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-: HAND WRITTEN NOTES:-

OF

CIVIL ENGINEERING

1

-: SUBJECT:-

RAILWAY ENGINEERING

5

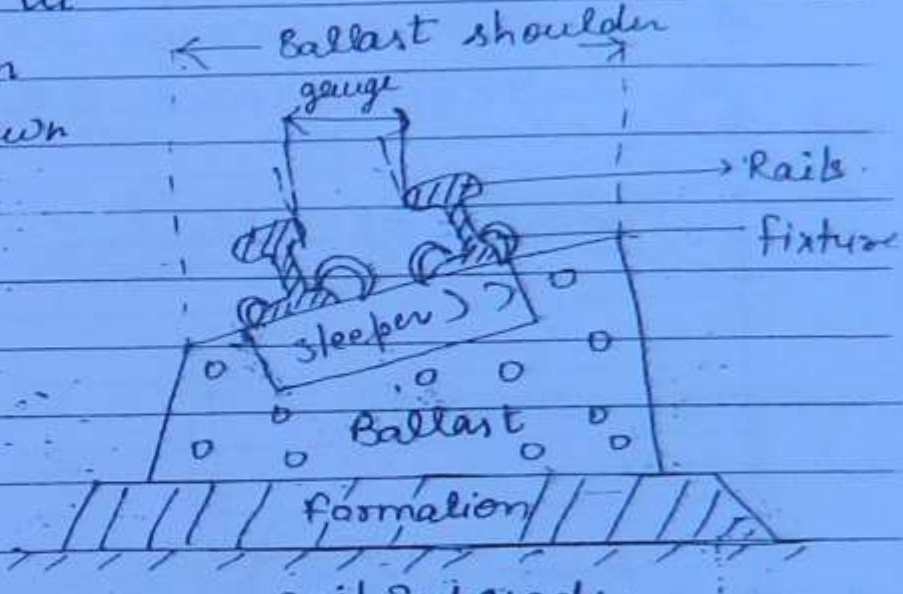
2

Railway Engg

INTRODUCTION

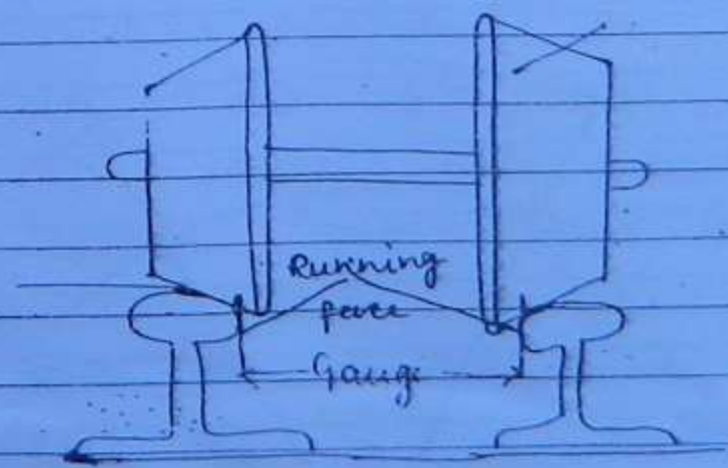
Important Terms :-

Cross-Section of a railway Track (on curve) is shown in figure →



(3)

1. Gauge :- Inner distance b/w two rails. (distance b/w running faces of two rails).

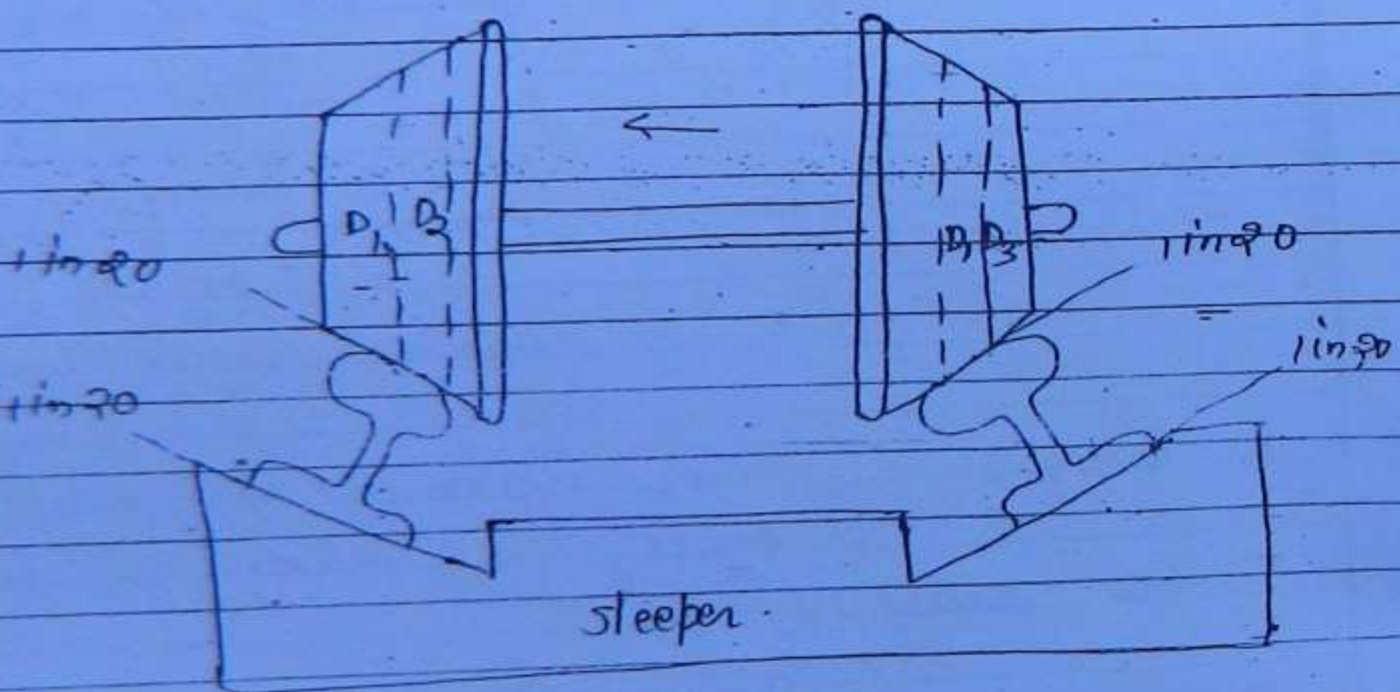


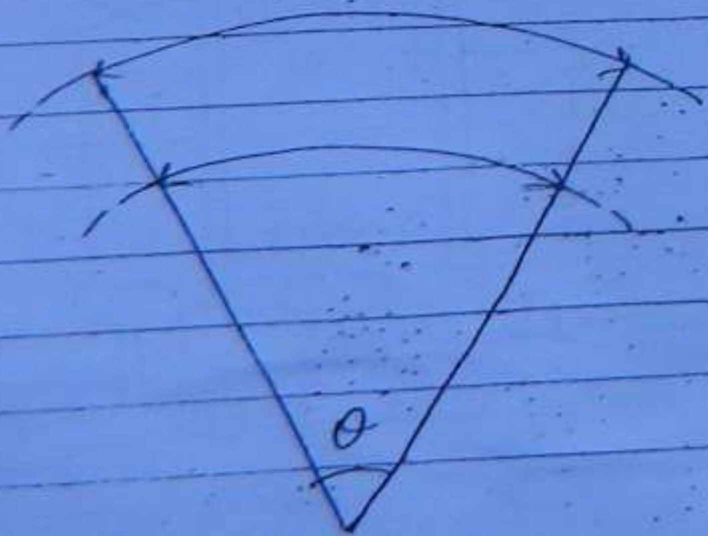
Different Gauge :-

1. Broad Gauge (BG) = 1.676 m.
2. Meter Gauge (MG) = 1.0 m.
3. Narrow Gauge (NG) = 0.762 m.
4. Feether Track Gauge (LG) = 0.61 m.

Coning of wheels :-

(9)





A slope of 1 in 20 is provided on wheel surface and over rails also. This slope provided to wheels is called coning of wheels

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Purpose:-

1. To keep the train just in central position during movement on a straight track.

2. To adjust the distance travelled on two rails on a curved trac

3. To reduce wear & tear of rails & wheels (A gap b/w flange and rail shall be maintained).

Theory:-

on Straight track:-, Axle moves in central position, so that diameter of wheel on two rails are same. If there is any side movement, dia of wheel over one rail increases, and decreases over another, So the axle is diverted back to its central position automatically.

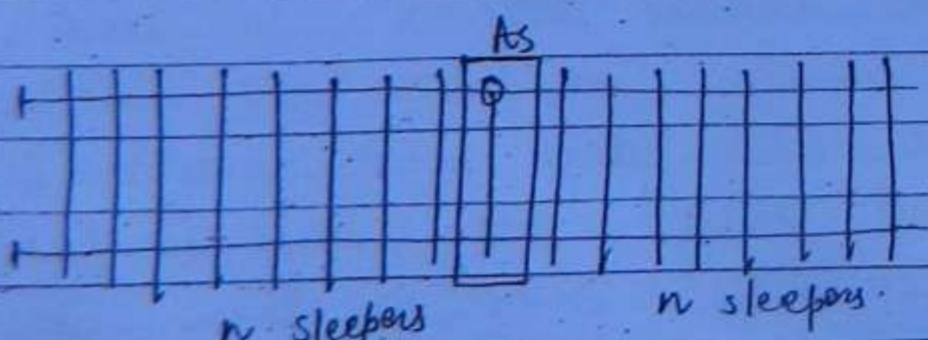
On curved track, the axle is moved outward due to centrifugal force, resulting increase of dia over outer rail. So distance to be travelled on outer and inner rails are adjusted.

(6)

Welded Rails (Long welded rails)(LWR) -

To avoid expansion joints, rails are welded. Stress developed due to increase in length of rails due to temp. is arrested by fixtures & sleepers.

In case of LWR rails are not allowed to expand. Thus stresses are developed. Force developed due to this stress is arrested by fixtures.



if l = length of rail
increase in length due to $T^{\circ}C$ temp.

increase . $\delta l = l.\alpha T$

if δl movement is not allowed
strain developed .

(7) $e = \frac{\delta l}{l} = \frac{l \alpha t}{l} = \alpha T$

stress developed → $\frac{\text{stress}}{\text{strain}} = E$

p_s = stress = $e E_s = \alpha T . E_s$

if A_s = c/s area of steel (one rail)

force developed

$f = A_s \times p_s$

$= A_s \times \alpha T . E_s$

if one sleeper can provide R resistence
no. of sleeper required to resist F
force

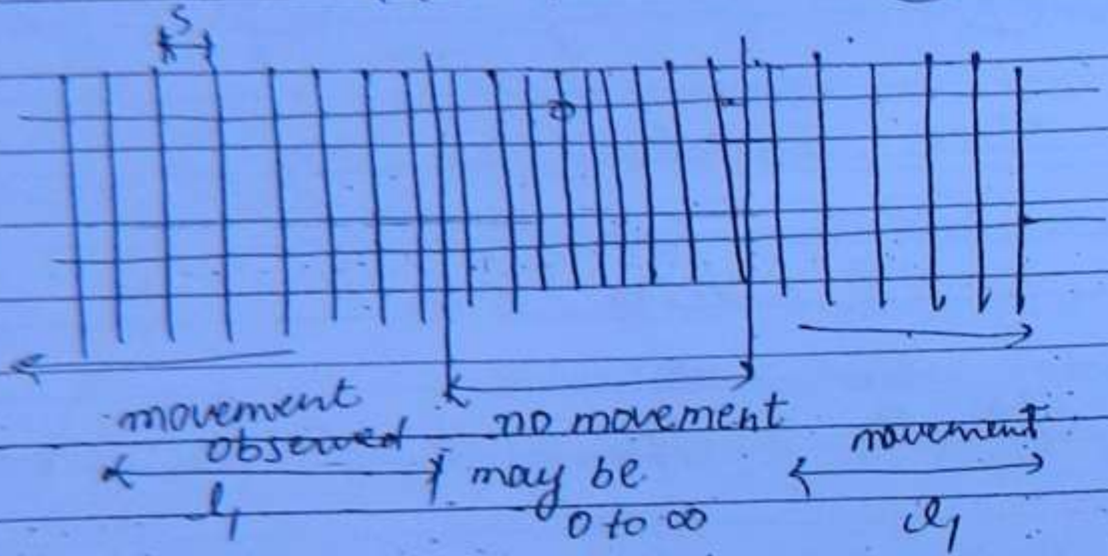
$n = \frac{F}{R} = \frac{A_s \times \alpha . T . E_s}{R}$.

if s = spacing of sleepers
min^m length of rail on one side
required so that rail does not
move = $(n-1)s$

Total min^m length of LWR so that central portion does not move.

$= 2l_1$

$= 2(n-1)s$. 8 8



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Ques. Determine the min^m theoritical length of LWR beyond which the central portion of a 52 kg rail would not be subjected to longitudinal movement, due to 30°C temp. variation. use following data

A) RAILS.

→ C/s area = 66.15 cm^2

$E_s = 2.1 \times 10^6$ kg/cm^2

$\alpha = 11.5 \times 10^{-6}$ /°C

B) SLEEPERS –

→ $s = 60$ cm.

→ Avg. resistence force/ Sleeper Rail = 300 kg.

Min^m length

increase in length = $l \cdot \alpha \cdot T$

Strain developed if above increase is not allowed

$$\frac{\delta l}{l} = \alpha T$$

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stress developed $= \alpha T \cdot E_s$

$= 11.5 \times 10^{-6} \times 30 \times 2.1 \times 10^{6}$

$= 724.5$ kg/cm^2.

Force developed $= A_s \times p_s$

$= 66.15 \times 724.5$

47925.675 kg

no. of sleepers (on one side) $= \frac{47925.675}{300}$

$= 159.75$

$\simeq 160$

min^m length of LWR required $= 2(n-1)s$

$= 2(160-1) \times 60 \times 10$

$= 190.80$ m

Sleepers:-

(1) Composite sleeper Index :- It is an Index to determine suitability of a wooden sleeper for use on a railway track.

(18)

$$\boxed{C.S.I. = \frac{S+10H}{20}}$$

S = strength index of timber at 12% moisture content.

H = hardness index of timber at 12% moisture content

	CSI values
Track sleeper	783
Crossing sleeper	1352
Bridge sleeper	1455

2) Sleeper density :- No of sleeper to be used for one rail length. It is denoted by $(n+x)$

n = length of one rail in metre
x = 3 to 6

$(n+3)$ to $(n+6)$. 11

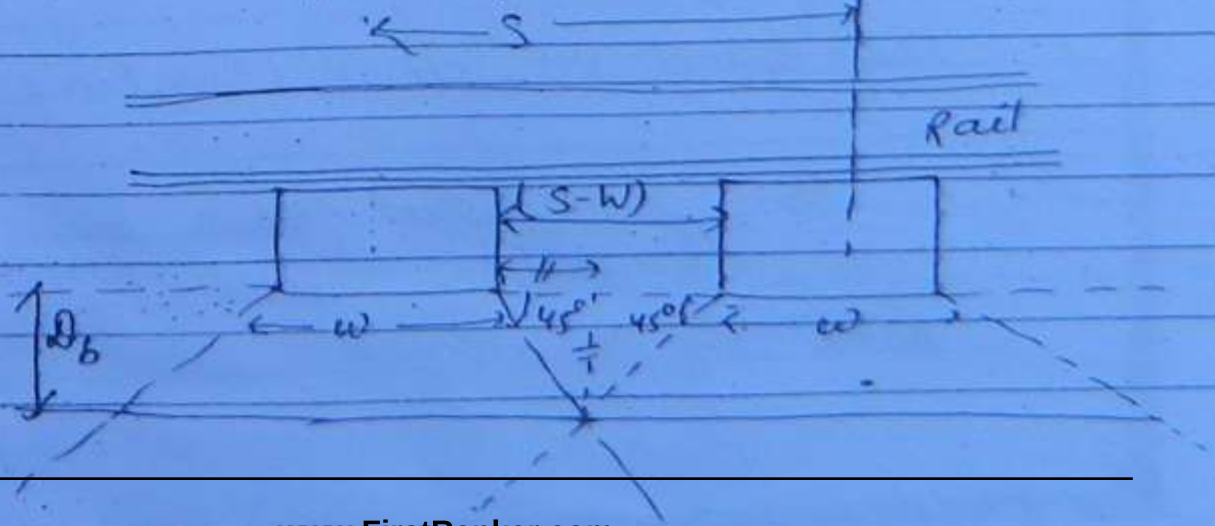
eg:- if sleeper density is $(n+5)$ for BG track. Calculate number of sleepers required per km length of track.

length of one rail = 12.8 m . ≈ 13 m

Sleeper density = $n+5$
$= 13+5 = 18$

12.8 — 18 number
1000 m — $\frac{18}{12.8} \times 1000$
= 1406 sleepers

Min^m depth of ballast cushion :-



be

Min^m depth of ballast

$$D_b = \frac{S-W}{2}$$

Geometrical Designs :- (12)

① Speed of train -

Max^m speed that can be allowed on a railway track shall be min^m of following.

1- Safe speed on curve
(Martin's formula) - max^m speed.

2. Speed as per S.E. formula (Cant).

3. Speed as per length of transition curve.

4. Max^m Speed Sanctioned by Railway Board.

1. Safe Speed on curve (Martin's formula) -

a) On transitioned curve -
(when transition curve have been provided with simple curved)

(i) for BG & MG track –

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

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for NG.

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

b) On Non-transitional curve :–
(When transition curve has not been provided) – 80% Vmax for transition curve.

i) for BG & MG :

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

ii) for NG

$$\boxed{V_{max} = 0.80 \times 3.65\sqrt{R-6}}$$

c) For High speed trains –

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

in all above formula

R = radius of curve in (m)

V_{max} = kmph.

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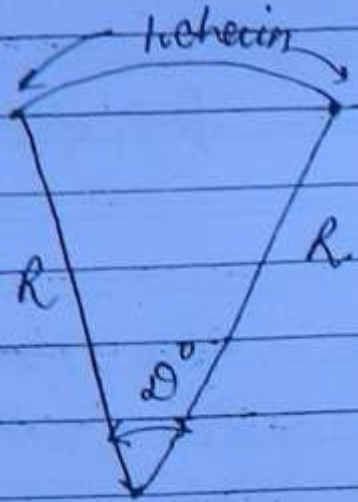
Q. Radius of curve / Degree of curve.
(R) (D°)



Angle made at centre by one chain length of curve is called degree of curve (D°).

(i) for 20 m. chain length

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

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

$$D^\circ = \frac{1718.9}{R}$$

$$\boxed{D^\circ = \frac{1720}{R}}$$ — (A)

D	1°	2°	3°	4°	5°
R for 30 m	1720 m	860 m	573 m	430 m	344 m
R for 20 m	1150	575	373 m	288 m	230 m

(ii) for 20 m chain length

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

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

$$\boxed{D^\circ = \frac{1150}{R}}$$

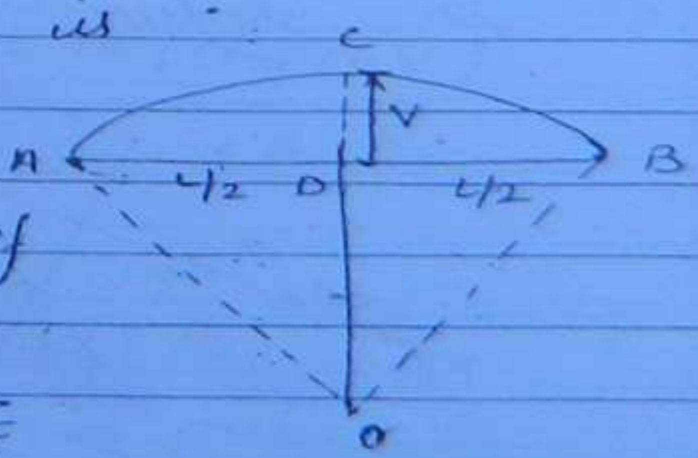
12/11/11

Max^m degree of curve :-

$$\left.\begin{array}{l} BG = 10^\circ \\ MG = 16^\circ \\ NG = 40^\circ \end{array}\right\} \text{max}^m \text{ values.}$$

3. Versine of curve :-

For a chord AB, distance ($CD = V$) is called versine of curve.



