aggregate 19mm.
→ compaction using rammer or vibrating plate compactor

→ Apply binder over the surface.

→ Distribution of aggregate 12mm scattered by shovel from the truck or trailer.

→ compaction using rammer or vibrating plate compactor.

4. Maintenance of cement concrete roads:

- Little maintenance is necessary
- Mainly maintenance of cracks and joints.
- Maintenance of cracks:
  - Non-structural cracks:
    hair cracks, shrinkage cracks, warping cracks
  - Structural cracks:
    mostly appearance on the edge and corner regions due to load and warping stresses.

* Maintenance of non-structural cracks:

- Hairline cracks are harmless. However if widen, it allows infiltration of water.
- They should be seal off to prevent entering the water

→ The cracks are thoroughly cleaned using a sharp tool; stiff brush and air compressor.

→ kerosene oil is applied for better bond.

- The cracks are filled with bituminous seal.
- Sealer is placed 3 mm above the level and layer of sand is spread over it for protection.

* Maintenance of structural cracks

- Need Immediate attention
- Cause of failure are investigated and remedial measures are taken.
- For localized failure which may be due to settlement, recasting of slab is done.
- General structural cracks, provide a flexible or rigid overlay.
- Reconstruction of new flexible or rigid pavement if pavement is badly damaged.

- Joint Maintenance
  - → opened up joints are cleaned with brush or air compressor
  - → Refill the suitable sealer before start of the rain.
  - → Replacing the filler and sealer materials.

- Maintenance of Mud pumping
  - provide effective sub-surface drainage
  - localized failure, patching of portion of slab (either asphalt or concrete)
  - Mud jacketing & uplift of slab
    - ↳ Drill number of holes about 5cm dia and about 1 to 3m apart.
    - ↳ Grouting of 1:3 cem. sand mix, cement soil, or bitumen under pressure
    - ↳ slabs are raised upto desired ht. by pressure.

☐ Evaluation of Pavement Distress and pavement condition:

- Assess the existing conditions and find out pavement service condition so that the maintenance and strengthening works can be planned on time.
- It covers a thorough study of various factors such as:
  - > Subgrade support
  - > Pavement composition and its thickness
  - > Present traffic Loading
  - > Environmental conditions

- The method of pavement evaluation:
  - Structural evaluation of pavements
  - Evaluation of pavement surface condition (Functional Evaluation)

* Structural Evaluation of Pavement

- Structural condition is concerned with the structural capacity of the pavement i.e. whether the pavement is structurally capable for design traffic, and climatic condition.
- Structural capacity measured by deflection, stresses, strain at critical points in pavement layers under the application of load. Also layer thickness and material properties are also studied.
- Benkelman beam is commonly used, where deflection of pavement under standard load of 8.2 tons is used to find pavement overlay thickness

* Evaluation of pavement surface
- Concerned with the ride quality or surface texture of a highway section.
- Pavement may be evaluated by the raveling, ruts, patches, cracks and surface roughness.
- Evaluated by present serviceability rating, surface distress index (SDI), and international roughness index (IRI), skid resistance, etc.

Strengthening of existing pavements

- After maintenance, pavement should have adequate stability to withstand the design traffic under prevailing climate and sub-grade conditions.
- If the pavement have to support increased wheel loads and more load repetitions, strengthen of the existing pavement is required.
- Strengthening required additional thickness of pavement, which is called overlay

* Overlay

→ One or more layers of bituminous or cement concrete construction on an existing pavement.
- The overlay generally includes a levelling course to correct surface irregularity of the old pavement, followed by an overlay of uniform thickness.
- The type of material for overlay ~~design~~ depends on factors such as:
  - Importance of the road
  - Design traffic
  - Thickness, and condition of existing pavements
  - Construction convenience
  - Economics

• Types of overlay

S.No.	Existing Pavement	Overlay
1	Flexible	Flexible
2	Flexible	Rigid
3	Rigid	Flexible
4	Rigid	Rigid

1.

→ CBR values of subgrade soil is determined

- Total design thickness of the flexible pavement for the design traffic volume is determined.
- The existing thickness of pavement is found from test pits
- Total overlay thickness

$$h_0 = h_d - h_e$$

where,

h_0 = overlay thickness required, cm

h_d = total recent design thickness, cm

h_e = thickness of existing pavement, cm

4.

- Total overlay thickness

$$h_0 = (h_d^a - x h_e^b)^n$$

where,

h_o = overlay thk. reqd , cm

h_d = total recent design thk, cm.

h_e = thk. of existing thickness, cm

values of a, b, X and n depend on pavement and the method of overlay construction.

