12

214

216

-: HAND WRITTEN NOTES:-

OF

CIVIL ENGINEERING

1

-: SUBJECT:-

TRANSPORTATION

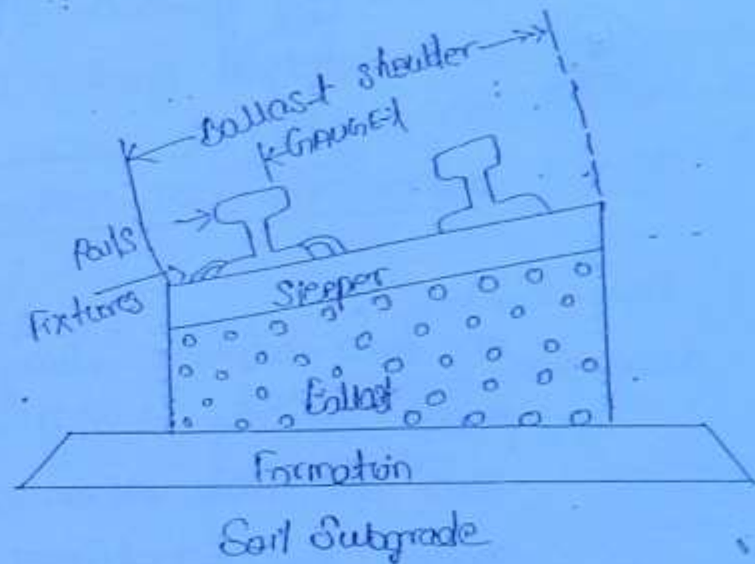
12

[redacted]

Introduction :->

(1) Cross Section of a Railway Track

(3)



(2) Gauges In India :->

1. BG (Broad gauge) -> 1.676 m
2. MG (Meter gauge) -> 1.0 m
3. NG (Narrow gauge) -> 0.762 m
4. LG (Feather track gauge) -> 0.61 m

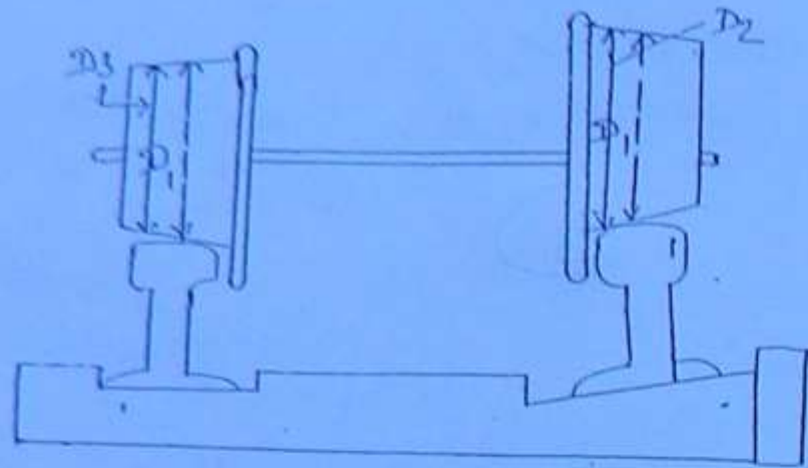
-> Gauge is distance b/w inner face of rails (Running faces)

(4) Coning of wheels :->

theory :-> A slope of about 1 in 20 is provided to wheel in a cone shape. the same slope is provided to the top surface of rails This slope provided to wheel is called coning of wheel.

The wheel assembly (one axle) moves on the rail just in central position such that dia. of wheel

4



on two rails are always equal. Whenever the train moves sideway in any direction. Diameter of wheel over one rails increases and it decreases over another. Due to diffrent of dia & distance travelled over one wheel increases that result in auto-matic direction of wheel assembly in its original central position.

Purpose:→ ① To keep train just in central position during movement.

② To reduce wear & Tear of Flange and rails.

③ Over curve track, distance required to be travelled on outer rail is more than that of on inner rail. Due to coning and centrifugal force, the wheel assembly is pushed outward & distance travelled on two rails are adjusted automatically.

(11) Welded Rails :->

(5)

Long welded Rails :->

-> Gaps are provided generally for allowing expansion due to ~~t~~ increase in temperature. For Gaps a large No. of joints are required.

-> To avoid joints, Rails are welded.

-> In long welded rails, rails are not allowed to expand, Due to which the stresses are developed in rail section. This stresses are arrested by Fixtures & sleepers.

IF l = length of welded rail

Due to T temperature increase

Increase in length = $l.\alpha.T$

than

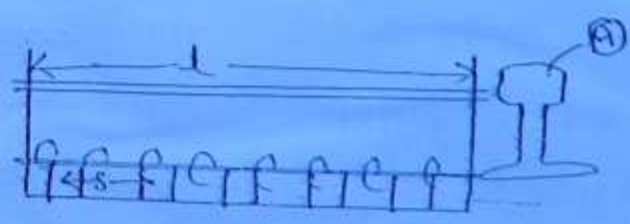
Strain developed in rail = $\frac{\delta l}{l} = \frac{l.\alpha.T}{l}$

$= \alpha T$

Stress developed (If above strain is not allowed)

$p = E_s \times \text{strain}$

$$\boxed{p = E_s \alpha T}$$



Force developed in Rail Section

$P = A \times p$

$P = A \times E_s \alpha T$

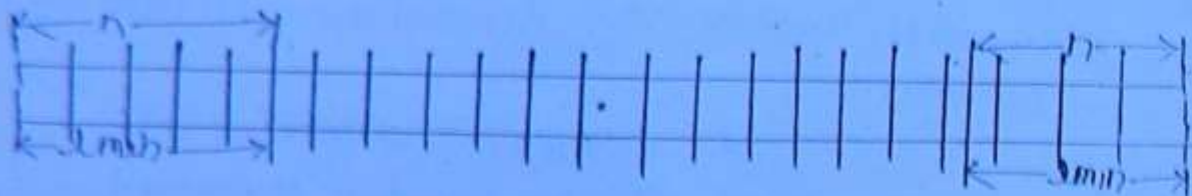
If one sleeper is provided 'R' Resistance.

Min No. of Sleeper required to resist P force.

$$\boxed{n = P/R} \quad (6)$$

Min length of long welded rail required

$l_{min} = (n-1) S$



Min length of Rail required so that central portion of rails does not move = $2 l_{min}$

2001 ©-®
Problem :-> Determine the min theoretical length of LWR beyond which the central portion of 52 kg rail would not be subjected to longitudinal moment due to 30°c Temperature variation.
Use following data

(A) Rail (1) 52 kg rail Section
(2) C/S A = 66.15 sq. cm
(3) $E_s = 2.1 \times 10^6$ kg/cm²
(4) $\alpha = 11.5 \times 10^{-6}$

(B) Sleepers
(1) Sleeper spacing is 60 cm
(2) Average resistance force/sleeper/rail = 300 kg

Solution :->
S = 60 cm
R = 300 kg

Due to 30°c temperature increase:
Increase in length $= l \alpha T$

Strain = αT

Stress = $E_s \alpha T$

Force developed in Rail Section if no moment is allowed

$P = A_s \times E_s \times \alpha \times T$

$P = \underset{cm^2}{66.15} \times \underset{kg/cm^2}{2.1 \times 10^6} \times 11.5 \times 10^{-6} \times 30$

$\boxed{P = 47925.675 \text{ kg}}$

Min no. of sleeper are required $= \frac{P}{p} = \frac{47925.67}{300}$

$= 159.75 \simeq 160$ Nos

Min. length of rail on one side required $= (n-1) \times s$

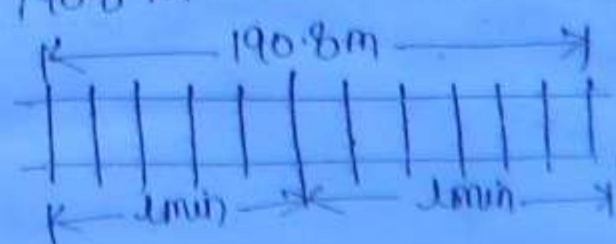
$l_{min} = (160-1) \times 0.60$

$l_{min} = 95.4 \text{ m}$

Total min length are required (for no movement of central portion) $= 2 \times l_{min}$

$= 2 \times 95.4$

$= 190.8 \text{ m}$



(7) Sleepers :→

(1) Composite Sleeper Index :→
(About wooden Sleeper) (8)

→ This is an index to find out the suitability of a particular timber to be used as wooden sleeper.

→ $C.S.I. = \frac{S+10H}{20}$

∀ S = Strength Index at 12% moisture content.
H = Hardness " " " " ".

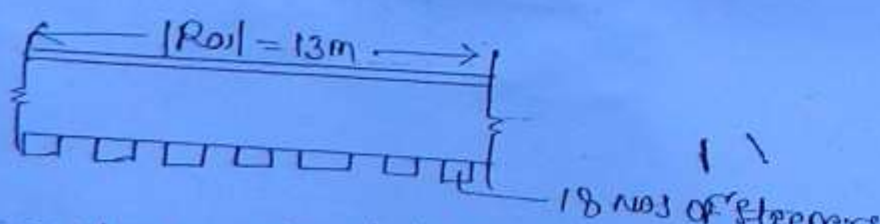
Min Value of CSI
(a) Track Sleeper = 783
(b) Crossing " = 1352
(c) Bridge " = 1455

(2) Sleeper Density :→ No. of Sleeper are required for one rail is called sleeper density. It is denoted by (n+x).

Generally value is (n+x) to (n+6)
n = length of one rail in meter

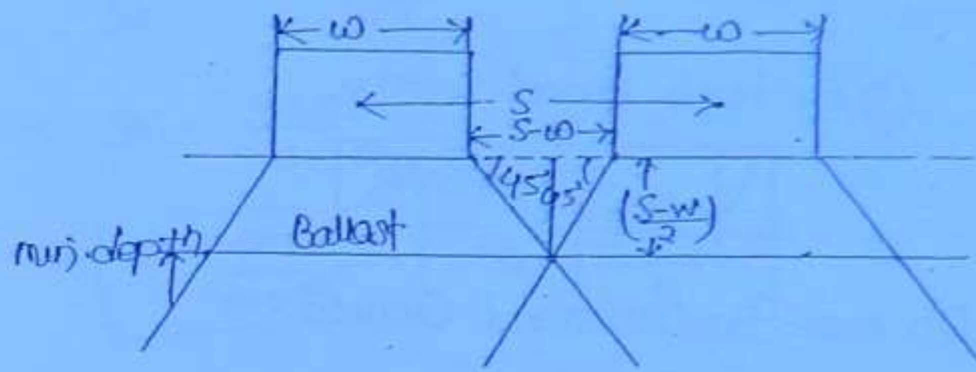
If B.G. track n = 12.8 m ≈ 13 m

Sleeper density = (n+5)



No. of sleeper provided = n+5
= 13+5
= 18 nos

Minimum Depth of Ballast :→



If S = Spacing of sleepers
W = width of Sleepers
Min Depth of Ballast Cushion required.

$$\boxed{D_{min} = \frac{S-W}{2}}$$

Geometrical Design :→

(1) Speed of Train :→ Design speed is decided as per followi

(1) Max. Speed decided by Indian Railways.
(2) Safe Speed from Martin's formula on curve.
(3) Max. Speed as per Cant provided.
(4) As per Length of Transition curve.

→ Safe Speed on Curve (Martin's formula) :→

(a) On Transition Curve :→

For Safe Speed

(1) For BG & MG

$$\boxed{V_{max} = 4.35\sqrt{R-67}}$$

(2) for NG Track

$$\boxed{V_{max} = 3.65\sqrt{R-6}}$$

R = Radius of curve in m

V_{max} = Km/h

(3) for High speed train:-

$$\boxed{V_{max} = 4.58\sqrt{R}}$$

(6) On Non-Transitioned Curved :→

(a) On BG & MG Track

V_{max} = 80% for Transition curve

$$\boxed{V_{max} = 0.80 \times 4.35\sqrt{R-67}}$$

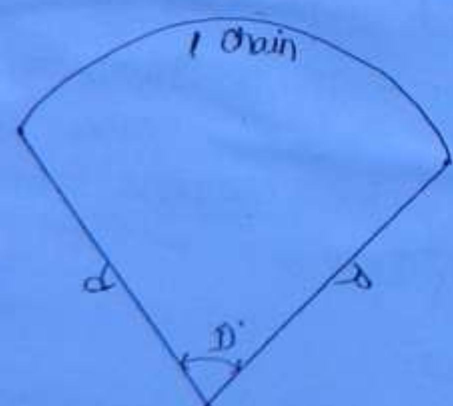
(b) on NG Track

$$\boxed{V_{max} = 0.8 \times 3.65\sqrt{R-6}}$$

(c) for high speed train

$$\boxed{V_{max} = 4.58\sqrt{R}}$$

(7) <u>Radius of Curve</u> / <u>Degree of Curve</u> :→



- Angle formed at centre by one chain length of arc is called degree of curve.

(1) For 30 m chain length

$$\Rightarrow \frac{30}{D^{\circ}} = \frac{2\pi R}{360^{\circ}}$$

$$\Rightarrow D^{\circ} = \frac{30 \times 360}{2\pi R}$$

$$\Rightarrow \boxed{D^{\circ} = \frac{1718.9}{R}} \approx \boxed{\frac{1720}{R}}$$

$$\boxed{R = \frac{1720}{D^{\circ}}}$$

D°	1°	2°	3°	4°	5°
R	1720	860	573	430	344

meter

(2) For 20 m chain length:-

$$\frac{20}{D^{\circ}} = \frac{2\pi R}{360}$$

$$D^{\circ} = \frac{30 \times 360^{\circ}}{2\pi R}$$

$$\boxed{D^{\circ} = \frac{1146}{R}}$$

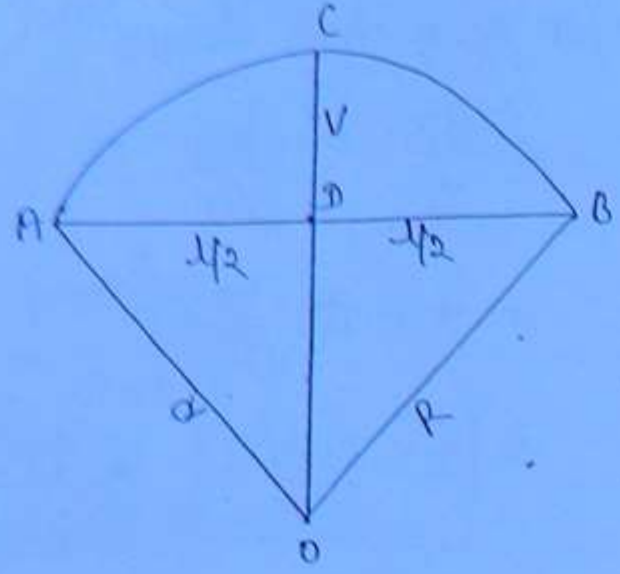
$$\boxed{R = \frac{1146}{D^{\circ}}}$$

D°	1°	2°	3	4	5
R	1146	573	382		

meters

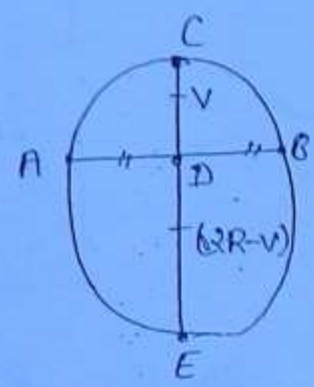
(7) Versine of Curve :→

12



→ If $AB = l$

For a chord length AB, Versine of curve is length CD



Using properties of circle

$\Rightarrow AD \times DB = CD \times DE$

$\frac{l}{2} \times \frac{l}{2} = V(2R - V)$

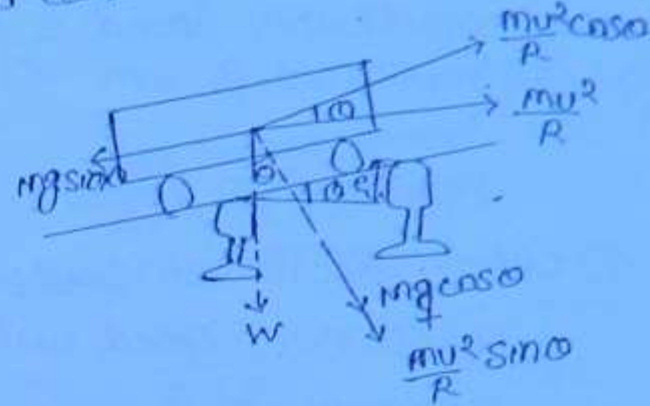
Hence $(2R - V) \approx 2R$

$\frac{l^2}{4} = V \cdot 2R$

$$\boxed{V = \frac{l^2}{8R}}$$

(11) Super elevation and Cant :→

→ To counteract the effect of centrifugal force, outer rail is raised w.r.t. inner rails, this raise is called Super-elevation and cant.



→ Weight $= mg$

Centrifugal force $= \frac{mv^2}{R}$

For equilibrium condition

Equating forces along the surface of two rails.

$$mg\sin\theta = \frac{mv^2}{R}\cos\theta$$

$$\boxed{\tan\theta = \frac{v^2}{Rg}}$$

Superelevation or cant

$$e = G\cdot\tan\theta = \frac{Gv^2}{gR}$$

$$e = \frac{G(0.278V)^2}{9.81R}$$

$$\boxed{e = \frac{GV^2}{127R}}$$

Ex: for B.G. Track

$$\boxed{e = \frac{1.676V^2}{127R}}$$

Equilibrium Cant:-

→ Different trains with different speed are moving on a track.

→ Actual cant provided & kept for an average speed, called equilibrium speed & cant provided is called equilibrium cant.

Equilibrium speed

① When Sanctioned speed is > 50 kmph

Equilibrium speed will be

Minimum of

(i) $V_{av} = \frac{3}{4} V_{max}$

(ii) Safe speed calculated for martins formula.

② When Sanctioned speed < 50 kmph

Minimum of

(i) $V_{av} = V_{max}$.

(ii) Safe speed from martins formula

③ Weighted average speed.

n_1 no. of train → V_1 speed

n_2 " " " → V_2 "

$$\text{weighted average speed} = \frac{n_1 V_1 + n_2 V_2 + \cdots}{n_1 + n_2 + \cdots}$$

$$\boxed{V_{average} = \frac{\Sigma nv}{\Sigma n}}$$

Cant provided = actual cant

$$= \boxed{\frac{G V_{av}^2}{127R}}$$

(B)

Cant Deficiency :→

max Speed on track (BG) = 100 kmph.

Equilibrium Speed = 75 kmph

R = 573 m

Actual cant provided

$$= \frac{Gv^2}{127R} = \frac{1.676 \times 75^2}{127 \times 573}$$

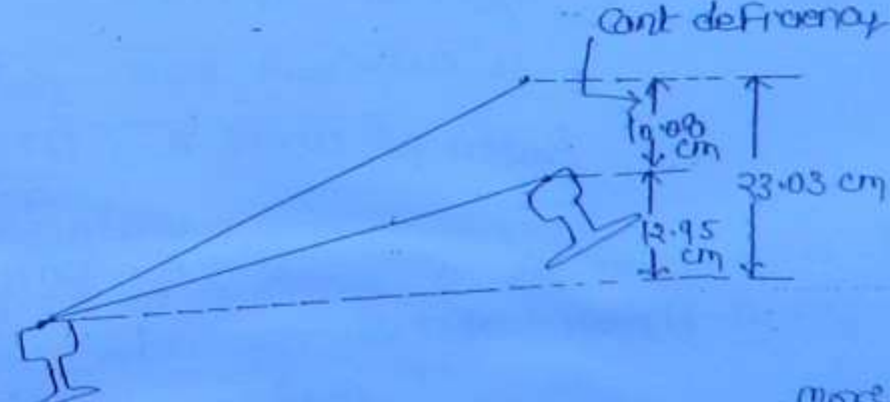
$$= 0.1295 \text{ m}$$

$$= 12.95 \text{ cm}$$

Cant required for max speed at 100 kmph

$$= \frac{Gv^2}{127R} = \frac{1.676 \times 100^2}{127 \times 573}$$

$$= 23.03 \text{ cm}$$



For a high Speed train, total Cant required is ~~less~~ more than that actually provided for equilibrium Speed. The deficiency of cant for a high Speed train is called cant deficiency. A train is allowed to move with a certain max. value of cant deficiency.

(76) Limits of Actual cant provided and cant deficiency.

Types of Track	Actual cant provided (C)	Cant deficiency (D)
(1) BG	(i) Speed ≤ 120 kmph = 16.5 cm	(i) Speed ≤ 100 kmph = 7.60 cm
	(ii) Speed > 120 kmph = 18.5 cm	(ii) Speed > 100 kmph = 10.0 cm
(2) MG	≤ 100 kmph = 10.0 cm	5.10 cm
(3) NG	7.6 cm	3.80 cm

Problem:- Equilibrium cant is provided for a speed of 80 kmph on a 4° curve. (B.G Track)

(i) what is the value of actual cant provided.

(ii) what max. speed can be allowed on this track.

Solution:→ $V_{av} = 80$ kmph

4° curve

Radius of curve $R = \frac{1720}{4°}$

$R = 430\ m$

(i) actual cant required

$$e = \frac{GV^2}{127R} = \frac{1.676 \times 80^2}{127 \times 430}$$

$e = 0.1964\ m$

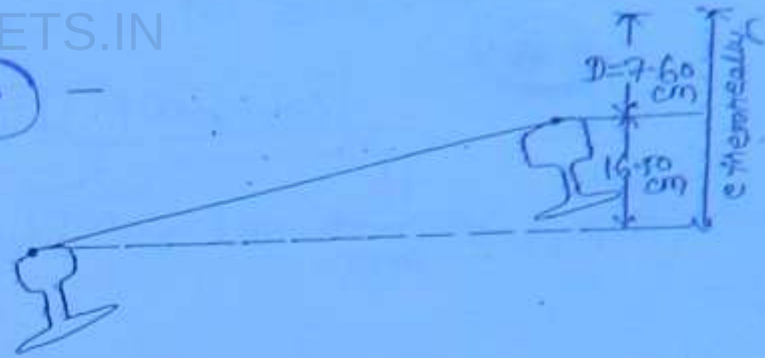
$\boxed{e = 19.64\ m}$

max. limit of e = 16.50 cm

Actual cant provided = 16.50 cm

(ii)

(17) —



(ii) After allowing max cant deficiency = 7.60 cm

Theoritical cant

$$e_{th} = e_{act} + D = 16.750 + 7.60$$
$$= 24.1 \text{ cm}$$

$$\text{Max. Speed} = \frac{G V_{max}^2}{127R} = \left(\frac{24.1}{100}\right) = e_{th}$$

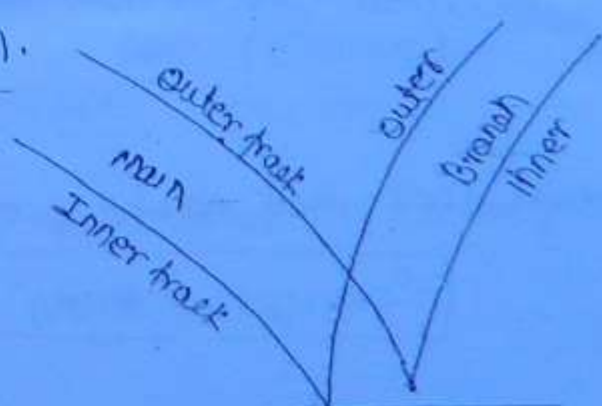
$$V_{max} = \sqrt{\frac{127R \cdot e_{th}}{G}}$$

$$V_{max} = \sqrt{\frac{127 \times 480 \times 0.24}{1.676}}$$

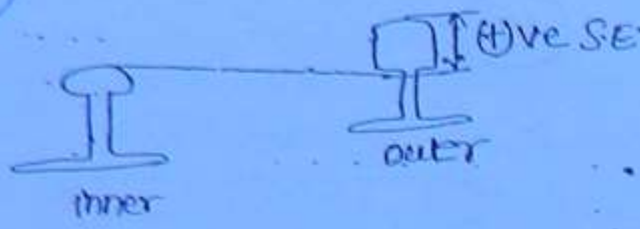
$$\boxed{V_{max} = 88.6 \text{ kmph}}$$

(17) Negative Superelevation :→

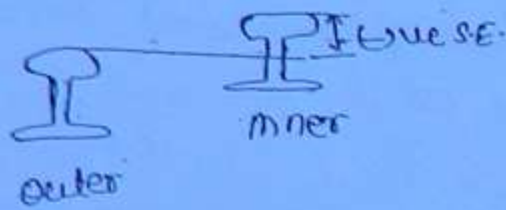
→ If outer track of a curve is provided at a lower level than the inner rail, it is called a negative superelevation.



Main Track



Branch Track



→ For example :→ If a branch curve track is diverted in opposite direction from main curved track (+) ve S.E. provided for main track shall become a (-) ve S.E. for branch track.

If max. Speed allowed on main track

$= V_{max(main)}$ | Max. Speed → e_{th} ↑ D ↓ average Speed → e_{act}

$$e_{th} = e_{act} + D$$

$$e_{act} = e_{th} - D$$

→ Theortical cant on main track $= \dfrac{G\,V^2_{(max)(main)}}{127R} = e_{th(m)}$

→ Actual cant that can be provided on main track

$$\boxed{e_{act(m)} = e_{th(m)} - D}$$

→ Cant. Cant available for branch track

$$\boxed{e_B = -e_{act}(m)} \quad -(19)$$

→ Theoritical cant for branch = $e_{th(B)} = e_B + D$

$= -e_m + D$

max speed allowed on branch track

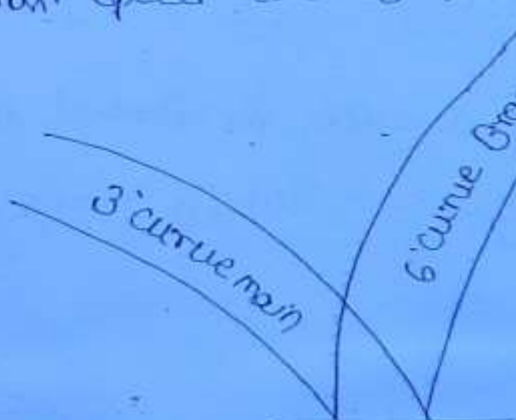
$$\boxed{V_{max(B)} = \sqrt{\frac{127 \cdot e_{th(B)} \cdot R}{G}}}$$

Problem:→ A branch track of 6° curve is diverting from a 3° main curve in opposite direction. (B.G. Track)

If max. speed allowed on main track is 65 km

Calculated actual cant provided for main/branch track & max. speed allowed for the branch track.

Solution:→



Radius of main track (3° curve)

$$R_m = \frac{1720}{3^\circ} = 573 \text{ cm}$$

Radius of Branch track (6° curve)

$$R_B = \frac{1720}{6} = 287 \text{ m}$$

max Speed allowed on main track

20

$$V_{m(max)} = 65 \text{ kmph}$$

Theoretical cant for main track

$$e_{th(m)} = \frac{GV^2}{127R_m} = \frac{1.676 \times 65^2}{127 \times 573}$$

$$e_{th(m)} = 0.097 m$$

$$e_{th(m)} = 9.73 \text{ cm}$$

Actual cant provided

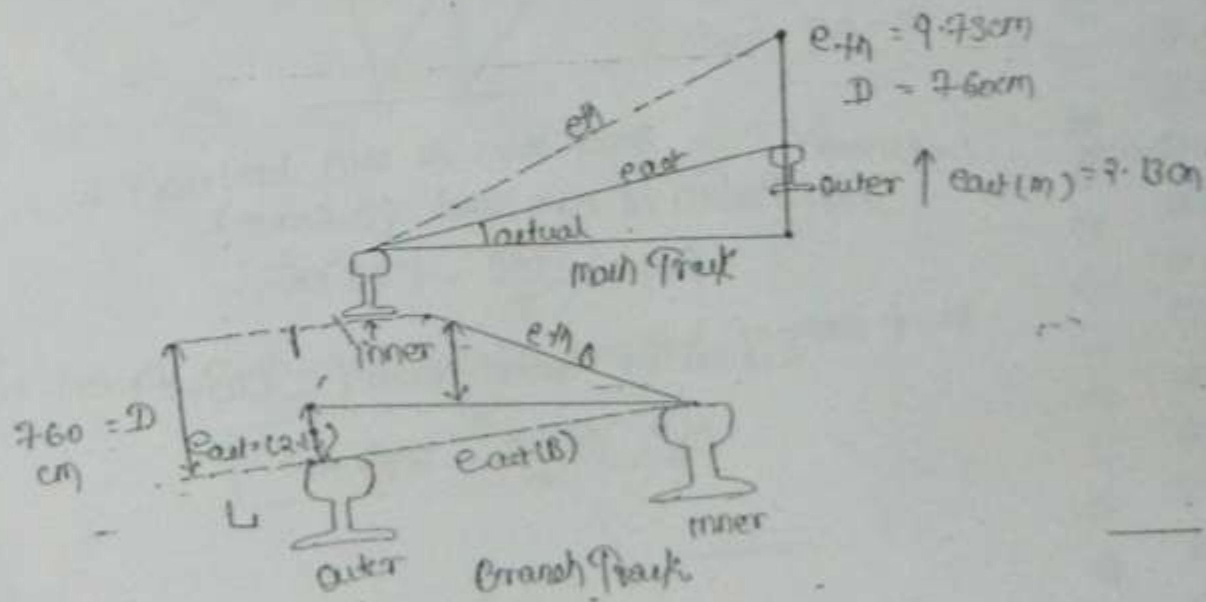
$$e_{act(m)} = e_{th(m)} - D$$

$$e_{act(m)} = 9.73 - 7.60$$

$$\boxed{e_{act(m)} = 2.13 \text{ cm}}$$ (+)ve S.E. for main track

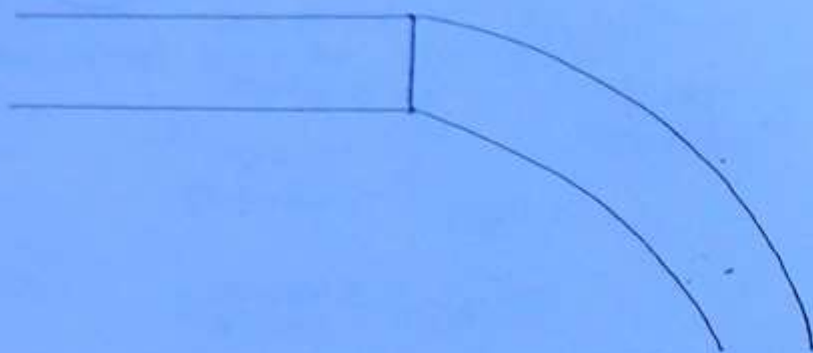
Actual cant avalible for Branch track

$$e_{act(B)} = -e_{act(m)} = -2.13 \text{ cm}$$



* Transition Curve :-

(22)



→ Purpose :→ A parabolic curve is introduced b/w straight & curve track to serve the following purpose:

(i) To provide super elevation (cant) in a gradual manner. (from 0 to e)

(ii) To reduce the radius of curve gradually (from R = ∞ at straight junction to R = R at curve junction)

(iii) To reduce the effect sudden jerk due to centrifugal force.

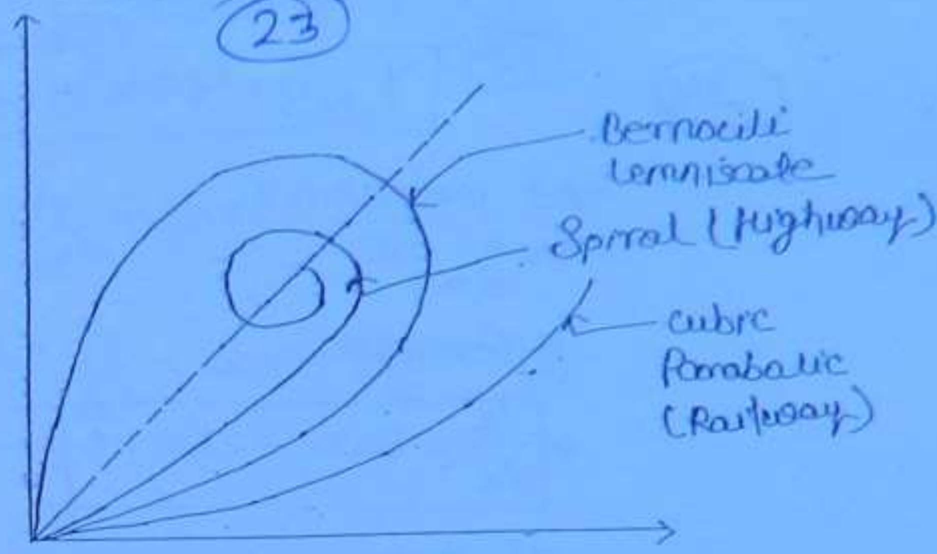
* Requirement of an ideal transition curve :→

(i) The curve should be perfectly tangential to its junction points at straight junction $R = \infty$

at curved junction $R = R$

(ii) Rate of change of curvature should same as rate of change of superelevation so that full S.E. can be provided with in length of transition curve.

(ii) Types:-



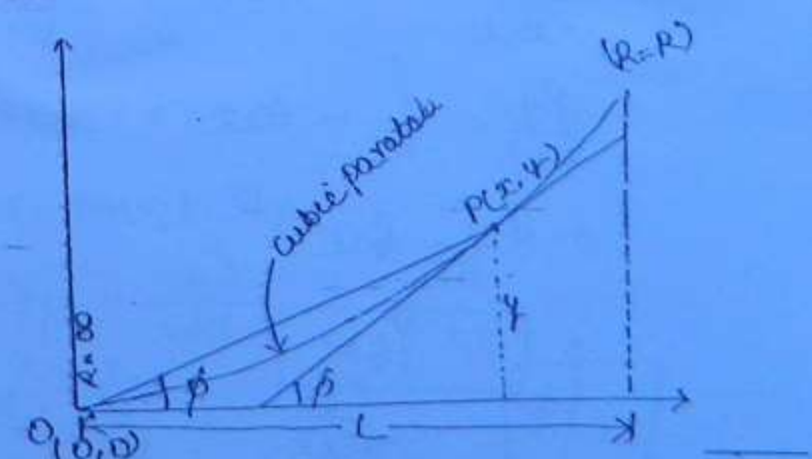
→ For Railway's Transition curve cubic Parabola is preff-ered.

→ All these three curve are almost same upto a deflec-tion angle of 3° to 5°

→ Path followed by there 3 curve are almost same upto 9° deflection.

→ cubic parabola used railways is also called "Froud's curved

(iii) Cubic parabola :→



General eq. for a cubic parabola

24

$$\boxed{y = ax^3 + bx^2 + cx + d} \rightarrow \text{Deflection eq.}$$

At $x=0, y=0$

than $d=0$

Differentiate

$$\Rightarrow \boxed{\frac{dy}{dx} = 3ax^2 + 2bx + c} \longrightarrow \text{slop eq.}$$

at $x=0$

$$\frac{dy}{dx} = 0$$

than $\boxed{c=0}$

$$\Rightarrow \boxed{\frac{d^2y}{dx^2} = 6ax + 2b} \longrightarrow \text{Curvature eq.}$$

at $x=0$, $\frac{d^2y}{dx^2} = 0$

$$\frac{1}{R} = \frac{1}{\infty} = 0$$

than $b=0$

At end point

$\because x=l$

$$\Rightarrow \frac{d^2y}{dx^2} = \frac{1}{R} = 6ax$$

$$\Rightarrow \frac{1}{R} = 6al$$

$$\Rightarrow \boxed{a = 1/6Rl}$$

for cubic parabola.

(1) Deflection = $y = ax^3 = \frac{x^3}{6RL}$

(2) Slope = $\frac{dy}{dx^2} = 3ax^2 = \frac{3x^2}{6RL} = \frac{x^2}{2RL}$

(3) curvature = $\frac{d^2y}{dx^2} = 6ax = \frac{6x}{6RL} = \frac{x}{RL}$

(4) Slope at end

at $x = L$

$$\frac{dy}{dx} = \frac{x^2}{2RL} = \frac{L^2}{2RL} = \frac{L}{2R}$$

(5) Spiral angle (ϕ) :→ it is the slope of tangent at any pt on the curve.

$\Rightarrow \phi = \tan\phi$

$\Rightarrow \tan\phi = \frac{dy}{dx} = \frac{x^2}{2RL}$

$\Rightarrow \phi_{max}$ at $(x = L)$

$\frac{L^2}{2RL} = \frac{L}{2R}$

(6) Deflection angle (α) :→

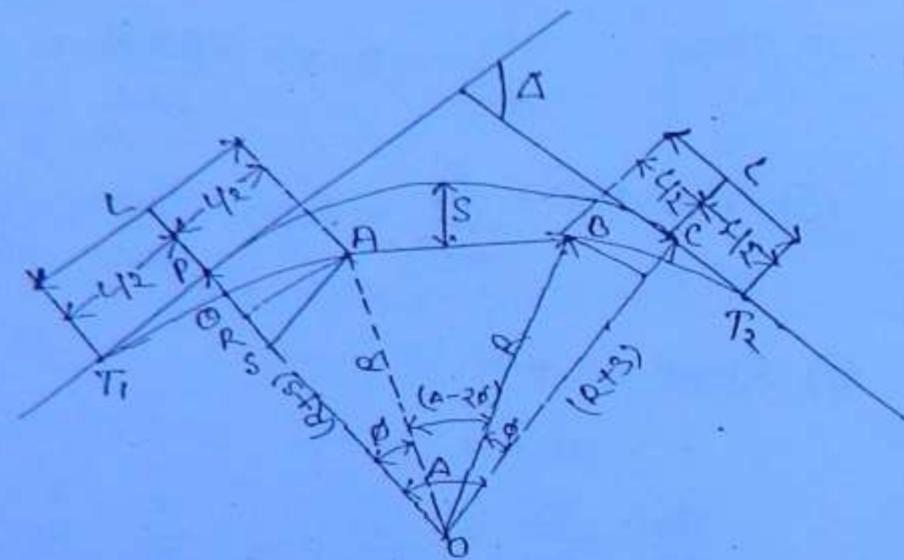
$\alpha = \tan\alpha = y/x$

$\Rightarrow y/x = \frac{x^3}{6RLx} = \frac{x^2}{6RL}$

$\Rightarrow \alpha = \frac{x^2}{6RL} = \frac{x^2}{3 \times 2RL} = \boxed{\phi/3}$

$$\boxed{q_{max} = L^2/6R}$$

(#) Providing Transition Curve : on a Railway Track :→



Transition curve is provided as shown in Fig.

if R = Radius of curve.

S = Shift of curve due to transition curve

T_1 = First tangent point.

T_2 = Last " "

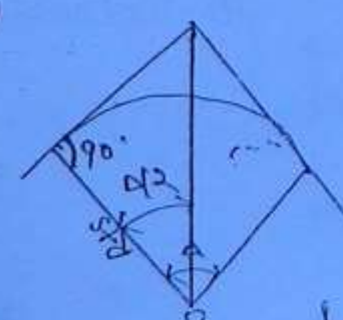
$$\angle QOA = \frac{L/2}{R} = \frac{L}{2R}$$

$= \phi$ Spiral angle

So $\angle AOB = (\Delta - 2\phi)$

(#) if chainage of point V = given

The value of Shift $S = \frac{L^2}{24R}$



Radius = $(R+S)$

Tangent length

$P_V = (R+S)\tan \Delta/2$

Total tangent length.

$$T_1V = L/2 + PV = (R+S)\tan\frac{\Delta}{2} + L/2$$

chainage to T_1

chainage $V - VT_1$

chainage of A

chainage of $T_1 + L$

length AB

length of simple curve

$$l = \frac{2\pi R}{360} \times (\Delta - 2\phi)$$

chainage of B

chainage of A + l

chainage T_2 = chainage of B + L

Shift $PR = PRS - RS$

$$= Y - (OR - OS)$$

$$= Y - (R - R\cos\phi)$$

$$= Y - R(1 - \cos\phi)$$

$$= Y - R\,2\sin^2\phi/2$$

$$\Rightarrow S = \frac{L^2}{6R} - 2R(\phi/2)^2$$

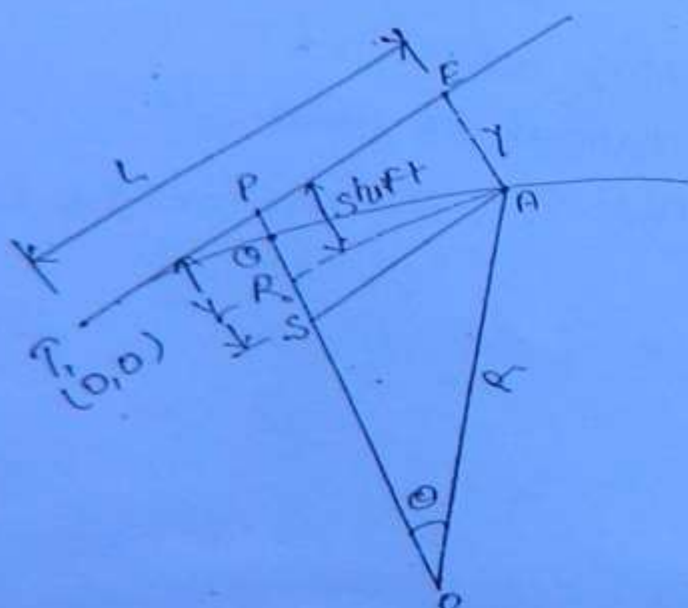
$$\Rightarrow S = \frac{L^2}{6R} - 2R(L/4R)^2$$

$$\Rightarrow S = \frac{L^2}{6R} - 2R\, L^2/16R^2$$

$$\Rightarrow S = \frac{L^2}{6R} - \frac{L^2}{8R}$$

$$\Rightarrow S = \frac{(4-3)L^2}{24R}$$

$$\boxed{S = \frac{L^2}{24R}}$$



Length of Transition Curve:→

There are two approach

(1) First approach
(As per Indian Railway)

(i) $L = 7.20e$ — e = Cant in cm, L = length in meter

(ii) $L = 0.073 D \cdot V_{max}$

D = cant deficiency in cm
V_{max} = Speed in kmph.

3(iii) $L = 0.073\, e \cdot V_{max}$

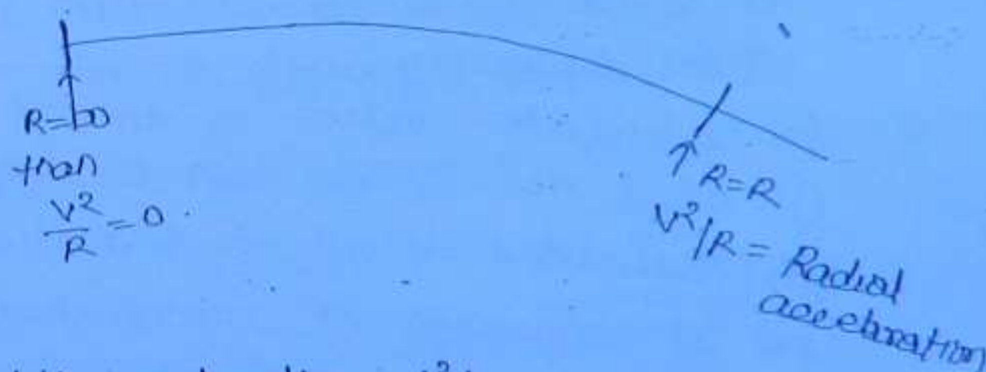
(3) Length of Transition curve :→

(i) $L = 4.4\sqrt{R}$ ∀ R = Radius in meter
L = Length in meter

(ii) $L = 3.6\, e$ ∀ e = cm
L = m

(3) Based on rate of change of radial acceleration :→

$$L = \frac{3.28\, V^3}{R}$$ ∀ V = Speed in m/sec
R = m
L = m



→ Radial acceleration $= V^2/R$

at Straight junction $= R = \infty$

$$\frac{V^2}{R} = \frac{V^2}{\infty} = 0$$

at Curved junction $= V^2/R$

Radial acceleration changes from 0 to $\frac{V^2}{R}$

If Train takes T sec in the change

Time $T = L/V$

Rate of change of radial acceleration $= \frac{a}{L}$ c

$ca = V^3/R$

$$T = \frac{v^2}{\frac{a}{C}R}$$

Equating

$$\Rightarrow \frac{L}{v} = \frac{v^2}{CR}$$

$$\Rightarrow L = \frac{v^3}{CR}$$

$$\Rightarrow L = \frac{v^3}{0.3048R}$$

$$\Rightarrow \boxed{L = \frac{3.28v^3}{R}}$$

Problem:- Equilibrium cant is provided on a BG track of 4° curve for an equilibrium speed of 80 Kmph. Total deflection angle $\Delta = 45°$

(i) calculate value of actual cant provided.

(ii) what max. speed can be allowed on this track.

(iii) Calculated length of transition curve required.

(iv) If chainage of intersection point is 8052m Calculate chainage of important points on the curve with transition curve.

(v) Set out the transition curve of every 10m distance.