By using property of circle

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

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

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

$$\frac{L^2}{4} = 2RV$$

$$\boxed{V = \frac{L^2}{2R}} \leftarrow \text{versine of curve.}$$

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4. Superelevation or Cant :-

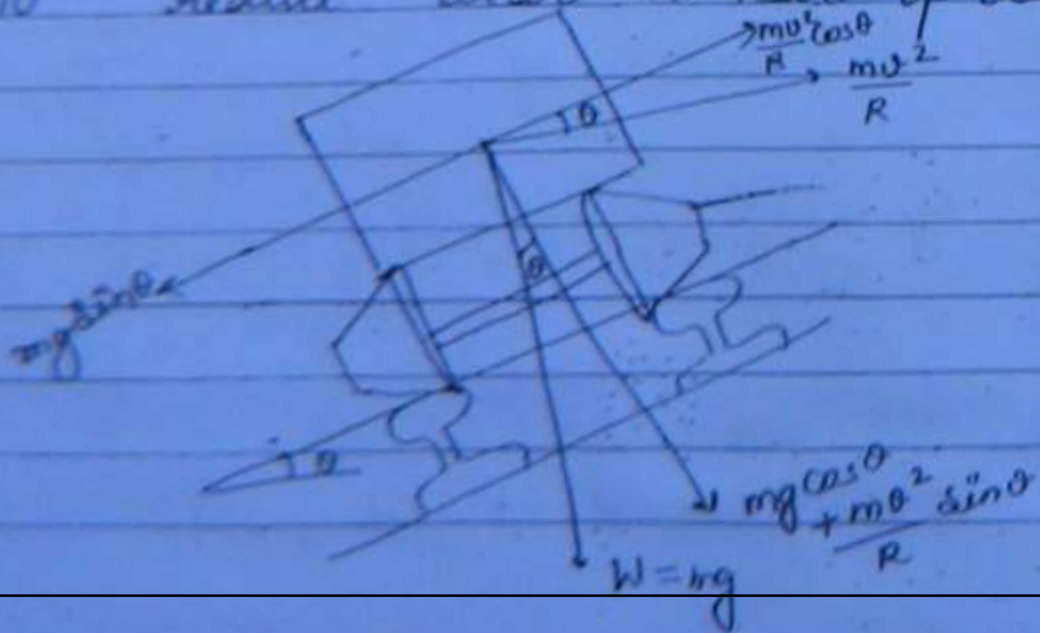
Outer rail is raised w.r.t. inner edge at the location of curve. This is called S.E or Cant.

Purpose -

1) To counteract the effect of centrifugal force on curve.

2) To reduce the chance of derailment.

3) To reduce wear & tear of rails.



outward component of centrifugal force in dirn of rail surface = $\frac{mv^2}{R}\cos\theta$

inward component of weight = $mg\sin\theta$
(There is no force of friction b/w rail & wheel in lateral dirn)

$$mg\sin\theta = \frac{mv^2}{R}\cos\theta \quad 17$$

$$\tan\theta = \frac{v^2}{gR}$$

Super elevation or Cant

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

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

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

where G = gauge in meter
V = speed in kmph
R = radius in meter.

5. Equilibrium Cant :-

Cant Required -

$$e = \frac{GV^2}{127R} \quad (18)$$

→ Different trains are moving with different ~~with~~ speed. So we need to design the cant for an avg. speed that is called equilibrium speed & cant provided for this speed is called equilibrium cant. This is the actual cant that is provided on the track.

Equilibrium Speed -

1) if Sanctioned speed > 50 kmph

$$V_{eq} = \frac{3}{4} \text{ max. speed}$$

$$\boxed{V_{eq} = \frac{3}{4} V_{max}}$$

2) if Sanctioned speed ≤ 50 kmph

$$\boxed{V_{eq} = V_{max}}$$

3. Weighted avg. speed –

n_1 trains $\rightarrow$ V_1 speed
n_2 trains $\rightarrow$ V_2 speed.
– – – – – – – –
– – – – – – – –

weighted avg. speed

$$V_{av} = \frac{n_1V_1 + n_2V_2 + \cdots}{n_1 + n_2 + \cdots}$$

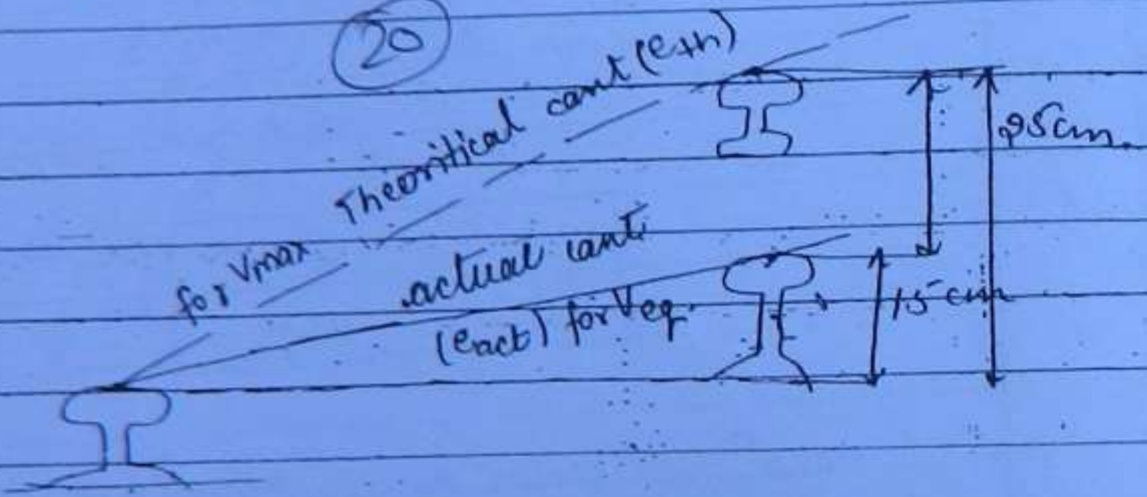
$$\boxed{V_{av} = \frac{\Sigma nv}{\Sigma n}}$$

max^m limit of superelevation –
(actual cant provided) –

Type	e_{max}
① BG	
speed < 120 kmph	16.5 cm
speed > 120 kmph	18.5 cm
② MG	10.0 cm
③ NG	7.6 cm

(6) Cant deficiency :- (D)

Cant required for a high speed train shall be more than actually provided value of cant on track (for equilibrium). There will be a deficiency of cant for this high speed train, this deficiency is called cant deficiency.



Limits of cant deficiency –

1. BG track

V < 100 Kmph	7.60cm
V > 100 kmph	10.0cm

2. MG — 5.10 cm

3. NG — 3.80cm

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

eg:- For 3° curve if actual cant is provi for eq^m sp. of 75 kmph on a BG track. Calculate max^m speed that can be allowed on the track.

(2) For 3° curve, $R = \frac{1720}{3} = 573\,m$

$R = 573\,m$

(1) Martin's Formula.

max^m safe sp on the curve =

$$4.35\sqrt{R-67}$$
$$= 4.35\sqrt{573-67}$$
$$= 97.85 \text{ kmph}$$

(2) from cant formula -

actual cant provided for

$V_{eq} = 75$ kmph

$$e_{act} = \frac{GV^2}{127R} = \frac{1.676 \times 75^2}{127 \times 573}$$
$$= 0.129\,m$$
$$e_{act} = 12.9\text{ cm}$$

Theoritical cant allowed

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

$e_{th} = 12.90 + 7.60$

$= 20.50\ cm = 0.205\ m$

for max^m speed

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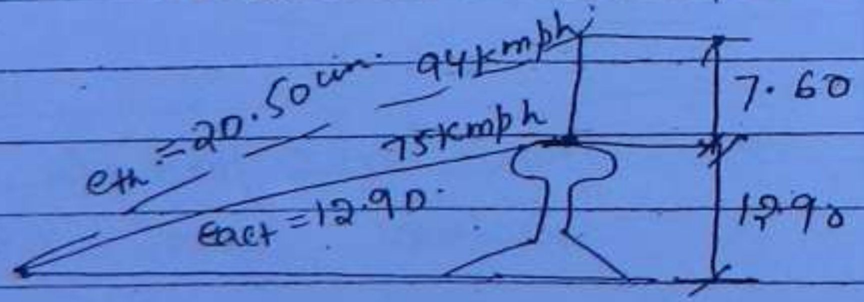
$$e_{th} = \frac{G \cdot V_{max}^2}{127 R}$$

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

$$= \sqrt{\frac{127 \times 573 \times 0.205}{1.676}}$$

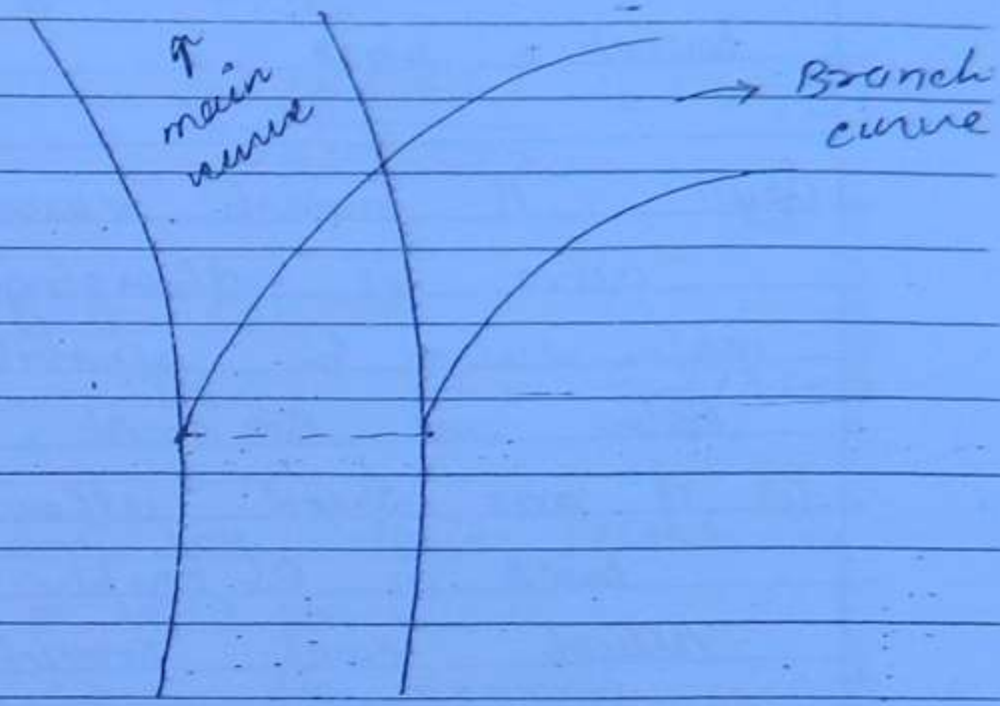
$= 94.34$ kmph

max speed allowed = 94 kmph



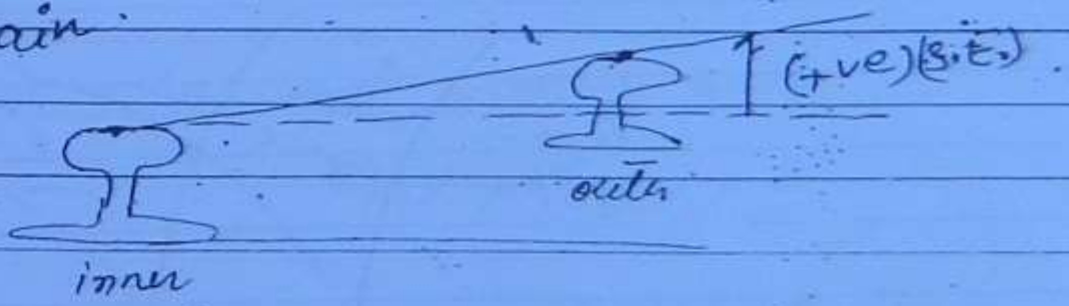
Negative Super elevation :-

If outer rail is provided at lower elevation, w.r.to inner rail it is called a negative superelevation

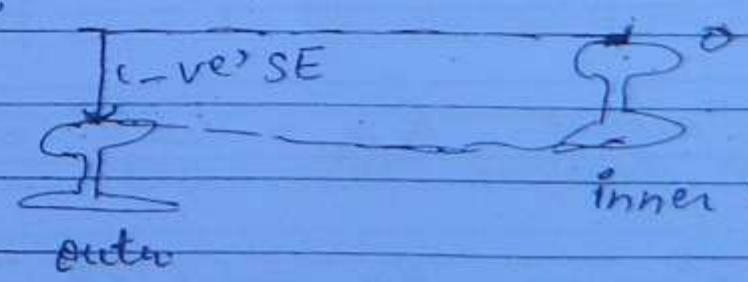


Q3

main



Branch



in case when a branch curve track is diverging from a main curved track in opposite dir^n, +ve

SE provided for main track will become a negative SE for branch track.

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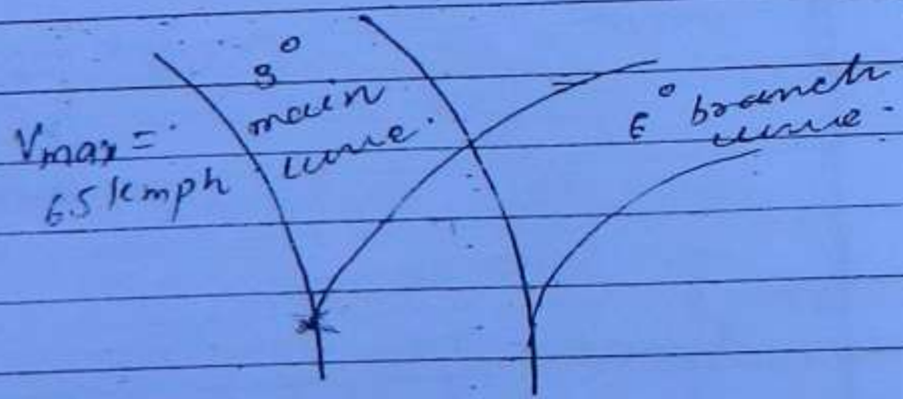
Ques- A branch curved track of 6° curve is diverging from a 3° main curve in opposite dir^n. Both are BG track.

(1) if max speed allowable on main track is 65 kmph. Calculate actual cant provided and max^m speed allowed on branch track.



for 3° curve $R_A = \frac{1720}{3} = 573\ m$.

for 6° curve $R_B = \frac{1720}{6} = 286\ m$.

max^m speed on main curve

$(V_{max})_{main} = 65$ kmph.

$$e_{th} = \frac{G \cdot V_{max}^2}{127 R_A}$$

$$e_{th} = \frac{1.676 \times 65^2}{127 \times 573} = 9.73 \text{ cm}$$

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

$$= 9.73 - 7.60 = 2.13 \text{ cm}$$

actual cant on main track is '+' ve. = 2.13 cm

actual cant on branch track is '-ve = −2.13 cm

e_{th} for branch track →

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

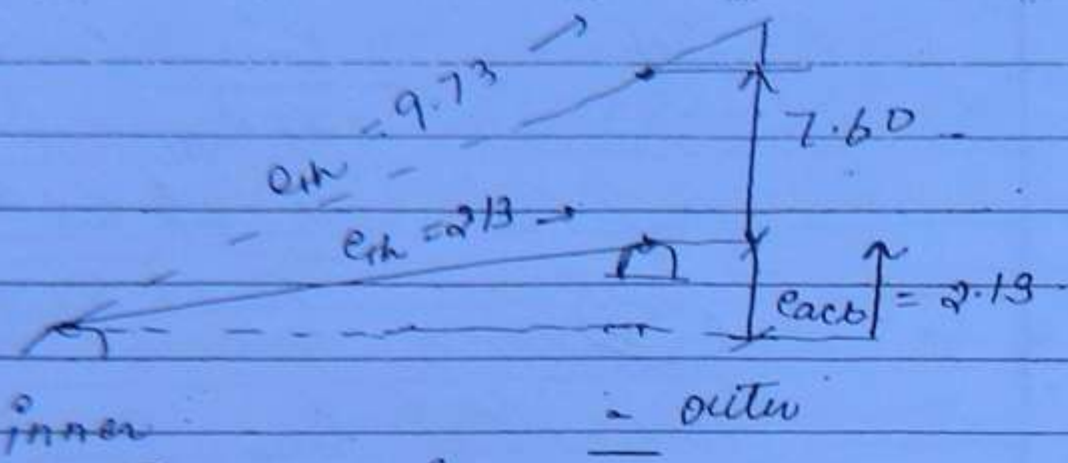
$$= -2.13 + 7.60$$

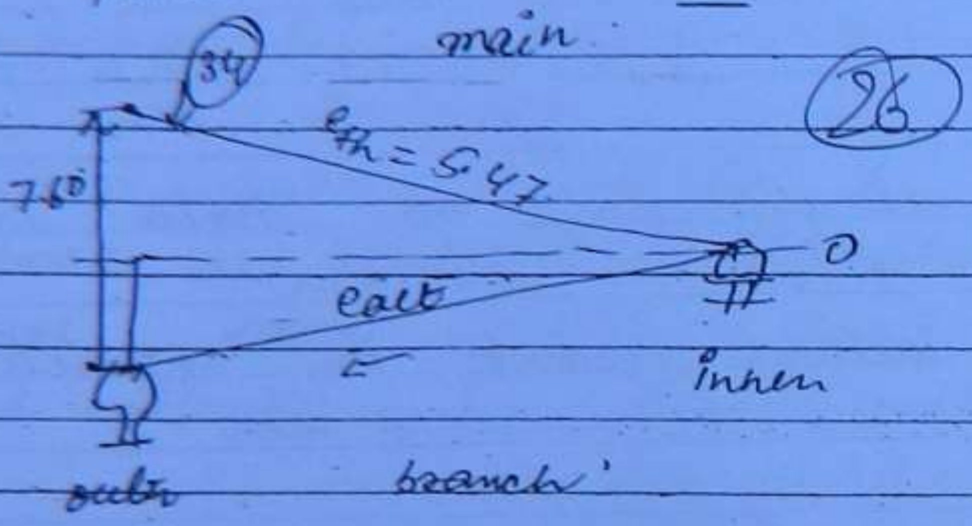
$$= 5.47 = 0.0547 \text{ m}$$

V_{max} for branch track.

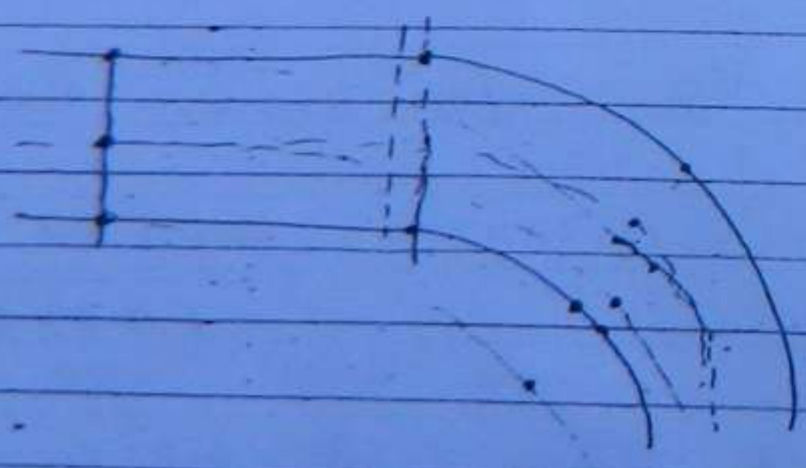
$$0.0547 = \frac{1.676 \times V_{max}^2}{127 \times 286}$$

$$V_{max} = 34.43 \text{ kmph}$$





3. Transition Curve :-



A parabolic curve is introduced b/w straight portion and curved portion of railway track to serve following purpo

1. To provide S.E. in a gradual manner from 0 to e

(27)

2. To reduce the radius of curve (∞ at straight track) to (R at curve track) in a gradual manner.

3. To reduce the effect of sudden jerk when there is a change from straight to curved.

This is called 'Transition Curve'

Requirements of an ideal transition curve:-

The curve should be perfectly tangential to its junction points
(At straight junction → Radius of transition curve = ∞)

At curved junction → Radius of T.C = Radius of simple curve

(2) The rate of change of curvature should be same as rate of change of SE (curvature = $\frac{1}{R}$).

Types :-

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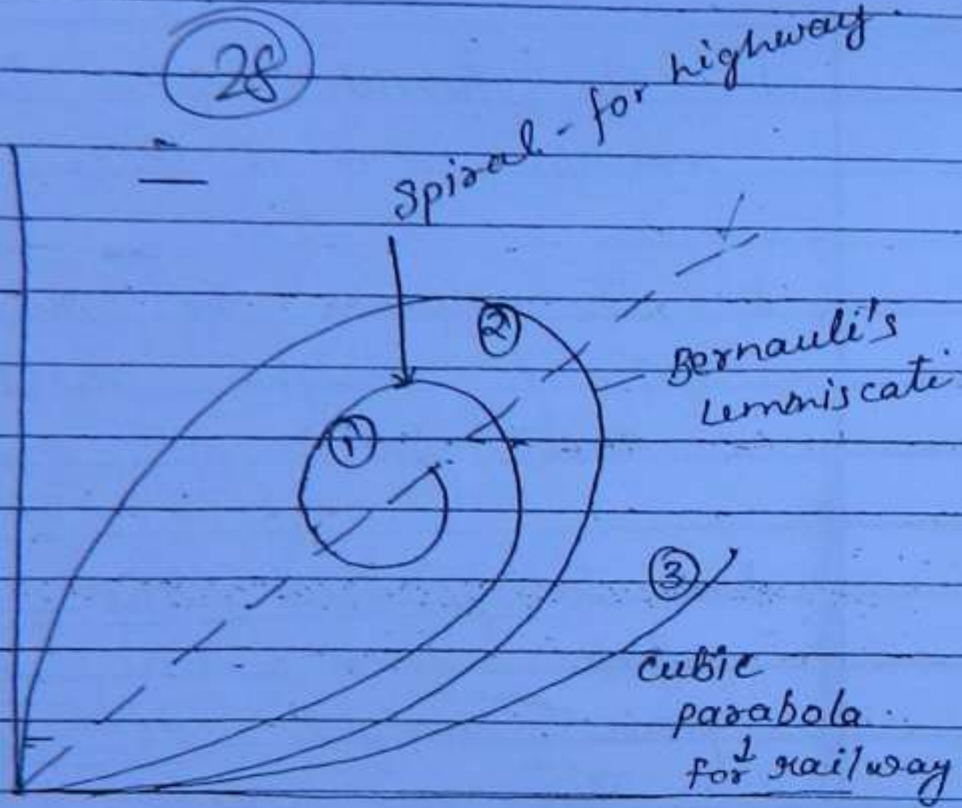

Cubic Parabola - Cubic Parabola is used for railway Transition curve.