Agency	Existing pavement condition	X
Crops of Engineers and PCA	(i) Good condition	1.00
	(ii) Initial cracking	0.75
	(iii) Badly cracked	0.35

Agency	construction period	a	b	n
Crops of Engineers	(i) Poured directly on old pavement	1.40	1.40	1/1.4
	(ii) levelling course	2.20	2.0	1/3
PCA	(i) as (i) above	1.87	2.0	1/2
	(ii) as (ii) above	2.20	2.0	1/2

3.

- wheel load distributed over large area
- Warping stresses reduced.
- Total overlay thickness given by

$$h_0 = 2.5(Fh_d - h_e)$$

F → factor which depends upon modulus of ~~elas~~ existing pavement

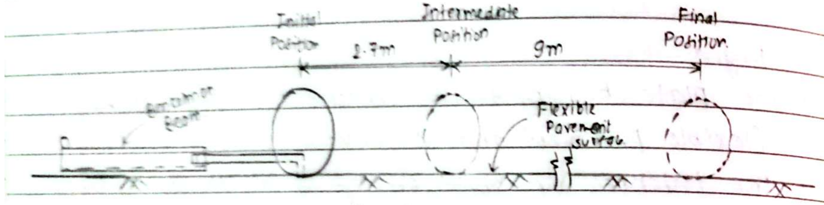
2. Rigid

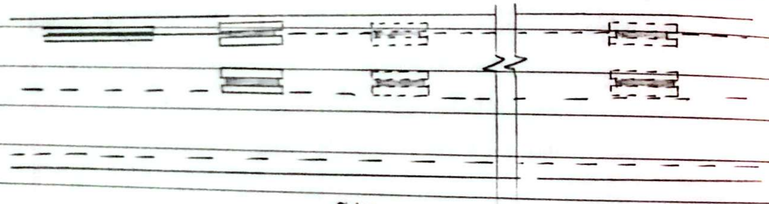
→ The plate bearing test is conducted on the existing flexible pavement and k value is obtained.

→ The thickness of rigid overlay is calculated by using design criteria for rigid pavements

Deflection approach of overlay Design

- The structural strength of pavement is assessed by measuring surface deflections under a standard axle load (8.2 ton)
- larger pavement deflections imply weaker pavement and subgrade
- The overlay must be thick enough to reduce the deflection to a tolerable amount.
- Rebound deflections are measured with the help of a Bentelman Beam.



Elevation.

PLAN.

~~* Loading and other standards~~

~~→ Axle load of 8170 kg/~~

* Nos. of Deflection Mearurement

- At least 10 deflection measurements are made each section per lane subject to a minimum of 20 measurements per km.
- If the highest or the lowest deflection values for the section differ from the mean by more than one-third of the mean, then extra deflection measurement should be made at 25m on either side of point where high or low values are observed.

* Loading and other standards

- Axle load of 8170kg / load of 4085kg on dual wheels
- Tyre pressure, $p = 5.6 kg/cm^2$
- Standard pavement temperature = 35°C
- Highest subgrade moisture content soon after monsoon.
- Variation of individual values, not more than one third of mean value.

* Other Data measured

- Measurement of pavement temperature (at one hour intervals)
- Measurement of field moisture content of subgrade soil.
- Typical subgrade soil samples for lab. Tests (soil classification)
- Annual rain-fall.
- Traffic data, growth rate, axle load data, VDF values.

* Analysis of Data

- If $(D_i - D_f)$ is less than 0.025mm (2.5 div),

  $D = 0.02 (D_0 - D_f)$, where D in divisions (1 div = 0.01mm)
- If $(D_i - D_f)$ is more than 0.025mm (2.5 div.),

  $D = [0.02 (D_0 - D_f) + 0.0582 (D_i - D_f)]$

  where D in divisions [1 div = 0.01 mm]

  $D = 0.[2(D_0 - D_f) + 2 * 2.91 (D_i - D_f)]$, where D in mm.

- Mean deflection, $\bar{D} = \frac{\Sigma D}{n}$
- Standard Deviation, $\sigma = \sqrt{\frac{\Sigma(\bar{D} - D)^2}{n-1}}$
- characteristic Deflection,
  - $D_c = \bar{D} + 2\sigma$ for important roads to cover 97.7% deflection values,
  - $D_c = \bar{D} + \sigma$ for low traffic roads, to cover 84.1% deflection values.