Solution:→ Radius of curve $R = 1720/4° = 430$ m

equilibrium speed $V_{av} = 80$ kmph

(i) Equilibrium cant (actual cant) provided

$$e = \frac{Gv^2}{127R} = \frac{1.676 \times 80^2}{127 \times 430}$$

$$e = 0.196 = 19.6\text{ cm}$$

$e_{max} = 16.50\ cm$ (3)

Provided $e = 16.50\ cm$

(ii) Max. Speed

(a) Cant + Cant efficiency

Cant $e = 16.50$

Allow max. and deficiency $= 7.60$

Total / Theoritical cant $= 24.1\ cm$

$= .241\ m$

$$V_{max} = \sqrt{\frac{127 \cdot R e_{th}}{G}}$$

$$V_{max} = \sqrt{\frac{127 \times 430 \times 0.241}{1.676}}$$

$V_{max} = 88.6$ Kmph

(b) max. Safe Speed on curve by martin formal

$$V_{max} = 4.35\sqrt{R-67}$$

$$V_{max} = 4.35\sqrt{430-67}$$

$V_{max} = 82.90 \simeq 83$ kmph

Max. Speed allowed $= 83$ kmph

(iii) length of transition curve

(a) $L = 4.4\sqrt{R} = 4.4\sqrt{430} = 91.24\ m$

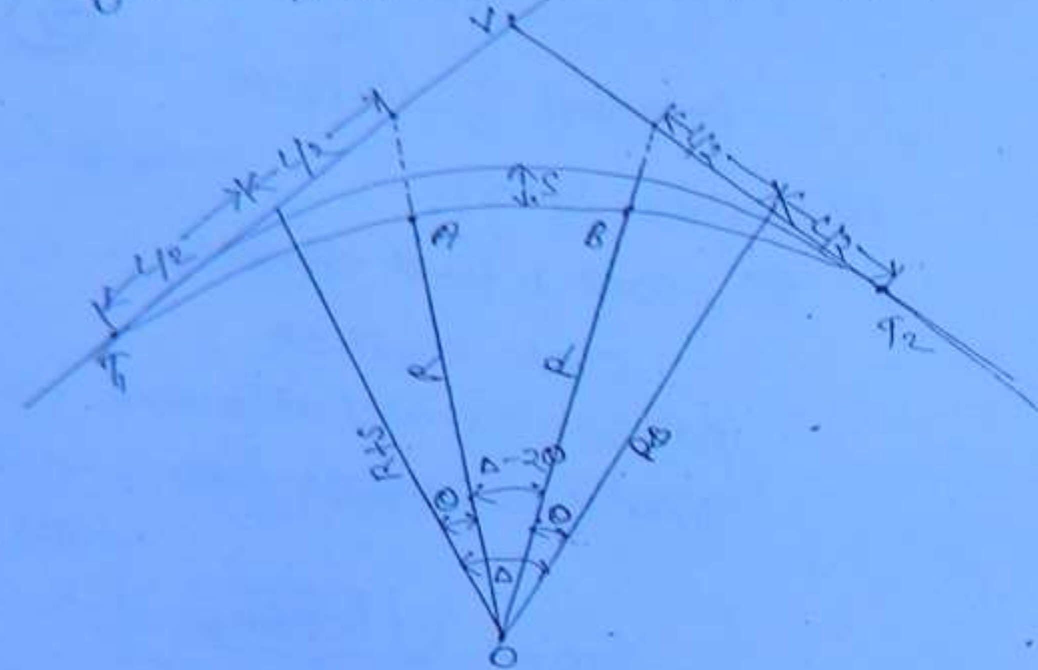
(b) $L = 3.6e = 3.6 \times 16.50 = 59.4\ m$

(c) $L = \frac{3.28 V^3}{R} = \frac{3.28 \times (0.278\ V_{max})^3}{R}$

$= 3.28 \times (0.278 \times 83)^3 / 430$

$= 93.70\ m \simeq 94\ m$

So length of transition curve $L = 94m$



(iv) chainage of important points:→

chainage of $V = 8052\ m$

$$R = 430\ m$$

$$\text{Shift } S = \frac{L^2}{24R} = \frac{94^2}{24 \times 430}$$

$$= 0.86\ m$$

Total tangent length

$$VT_1 = T_1P + PV$$

$$VT_1 = \frac{L}{2} + (R+S)\tan\Delta/2$$

$$VT_1 = \frac{94}{2} + (430 + 0.86)\tan\frac{85}{2}$$

$$VT_1 = 441.81$$

chainage AB $= T_1 =$ chainage of $V - VT_1$

$$= 8052 - 441.81$$

$$= 7610.19m$$

length AB $= l = \frac{2\pi R}{360} \times (\Delta - 2\phi)$

(33)

$= \frac{2\pi \times 430}{360} (85 - 2\times 6^\circ 15' 45'')$

$= 543.92 \, m$

Point $T_1 = 7610.19 \, m$

$+ \, L = 94$

chainage A $= 7704.19 \, m$

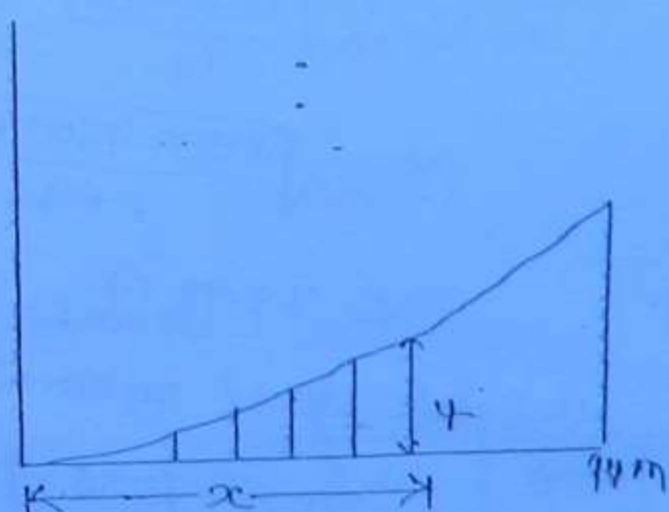
$+ AB = 543.92 \, m$

$8248.11 \, m$

$+ L \quad 94$

chainage of T_2 $= 8342.11 \, m$

(v) Setting out of transition curve



Equation of curve

$y = \frac{x^3}{6RL} = \frac{x^3}{6 \times 430 \times 94}$

$y = \frac{x^3}{242520}$

34

x	0	10	20	30	40	50	60	70	80	90	94
y (m)	0					0.58				3.01	3.42

ES-2009
Problem:→ Determine the length of transion curve & offsets at every 15m distance for a BG curved track having 4° curvature & cant of 12cm. Max. permissible speed on the curved is 85 kmph.

Solution:→ (i) max. Speed

(a) cant formula

Theoritical cant = Actual cant + cant deficie

$= 12+7.6 = 19.60\ cm$

$= 0.196 m$

$$V = \sqrt{\frac{127 R \cdot e_{th}}{G}}$$

$R = 1720/4$

$$V = \sqrt{\frac{127 \times 430 \times 0.196}{1.676}}, \quad R = 430\ m$$

$V = 79.90\ m$

(b) Safe speed on curve by martin's formula

$V_{max} = 4.35\sqrt{R-67}$

$V_{max} = 4.35\sqrt{430-67}$

$\boxed{V_{max} = 82.87}$ kmph

(C) Max. Speed permissible = 85 kmph

max. allowable speed = 79.90 kmph

≈ 80.00 kmph

(6) Length of Transition curve

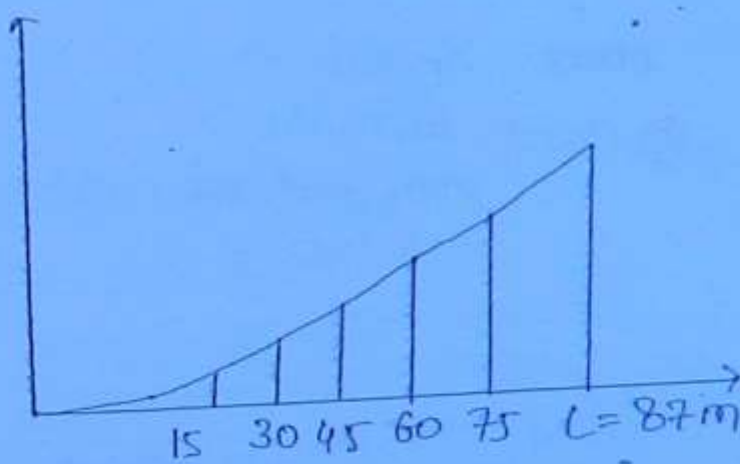
(i) $L = 7.20 \times e = 7.20 \times 12 = 86.4\ m$

(ii) $L = 0.073 \cdot e \cdot V_{max} = 0.73 \times 12 \times 80 = 70.08\ m$

(iii) $L = 0.073 \cdot D \cdot V_{max} = 0.73 \times 0.76 \times 80$
$= 44.38\ m$

80 $\boxed{h = 86.4\ m \simeq 87\ m}$

(7) Setting out the transition curve



$$Y = \frac{x^3}{6RL} = \frac{x^3}{6 \times 430 \times 87}$$

$$Y = \frac{x^3}{224460}$$

x m	0	15	30	45	60	75	87
Y m	0	0.015	0.12	0.406	0.962	1.879	1.92

Problem :-> 4° curve, cant = 12 cm, max. design speed = 100 kmph cant deficiency = 7.60 cm. Determine length of transition curve = ? & off sets at every 15 m.

(36)

13 वर्ष 6(e)

Problem :-> Define cant & cant deficiency calculated length of transition curve for a BG curved track having 5° deflection & a cant of 14 cm max. permissible speed = 80 kmph.

Solution :-> 5° curve

$$\text{Radius} = \frac{1720}{5} = 344\text{ m}$$

Max. Speed

(a) Cant formula

Theoretical cant = $e_{th} = e + D$

$= 14 + 7.60$

$= 21.60\text{ cm}$

$= 0.276\text{ m}$

$$V_{max} = \sqrt{\frac{127 R e_{th}}{G}}$$

$$V_{max} = \sqrt{\frac{127 \times 344 \times .276}{1.676}}$$

$\boxed{V_{max} = 75.03} \simeq 75\text{ kmph}$

(b) Safe speed on curve by martins formula

$V_{max} = 4.35\sqrt{R - 67}$

$V_{max} = 4.35\sqrt{344 - 67}$

$V_{max} = 72.39\text{ kmph}$

(c) Max. permissible speed = 80 kmph

Allowable speed $V_{max} = 72.39 \simeq 72\text{ kmph}$

Length of transition curve

37

(1) $L = 4.4\sqrt{R} = 4.4\sqrt{344}$

$= 81.6\ m$

(2) $L = 3.6e = 3.6 \times 14 = 50.4\ m$

(3) $L = \frac{3.28 \times (0.278V)^3}{R}$

$L = \frac{3.28 \times (0.272 \times 72)^3}{344}$

$L = 76.4\ m$

$\boxed{\text{So } L = 81.6 \simeq 82\ m}$

Problem:→ on a transitional curve on BG Track Speed railway board formula $V = 4.35\sqrt{R-67}$ is 1.35 times speed obtained by cant formula allowing cant deficiency of 7.60 cm. If actual cant is provided for 80 kmph speed. Calculated

(i) Radius of curve:

(ii) Max. Speed allowed on the track.

(iii) Actual value of cant provided.

Solution:→ $V = 4.35\sqrt{R-67}$ — (1)

If Radius $= R$

Actual cant $e = \frac{GV^2}{127R} = \frac{1.676 \times 80^2}{127 \times R}$

$e = \frac{84.4}{R}$

Theoretical cant $e_{th} = e + D$

$e_{th} = \frac{84.4}{R} + \frac{7.60}{100}$

$e_{th} = \frac{84.4}{R} + 0.076$

Speed by cant formula

$$V_{max} = V_2 = \sqrt{\frac{127 R e_{th}}{G}}$$

(38)

$$V_2 = \sqrt{\frac{127 \times R \times}{1.676}\left(\frac{84.4}{R} + 0.076\right)}$$

$$\because V_1 = 1.85 V_2$$

$$\Rightarrow 4.85\sqrt{R-67} = 1.85\sqrt{\frac{127 \times R}{1.676} \times \left(\frac{84.4}{R} + 0.076\right)}$$

Square on both sides

$$10.38(R-67) = \frac{127}{1.676}(84.4 + 0.076R)$$

$$10.38R - 695.64 = 6395.46 + 5.76R$$

$$\boxed{R = 1534.87 m} \approx 1535 m$$

(b) Max. Speed

for cant formula

$$V_{max} = V_2 = \sqrt{\frac{127 \times 1535}{1.676}\left(\frac{84.4}{135} + 0.076\right)}$$

$$\boxed{V_2 = 123.43 \ kmph}$$

(c) Actual cant

$$e = 84.4/R$$

$$e = \frac{84.4}{1535}$$

$$e = 0.055 m$$

$$\boxed{e = 5.5 cm}$$

problem:→ Calculated max. Speed allowed on a curve for a BG track for given particulars.

A) = 2° curve.

B = Max. Speed allowed by Railway = 140 kmph

C = length of transition curve = 120 m

Solution:→ curve $R = \frac{1720}{2°} = 860 m$

max. Speed shall be min at following

(1) Safe Speed from Martin's Formula

$$V = 4.35\sqrt{R-67}$$

$$V = 4.35\sqrt{860-67}$$

$$V = 122 \text{ kmph}$$

Use formula for high Speed trains

$$V = 4.58\sqrt{R}$$

$$V = 4.58\sqrt{860}$$

$$V = 134.3 \text{ kmph}$$

(2) Cant formula

$$\text{Theoretical formula} = \frac{GV^2}{127R}$$

$$= \frac{1.676 \times 134^2}{127 \times 860}$$

$$= 27.55$$

Use max. actual cant = 18.50 cm

cant deficiency D = 10 cm

total eth = 28.50 cm

$$V_{max} = \sqrt{\frac{127 \cdot R e_{th}}{G}} = \sqrt{\frac{127 \times 860 \times .285}{1.676}}$$

$$\boxed{V_{max} = 136.28 \text{ kmph}}$$

③ As per length of transition curve

Max^m speed for speed upto 100 kmph

$$V_{max} = \frac{134L}{e} \quad L = \text{length (m)}$$

$$V_{max} = \frac{134L}{D} \quad e = \text{cant (mm)}$$

Max speed for speed > 100 kmph

$$V_{max} = \frac{198L}{e}$$

$$V_{max} = \frac{198L}{D}$$

$$V_{max} = \frac{198L}{e} = \frac{198 \times 12}{185}$$

$$V_{max} = 128.41 \text{ kmph}$$

④ Max. speed allowed = 145

So max. speed = 128 kmph

(i) Max. speed → cant, → Martin, → Max. allowed, → Transition curve } max.

(ii) length of transition curve

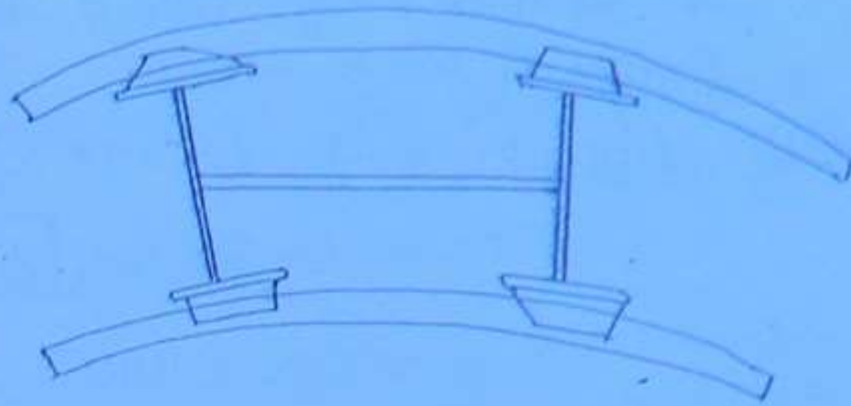
→ Use V_{max} | consider max. length L

(iii) $e_{th} = e + D$

e_{th} ↓ max. speed; e ↓ avg. speed

Extra Wideing:

(41)



Extra widening on curve

$$d = \frac{(B+L)^2}{R} \text{ cm}$$

∀ B = Rigid wheel Base (in m)
= 6.0m (for B.G. Track)
= 4.88m (For M.G. Track)

R = Radius of curve (in m)
L = Lap of flange (in m)

$$\boxed{L = 0.02\sqrt{h^2 + Dh}}\ m$$

h = Depth of wheel flange below top level of rail (in m)

D = Diameter of wheel (in cm)

Problem:→ (42) For a B.G. track wheel base is 6m. Dia of wheel is 1.52m. Determine extra width required if depth of flange below top of rail is 3.5cm. Radius of curve = 480m

Solution:→ lap of flange $L = 0.02\sqrt{h^2 + Dh}$

$$L = 0.02\sqrt{3.15^2 + 152 \times 3.15}$$

$$L = 0.44m$$

$$d = \frac{13(B+L)^2}{R}$$

$$d = \frac{13(6+0.44)^2}{480}$$

$$\boxed{d = 1.25\,cm}$$

Vertical Curve

(ii) Gradient

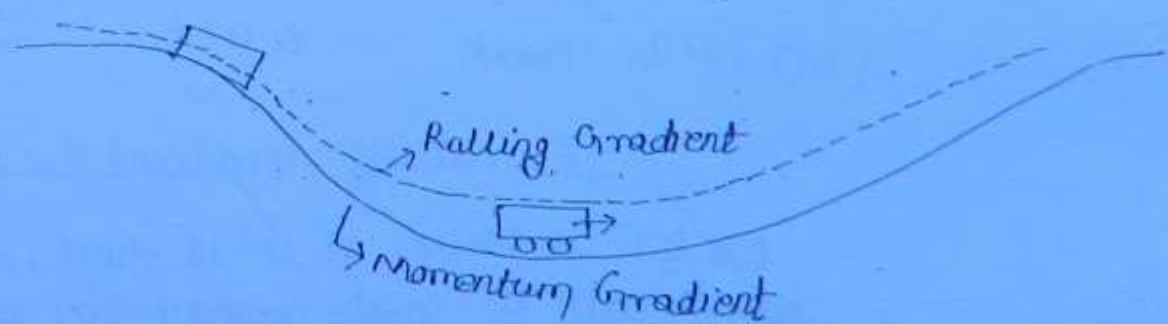
(1) Ruling Gradient :→ The max. gradient that can be provided in most general condition is called Ruling Gradient.

For plains :→ 1 in 150 to 1 in 200

For Hilly :→ 1 in 100 to 1 in 150

No gradient should be more than than ruling gradient in general conditions.

(2) Momentum Gradient :→ when an upgradient is meet a down gradient as shown fig. in case of a valley curve



Than train get monetum during downward movement, that is used for upward moment. So we can provided the gradient slightly more than, Ruling gradient the gradient provided is called momentum gradient.

(3) Pusher Gradient :→ In very extraordinary situation pusher gradient can be provided more steeper than ruling gradient. In this case, extra locomo-tive is required to pull the train.

 Gradient of 1 in 95 to 1 in 100 will require

44 red one extra locomotive.

(4) Gradient in Station yards :→ A min. Slope is required Just for draining purpose high gradient should be avoided to avoid automatic movement of trains.

Max. Gradient in Station yards = 1 in 400
Min Gradient for drainage = 1 in 1000

(5) Grade Compensation on curves :→ Due to curve, train has to resist some resistance, So max. gradient provided should be reduced at the location of curve.

Track	Grade compensation
(i) B.G. Track	— 0.04 % per degree of curve
(ii) M.G. Track	— 0.03 % " " " "
(iii) N.G. Track	— 0.02 % " " " "

IF ruling gradient = 1 in 150

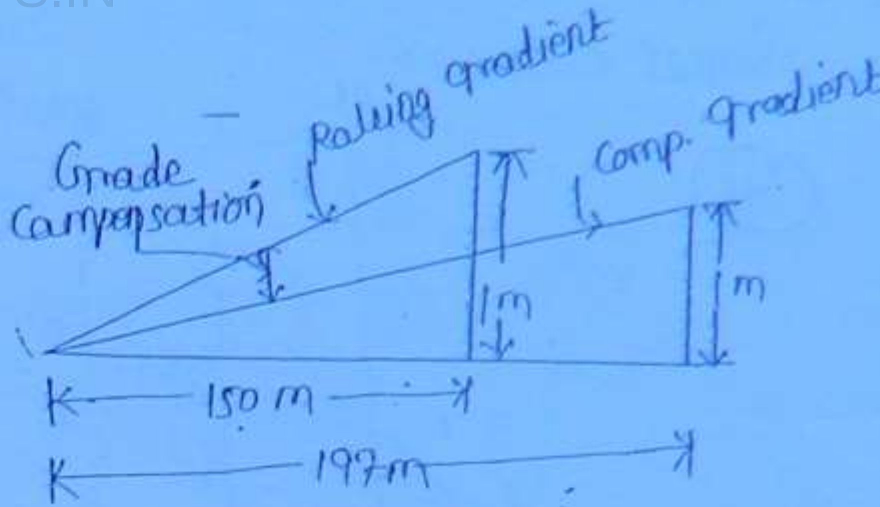
Ex:- IF a curve of 4° is there, on a B.G. track, what will be grade compensation and compensated gradient.

Sol:→ Grade compensation $= \frac{0.04}{100} \times 4 = 0.0016$
$= 1/625$

Compensated Gradient $= \frac{1}{150} - \frac{1}{625}$

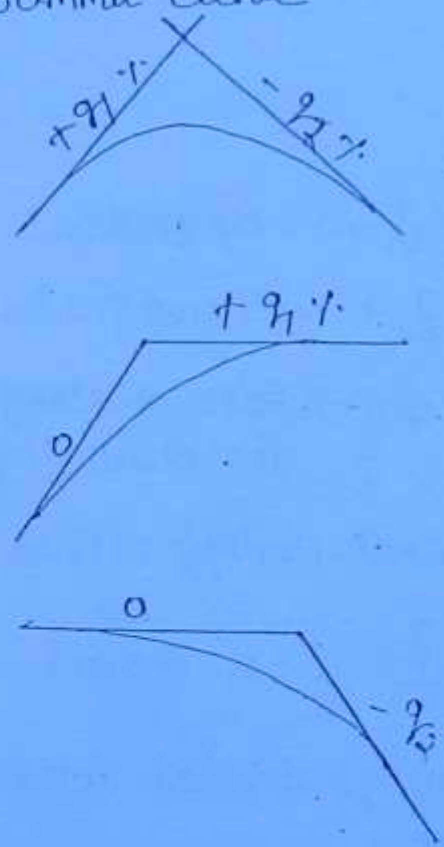
$= 1/197$

(45)

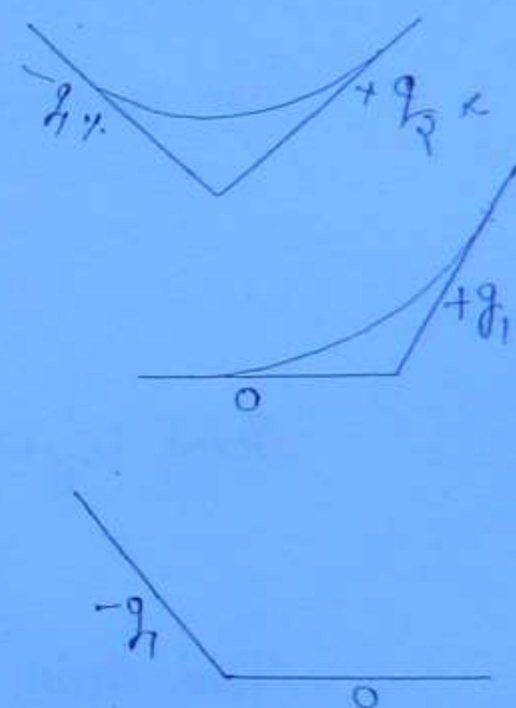


Vertical Curve

① Summit curve



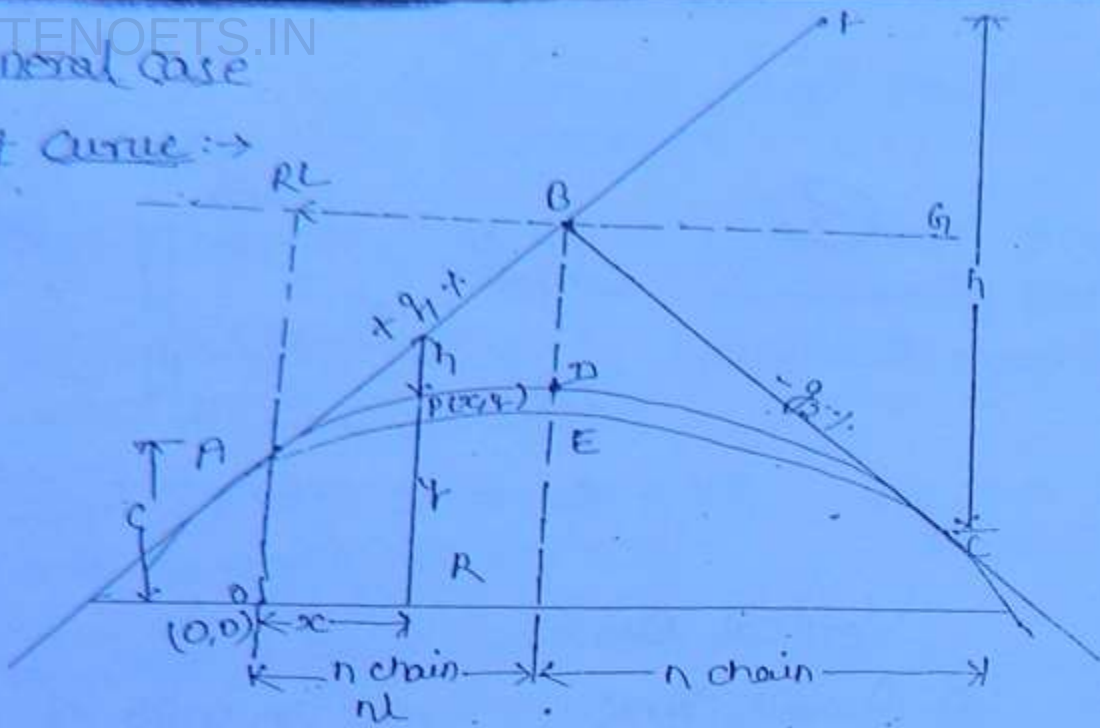
② Valley curve



(ii) A general case

Summit curve :->

46



BD = DE

Two gradient are $+g_1\%$ → up gradient 1st gr. &

$-g_2\%$ → Down gradient 2nd gradient

$r\%$ → Rate of change of gradient Per chain length

Total length of Summit (valley) curve

$$L = \frac{g_1 - g_2}{r} = 2n \text{ chains}$$

Total chain is equally divided into two parts from point of intersection.

IF length of chain = l

1. chainage of B = Known
2. chainage of A = chainage of B − $n \times l$
3. chainage of C = chainage of B + $n \times l$

Reduced level

(1) RL of B = Given

(2) RL OF A = RL OF B $- g_1 \frac{nl}{100}$

(3) RL OF C = RL OF B $- g_2 \frac{nl}{100}$

(4) RL OF E = $\frac{RL(A) + RL(C)}{2}$

(5) RL OF D = $\frac{RL(B) + RL(E)}{2}$

Equation of parabolic curve (Summit)
(Simple parabolic curve is used)

$$y = ax^2 + bx + c \quad \text{--- (1)}$$

at A
$x = 0$
$y = 0 + 0 + c = c$

Slope Eq.

$$\frac{dy}{dx} = 2ax + b$$

Slope @ $x = 0$

$$\frac{dy}{dx} = +g_1 \%.$$

$$+g_1 = b$$

Equation

$$\boxed{y = ax^2 + g_1 x + c} \quad \text{--- (2)}$$

- P(x, y) is point on the curve to get RL OF LP
RL OF Q = RL OF A + g_1 % OF x

RL of P = RL of Q − PQ

48 Value of PQ (h)

$PQ(h) = RQ - PR$

$= (c + g_1 x) - y$

$= (c + g_1 x) - (ax^2 + g_1 x + c)$

$= -ax^2$

$= kx^2$

Value of 'h' for last point of curve

$F_c = F_{G_1} + G_e$

$F_c = g_1 \frac{nl}{100} + g_2 \frac{nl}{100}$

e_1 = Rise/fall per chain length

$e_1 = g_1 \times \frac{l}{100}$

$e_2 = g_2 \frac{l}{100}$

$h = e_1 n + e_2 n$

General eq.

$h = n(e_1 - e_2)$

$kx^2 = n(e_1 - e_2)$

$k(2n)^2 = n(e_1 - e_2)$

$k4n^2 = n(e_1 - e_2)$

$k = \left(\frac{e_1 - e_2}{4n}\right)$

Note :→ Value of x for C point = 2n chains

Eq. for $h = Kx^2$

$$= \left(\frac{e_1 - e_2}{4n}\right)x^2 \quad (49)$$

Here value of x = no. of chains

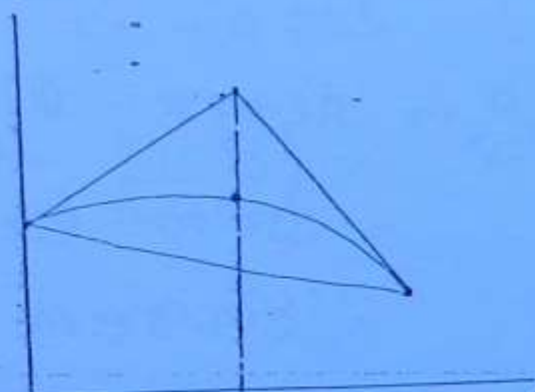
$= 1, 2, 3, 4 - - -$

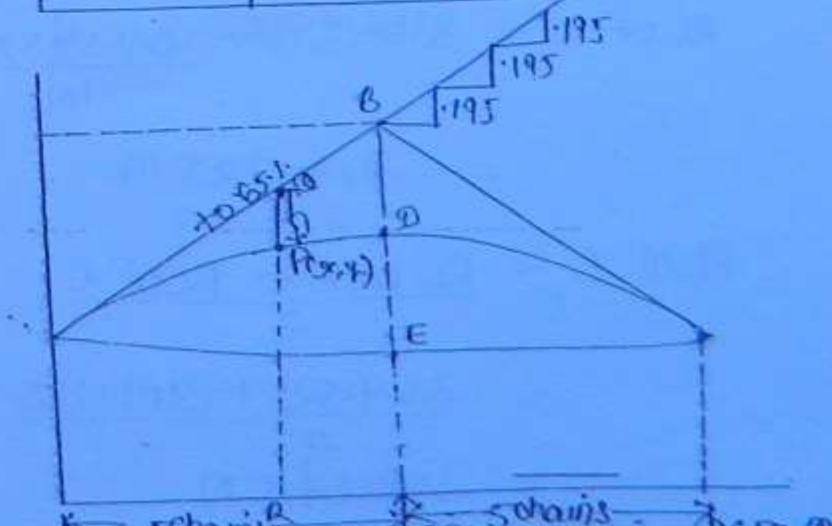
RL of point P = RL of Q − PQ

= RL of Q − h

Problem:- A summit curve has two gradient +0.65% & −0.85%, Rate of change of gradient per chain length is 0.15%. If RL & chainage of point of intersection is 350.50 m & 2500 m respectively. calculated RL & chainage of different point of the summit curve use 30 m chain.

Solution:-





$g_1 = +0.65\%$

$g_2 = -0.85\%$

(50) $r = 0.15\%$ per chain length

length of curve

$l = \frac{g_1 - g_2}{r} = \frac{+0.65-(-0.85)}{2}$

$l = 10$ NOS

$l = 2n$

chainage of point A = chainage of B − nl

$= 2500 - 5 \times 10$

$= 2350$ m

chainage of point C = chainage of B + nl

$= 2500 + 150$

$= 2650$ m

RL OF A = RL OF B − $\frac{g_1 nl}{100}$

$= 350.50 - \frac{0.65 \times 5 \times 30}{100}$

$= 349.525$ m

RL OF C = $350-50 - \frac{085 \times 5 \times 30}{100}$

$= 349.225$ m

RL of E = $\frac{\text{RL OF A} + \text{RL OF C}}{2}$

$= \frac{349.525 + 349.225}{2}$

$= 349.375$ m

$$RL\ OF\ D = \frac{RL\ OF\ B + RL\ OF\ E}{2}$$

(5) $= \frac{350.50 + 349.375}{2}$

$= 349.9375\ m$

value OF $h = Kx^2$

$$= \left(\frac{e_1 - e_2}{4n}\right)x^2$$

$$V \Rightarrow e_1 = +\frac{g_1 l}{100} = \frac{0.65 + 30}{100}$$

$$e_1 = 0.195$$

$$\Rightarrow e_2 = -\frac{g_2 l}{100} = -\frac{0.85 \times 30}{100}$$

$$e_2 = 0.255$$

$$K = \left(\frac{e_1 - e_2}{4n}\right) = \frac{0.195 - (0.255)}{4 \times 5}$$

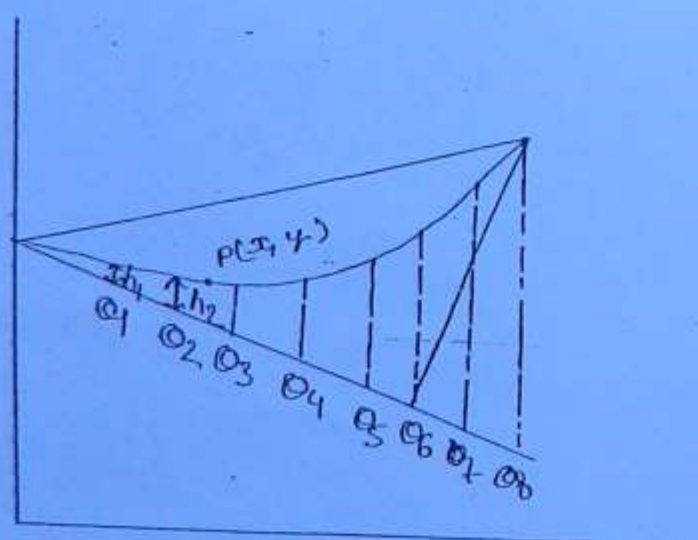
$$K = 0.0225$$

$$h = 0.225x^2$$

Point A	Chainage	RL of 1st tangent	h = Kx^2	RL of point on curve
0	2350	349.525	0	349.525
1	2380	349.720	0.0225	349.6975
2	2410	349.915	0.09	349.825
3	2440	350.110	0.2025	349.9075
4	2470	350.305	0.36	$\boxed{349.945}$ Apex point
(B) 5	2500	350.500	0.5625	349.9375
6	2530	350.695	0.81	349.885
7	2560	350.890	1.1025	
8	2590	351.085	1.44	
9	2620	351.280	1.8225	
(C) 10	2650	351.475	2.25	349.225

(52)

Valley curve:→



RL of P = RL of O + h
(on first tangent)

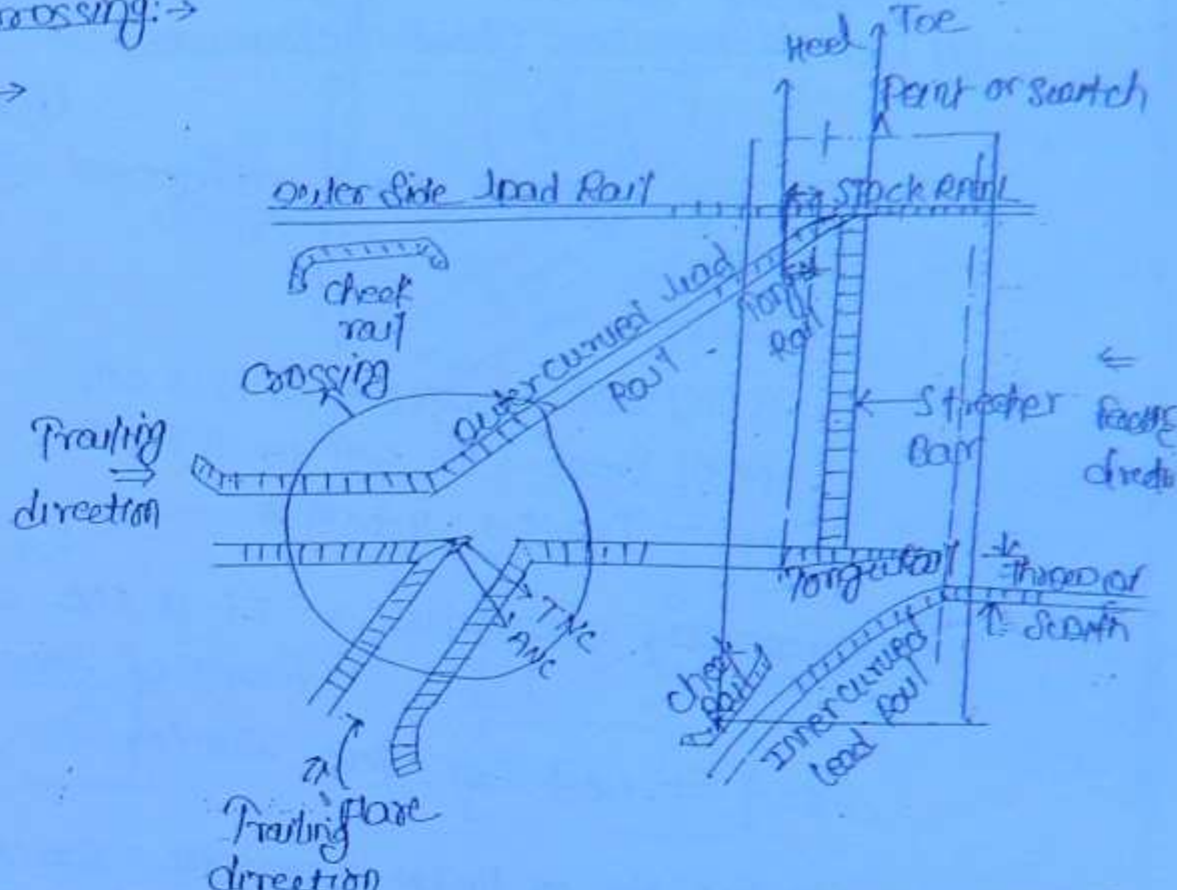
ES 2006 [redacted]

Railway :->

* Point and crossing :->

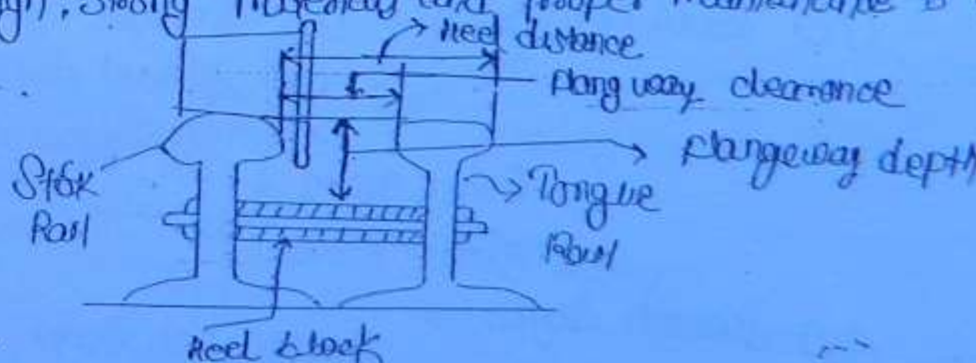
① Turnout :->

(53)



-> Turnout is a combination of point and crossing, it is used to direct the train from one track to another, so that flexibility of movement can be obtained b/w different tracks.

There are the weakest location of railway track. so proper design, strong materials and proper maintanance is nec



(Cross Section at Heel of the Switch)

(a) Switch & points :→

(54)

Important terms :- –

(i) Heel divergance (heel clearance) :→ It is the distance b/w running of stock rail and tongue rail measured at the heel of the switch.

In India

B G Track → 13.7 cm to 13.3 cm

M G Track → 12.1 cm to 11.7 cm

N G Track → 9.8 cm to

(ii) Flangeway clearance :→ It is the distance b/w adjacent faces of stock rail and tongue rail at heel of the switch.

Value for Indian Railway ① for 1 in 12 crossing = 6.0 cm + 0.3 cm = 6.3 cm (for wear)

② for 1 in 8 crossing = 6.0 + 0.6 cm = 6.6 cm

(iii) Flangeway Depth :→ Depth from top of rail to to top of heel block is called flangeway depth.

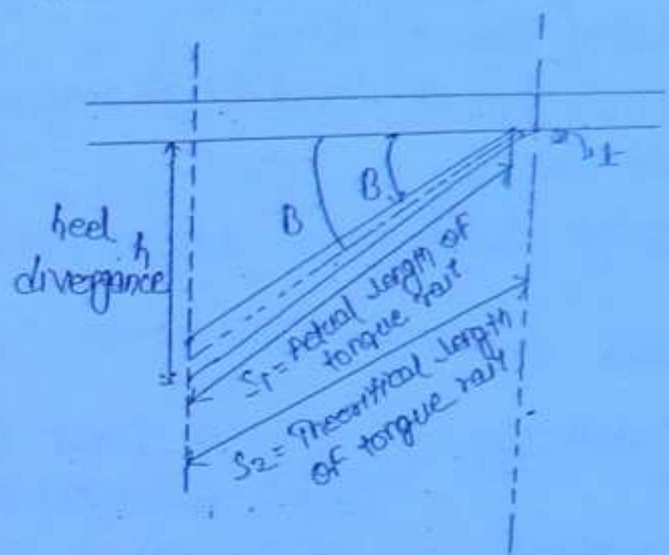
(iv) Throw of Switch :→ The distance by which the toe of tongue rail moves sideway at toe is called throw of switch.

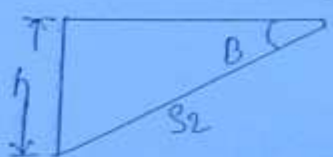
B.G. = 9.5 cm
M.G. = 8.9 cm } In india

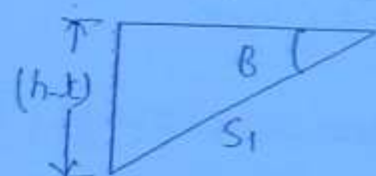
(v) Switch Angle :→ Angle b/w stock rail and tongue rail when tongue rail is touching the stock rail is called angle of switch.

B = Switch angle

(55)







$$\boxed{\sin B = \frac{h}{S_2}} \quad -(1)$$

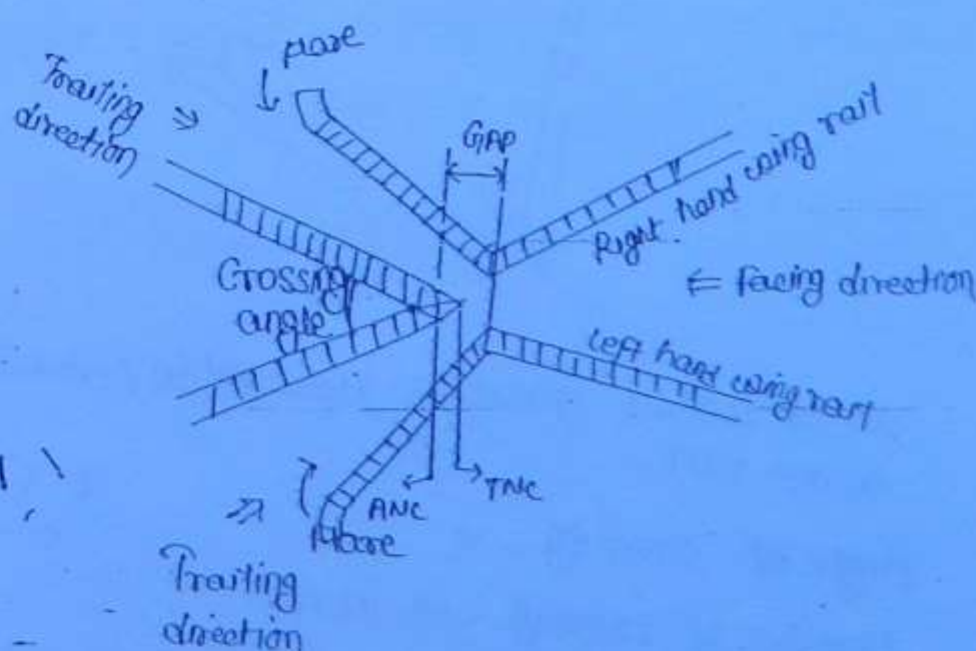
$$\boxed{\sin B = \frac{h-t}{S_1}} \quad -(2)$$

$$\boxed{\sin B = \frac{h}{S_2} = \frac{h-t}{S_1}} \quad -(A)$$

Switch angle

$$\boxed{B = \sin^{-1}\left(\frac{h}{S_2}\right) = \sin^{-1}\left(\frac{h-t}{S_1}\right)}$$

(b) Crossing :→



(1) Crossing should be rigid enough to sustain heavy impact loading from wheel.
(2) Special type of steel (high magnese steel) is used for point and crossing.
(3) Crossing should be as long as possible.