→ upto a certain value of defl^{n} angle, shape of all these three curves are similar.

→ Cubic parabola is used for railway b/c it is easy to lay.

Cubic Parabola :-

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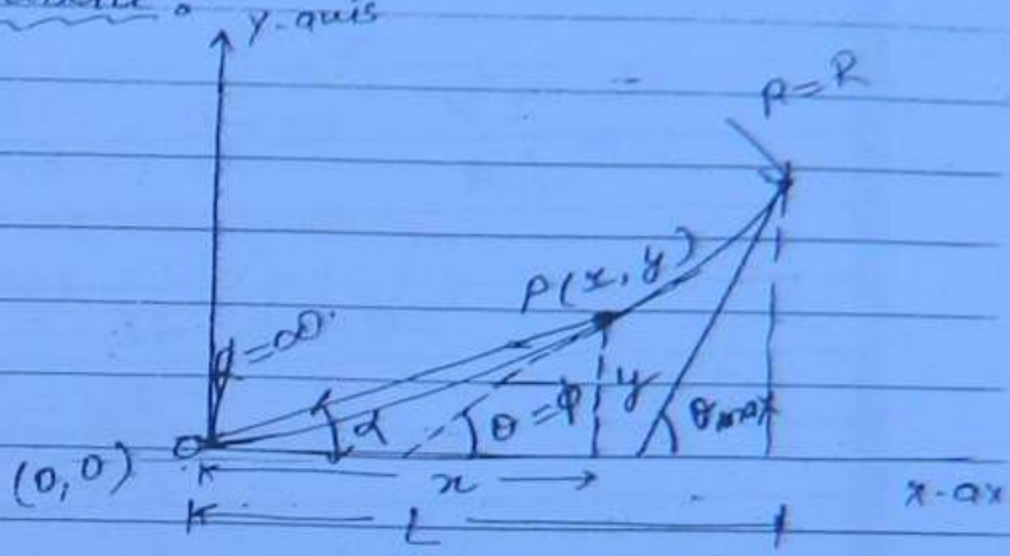

General eqn of cubic parabola.

defln eqn → $y = ax^3 + bx^2 + cx + d$ —— (1)

at $x = 0$, $y = 0$ –

$0 = 0 + 0 + 0 + d$

$\boxed{d = 0}$

now differentiate –

$$\frac{dy}{dx} = 3ax^2 + 2bx + c$$

at $x = 0$, slope $\frac{dy}{dx} = 0$

then $\boxed{c = 0}$

again differentiate –

curvature eqn $\frac{d^2y}{dx^2} = 6ax + 2b = \frac{1}{R}$

at $x = 0$, $R = \infty$

$$\frac{d^2y}{dx^2} = \frac{1}{R} = \frac{1}{\infty} = 0$$

$$6ax + 2b = 0 \quad (80)$$

$$0 + 2b = 0$$

$$\boxed{b = 0}$$

at $x = L$

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

$$\frac{1}{R} = 6aL + 2\times 0$$

$$\boxed{a = \frac{1}{6RL}}$$

$$\boxed{y = \frac{1}{6RL}x^3} \quad (\text{defl}^n \text{ eq}^n)$$

$$\tan\theta = \theta = \boxed{\frac{dy}{dx} = \frac{x^2}{2RL}} \quad (\text{slope eq}^n)$$

$$\frac{d^2y}{dx^2} = 6ax = 6 \times \frac{1}{6RL} \times x$$

$$\boxed{\frac{d^2y}{dx^2} = \frac{x}{RL}} = \frac{1}{R} \quad (\text{curvature eq}^n)$$

max^m slope

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

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$$\boxed{\theta_{max} = L/2R}$$

Spiral Angle :- (ϕ).

It is the slope of tangent a any point on the curve.

$$\boxed{\phi = \theta}$$

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

$$\boxed{\phi_{max} = \frac{L}{2R}}$$

Deflection Angle :- (α) :-

It is the slope of line joining a point (P) from origin.

$$\alpha = \tan\alpha = \frac{y}{x} = \frac{x^3}{6RL \cdot x} = \frac{x^2}{6RL}$$

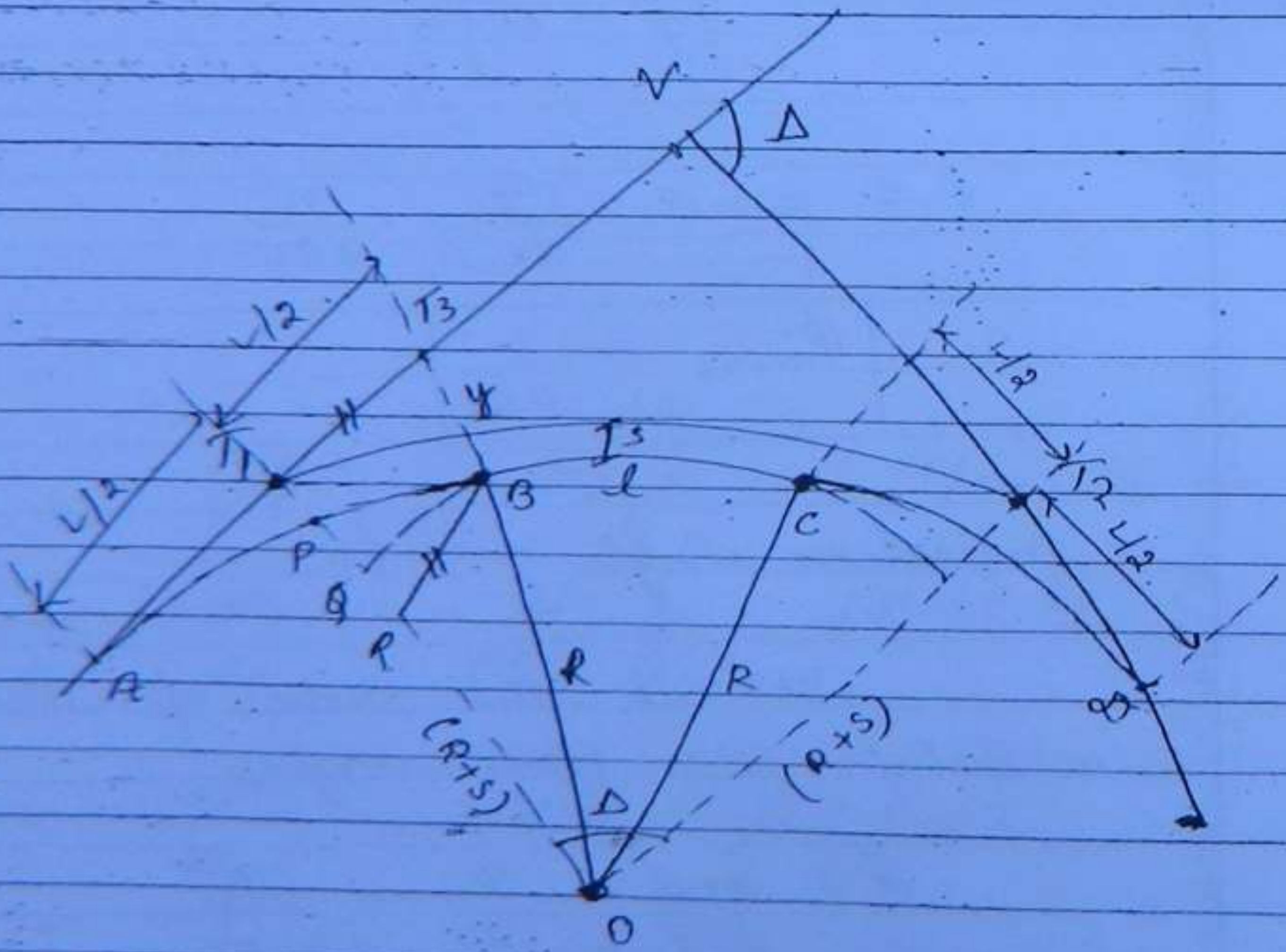
$$\alpha = \frac{x^2}{6RL} = \frac{1}{3} \times \frac{x^2}{2RL}$$

$$\boxed{\alpha = \frac{1}{3}\phi}$$

$$\boxed{\text{defl}^{n} \text{ angle} = \frac{1}{3} \times \text{spiral angle}}$$

$$\boxed{\alpha_{max} = \frac{L^2}{6RL} = \frac{L}{6R} = \frac{\phi_{max}}{3}}$$

Providing cubic Parabola as Transition curve on a railway track :-



Two transition curve have been provided on both side of simple curve.

→ Transition curve is provided such that ½ length is available on both side of initial tangent points (T_1 or T_2).

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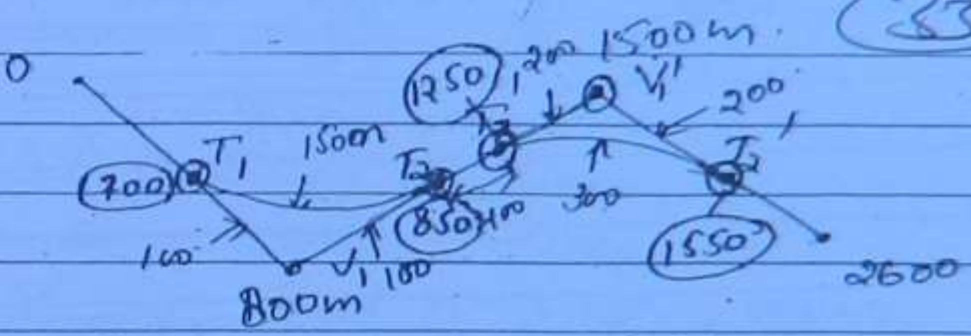
eg:-



→ If chainage of V = given

→ 1^{st} tangent length $= AV$

$= AT_1 + T_1V$

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

chainage A = chainage V − AV.

chainage of (B) = chainage (A) + AB

= chainage (A) + L

chainage of (C) = chainage (B) + BC

= chainage B + l

chainage of (D) = chainage (C) + L

Angle $\angle POB = \frac{L/2}{R} = \frac{L}{2R} = \phi$

= spiral angle.

$\angle BOC = (\Delta - 2\phi)$

Length of simple curve. 34

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

Shift :- $(s) = \frac{l^2}{24R}$

$$s = T_1Q = T_1M - QM$$
$$= T_3B - (OQ - OM)$$
$$= y - (R - R\cos\phi)$$
$$= \frac{x^3}{6RL} - R(1 - \cos\phi)$$
$$= \frac{L^2}{6R} - R\left(2\sin^2\frac{\phi}{2}\right)$$
$$= \frac{L^2}{6R} - 2R\left(\frac{\phi}{2}\right)^2$$
$$= \frac{L^2}{6R} - 2R \times \left(\frac{L}{4R}\right)^2$$
$$\boxed{s = L^2/24R}$$

Length of transition curve on Railwa

There are two approach -
1st approach -

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1. $L = 7.2 e$
e = cant in cm.
L = length of T.C. in m.

2. $L = 0.073\ e \cdot V_{max}$
e = cant in cm.
V_{max} = Speed in kmph max.
L = in m.

3. $L = 0.073\ D \cdot V_{max}$.

D = cant deficiency
V_{max} = Kmph.
L = meter.

2nd approach.

1. $L = 4.4\sqrt{R}$ → Railway Board forme
R = radius of curve in m
L = in m

2. $L = 3.6e$ Based on superelevation

$e =$ cant in cm

$L =$ length in m. 36

3. Length as per rate of change of radial acceleration -

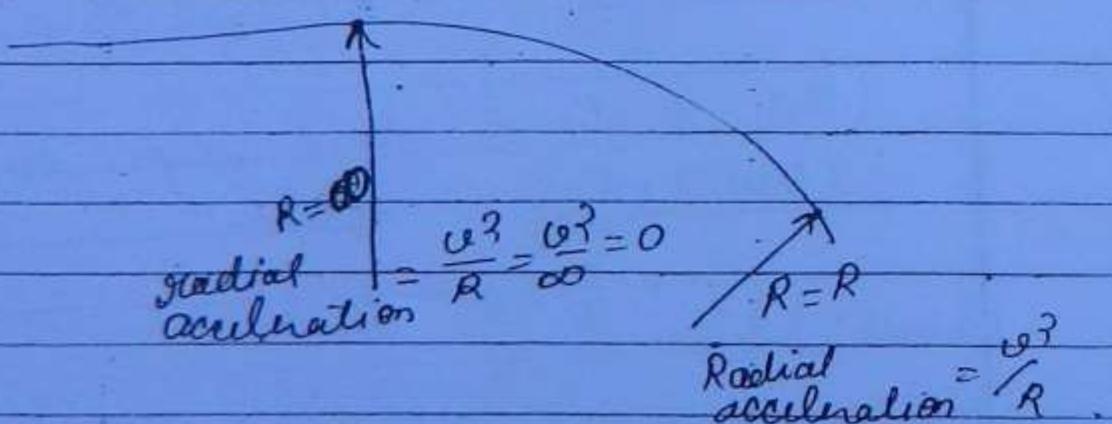
$$L = \frac{3.28\,v^3}{R} = \frac{v^3}{CR}.$$

here $C = 0.3048\ m/sec^3$.

$v =$ speed in m/sec.

$R =$ radius in m.

$L =$ Length of T.C in m.



at straight junction $= \frac{v^2}{R} = \frac{v^2}{\infty} = 0$

at curved junction $= \frac{v^2}{R}$.

celerat

change in R A = 0 to $\frac{v^2}{R} = \frac{v^2}{R}$.

if rate of change of radial accelerat is C.

(3T)

of

Total change of RA in T-sec $= C.T = \frac{v^2}{R}$

$$T = \frac{v^2}{CR} \quad \text{—(1)}$$

$$L = v.T$$

$$T = \frac{L}{v} \quad \text{—(2)}$$

equating (1) & (2)

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

$$v^3 = LCR$$

$$\boxed{L = \frac{v^3}{CR}}$$ ← length of T.C based on rate of change of R.A

$\frac{v^3}{R}$.

$C = 0.3048$

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

O

Max^m speed based on length of transition curve -

① For normal speed -

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$$V_{max} = \frac{134 L}{e}$$

or

$$V_{max} = \frac{134 L}{D}$$

here L = length of T.C. in (m)
e = cant in mm
D = cant deficiency in mm.

② For High Speed Train -

$$V_{max} = \frac{198 L}{e} \text{ or } \frac{198 L}{D}$$

Q. Equilibrium cant is provided on a BG track of 4° curve, for an equilibrium speed of 80 kmph. Calculate actual cant provided. What max^m speed can be allowed on this track.
calculate length of transition curve

required. If chainage of Intersection point is 8052m & diffn angle = 85°. calculate chainage of important points on the curve.

Set out the transition curve at every 10m distance.

Sol^n $4°$ curve $\Rightarrow$ $R = \frac{1720}{4} = 430$

$G = 1.676m$. (39)

$V_{eq} = 80$ kmph.

$e_{act} = ??$

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

$= 19.64$ cm

$e_{max} = 16.50$ cm.

So actual cant provided $= 16.50$ cm

Max^m speed allowed —

1) safe speed on curve.

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

82.87 kmph.

2) as per cant formula -

$e_{th} = e_{act} + D$
$= 16.50 + 7.60 = 24.10$ cm
$= 0.241$ m

$e_{th} = \frac{G V_{max}^2}{127 R}$ (40)

$0.241 = \frac{1.676 \times V_{max}^2}{127 \times 430}$

$V_{max} = 88.61$ kmph

Max^m. speed that can be allowed
$= 82.88$ kmph

Length of transition curve -
(should be calculated using max^m speed allowed) -

using 1st approach -

(1) $L = 7.2e$
$L = 7.2 \times 16.50$
$= 118.8$ m $\simeq 119$ m

(2) $L = 0.073 \times e \times V_{max}$
$= 0.073 \times 16.50 \times 82.88 = 99.8$ m

(3) $L = 0.073 \times D \times V_{max}$

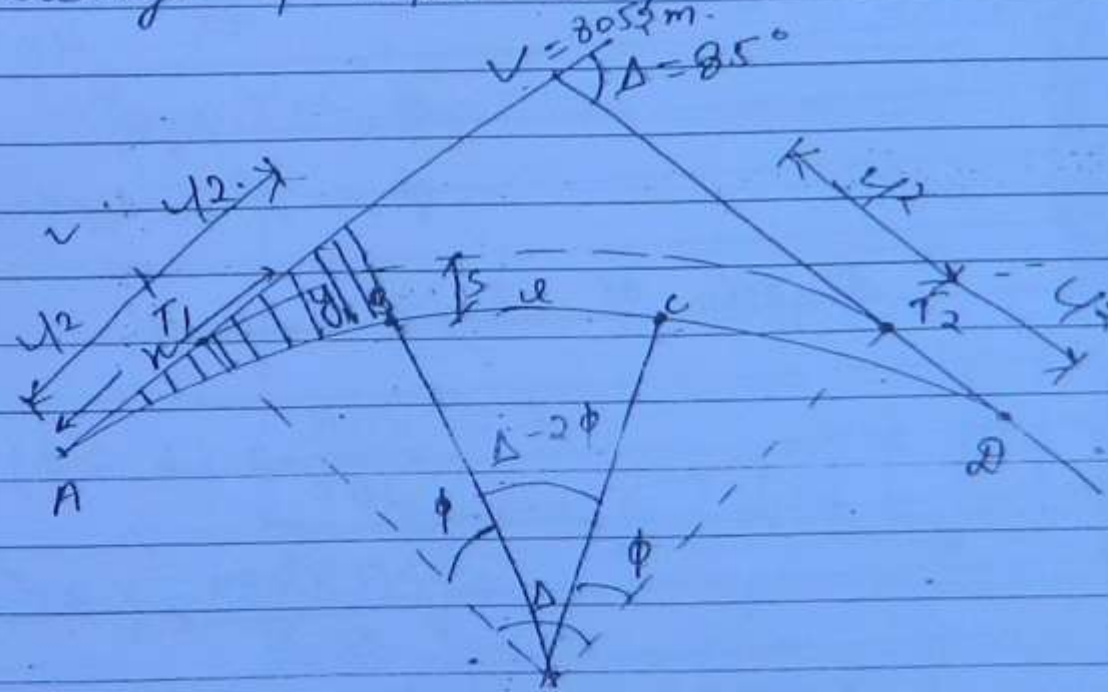
$= 0.073 \times 7.60 \times 82.88$

(4) $= 45.98$ m

So length of transition curve = 119

using on a curve

chainage of important points -



chainage V = 8052 m

Shift $S = \frac{L^2}{24R} = \frac{119^2}{24 \times 430} = 1.37$ m

1st tangent length -

-8 m

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

$$= \frac{119}{2} + (430 + 1.37)\tan\frac{85}{2}$$

$$= 454.78\,m$$

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Length of simple curve.

spiral angle $\phi = \frac{L}{2R} = \frac{119}{2 \times 430} = 0.138$ radian

$\phi = 7.928$

$\phi = 7^\circ 55' 41''$

Length of simple curve.

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

$$= \frac{2\pi \times 430}{360} \times (85^\circ - 2 \times 7^\circ 55' 41'')$$

$$= 518.92\,m$$

chainage V = 8052 m

$-(VA) = -454.78\,m$

Chainage of (A) = 7597.22

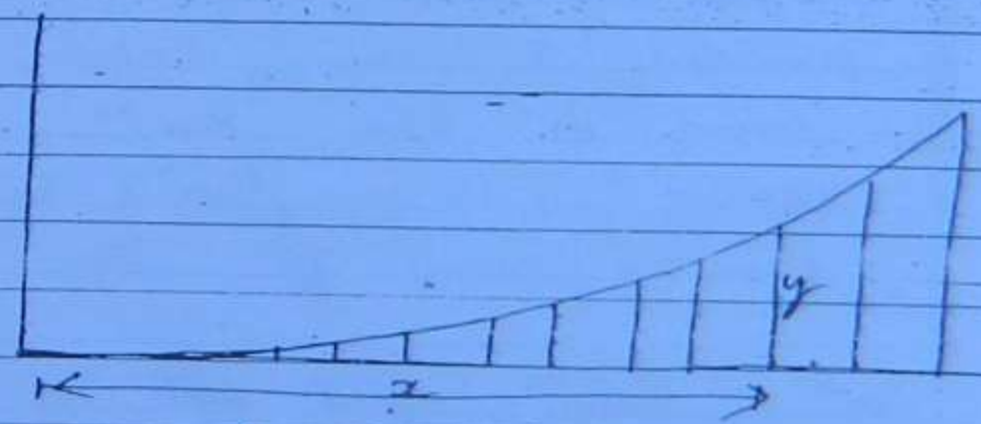
chainage of (B) = chainage of (A) + 119

chainage of B = 7597.22 + 119
= 7716.22 m

chainage of C = chainge of B + l
(43)
= 7716.22 + 518
8235.14 m

chainge of D = chainge of C + L
= 8235.14 + 119
= 8354.14 m

Setting of transition curve:-



$$y = \frac{x^3}{6RL} = \frac{x^3}{6 \times 430 \times 119} = \frac{x^3}{307020}$$

x	0	10	20	30	40	50	60	70	80	90
y	0	0.0032	0.026	0.087	0.208 m	0.407 m	0.703	1.117	1.66	2.37 m

100	110	119
3.25	4.33	5.48 m

ES-08 solⁿ is given of the valley curve.