* Corrections

- Temperature correction factor +0.0065 mm per °C for pavement temperature below 35°C and -0.0065 mm per °C for pavement temperature above 35°C

→ Tentative correction factor of 2 for clayed soil and 1.3 for sandy soil if the measurements were taken during dry conditions.

* IRC formula of Overlay Thickness

→ $$h_o = 550 \log_{10}\left[\frac{D_c}{D_a}\right]$$

→ D_a = 1.0, 1.25 and 1.5mm if the projected traffic is 1500-4500, 450-1500 and 150-250 vpd respectively.

where, $A = P[1+r]^{n+y}$

when bituminous concrete is used, equivalency factor of 2 be used.

* Overlay Design- Example

Benkelman beam deflection studies were carried out on 10 selected points on a stretch of flexible pavements during summer. The deflection values obtained in mm are as below. If the present traffic consists of 800 commercial vehicles per day (cvpd), determine the thickness of bituminous overlay required. The pavement temperature during test was 30°C, and the soil type is sandy subgrade soils. Assume annual rate of growth of traffic as 7.5%. Design life 5 years, construction period 6 month.

S.NO.	Dial Gauge Reading		
	Initial	Intermediate	Final
1	0	0.54	0.56
2	0	0.54	0.54
3	0	0.50	0.51
4	0	0.53	0.53
5	0	0.48	0.49
6	0	0.46	0.49
7	0	0.50	0.51
8	0	0.57	0.57
9	0	0.54	0.56
10	0	0.53	0.54

S.N.	DGR			$D_0 - D_i$	$D_0 - D_f$	Check $(D_0-D_i)-(D_0-D_f)$, mm	Deflection (mm)
	D_0	D_i	D_f				
1	0	0.54	0.56	−0.54	−0.56	0.02 < 0.025	0.56 × 2 = 1.12
2	0	0.54	0.54	−0.54	−0.54	0.00 < 0.025	0.54 × 2 = 1.08
3	0	0.50	0.51	−0.50	−0.51	0.01 < 0.025	0.51 × 2 = 1.02
4	0	0.53	0.53	−0.53	−0.53	0.00 < 0.025	0.53 × 2 = 1.06
5	0	0.48	0.49	−0.48	−0.49	0.01 < 0.025	0.49 × 2 = 0.98
6	0	0.46	0.49	−0.46	−0.49	0.03 > 0.025	0.49 × 2 + 2 × 2.91 × (0.49 − 0.46) = 1.155
7	0	0.50	0.51	−0.50	−0.51	0.01 < 0.025	0.51 × 2 = 1.02
8	0	0.57	0.57	−0.57	−0.57	0.00 < 0.025	0.57 × 2 = 1.14
9	0	0.54	0.56	−0.54	−0.56	0.02 < 0.025	0.56 × 2 = 1.12
10	0	0.53	0.54	−0.53	−0.54	0.01 < 0.025	0.54 × 2 = 1.08

Mean deflection:

$$\bar{D} = \frac{\Sigma D}{n} = \frac{1.12 + 1.08 + 1.02 + \cdots + 1.12 + 1.08}{10} = 1.0775\,\text{mm}$$

Standard deviation:

$$\Sigma(D-\bar{D})^2 = (1.12 - 1.0775)^2 + (1.08 - 1.0775)^2 + \cdots + (1.08 - 1.0775)^2$$

$$= 0.0299$$

$$\sigma = \sqrt{\frac{\Sigma(D-\bar{D})^2}{n-1}} = \sqrt{\frac{0.0299}{10-1}} = 0.0576$$

Characteristic deflection $= 1.0775 + 2(0.0576) = 1.1922$ mm.

- correction for temperature:
  Test Temp = 30°c
  correction for temperature = 0.065 (35-30) = 0.0325mm
  Characteristic deflection after temp. correction
  = 1.1927 + 0.0325 = 1.2252mm.

- Correction for Moisture:
  Sandy subgrade:
  correction for Moisture = 1.3
  Characteristic deflection after correction for moisture
  = 1.3 * 1.2252
  = 1.5928mm.

- Traffic volume at the end of design period

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

$$= 800\,[1+0.075]^{1/2+5} = 1191 \text{ veh/day}$$

- IRC formula for overlay:

$$h_o = 550 \log_{10} \frac{D_c}{D_a}$$

D_a = 1 for Traffic (1500-4500 vpd),
1.25 for (450-1500 vpd.)

$$h_o = 550 \log_{10} \frac{1.5928}{1.25} = 57.889 \approx 58\text{mm}.$$

Thickness in terms of DBM/AC = $\frac{58}{2}$ = $\underline{\underline{29\text{mm}}}$