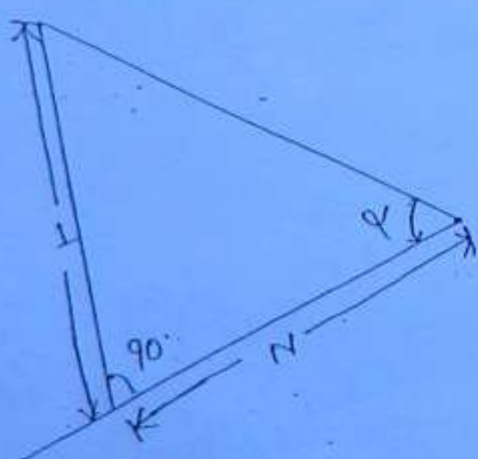
Important terms:→ (56)

(1) ANC and TNC :→ Due to blunt nose, actual position of nose is called ANC (Actual nose of crossing). TNC (theoretical nose of crossing) is possible only if thickness at nose is zero.

(2) Number of crossing (Angle of crossing) :→

$$\text{Number of crossing} = \frac{\text{Spread of leg of crossing}}{\text{length of rail from TNC}}$$

(a) Cole's method (Right Angle Method) :→ (use for Indian Railway)



In this method spread is measured on perpendicular length on one rail

Angle of crossing = α

Number of crossing = 1 in N

$\tan\alpha = 1/N$

No. of crossing $\boxed{\cot\alpha = N}$ — (A)

Angle of crossing $\boxed{\alpha = \cot^{-1} N}$ — (B)

57

(1) Diffent Number of crossing used Purpose

(1) 1 in 6 → Used in Symmetrical split ($\alpha = 9°27'44''$)

(2) 1 in $8\frac{1}{2}$ → Used in Station yards where space is restrick or on sharp turnout) ($\alpha = 6° 42' 35''$)

(3) 1 in 12 → Used in Station yards of mainline. ($\alpha = 4° 45' 49''$)

(4) 1 in 16 → Used in High Speed turn out on BG/M.G. Track ($\alpha = 3° 34' 35''$)

Example:- No. of crossing 1 in 12

$N = 12$

$N = \cot\alpha$

$\tan\alpha = 1/12$

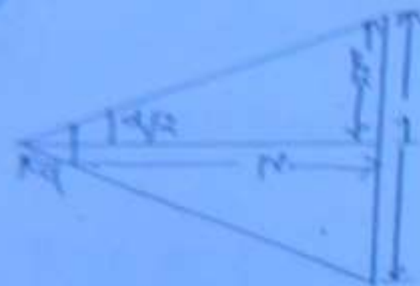
$\alpha = \tan^{-1}(1/12)$

$\boxed{\alpha = 4° 45' 49.11''}$

(b) Centre Line Method :->

(This method is used in USA and UK.)

SR



$\Rightarrow \tan\frac{\alpha}{2} = \frac{1/2}{N} = \frac{1}{2N}$

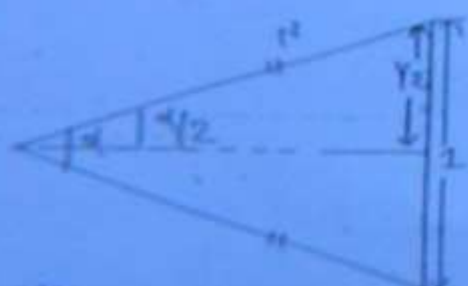
$\cot\frac{\alpha}{2} = 2N$

$\alpha/2 = \cot^{-1} 2N$ Number of crossing = $\boxed{N = \frac{1}{2}\cot\frac{\alpha}{2}}$

$\boxed{\alpha = 2\cot^{-1} 2N}$

(c) Isosceles Triangle method :->

(Used for Tramways)



$\Rightarrow \sin\alpha/2 = \frac{1/2}{N} = \frac{1}{2N}$

$\operatorname{cosec}\frac{\alpha}{2} = 2N$

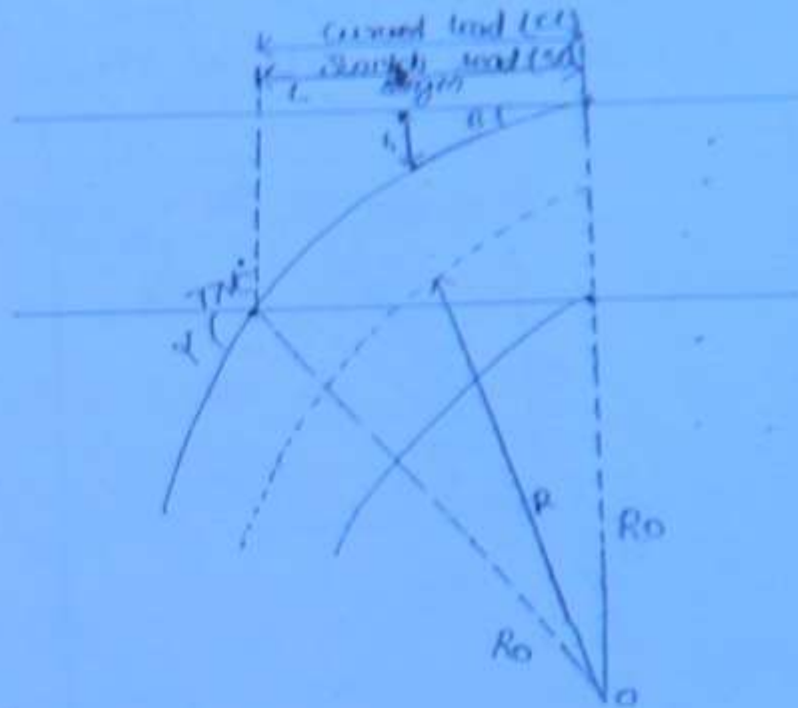
$\frac{\alpha}{2} = \operatorname{cosec}^{-1}(2N)$

$\boxed{\alpha = 2\operatorname{cosec}^{-1}(2N)}$ & $\boxed{N = \frac{1}{2}\operatorname{cosec}\alpha/2}$

☆ Design calculation of a Turn out :→

R_o - Outer radii
R - Actual radii

(59)



☆ Important Terms :-

(1) Curved lead (CL) :- Distance b/w Toe of Switch to TNC along Straight track.

(2) Switch lead (SL) :→ Distance b/w toe of Switch to heel of Switch along Straight track.

(3) Crossing lead (L) :→ Distance b/w heel of Switch and TNC along Straight track.

$$\boxed{CL = SL + L} \text{ --- (A)}$$

(4) Outer Radius Curve (R_o) :→
Centre Radius curve (R) :→ $\boxed{R = R_o - \frac{G}{2}}$ — (B)

(5) Angle of Switch (β)

(6) Angle of crossing (α) / No. of Crossing

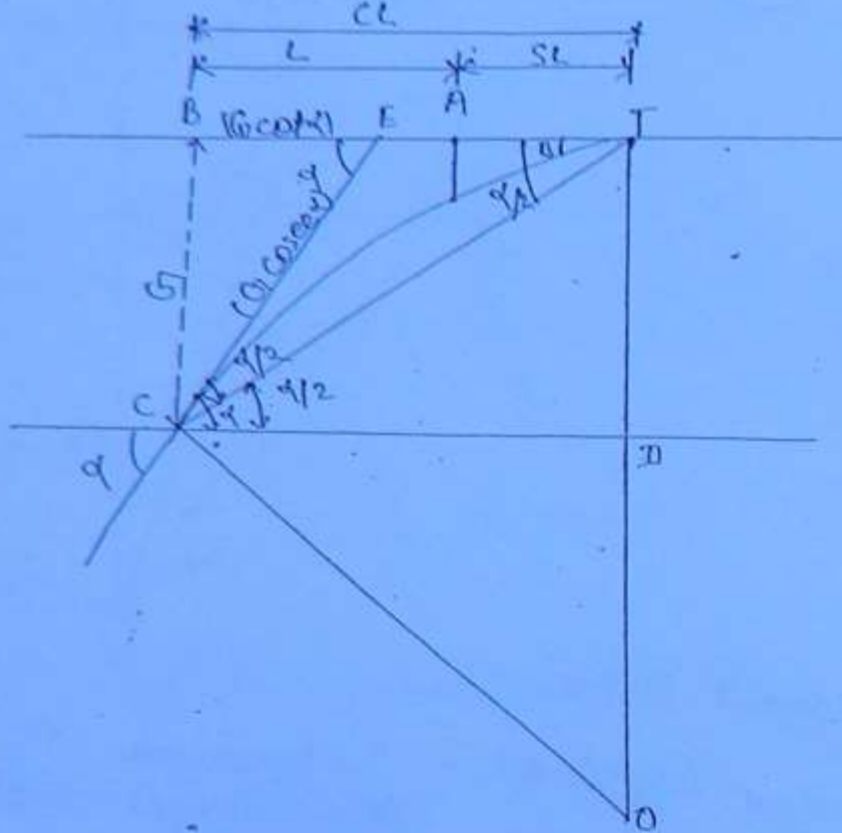
$$\boxed{N = \cot\alpha} \text{ — (C)}$$

(7) heel divergence (h) or (d) (8) Gauge (G)

(ii) Design Calculations :→

(1) Method - 1 In this case, curve is starting from toe of switch and end at TNC.

60



Given value

~~G = gauge~~

N = No of crossing.

(1) Curve lead (CL) :→

$\Rightarrow CL = BT.$

$\Rightarrow CL = BE + ET$

$\Rightarrow CL = G\cot\alpha + EC$

$\Rightarrow CL = G\cot\alpha + G\operatorname{cosec}\alpha$

$\Rightarrow CL = GN + G\sqrt{1+\cot^2\alpha}$

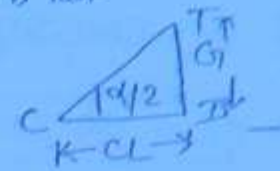
$\Rightarrow CL = GN + G\sqrt{1+N^2}$ $\boxed{\because \sqrt{1+N^2} \simeq N}$

$\Rightarrow CL = G(N+\sqrt{1+N^2}) \simeq GN + GN \simeq 2GN$

$\boxed{CL = 2GN}$

→ G is given but N is not given then

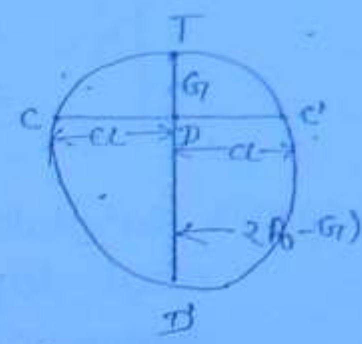
(2) $\tan\frac{\alpha}{2} = \frac{G}{CL}$



$\boxed{CL = G\cot \alpha/2}$

(1)

(3) Using property of circle :-



$CL^2 = \cancel{2}G(2R_O - G)$

$CL^2 = G\,2R_O$

$\boxed{CL = \sqrt{2GR_O}}$

(2) Radius (R_O)

$\Rightarrow R_O = OD + DT$

$\Rightarrow R_O = CL\cot\alpha + G$

$\Rightarrow R_O = 2GN \cdot N + G$

$\Rightarrow R_O = G + 2GN^2$

$\left\{ \tan\alpha = \frac{CL}{OD} \qquad OD = CL\cot\alpha \right\}$

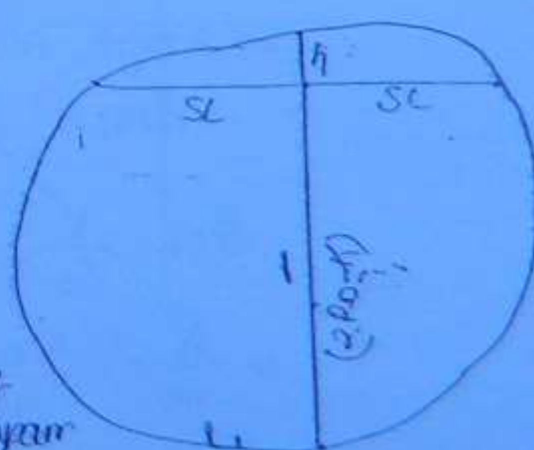
As per Indian Railway

$\boxed{R_O = 1.5G + 2GN^2}$

$\boxed{R = R_O - \frac{G}{2}}$ → Central Radius.

(3) Search lead (SL) :→

using property of circle



$\Rightarrow SL \times SL = h(2R_O - h)$

$\Rightarrow SL^2 = 2hR_O$ (h is very very less as compare to R_O)

$\Rightarrow \boxed{SL = \sqrt{2hR_O}}$

(4) Lead or crossing lead :→

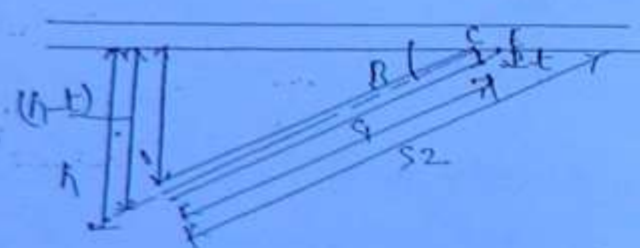
$$\boxed{L = CL - SL}$$

(5) Heel divergance :→ 62

$$\boxed{h = \frac{SL^2}{2R_0}}$$

Problem:→ calculate angle of switch and heel divergance if theoretical length of tongue rail = 5.10m. Thickness of toe of tongue rail = 0.65 cm. Actual length of tongue length rail = 4.80 m

Solution:→



$S_1 = 4.80m$

$S_2 = 5.10m$

$t = 0.65cm$

In triangle ADE

$\sin B = h/S_2$ —(1)

In triangle ABC

$\sin B = \frac{h-t}{S_1}$ —(2)

$\sin B = \frac{h}{S_2} = \frac{h-t}{S_1}$

$\Rightarrow \frac{h}{510} = \frac{h-0.65}{480}$

$\Rightarrow 480h = 510h - 0.65 \times 510$

$$h = \frac{331.5}{(510-480)}$$

$$h = 11.05\,cm$$

(63)

on eq. (1)

$$\sin B = h/S_2 = \frac{11.05}{510}$$

$$B = \sin^{-1}\left(\frac{11.05}{510}\right)$$

$$B = 1^\circ 14' 29.42''$$

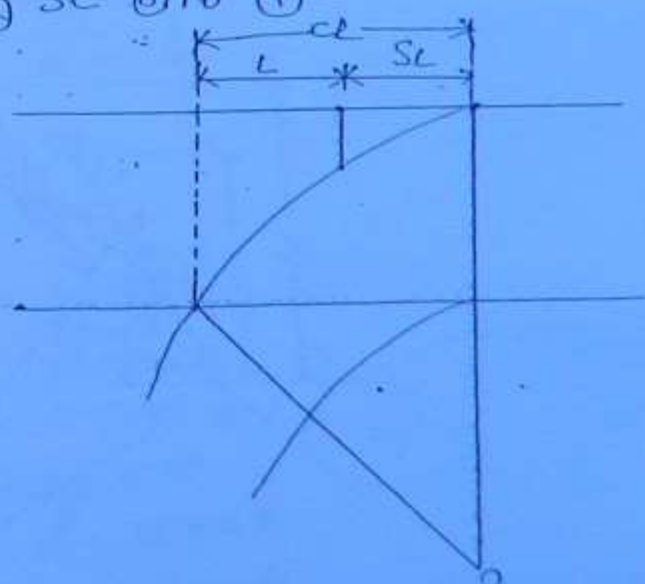
Problem (2) Calculate necessary elements to set out a ~~ten~~ turnout taking from a straight B G Track.

No. of crossing = 1 in 12

Heel divergence = 12.0 cm

curve is starting from toe of Switch and passes through TNC

Calculate (1) CL (2) SL (3) Ro (4) L



Solution:→

(1) curved lead

$$CL = 2GN$$

$$CL = 2 \times 1.676 \times 12$$

$$CL = 40.224\,m.$$

(2) Radius (R_0)

$$R_0 = 1.5G + 2GN^2$$

$$R_0 = 1.5 \times 1.676 + 2 \times 1.676 \times 12^2$$

$$R_0 = 485.20\,m$$

$$R = R_0 - G/2 = 485.20 - \frac{1.676}{2} = 484.364\,m$$

(3) Switch lead (SL) :→

64

$\Rightarrow SL = \sqrt{2R_0 h}$

$SL = \sqrt{2 \times 485.20 \times 0.12}$

$\boxed{SL = 10.79\ m}$

(4) Crossing lead :→

$L = CL - SL$

$L = 40.224 - 10.79$

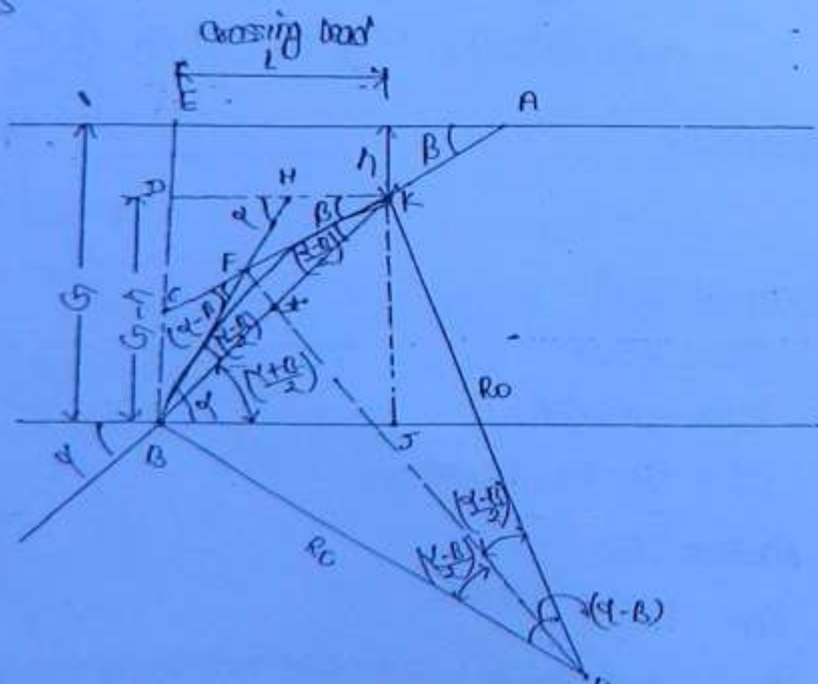
$\boxed{L = 29.434\ m}$

☆ Method - II :- In this case curve is starting from heel of the Switch and ends at TNC

we have to calculate

(1) only crossing lead (L)

(2) Radius



Angle of crossing = α

Angle of Switch = β

(i) Crossing lead:→

$$\Rightarrow L = (G - h - x\sin\alpha)\cot\left(\frac{\alpha+\beta}{2}\right) + x\cos\alpha$$

(ii) Radius:→

$$R_0 = \frac{(G - h - x\sin\alpha)}{(\cos\beta - \cos\alpha)}$$

ES 1994

Problem:→ (88) Calculate the necessary elements to set out a 1 in 8½ turnout taking from a straight BG Track with its curve starting from heel of the switch and ending at a distance 864 mm from TNC. Given that

heel divergance = 136 mm

Switch angle = 1°34'27"

Make a free hand sketch showing Value of calculated elements.

Solution:→ No. of crossing

$N = 8\frac{1}{2} = 8.5$

$N = \cot\alpha = 8.5$

$\alpha = \tan^{-1}(1/8.5)$

$\alpha = 6°42'35.4"$

Switch angle $\beta = 1°34'27"$

$h = 136\ mm$

$h = 0.136\ m$

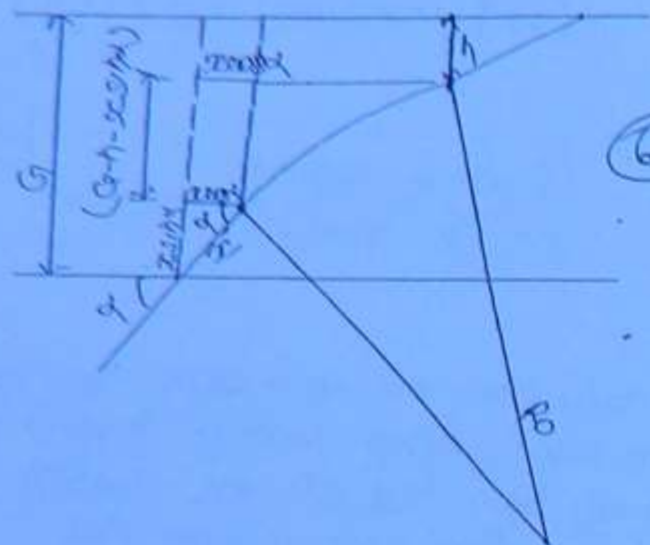
Straight length (x) before TNC

$x = 864\ mm$

$G = 1.676\ m$

(i) Crossing lead

$$L = (G - h - x\sin\alpha)\cot\left(\frac{\alpha+\beta}{2}\right) + x\cos\alpha$$



66

$$\Rightarrow L = (1.676 - 0.136 - 0.864 \times \sin 6^\circ 42' 35.4'')\cot\left(\frac{6^\circ 42' 35.4'' + 1^\circ 34' 27''}{2}\right)$$
$$+ 0.864 \times \cos 6^\circ 42' 35.4''$$

$$\Rightarrow \boxed{L = 20.73\, m}$$

Ⓑ Radius $R_0 = \dfrac{(G - h - x\sin\alpha)}{(\cos B - \cos\alpha)}$

$$R = \frac{(1.676 - 0.136 - 0.864 \sin 6^\circ 42' 35.4'')}{\cos 1^\circ 34' 27'' - \cos 6^\circ 42' 35.4''}$$

$$\boxed{R = 222.3\, m}$$

$\Rightarrow \angle CFB = (\alpha - \beta)$

$\Rightarrow \angle FBI = \angle FKI = \frac{\alpha-\beta}{2}$

(BF & FK are two tangent from same point G on circle; BF = FK)

$\Rightarrow \angle KBJ = \alpha - \left(\frac{\alpha-\beta}{2}\right) = \frac{2\alpha-\alpha+\beta}{2}$

$\Rightarrow \angle KBJ = \left(\frac{\alpha+\beta}{2}\right)$

67

④ <u>Crossing lead (L)</u> :—

In triangle

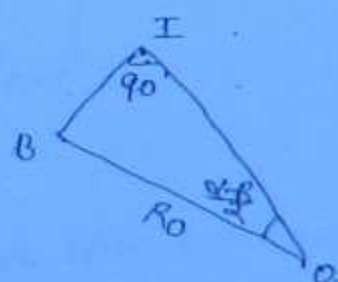
BKJ

$\Rightarrow \tan\left(\frac{\alpha+\beta}{2}\right) = \frac{KJ}{BJ}$

$\Rightarrow \tan\left(\frac{\alpha+\beta}{2}\right) = \left(\frac{G-h}{L}\right)$

$$\Rightarrow \boxed{L = (G-h)\cot\left(\frac{\alpha+\beta}{2}\right)}$$

⑤ <u>Radius R_0</u> :→ In triangle BIO



$\Rightarrow \sin\left(\frac{\alpha-\beta}{2}\right) = \frac{BI}{OB}$

$\Rightarrow OB = R_0 = \frac{BI}{\sin\left(\frac{\alpha-\beta}{2}\right)}$ — ①

In triangle BKJ

$\Rightarrow \sin\left(\frac{\alpha+\beta}{2}\right) = \frac{KJ}{BK}$

$\Rightarrow BK = \frac{(G-h)}{\sin\left(\frac{\alpha+\beta}{2}\right)}$

$BK = 2BI$

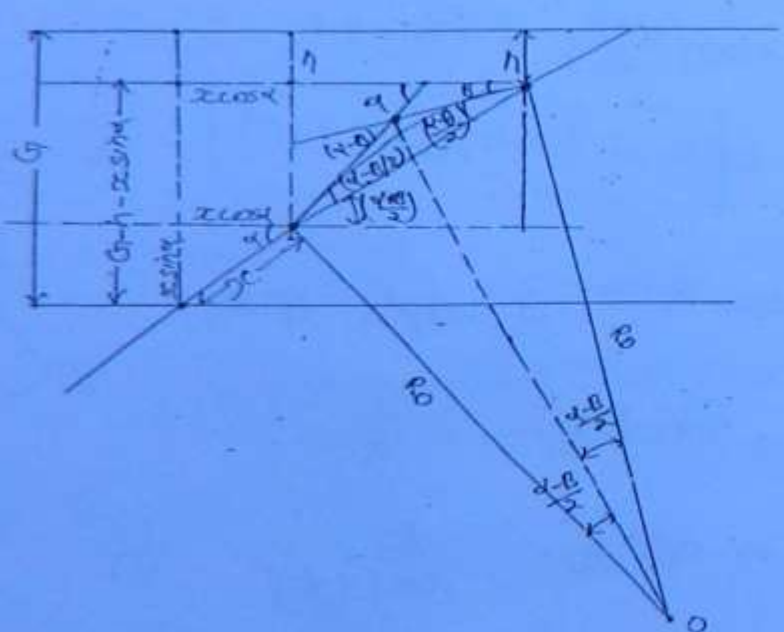
$$\Rightarrow BI = \frac{(G-h)}{2\sin\left(\frac{\alpha+\beta}{2}\right)} \quad -(8)$$

Put BI in eq-(7)

$$\Rightarrow R_O = \frac{(G-h)}{2\sin\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha-\beta}{2}\right)}$$

$$\Rightarrow \boxed{R_O = \frac{(G-h)}{(\cos\beta - \cos\alpha)}}$$

★ Method-III :→



→ In this case, a straight length is provided just before TNC also. curve is starting from heel of Switch and end at starting point of straight length before ETNC.

we need.

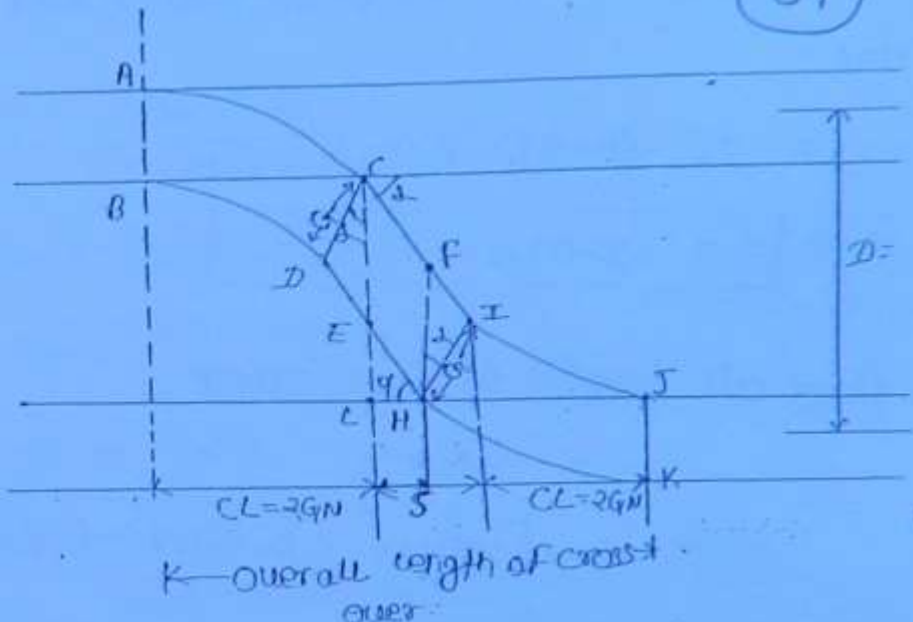
(1) Crossing lead (L)

(2) Radius.

(This method is used in Indian Railway)

Cross Overs:→ Combination of two turnout provided at two parallel tracks to divert the train from one track to another is called cross over.

Case(I):→ With an intermediate straight portion b/w two turnout



⇒ length of turnout = curve lead

$CL = 2GN$

→ Straight length of cross over b/w two turnout

$LH = S$

if D = Distance b/w c/c of two tracks.

In traingle DCE

$\Rightarrow EC = G \sec\alpha$

$\Rightarrow EL = (D - G) - G\sec\alpha$

In traingle ELH

$$\Rightarrow \tan\alpha = \frac{EL}{LH}$$

78

$$\Rightarrow LH = EL\cot\alpha$$

$$\Rightarrow LH = [(D-G) - G\sec\alpha]\cot\alpha$$

$$\Rightarrow LH = (D-G)N - NG\sqrt{1+\tan^2\alpha}$$

$LH = S$

$$\Rightarrow S = (D-G)N - GN\sqrt{1+1/N^2}$$

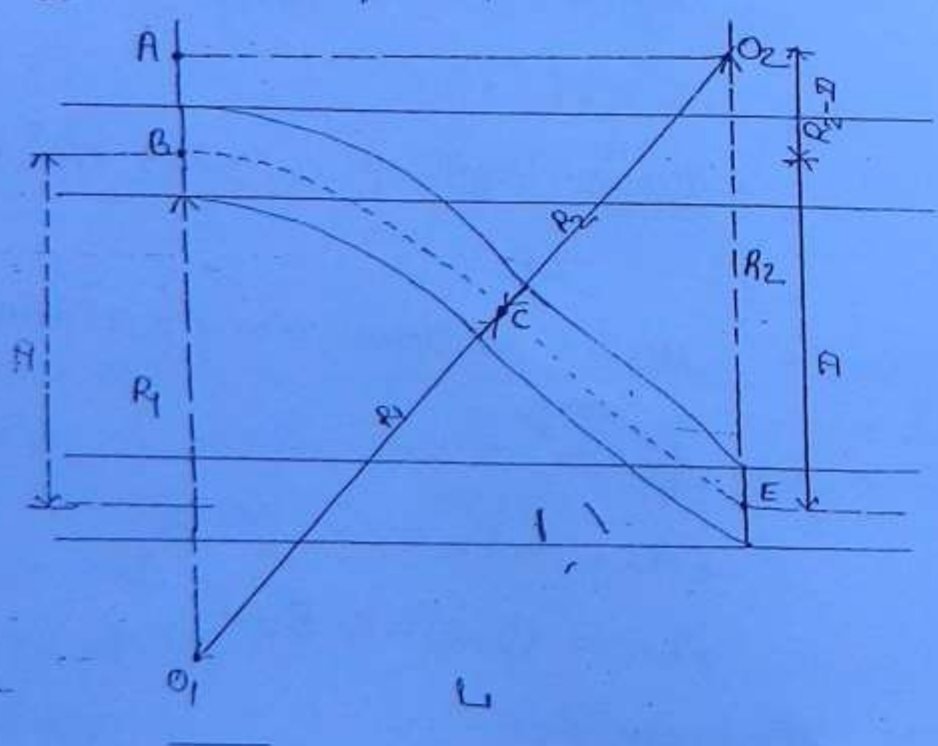
$$\Rightarrow \boxed{S = (D-G)N - G\sqrt{1+N^2}}$$

Over all length of Cross over

$$= 4GN + S$$

$$= \boxed{4GN + (D-G)N - G\sqrt{1+N^2}}$$

Case (2):→ without any Straight portion b/w two turnout. Intermediat portion is also curved. (No straight Portion)



Given value:→ Note:→ N/o.

(1) G

(2) No. of crossing in N_1 and in N_2

(71)

$\Rightarrow R_{10} = 1.5G + 2GN_1^2$

$\Rightarrow \therefore R_1 = R_{10} - G/2$

$\Rightarrow R_{20} = 1.5G + 2GN_2^2$

$\Rightarrow \therefore R_2 = R_{20} - G/2$

length O_1 and O_2

$O_1O_2 = R_1 + R_2$

If D = cen/c distance b/w two tracks

$O_1A = R_1 + (R_2 - D)$

$\Rightarrow \boxed{O_1A = (R_1 + R_2 - D)}$

over all length of cross over along track

$\Rightarrow O_2A = \sqrt{O_1O_2^2 - O_1A^2}$

$\Rightarrow O_2A = \sqrt{(R_1+R_2)^2 - (R_1+R_2-D)^2}$

$\Rightarrow O_2A = \sqrt{(2R_1 + 2R_2 - D)D}$

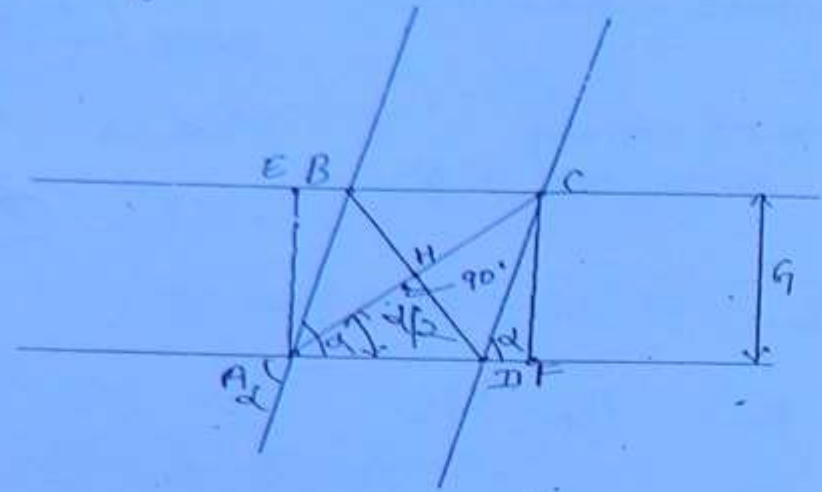
If $N_1 = N_2$

$R_1 = R_2$

Over all length $= \sqrt{(4R-D)D}$

* Diamond Crossing :->

(72)



$\Rightarrow$ if 1 in N is number of crossing

$N = \cot\alpha$

$\alpha = \cot^{-1}(N)$

Components

(1) Length $AB = BC = CD = DA = G \operatorname{cosec}\alpha$

(2) Length $BE = DF = G \cot\alpha$

$\left\{ \begin{array}{l} \text{in triangle DCF} \\ \tan\alpha = \frac{G}{DF} \\ DF = G\cot\alpha \end{array} \right\}$

(3) Diagonal AC

In triangle ACF

$\sin\alpha/2 = \frac{G}{AC}$

$AC = G \operatorname{cosec}\alpha/2$

(4) Diagonal $BD = 2DH$

In triangle ADH

$\tan\alpha/2 = \frac{DH}{AH}$

$\Rightarrow DH = AH \tan \alpha/2$

$\Rightarrow DH = \frac{1}{2} AC \tan \alpha/2$

(73)

$\Rightarrow DH = \frac{1}{2} G \operatorname{cosec} \frac{\alpha}{2} \cdot \tan \frac{\alpha}{2}$

$\Rightarrow DH = \frac{1}{2} G \frac{1}{\sin \alpha/2} \cdot \frac{\sin \alpha/2}{\cos \alpha/2}$

$\Rightarrow \boxed{DH = \frac{1}{2} G \sec \alpha/2}$

then

$BD = 2DH$

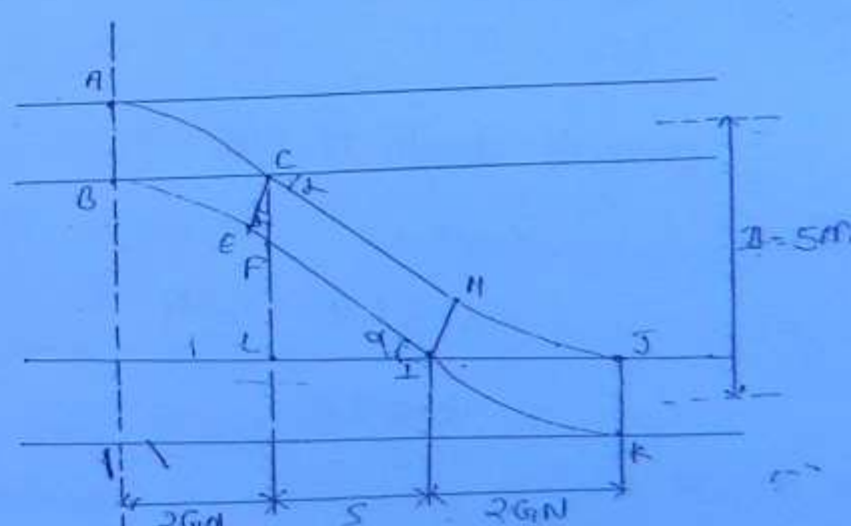
$\Rightarrow BD = 2 \times \frac{1}{2} G \sec \alpha/2$

$\Rightarrow \boxed{BD = G \sec \alpha/2}$

ES-1995

Problem: A cross over occurs b/w two parallel BG track of
40 Same crossing No. 1 in 8½ with a straight intermediate portion b/w reverse curve. c/c distance b/w track is 5m,
Find the overall length of cross over.

Solution:→



Crossing Number

$N = 8.5$

$\Rightarrow CL = 2GN$

$CL = 2 \times 1.676 \times 8.5$

$CL = 28.492\ m$

(74)

$\Rightarrow CFL = D - G$

$CFL = 5 - 1.676$

$CFL = 3.324$

$\Rightarrow CF = G \sec\alpha$

$CF = 1.676\sqrt{1 + 1/N^2}$

$CF = 1.676\sqrt{1 + 1/8.5^2}$

$CF = 1.687$

$\Rightarrow FL = 3.324 - 1.687$

$FL = 1.636$

$\Rightarrow LI = FL \cot\alpha$

$LI = 1.636 \times 8.5$

$LI = 13.91$

Overall length of C/O

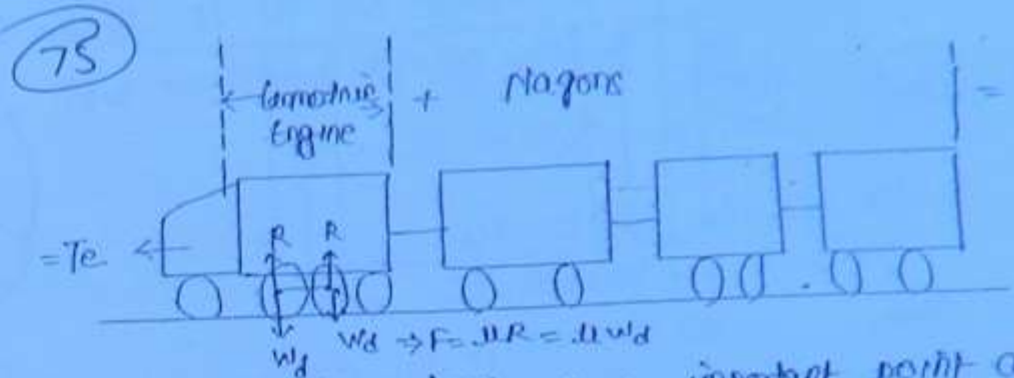
$= 4GN + S$

$= 2 \times 28.492 + 13.91$

$= 70.89\ m$ Ans

 (Railway) :→ [redacted]

A Traction and Tractive Effort :→



⇒ To understand this topic, three important point are :-

(1) Tractive effort (Te) → The power generated by the engine and transferred to the driving wheel for movement of train is called tractive effort.

This tractive effort should be sufficient to overcome all resistances.

(2) Hauling Capacity : → Hauling capacity is the force of Friction available b/w rail surface and driving wheels, which is ∴ This value of hauling capacity should be more than total resistance offered by train

$H.C. = F = \mu R = \mu_i W_d$

$H.C. = \mu \cdot n \cdot W_d$

If n = No. of pair of the driving wheel.

W_d = wth. of one pair of driving wheel

the train will not move if hauling capacity is less than total resistance.

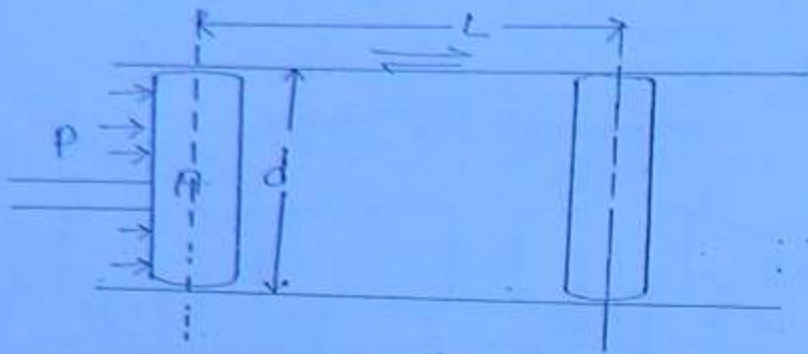
(3) Total Resistance :→ Resistance offered by the train due to various reasons.

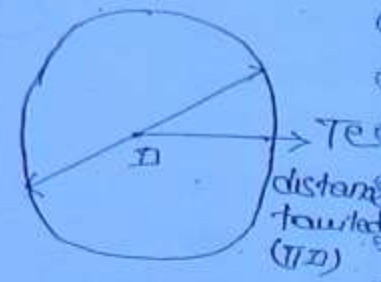
for movement of train

Total resistance < H.C < Te

Tractive effort :⇒

76





Steam Engine Cylinder

→ Let us consider a Steam engine for which

- A = Area of piston/cylinder
- P = Pressure diffrence
- L = Length of stoke
- n = No of cylinder
- D = Dia of wheel
- d = Dia of cy piston

⇒ Power generated = work done on wheel

$$\Rightarrow \quad n \cdot P \cdot A \cdot 2L = \pi \cdot D \cdot T_e$$

$$\Rightarrow \quad n \cdot P \cdot \frac{\cancel{\pi}}{\cancel{4}_2} d^2 \cdot \cancel{2} L = \cancel{\pi} D T_e$$

$$\Rightarrow \quad \boxed{T_e = \frac{n P L d^2}{2D}}$$ — Tractive effort.

Speed ∝ Diameter of wheel (D)

but $T_e \propto \frac{1}{D}$

So a there should be a balance, So that sufficient speed is obtained with out reducity the tractive effort.

(2) Hauling Capacity :→

Hauling capacity depends upon weigh on driving wheel. It is the force of friction that can be develope b/w rail and driving wheel.

$$Hc = \mu \cdot n \cdot W_d$$

W_d = wt of one driving wheel.

μ = coefficient of friction.

= 0.10 to 0.30

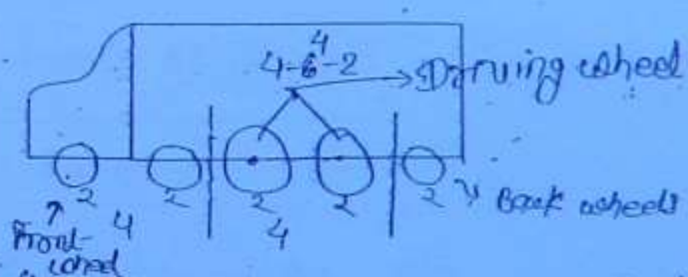
Note → 0.10 → at high Speed
0.30 → at low Speed

Generally μ = 0.20 may be considerd.

$\boxed{\mu = \frac{1}{6} = .166}$ → as per old Book

(1) Driving wheel:

Locomotive :→



for a 4-6-2 locomotive No. of pairs of driving wheel

(1) 4-4-2 = 4/2 = 2

(2) 4-6-2 = 6/2 = 3

⇒ The value of μ at low Speed → μ is more
at High Speed → μ is less.

$\boxed{\text{Hauling capacity = Total Resistance}}$

(3) Total Resistance :-

(a) Train Resistance :→
(b) Resistance due to track profile.
(c) Resistance due starting and acceleration
(d) Wind Resistance.

78

(1) Train Resistance (R_T) :→

(i) Resistance independent of speed (Rolling Resistance) :- (R_{T_1})

(a) due to :-
Journal Friction :→ Friction of locomotive, wagons etc.
(b) friction b/w wheel and rail.
(c) wave action of rail. (Note- the rail move (~~~~) in this direction)
(d) Internal resistance.

$$\boxed{R_{T_1} = 0.0016\,w} \rightarrow \text{Rolling Resistance}$$

if w = wt of train in tonnes

(ii) Resistance depended on Speed. (R_{T_2}) :→

$$\boxed{R_{T_2} = 0.00008 \cdot w \cdot V}$$

w = wt. of train in tonnes (total wt. of train locomotive + wagons)

V = Speed is kmph.

(iii) Atmospheric Resistance :→ (R_{T_3}) → IF wind velocity is zero.

$$\boxed{R_{T_3} = 0.0000006\,w \cdot V^2}$$

Total rail resistance

$$\boxed{R_T = R_{T_1} + R_{T_2} + R_{T_3}}$$

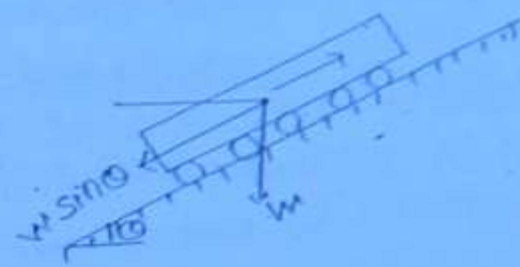
$\Rightarrow R_T = 0.0016\,W + 0.00008\,W V + 0.0000006\,W V^2$

$R_T = 0.0016808$

79

(b) Resistance due to Track profile :→

(1) Due to Gradient :→



Resistance $R_g = w \tan\theta$

$R_g = w \sin\theta$.