Ques. Design the length of a transition curve for a B.G track, having 4° curve and a cant of 12cm. The max^m design speed on the curve is 100 kmph. Also calculate the offsets at every 15m distance and shift of circular curve. Assume cant deficiency of 7.60cm.

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Ques. Calculate the max^m permissible speed on a BG Track of 2° curve. S.E. provided is 9cm. Length of Transition curve is 125m. Max^m cant deficiency allowed is 10 cm. Max^m sanctioned speed by Railway Board on the track is 145 kmph.

Solⁿ. Max^m speed shall be minimum of following –

① Safe speed by Martin's formula.

$$D^\circ = 2^\circ$$

$$R = \frac{1720}{2} = 860$$

$$V_{max} = 4.35\sqrt{R-67} = 4.35\sqrt{860-67}$$

$$= 122.5 \text{ kmph}$$

use high speed formula -

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

$= 4.58\sqrt{860}$

(45) $= 134$ kmph

(2) as per cant formula -

Cant = 9 cm

cant deficiency = 10 cm

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

$= 9 + 10$

$= 19\text{ cm} = 0.19\text{ m}$

$$V_{max} = \sqrt{\frac{127 R \cdot e_{th}}{G}} = \sqrt{\frac{127 \times 860 \times 0.19}{1.676}}$$

$V_{max} = 111.27$ kmph

(3) as per length of transition curve

$$V_{max} = \frac{198 L}{e} \text{ or } \frac{198 L}{D}$$

$$= \frac{198 \times 125}{90} \text{ or } \frac{198 \times 125}{100}$$

$= 275$ kmph or $= 247.5$

(4) Max^m sanctioned speed by railway = 145 kmph

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So max^m speed allowed = 111 kmph. Ans

Q On a transition curve on BG track. the speed by railway board formula (Martin's formula) $V = 4.35\sqrt{R-67}$ is 1.35 times speed calculated by cant formula after allowing a cant deficiency of 7.6 cm. If actual cant is provided for a speed of 80 kmph. Calculate :-

1- Radius of curve.
2. max^m speed allowed
3. Actual value of cant provided.

(1) $$4.35\sqrt{R-67} = 1.35\sqrt{\frac{127R \cdot e_{th}}{1.676}}$$

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

$$e_{th} = \frac{84.46}{R} + 7.6\times10^{-2}$$

$$e_{act} = \frac{GV^2}{127R} = \frac{1.676\times 80^2}{127R} = \frac{84.46}{R}$$

$$4.35\sqrt{R-67} = 1.35\sqrt{\frac{127R}{1.676}\left\{\frac{84.46}{R} + 7\times10^{-}\right.}$$

$$4.35\sqrt{R-67} = 1.35\sqrt{6400 + 5.758R}$$

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$$(4.35)^2(R-67) = (1.35)^2(6400 + 5.758R)$$

$$18.9225R - 1267.8075 = 11664 + 10.4939R$$

$$8.4286R = 12931.8075$$

$$R = 1534.5$$

$$R = 1535\ m$$

(3) $e_{act} = \frac{84.46}{R} = \frac{84.46}{1535} = 0.055m$

$= 0.055 \times 100$
$= 5.5\ cm$

(2) By martin's formula

$V = 4.35\sqrt{R-67} = 166.66$

By cant formula

$$V = \sqrt{\frac{127 \times 1535 \times}{1.676}\left(\frac{84.46}{1535} + 0.076\right.}$$

$V = 123$ kmph

So max^{m} speed $= 123$ kmph.

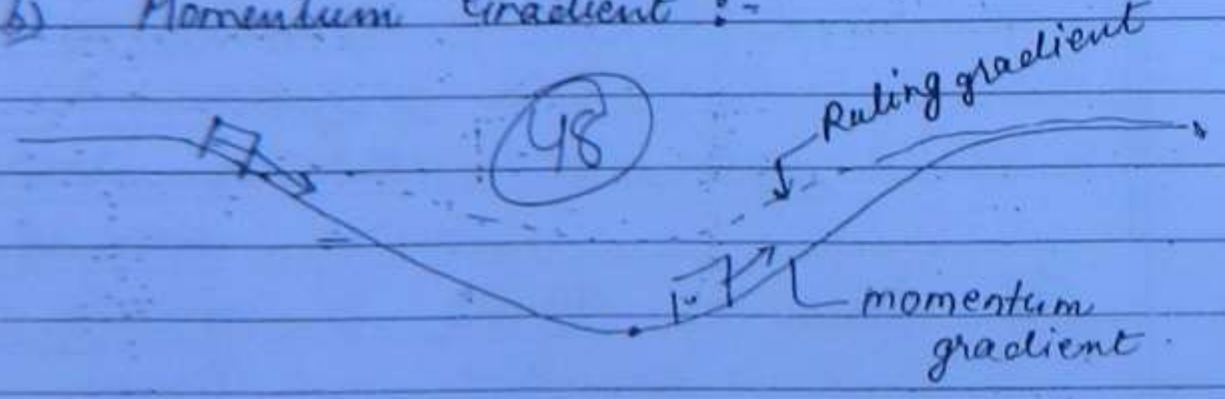
Design of Vertical ~~A~~lignment :-

1. Gradients :- Max^m slope that can be provided in longitudinal dir^n.

a) Ruling Gradient :- Max^m gradient that can be provided in most general condition.

Slope - in plains - 1 in 150 to 1 in 200
in hilly area - 1 in 100 to 1 in 150

b) Momentum Gradient :-



In a particular situation, as shown in fig., when extra momentum gained during d/w movement can be used for upward movement, A slope slightly more than ruling gradient can be provided, that is called momentum gradient.

c) Pusher Gradient :- In very extra
(49) ordinary situation,
there is no other option, Pusher Gradi.
can be provided that need extra
engine to push the train on
steeper gradient.
1 in 75 slope can be provided
with one extra locomotives.

d) Gradient in station Yards :- Slope in
station yard
should be min^m slope, so that train does
not move automatically.
Min^m slope is required for drainag
1 in 1000 → for good surface
1 in 200 → for an inferior surface.

on station yard -
max^m slope - 1 in 400
min^m slope - 1 in 1000.

e) Grade Compensation on curve :-

curve restrict resistance
restrict the speed to accomodate
the effect of curve. The value of

gradient is slightly reduced at curve location. This reduction of gradient at curve is called grade compensation.

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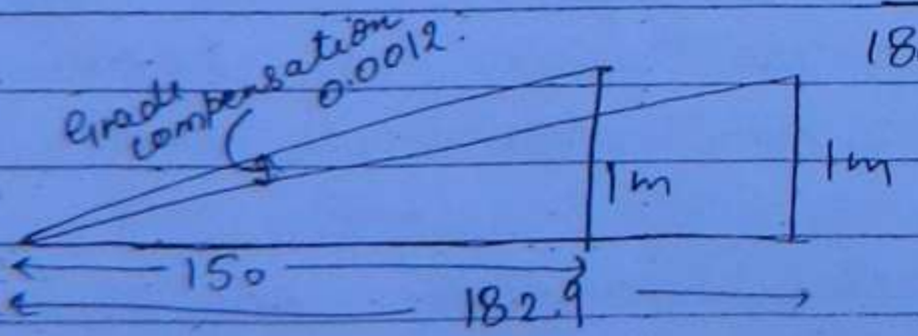
BG = 0.04 % per degree of curve = 0.0004 D°
MG = 0.03 % per degree of curve = 0.0003 D
NG = 0.02 % per degree of curve = 0.0002 D°

eg:- Ruling gradient = 1 in 150
curve of 3° on a BG Track.
Grade compensation = 0.04% per degree
$= \frac{0.04}{100} \times 3 = 0.0012$

compensated gradient $= \frac{1}{150} - 0.0012$
$= 5.467 \times 10^{-3}$
$= \frac{1}{182.9}$

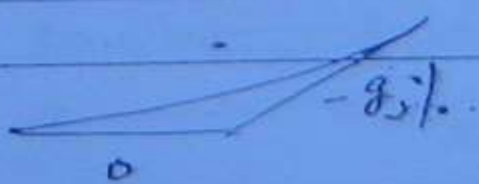


Vertical Curve -

(1) Summit Curve
(2) Valley Curve

(1) Summit Curve :-

(2) Valley Curve -



Summit Curve :-

1^{st} gradient $= +g_1\%$

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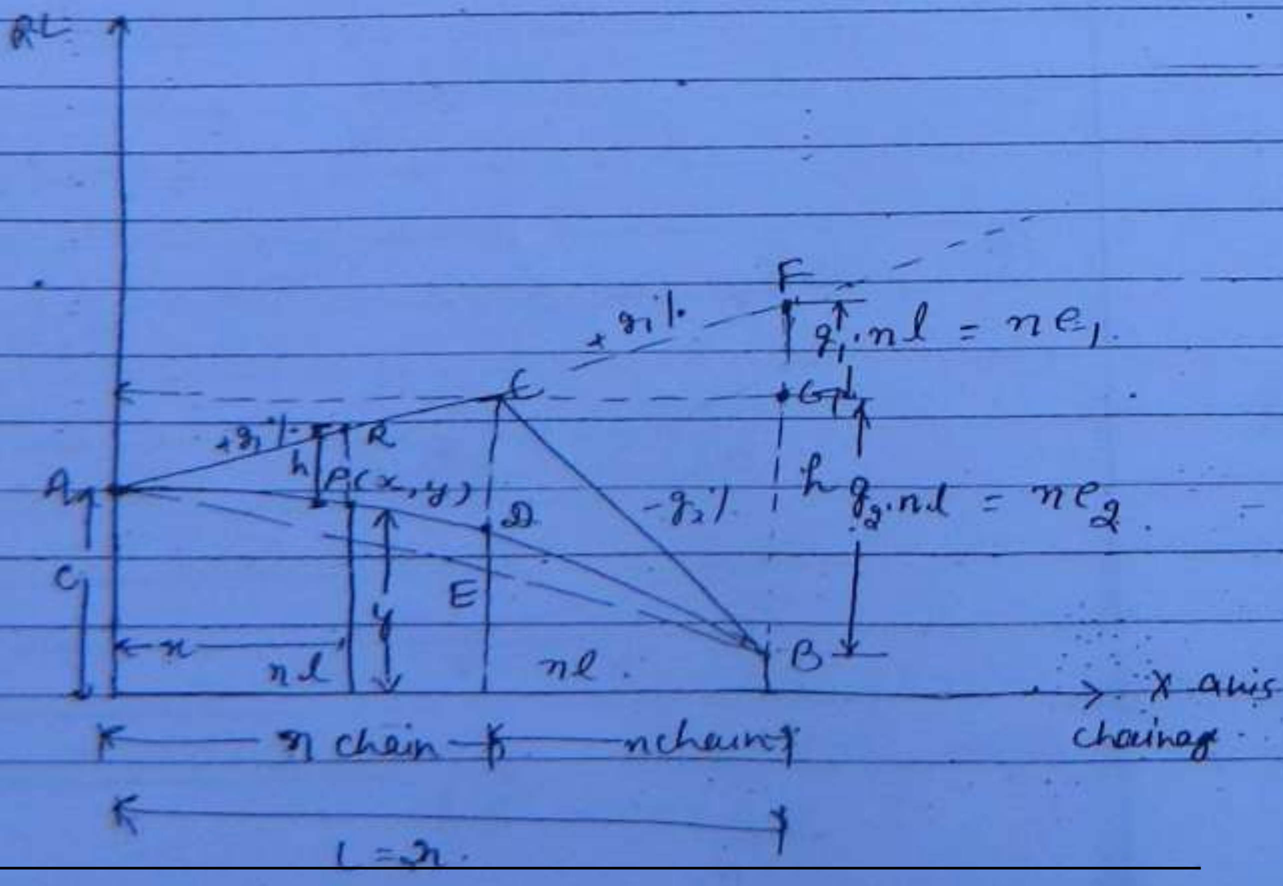
2^{nd} gradient $= -g_2\%$

if r = rate of change of gradient per chain length.

Length of summit curve :

$$\boxed{L = \left|\frac{(g_1 - g_2)}{r}\right|}$$ ← General formula.

$= 2n$ chains



if RL of C = known

RL of A = RL of C $- \frac{g_1}{100} \times n l$.

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RL of B = RL of C $- \frac{g_2}{100} \times n l$

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

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

(here l = length of one chain (30 m or 20 m

→ if P is a point on the curve having co-ordinate (x, y)

→ A simple ~~curve~~ parabola is used for summit curve.

General eq^n of curve –

diffl^n eq^n – $y = ax^2 + bx + c$ —— (1)

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

$y = c$

slope eq^n : $\frac{dy}{dx} = 2ax+b$.

at $x=0$

$$\frac{dy}{dx} = g_1 = 0+b$$

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$$b = g_1.$$

$\therefore$ eq^n $\rightarrow$

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

To find out RL of (P)

$$RL \text{ of } (R) = RL \text{ of } (A) + g_1 x$$
$$= c + g_1 x.$$

$$RL \text{ of } P = RL \text{ of } R - h$$
$$h = RL \text{ of } R - RL \text{ of } P.$$
$$= c + g_1 x - y$$
$$h = c + g_1 x - (ax^2 + g_1 x + c)$$
$$h = -ax^2.$$

$-a$ is a const. Put $K = -a$.

$$\therefore \boxed{h = Kx^2}$$

e_1 = rise per chain length (for $+g_1$)

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

e_2 = fall per chain length (for $-g_2$)

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$$= -\frac{g_2}{100} \times l$$

For last point on curve

$$FB = h = ne_1 - ne_2 = n(e_1 - e_2)$$

For point B $\quad x = 2n$

$$h = Kx^2$$

$$h = K(2n)^2$$

$$h = K \cdot 4n^2$$

$$h = n(e_1 - e_2)$$

$$K \cdot 4n^2 = n(e_1 - e_2)$$

$$\boxed{K = \frac{(e_1 - e_2)}{4n}}$$

Final value

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

for diff^n point on the curve

$x = 0, 1, 2, 3, 4$ --- no. of chains.

Q. A summit curve has two grade +0.65% and −0.85%. Rate of change of gradient per chain length is 0.15%. Chainage & RL of point of intersection is 2500 m and 350.50m respectively. Calculate length of summit curve and RL and chainage of diffn points on the curve. Find out apex of the curve also. (use 30m chains).

$g_1 = +0.65\%$

$g_2 = -0.85\%$

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$r = 0.15\%$

$$\text{length of curve} = \frac{g_1 - g_2}{r} = \frac{+0.65-(-0.85)}{0.15}$$

$= 10 \text{ chain } (2n)$

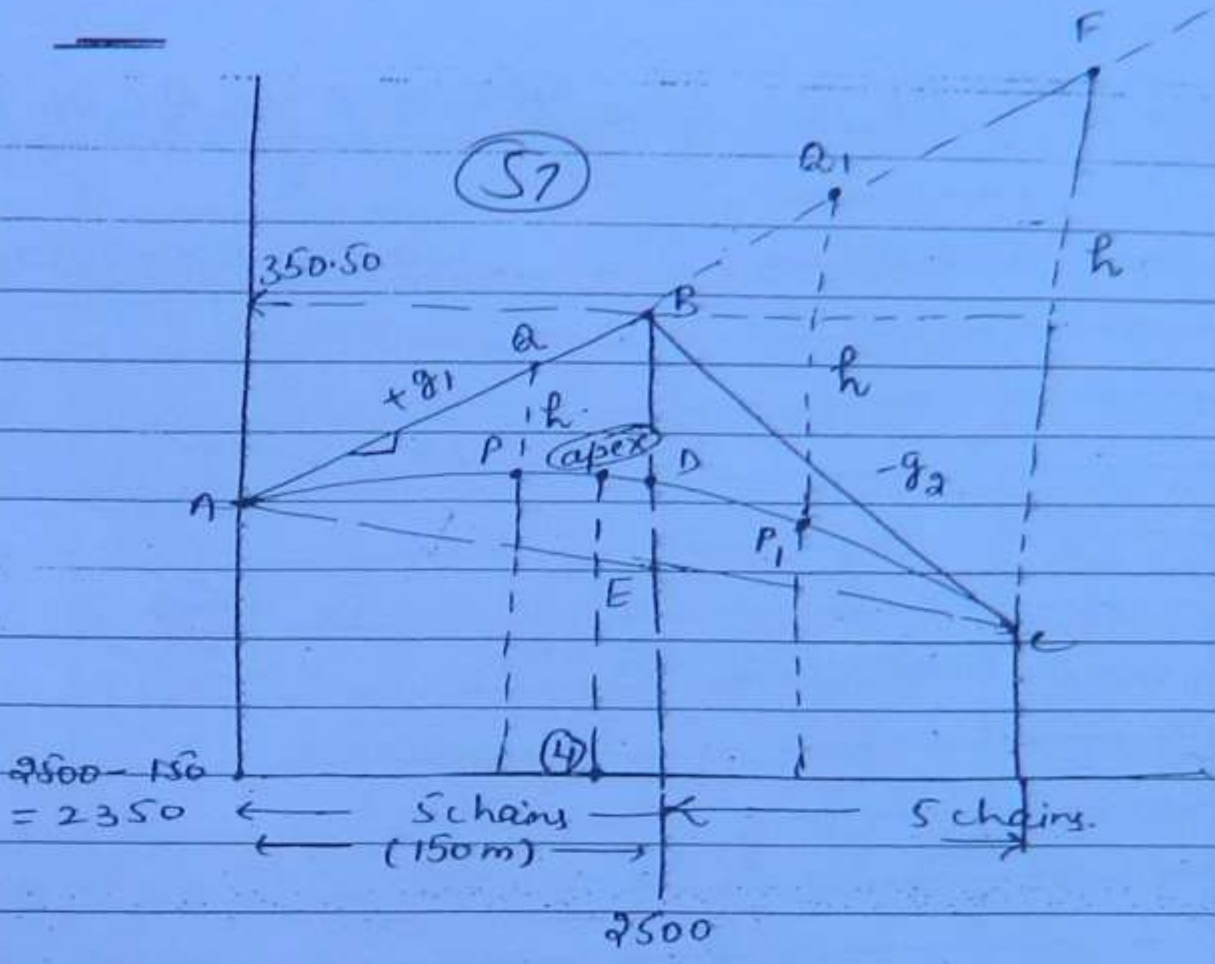
$n = 5$ chains.

$$\text{R.L of A} = \text{R.L of B} - \frac{0.65}{100} \times 150$$

$$= 350.50 - \frac{0.65}{100} \times 150$$

$= 349.525\text{m}$

(57)



$$RL\ of\ C = RL\ of\ B - \frac{0.85}{100} \times 150$$

$$= 350.50 - \frac{0.85}{100} \times 150$$

$$= 349.225$$

$$R.L.\ of\ E = \frac{RL\ of\ A + RL\ of\ C}{2}$$

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

$$= 349.375\ m$$

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

$$= \frac{350.50 + 349.375}{2}$$

$$= 349.9375\ m$$

$$h = kx^2$$

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here $k = \dfrac{e_1 - e_2}{4n}$

$$e_1 = \frac{g_1 l}{100} = \frac{0.65 \times 30}{100} = 0.195$$

$$e_2 = -\frac{g_2 l}{100} = \frac{-0.85 \times 30}{100} = (-0.255)$$

$$k = \frac{0.195 + 0.255}{4 \times 5}$$

$$= 0.0225$$

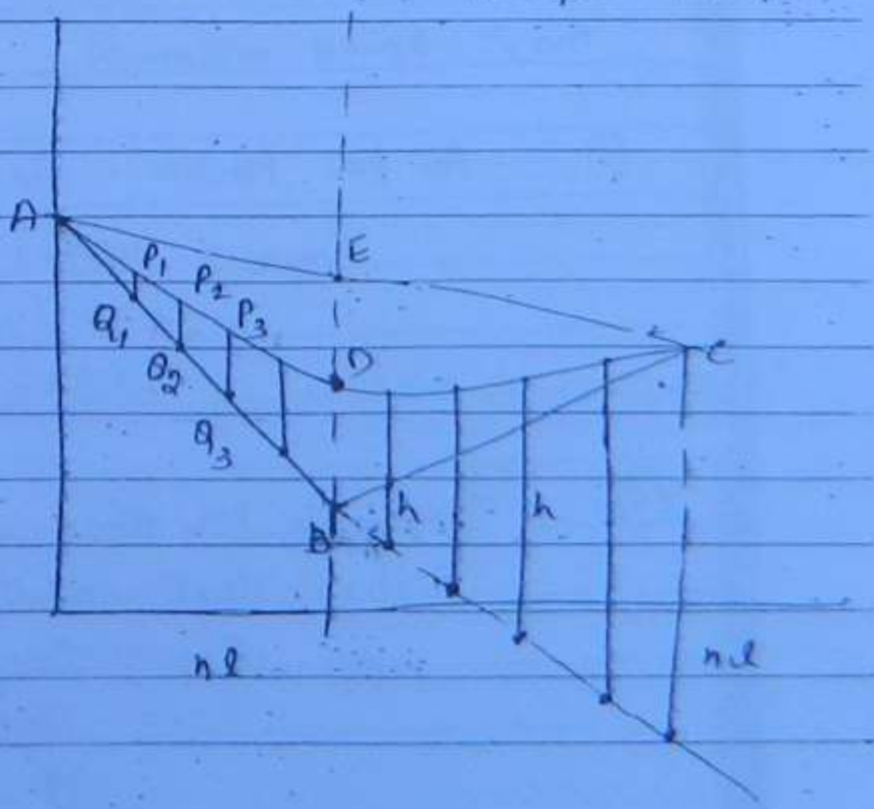
$$h = kn^2$$

$$= 0.0225\, x^2 \quad \{ \; n = 0, 1, 2, 3, \ldots$$

Points	Chainage	RL on points on 1st tangent $\left(\frac{0.65}{100} \times 30 = 0.195\right)$	$h = kx^2$	RL on point on curve
			0	
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	apex 349.945
5	2500	350.500	0.5625	349.9375
6	2530	350.695	0.81	349.885
7	2560	350.890	1.1025	349.7875
8	2590	351.085	1.44	349.645
9	2620	351.280	1.8225	349.457
10	2650	351.475	2.25	349.225

RL of (P) = RL of Q + h

Valley curve:-



Q. A sag curve has a down grade 0.8% followed by an up gradient of 1.20%. Allowable rate of change of gradient is 0.20%. RL & chainage of point of intersection are 1200m & 120.50m. Calculate RL and chainage of diffⁿ points on valley curve (use 20m chain).