(For small θ, $\sin\theta = \tan\theta$)

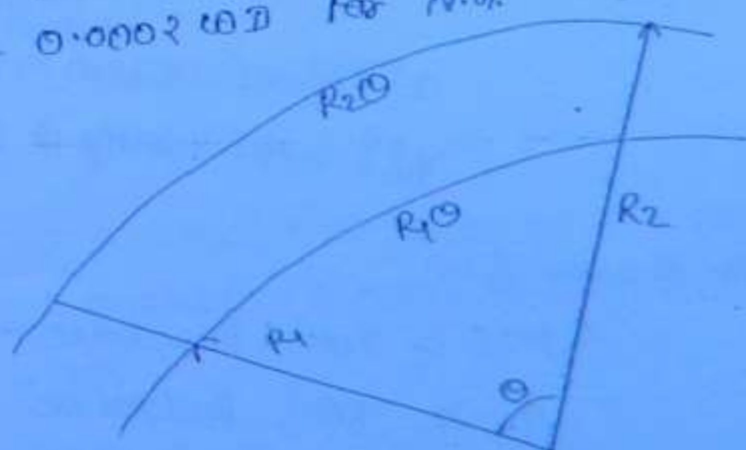
(ii) Due to curve (Curve Resistance) :→

$R_c = 0.04\ \%$ of $W.D$

$R_c = 0.0004\,W D$ for BG

$R_c = 0.0003\,W D$ for MG

$R_c = 0.0002\,W D$ for N.G.



(C) Resistance Due to Starting and accelaration:→

(1) Due to Starting = $\underbrace{0.15w_1}_{\text{locomotive}} + \underbrace{0.005w_2}_{\text{wagon}}$

w_1 = wt. locomotive

w_2 = wt of wagon.

(88)

(2) Due to accelaration:→

If a = accelaration

$$a = \left(\frac{V_2 - V_1}{t}\right)$$

$$R_{acc} = 0.028wa$$

$$\boxed{R_{acc} = 0.028w\left(\frac{V_2 - V_1}{t}\right)}\ \text{kmph/sec.}$$

V_1 and V_2 are in kmph

t = Sec.

w = tonnes.

(D) Wind Resistance:→

$$R_w = 0.000017 \cdot a\, V_w^2$$

a = Exposed area of train in m^2

V_w = wind velocity in kmph

(4) For movement:→

H.C ≥ Total Resistance

Te ≥ total Resistance

* For Solving question:

$$T_e = H.C. = \text{Total Resistance}$$

(81)

In Normal case total Resistance $= R_{T_1} + R_{T_2} + R_{T_3}$

Problem:→ ES-1992
Determine the max. permissible train load that can be pulled by a locomotive having 4 pairs of driving wheels carrying an axial load of 24t each. The train has to run at a speed of 80 kmph. On a straight level track. Also determine the reduction in speed of the train has to climb a gradient of 1 in 200.

Solution:→

Locomotive ⇒ No. of pairs of driving wheel

$$n = 4$$

weight on each pair (axle)

$$W_d = 24 t$$

Hauling capacity

$$H.C. = \mu n W_d$$

$$H.C. = 0.20 \times 4 \times 24$$

$$HC = 19.2\ t$$

Case(I) Train loading $= W$

$$H.C. = \text{Total Resistance}$$

$$\Rightarrow 19.2 = R_{T_1} + R_{T_2} + R_{T_3}$$

$$\Rightarrow 19.2 = 0.0016W + 0.00008W \cdot V + 0.0000006 W \cdot V^2$$

$$\Rightarrow 19.2 = 0.0016W + 0.00008 W \cdot 80 + 0.0000006 \cdot W\, 80^2$$

$$\Rightarrow 19.2 = W l$$

$$\Rightarrow W = 1621.62\ t$$

Case (i) if a gradient 1 in 200 is there

$$H.C. = RT_1 + RT_2 + RT_3 + \omega \cdot \tan\theta$$

$$\Rightarrow 19.2 = \omega(0.0016 + 0.00008v + 0.0000006v^2) + \omega\tan\theta$$

$$\Rightarrow 19.2 =$$

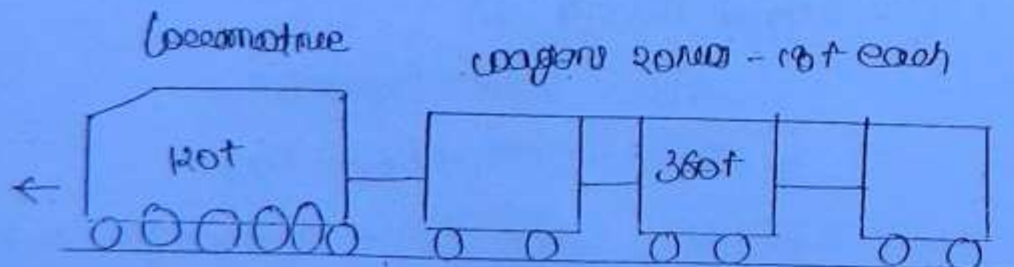
(82)

$$v =$$

$$\Rightarrow v = 48.26 \text{ Ans}$$

ES-1995
Problem (90) :→ A Train having 20 wagon weighing 18 t each, is to run at a speed of 50 kmph. The tractive effort of a 2-8-2 Locomotive with 22.5 t load on each driving axle is 15 t. The wt. of locomotive is 120 tonnes. Rolling resistance (R) of wagon and locomotive are 2.5 kg/t and 3.5 kg/t respectively. The resistance which depends upon speed is 2.65 tonnes. Find out the steepest gradient for conditions.

Solution:-



weight of wagons $= 20 \times 18$
$= 360\ t$

weight of Locomotive $= 120\ t$

weight of train $_{\omega} = 480\ t$ Total

Locomotive ⇒ 2-8-2

No. of pairs of driving wheel $n = 4$

weight of each pair of driving wheel $W_d = 22.5\,t$

(83)

⇒ Hauling capacity :⇒ $\mu n W_d$

$= 0.20 \times 4 \times 22.5$

$= 18\,t$

The tractive ~~force~~ effort $T_e = 15\,t$

So this train can move with H.C. 1 Te of 15 t

only.

Train load $W = 480\,t$

Speed $V = 50$ kmph

Maximum Gradient $\tan\theta = ?$

⇒ H.C (or Te) = Total Resistance

$= R_{T_1} + R_{T_2} + R_{T_3} + W\tan\theta$

$\Rightarrow R_{T_1} = \underbrace{2.5\,kg/t \times 360}_{wagon} + \underbrace{3.5\,kg/t \times 120}_{Locomotive}$

$\Rightarrow R_{T_1} = 1320\,kg$

$\Rightarrow R_{T_1} = 1.320\,t$

$\Rightarrow R_{T_2}$ = Resistance depended on speed.

$R_{T_2} = 2.65\,t$

$\Rightarrow R_{T_3} = 0.0000006\,W \cdot V^2$

$\Rightarrow R_{T_3} = 0.0000006 \times 480 \times 50^2$

$\Rightarrow R_{T_3} = 0.72\,t$

$\Rightarrow H_C = R_{T_1} + R_{T_2} + R_{T_3} + W \tan\theta$

$\Rightarrow 15.t = 1.320 + 2.65 + 0.72 + 480 \tan\theta$

$\Rightarrow \boxed{\tan\theta = \frac{1}{46.556}}$

84

Problem:→ Determine the tractive effort developed by a two cylinder engine from the following data:

1. wheel load on driving wheels = 5.80 t.
2. Difference of pressure in cylinder = 2.75 kg/cm2
3. Dia of piston = 32cm
4. length of stroke = 42cm
5. Dia of wheel = 153 cm

State whether working of engine is Satisfactory or Not?

Solution:→ $W_d = 5.80\ t$

$P = 2.75\ kg/cm^2$

$d = 32cm$

$L = 42cm$

$D = 153cm$

Tractive effort developed by engine

$$\Rightarrow T_e = \frac{n p L d^2}{2D}$$

$$\Rightarrow T_e = \frac{2 \times 2.75 \times 42 \times 32^2}{2 \times 153}$$

$$\Rightarrow T_e = 773\ kg$$

$$\Rightarrow T_e = 0.773\ \text{Tonnes}.$$

$\Rightarrow H.C. = \mu W_d = 0.20 \times 5.80$

$\Rightarrow H_c = 1.16\ t$

Tractive effort < Hc.

So engine is not satisfactory

ES-1990

Problem:→ A locomotive with 3 pairs of driving wheels is to haul a train on a BG Track at 75 kmph. The load on each axle of driving wheel is 22 tonnes. The coeff of friction is 0.2. What is max load the engine can pull on a straight & level track.

→ when the same track goes up a slope of 1 in 180 how much speed will be adjusted for same load condition

→ when the track goes on a 2° curve on level ground speed = ?

gradient + curve → Speed

Solution:→ (1) Hauling capacity

Pairs of driving wheels

$n = 3$

weight on each pair $W = 22\ t$

$H_c = \mu . n . w$

$= 0.20 \times 3 \times 22 = 13.2\ t$

(a) On a straight & level track

Hc = Train Resistance

$H.C. = 0.0016W + 0.00008\,WV + 0.0000060\,WV^2$

$13.2 = 0.0016\,W + 0.00008 \times W \times 75 + 0.0000060\,W\,75^2$

$W = 1302.73\ t$

(b) when track goes on a gradient 1 in 180

86

$$H.C. = 0.0016\,\omega + 0.00008\,\omega v + 0.0000006\,\omega v^2 + \omega \tan\theta$$

$$\Rightarrow 13.2 = 0.0016 \times 1202.73 + 0.00008 \times 1202.73 \times v + 0.0000008 \times 1202.73\,v^2 + 1202 \tan\theta\ ^{1/180}$$

$$\Rightarrow 13.2 = 1.925 + 0.097\,v + 0.00096\,v^2 + 6.68$$

$$\Rightarrow 4.597 = 0.097\,v + 0.00096\,v^2$$

$$\Rightarrow V = 37.3 \text{ kmph}$$

Reduction in Speed $= 75 - 37.3$

$= 37.7$ kmph

(c) when it is a curve of 2'

$$He = \qquad + 0.0004\,\omega D' + 0.0004 \times 1202.73 \times 2.$$

$$He = \qquad + 0.962$$

$V =$

(d) ~~when gradient & curve~~

$$He = \text{------} + \frac{1202.73}{180} + 0.962$$

$V =$

(ii) Highway Engg:->

87

Introduction:->

Important events:->

(1) JayKar Committee recomendation

For in 1927

Submitted report -> 1928 (Feb)

(2) Central Road Fund -> 1929

(3) Indian Road Congress -> 1934

(4) Motors Vehicle act -> 1939

(5) I^{st} 20 year road plan -> 1943 (Nagpur)

(6) CRRI -> central road Research institute -> 1950

(7) 2^{nd} 20 year road plan -> 1961 (Bombay road plan)

(8) 3^{rd} 20 year road plan -> 1981 (Lucknow)

(9) National Highway Act -> 1956

(ii) Jaykar Committee recomendation:->

(1) Road development in India should be considerd as of national interest.

(2) As tax on petrol should be levied for road development.

Result -> central Road Found (1929)

(3) A Semi official Government body should be formed for road development planning.

Result -> Indian road Congress -> 1934

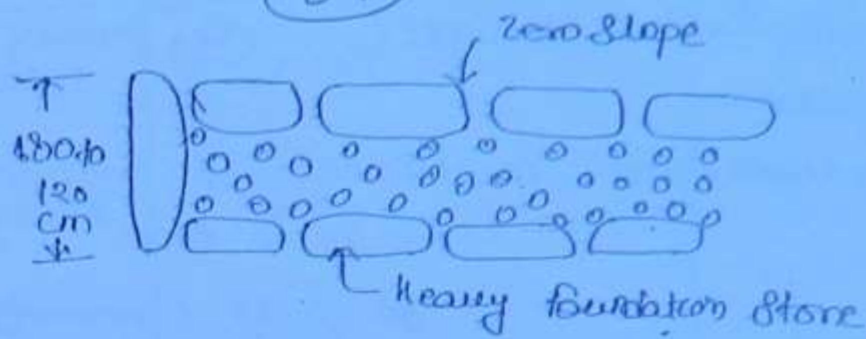
[redacted] (4) A re-search institute should initiated for research & developement work.

Result → CRRI → 1950.

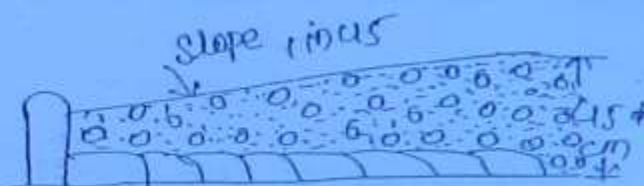
88

Road developement plane	First	Second	Third
(1) Venue	Nagpur	Bombay	Lucknow
(2) Target	$\frac{16 \text{ km}}{100 \text{ sq km}}$	32 km / 100 sq km	$\frac{82 \text{ km}}{100 \text{ sq km}}$
(3) classification			
~~(a) NH~~	(a) NH ~~Express~~ (b) S.H (c) MDR (d) ODR (e) VR	Express way	(a) Primary → Express way → NH (b) Secondary → SH → MDR (c) Teritory → ODR → VR

(4)(1) Roman Roads :→



(2) Tresguete Construction :→



(3) Macadum :→

Macadum :→ Macadum was First who used Smalled Stresses Stones for bottom layers.

→ Stress at bottom layers are less than Stresses at top layers → this theory was introduced by macadum.

→ Slope at top & bottom layers.

→ Side drains.

Geometrical Design:→

(1) Cross-Section Elements:→ (96)

(2) Friction:→

→ Longitudinal co-efficient of friction

$\mu = 0.35$ to 0.45

ge 0.35 (generally) Considered.

→ lateral coefficient of friction

$\boxed{\mu = 0.5}$

Skid:→ when brakes are applied

Longitudinal movement > circumferential moment

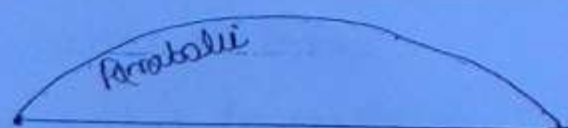
Slip:→ when vehicle is being accelarated

Circumf. moment > Longitudinal movement.

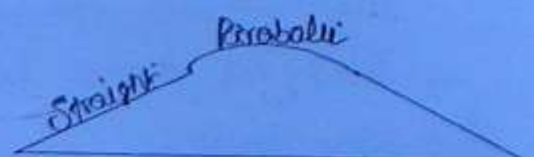
(3) Camber:→ To drain off water from road surface

(1)

(2)



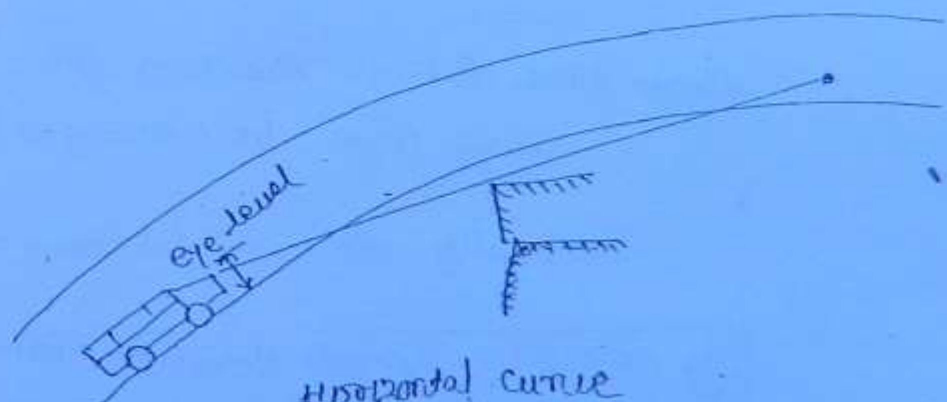
(3)



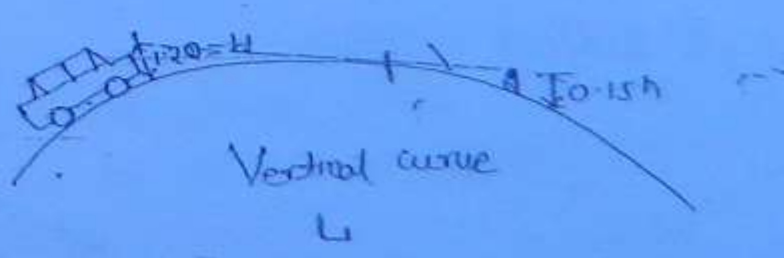
Type of Pavement	Light rain fall	Heavy rain fall
① Cement concrete pavement or Hight quality Bitumminous	1.7%	2.0% (1 in 50)
② Simple Bitumnous or WBM	2.0%	2.5% (1 in 40)
③ Gravel road	2.5%	3.0% (1 in 33.3)
④ Earth road	3.0%	4.0% (1 in 25)

⑪ Side Distance :->

① Stopping Sight distance :-> As per IRC



Horizontal curve



Vertical curve

Stopping Sight distance :→

92

= lag distance + Braking distance

① Lag distance :→ Distance travelled by the vehicle during reaction time of driven

PIEV theory :-

P → Perception → Time taken to. Send signal from eye of brain.

I → Intellection → Time taken to understand a station, rearranging different thought.

E → Emotion → Extra time taken due to Emotions.

V → Valition → Time for final action.

Total time taken = Reaction time
Varey from (0.5 to 5 sec)

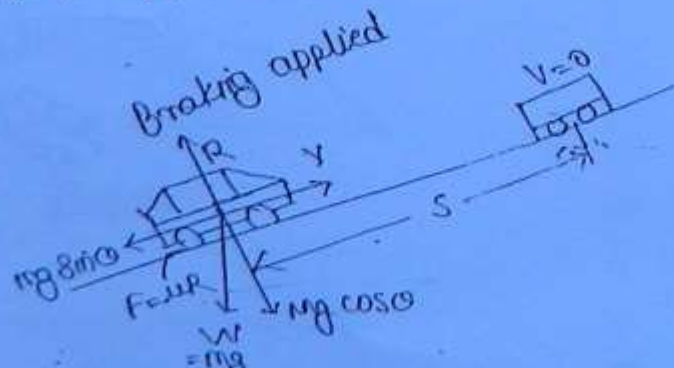
Generally t_R = 2.5 / 3 sec.

$$\boxed{\text{Lag distance} = \text{Speed} \times \text{Reaction time}}$$

Lag distance = $v \times t_R$

$= 0.278\, V \cdot t_R$

② Braking distance :→



After application of brake, Vehicle moves S distance

① Full brake efficiency (100%) is to be considered as after brakes, wheels are fully jammed.

93

Kinetic energy loss = work done

$$\Rightarrow \frac{mu^2}{2} = (FR) \times S$$

$$\Rightarrow \frac{mu^2}{2} = (mg\sin\theta + \mu R)S$$

$$\Rightarrow \frac{\cancel{m}u^2}{2} = (\cancel{m}g\sin\theta + F\cancel{m}g\cos\theta)S$$

Stopping Sight distance

$$\Rightarrow S = \frac{V^2}{2g(\sin\theta + F\cos\theta)}$$

$$\Rightarrow S = \frac{V^2}{2g(\tan\theta + F)}$$

$$\Rightarrow S = \frac{V^2}{2g(F + S\gamma)}$$

Total stopping Sight distance

= lag distance + Stopping distance

$$= (0.278\,V t_R) + \frac{(0.278\,V)^2}{2g(F \pm S\gamma)}$$

(+) ve for upward slope

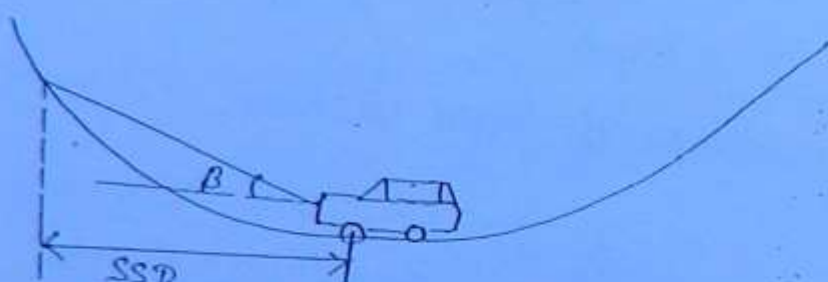
(−) ve for downward slope

(1) one way traffic/ one lane road — → SSD

(2) Two lane road Two way traffic → SSD (94)

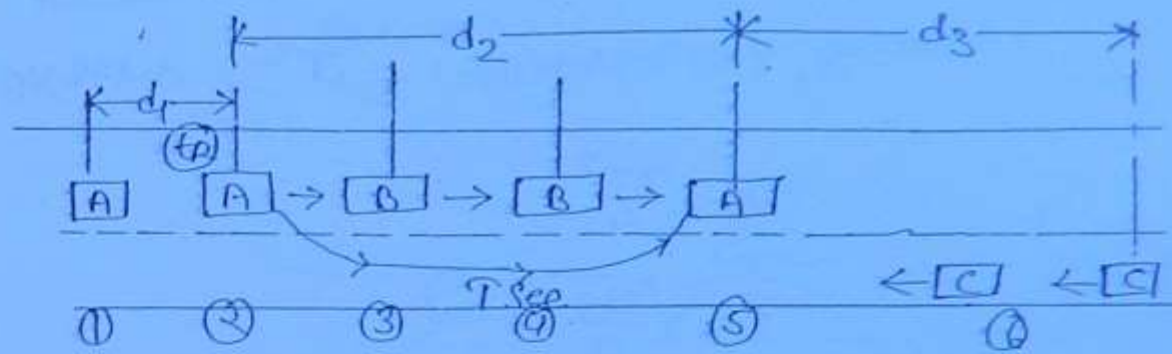
(3) one lane road/ Two way traffic → ISD → Intermediate Sight distance = 2·SSD

(4) Head light Sight distance → SSD



Head light Sight distance

☆ Overtaking Sight distance :→



A → Overtaking vechile (Speed V_A)

B → Overtaking vechile (" V_B)

C → " from opposite Side (speed V_C)

① Distance d_1 :→

d_1 = distance travelled by Ⓐ in reation time

$d_1 = 0.278 \times V_B \times t_R$. —①

(A = is forced to move with Same Speed, that of B

Speed of just befor B = V_B

② Distance d_2 →

If T sec is total time required from A to move from

2 to 5

$d_2 = V_B \cdot T + \frac{1}{2} a T^2$

$$\boxed{d_2 = 0.278\, V_B T + \frac{1}{2} a T^2} \quad —②$$

According to vechile Ⓑ

$d_2 = b + 2s$

$d_2 = 0.278\, V_B T + 2s$ — (3)

Eq. (2) & (3)

$d_2 = 0.278\, \cancel{V_B T} + \frac{1}{2} a T^2 = 0.278\, \cancel{V_B T} + 2s$

$S = \frac{aT^2}{4}$

$T = \sqrt{\frac{4S}{a}}$

Where a = acceleration of vehicle A.

S = min. distance to be maintained b/w two vehicles

$S = 0.7 \times V_B + l$

$S = 0.7 \times 0.278\, V_B + 6$

$\boxed{S = 0.2 V_B + 6}$

0.7 sec Reaction time

l = length of vehicle

(3) Distance d_3 :→

$\boxed{d_3 = 0.278\, V_c \cdot T}$

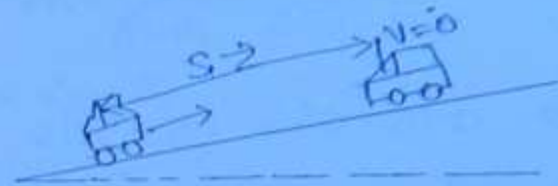
Total overtaking sight distance $= d_1 + d_2 + d_3$

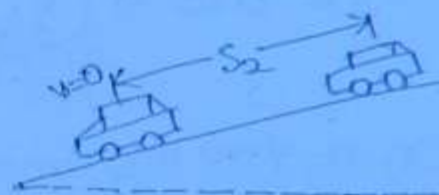
IES-1994 Problem :-> The driver of vehicle travelling 60 kmph. up a gradient required 9 m less to stop after applies the brakes than a driver travelling with same speed down the same gradient

$f = 0.4$ What is the % gradient.

(97)

Solution:->





$$S_2 - S_1 = 9\,m$$

Moment up the gradient

$$S_1 = \frac{V^2}{2g(f+S\%)}$$

$$S_1 = \frac{(0.278\times 60)^2}{2\times 9.81(0.40+S)}$$

$$S_1 = 14.18/(0.40+S)$$

Down the gradient:-

$$S_2 = \frac{(0.278\times 60)^2}{2\times 9.81(f-S)} = \frac{14.18}{(0.40-S)}$$

$$S_2 - S_1 = 9$$

$$\Rightarrow \frac{14.18}{0.48-S} - \frac{14.18}{0.40+S} = 9$$

98

$$\Rightarrow \frac{(0.45+S-0.40+S)}{(0.4^2-S^2)} = 9$$

$$\Rightarrow \frac{2S}{0.16-S^2} = \frac{9}{14.18}$$

$$\Rightarrow 0.16 - S^2 = 1.57565$$

$$\Rightarrow S^2 + 1.57565 - 0.16 = 0$$

$$\Rightarrow S = 0.05 \approx \boxed{1/20} \text{ Ans.}$$

ES-1997

Problem:→ On a two way road the Speed of overtaking & overtaken vechiles are 65 & 40 kmph respectively.

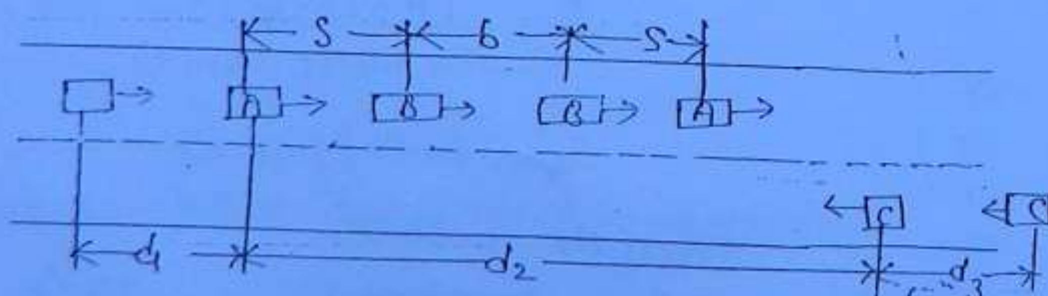
$a = 0.92 \ m/sec^2$

Determine

(1) Safe overtaking Side distance.

(2) Min. length of over taking zone. & Show the detalies of over taking zone by a neat Sketch.

Solution:→



$V_A = 65$ kmph

$V_B = 40$ kmph

(1) Distance d_1

$$d_1 = 0.278\ V_B\ t_R$$

$$d_1 = 0.278 \times 40 \times 2.5$$

$$\boxed{d_1 = 27.8m}$$

(2) Distance d_2 :→

$$d_2 = 0.278\ V_B T + \frac{1}{2} a T^2 .$$

$$S = 0.2\ V_B + 6$$

$$\Rightarrow S = 0.2 \times 40 + 6$$

$$\boxed{S = 14m}$$

$$T = \sqrt{4S/a} = \sqrt{\frac{4 \times 14}{0.92}}$$

$$\boxed{T = 7.8\ sec}$$

$$d_2 = 0.278 \times 40 \times 7.8 + \frac{1}{2} \times 0.92 \times (7.8)^2$$

$$\boxed{d_2 = 114.72m}$$

(3) Distance d_3 :→

$$d_3 = 0.278\ V_C T$$

$$d_3 = 0.278 \times 65 \times 7.80$$

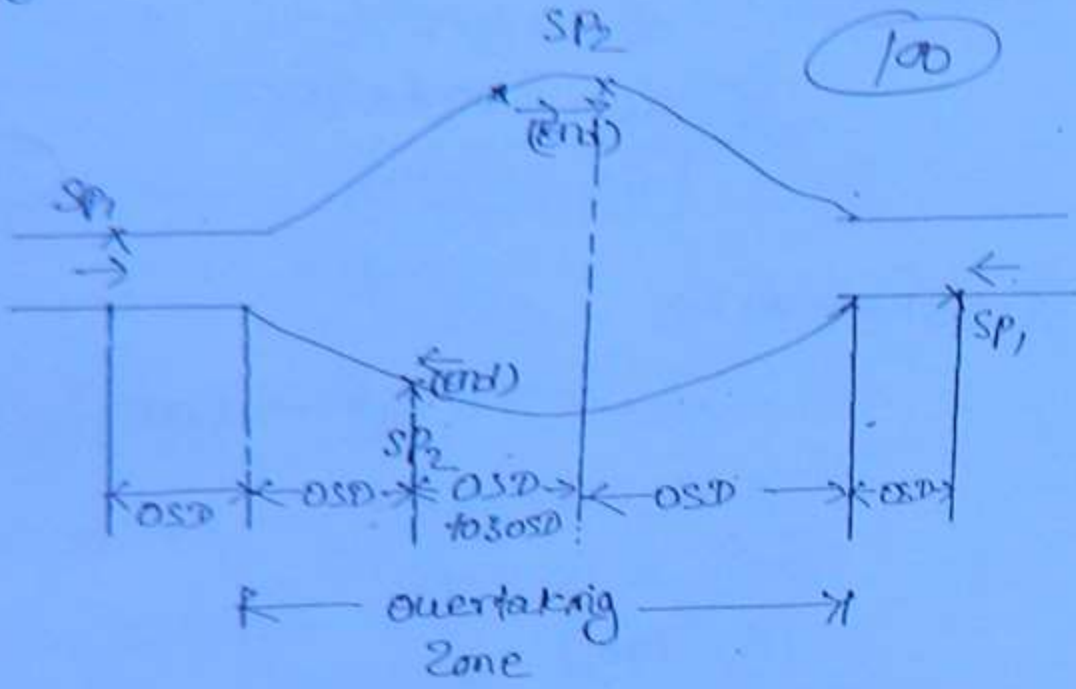
$$\boxed{d_3 = 140.95m}$$

Total OSD $= d_1 + d_2 + d_3$

$= 27.8 + 114.72 + 140.95$

$= \boxed{283.47m}$

Overtaking Zone :→



$$\text{Min. length} = 3 \times OSD$$
$$= 3 \times 283.47$$
$$= 850.41\ m$$

(7) Desirable length of overtaking :→

$$= 5 \times OSD$$
$$= 5 \times 283.47$$
$$= 1417.35\ m$$

SP_1 → Overtaking Zone ahead.

SP_2 → end of Overtaking Zone.

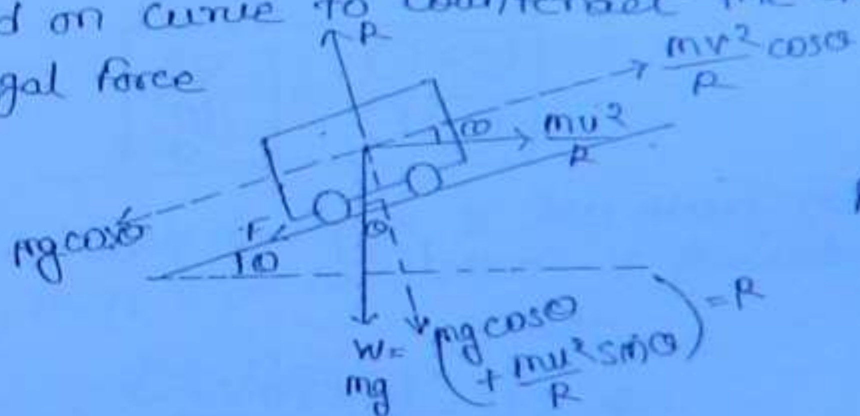
Value of acceleration

Value of acceleration & OSD :→

Speed	a m/sec²	OSD
25	1.41	—
30	1.30	90 m
40	1.24	165 m
50	1.11	235 m
65	0.92	340 m
80	0.72	470 m
100	0.53	640 m

(7) Super elevation :→

→ provided on curve to counteract the effect of centrifugal force



$F = \mu R$

Weight = mg

centrifugal force = $\frac{mu^2}{R}$

→ Reaction $R = mg\cos\theta + \frac{mu^2}{R}\sin\theta$

→ Force of Friction $= F = FR = F\left(mg\cos\theta + \frac{mu^2}{R}\sin\theta\right)$

- Equating all force along Surface of road.

$$\Rightarrow mg\sin\theta + F = \frac{mv^2}{R}\cos\theta$$

$$\Rightarrow mg\sin\theta + F\left(mg\cos\theta + \frac{mv^2}{R}\sin\theta\right) = \frac{mv^2}{R}\cos\theta$$

$$\Rightarrow g\tan\theta + Fg + F\frac{v^2}{R}\tan\theta = \frac{v^2}{R}$$

Super elevation

put $\tan\theta = e$

$$\Rightarrow ge + Fg = \frac{v^2}{R}(1-eF)$$

$$\Rightarrow \frac{g(e+F)}{(1-eF)} = \frac{v^2}{R}$$

$$\Rightarrow \boxed{\frac{(e+F)}{(1-eF)} = \frac{v^2}{gR}}$$

$1-eF \approx 1.00$

than

$$\Rightarrow e+F = \frac{(0.278v)^2}{9.81R}$$

$$\Rightarrow \boxed{e+F = \frac{v^2}{127R}}$$

Friction force

$$\Rightarrow \boxed{e = \frac{v^2}{127R} - F}$$

(ii) Max Value of Superelevation:-

(1) On plain & Rolling = 7% = 0.07

(2) on hilly Road = 10% = 0.10

(3) on Urban road (with = 4% = 0.04
frequent intersection)

(iii) Design Steps: →

(1) If design Speed = V kmph
Superelevation is calulated for 75% for design Speed
(Value of F is not considerd)

$$e = \frac{(0.75V)^2}{127R}$$

$$\boxed{e = \frac{V^2}{225R}}$$

(2) If value calulated above is less than max. permissible value, then S.E. calulated is provided

$$e < e_{max}$$

(3) If $e > e_{max}$
than check value of f considering full design speed using e_{max} value.

Provide e_{max}

$$e + f = \frac{V^2}{127R}$$ — full design Speed

$$f = \frac{V^2}{127R} - e_{max} < 0.15$$

If $F < 0.15$ OK

Provide e_{max}.

(4) If $F > 0.15$

Design Speed should be restricted.

Max. Speed allowed

$$\Rightarrow (e_{max} + f_{max}) = \frac{V^2}{127R}$$

$$\boxed{V_{max} = \sqrt{127R(e_{max} + f_{max})}}$$

(#) Example:- If S.E. is to be designed for a design speed of 110 kmph. of a road in plain area for a curve of Radius = 420m. What should be the value of S.E provided. Check max. allowed speed.

Solution:→ $V = 1100$ kmph

(1) Superelevation

$$e = \frac{(0.75 \times v)^2}{127R} = \frac{(0.75 \times 110)^2}{127 \times 420}$$

$e = 0.127$

$e_{max} = 0.07\%$

$e > e_{max}$

(2) $e_{max} = 0.07$

Check

$$e_{max} + f = \frac{V^2}{127R}$$

$$0.07 + f = \frac{110^2}{127 \times 420}$$

$F = 0.1568 > 0.15$

(3) Max. Speed allowed

$$\Rightarrow e_{max} + f_{max} = \frac{V^2_{max}}{127R}$$

$$\Rightarrow V_{max} = \sqrt{127R(e_{max} + f_{max})}$$

$$\Rightarrow V_{max} = \sqrt{127 \times 420(0.07 + 0.15)}$$

$$\Rightarrow \boxed{V_{max} = 108.2 \text{ kmph}} \text{ Ans}$$

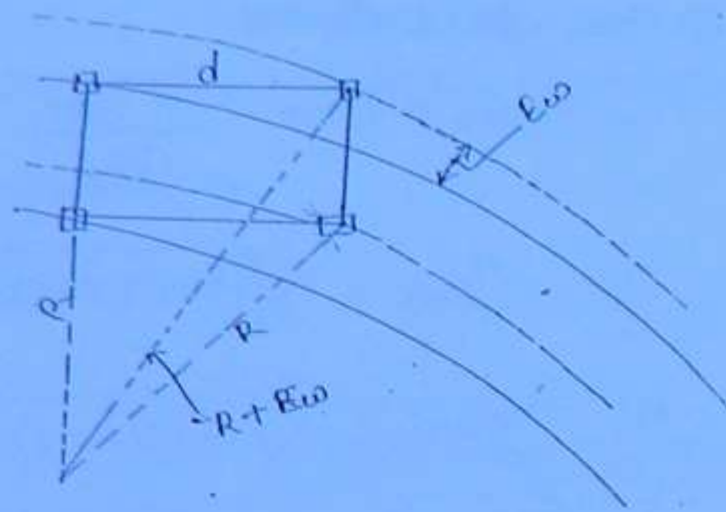
Min radius of curve :→

$$\Rightarrow e_{max} + f_{max} = \frac{V^2}{127R}$$

$$\Rightarrow \boxed{R_{min} = \frac{V^2}{127(e_{max} + f_{max})}}$$

$$\Rightarrow R_{min} =$$

(17) Extra widening :->



Ew = Extra width required

R = Outer radius of road

$\Rightarrow R^2 + d^2 = (R + E_w)^2$

$\Rightarrow \cancel{R^2} + d^2 = \cancel{R^2} + E_w^2 + 2R \cdot E_w$

$\Rightarrow d^2 = E_w(E_w + 2R)$

$\Rightarrow$ Extra width

$E_w = \dfrac{d^2}{2R + E_w}$

$\boxed{E_w = \dfrac{d^2}{2R}}$ $(2R + E_w \approx 2R)$

If n = Total no. of lanes

$\boxed{E_w = \dfrac{nd^2}{2R}}$

or

(1) $\boxed{e_{w} = \frac{nl^2}{2R}}$ Mechanical widening.

(2) Psychological widening :→

$$= \frac{V}{9.5\sqrt{R}}$$

Total Extra widening required $= \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

(4) Transition Curve :→

→ Length of Transition curve :→

(1) As per rate of change of radial acceleration (C)

Length of Transition curve $= \frac{v^3}{CR}$

$$= \frac{(0.278V)^3}{CR}$$

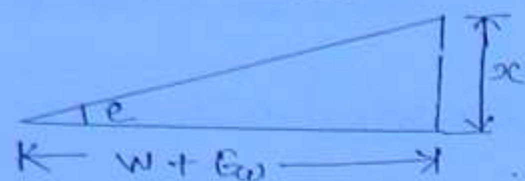
V.F $C = \left(\frac{80}{V+75}\right)$

$$C = [0.50 < C < 0.80]$$

(2) As rate of change of Super elevation :→

Calculate Super elevation , $e = \frac{V^2}{225R}$

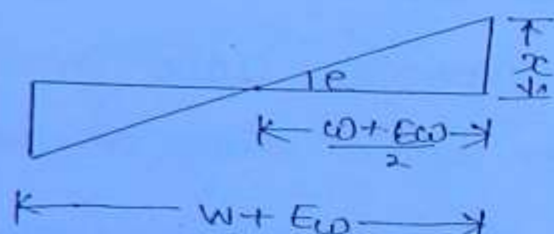
(1) if pavement is rotated about inner edge



Raise of pavement edge

$$x = (W + E_w)e$$

② If pavement is rotated about centre



Raise of pavement edge

$$x = \left(\frac{W + E_w}{2}\right)x$$

length of transition curve as per super elevation

= 150·x → for plain region

= 100x → for built up area

= 60x → for hilly area.

③ As per Empirical formula.

For plain & Rolling =

$$\boxed{L = \frac{2.70V^2}{R}}$$

$\forall$ V = kmph

$R = m$

(2) For mountaneous & steep terrain

$$\boxed{L = V^2/R}$$

(#) Terrain classification:→

① Steep terrain → cross slope > 60%.

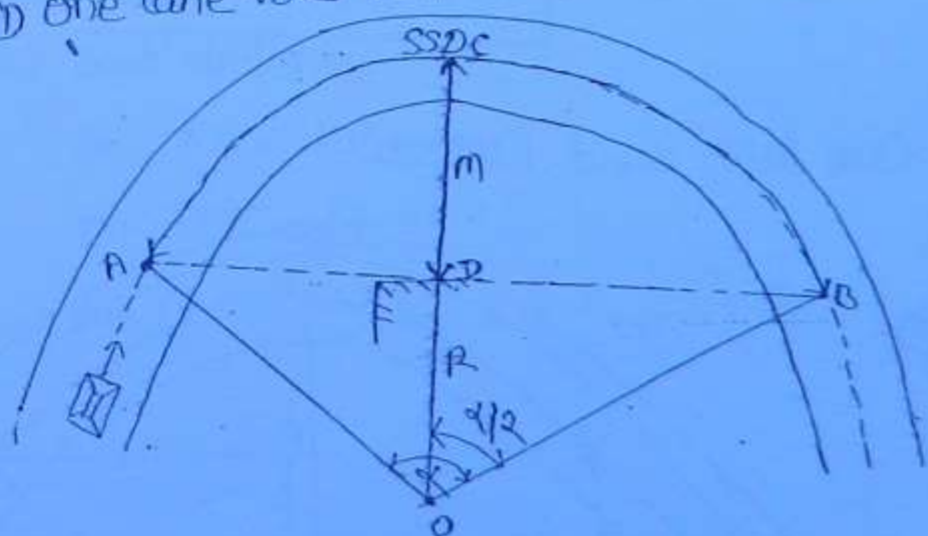
② mountaneous region → 25 to 60%.

③ Rolling terrain → 10 to 25%.

④ plane terrain → <10%.

(#) Set back Distance:→

Case(I) one lane road (L > SSD)



- Set back distance is min clearance required from cent line of the road to any obstruction, such that sight distance is available through the length of road

Set back distance = CD = m

Distance ACB = SD = S

110

$$\Rightarrow \frac{SD}{2\pi R} = \frac{\alpha}{360}$$

$$\Rightarrow \alpha = \frac{180 S}{\pi R}$$

$$\Rightarrow \boxed{\frac{\alpha}{2} = \frac{180 S}{2\pi R}}$$

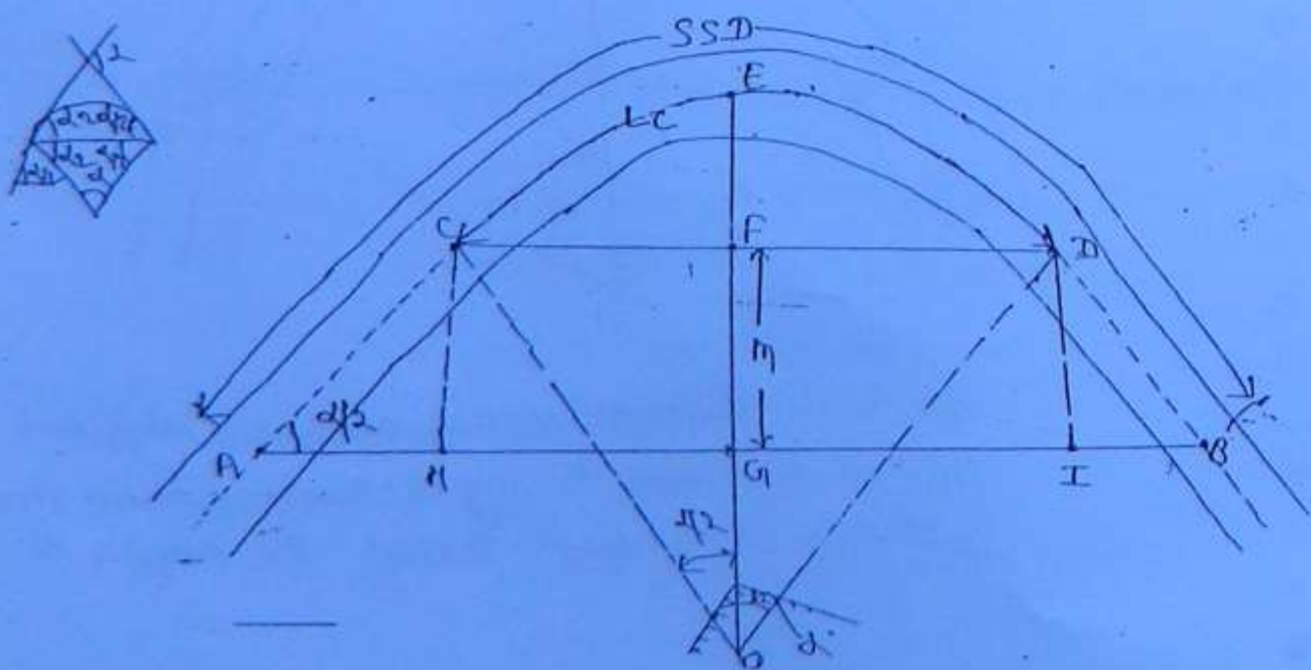
Set back distance CD = m

$$m = OC - OD$$

$$m = R - R\cos\alpha/2$$

$$\boxed{m = R(1 - \cos\alpha/2)}$$

Case② One lane road (L < SD)



length AC $= \frac{SD - Lc}{2}$

$= \frac{(S - L_c)}{2}$

(11)

Sight distance = ACEDB = S

length of curve = CED = Lc

$$\boxed{L_c < S}$$

$$\Rightarrow \frac{L_c}{2\pi R} = \frac{\alpha}{360}$$

$$\Rightarrow \alpha = \frac{180 L_c}{\pi R}$$

$$\Rightarrow \boxed{\frac{\alpha}{2} = \frac{180 L_c}{2\pi R}} \text{ — (1)}$$

Set back distance

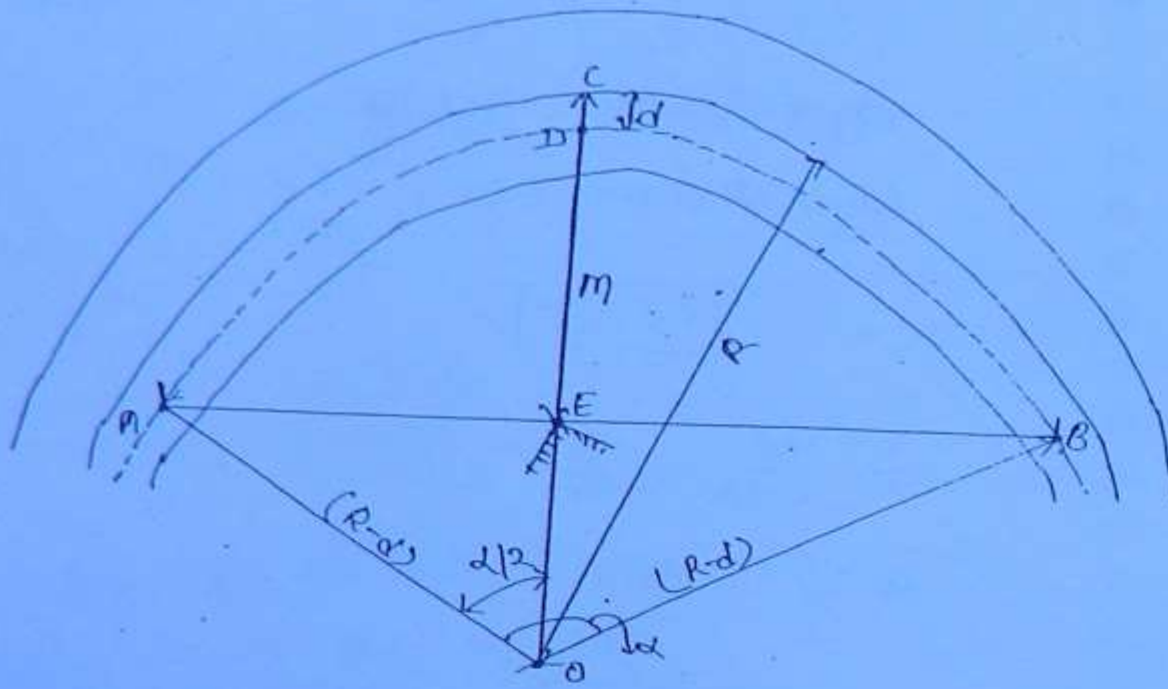
$m = EG = EF + FG$

$m = (OE - OF) + CH$

$m = (R - R\cos\alpha/2) + \left(\frac{S - L_c}{2}\right)\sin\alpha/2$

Case③ Two lane Road (L>S)

(112)



ADB = S

→ Radius is measured from centre of Road (total width)

OA = (R-d)

d = half of inner lane

→ Set back distance is measured from centre line of total width of road.

m = CE . distance

$$\Rightarrow \frac{S}{2\pi(R-d)} = \frac{\alpha}{360}$$

$$\Rightarrow \alpha = \frac{180\,S}{\pi(R-d)}$$

$$\Rightarrow \boxed{\alpha/2 = \frac{180\, S}{2\pi(R-d)}}$$

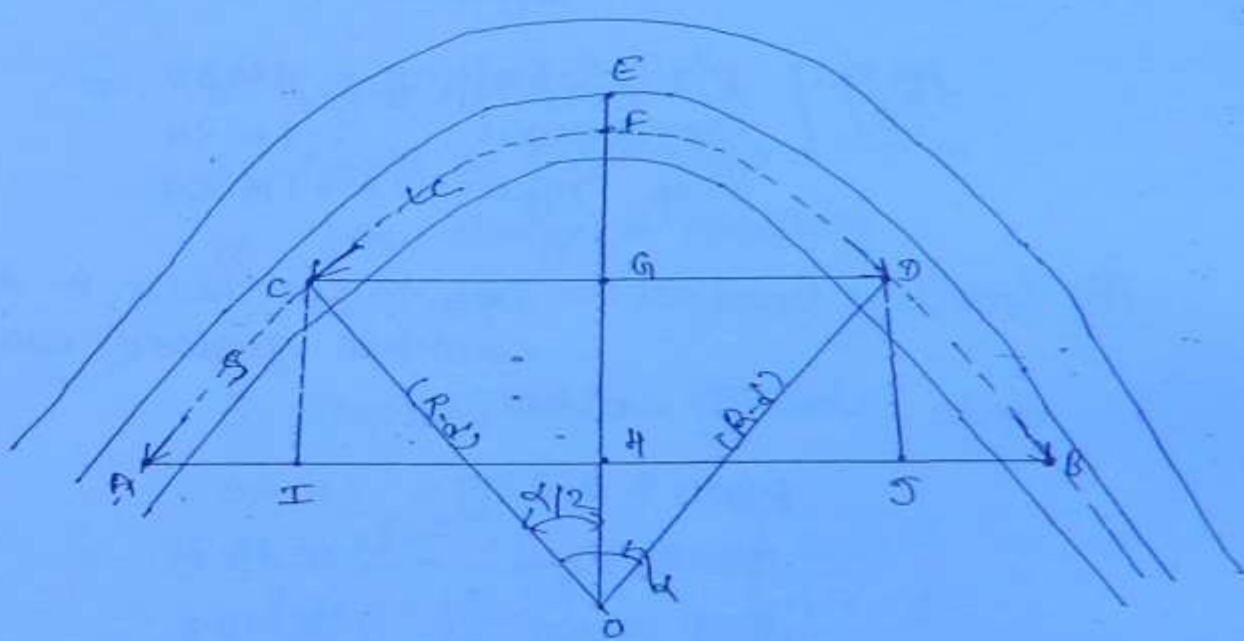
113

Set back distance

$m = CE = OC - OE$

$$\boxed{m = R - (R-d)\cos\alpha/2}$$

Case ④ Two lane road if length of curve :->



$$\Rightarrow AC = \frac{S - Lc}{2}$$

$$\Rightarrow \frac{Lc}{2\pi(R-d)} = \frac{\alpha}{360}$$

$$\Rightarrow \alpha = \frac{180\, Lc}{\pi(R-d)}$$

$$\Rightarrow \alpha/2 = \frac{180\, Lc}{2\pi(R-d)}$$

Set back distance :-

$m = EH$

114

$m = EG + GH$

$m = (OE - OG) + CI$

$m = R - (R-d)\cos\alpha/2 + \left(\frac{S-L_c}{2}\right)\sin\alpha/2$

Design of Vertical alignment :→

① Gradient :→

ⓐ Ruling Gradient :→ Max gradient that can be provided in general conditions

As per IRC

plain & Rolling	=	1 in 30
mountaneous	=	1 in 20
Steep region	=	1 in 16.7

ⓑ Limiting Gradient :→ Due to cost factor & topographic condition gradient can be increased upto Limiting Gradient

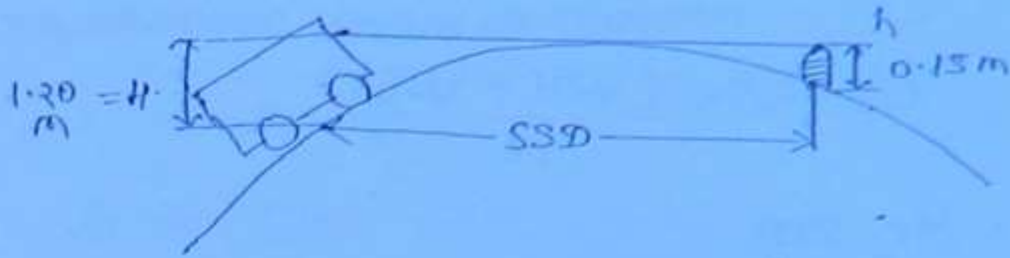
plain & Rolling	=	1 in 20
mountaneous	=	1 in 16.7
Steep region	=	1 in 14.3

ⓒ Extra ordinary Condition :→ Exceptional gradient can be provided

plain & Rolling	=	1 in 15
mountaneous	-	1 in 14.3
Steep region	=	1 in 12.5

(ii) Length of Summit Curve :→

Case (1) $L > (SSD \text{ or } OSD)$



$$\Rightarrow L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2}$$

$\Psi =$ $H =$ height of driver eye = 1.20 m

$h =$ height of obstruction = 0.15 m

$N =$ Total change in gradient

$N = |N_1 - N_2|$

$S =$ Stopping Sight distance.

$$\Rightarrow L = \frac{NS^2}{(\sqrt{2 \times 1.2} + \sqrt{2 \times 0.15})} = \boxed{\frac{NS^2}{4.4}}$$

(2) for overtaking sight distance :→ $h = H = 1.20$ m

$$\Rightarrow L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2}$$

$$\Rightarrow L = \frac{NS^2}{(\sqrt{2 \times 1.2} + \sqrt{2 \times 1.2})^2}$$

$$\boxed{L = \frac{NS^2}{9.6}}$$

116

Case ② If $L < SSD$ or OSD

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

for SSD

$$\boxed{L = 2S - \frac{4.4}{N}}$$

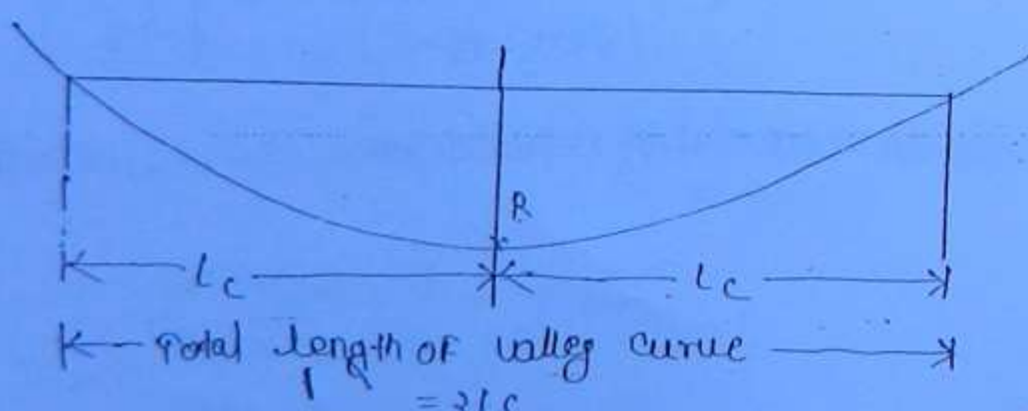
for OSD

$$\boxed{L = 2S - \frac{9.6}{N}}$$

⑦ Valley Curve :→

length is calculated

① Comfort Condition :→ Based on rate of change of radial acceleration (C)



In this case two transition curve are provided back to back to complete the total length of valley curve.

⇒ Length of Transition Curve :→

$$L_c = \frac{V^3}{CR}$$ (117)

→ In this case, Radius at junction

$$R = \frac{L_c}{N}$$

$$\Rightarrow \quad L_c = \frac{V^3 N}{C \cdot L_c}$$

$$\Rightarrow \quad L_c^2 = \frac{N V^3}{C}$$

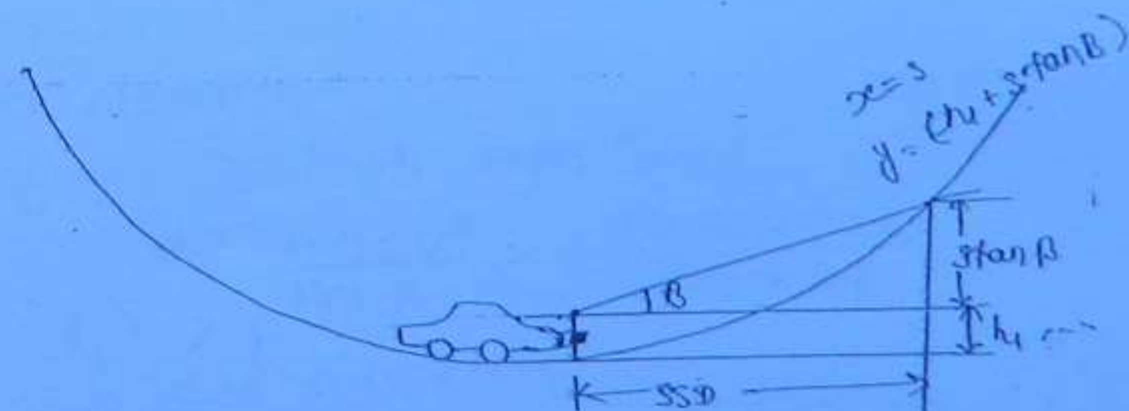
$$\Rightarrow \quad L_c = \sqrt{\frac{N V^3}{C}}$$

Total, length of valley curve

$$L = 2 \cdot L_c$$

$$\boxed{L = 2 \cdot \sqrt{N V^3 / C}}$$

(2) As per head light sight distance :→



For Simple Parabolic curve

$$y = ax^2$$

$\because a = \left(\frac{N}{2L}\right)$

$\Rightarrow h_1 + S\tan B = aS^2$

$\Rightarrow h_1 + S\tan B = \left(\frac{N}{2L}\right)S^2$

length of curve

$$L = \frac{NS^2}{2(h_1 + S\tan B)} \quad \forall\ (L > S)$$

$$L = 2S - \frac{2(h_1 + S\tan B)}{N} \quad \forall\ (L < S)$$

generally

h_1 = height of headlight above ground

$= 1.20\text{ m}$

B = Beam angle

$B = 1^\circ$

[redacted]

Problem:→ A National highway in hilly area has a curve of radius equal to minimum ruling radius. Design all geometrical features of this curve.
Calculate set back distance also stopping sight distance. If road is of two lane.

(119)

Solution:→ Design Speed

for National highway in hilly road.

$$V = 50 \text{ kmph}$$

Min ruling radius

$$e + f = \frac{V^2}{127R}$$

$$R_{min} = \frac{V^2}{127(e+f)}$$

$$e_{max} = 0.10$$

$$f_{max} = 0.15$$

$$R_{min} = \frac{50^2}{127(0.10 + 0.15)}$$

$$R_{min} = 78.74 \simeq 79 m$$

Super elevation

(i) design for 75% kmph design speed

$$e = \frac{0.75V^2}{127R} = \frac{(0.75 \times 50)^2}{127 \times 79}$$

$$e = 0.14 > 0.10$$

provide $e = 0.10$

for all design speed

$$e+f = \frac{v^2}{127R}$$

120

$$F = \frac{50^2}{127\times79} - 0.10$$

$F = 0.149 < 0.15$ so ok

provide S.E. = 0.10

3) Extra widening

For a two lane road

width = w = 7.0 m

$$E_w = \frac{nl^2}{2R} + \frac{V^2}{9.5\sqrt{R}}$$

$$E_w = \frac{2\times6^2}{2\times79} + \frac{50}{9.5\sqrt{79}}$$

$E_w = 1.05$ m.

Total width of road $= w + E_w$

$= 7 + 1.05$

$= 8.05$ m

4) Transition curve

1) As per rate of change of ~~radius~~ radial acceleration

$$L_s = \frac{v^3}{CR}$$

$$C = \frac{80}{75+v} = \frac{80}{75+50} = 0.64$$

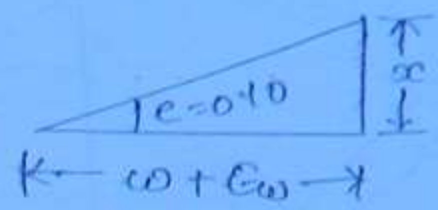
$0.50 < C < 0.80$ — ok

$$L_s = \frac{(0.278\times50)^3}{0.64\times79} = 53.1\ m$$

ii) As per rate of change of S.E.

Assume pavement is rotated outer edge

(12)



$x = (W + E_w)\, e$

$x = 8.05 \times 0.10 = 0.805\ m$

length of T. curve $= 60 \times x$

$= 60 \times 0.805$

$= 48.3\ m$

(iii) As per empirical formula

$$L_s = \frac{V^2}{R} = \frac{50^2}{79} = 31.64\ m$$

length of transition curve $= 53.10\ m$

5) Set back distance

Assume length of curve > SSD

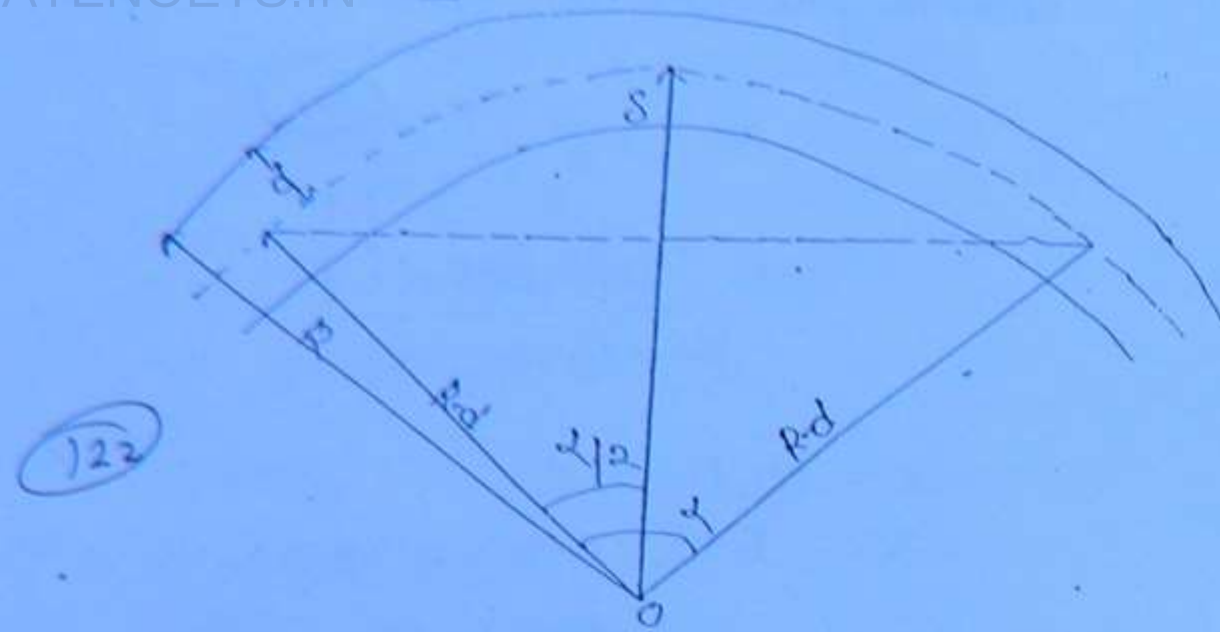
$L > SSD$

Stopping Sight distance

$$S.S.D = 0.278\, V \cdot t_R + \frac{(0.278\, V)^2}{2g(f \pm S\%)}$$

$$S.S.D. = 0.278 \times 50 \times 2.5 + \frac{(0.278 \times 50)^2}{2 \times 9.81 \times (0.35 + 0)}$$

$S.S.D. = 62.90\ m.$



122

$$\Rightarrow d = \frac{w + E_{10}}{4} = \frac{8.05}{4} = 2.01\,m$$

$$\Rightarrow \frac{\alpha}{360} = \frac{S}{2\pi(R-d)}$$

$$\Rightarrow \frac{\alpha}{2} = \frac{180\,S}{2\pi\,(R-d)} = \frac{180 \times 62.90}{2\times\pi(79-2.01)}$$

$$\Rightarrow \boxed{\alpha = 23.405}$$

Set back distance

$$\Rightarrow m = R - R(-d)\cos\alpha/2$$

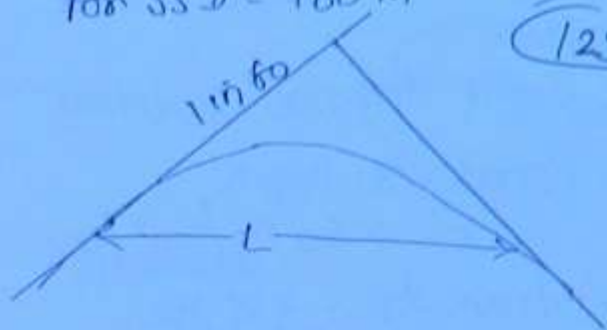
$$\Rightarrow m = 79 - (79 - 2.01)\cos 23.405$$

$$\Rightarrow \boxed{m = 8.34m}$$

2002
ES

Problem:→ As ascending gradient 1:60 meet a descending gradient 1 in 50. Find the length of summit curve for SSD = 180 m

(123)



Solution:- $N = |N_1 - N_2| = \frac{1}{50} - (-\frac{1}{60}) = \frac{1}{50} + \frac{1}{60}$

$= \frac{1}{27.27}$

length of summit curve

Assuming $(L > S.S.D)$

$\Rightarrow L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2}$

$\Rightarrow L = \frac{\frac{1}{27.27} \times 180^2}{(\sqrt{2 \times 1.2} + \sqrt{2 \times 0.5})^2}$

$\Rightarrow L = 270\ m > (180\ ms)$

$L > SSD$ (Assumption is correct)

$L = 270\ m$ Ans

ES 2005 (1-2) WWW.GATENOETS.IN

Problem:- A Valley curve of a S.H is formed by a descending gradient of 1 in 20 meeting an up gradient of (1 in 30).
Design the length of Valley curve to
(i) Comfort condition
(ii) Head light Sight distance condition

Design Speed = 80 kmph

$c = 0.60\ m/sec^2/sec$

(124)

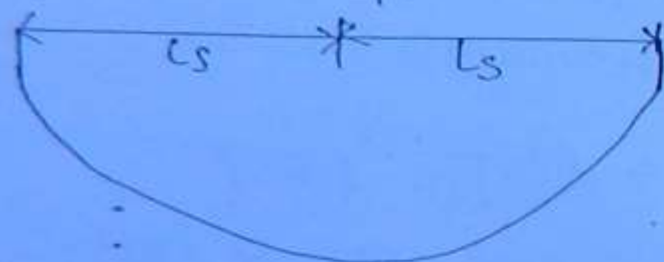
Reaction time $t_R = 2.5$ sec

$f = 0.35$ m

Solution → (1) Comfort condition

Based on rate of change of radial acceleration

$c = 0.60\ m/sec^3$



Total length of curve

$\Rightarrow L = 2L_s = 2\sqrt{\frac{NV^3}{C}}$

$L = 2\sqrt{\frac{1}{12}\left(\frac{0.278 \times 80^3}{...}\right)}$

$\boxed{L = 78.17\ m}$

$N = |N_1 - N_2|$

$N = \left|-\frac{1}{20} - \left(+\frac{1}{30}\right)\right|$

$N = \left|-\frac{1}{80} - \frac{1}{30}\right|$

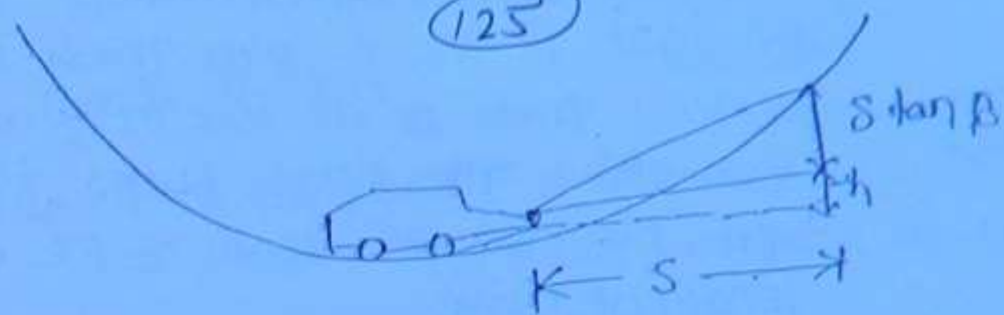
$N = \frac{50}{600}$

(2) Head light Sight distance condition

$H.S.D. = S.S.D. = 0.278\,V t_R + \frac{(0.278V)^2}{2g(f \pm S\%)}$

$= 0.278 \times 80 \times 2.5 + \frac{(0.278 \times 80)^2}{2 \underset{9.81}{g} (\underset{0.35}{f} \pm 0)}$

=



Assuming

$(L > S)$

$\Rightarrow L = \dfrac{NS^2}{2(h_1 + S\tan B)}$

$\Rightarrow L = \dfrac{\frac{1}{12} \times 127.6^2}{2(0.75 + 127.6\tan 1)}$

$\Rightarrow L = 227.8m > S = (127.6)$

$(L > S)$ Assumption is correct

$L = 227.8m$

$\Rightarrow$ length of valley curve provided

= Max of above two

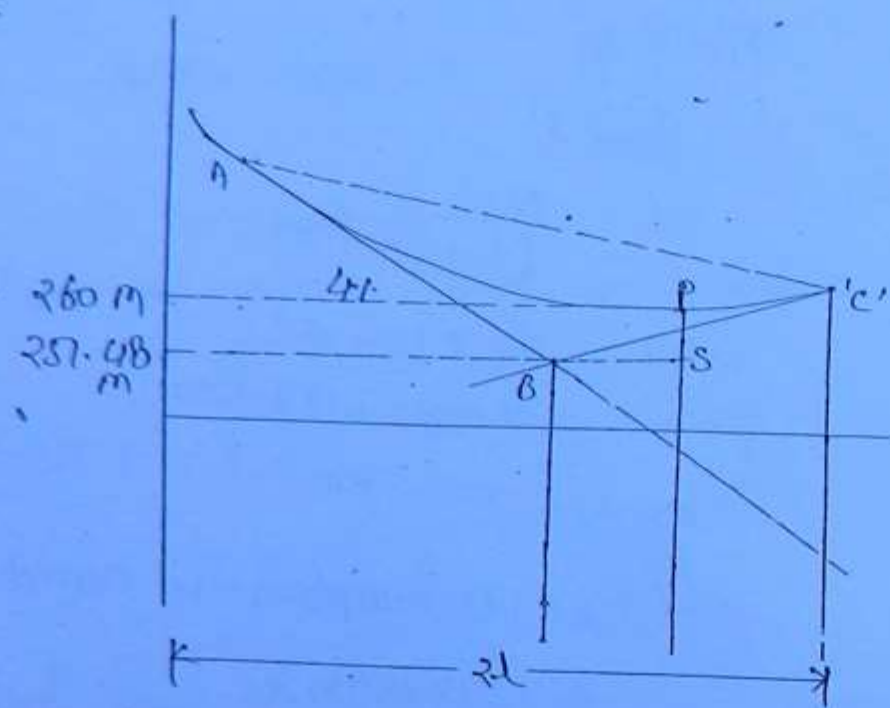
= 227.80 m.

CE
ES-1998

Que 6(a): A vertical parabolic curve is to be used under a grade separation structure. The min grade left to right is 4% & plus grade is 3%. The intersection of two grade is at 435 m & at an elevation of 251.48 m. The curve passes through its fixed point at a chainage of 460 m & RL of 260 m. Find the length of curve.

(126)

Solution:->



Assume length of curve $= 2l$

R.L of B $= 251.48$ m

R.L of Q = R.L of B − 25×4/100

$= 251.48 - 25 \times 4/100$

$= 250.48$ m

h value for point P

$h = PQ$ = RL of P − RL of Q

$= (260 - 250.48)$

$h = 9.52m$

$Kx^2 = 9.52\,m$

Value of x for point P = $(l+25)$

$K(l+25) = 9.52\,m$ —(i)

Value of h for last point C

$x = 2l$

$\Rightarrow h = 3\%$ of L + 4% of L

$\Rightarrow h = 0.03l + 0.04l$

$\Rightarrow h = 0.07l$

$h = Kx^2 = K\cdot(2l)^2$

$K \times 0.4l^2 = 0.07l$

$\Rightarrow K = \frac{0.07l}{4l^2} = 0.0175/l$

$\Rightarrow K = \frac{0.07l}{4l^2} = 0.0175/l$ —(ii)

put in eq. (i)

$\Rightarrow \frac{0.0175}{l}(l+25)^2 = 9.52$

$\Rightarrow l^2 + 50l + 625 = 544l$

$\Rightarrow l^2 - 494l + 625 = 0$

$l = 492.73\,m$

Total length of curve is $2l = 2 \times 492.73$

$= \boxed{985.46\,m}$ Ans

Traffic Engineering

(i) Traffic Engineering can be divided into

(1) Traffic characteristics:-
- → Road User Behaviour.
- → Vehicle characteristics.
- → Braking characteristics

(2) Traffic Studies:-
- → Traffic volume
- → Speed Study
- → OSD Study
- → Delay Study
- → Capacity
- → Parking Study
- → Accident Study.

(3) Traffic Operation :→

(a) Traffic regulation
- → Traffic control device.
- → warning
- → Inspection of grade Sepnators.
- → Regulatory.

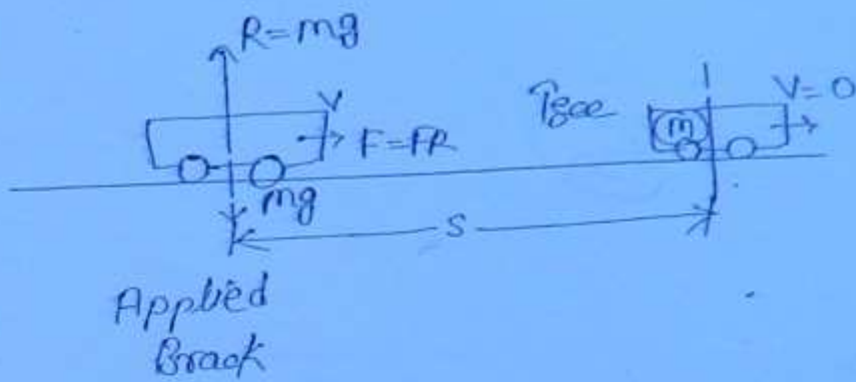
(b) Traffic Signal.

(c) Road marking.

(d) Traffic Island. Rotary

(e) Parking & lighting.

Braking charatersitics:→



Assumption:→

① 100% brack efficiency is there after application of brack. Brack are tully applied whels are fammed vehicle is ~~it~~ skidding over the road surface.

∀ m = mass of vehicle

K.E lost = work done

$\frac{1}{2}mv^2 = F \times S$

$= F \cdot RS \cdot = F mg \cdot s$

$\boxed{V^2 = 2gfS}$

Distance travelled

$S = \frac{V^2}{2gf}$ —— ①

If retardation = a

130

(4) Capacity :→ Based on traffic condition max volume that can be accomodated on a road is called capacity of road.

132

(1) Basic capacity :→ In most ideal condition max. volume that can be found on a road is called Basic capacity.

(2) Possible capacity :→ In general condition of traffic, traffic volume vary in different condition

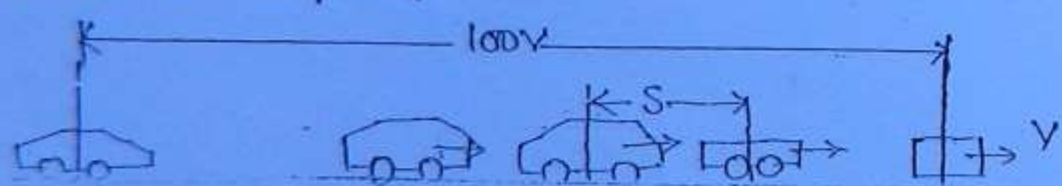
Incorrect condition = 0

In most Ideal condition = Basic capacity

(It may be zero to Basic capacity)

(3) Practical capacity :→ In general condition of traffic, volume generally found on the road is called practical capacity.

(4) Theoritical Capacity :→



$$\text{Theoritical capacity} = \frac{100\,V}{S} \text{ (vechical/hr)}$$

∀ S = The min clearenees required b/w two vechicles.

$$S = (0.7 \times V + l)$$

$\Rightarrow S = (0.2V + 6)$

theoritical capacity :- if time headway b/w two vechicle $= t_h$ sec.

$$\text{Theoritical capacity} = \frac{60 \times 60}{t_h}$$

Problem:→ Estimate theoritical capacity of highway with oneway traffic flow at 55 kmph speed for one lane. Assume average length of vechicle = 5.20m
time headway = 4.5 sec.

Solution (1) Case on speed

theoritical capacity $= 100V/S$

$\because S = 0.2V + l$

$S = 0.2 \times 55 + 5.2 = 16.2\,m$

$$\text{Capacity } C = \frac{100 \times 55}{16.2}$$

$C = 3395$ veh./hr.

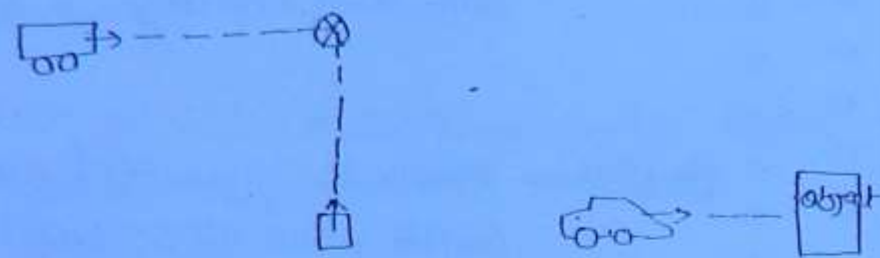
(2) Based on time headway

$$C = \frac{3600}{4.5} = 800 \text{ veh/hr}$$

(7) Accident Analysis :->

Types:-> 134

(1) A moving vechicle hits a parked vehicle.
(2) Two vehicle moving towards on crossing from right angle collide at an intersection.



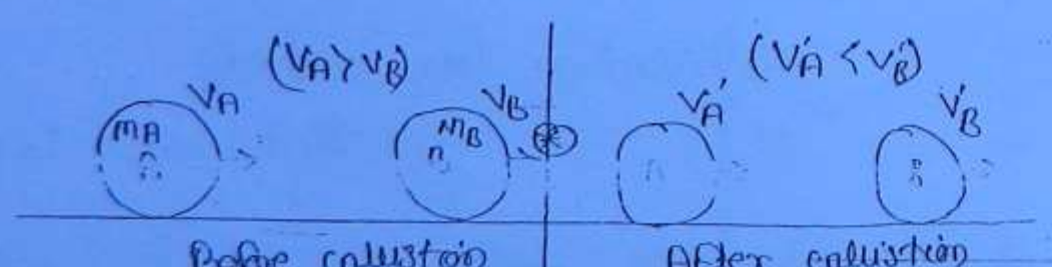
(3) A moving vehicle collide with an object.
(4) Head on collision.

⇒ Assumptions:->

Analysis of Accident:->

(1) After application of brakes, wheels are fully jammed. 100% brake capacity.
(2) collision of two vehicles is considerd plastic collision.

⇒ collision of two bodies:->



A & B are two bodies colliede at a point.

- Befor collision Speed of A = V_A

Speed of B = V_B

For collision

$$V_A > V_B$$

Velocity of approach $= (V_A - V_B)$

After collision

Velocity of A & B $= V_A'$ & V_B'

for Seperation $V_B' > V_A'$

Velocity of Seperation $= (V_B' - V_A')$

Newtons law of collision:→ As per Newton's law Velocity of Seperation bears a constant ratio with Velocity of approach. The constant is called co-efficient of resititution denotated by 'e'.

$$e = \frac{\text{Velocity of Seperation}}{\text{Velocity of approach}} = \frac{V_B' - V_A'}{V_A - V_B}$$

Value of e is b/w 0 to 1

(1) For Perfectly Elastic collision:→

Value of $e = 1.0$

$$\Rightarrow \frac{V_B' - V_A'}{V_A - V_B} = 1.0$$

$$\Rightarrow (V_B' - V_A') = (V_A - V_B)$$

(2) for Perfectly plastic collision -

Value of $e = 0$

$$\Rightarrow \frac{V_B' - V_A'}{V_A - V_B} = 0$$

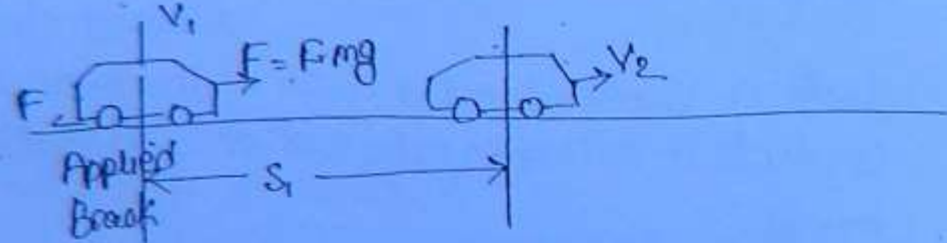
(136)

$$\Rightarrow V_B' - V_A' = 0$$

$$\boxed{V_B' = V_A'}$$

Both bodies will move together.

Analysis:→
Analysis of a vehicle applied brakes.



Kinetic energy lost = work done

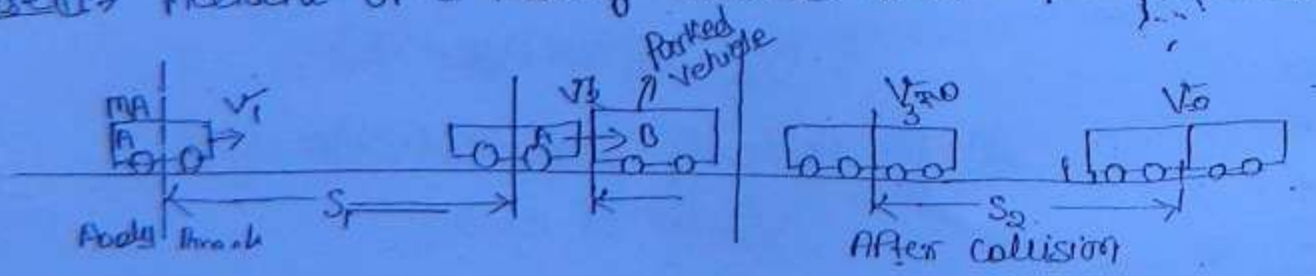
$$\Rightarrow \frac{1}{2}mu_1^2 - \frac{1}{2}mu_2^2 = Fs_1 = Fmg\,S_1$$

$$\boxed{V_1^2 - V_2^2 = 2gF\cdot S_1}$$

$$\Rightarrow V_2^2 - 0 = 2g\cdot FS_2$$

$$\boxed{V_2^2 = 2gF\cdot S_2}$$

Case ①:⇒ Accident of a moving vehicle with a parked vehicle.



① Before collision :-

For vehicle Ⓐ

$$\boxed{V_1^2 - V_2^2 = 2g \cdot f S_1} \quad \text{—— ①}$$

② Momentum equation :-

Total momentum just before collision = Total momentum just after collis

$$\Rightarrow m_A V_2 + m_B \cdot 0 = (m_A + m_B) V_3$$

$$\Rightarrow \boxed{V_2 = \left(\frac{m_A + m_B}{m_A}\right) V_3} \quad \text{—— ②}$$

③ After collision :-

$$V_3^2 - 0 = 2gf S_2$$

(For combined vehicle A & B)

$$V_3^2 = 2gfS_2$$

$$\boxed{V_3 = \sqrt{2gfS_2}} \quad \text{—— ③}$$

Step ① Find V_3

② Calculate V_2 from momentum eq.

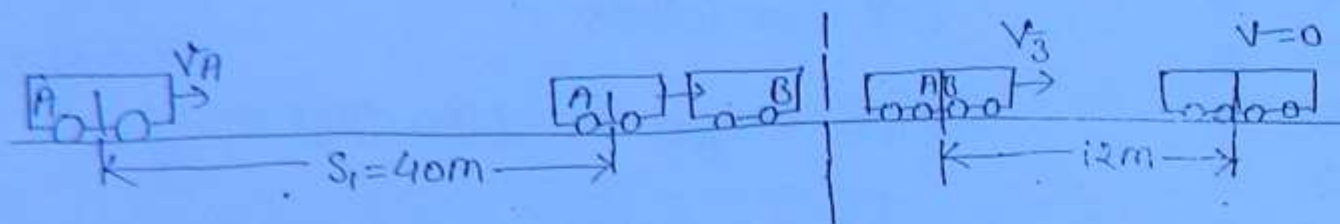
③ Calculate V_1 from before collision eq.

(S-1998 Q5(b))

138 Problem :-> A vehicle applied brakes & skid through a distance 40 m before colliding another parked vehicle, the weight of which is 60% of former. From fundamental principle computed the initial speed of moving, if distance which both vehicle skid after collision is 12 m

$F = 0.60$

Solution :->



① After collision

for Vehicle A + B

$$V_3^2 = \sqrt{2gFs_2} = \sqrt{2\times 9.81\times 0.60\times 12}$$

$$V_3^2 = 11.89 \text{ m/sec}$$

② Momentum eq.

$$V_2 = \left(\frac{m_A + m_B}{m_A}\right) V_3$$

weight of parked vehicle = 60% weight of moving vehicle

$$m_B g = 0.60 m_A g$$

$$m_B = 0.60 m_A$$

$$V_2 = \left(\frac{m_A + 0.60 m_A}{m_A}\right) V_3$$

$$V_2 = 1.60 \times V_3 = 1.60 \times 11.89$$

$$V_2 = 19.02 \text{ m/s}$$

(3) Befor collision:→

For Vehicle (A)

$$V_1^2 - V_2^2 = 2gFS_1$$

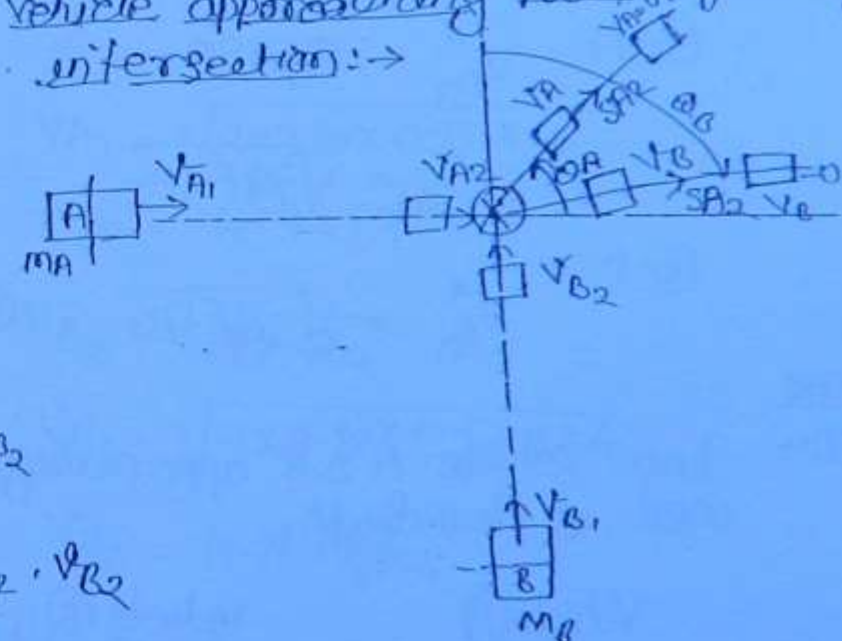
$$V_1 = \sqrt{V_2^2 + 2gFS_1}$$

$$V_1 = \sqrt{(19.02)^2 + 2 \times 9.81 \times 0.60 \times 40}$$

$$V_1 = 28.85 \text{ m/sec}$$

$$V_1 = 103.78 \text{ kmph}$$ Ans

Case (2):→ Two vehicle approaching from right angle collis at an intersection:→



Note
Given:–
$S_{A_1}, S_{B_1}, S_{A_2}, S_{B_2}$
θ_A, θ_B
Find:– $V_A, V_B, V_{A_2}, V_{B_2}$
V_{A_3}, V_{B_3}

Before collision :→

For (A) $V_{A_1}^2 - V_{A_2}^2 = 2gFS_{A_1}$ — (1)

$$\boxed{V_{A_1} = \sqrt{V_{A_2}^2 + 2gFS_{A_1}}}$$

For B $V_{B_1}^2 - V_{B_2}^2 = 2gFS_{B_1}$

$$\boxed{V_{B_1} = \sqrt{V_{B_2}^2 + 2gFS_{B_1}}} \quad (2)$$

(2) Momentum equation :→

In the direction of V_{A_1}

$$\Rightarrow M_A \cdot V_{A_2} + M_B \cdot 0 = M_A V_{A_3} \cos\theta_A + M_B V_{B_3} \sin\theta_B$$

140

$$V_{A_2} = \frac{1}{M_A}\left(M_A V_{A_3} \cos\theta_A + M_B V_{B_3} \sin\theta_B\right) \quad —(3)$$

In the direction of V_{B_1}

$$\Rightarrow M_A \cdot 0 + M_B V_{B_2} = M_A V_{A_3} \sin\theta_A + M_B V_{B_3} \cos\theta_B$$

$$V_{B_2} = \frac{1}{M_B}\left(M_A V_{A_3} \sin\theta_A + M_B V_{B_3} \cos\theta_B\right) \quad —(4)$$

(3) After collision :→

For A $\quad V_{A_3}^2 = 2gFS_{A_2}$

$$V_{A_3} = \sqrt{2gFS_{A_2}} \quad —(5)$$

For B $\quad V_{B_3}^2 = \sqrt{2gFS_{B_2}} \quad —(6)$

IAS-1996

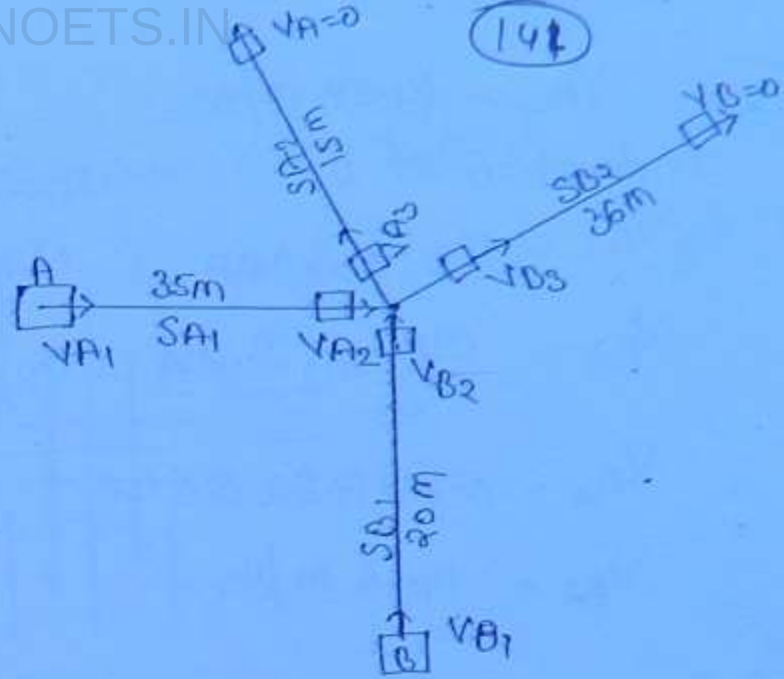
Problem :→ Two vehicle A & B apporaching at right angle. A from west, B from South.