Solⁿ of Ques ESE 08

(68)

4° curve

$$R = \frac{1720}{4^\circ} = 430\text{ m}$$

cant = 12cm

max^m design speed = 100 kmph

cant deficiency = 7.6cm

max^m speed allowed

① As per Martin's formula

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

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

$$= 82.88\text{ kmph}$$

② Speed as per cant formula

theoritical cant

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

$$= 12 + 7.60$$

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

max^m speed allowed -

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

$$= \sqrt{\frac{127 \times 430 \times 0.196}{1.676}}$$

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$$= 79.9 \text{ Kmph}$$

So max^m speed allowed on track = 100 kmph

$\therefore$ So max^m speed = min^m of above three

$= 79.9 \simeq 80$ kmph

using 2nd approach -

① $L = 4.4\sqrt{R}$

$= 4.4\sqrt{430}$

$= 91.24$ m

② $L = 3.6e$

$= 3.6 \times 12 = 43.2$ m

③ $L = \frac{3.28\ v^3}{R} = \frac{3.28 \times (0.278 \times 80)^3}{430}$

$= 83.9$ m

$L = 91.24\text{m} \simeq 92$m

Shift $= \frac{L^2}{24R} = \frac{92^2}{24 \times 430} = 0.82m$

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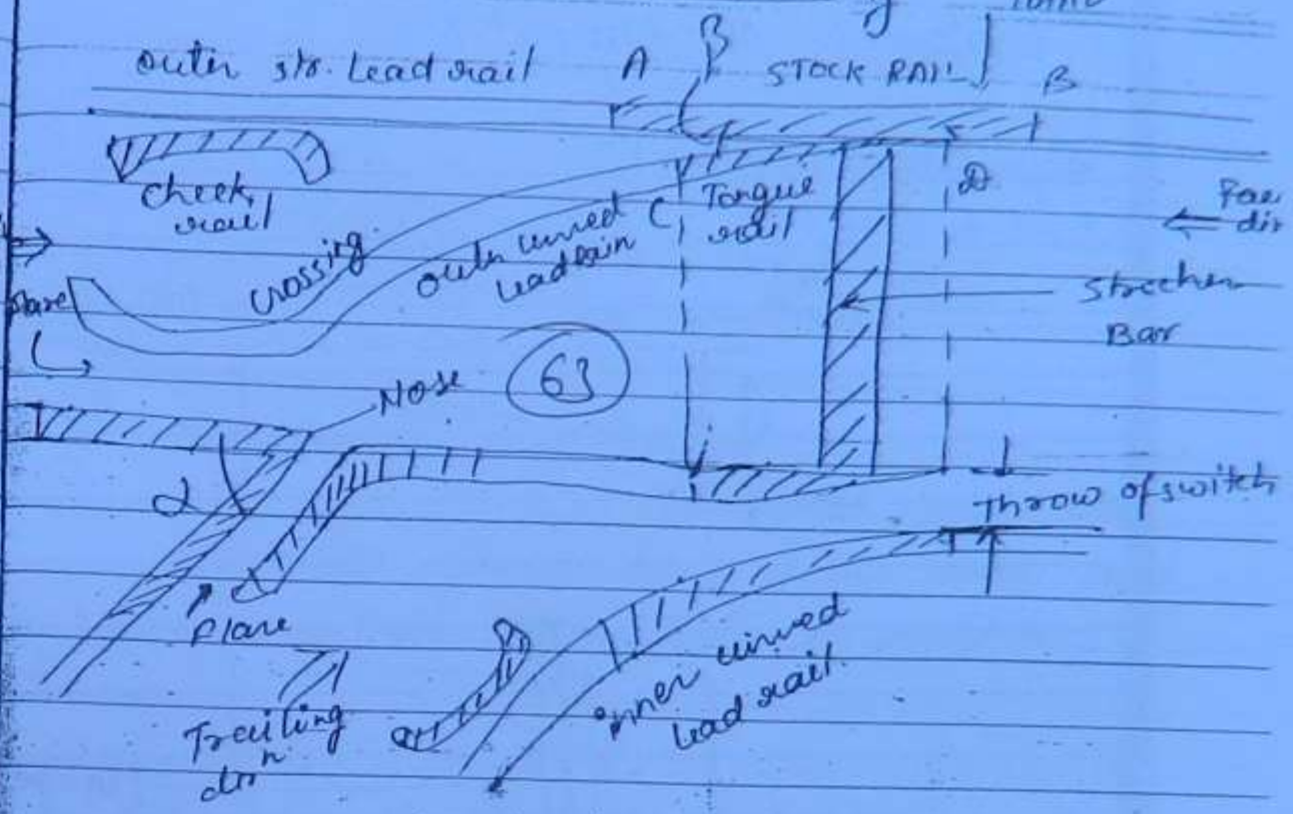
eq^n of T.C

$y = \frac{x^3}{6RL} = \frac{x^3}{6 \times 430 \times 92} = \frac{x^3}{237360}$

Trail(ing) dir^n

x	0	15	30	45	60	75	90	92
y	0	0.014	0.113	0.384	0.91	1.78	3.07	3.28

Point & Crossing



Turn out :- Turnout is an arrangement to divert the train from one track to another, to get better flexibility of movement b/w different tracks.

→ These are one of the weakest location of railway track, so very strong material is required. High magnese steel is used for points & crossing.

→ Diffn component are shown in fig.

Component of turnout :-

(a) Point (Switch) :-

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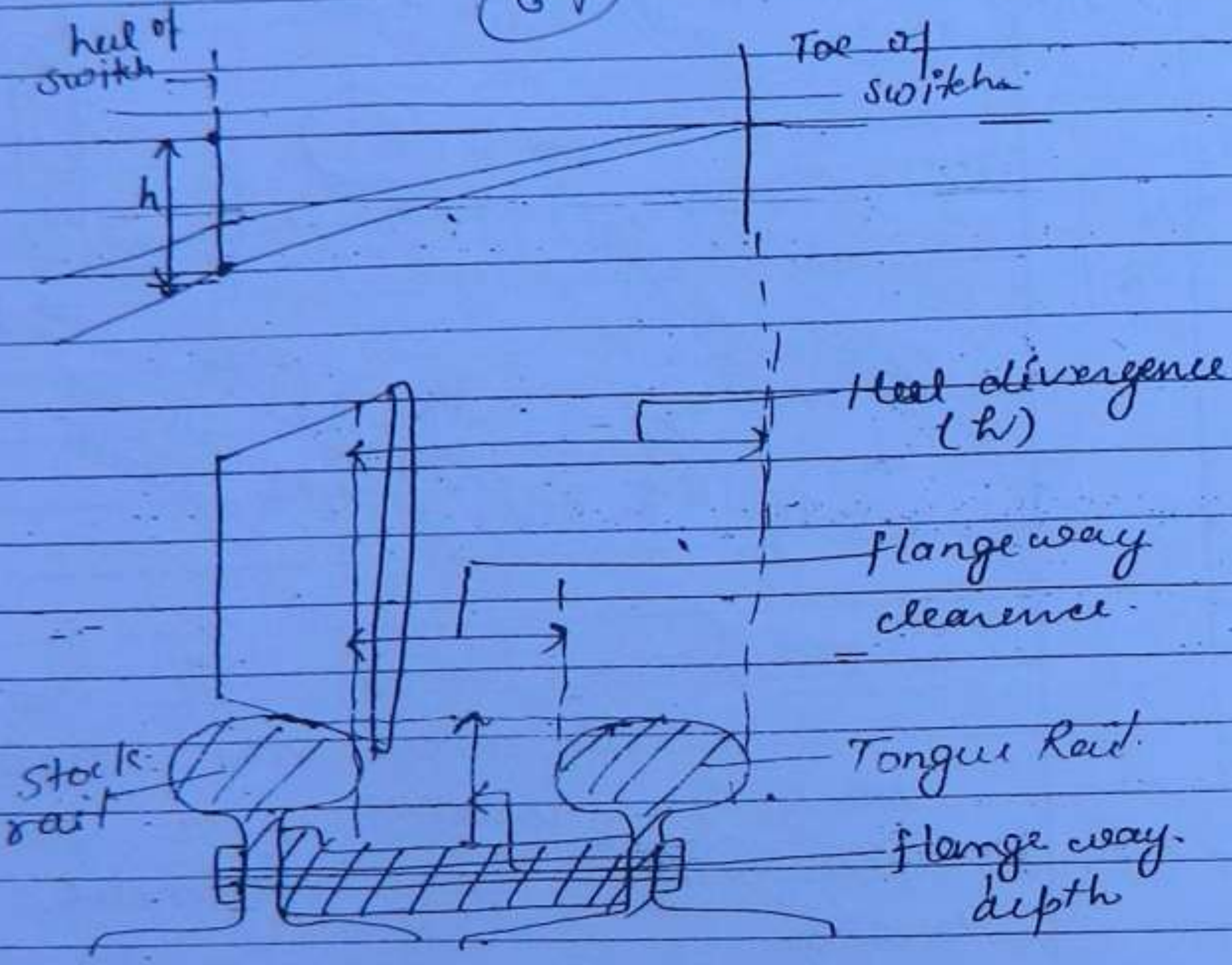

Section at heel of switch

① Heel Divergence :- Distance b/w running faces of Stock rail and tongue rail at heel of switch.

In india	values
BG	13.7 to 13.3 cm.
MG	12.1 to 11.7 cm.
NG	9.8 cm.

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(2) Flangeway clearance:- Distance b/w the adjacent faces of stock rail and tongue rail at heel of switch.

Value in India -
for 1 in 12 crossing = 6.3 cm
for 1 in $8\frac{1}{2}$ crossing = 6.6 cm.

(3) Flangeway depth:- Vertical distance b/w top of rails to heel ~~heel~~ block.

(4) Throw of Switch:- The distance by which toe of tongue rail moves side ways.

Values	in india
BG -	9.5 cm.
MG/NG - -	8.9 cm.

(5) Switch Angle :-
S

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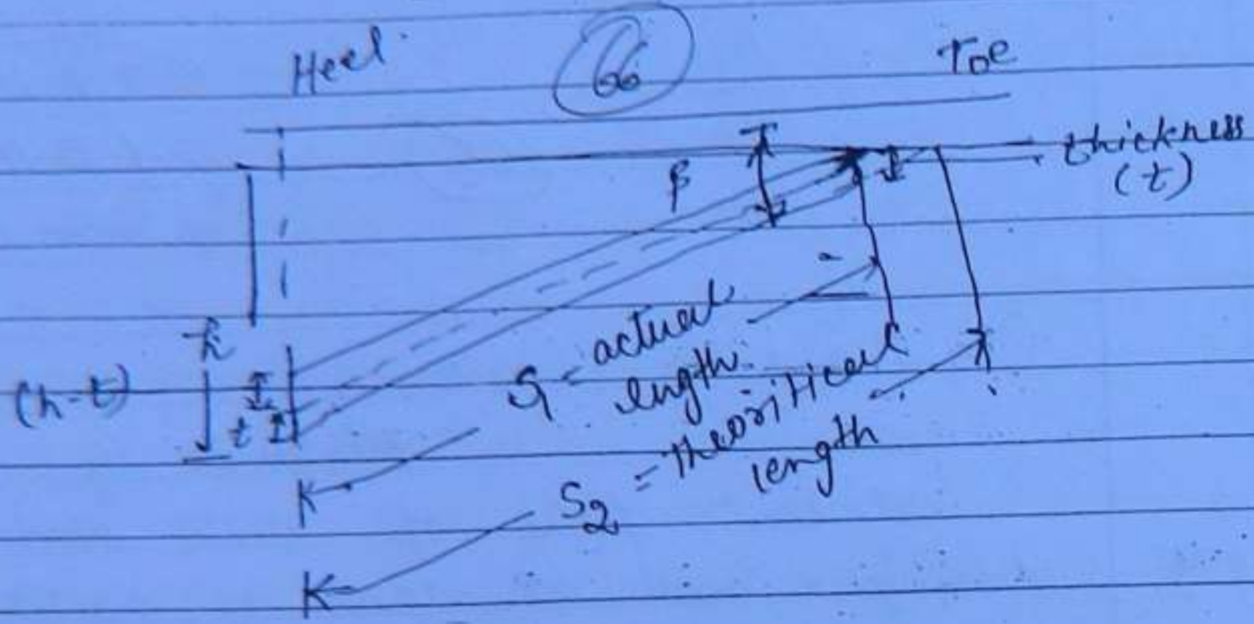
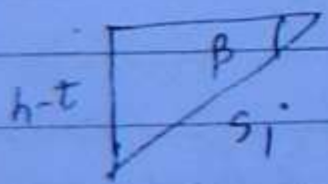
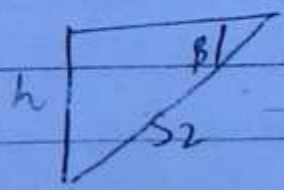


if s_1 = actual length of tongue rail
s_2 = Theoritical length of tongue rail

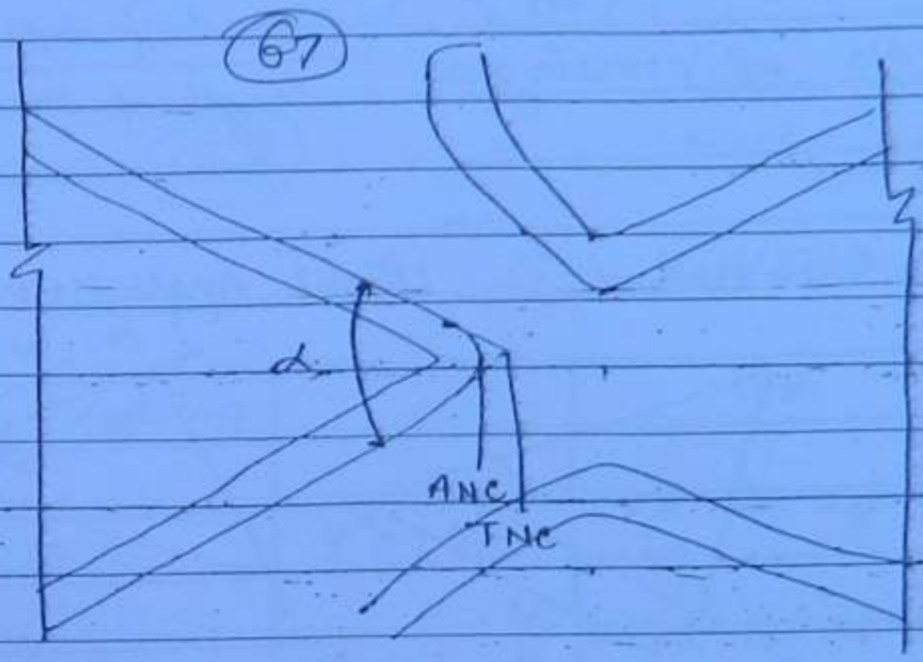




$$\boxed{\sin\beta = \frac{h-t}{s_1} = \frac{h}{s_2}}$$

$$\beta = \sin^{-1}\left(\frac{h-t}{s_1}\right) = \sin^{-1}\left(\frac{h}{s_2}\right).$$

Crossing :-



→ Crossing should be rigid to sustain severe impact loads, vibration etc.

→ Medium or high ~~mg~~ magnese. steel is used.

Important Points :-

(1) ANC → Actual Nose of crossing due to blunt face.

(2) TNC → Theoritical nose of crossing intersection points of two rails

(5) Angle of crossing OR Number of crossing :-

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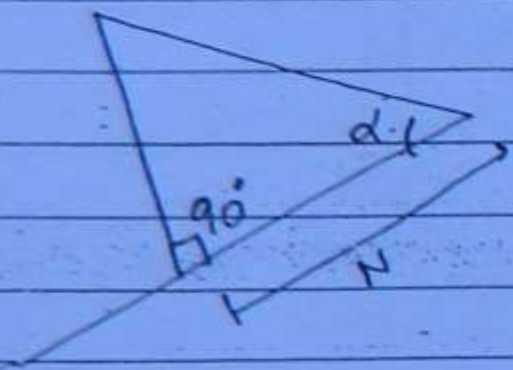
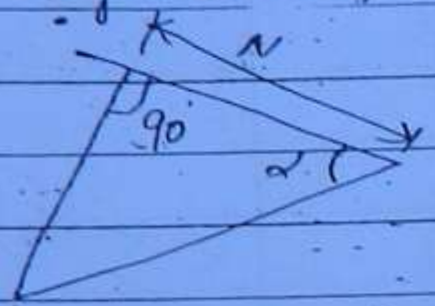
$$\text{No. of crossing} = \frac{\text{spread of two legs of crossing}}{\text{length of rail from TNC}}$$

(a) Cole's Method :- (Right Angle Method)





$$\tan\alpha = \frac{1}{N}$$

$$\boxed{N = \cot\alpha}$$

$$\alpha = \cot^{-1} N = \tan^{-1}\left\{\frac{1}{N}\right\}$$

α = angle of crossing.

1 in N = number of crossing.

This method is used on indian railway.

eg:- If No. of crossing is 1 in 12

$$\cot\alpha = 12$$

$$\tan\alpha = 1/12$$

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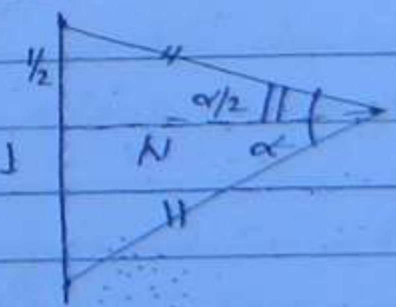
$$\alpha = \tan^{-1}\left\{\frac{1}{12}\right\} = 4.76$$

$$\alpha = 4^\circ 45' 49.11'' \text{ Ans.}$$

No. of crossing	α	use.
1 in 6	$9^\circ 27' 44''$	used in symmetrical split
1 in $8\frac{1}{2}$	$6^\circ 42' 35''$	used in station yard where space is restricted and speed is low
1 in 12	$4^\circ 45' 49''$	used on station yard of main line
1 in 16	$3^\circ 34' 35''$	used on high speed turns on main line of BG/NG tracks.

(2) Centre line Method :-



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

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

$$\boxed{N = \frac{1}{2}\cot\frac{\alpha}{2}} \leftarrow \text{No. of crossing.}$$

$$\frac{\alpha}{2} = \cot^{-1}(2N).$$

$$\boxed{\alpha = 2\cot^{-1}(2N)}$$ angle of crossing

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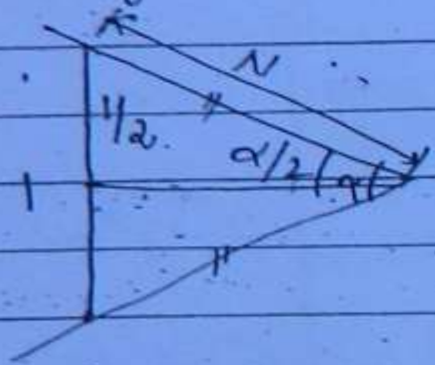
This method is used in US & UK.

3. Isoseles Triangle method :-



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

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

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

$$\boxed{N = \frac{1}{2}\operatorname{cosec}\frac{\alpha}{2}}$$ no of crossing.

$$\boxed{\alpha = 2\operatorname{cosec}^{-1}(2N)}$$ angle of crossing.

This method is usedin tramways.

sing

Design Calculation of Turnout

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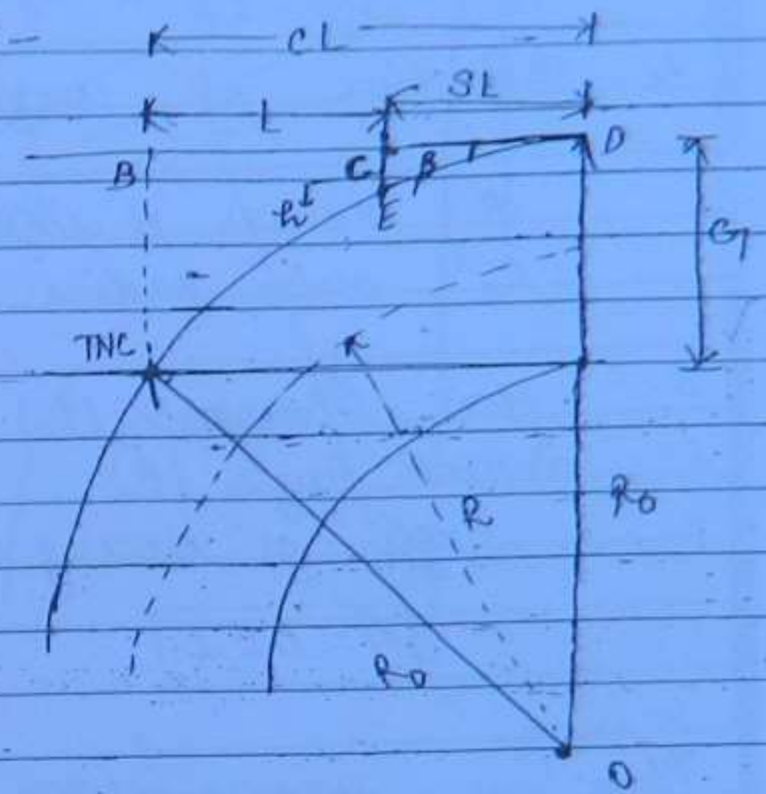
Components :-



① Curve lead (CL) :- The distance b/w toe of switch ~~to~~ to TNC measured along straight lead rail

② Switch lead (SL) :- The distance b/ toe of switch to heel of switch measured along straight rai.

③ Lead (L) or Crossing lead :- Distanc b/w heel of switch to TNC measured along straight rail.

Relation – $\boxed{CL = SL + L}$

4. Radius of curve :–

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R = radius of centre

R_0 = outer radius $= R + \frac{G}{2}$ $\Big\}$ G = gauge

5. Heel Divergence (h)

6. Switch Angle (β)

7. Angle of crossing (α)

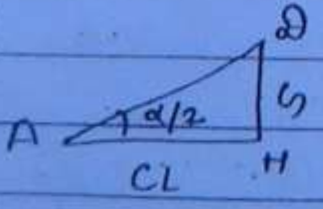
$$\boxed{N = \cot \alpha}$$

There are three method :–

1. Method-1 – In this method curve is starting from toe of switch & ends at TNC.

Given values – G, α or N.

1. Curve lead (CL) –

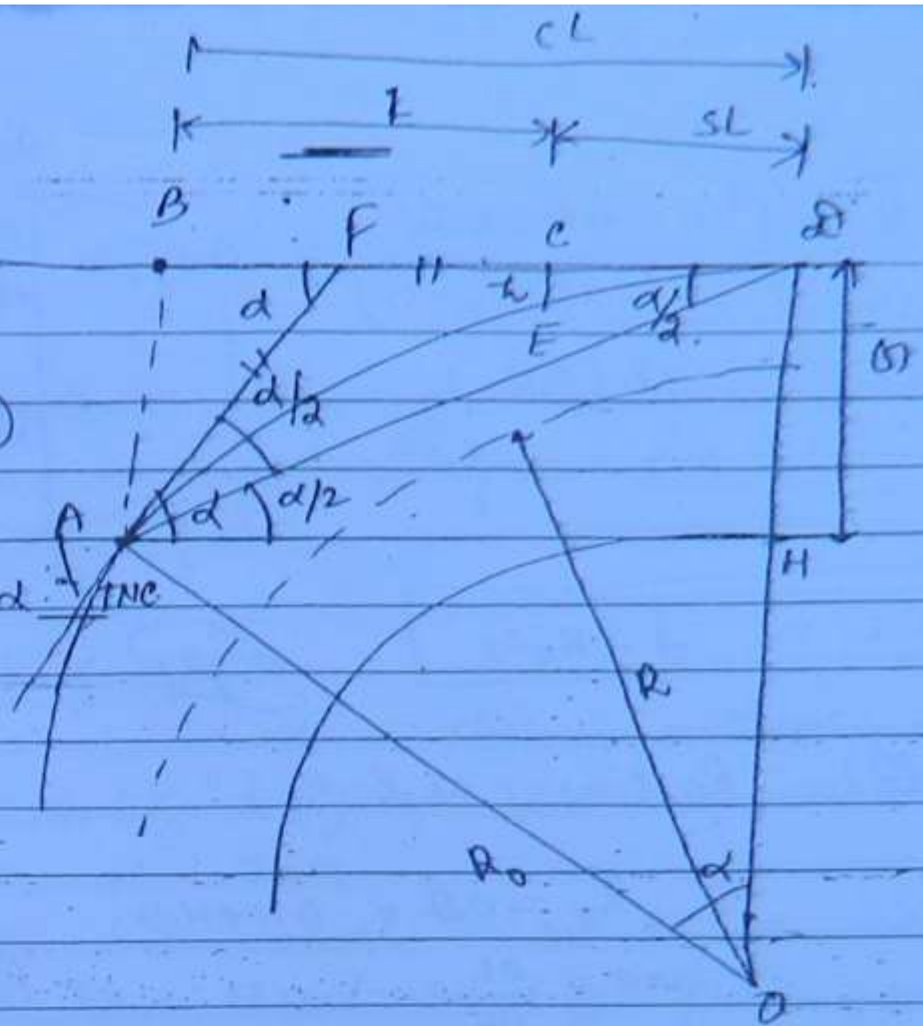


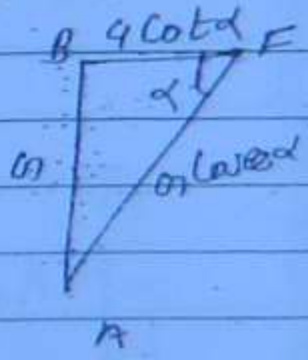
(a) $CL = BD = AH$

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

$$CL = \frac{G}{\tan\frac{\alpha}{2}} = G\cot\frac{\alpha}{2} \quad \text{— (1)}$$

(3)





2(b) $CL = BD = BF + FD$

$ = BF + AF$

$CL = G\cot\alpha + G\,\mathrm{cosec}\,\alpha$

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

$= GN + G\sqrt{1+N^2}$

$= GN + GN$

$= 2GN$

$\boxed{CL = 2GN}$ most widely used.

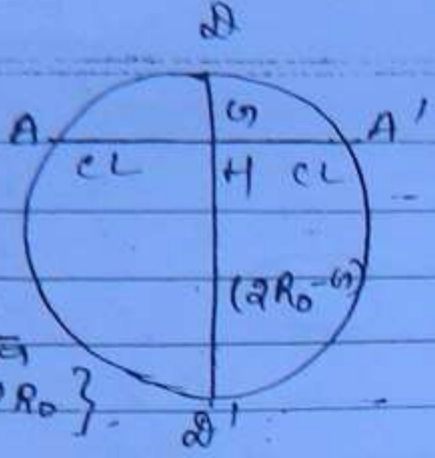
(c) using property of circle :-

$AH \times HA' = DH \times HD'$

$(CL)^2 = G \times (2R_0 - G)$

$(CL)^2 = G \times (2R_0)$

$\{2R_0 - G \approx 2R_0\}$.



$$\boxed{CL = \sqrt{2R_0 G}}$$

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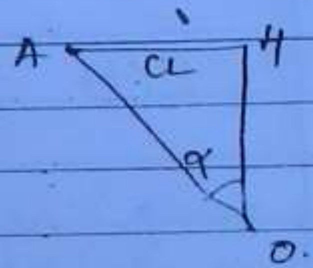
(2) Radius (R & R_0) :–

$R_0 = OD = OH + HD$

$\tan\alpha = \frac{CL}{OH} \Rightarrow OH = CL \cot\alpha$



$R_0 = CL \cot\alpha + G$

$= G + 2GN \cdot N$

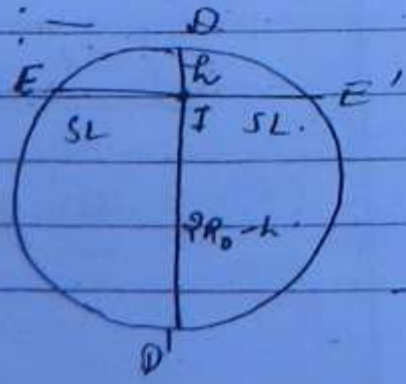
$$\boxed{R_0 = G + 2GN^2}$$

As per Indian Railway.

$$\boxed{R_0 = 1.5G + 2GN^2}$$ $$\boxed{R = R_0 - \frac{G}{2}}$$

8. Switched ~~Rail~~ Lead (SL) :–

Property of circle :–



$h(2R_0 - h) = (SL)^2$.

$(2R_0 - h \approx 2R_0)$.

$h \times 2R_0 = SL^2$

$$SL = \sqrt{2 R_o h}$$

4. Lead Crossing lead - $\boxed{L = CL - SL}$

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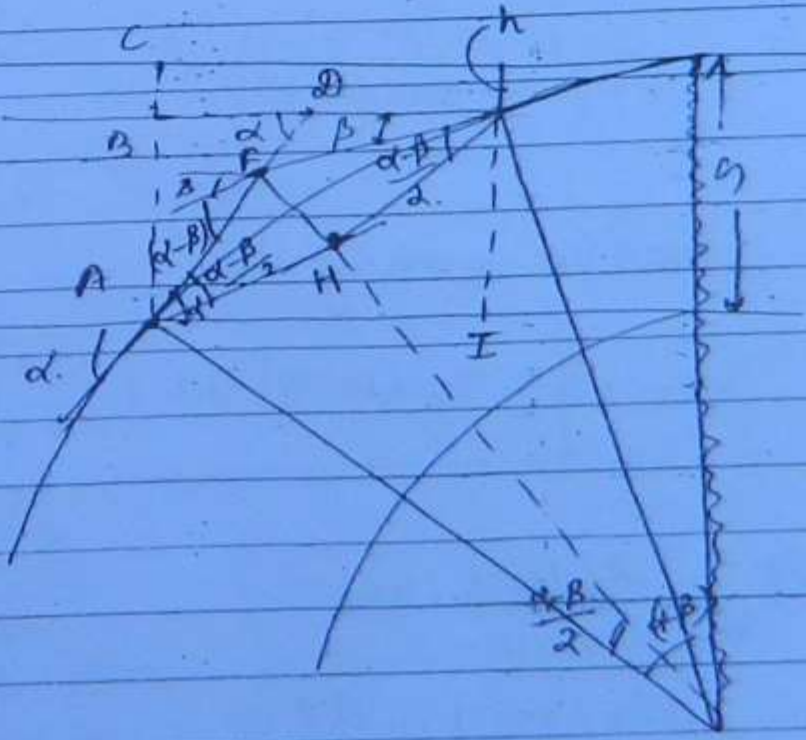
Method-2

In this method, the curve is starting from heel of switch & ends at TNC.

Only two values are to be calculated

1. Lead or crossing lead (L)
2. Radius (R_o or R)



Deflection angle $= \alpha - \beta$

$$\angle FAH = \angle FEH = \frac{\alpha-\beta}{2}$$

$$\angle HAI = \alpha - \frac{\alpha-\beta}{2} = \frac{\alpha+\beta}{2}$$

$$\angle AOE = \alpha - \beta = \text{defl}^n \text{ angle.}$$

$$\angle AOH = \frac{\alpha-\beta}{2}$$

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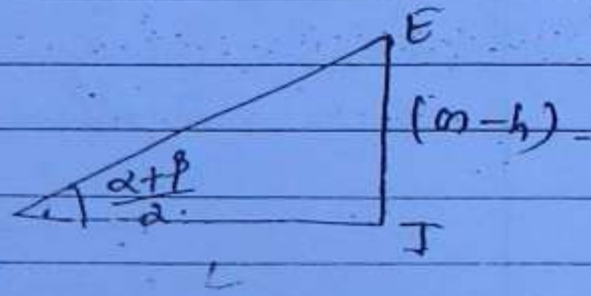
① Lead or crossing lead –

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

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



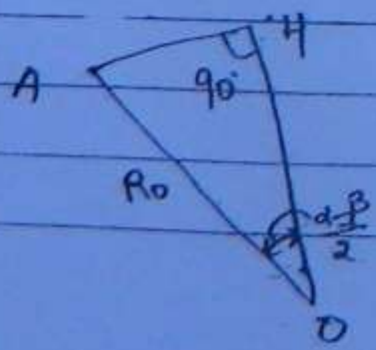
Lead or crossing Lead.

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

② Radius :–

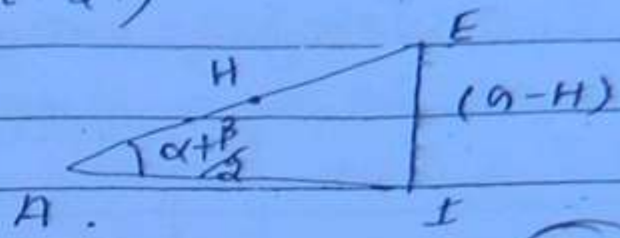
In Δ AHO

$$\sin\left(\frac{\alpha-\beta}{2}\right) = \frac{AH}{R_O}$$



$$R_0 = \frac{AH}{\sin\left(\frac{\alpha-\beta}{2}\right)} \quad \text{—(I)}$$

In Δ AEI



$\cancel{\sin\left(\frac{\alpha+\beta}{2}\right) = \frac{a-h}{\sin\left(\frac{\alpha+\beta}{2}\right)}}$

$\cancel{AE = (a-h}$

(II)

$$\sin\left(\frac{\alpha+\beta}{2}\right) = \frac{a-h}{AE}$$

$$\therefore \quad AE = \frac{(a-h)}{\sin\left(\frac{\alpha+\beta}{2}\right)}$$

$$\therefore \quad AH = \frac{1}{2} AE$$

$$AH = \frac{(a-h)}{2\sin\left(\frac{\alpha+\beta}{2}\right)}$$

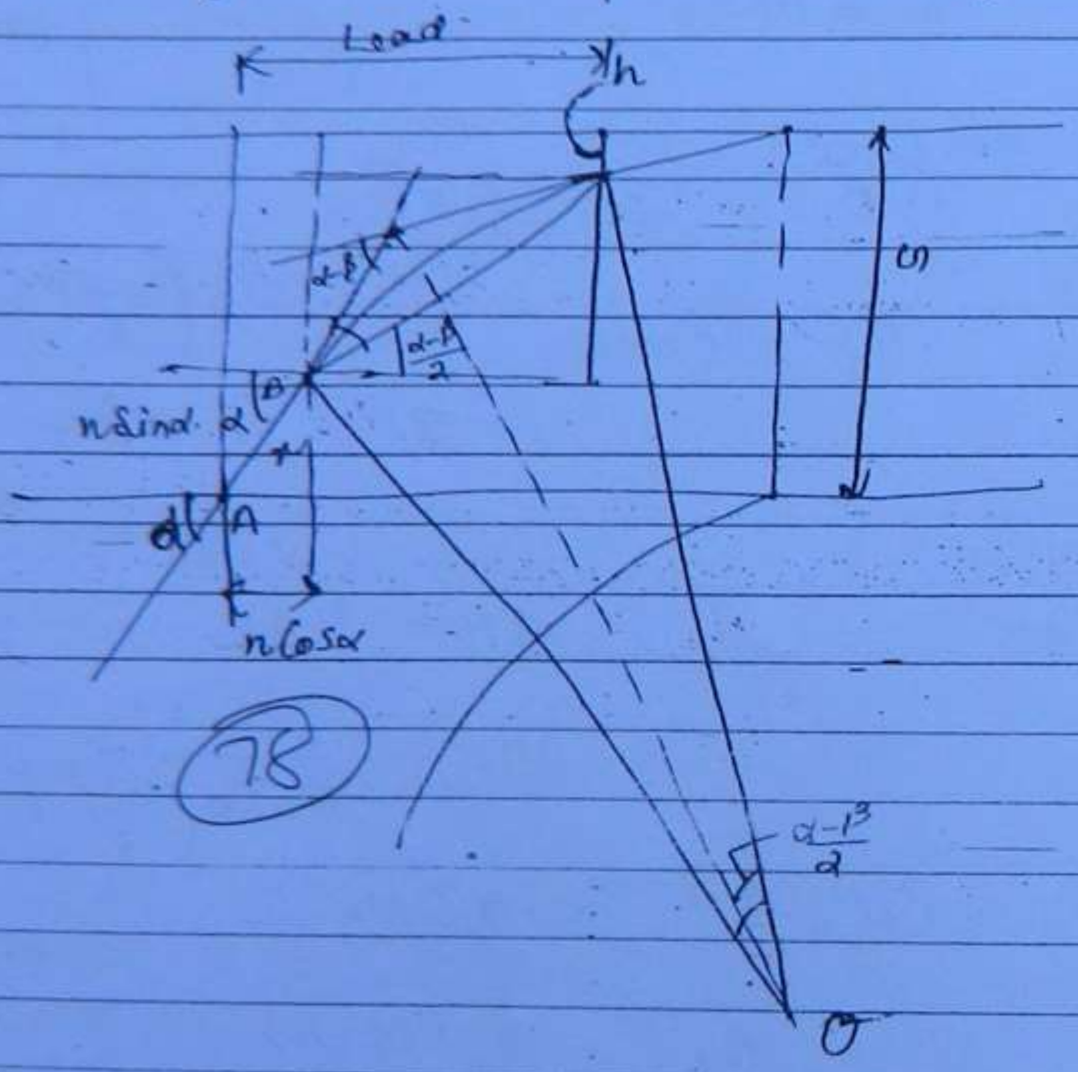
Put AH in eq^n (I)

$$R_0 = \frac{(a-h)}{2\sin\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha+\beta}{2}\right)}$$

$$\boxed{R_0 = \frac{a-h}{(\cos\beta - \cos\alpha)}}$$

$$\boxed{R = R_0 - \frac{a}{2}}$$

Method - 3 Curve is starting from heel of switch and ends at starting point of straight portion provided before TNC.



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① Lead or crossing lead -

$$\boxed{L = n\cos\alpha + (G - h - n\sin\alpha)\cot\frac{\alpha+\beta}{2}}$$

② Radius -

$$\boxed{R = \frac{(G - h - n\sin\alpha)}{\cos\beta - \cos\alpha}}$$

Derivation is same as method ②.

Q: What will be angle of switch and heel divergence if
theoritical length of switch = 5·10 m
thickness of tongue rail at toe = 0·65 cm
Actual length of tongue rail = 4·80 m.

Sol^n

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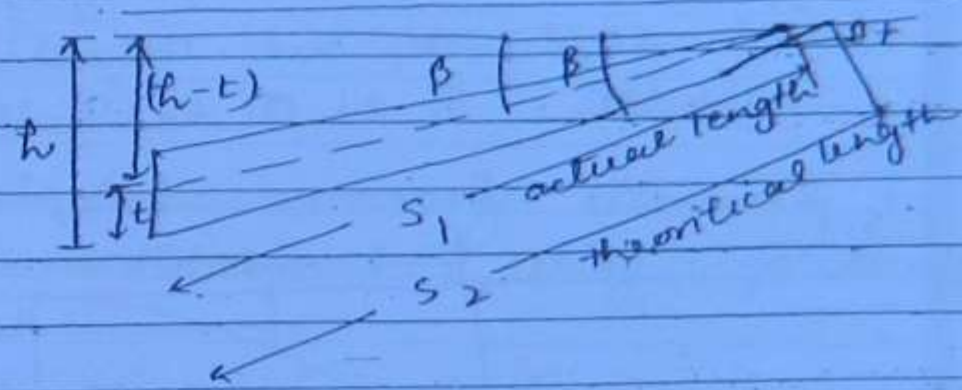
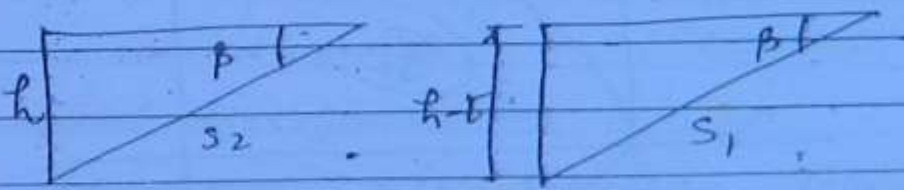




$$\sin\beta = \frac{h}{S_2} = \frac{h-t}{S_1}$$

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

$$\frac{h}{510} = \frac{h-\cdot65}{480}$$

$$h = \frac{0\cdot65\times510}{510-480} = 11\cdot05 \text{ cm}$$

Switch angle $\sin\beta = \dfrac{h}{S_2} = \dfrac{11\cdot05}{510}$

$\beta = 1^\circ 14' 29.42''$ Ans.