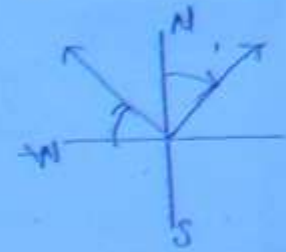
	Vehicle (A)	Vehicle (B)
Before collision	A from west	B from South
After collision	50° N of W	60° E of N
S_{A_1}	$S_{A_1} = 35m$	$S_{B_1} = 20m$
S_2	$S_{A_2} = 15m$	$S_{B_2} = 36m$
Wt of Vehicle	75% of B	6t

→ Find out the speed of vehicle

$F = 0.55$

Solution:->





(1) After collision:-

for (A) $V_{A3}^2 = 2gfS_{A2}$

$V_{A3} = \sqrt{2\times 9.81\times 0.55\times 15}$

$V_{A3} = 12.72$ m/sec

for (B) $V_{B3} = \sqrt{2gfS_{B2}}$

$V_{B3} = \sqrt{2\times 9.81\times 0.55\times 36}$

$V_{B3} = 19.71$ m/sec

(2) Momentum equation

$\theta_A = 180 - 50 = 130°$

$\theta_B = 60°$

$M_A = 6/g$

$M_A = 6\times 0.75/g$

$\frac{M_A}{M_B} = 0.75$

$V_{A2} = \frac{1}{M_A}\left(M_A V_{A3}\cos\theta_A + M_B V_{B3}\sin\theta_B\right)$

$V_{A2} = \underline{12.72}\times\cos 180 + \frac{1}{0.75}\, 19.71 \sin 60$

(148) $V_{A_2} = 14.58\ m/sec$

Indirection of B

$$m_B V_{B_2} = m_A V_{A_3} \sin\theta_A + m_B V_{B_3} \cos\theta_B$$

$$V_{B_2} = \frac{m_A}{m_B} V_{A_3} \sin\theta_A + V_{B_3} \cos\theta_B$$

$$V_{B_2} = 0.75 \times 12.72 \sin 180^\circ + 19.71 \cos 60^\circ$$

$$V_{B_2} = 17.16\ m/sec$$

(3) Befor collision

$$\Rightarrow V_{A_1} = \sqrt{V_{A_2}^2 + 2gFS_{A_1}}$$

$$V_{A_1} = \sqrt{14.58 + 2 \times 9.88 \times 0.55 \times 35}$$

$$V_{A_1} = 24.295\ m/s$$

$$V_{A_1} = 87.34\ kmph$$

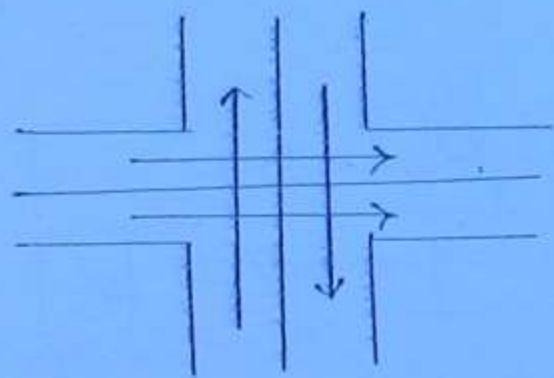
$$\Rightarrow V_{B_2} = \sqrt{V_{B_2}^2 + 2gF S_{B_2}}$$

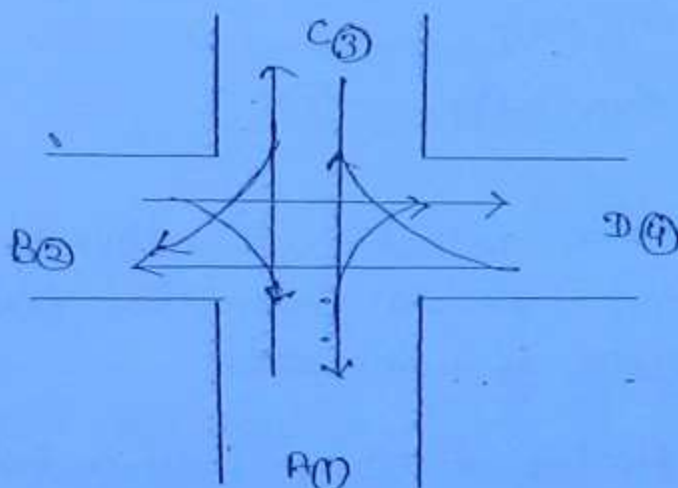
$$V_{B_2} = \sqrt{17.16 + 2 \times 9.81 \times 0.55 \times 20}$$

$$V_{B_2} = 22.58\ m/s$$

$$V_{B_2} = 81.6\ kmph$$

Signal design:→

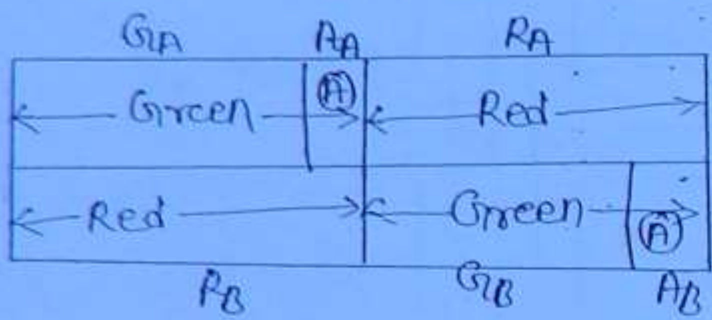


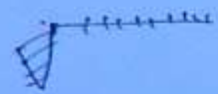


for a Two phase Signal System:-

① Total Red time on one Road = Green time + Amber time on another road

144



XS_1 = 

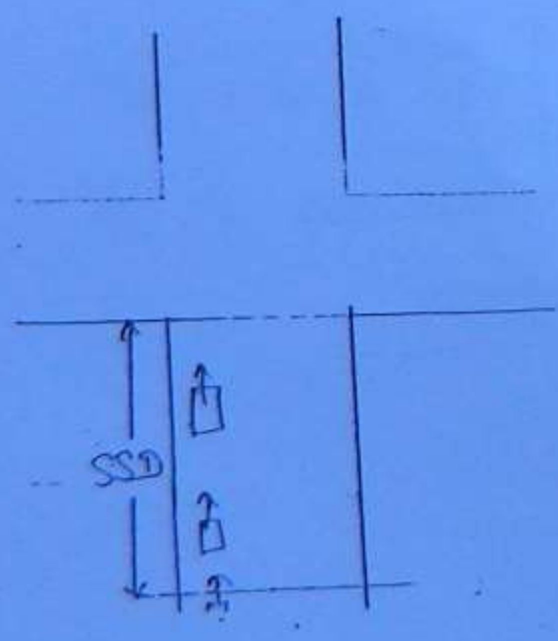
$R_A = G_B + A_B$ — ①

$R_B = G_A + A_A$ — ②

② Green time:-> when vehicle are allowed to go. the Green time is calulated based on traffic Volume on two roads.

③ Amber time:-> Amber time or yellow time is provided to serve following purpase

(i) All the vehicles that has entered into danger zone (within SSD distance from intersection) should be allowed to cross the intersection



Total distance required to travelled for crossing vehicles = (SSD + w + l)

Min Time required = $\frac{\text{Distance}}{\text{Velocity}}$

$$t_1 = \frac{(SSD + w + l)}{v}$$

= min amber time for crossing vehicle

(ii) To allowed sufficient time to stop the vehicle approaching the intersection.

for vehicle beyond SSD line

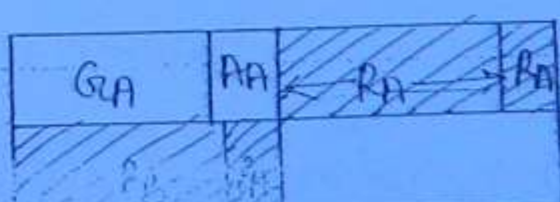
Min time required

t_2 = Reaction time + Braking time

$$t_2 = t_R + \left(\frac{v}{a}\right)$$

∵ a = retardation

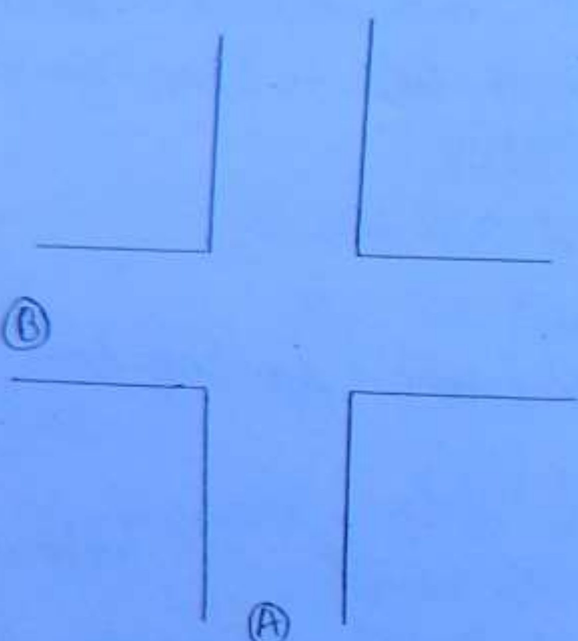
(iii) Red amber time is also provided sometime at the end of 'red time'. But it is part of red time only



(17) Design of Signal timings :→

1. Trial cycle method.
2. Approximate method.
3. webster's method. (146)
4. IRC Method.

(1) Trial Cycle Method :→ (Two phase Signal System :-)



If 15 minute traffic count is n_A & n_B on two roads

Step→

(1) Assume a cycle time = T sec

(2) Number of vehicle accumulated on two roads in one cycle time

$$\Rightarrow x_A = \frac{n_A}{15 \times 60} \times T$$

$$\boxed{x_A = \frac{n_A}{900} \times T}$$

$$\boxed{x_B = \frac{n_B}{900} \times T}$$

15 min n_A vehicle so in T sec how much time require

(3) Min. Green time required (If time headway = t_h Second)

$$G_A = x_A t_h$$

$$G_B = x_B \cdot t_h$$

(4) Total cycle time :- $T_1 = (G_A + A_A) + (G_B + A_B)$

Note :-> T & T_1 should be equal.

Problem :-> If 15 minute traffic count on two roads are 180 & 150 vehicle per lane. If time head way is 3 sec during green phase & Amber time on two roads are 4.0 sec. design signal timings by trail cycle method.

Solution :-

n_A in 15 min = 180 Veh/lane

n_B in 15 min = 150 Veh/lane

Let us assume cycle time = 60 sec

In one cycle time
No. of vehicles accumulated

$$\Rightarrow x_A = \frac{n_A}{15 \times 60} \times T$$

$$x_A = \frac{180}{15 \times 60} \times 60 = 12$$

$$\Rightarrow x_B = \frac{150}{15 \times 60} \times 60 = 10$$

Green time required

$G_A = 12 \times 3 = 36$ sec.

$G_B = 10 \times 3 = 30$ sec

Total cycle time = $(G_A + A_A) + (G_B + A_B)$

$= (36+4) + (30+4)$

$= 74$ sec

24/04/2011

WWW.... (2) Approximate Method :- This method is based on pedestrian time to cross the road & traffic volume

148

(1) Time required for pedestrian to cross the road

$$= \frac{W_A}{\text{speed}} = \frac{W_A}{1.2\,m/sec} = \text{clearance Interval}$$

(2) Minimum Green time for Pedestrial Signal

for Road A $= 7\,\text{Sec} + \frac{W_A}{1.2}$

Initial walk period — clearance Interval

$G_{PA} = 7\,\text{sec} + \frac{W_A}{1.2} = R_A$

$G_{PB} = 7\,\text{sec} + \frac{W_B}{1.2} = R_B$

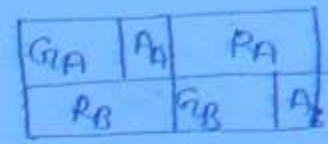
(3) Min. Red time required for traffic Signal

$R_A = G_{PA}$

$R_B = G_{PB}$

④ Min Green time for traffic Signal:→

$$G_A = R_B - A_A$$



$$G_B = R_A - A_B$$

⑤ Considerd any one Green time & another is calculated bas on traffic Volume

$$\frac{G_A}{G_B} = \frac{n_A}{n_B}$$

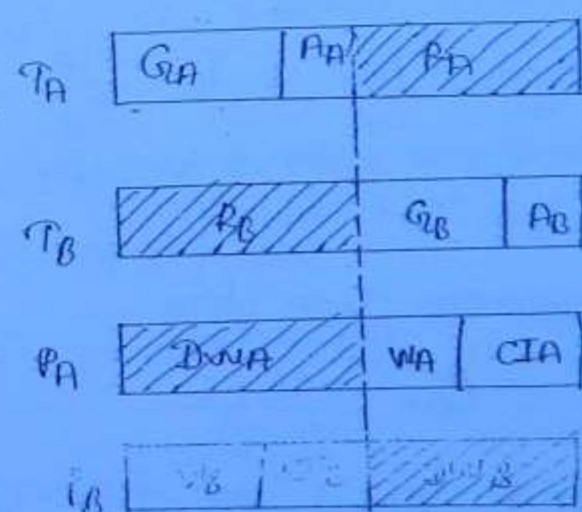
If G_A is considerd

$$\boxed{G_B = \frac{n_B}{n_A} \times G_A}$$

⑥ Total cycle time:→

$$T = (G_A + A_A) + (G_B + A_B)$$

T sec



⑦ Red time:→

$$R_A = G_B + G_B$$

$$R_B = G_A + A_A$$

⑧ Donot walk period:·

$$DW_A = G_A + A_A$$

$$DW_B = G_B + A_B$$

(9) Clearance Interval:→

$$CI_A = \frac{W_A}{1.2}$$

150

$$CI_B = \frac{W_B}{1.2}$$

(10) Walk period:→

$$W_A = R_A - CI_A$$

$$W_B = R_B - CI_B$$

(5) Webster's method:→ This method is based on normal flow (Traffic volume) & Saturation flow on two road.

	Normal	Saturation
A→	n_A	S_A
B→	n_B	S_B

(1) $y_A = \frac{n_A}{S_A}$, $y_B = \frac{n_B}{S_B}$

(2) $y = y_A + y_B = Y$

(3) Optimum cycle time

$$C_0 = \frac{1.5L + 5}{(1-Y)}$$

∀ L = Total lost time per cycle.

$= (2n + R)$

n = No. of phase.

R = All Red time (Generally 1 \ 16 Sec)

(4) Green time required :→

$$G_A = \frac{Y_A}{Y}(C_0 - L)$$

(157)

$$G_B = \frac{Y_B}{Y}(C_0 - L)$$

(4) IRC Method :→ It is a combination of Approximate method, webster method & another check suggested by IRC.

Design speed step :→

(1) Use approximate method :-

$$T = (G_A + A_A) + (G_B + A_B)$$

(2) IRC check

Calculate No. of vehicles accumulated on two road in one cycle time :-

$$\text{Road } A = \frac{n_A}{\underbrace{60 \times 60}_{\text{sec}}} \times T = x_A \text{ (No of traffic / vehicles)}$$

Min Green time required to clear x_A traffic

$$= \underset{\text{for first vehicle}}{6 \text{ sec}} + (x_A - 1) \times \underset{\text{for remaining}}{2 \text{ sec}}$$

Rdn -

$$x_B = \frac{n_B}{60 \times 60} \times T \text{ sec}$$

$$G_B = 6 + (x_B - 1) \times 2 \text{ sec}$$

G_A & G_B calculated by approximate method should not be less then above values.

(3) check by webster method :→

Saturation flow value

Approach road width	Saturation flow
3.0 m	1850
3.5 m	1890
4.0 m	1952
4.5 m	2250
5.0 m	2550
5.5 m	2990
> 5.5 m	525 veh/hour per meter width of road.

152

Problem :→ A right angle intersection for two roads A & B

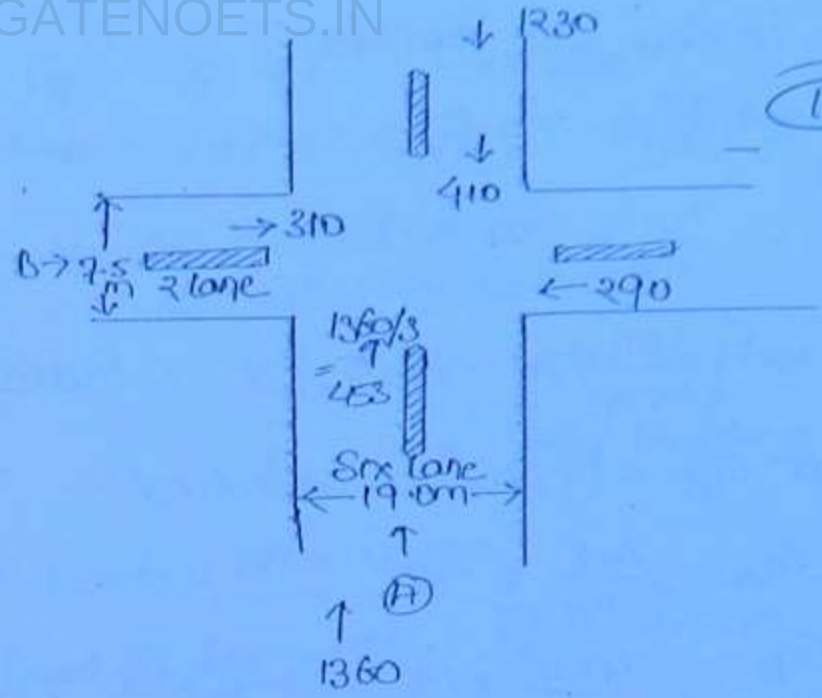
	Road A	Road B
no. of lan	six	two
width	19.0 m	7.5 m
Volume of traffic in one direct.	1360 veh/hr	310 veh/hr
In other direction	1230 veh/hr	290 veh/hr
Amber time	4 sec	4 sec

Design signal timing for a two phase traffic signal using IRC method.

Solution :→ Design volume per lane

For Road A = $n_A = \frac{1360}{3} = 454$

→ for 3 lane road



For road $B = 310 = N_B$

(1) Approximate method:-

(a) Min Green time for pedestrial:-

$\Rightarrow G_{P_A} = 7\text{ sec} + \frac{W_A}{1.2}$

$G_{P_A} = 7 + \frac{19}{1.2} = 22.83 \simeq 23$ sec.

$\Rightarrow G_{P_B} = 7\text{ sec} + \frac{W_B}{1.2}$

$G_{P_B} = 7 + 7.5/1.2 = 13.25\text{ sec} \simeq 14$ sec.

(b) min Red time on traffic signal

$R_A = G_{P_A} = 23$ sec

$R_B = G_{P_B} = 14$ sec.

(c) Min Green time on traffic signal

$G_A = R_B - A_A$

$= 14 - 4 = 10$ sec

$G_B = R_A - A_B = 23 - 4 = 19$ sec

(3) If $G_A = 10$ sec is considerd

$$\Rightarrow \frac{G_A}{G_B} = \frac{n_A}{n_B} \quad (154)$$

$$G_B = \frac{n_B}{n_A} \times G_A$$

$$G_B = \frac{310}{454} \times 10 = 6.8 \text{ sec.} < G_B \ (\times)$$

than If $G_B = 19$ sec is considerd.

$$G_A = \frac{n_A}{n_B} \times G_B$$

$$G_A = \frac{454}{310} \times 19 = 27.8222 \quad 28 \text{ sec.}$$

Total cycle time

$$T = (G_A + A_A) + (G_B + A_B)$$

$$T = (28+4) + (19+4)$$

$$T = 55 \text{ sec}$$

(2) check for IRC method.

check for Green time required to clear traffic

→ Total No. of vehicle accumulated in one cycle time

→ on Road (A) = $x_A = \frac{n_A}{60 \times 60} \times T$

$$x_A = \frac{454}{60 \times 60} \times 55 = 6.94 \approx 7 \text{ nos}$$

$$G_A = 6 \text{ sec} + (7-1) \times 2$$

$$G_A = 18 \text{ sec} < 28 \text{ sec calulated}$$

on road B = $x_B = \frac{n_B}{60 \times 60} \times 55$ (with $n_B = 310$)

$$x_B = 4.76 \approx 5 \text{ Nos}$$

$G_A = 6 + (5-1) \times 2$ sec

$G_A = 14$ sec. < 19 sec. provided ok.

③ Webster method:→

Normal flow values.

$n_A = 454$ veh/hr/lane

$n_B = 310$ veh/hr/lane.

Saturation flow value

Road Ⓐ for width $= \frac{19}{2} = 9.5$ m

$S_A = 9.5 \times 525 = 4987.5$ veh/hr/3 lane

$S_A = \frac{4988}{3}$ veh/hr/lane

$S_A = 1663$ veh/hr/lane

Road Ⓑ For width $= \frac{7.5}{2} = 3.75$ m

$S_B = \frac{1890 + 1950}{2} = 1920$ veh/hr/lane.

$y_A = \frac{n_A}{S_A} = \frac{454}{1663} = 0.27$

$y_B = \frac{n_B}{S_B} = \frac{310}{1920} = 0.16$

$y = y_B + y_A = 0.27 + 0.16$

$y = 0.43$

Total lost time $L = 2n + R = 2 \times 2 + 16 = 20$ sec.

Optimum cycle time $C_o = \frac{1.5L + 5}{(1-y)}$

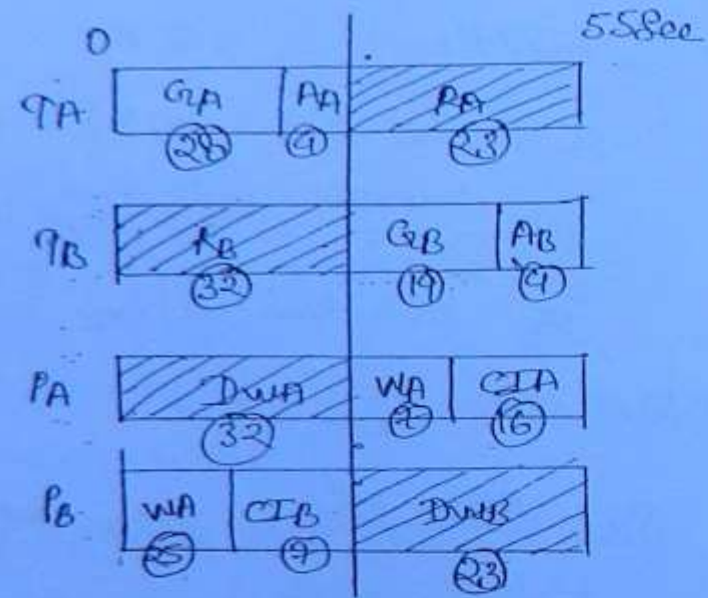
$$C_0 = \frac{1.5\times 20+5}{1-0.43} = 61.4 \text{ sec}$$

$$G_A = \frac{y_A}{y}(C_0 - L) = \frac{0.27}{0.43}(61.4 - 20)$$

$G_A = 26$ sec $<$ 28 sec (Provided O/K)

$$G_B = \frac{y_B}{y}(C_0 - L) = \frac{0.16}{0.43}(61.4 - 20)$$

$G_B = 15.4$ sec $<$ 19 sec (provided So ok)



(1) Red time

$R_A = G_B + A_B = 19+4 = 23$ sec

$R_B = A_A + G_A = 28+4 = 32$ sec

(2) Donot walk periods

$DW_A = G_A + A_A = R_B = 32$ sec

$DW_B = G_B + A_B = R_A = 23$ sec

(4) Clearance Interval

$CI_A = \frac{W_A}{1.2} = \frac{19}{1.2} = 15.83 \approx 16$ sec

$CI_B = \frac{W_B}{1.2} = \frac{7.5}{1.2} = 6.25 \approx 7$ sec

(4) Walk periods:→

$W_A = R_A - CI_A$

$= 23 - 16 = 7 sec$

$W_B = R_B - CI_B$

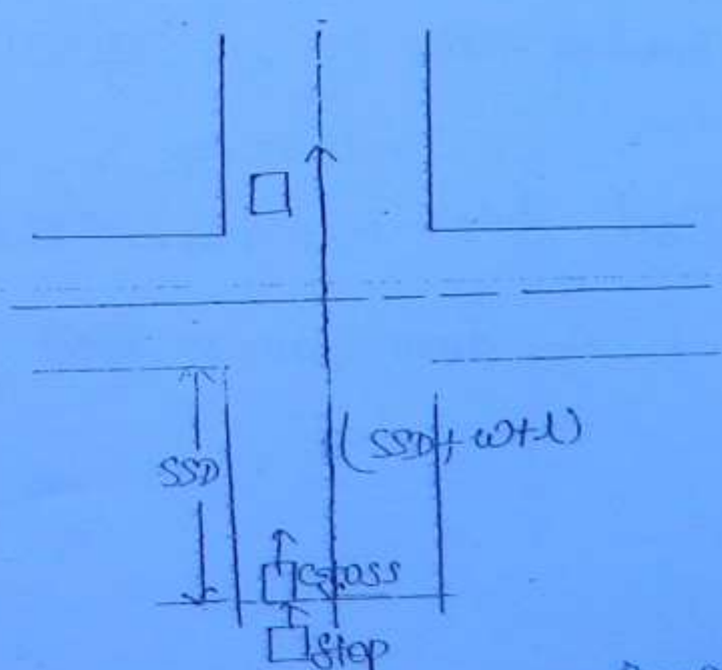
$= 32 - 7 = 25 sec.$

56) ES 1995

Problem:→ A driver traveling at the speed of 50 kmph. was cited for crossing an intersection. He claimed that the duration of amber display was improper & consequently a dilema zone existed at that location. Using the following data, determinate wheter drivers clam was correct

Amber time = 4.5 sec.
reaction time = 1.5 sec.
retardation = 3 m/sec²
car length = 4.6 m
Intersection width = 15 m

Solution:→



Amber time is required for two purpose

(1) To Allow the vehicle just head of danger area to cross the intersection

$$\Rightarrow SSD = 0.278\,V \cdot t_R + \frac{(0.278\,V)^2}{2g(F \pm S\%)}$$

$$SSD = 0.278 \times 50 \times 1.5 + \frac{(0.278 \times 50)^2}{2 \times 9.81\,(0.35)}$$

158

$$= 48.98\ m$$
$$\simeq 49\ m$$

Total distance to be traveled to cross = SSD + W + l

$$= 49 + 15 + 4.5 = 68.6\ m$$

Time required to traveled $= \frac{68.6}{0.278 \times 50} = 4.93\ sec > 4.5\ sec.$

yes dilema zone exist for crossing vehicle.

(2) For stopping vehicle

Total time required to stop = Reaction time + Braking time

Braking time $= \frac{v}{a} = \frac{0.278 \times 50}{3}$

$$= 4.63\ sec.$$

Total time $= 1.5 + 4.63 = 6.13\ sec > 4.5\ sec$

So yes driver claim is correct.

ES-1993 ? 70

Problem:- The speed density relationship for a particular road was found to be $U = 42.76 - 0.22K$

If U is speed in km/hr.

K is density in Veh/km.

(159)

Find the capacity of road. Give your comment on the result. Sketch relationship b/w density & flow & shown important traffic flow parameter.

Solution:→ Speed $U = 42.76 - 0.22K$

Capacity of the road = Traffic volume

C = Speed × density

km/hr × veh/km = Veh/hr

$C = U.K$

$C = (42.76 - 0.22K)K$

$$\boxed{C = 42.76K - 0.22K^2} \quad —(1)$$

If $C=0$, $K=0$

$42.76K - 0.22K^2 = 0$

$\therefore K = \frac{42.76}{0.22} = 194.36$

for max C

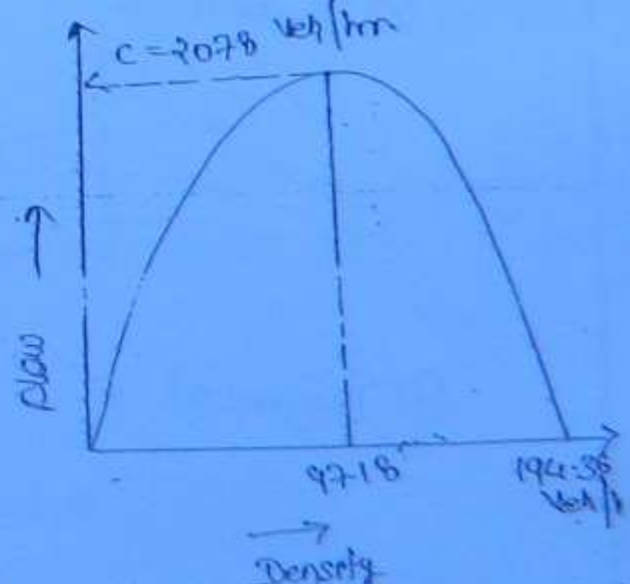
$\frac{dc}{dk} = 42.76 - 0.44K = 0$

$K = \frac{42.76}{0.44} = 97.18$

max c

$C = 42.76 \times 97.18 - 0.22 \times 97.18^2$

$C = 2078$



Comment:

(1) Relation b/w C & K is Parabolic.

(2) Value of C is zero to K=0 & K= 194.36 Veh/hr.

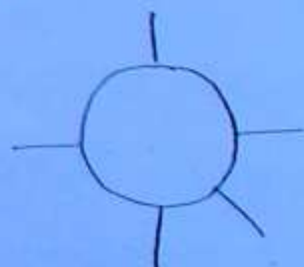
(3) Value of capacity increase with increase in density upto 97.18 Veh/hr, where C is max = 2078 Veh/hr after which capacity reduces.

160

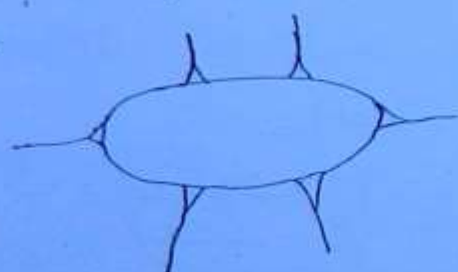
(11) Design of Rotary Intersection:→

(1) Shapes:→

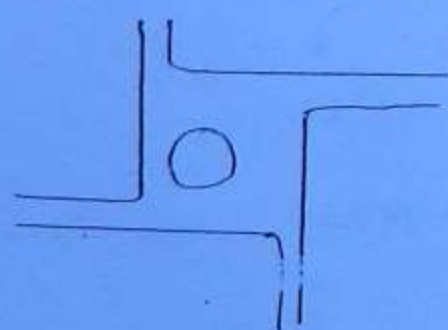
(a) Circular:→



(b) Elliptical:→



(c) Turbine:→



(d) Tangential:→

② Design Speed Values:→

Rural area = 40 kmph

Urban area = 30 kmph

161

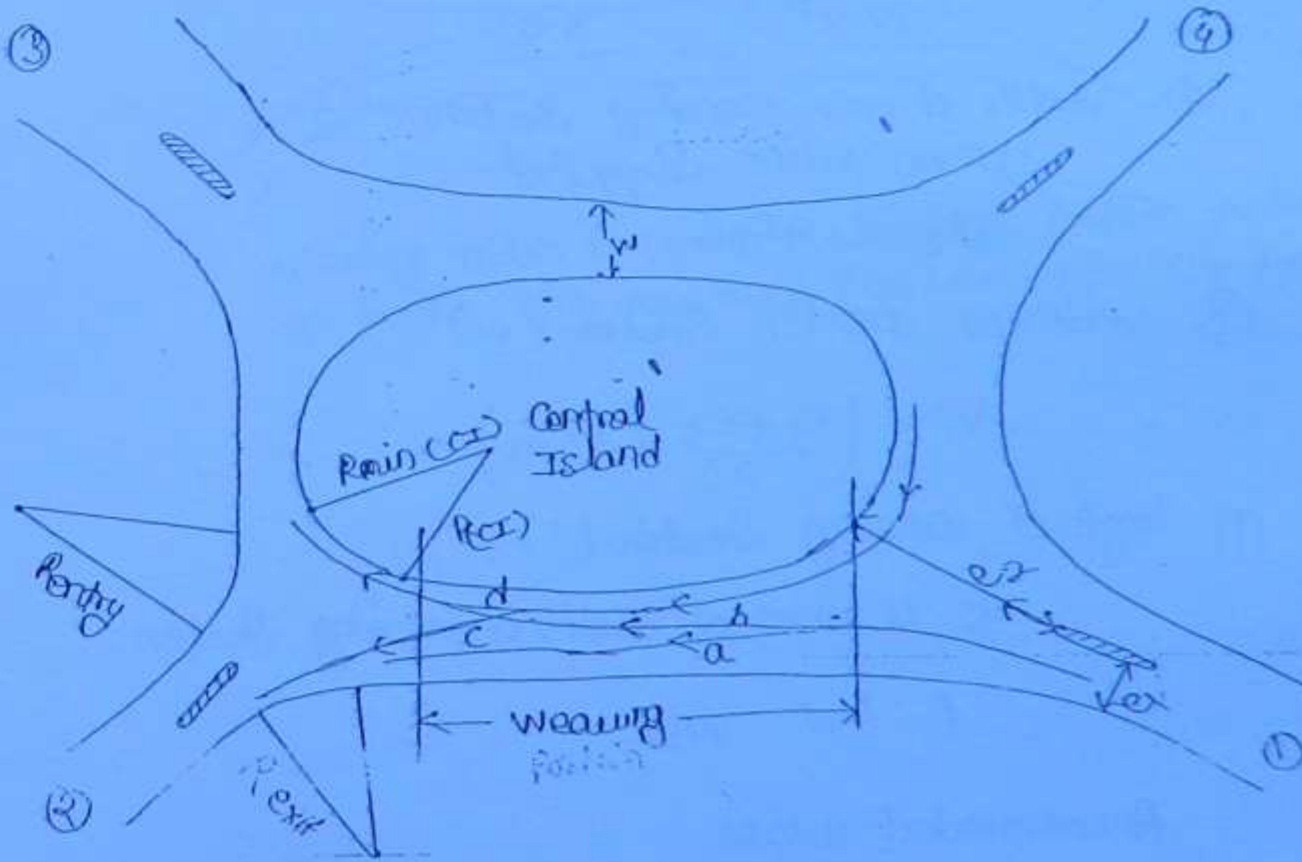
③ Radius of rotary:→

No S.E. is provided = e = 0

$$R_{min} = \frac{V^2}{127(e+f)} = \frac{V^2}{127f}$$

Value of F = 0.43 → 40 kmph

0.47 → 30 kmph



e_2 = width at non-weaving section

e_1 = width of entry

(4) Radius of entry curve:→

R_{entry} = 20 to 35m → For 40 kmph

= 15 to 25m → For 30 kmph

(5) Min radius of central Island :-

= 1.33 R_{entry}

(6) width of entry = e_1

minimum = 5m

162

As per Road width	e_1
7.0 m	6.5m
10.5m	7.0m
14.0m	8.0m

(7) width of non-weaving Section = e_2

IF no value suggested

take $e_2 = e_1$

(8) width of weaving Section (w)

$$W = \left(\frac{e_1+e_2}{2} + 3.5m\right)$$

(9) length of weaving Section (L) :-

≮ 4 times of width of weaving Section

$l = 4W$ min.

Recommended Values

40 kmph → 45 to 90 m

30 kmph → 30 to 60 m

(10) Capacity of Rotary :→

$$- C = \frac{280 w\left(1+\frac{e}{w}\right)\left(1-\frac{P}{3}\right)}{\left(1+ w/L\right)}$$

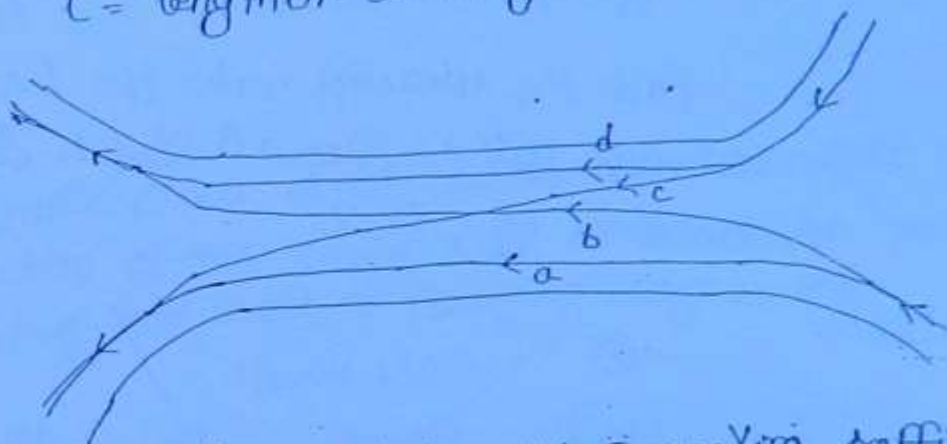
∀ w = width of weaving section

$e = \frac{e_1+e_2}{2}$

163

P = weaving ratio $= \frac{b+c}{(a+b+c+d)} =$

L = length of weaving section.



weaving ratio is ratio of weaving traffic to total of traffic b/w two road. (value b/w 4.5 to 1.0)

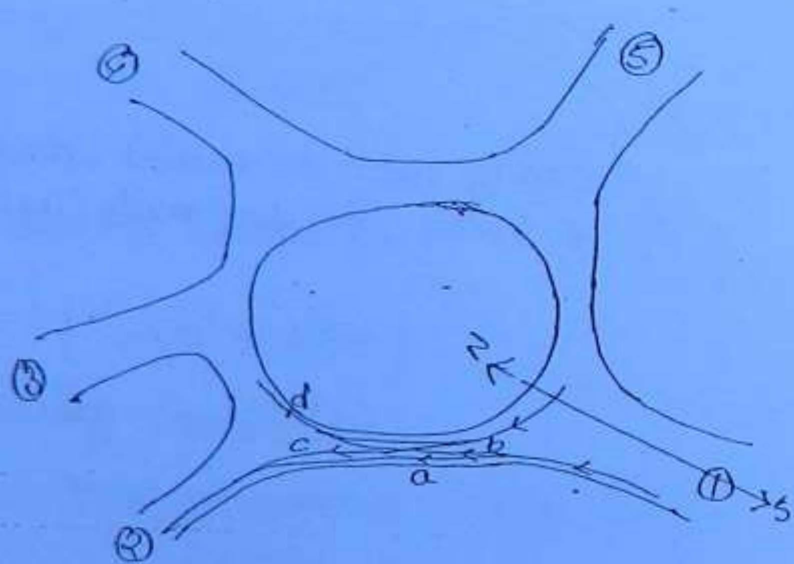
Q(8)
ES-2006 →

Problem:→ A road intersection has five legs designed as 1,2,3,4 & 5. leg 1 is in N-S direction & others are marked clockwise.

$V_{12} \to 37$	$V_{31} \to 466$	$V_{41} \to 182$	$V_{51} \to 45$
$V_{13} \to 303$	$V_{32} \to 122$	$V_{42} \to 54$	$V_{52} \to 132$
$V_{14} \to 64$	$V_{34} \to 47$	$V_{43} \to 18$	$V_{53} \to 62$
$V_{15} \to 52$	$V_{35} \to 657$	$V_{45} \to 116$	$V_{54} \to 15$

Find the weaving ratio b/w leg 1 & 2. What the use of this value. Draw a sketch showing the traffic volume b/w 1 & 2.

Solution:→



for weaving ratio b/w 1 & 2

$a = V_{12} = 37$

$b = V_{13} + V_{14} + V_{15}$

$b = 303 + 64 + 52 = 419$

$c = V_{32} + V_{42} + V_{52}$

$c = 122 + 54 + 132 = 308$

$d = V_{43} + V_{53} + V_{54}$

$d = 18 + 62 + 15$

$d = 95$

Weaving ratio $P = \frac{b+c}{a+b+c+d} = \frac{\cancel{37}\ 419 + 308}{37+419+308+95}$

$P = 0.846$

① Weaving ratio is ratio of weaving traffic to total traffic

② It is used to calculated capacity of rotary.

7(d) ES-2007

Problem:→ Traffic flow in an urban area at right angle intersection of two major road, in the design year are given below. Total width of carrying way is 15m.

Traffic flow

Approach Road	left turning	Straight	Right turning
North	415	650	300
East	300	550	250
South	350	400	225
West	400	500	300

Design a rotary intersection and check for practical capacity making suitable assumption as per IRC

Solution:→ weaving ration:-

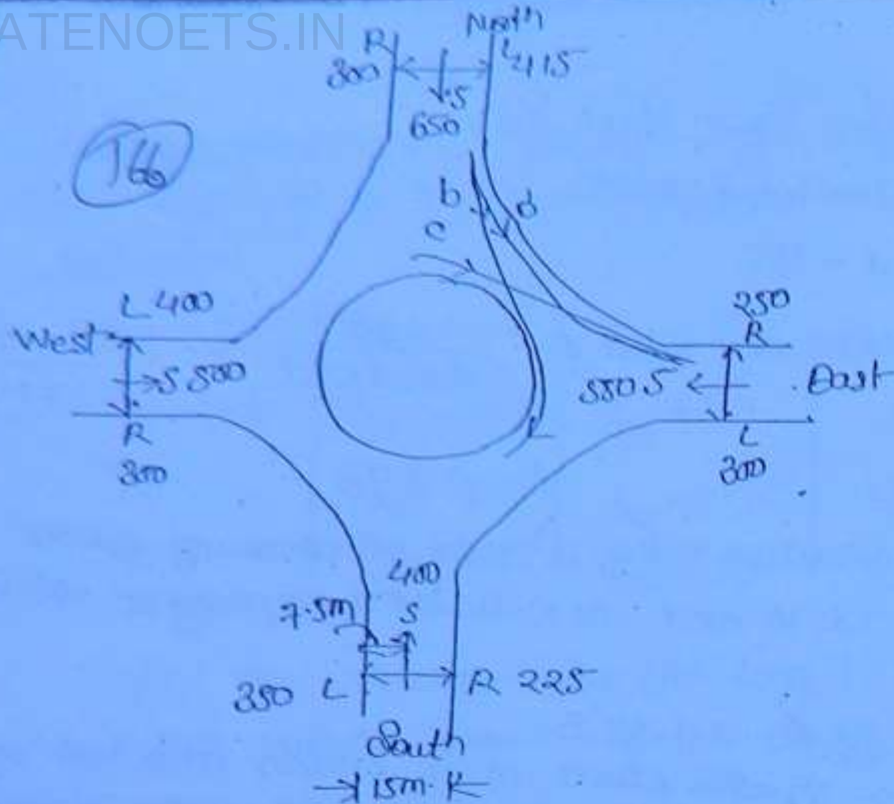
① Between North to East (NE)

$a = 45$

$b = 650 + 300 = 950$ $\quad d = 300$

$c = 500 + 225 = 725$

166



$$P = \frac{b+c}{a+b+c+d} = \frac{950+725}{415+950+725+300}$$

$$P = 0.70$$

(2) Between E-S

~~a = 300~~

$b = 550+250 = 800$

$c = 650+300 = 950$

$d = 300$

$$P = \frac{800+950}{800+300+950+300} = 0.745$$

(3) Between S-W

$a = 350$

$b = 400+225 = 625$

$c = 550+300 = 850$

$d = 250$

$$P = \frac{b+c}{a+b+c+d} = \frac{625+850}{350+625+850+250} = 0.71$$

(i) Between W-N

$a = 400$

$b = 500 + 300 = 800$

$c = 400 + 250 = 650$

$d = 225$

167

$$P = \frac{800 + 650}{400 + 800 + 650 + 225} = 0.698 \simeq 0.70$$

we use

$P = 0.745$

capacity $$C = \frac{280\,w\,(1 + e/w)\,(1 - P/3)}{(1 + w/L)}$$

$e_1 = 6.5m$ (for 7.5m)

$e_2 = e_1$

$$e = \frac{e_1 + e_2}{2} = 6.5m$$

$$w = \frac{e_1 + e_2}{2} + 3.5 = 6.5 + 3.5$$

$w = 10m$

$L = 4 \times w = 40m$

$$C = \frac{280 \times 10\,(1 + 6.5/10)\,(1 - \frac{0.745}{3})}{(1 + 10/40)}$$

$C =$

$$\boxed{C = 2778 \text{ veh/hr}}$$ ans

 Pavement Design

Types:->

168

① Flexible Pavement:-> constructed by using stone aggregate with bounder materials like earth, bituminous etc.