Q. Calculate necessary elements to set out a turnout taking from a straight BG track.

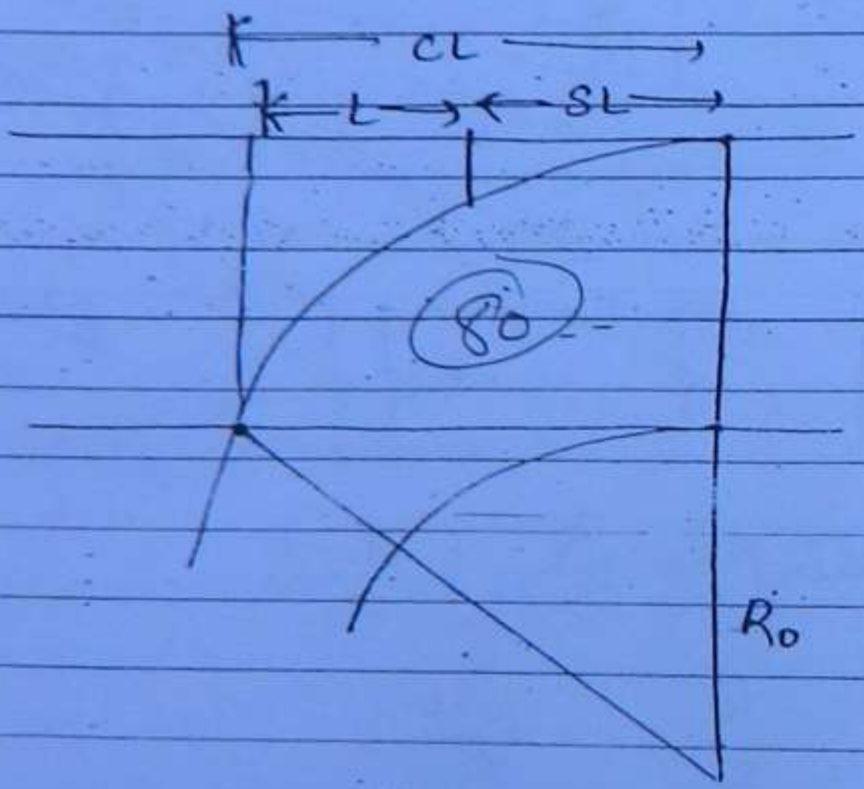
No of crossing = 1 in 12.

Heel divergence = 12 cm.

The curve is starting from toe of switch and ends at TNC.

- calculate ① CL ② R_0 ③ SL ④ L.

Sol^n



$CL = 2GN$

$= 2 \times 1.676 \times 12$

$\boxed{CL = 40.224\, m}$

$R_0 = 1.5G + 2GN^2$

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

$\boxed{R_0 = 485.202\, m}$

$$SL = \sqrt{2 R_0 h}$$
$$= \sqrt{2 \times 485.202 \times 0.12}$$
$$\boxed{SL = 10.819\ m}$$

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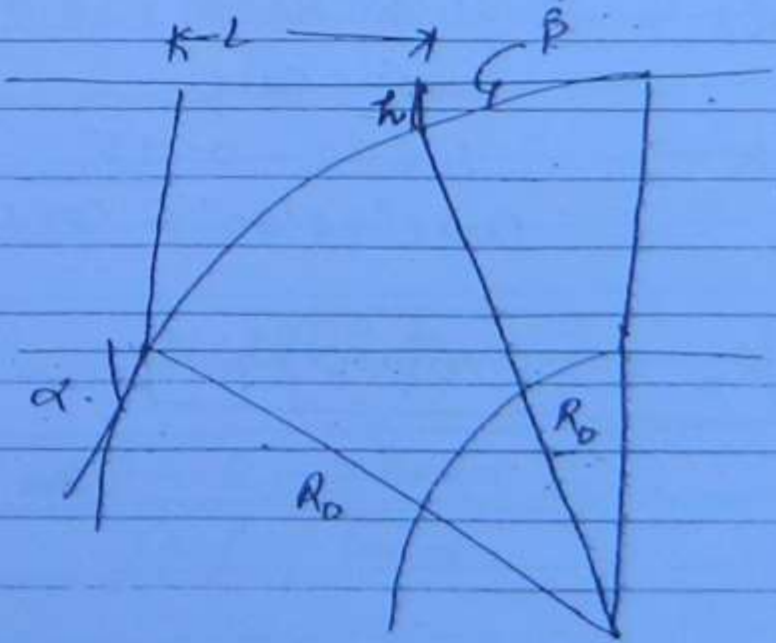
$$L = CL - SL$$
$$\boxed{L = 29.404\ m}$$

Q. calculate necessary elements to set out a turnout using following dat BG track.

no. of crossing 1 in 16
switch angle - 1°42' 30'
heel divergence - 13.5 cm.

The curve is starting from heel of switch & ends at TNC

Sol^n.



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

$\alpha = \tan^{-1}\left\{\frac{1}{N}\right\}$

$= \tan^{-1}\left\{\frac{1}{16}\right\}$

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$\alpha \doteq 3^{\circ}34'35''$

Switch Angle $\beta = 1^{\circ}42'30''$

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

$= \dfrac{1.676 - 0.135}{\tan\left(\frac{3^{\circ}34'35'' + 1^{\circ}42'30''}{2}\right)}$

$\boxed{L = 33.39\ m.}$

$R_0 = \dfrac{G-h}{\cos\beta - \cos\alpha}$

$= \dfrac{1.676 - 0.135}{\cos 1^{\circ}42'30'' - \cos 3^{\circ}34'35''}$

$\boxed{R_0 = 1025.27\ m}$

ES. 1994

Q. Calculate necessary elements to set out a 1 in $8\frac{1}{2}$ turnout taking off from a straight BG track, with its curve starting from heel of the switch and ending at a distance 864 mm from TNC.
heel divergence is 136mm
switch angle = $1°34'27''$.
Make a free hand sketch and show the calculated values.

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$$\alpha = \cot^{-1}\left(8\tfrac{1}{2}\right).$$

$$\alpha = 6°42'35.41''$$

$$\beta = 1°34'27''$$

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

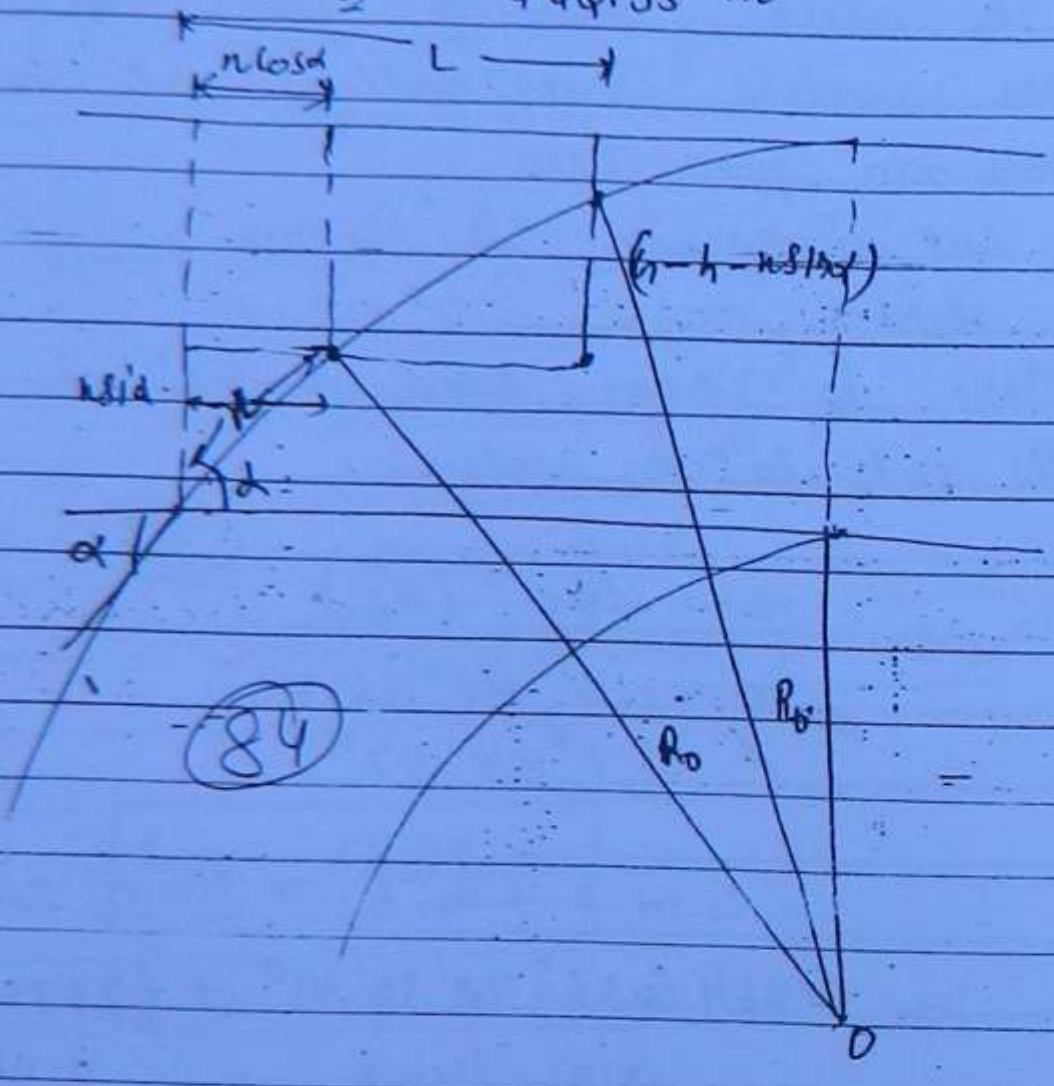
$$= 0.864\cos 6°42'35.41'' + (1.676 - 0.136 - 0.864\sin 6°42'35'')\cot\left(\frac{6°42'35.41'' + 1°34'27''}{2}\right)$$

21.1389 m.

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

$$= \frac{1.676 - 0.136 - 0.864 \times \sin 6^\circ 42' 35.41''}{\cos 1^\circ 34' 27'' - \cos 6^\circ 42' 35.41''}$$

$$= 222.35\ m$$



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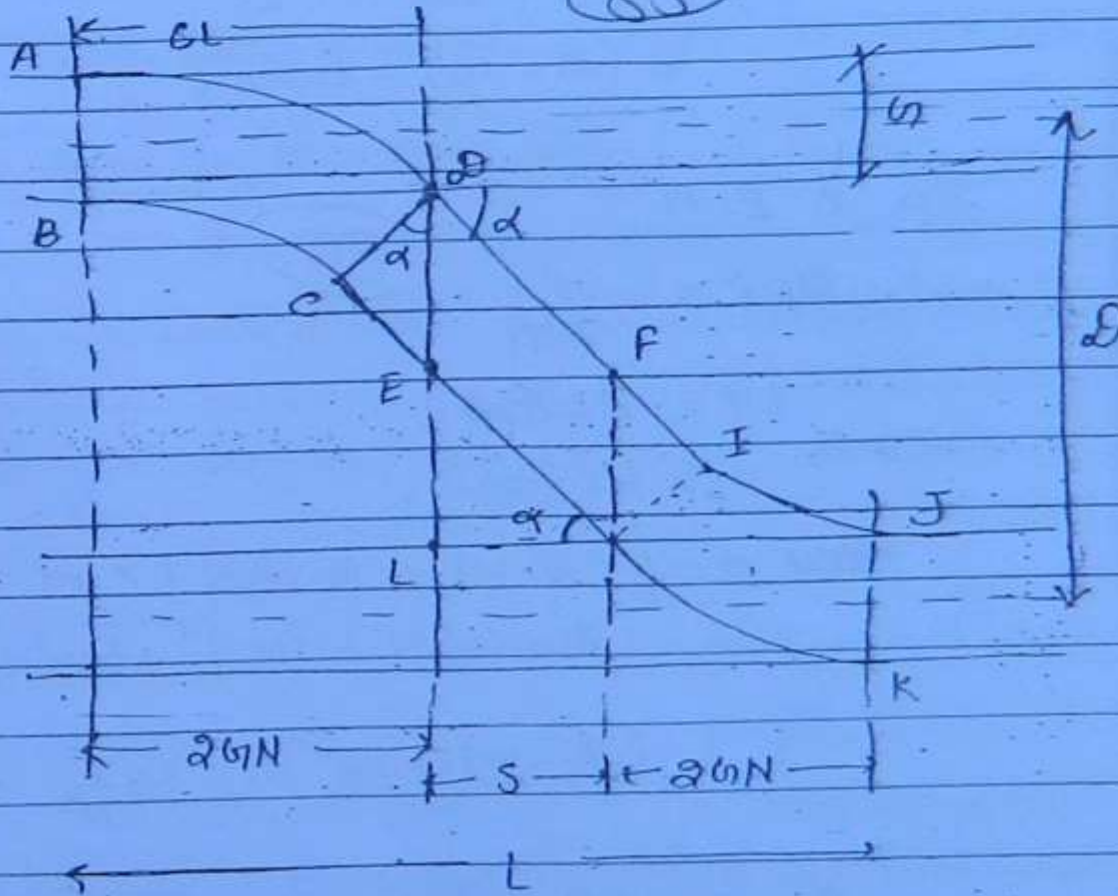
CROSSOVER :-

Type-1 :- Crossover b/w two parallel track with a straight intermediate portion.



CD = G = gauge

in this case total length of cross over

$= BD + LH + HJ$

$= 2GN + S + 2GN$

$= 4GN + S$

S = strength portion of crossover b/w two turnout

In Δ CED

$$\cos\alpha = \frac{CD}{ED} = \frac{G}{ED}$$

$$ED = \frac{G}{\cos\alpha} = G\sec\alpha.$$

$$EL = LD - ED$$

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

In Δ ELH

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

$$LH = EL\cot\alpha$$

$$S = EL\cot\alpha.$$

$$S = [(D-G) - G\sec\alpha] \times \cot\alpha.$$

$$(D-G)N - (G\sqrt{1+\tan^2\alpha}) \times N$$

$$S = (D-G)N - G\sqrt{1+\frac{1}{N^2}} \cdot N.$$

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

Overall length of crossover

$$L = 4GN + S$$

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

ES-1995

Q. A crossover occurs b/w two parallel BG track, of same crossing number 1 in $8\frac{1}{2}$ with straight intermediate portion b/w the reverse curve. Distance b/w centre of tracks is 5m.

Find the overall length of crossover.

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Sol^n: refer to previous dig.

$D = 5m$, $G = 1.676\,m$, $N = 8.5$

$\alpha = \tan^{-1}\left(\frac{1}{8.5}\right) = 6^\circ 42' 35.4''$

To get length of straight portion s

$CD = G = 1.676\,m$

$ED = G\sec\alpha = 1.676 \sec 6^\circ 42' 35.4''$

$= 1.688\,m$

$EL = (D - G) - ED$

$= (5 - 1.676) - 1.688$

$= 1.636\,m$

$S = EL \cot\alpha = \dfrac{1.636}{\tan 6^\circ 42' 35.4''}$

$= 13.91\,m$

overall length $L = 4GN + S$

$= 4 \times 1.676 \times 8.5 + 13.91$

$= 70.89\,m$

Type-2 - Crossover with curved portion b/w two turnout :-

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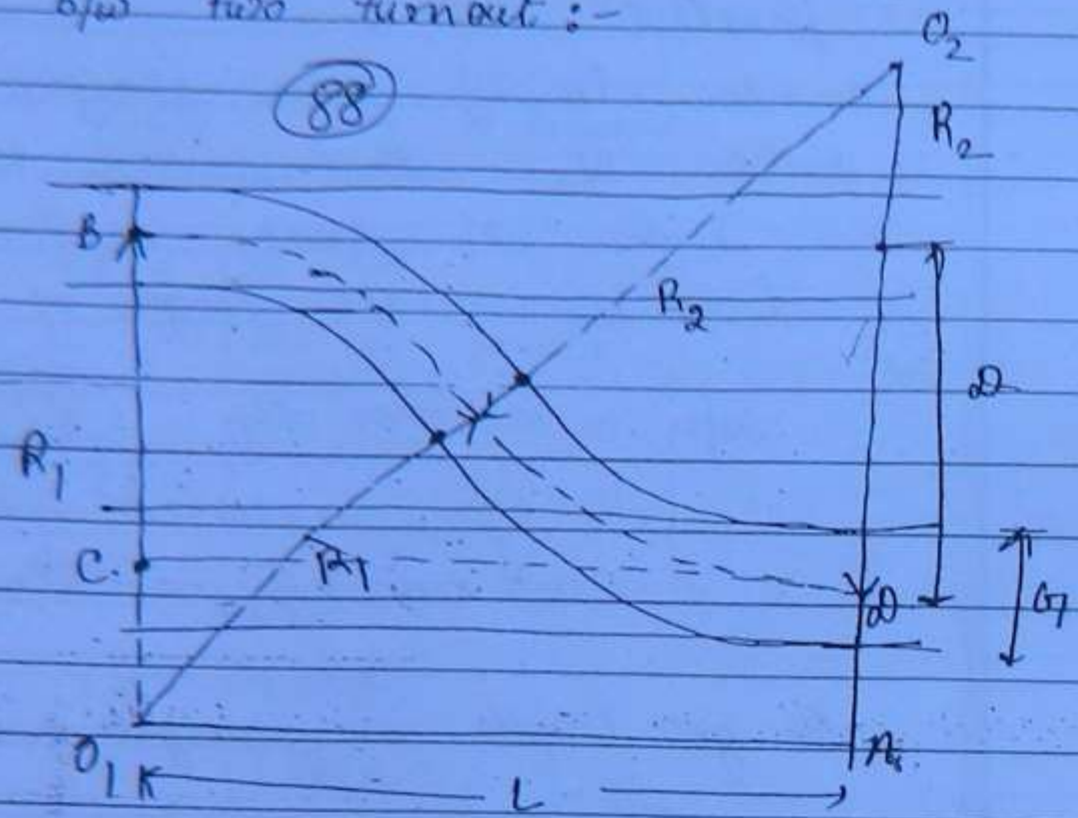

if 1^{st} turnout is 1 in N_1
2^{nd} turnout is 1 in N_2 .

1. Radius - R_1 -

$$R_{1_0} = 1.5G + 2GN_1^2$$

$$R_1 = R_{1_0} - \frac{G}{2}.$$

Radius R_2 -

$$R_{2_0} = 1.5G + 2GN_2^2$$

$$R_2 = R_{2_0} - \frac{G}{2}$$

$$AD = O_1C = O_1B - CB$$
$$= R_1 - D$$

D = centre to centre distance b/w tracks.

In triangle $O_1 O_2 A$.

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$$O_1O_2 = R_1 + R_2$$
$$O_2A = R_2 + AD = R_2 + (R_1 - D)$$
$$= R_1 + R_2 - D$$

overall length of crossover

$$L = \sqrt{O_1O_2^2 - O_2A^2}$$

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

$$\boxed{L = \sqrt{(2R_1+2R_2-D)\,D}}$$

Que A crossover is found b/w two parallel tracks using 1 in 12 turnout on one side & 1 in 16 turnout on other. Portion b/w two turnout is also curved. Find out overall length of crossover b/w these two BG track. centre to centre b/w track = 5.20m.

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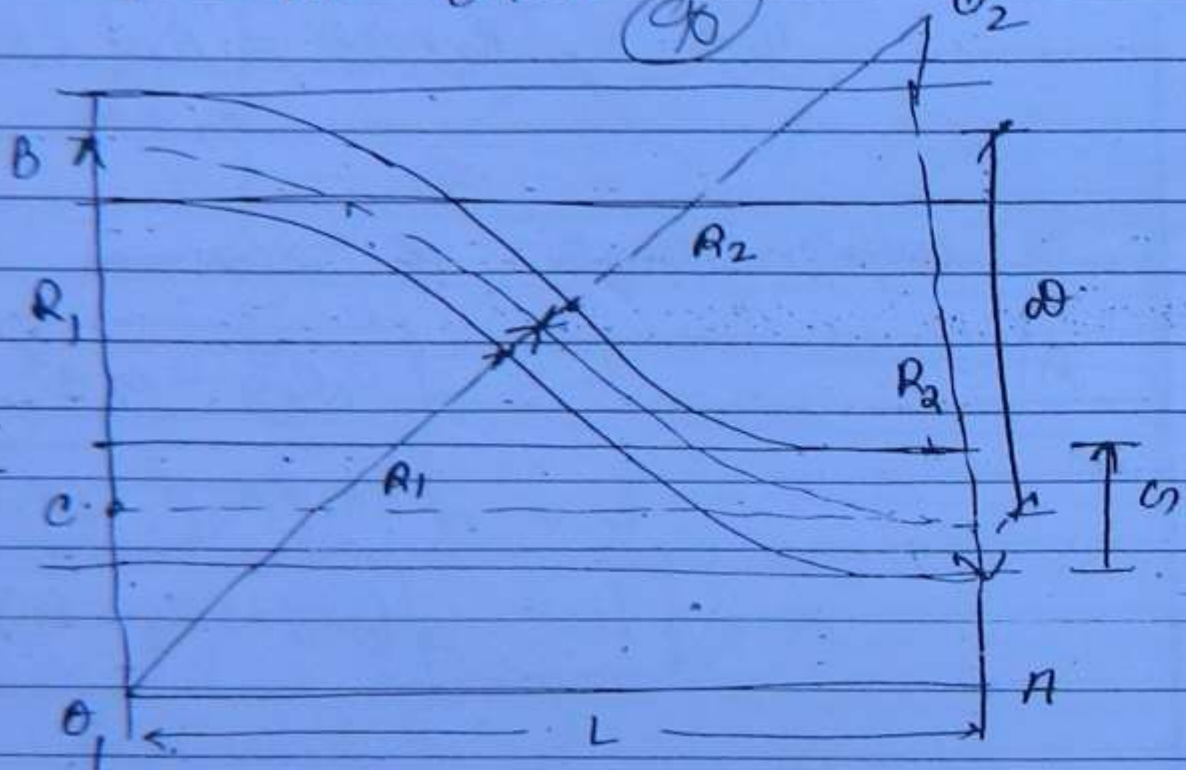
Sol^n



Turnout (1) = 1 in 12.