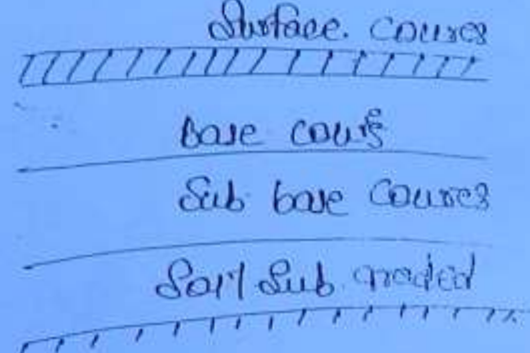
-> It consists of four layers.

① Surface course.

② Base course.

③ Sub base course.

④ Soil subgraded.



-> flexible pavement have very low flexibility strength.

-> load transfer is by grain to grain transfer.

-> slab may be deflected to the slope of bottom layers.

② Rigid Pavement:->

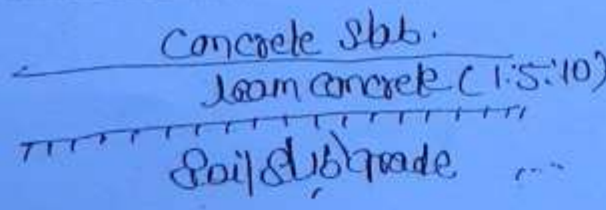
-> Constructed by using pcc, Rcc, (cement concrete) or prestreted concrete slab.

-> only three layers.

① pavement slab.

② lean concrete.

③ Soil sub grade



-> Flexural strength is high.

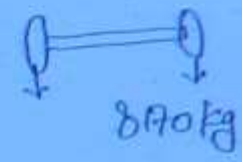
-> load transfer is by slab action

-> It can bridge over minor undulations.

(3) Semi rigid pavement:→ Semi rigid pavement constructed by using soil cement soil lime mixture
Pozzolanic cement etc.
It has comparatively high strength. 169

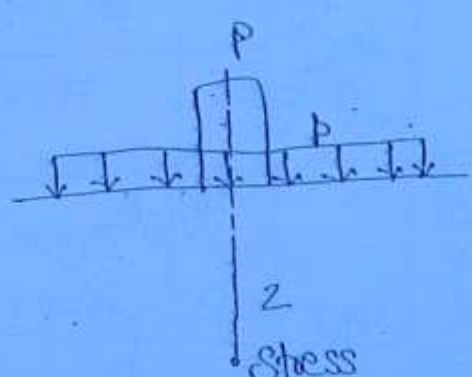
(4) Design of flexible pavement:→

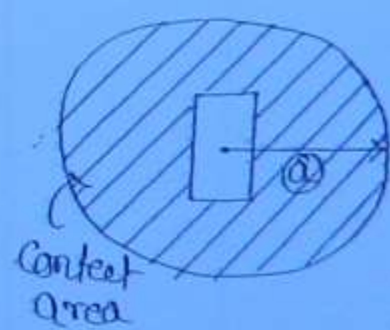
Some important design parameters.



(1) Max. wheel load
As per IRC
Max. legal axial axle load = 8170 kg
→ Max. Equivalent single wheel load (ESWL) = 4085 kg

(2) Stress due to a wheel load below ground level:→



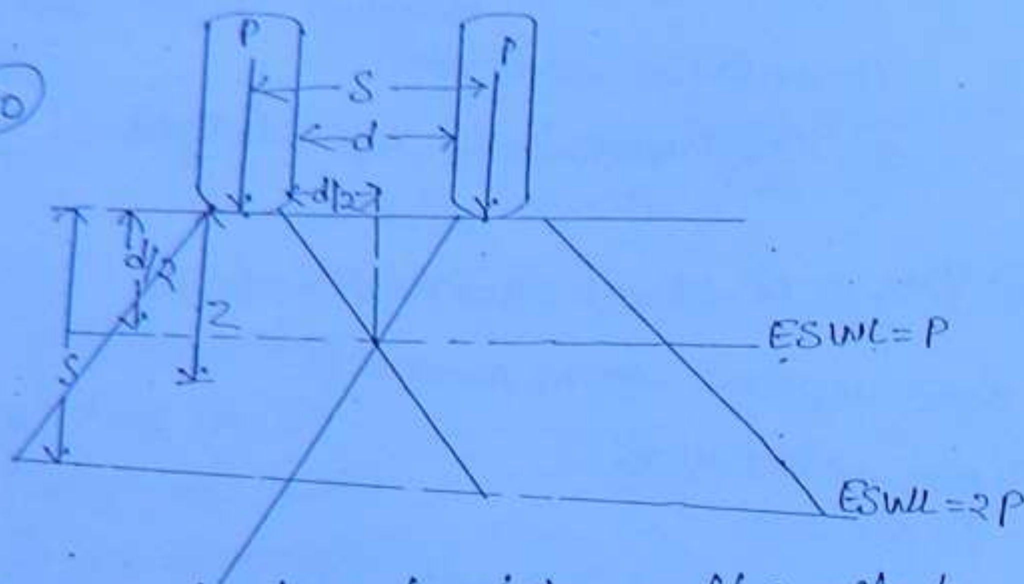


at z depth below ground, due to load P.

$$\sigma_z = p\left[1 - \frac{z^3}{(a^2+z^2)^{3/2}}\right]$$ → Boussinesque's eq.
p= surface pressure

(3) ESWL :- For a dual wheel assembly :-

170

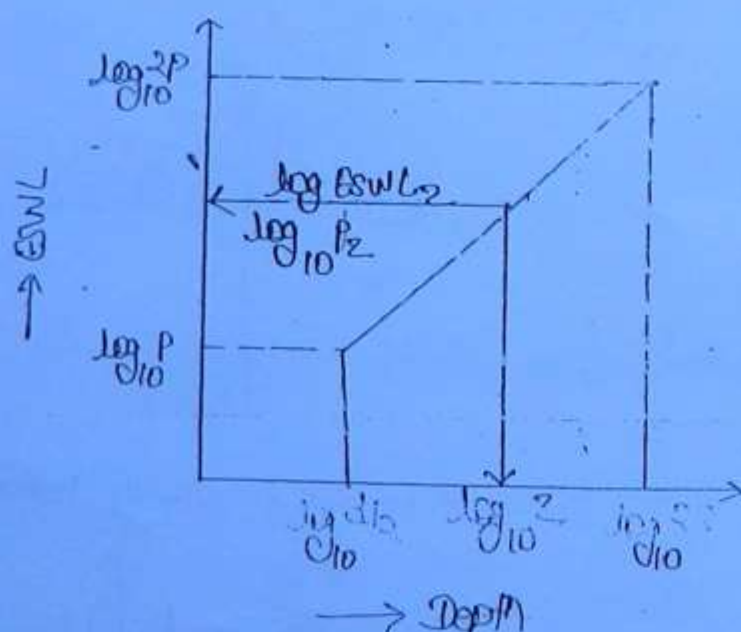


IF S = centre to centre distance b/w wheels.

d = clear distance b/w wheels

At = $\frac{d}{2}$ depth = ESWL = P

at 2s depth = ESWL = 2P



Problem:→ Calculate ESWL of a dual wheel assembly, carrying 2050 kg each wheel, for pavement thickness 15, 20 & 25 cm. If c/c spacing b/w tyres is ~~60~~ 30 cm & clear distance b/w tyres is 12 cm.

(171)

Solution:→ $S = \cancel{60}\ 30$ cm

$d = 12$ cm

$d/2 = 6$ cm

$P = 2050$ kg

$ESWL = P = 2050$ kg

at 25 depth $= 2 \times \cancel{60}\ 30 = \cancel{120}\ 60$ |

$ESWL = 2P = 4100$ kg

Depth	log(depth)	ESWL	log(ESWL)	
6 cm	0.778	2050	3.312	
15 cm	1.176	2703 kg	3.432	
20 cm	1.301	2947		
25 cm	1.398	3152		
60 cm	1.778	4100	3.613	

$$\Rightarrow 3.312 + \frac{(3.613 - 3.312)}{(1.778 - 0.778)} \times (1.1\ldots - 0.778)$$

Plotting from = 2703 kg

$$\Rightarrow 3.312 + (3.613 - 3.312) \times (1.301 - 0.778)$$

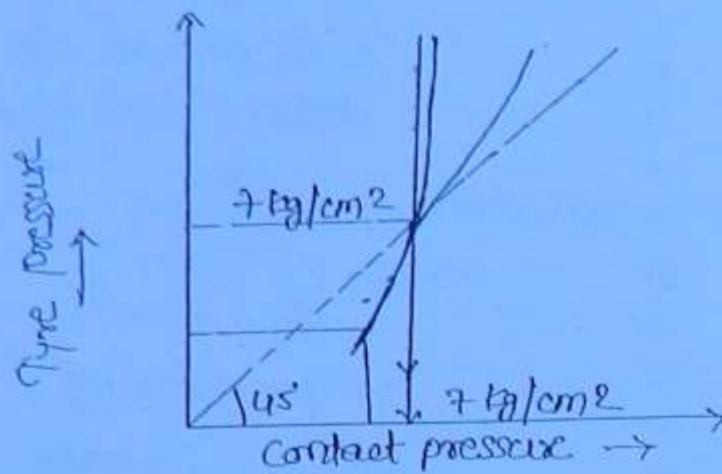
$$\Rightarrow 3.312 + (3.613 - 3.312) \times (1.398 - 0.778)$$

④ Rigidity factor :→ $\dfrac{\text{Contact pressure}}{\text{Tyre Pressure}}$

(172)

→ Tyre pressure is effective for top layers (Surface layer only)

→ Contact pressure effect bottom layers.



	Case ①	Case②	Case③
Tyre Pressure	7	< 7 kg/cm²	> 7 kg/cm²
Contact Pressure	7	> Tyre pressure	< Tyre pressure
R.F	1.0	> 1.0	< 1.0

Design method :→

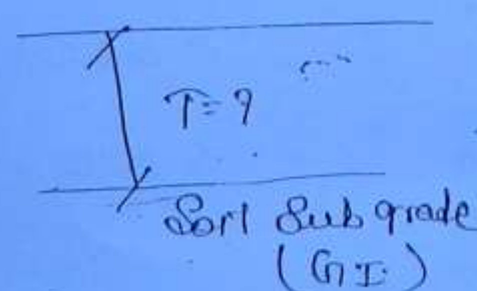
① Group Index Method :→

→ This method depends upon G.I value of Soil over which pavement is to be laid.

→ Total thickness of pavement is found using G.I value.

→ Group Index value

$$G.I. = 0.2a + 0.005ac + 0.01bd$$



* $a = P - 35 \ngtr 40$

$b = P - 15 \ngtr < 10$

$c = \text{W.L} - 40 \ngtr 20$

$d = \text{I.P} - 10 \ngtr 20$

P = percent fines passing from 0.074 mm sieve.

W_L = liquid limit

I_P = plasticity Index

→ G.I values are found b/w 0 to 20.

→ Higher G.I value show — poor soil

→ thickness of pavement are found based on above G.I value

(Table & charts are used

G.I values	Base course	Sub base course
0-4	15	10
5-9	20.5	20
10-20	30 cm	30 cm

limitation :→

→ Quality of pavement is not considerd. Same thickness required even better quality materials are used.

Problem → A soil subgrade has following data.

① Soil passing = 0.074 mm sieve

$p = 60\%$

② Liquid limit = 45%. 174

③ plastic limit = 20%.

Find out thickness of pavement required above this soil subgrade, using following data.

G.I value	Total thickness of pavement req
0	30 cm
5	45 cm
10	62 cm
15	78 cm
20	90 cm

Solution:- $p = 60\%$

$w_L = 45\%$

$w_p = 20\%$

Plasticity Index: $I_p = w_L - w_p = 45-20$

$I_p = 25\%$

$a = p - 35 = 60 - 35 = 25 < 40$ ok

$b = p - 15 = 60 - 15 = 45 > 40$ so take 40

$c = w_L - 40 = 45 - 40 = 5 < 20$ ok

$d = I_p - 10 = 25 - 10 = 15 < 20$ so ok

Group Index:-

$G.I. = 0.2a + 0.005ac + 0.01bd$

$= (0.2 \times 25) + (0.005 \times 25 \times 5) + (0.01 \times 40 \times 15)$

$= 11.625$

175

Total thickness required

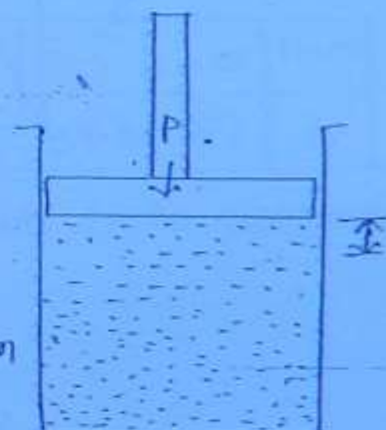
$= 62 + \frac{(78-62)}{(15-10)} \times (11.625 - 10)$

$= 67.2\,cm$ Ans

② CBR Method:→ (California bearing Ratio method):→

→ CBR value (CBR Test)

① A Soil Sample is kept in a vessel & load is applied over Soil. Load values & corresponding penetration both are measured.



② Load values for 2.5 mm & 5.00 mm penetration are found (Say P_1 & P_2)

③ these load are compared with standard load values of 2.5 mm & 5.00 mm penetration over standard aggregate

Standard load values

For 2.5 mm → 1370 kg

For 5.0 mm → 2055 kg

④ CBR value

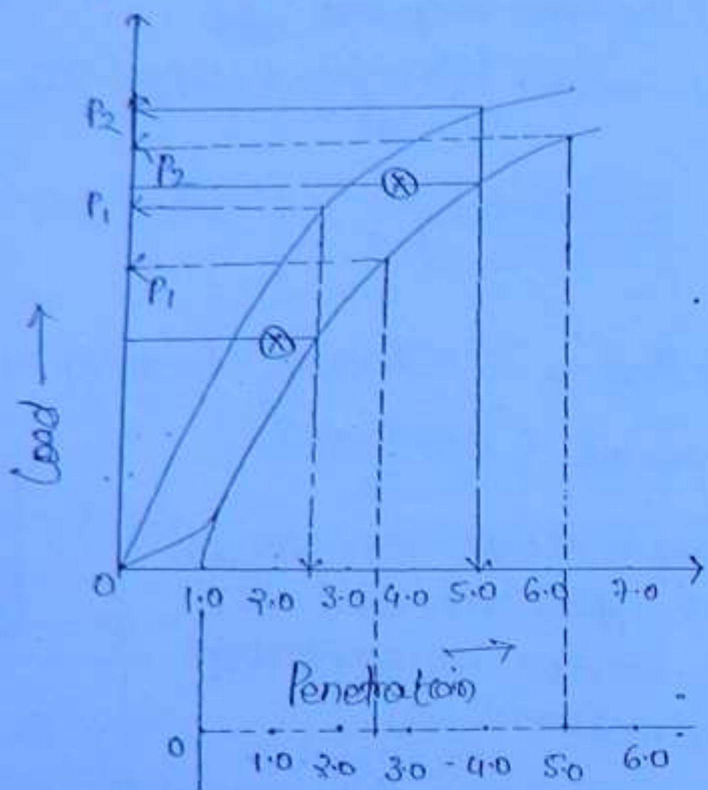
For 2.5 mm → $\frac{P_1}{1370} \times 100 = CBR_{2.5}$

For 5.0 mm → $\frac{P_2}{2055} \times 100 = CBR_{5.0}$

(5) Generally 2.5 mm - CBR value is found more. In this case this value is accepted as CBR value.

(6) If 5.0 mm CBR value is higher
→ Test is repeated, & if same result are found again higher CBR value (5.0 mm) is accepted as CBR value.

(176)



(7) If the curve show an initial concavity. It is due to false set of loose soil sample. In this case origin is get shifted by drawing a tangent from steepest point of curve to x-axis.

(8) Design of pavement:-

Thickness of pavement

$$T = \sqrt{\frac{1.75P}{CBR} - \frac{P}{p \cdot \pi}}$$

P = wheel load (in kg)
p = Tyre pressure = P/A

A = Contact area, πa^2
a = radius of contact area.
CBR = CBR value in %.

Limitation:→
Same as G.I method.
(1) Quality of material of pavement is not considerd.
(2) Thickness can be found for a limited CBR value only.

Problem:→ CBR test was conducted for a soil subgrade & following result was found.

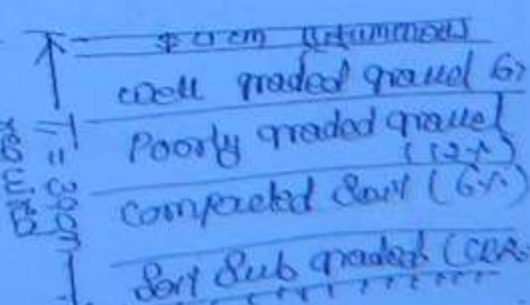
Penetration	0	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	7.5
Load	0	5.0	20	32	43	49.8	59	70	79	93

Following material are required to be used over this soil subgrade.

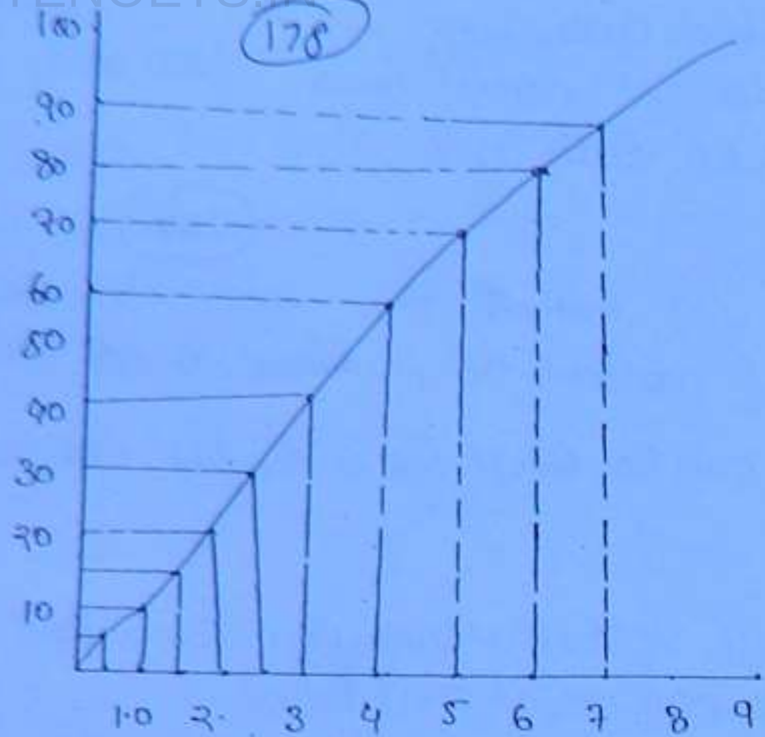
(a) Compacted soil (CBR = 6%)
(b) Poorly graded gravel (CBR = 12%)
(c) well graded gravel (CBR = 60%)
(d) Bituminous surface of 4 cm thick

Design the pavement using CBR method.

If wheel load = 4100 kg
tyre pressure = 7 kg/cm²



Solution:→ P_1 = 60 kg → for 2.5 mm
P_2 = 82 kg → for 5.0 mm



$$CBR(2.5) = \frac{P_1}{1370} \times 100 = \frac{60}{1370} \times 100 = 4.38\%$$

$$CBR(5.0) = \frac{P_2}{2055} \times 100 = \frac{82}{2055} \times 100 = 3.99\%$$

(1) Total thickness of pavement above soil surface (CBR = 4.38%)

$$T_1 = \sqrt{\frac{1.75P}{CBR} - \frac{P}{P\pi}} = \sqrt{\frac{1.75 \times 4100}{4.38} - \frac{4100}{7 \times \pi}}$$

$T_1 = 38.10$ cm ⇒ Say 39 cm

(2) Total thickness required above compacted soil (CBR = 6%)

$$T_2 = \sqrt{\frac{1.75 \times 4100}{6} - \frac{4100}{7 \times \pi}} = 31.77 \text{ cm} \approx 32 \text{ cm}$$

Thickness of compacted soil req.

$T_1 - T_2 = 39 - 32 = 7$ cm

(4) Total thickness required above poorly graded gravel

$$T_3 = \sqrt{\frac{1.75 \times 4100}{12} - \frac{4100}{7 \times \pi}} = 20.28 \text{ cm}$$

Say 21 cm

Thickness of poorly graded gravel

$T_2 - T_3 = 32 - 21 = 11 \text{ cm}$

(5) thickness of well graded gravel $= T_3 - 4\text{cm}$

$= 21 - 4 = 17 \text{ cm}$

Method

(3) California R-value (Resistance value) Method :→

This method is based on

(1) Stabilometer - 'R' value

(2) cohessiometer - 'C' value

Thickness of pavement required

$$T_{(cm)} = \frac{K \cdot TI\,(90-R)}{C^{1/5}}$$

If K = constant

TI = Traffic Index based on (EWL) value

$= 1.35\,(EWL)^{0.11}$

Thickness of pavement required

$$T = \frac{0.166 \times 1.35\,(EWL)^{0.11}\,(90-R)}{C^{1/5}}$$

$$\boxed{T = \frac{0.22\,(EWL)^{0.11}\,(90-R)}{C^{0.20}}}$$

EWL :→ Annual average of Equivalent wheel load based on 'AADT' value for different class of wheel As per No. of axle.

No. of axle	2	3	4	5	6
EWL constant	330	1070	2460	4620	3040

⇒ Thickness of two layers

$$\frac{T_1}{T_2} = \left(\frac{C_2}{C_1}\right)^{1/5} \rightarrow \text{(for equivalent thickness)}$$

Problem :→ calculate 10 year EWL & traffic index value using following data

No. of Axle	2	3	4	5
AADT	3750	470	320	120

Assume 60% increase in traffic in next 10 year then calculate thickness of pavement required in this case if

R-value = 48 — use California R-value

C-value = 16 Method.

Solution :→ EWL of presents

No of axle	AADT Volume	EWL constant	Total EWL Value
2	3750	330	1237500
3	470	1070	502900
4	320	2460	787200
5	120	4620	554400

(181)

$\Rightarrow 3082000$ Total present EWL

EWL of next 10 year $= 1.6 \times 3082000$
$= 4931200$

Average Value $= \dfrac{3082000 + 4931200}{2} = 4006600$

total EWL for 10 year period $= 10 \times 4006600$
$= 40066000$

Traffic index:-

$TI = 1.35(EWL)^{0.11} = 1.35(40066000)^{0.11}$

$TI = 9.26$

Thickness of pavement

$$T = \frac{K \cdot TI\ (90-R)}{C^{1/5}}$$

$$T = \frac{0.166 \times 9.26 \times (90-48)}{(16)^{1/5}}$$

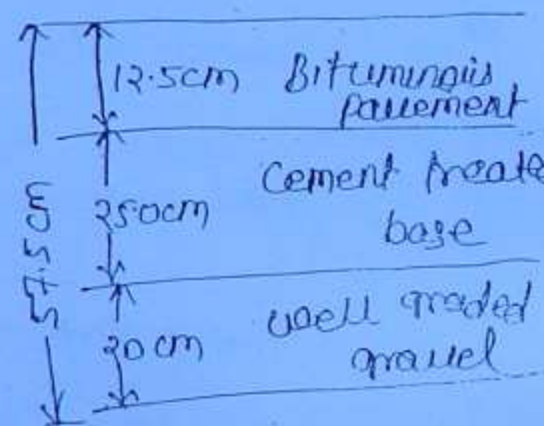
$\boxed{T = 37.08\ cm}$ Ans

Problem:→ Calculate equivalent 'c' value of a three layer pavement section having individual 'c' value as.

Material	Thickness	C-value
① Bituminous pavement	12.5 cm	62
② Cement treated Base	25.0 cm	180
③ well graded gravel	20 cm	25

182

Solution:→



Convert all thickness in terms of well graded gravel

① Bituminous

$T_B = 12.5\,cm \quad T_W = ?$

$C_B = 62 \quad C_W = 25$

$$\Rightarrow \frac{T_B}{T_W} = \left(\frac{C_W}{C_B}\right) \Rightarrow T_B\left(\frac{C_B}{C_W}\right)^{1/5} = T_W$$

$$T_{W_1} = 12.5\left(\frac{62}{25}\right)^{1/5} = 14.98\,cm$$

② Cement treated base

$T_c = 25 \quad T_W = ?$

$C_c = 180 \quad C_W = 25$

$$T_{W_2} = T_c\left(\frac{C_c}{C_W}\right)^{1/5} = 25\left(\frac{180}{25}\right)^{1/5}$$

$$T_{W_2} = 37.10\,cm$$

③ well graded gravel

$$T_{W_3} = 20\,cm$$

Total thickness of pavement in terms of well graded gravel $= T_{w_1} + T_{w_2} + T_{w_3}$

$T_w = 14.98 + 37.10 + 20$ cm

$T_w = 72.08$ cm

$C_w = 25$

$T_p = 57.5$cm

$C_p = ?$

$$\Rightarrow \frac{T_w}{T_p} = \left(\frac{C_p}{C_w}\right)^{1/5}$$

$$\Rightarrow C_p = C_w\left(\frac{T_w}{T_p}\right)^5 = 25\left(\frac{72.08}{57.5}\right)^5$$

$$\Rightarrow C_p = 77.38$$

Problem:→ Design a flexible pavement using WBM Base Cour plus 7.5cm thick, Bituminous Pavement by using california R-value method

C-value of WBM = 15

C-value of Bituminous pavement = 62

Traffic index = 9.5

Data for soil subgraded is

Moisture Content	R-value	Expansion Pressure	Exudation pressure	T_R (kg/cm²)	T_e
15%	56	0.135	36.5	37.20 cm	64.3
19%	44	0.099	26.5	42.20	47.1
21%	25	0.055	18.0	59.60	26.2
24%	14	0.034	15.0	69.7	16.2

Solution

Design procedure

In California R-value method pavement thickness should be as per

① R-value

② Expansion pressure

③ Exudation pressure

184

→ Exudation pressure is value of pressure required to force out water from a soil

Steps:→

① Calculate thickness based on R-value

$$T_R = \frac{K \cdot TI\,(90-R)}{C^{1/5}}$$

② Thickness is calculated as per expansion pressure

$$T_e = \frac{\text{Expansion pressure } (kg/cm^2)}{\text{Soil density } (0.0021\ kg/cm^3)} = cm$$

$2100\ kg/m^3$

③ Plot T_R/T_e on a graph sheet ~~Draw a 45° line cutting~~ point show the value where

$$T_R = T_e = T_1 \text{ cm}$$

④ Find out thickness corresponding to 28 kg/cm^2 exudation pressure. Say T_2 cm

⑤ ~~thickness of pavement~~

T = higher of T_1 & T_2

① Thickness as per R-value (using WBM layers)

$$T_R = \frac{0.166 \times 9.5 \times (90-R)}{(15)^{1/5}}$$

$$T_R = 0.9175(90-R)$$

185

$T_R = 0.9175 \times (90-56)$

$T_{R_1} = 31.20$ cm

$T_{R_2} = 0.9175 \times (90-44)$

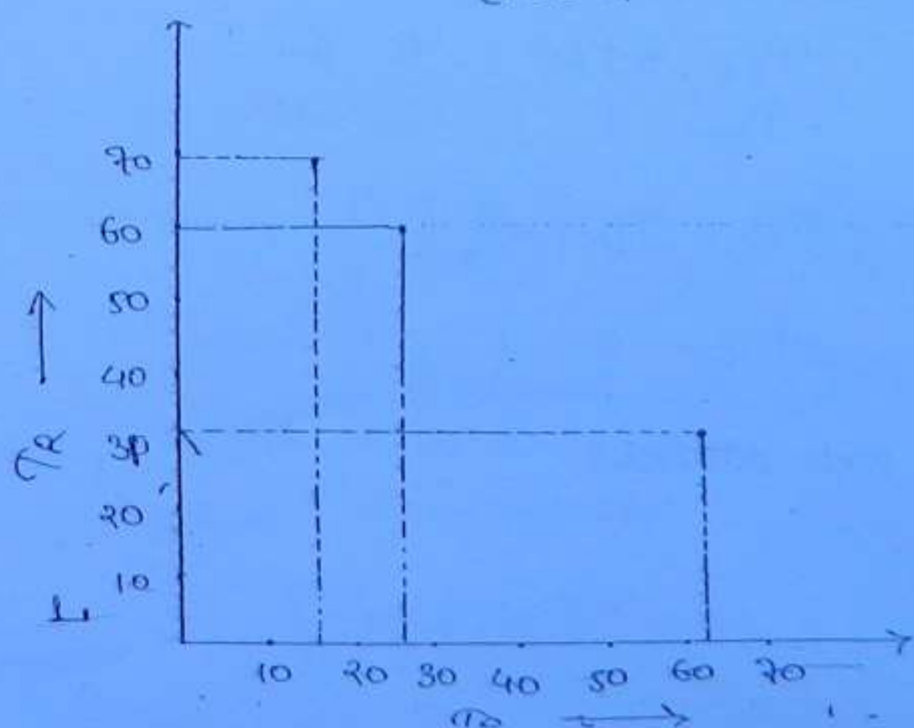
$T_{R_2} = 42.20$

T_{R_3}

$= 59.6$

② Thickness as per expansion pressure

$$T_e = \frac{\text{Exp pressure}}{0.0021}$$



Thickness of pavement $T_1 = T_R = T_C = 44\,cm$

(3) T_R for $28\ kg/cm^2$ 186

exudation pressure

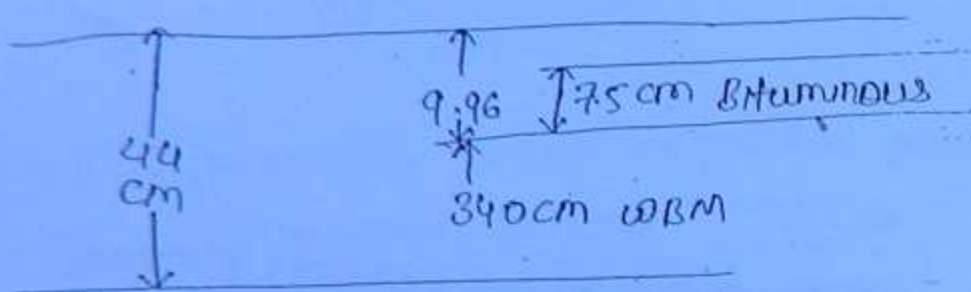
$$T_2 = 31.20 + \left(\frac{42.20 - 31.20}{36.5 - 26.5}\right)(36.5 - 28)$$

$$T_2 = 40.55\ cm$$

(4) thickness of pavement required (In term of WBM layer)

$$= \text{Max. of } T_1 \,\&\, T_2$$

$$= 44\ cm$$



7.5 cm thickness of Bituminous

$T_B = 7.5\,cm \qquad C_B = 62$

$T_W = ? \qquad C_W = 15$

$$\Rightarrow T_W = T_B\left(\frac{C_B}{C_W}\right)^{1/5}$$

$$T_W = 7.5\left(\frac{62}{15}\right)^{1/5} = 9.96\ cm$$

Net thickness of WBM layer

$$44 - 9.96$$

[redacted]

(4) Triaxial Method:→

(1) Thickness of pavement required

for single layer = $T = \sqrt{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2}$

187

P = wheel load in kg

X = Traffic coefficent

Y = Rainfall coefficient

E_S = Young's modulus of Soil Subgraded (kg/cm²)

a = radius of contact area in cm

Δ = design deflection in cm

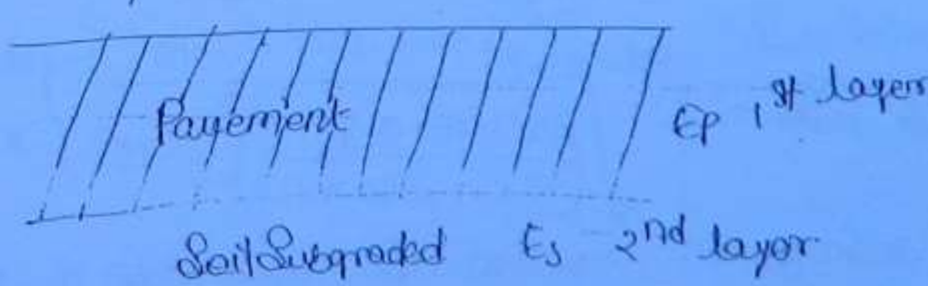
for two layer System = $T_P = \left[\sqrt{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2}\right] \times \left(\frac{E_S}{E_P}\right)^{1/3}$

∀ E_S = young's modulus of Soil Subgraded.

E_P = " " " pavement

T_P = Thickness of pavement in cm.

Two layer System



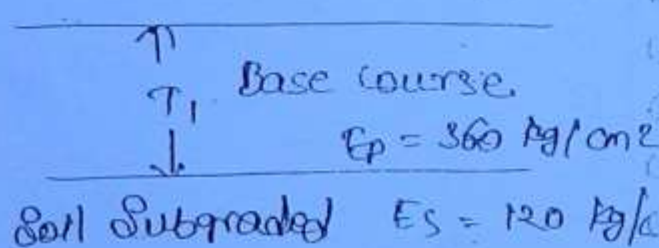
Compare two pavement

$\frac{T_1}{T_2} = \left(\frac{E_2}{E_1}\right)^{1/3}$

Question: Design a pavement Section by triaxial method using
wheel load = 4000 kg
Radius of contact area = 15 cm
Traffic coff = 1.6
Rainfall coff = 0.7 (188)
Design deflection = 0.25 cm
Pavement consists of
Bituminous layer 6cm thick $E_{Bit} = 1200\ kg/cm^2$
Base course = $E_B = 360\ kg/cm^2$
Soil Subgraded = $E_S = 120\ kg/cm^2$

Solution:→ let us design thickness of base course material requ over soil subgraded

Thickness of base course material req.
Two layer System



$$T_1 = \left\{\sqrt{\left(\frac{3PY}{(2\pi E_S A)}\right)^2 - a^2}\right\}\left(\frac{E_1}{E_S}\right)^{1/3}$$

$$T_1 = \left\{\sqrt{\left(\frac{3\times4000\times0.7}{(2\times\pi\times120\times0.25)}\right)^2 - 15^2}\right\}\times\left(\frac{120}{360}\right)^{1/3}$$

$T_1 = 48.3$ cm → (Total thickness of pavement) Note

Top layer of Bituminous 6cm
$T_{Bit} = 6m$ $E_{Bit} = 1200$
$T_{Base} = ?$ $E_{Base} = 360$

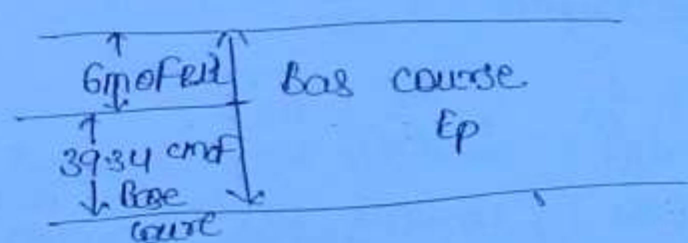
$$\Rightarrow \frac{T_{Base}}{T_{Bit}} = \left(\frac{E_{Bit}}{E_{Base}}\right)^{1/3}$$

$$T_{Base} = T_{Bit}\left(\frac{E_{Bit}}{E_{Base}}\right)^{1/3} = 6 \times \left(\frac{1200}{360}\right)^{1/3}$$

$$T_{Base} = 8.96 \text{ cm.}$$

Net thickness of base course $= 48.30 - 8.96$

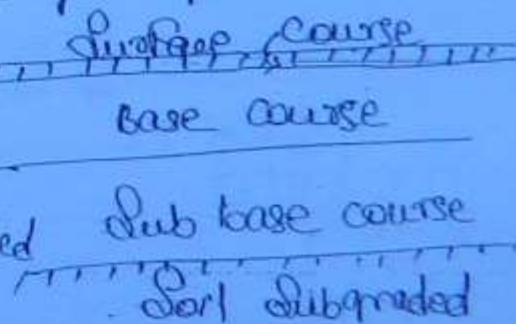
$= 39.34$ cm



⑤ <u>Burmister's Method</u>:→ This method is also based on young's modulus of Elasticity of different layer of pavement.

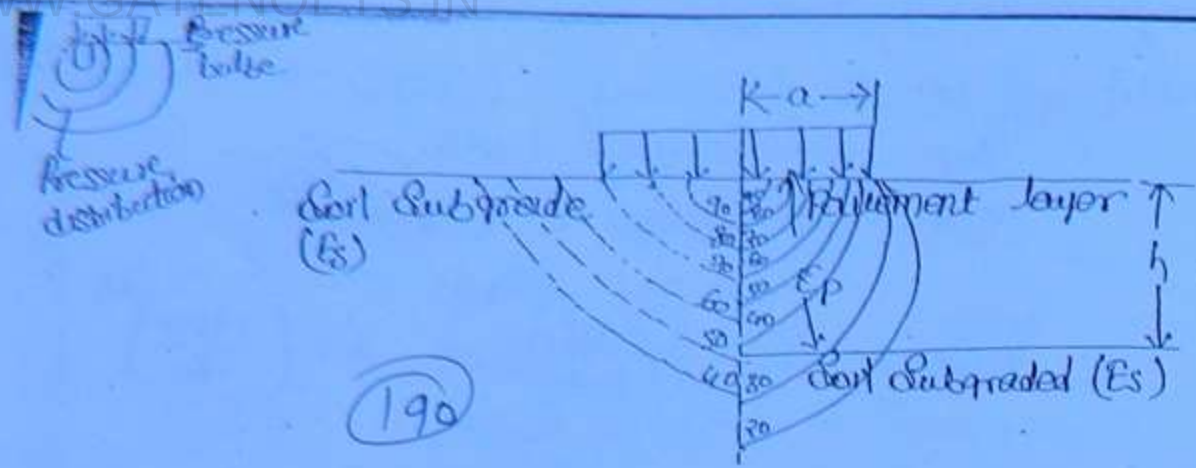
As per layer system

$E_{Surface} > E_{Base} > E_{Sub\ base} > E_{Soil\ Subgraded}$



<u>Assumptions</u>:→

(1) Materials in each layer are isotropic, Homogenous, & elastic
(2) Pavement forms a stiffer layer than soil subgraded ($E_p > E_s$)
(3) Surface layer is infinite in horizontal direction but finite in vertical direction.
(4) layer are in continuous contact.



⇒ Comparsion:-

when Stress are acting over a Soil Subgraded / over a pavement

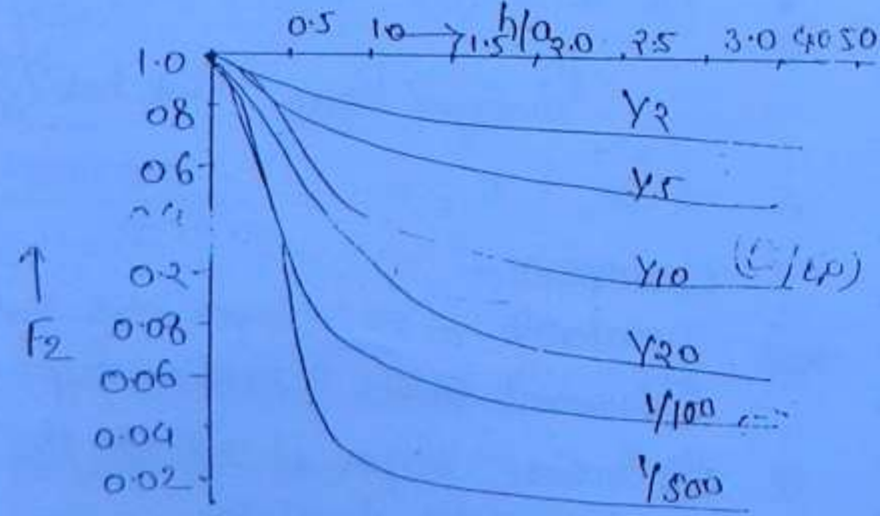
① Due to pavement layer, Stresses are reduced largly within Pavement layer.

② If $\frac{E_s}{E_p} = \frac{1}{10}$, $\frac{E_p}{E_s} = 10$

& $h = a$, in this particular example, Stresses reduced for 70% to 30% at particular location.

④ Design method:→

① Based on $\frac{E_s}{E_p}$ & $\frac{h}{a}$ value, Burminster introduced a factor called F_2



(2) For a single layer system :- (No pavement)

then $h = 0$

$h/a = 0$

$\therefore F_2 = 1.0$

(3) Displacement Relationship by Burminster :-

(a) For Flexible plate :-

$$\Delta = 1.50 \frac{pa}{E_s} \times F_2$$

(b) For Rigid plate

$$\Delta = 1.18 \frac{pa}{E_s} \times F_2$$

$\forall$ p = Pressure over surface (kg/cm²)

a = Radius of contact area. (cm)

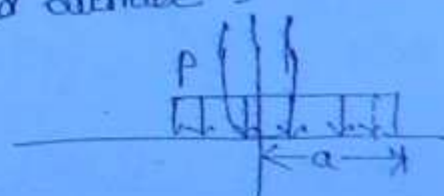
E_s = Modulus of Elasticity of Soil Subgraded (kg/cm²)

Δ = Design deflection (cm)

(4) (1) Flexible plate :->

when wheel load is acting over road surface. It is consid flexible case

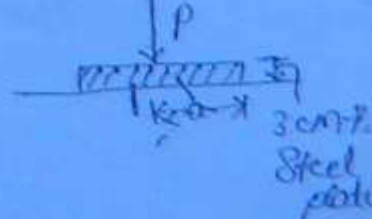
$p = P/A$



(2) Rigid plate :->

when plate load test is conducted over soil subgraded. over pavement

a = radius of steel plate



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

GATE (1999)

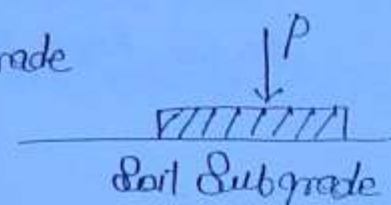
Problem:→ plate bearing test conducted with 30 cm diameter plate on a soil subgrade yielded pressure of 1 kg/cm2 at 5 mm deflection.

The test carried out over 18 cm base course yielded a pressure of 5 kg/cm2 at 5 mm deflection.

(192) Design the pavement section for a wheel load of 4100 kg with a tyre pressure of 6 kg/cm2 & allowable deflection of 5 mm. Use Burmister method.

Solution:→

① plate load test over soil subgrade



Dia of plate = 30 cm

than a = 15 cm

For single layer system

$F_2 = 1.0$

Pressure = $p = 1$ kg/cm2

Deflection $\Delta = 0.5$ cm

This is rigid case

For a rigid plate $\Delta = 1.18 \dfrac{P.a}{E_s} \times F_2$

$$0.5 = 1.18 \times \frac{1 \times 15}{E_s} \times 1$$

$$E_s = \frac{1.18 \times 15}{0.5} = 35.4 \text{ kg/cm}^2$$

② Plate load test over base course:

Thickness of pavement $h = 18$ cm

$p = 5$ kg/cm2

$\Delta = 5$ mm $= 0.5$ cm

$E_s = 35.4$ kg/cm2

(For two layer system)

for rigid plate $\Delta = 1.18 \times \frac{pa}{Es} \times F_2$

$$0.5 = 1.18 \times \frac{5 \times 15}{35.4} \times F_2$$

$\Rightarrow F_2 = 0.2$

193

Use the chart.

$h = 18\,cm$

$h/a = 15/12 = 1.2$

Based on $h/a = 1.2$ & $F_2 = 0.2$

get $\frac{Es}{Ep} = \frac{1}{100}$

$Ep = 100 \times Es = 100 \times 35.4$

$Ep = 3540\ kg/cm^2$

③ Design of pavement for wheel load

Flexible case

$\Delta = 1.5 \times \frac{pa}{Es} \times F_2$. ∵ $P = 4100\ kg$

$p = 6\ kg/cm^2$

$A = P/p = \frac{4100}{6} = 683.3$

$a = \sqrt{\frac{683.33}{\pi}} = 14.75\ cm$

$\Delta = 5mm = 0.5cm$

$Es = 35.4\ kg/cm^2$

For pavement

$0.5 = 1.5 \times \frac{6 \times 14.75}{35.4} \times F_2$

$F_2 = 0.133$

use the chart

for $F_2 = 0.133$

than $Es/Ep = 1/100$

read $h/a = 1.90$

$h = 1.9 \times 14.75$

$h = 28.025\ cm$

Rigid Pavement :→

(1) Modulus of Subgrade reaction (K)
(of Soil Subgrade)

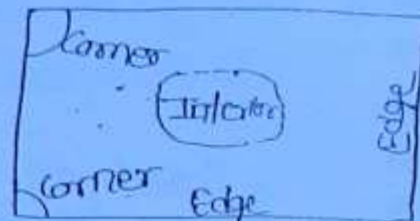
→ Value of pressure required for unit deflection of Soil Subgrade

$$K = \frac{\text{Pressure}}{\text{deflection}} = \frac{P}{\Delta} = (\text{kg}/\text{cm}^2)$$

194

(2) Radius of Relative Stiffness (l)

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



* E = Young's modulus of elasticity of cement concrete pavement (kg/cm²)
  h = pavement thickness (cm)
  K = Modulus of Subgrade reaction (kg/cm³)
  μ = Poision ratio.

(3) Equivalent radius of resisting Section. (Area effecting in resisting the B.M.)

(i) if $a < 1.724h$

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

(ii) if $a > 1.724h$

$$b = a$$

a = radius of contact area (cm)

h = Slab thickness (cm)

(4) Stresses due to load :→

Wester guard's stress equation

(1) Interior Stresses

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

(2) Edge Stress

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

(3) Corner Stress

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

ES-2000
2(b)

Problem:→ Define l & b. calculated wheel load stresses due to

(1) Design wheel load = 4200 kg

(2) E_{cement} concrete = 2.8×10^5 kg/cm2

(3) $h = 20m$

(4) $\mu = 0.15$

(5) $K = 7$ kg/cm^3

(6) Radius of contact area = 14cm

Solution:→ (1) Radius of relative thickness.

$$l = \left\{\frac{Eh^3}{12K(1-\mu^2)}\right\}^{1/4} = \left[\frac{2.8\times10^5 \times 20^3}{12 \times 7 \times (1-0.15^2)}\right]^{1/4}$$

$l = 73.27$ cm

(2) Equivalent radius of resisting section

$a = 14cm$, $h = 20cm$

$a < 1.724 h$

$$b = \sqrt{1.6a^2 + h^2} - 0.675h = \sqrt{1.6 \times 14^2 + 20^2} - 0.675 \times 20$$

$b = 13.21$ cm

Load Stresses (Using westerguard equation)

(a) Interior Stresses:—

(196)

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

$$S_i = \frac{0.316}{20^2}\left[4\log_{10}\left(\frac{72.27}{13.21}\right) + 1.069\right]$$

$$S_i = 13.34\ kg/cm^2$$

(b) Edge Stress:→

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

$$S_e = \frac{0.572}{20^2}\left[4\log_{10}\left(\frac{72.27}{13.21}\right) + 0.359\right]$$

$$S_e = 19.89\ kg/cm^2$$

(c) Corner Stress:→

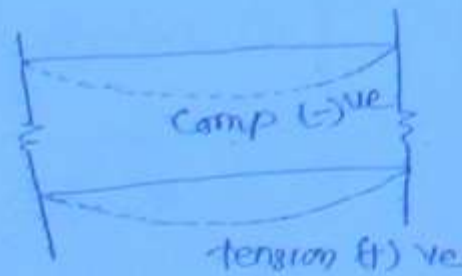
$$S_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

$$S_c = \frac{3 \times 4200}{20^2}\left[1 - \left(\frac{14 \times \sqrt{2}}{72.27}\right)^{0.6}\right]$$

$$S_c = 17.01\ kg/cm^2$$

(ii) Behaviour of load Stresses :→

① Interior Stress:-

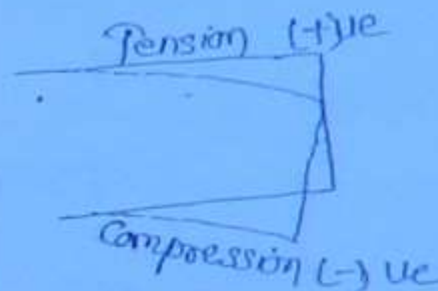


197

② Edge Stresses :→

C
(-)ve
T (+)ve

③ Corner Stresses : →

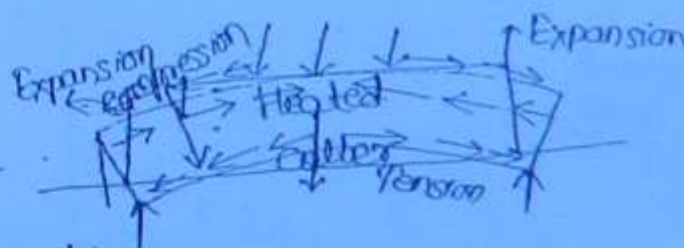


④ Temperature Stress :→

ⓐ Warping Stress:-

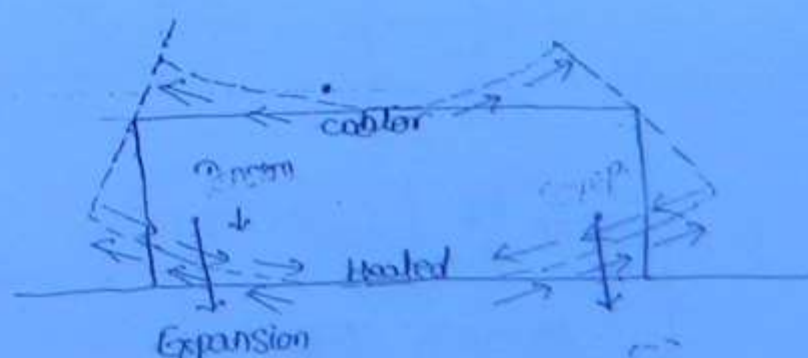
(i) During Day Stress:-

warping Stress C (-) ve
T (+) ve



(ii) During Night :→

C = (-)ve
T = (+) ve



Values (warping Stresses)

(1) Interior region. $S_{ti} = \frac{E\alpha T}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$

198

∀ E = Young's modulus of pavement.

α = coefficient of thermal expansion

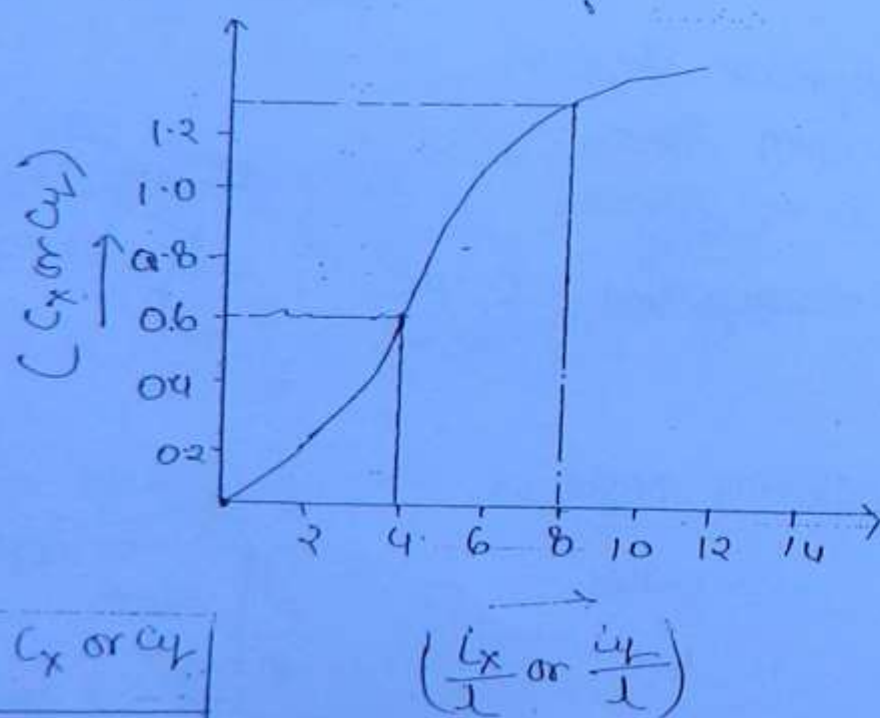
T = Temp. variation

C_x = Coefficient based on $\left(\frac{L_x}{l}\right)$ in desired direction

C_y = " " " $\left(\frac{L_y}{l}\right)$ " " "

l = radius of relative stiffness.

μ = poisson ratio

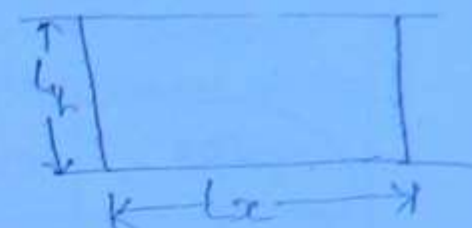


$\frac{L_x}{l}$ or $\frac{L_y}{l}$	C_x or C_y
0	0
4	0.6
8	1.1
12	1.02

② Edge Stress (warping)

$$S_{te} = \frac{C_x \cdot \alpha E T}{2} \text{ or } \frac{C_y \alpha E T}{2}$$

(whichever is more)



③ Corner Stress:-

$$S_{tc} = \frac{E\alpha T}{3(1-\mu)}\left(\sqrt{a/l}\right)$$

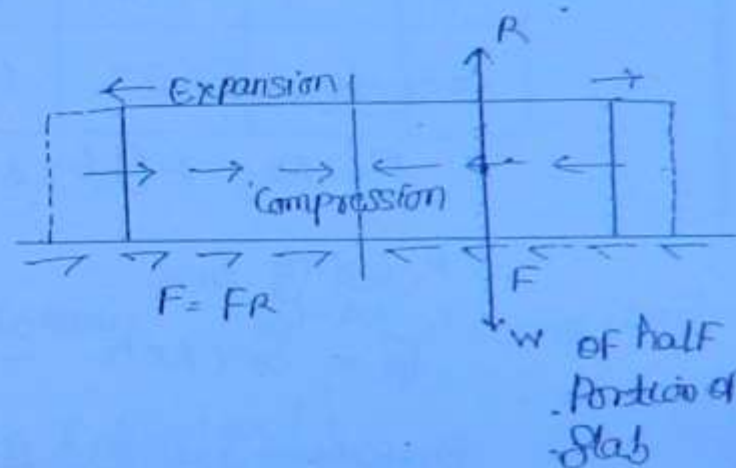
⑥ Frictional Stress:→

Due to Seasonal Variation of Temperature

① During Summer:→

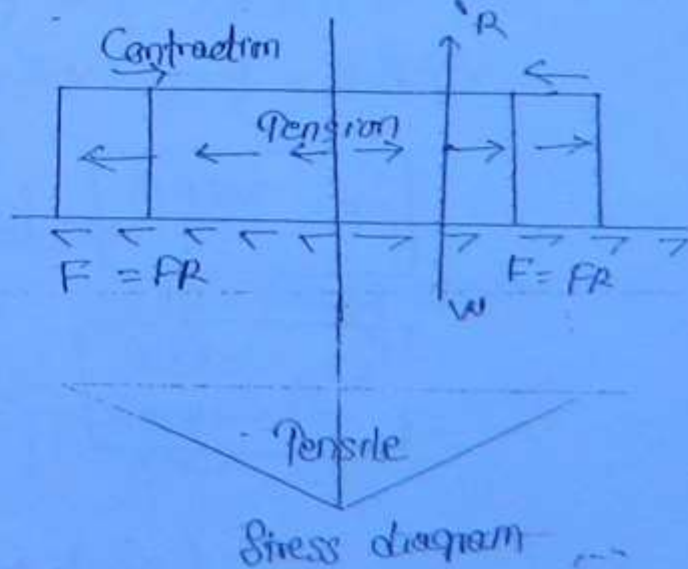
$c = (-)ve$

$T = (+)ve$



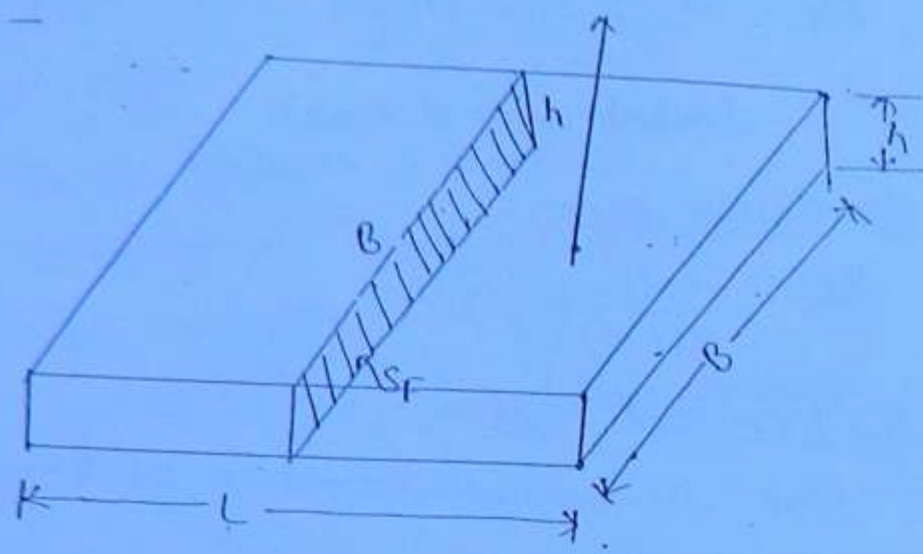
② During winter

Entire pavement will be tension.



(iii) Value of Frictional Stresses :-

200



$\Rightarrow$ Frictional force

$$F = F_R = F\left(\frac{1}{2} \times B \times h \times W\right) \quad \text{--- (1)}$$

$\Rightarrow$ Resisting force

$$F_R = S_F \times B \times h \quad \text{--- (2)}$$

Equating eq. (1) & (2)

$$S_F \cancel{B} \cdot \cancel{h} = F \cdot \frac{1}{2} L \times \cancel{B} \times \cancel{h} \times W$$

$$\boxed{S_F = \frac{W \cdot F L}{2}} \ \text{kg/m}^2$$

$$\boxed{S_F = \frac{W \cdot F L}{2 \times 10^4}} \ \text{kg/cm}^2$$ $\rightarrow$ Frictional stress developed.

(7) Worst Combination of Stresses:→

		load Stress	Warping Day	Warping Night	Frictional Summer	Frictional winter
Interior	Top	C(−)	C(−)	T(+)	C	T
	Bottom	$\boxed{T(+)}$	$\boxed{T(+)}$	C(−)	C	$\boxed{T}$
Edge	Top	C(−)	C(−)	T(+)	C	T
	Bottom	T(+)	T(+)	C(−)	C	T
Corner	Top	T(+)	C(−)	T(+)	C	T
	Bottom	C(−)	T(+)	C(−)	C	T

(1) At Interior:→

worst combination is

(1) during day (2) At bottom (3) At during winter.

$$\text{Stress} = \begin{pmatrix}\text{Load}\\ \text{Stress}\end{pmatrix} + \begin{pmatrix}\text{Warping}\\ \text{Stress}\end{pmatrix} + \begin{pmatrix}\text{Frictional}\\ \text{Stress}\end{pmatrix}$$

$$(S_i) + (S_{ti}) + (S_F)$$

(2) At edge (Same as above)

(3) At corner → worst Combination is

(1) At Top (2) At Night (3) At during winter

$$\text{Stress} = \begin{pmatrix}\text{load}\\ \text{Stress}\end{pmatrix} + \begin{pmatrix}\text{warping}\\ \text{Stress}\end{pmatrix} + \begin{pmatrix}\text{Frictional}\\ \text{Stress}\end{pmatrix}$$

$$= (S_c) + (S_{tc}) + (S_F)$$

Problem:→ A pavement slab 22 cm thick (cement concrete pavement) is constructed over a slab base having $k = 18\ kg/cm^2$. Spacing b/w joints are

Transverse joint = 5.50 m
Longitudinal joint = 4.20 m

202

$P = 4500\ kg$
$T = 20^c$ (Seasonal / day / night)

$a = 15\ cm$
$E_c = 3\times10^5\ kg/cm^2$
$\mu = 0.15$
$\alpha = 12\times10^{-6}/^\circ c$
$F = 15$

Find out stresses due to load / temp. & worst combination.

Solution:→

① Radius of Relative Stiffness.

$$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4} = \left[\frac{3\times10^5\times22^3}{12\times18(1-0.15^2)}\right]^{1/4}$$

$l = 62.37\ cm$

② Equivalent radius of resisting section

$a = 15\ cm,\ h = 22\ m$

$a < 1.724\ h$

$$b = \sqrt{1.6a^2+h^2} - 0.675h = \sqrt{1.6\times15^2+22^2} - 0.675\times22$$

$b = 14.20\ cm$

③ Load Stresses (Westergaard's equation)

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

(203)

$$= \frac{0.316 \times 4500}{22^2}\left[4 \log_{10}\left(\frac{62.37}{14.20}\right) + 1.069\right]$$

$$S_i = 10.69 \ kg/cm^2$$

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

$$S_e = \frac{0.572 \times 4500}{22^2}\left[4 \log_{10}\left(\frac{62.37}{14.20}\right) + 0.359\right]$$

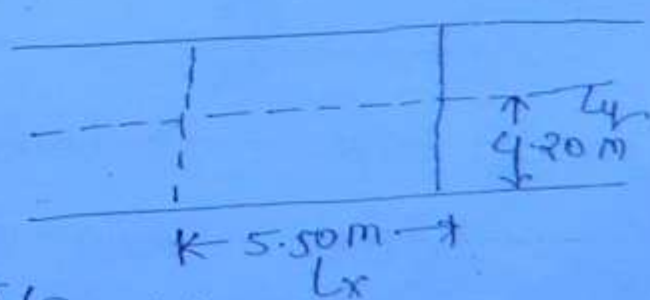
$$S_e = 15.58 \ kg/cm^2$$

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

$$S_c = \frac{3 \times 4500}{22^2}\left[1 - \left(\frac{15\sqrt{2}}{62.37}\right)^{0.6}\right]$$

$$S_c = 13.28 \ kg/cm^2$$

(4) Warping Stresses:→



$L_x = 5.80 \ m = 550 \ cm$
$L_y = 4.20 \ m = 420 \ cm$

$\frac{L_x}{l} = \frac{550}{62.37} = 8.82 \ \Big| \ C_x \simeq 1.05$ (from Interpolation)

$\frac{L_y}{l} = \frac{420}{62.37} = 6.73 \ \Big| \ C_y \simeq 0.6 + \frac{1.1 - 0.60}{4} \times 2.73 \simeq 0.94$

(a) Interior Stress

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

$$S_{ti} = \frac{3 \times 10^5 \times 12 \times 10^{-6} \times 20}{2}\left[\frac{1.04 + (0.15 \times 0.94)}{(1 - 0.15^2)}\right] = 43.50 \ kg/cm^2$$

(b) Edge Stress → $S_{tc} = \frac{C_x E \alpha T}{2} = \frac{1.05 \times 3\times10^5 \times 10^{-6} \times 20}{2}$

204

$S_{tc} = 37.44$ kg/cm²

(c) Corner Stress:-

$$S_{tc} = \frac{E\alpha T}{3(1-\mu)}\left(\sqrt{a/l}\right)$$

$$S_{tc} = \frac{3\times10^5 \times 12\times10^{-6} \times 20}{3(1-0.15)} \times \sqrt{15/62.37}$$

$$S_{tc} = 13.85 \text{ kg/cm}^2$$

(5) Frictional Stress:→ $S_F = \frac{WLF}{2\times10^4} = \frac{2400\times5.5\times1.50}{2\times10^4}$

$$S_F = 0.99 \text{ kg/cm}^2$$

Worst Combination:-

(1) Interior → At bottom + during day + during winter

$$\text{Stress} = S_i + S_{ti} + S_F$$
$$= 10.69 + 43.50 + 0.99$$
$$= 55.18 \text{ kg/cm}^2 \rightarrow \text{most critical}$$

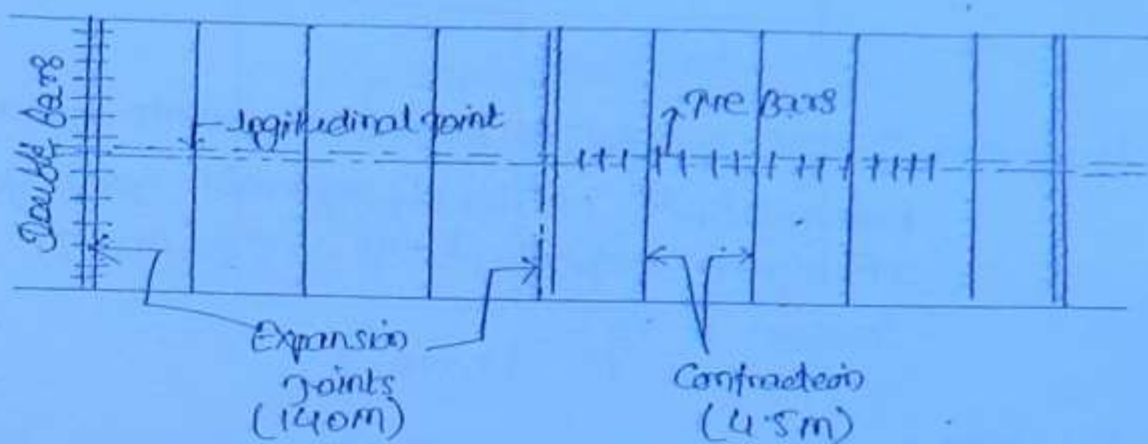
(2) Edge = at bottom + during day + during winter

$$\text{Stress} = S_{ti} + S_{te} + S_F$$
$$= 15.58 + 37.44 + 0.99$$
$$= 54.01 \text{ kg/cm}^2$$

(3) Corner = At top + during night + during winter

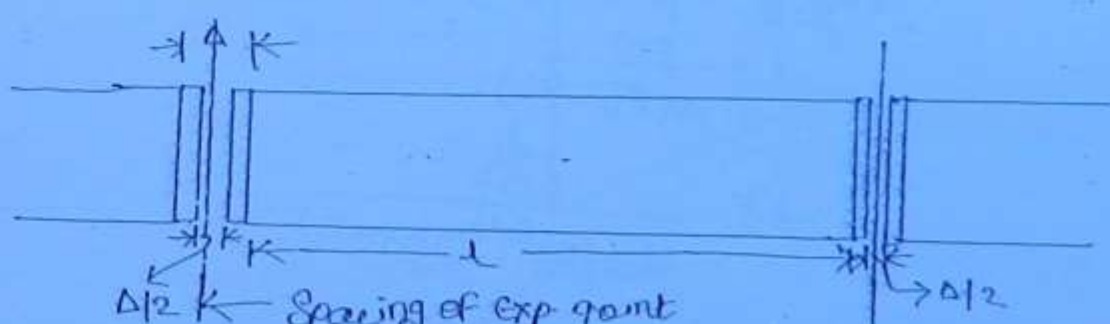
Stress: $S_c + S_{tc} + S_F = 13.28 + 13.84 + 0.99 \doteq 28.11$ kg/cm²

(17) Design of joints:→



① Expansion joints:→ Provided for allowing expansion due to T°C increase

Max Spacing = 140m



If Δ = Gap provided at expansion joint
(This Gap is such that (Δ/2) Gap is always there even after expansion)

Total expansion allowed = Δ/2
for one length of slab

$$L \cdot \alpha (T_2 - T_1) = \Delta/2$$

Spacing of Expansion joint

$$\boxed{L = \frac{\Delta}{2 \cdot \alpha \cdot (T_2 - T_1)}} \text{ —— (A)}$$

206

Problem:→ Design spacing of expansion joints for a cement concrete pavement, if width of expansion joint gap is 2.0 cm. If laying temperature is 20°C & max T°C in summer season is 48°C
$\alpha = 12 \times 10^{-6} / °C$

Solution:→ Max. expansion allowed

$$= \frac{\delta}{2} = \frac{2.0}{2} = 1.0 \text{ cm}$$

$L\alpha (T_2 - T_1) = 1.0$ cm

Spacing of expansion joint

$$L = \frac{1.0}{\alpha (T_2 - T_1)}$$

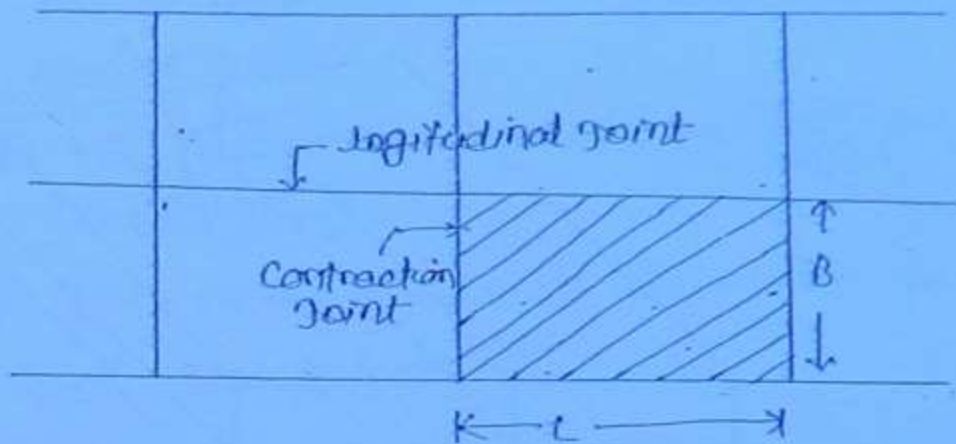
$$L = \frac{1.0}{12 \times 10^{-6} (48 - 20°C)}$$

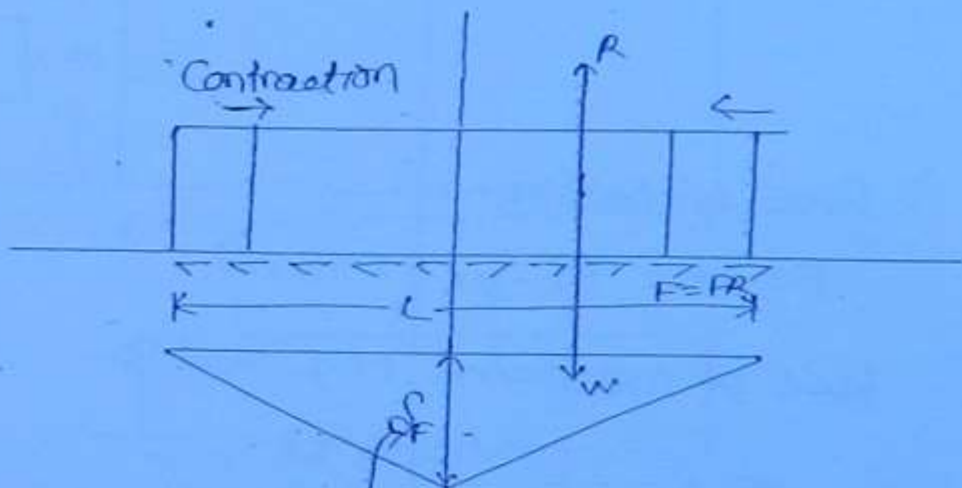
$L = 2976.2$ cm ≈

$L = 30$ m

(ii) Contraction Joint:→

Case(1) when no reinforcement is provided:→





In case of contraction of slab stress developed

$$\boxed{S_F = \frac{WLF}{2\times10^4}} \ kg/cm^2$$

Spacing of contraction joint

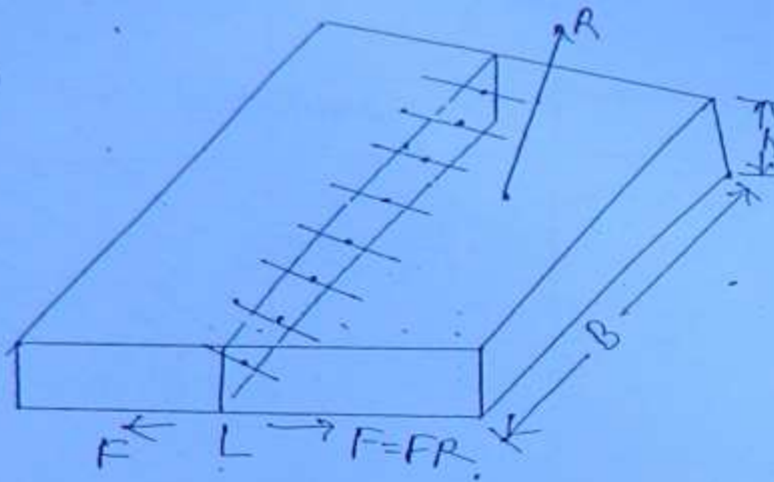
$$L = \frac{2\times10^4 S_F}{W.F.} \ m$$

- if S_F = tensile strength of concrete (kg/cm²)
- W = unit weight (kg/cm²)

(3):- When reinforcement is provided to bear tensile stresses:→

In this case tensile stresses are taken by steel alone.

208



Force of Friction:→

$F = FR = F(\frac{L}{2} \times B \times h \times W)$

Force of Resistance (By steel):→

$= A_{st} \times \sigma_{st}$

$A_{st} \times \sigma_{st} = F \cdot \frac{L}{2} \times B \times h \times W$

Spacing of contraction joint.

$$\boxed{L = \frac{2 \cdot A_{st} \cdot \sigma_{st}}{W \cdot F \cdot B \cdot h}} \text{ — (B) meter}$$

∗ A_{st} = Area of steel (cm^2)

σ_{st} = Permissible stress of steel (kg/cm^2)

W = unit weight (kg/cm^3)

B = width in meter

h = depth in meter.

Problem:- A pavement slab 4.5m width & 25 cm thick. Design contraction joint, if

209

(1) Pcc is used.

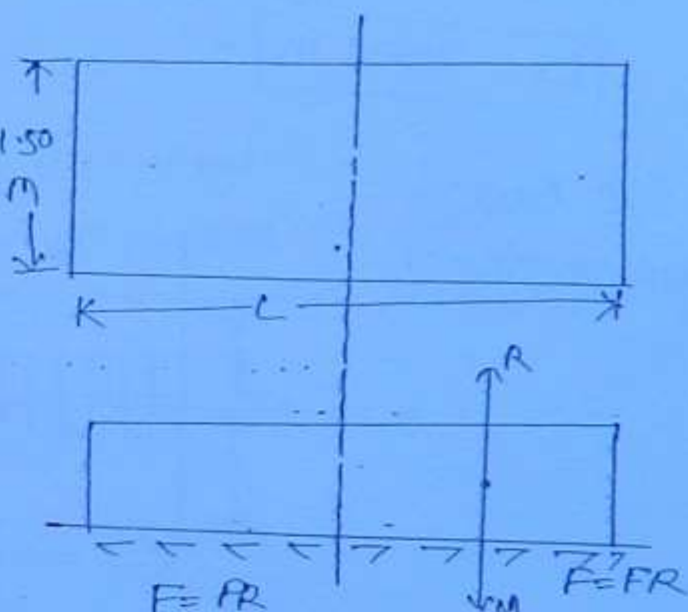
(2) Rcc is used.

$F = 1.5$, permissible stress for concrete in tension $= 0.8\ kg/cm^2$

For Rcc, 12 mm ϕ bars @ 300 mm c/c has been used

$\sigma_{st} = 1400\ kg/cm^2$

Solution:-



If (1) Pcc is used

$\Rightarrow B.K.\ S_F = F = FR = F \cdot \frac{L}{2} \times B \times h \times w$

$\Rightarrow$ Spacing of concrete joint

$$\Rightarrow L = \frac{2S_F}{WF} \times 10^4 = \frac{2 \times 10^4\, S_F}{WF}$$

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

$$\boxed{L = 4.44m}$$

(3) When RCC is used :→

$\Rightarrow A_{st}\,\sigma_{st} = F \times \frac{L}{2} \times B \times h \times W$

Spacing of concret contraction joint :→

210

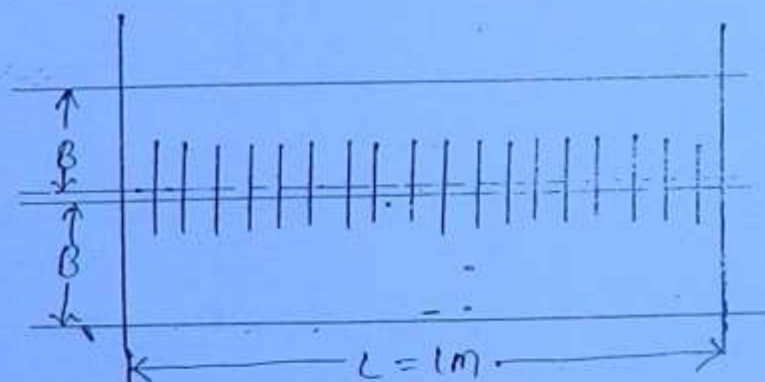
$$L = \frac{2 A_{st} \cdot \sigma_{st}}{W \cdot f \cdot B \cdot h}$$

$$L = \frac{2 \times \left(\frac{4500}{300}\right) \times \frac{\pi}{4}(1.2)^2 \times 1400}{2500 \times 1.5 \times 4.5 \times 0.25}$$

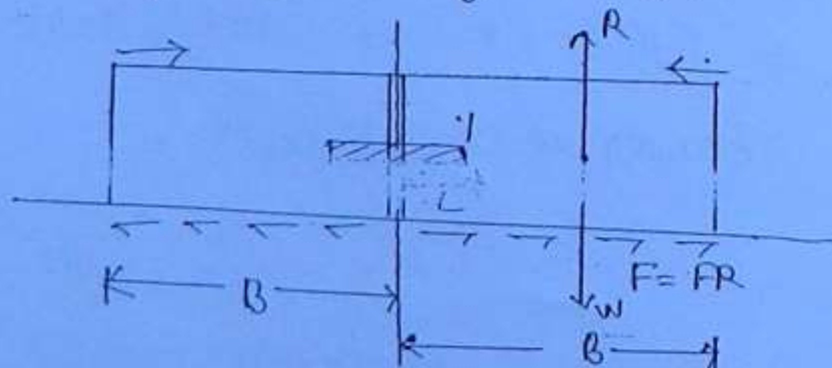
$$\boxed{L = 11.26\ m}$$

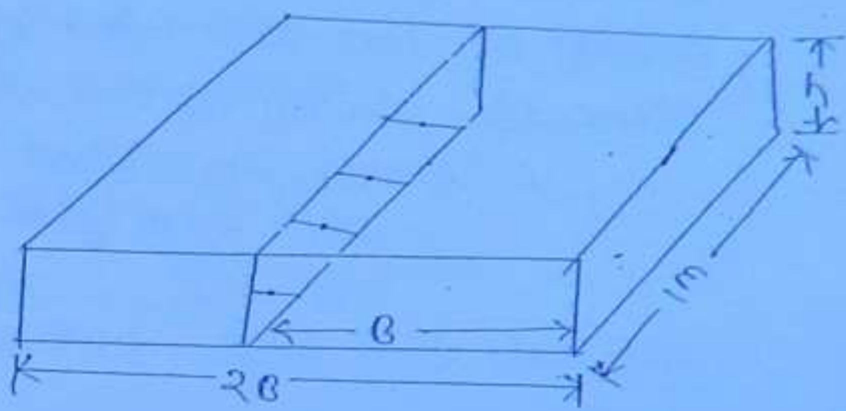
(4) Design of Tie Bars :→

At logitudinal joints :→



Tie bars are provided at logitudinal joint





$\Rightarrow R = B \times 1 \times h \times w$

$\Rightarrow$ force of friction $F = f \cdot R$

$F = f \times B \times h \times w$

$A_{st} \times \sigma_{st} = f \times B \times h \times w$

choose a diameter

$$A_{st} = \frac{f \cdot B \cdot h \cdot w}{\sigma_{st}}$$

Spacing of tie Bars $= \frac{1000}{A_{st}} \times \frac{\pi}{4}(\phi)^2$

Length of Tie Bars :->

Strength of Bar = Strength of Bond

$\Rightarrow A_{st} \cdot \sigma_{st} = \tau_{bd} \times \Sigma O \times L$

$\Rightarrow \frac{\cancel{\pi}}{4}(\phi)^{\cancel{2}} \times \cancel{n} \times \sigma_{st} = \tau_{bd} \times \cancel{\pi} \times \cancel{\phi} \times L \times \cancel{n}$

$\Rightarrow \boxed{L = \frac{\phi \sigma_{st}}{4 \tau_{bd}}}$ length of Tie bars $\boxed{= 2L}$

ES-1996-7(2)

Problem → A cement concrete pavements has a thickness of 24 cm & has two lanes of total width 7.2 m, with a longitudinal joint. Design the dimension & spacing of bars using following data.

Allowable working stress in steel.

(212)

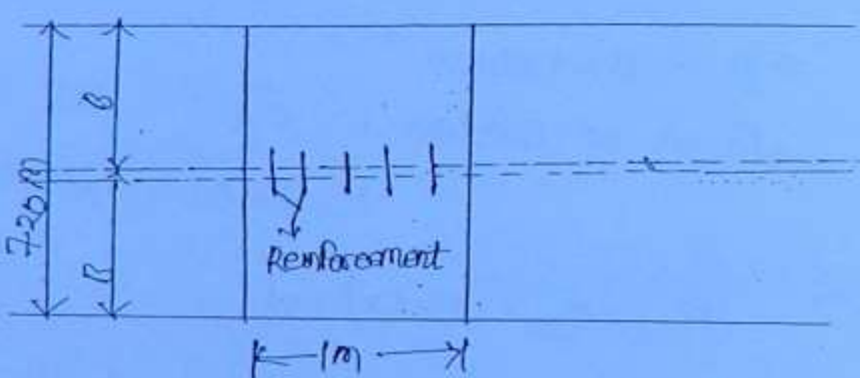
in Tension $= 1400\ kg/cm^2$

$W = 2400\ kg/m^3$

$F = 1.5$

Allowable bond stress $= 24.6\ kg/cm^2$

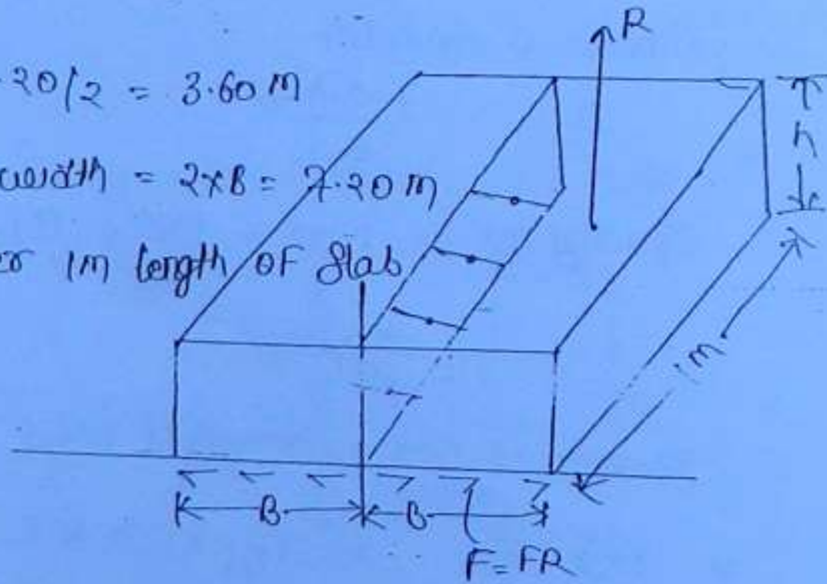
Solution: →



$B = 7.20/2 = 3.60\ m$

Total width $= 2 \times B = 7.20\ m$

Consider 1m length of slab



$\Rightarrow A_{st} \times \sigma_{st} = F = FR = F \times B \times 1 \times h \times W$

$A_{st} = \dfrac{F \cdot B \cdot h \cdot W}{\sigma_{st}}$

$$A_{st} = \frac{1.5 \times 3.60 \times 0.24 \times 1 \times 2400}{1400}$$

$A_{st} = 2.22 \text{ cm}^2$ (213)

$A_{st} = 222 \text{ mm}^2$

Using 8 mm ϕ bars

$$\text{Spacing} = \frac{1000}{222} \times \frac{\pi}{4}(8)^2$$

$= 226.4$

provided 8 mm ϕ @ 220 mm c/c

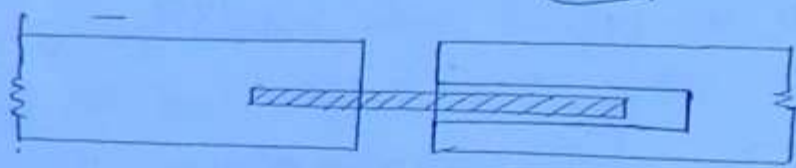
(3) length of tie bars $= 2 \times L_d$

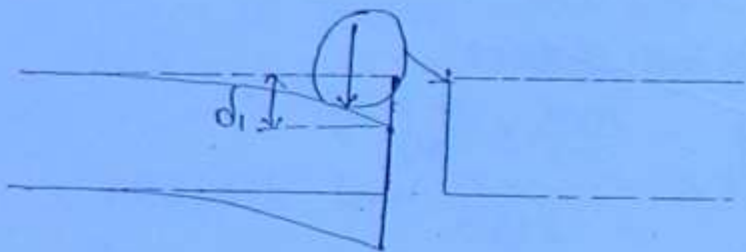
$$= 2 \times \frac{\phi \cdot \sigma_{st}}{4 \tau_{bd}}$$

$$= \frac{2 \times 0.8 \times 1400}{4 \times 24.6}$$

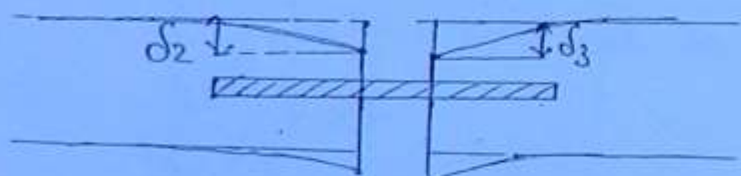
$= 22.76$ cm $\simeq 23$ cm

④ Dowel Bars :→





→ In this case
No Dowel bars provided



$(\delta_2 - \delta_3)$

Purpose of dowel bars

① To tranfer the load of wheel from one slab to another.

② To reduce differential deflection b/w two slab.

Design of dowel bars :→

Dowel bars are designed only. using Bradbury analysis

① Value of L_d (Length of embedment)

$$L_d = 5d\left[\frac{F_F}{F_b} \times \frac{L_d + 1.5d}{L_d + 8.8\delta}\right]^{1/2}$$

by trial & error, L_d is calulated.

② Total length of Dowel Bars :→ $L_d + \delta$

③ Load carrying capacity of a single dowel bar.

ⓐ For Shear (2,5)

$$P' = \frac{\pi}{4} (d)^2 \cdot F_s$$

ⓑ For Bending $P' = \dfrac{2 \cdot d^3 F_f}{L_d + 8.8\delta}$

ⓒ For bearing $P' = \dfrac{F_b \times L_d^2 \times d}{12.5 (L_d + 1.5\delta)}$

The value of P' is considerd min. of above three.

④ Load carrying capacity of dowel group system

$$\Rightarrow 40\% \text{ of wheel load}$$

$$= 0.40P$$

⑤ Required load capacity factor of dowel group system.

$$= \frac{\text{Load capacity of Group}}{\text{Load carrying Capacity}}$$

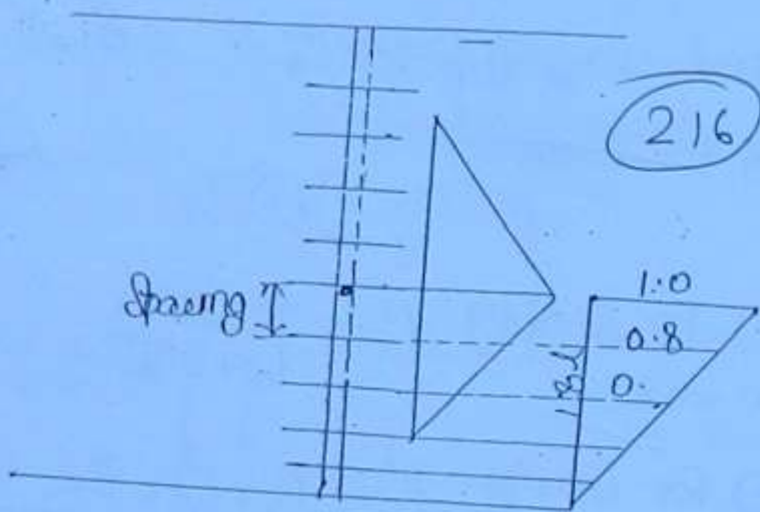
$$= \frac{0.40P}{P'}$$

⑥ Capacity factor of dowel group system = 1.0

= 1.0 For dowel bar just below wheel load.

= 0 For dowel bar at $(1.8\,l)$ distance from wheel load.

l = Radius of relative Stiffness



Total capacity factor of dowel group System

$$= 1.0 + \frac{(1.80l - S)}{1.80l} + \left(\frac{1.80l - 2S}{1.8l}\right) + \text{———}$$

The end