$N_1 = 12$.

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

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

$= 485.202$.

$R_1 = R_{10} - \frac{G}{2} = 485.202 - \frac{1.676}{2}$

$R_1 = 484.364m.$

Turnout (2) 1 in 16 , $N_2 = 16$

$$R_{2_0} = 1.5G + 2GN_2^2$$
$$= 1.5 \times 1.676 + 2 \times 1.676 \times 16^2$$
$$= 860.626\,m$$

$$R_2 = R_{2_0} - \frac{G}{2}$$
$$= 860.626 - \frac{1.676}{2}$$

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$$= 859.788\,m$$

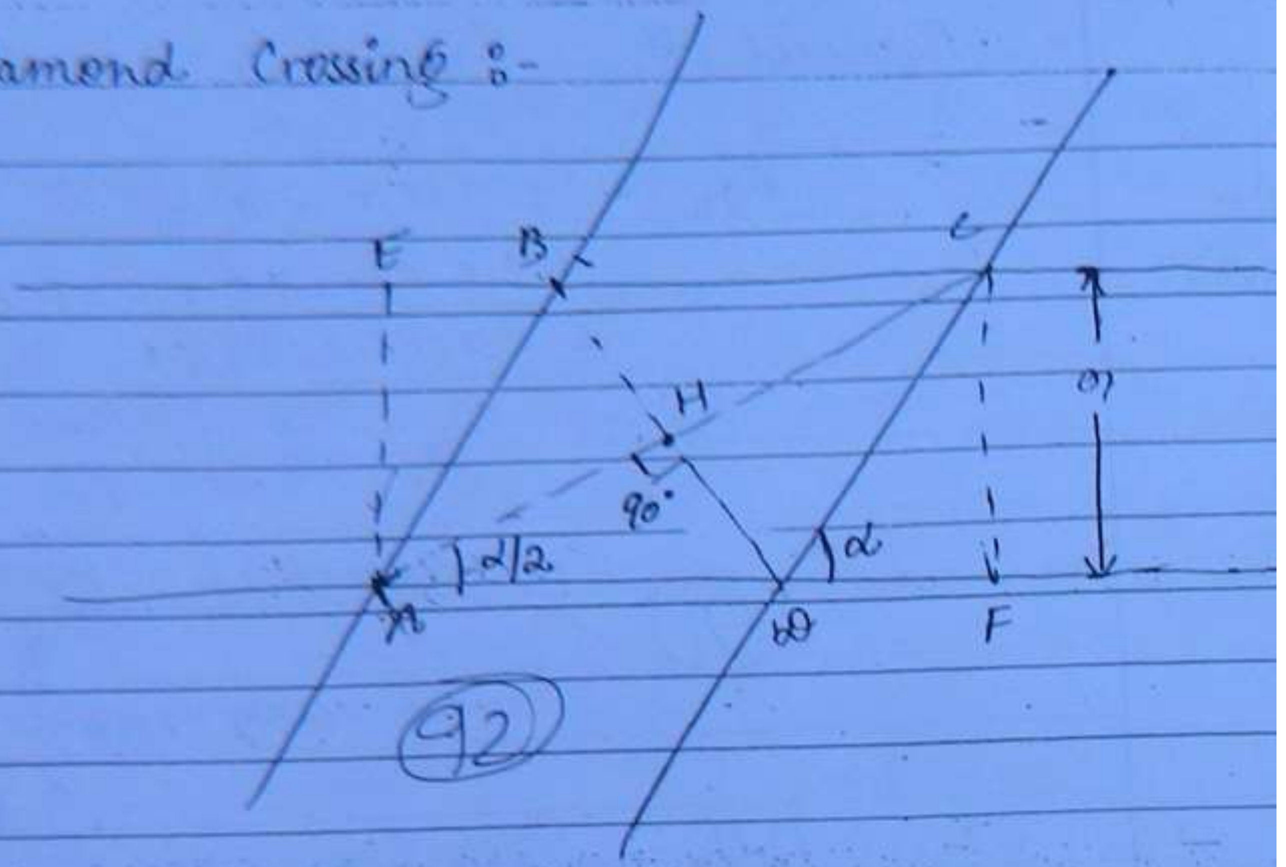
$$O_1O_2 = R_1 + R_2$$
$$= 484.364 + 859.788$$
$$= 1344.152\,m$$

$$O_2A = R_1 + R_2 - D$$
$$= 1344.152 - 5.20$$
$$= 1338.952\,m$$

overall length of cross over

$$L = \sqrt{O_1O_2^2 - O_2A^2}$$
$$L = \sqrt{(1344.152)^2 - (1338.952)^2}$$
$$\boxed{L = 118.12\,m}$$

Diamond Crossing :-



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length AB = BC = CD = DA

In ΔCDF --

$$\boxed{CD = G\,\mathrm{cosec}\,\alpha}$$

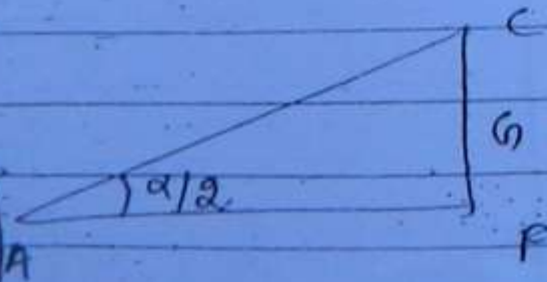
$EB = DF$

$$\therefore \tan\alpha = \frac{G}{DF}$$

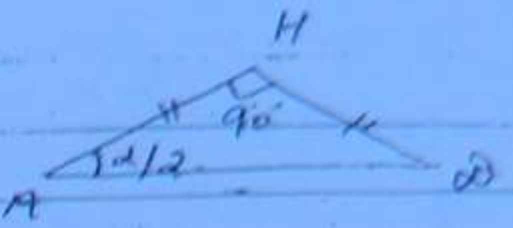
$$\boxed{DF = G\cot\alpha}$$

Diagonal AC

$$\boxed{AC = G\,\mathrm{cosec}\,\frac{\alpha}{2}}$$



$BD = 2HD$



$\tan\frac{\alpha}{2} = \frac{HD}{AH}$

$HD = AH \tan\frac{\alpha}{2}$

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$HD = \frac{AC}{2} \tan\frac{\alpha}{2}$

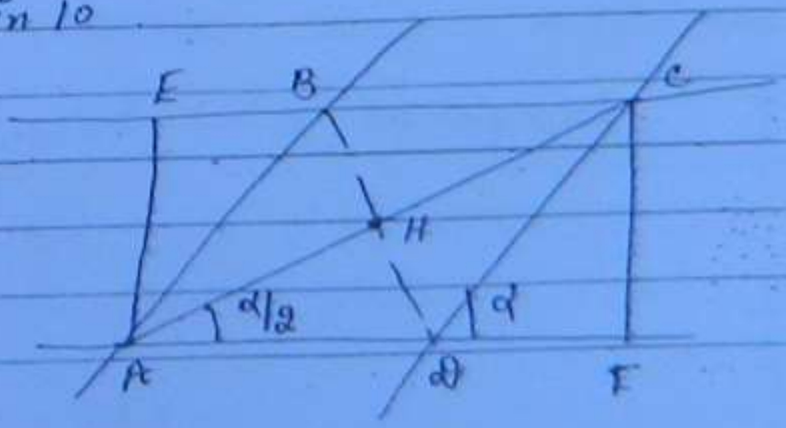
$HD = \frac{G \operatorname{cosec}\frac{\alpha}{2} \times \tan\frac{\alpha}{2}}{2}$

$HD = \frac{1}{2} G \sec\frac{\alpha}{2}$

$BD = 2HD$

$$\boxed{BD = G \sec\frac{\alpha}{2}}$$

ES-1997.
Ques. Design a diamond crossing b/w two BG tracks crossing each at an angle of 1 in 10.



$1 \text{ in } N = 1 \text{ in } 10$

$N = 10$

$\cot\alpha = 10$

$\alpha = \cot^{-1}(10)$

$\alpha = \tan^{-1}\left(\frac{1}{10}\right)$

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$\alpha = 5^\circ 42' 38.14''$

Length $AB = BC = CD = DA$

$= a \cdot \operatorname{cosec}\alpha$

$= \dfrac{1.676}{\sin 5^\circ 42' 38.14''}$

$= 16.84 \text{ m}$

Length $EB = DF$

$= a \cot\alpha = 1.676 \times 10 = 16.76 \text{ m}$

Diagonal $AC = a \operatorname{cosec}\frac{\alpha}{2} = \dfrac{1.676}{\sin\left(\frac{5^\circ 42' 38.14''}{2}\right)}$

$= 33.645 \text{ m}$

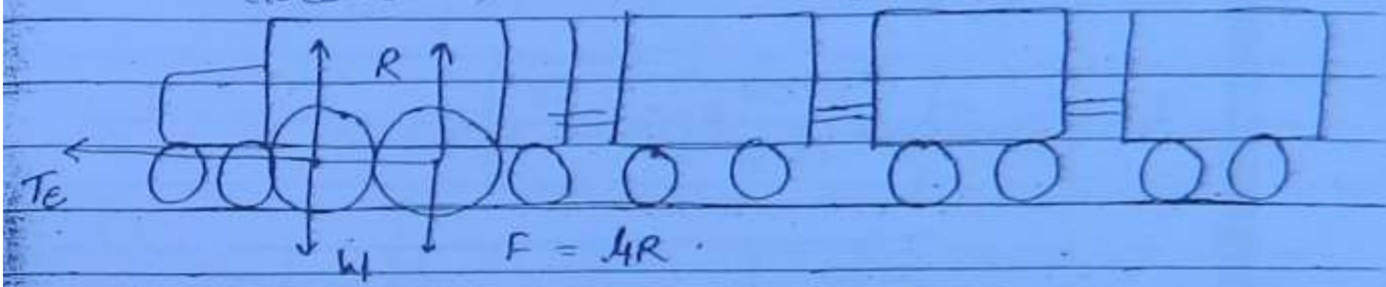
Diagonal $BD = a \sec\frac{\alpha}{2} = \dfrac{1.676}{\cos \frac{5^\circ 42' 38.14''}{2}}$

$= 1.678 \text{ m}$

TRACTION & TRACTIVE EFFORT :–

To understand this topic three important points are –

engine (locomotive) + wagons = train



① **Tractive effort :–** This is the force applied by engine on driving wheels for movement of train (T_E)

② **Hauling Capacity :–** This is the frictional force available b/w driving wheels and Rails. It depends upon the weight on driving wheels and coefficient of friction

$$F_f = \mu R = H.C.$$

$$H.C = F_f = \mu R = \mu . W$$

$$\boxed{HC = \mu n W_d}$$

5. Total Resistances :- Total resistance offered by train due to various reason during movement.

For movement of train

$T_e > HC >$ Total Resistance.

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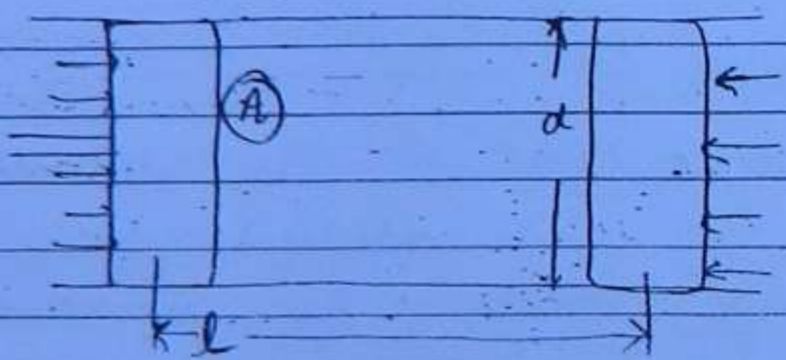
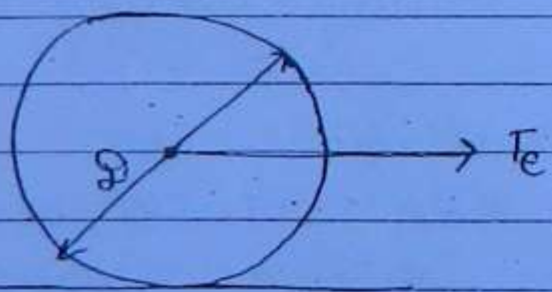
1. Tractive Effort (T_e) :-





Let us take an example of steam engine.

if A = area of piston

d = dia. of piston.

P = pressure diffⁿ on two side.

l = length of stroke
T_e = Tractive effort generated on wheel
D = Dia of wheel.
n = number of cylinder

Power generated = work done

$$\frac{\pi}{4}(d^2) \times p \times 2l \times n = T_e \times \pi D$$

$$\boxed{T_e = \frac{n p l d^2}{2 D}} \quad \text{— (A)}$$

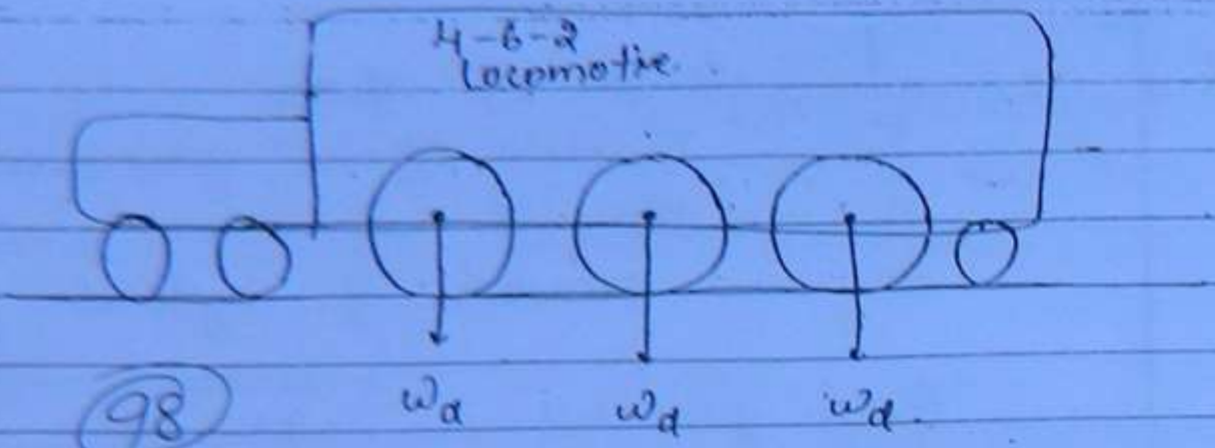
Tractive effort $T_e \propto \frac{1}{D}$

velocity of train $V \propto D$

Diameter of driving wheel should be selected such that, sufficient tractive effort can be generated without reducing the speed much.

2. Hauling Capacity :- (H.C) –

It is the frictional force available b/w driving wheels of locomotive and rails.



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n = no. of pairs of driving wheels.
w_d = wt on each pair of driving wheels.
μ = coff. of friction.

$$H.C = \mu W = \mu . n\, w_d .$$

value of μ

At low speed $\mu = 0.30$
at high speed $\mu = 0.10$

During movement

value of μ considered $\mu = 0.20$
or $\mu = \frac{1}{6} = 0.166$

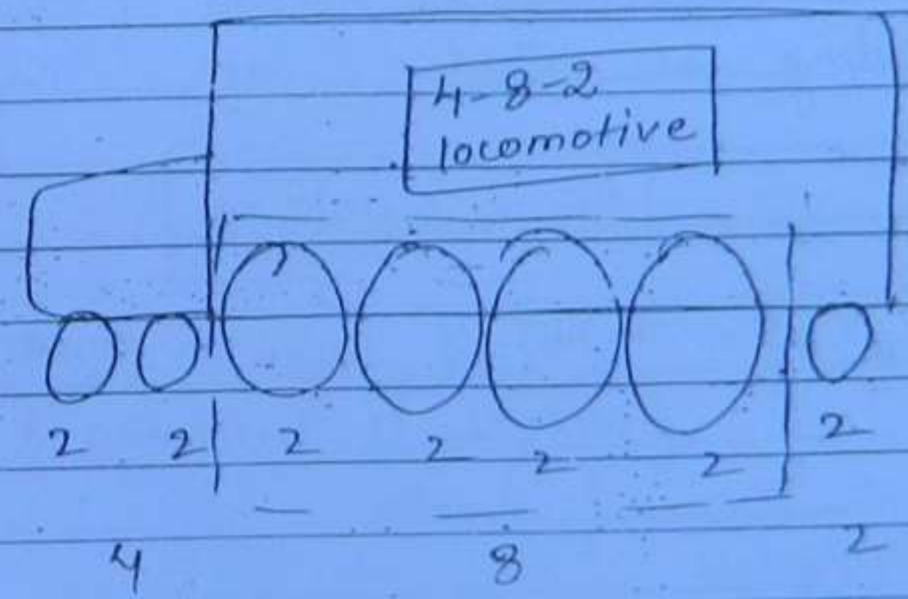
Designation of a locomotive -

A locomotive is designated as
$n_1 - n_2 - n_3$

n_1 = Total no. of front wheel.
n_2 = Total no of driving wheel
n_3 = Total no of rear wheels.

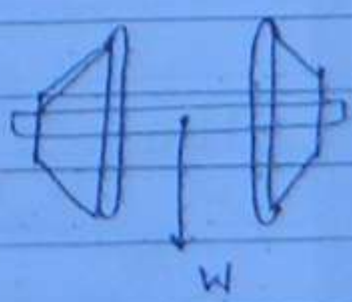
For hauling capacity

99 n = nos of pairs $= \frac{n_2}{2}$.



Max^m axle load :-

BG = 28.56 t
MG = 17.34 t
NG = 13.26 t



One axle = one pair of wheels

8. Total Resistances –

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1. Train Resistance (R_T)

a) Resistance independent of speed (R_{T_1})
(Rolling Resistance) :–

It is due to various frictional forces acting at wheels, rails, engine parts etc.

$$\boxed{R_{T_1} = 0.0016\, w}$$

Here: w = weight of train in tonnes
(weight of locomotive + wagons) in tonnes

b) Resistance dependent on speed (R_{T_2}) –

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

Here w = wt of train in tonnes
V = velocity (speed) of train in kmph

c) Atmospheric Resistance :– (R_{T_3})
(even when wind speed = 0)

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

Total train Resistance - (To)

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

$$\boxed{R_T = 0.0016\omega + 0.00008\,\omega V + 0.0000006\,\omega V^2}$$

always considered.

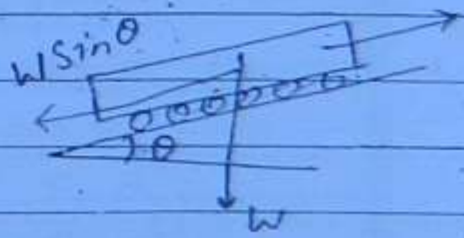
2. Resistance due to track profile -

(a) Due to Gradient :-

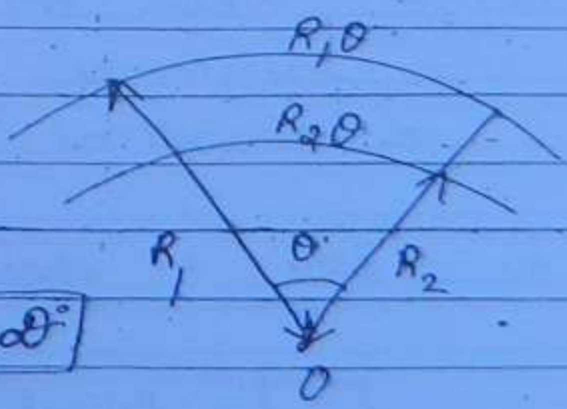
$$\boxed{R_g = \omega \tan\theta}$$

for small value of θ

$$\theta = \sin\theta = \tan\theta$$



b) Resistance due to curve -



for BG -

$$\boxed{R_c = 0.0004 \cdot \omega \cdot D^\circ}$$

for MG

$$\boxed{R_c = 0.0003\, \omega D^\circ}$$

for NG.

$$\boxed{R_c = 0.0002\, \omega D^\circ}$$

Here w = wt. of train in tonnes.
D° = degree of curve.

3 Resistance due to starting and acceleration –

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a) <u>Due to starting</u> –

$R_{locomotive} = 0.15\,w_1$

$R_{wagon} = 0.005\,w_2$

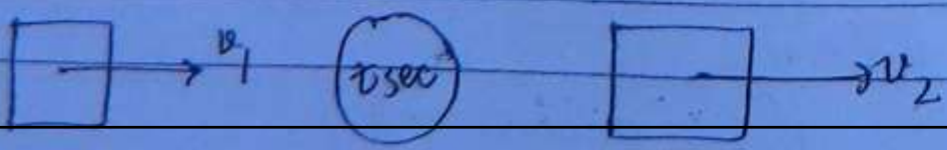
Total resistance.

$$\boxed{R_{st} = 0.15\,w_1 + 0.005\,w_2}$$

w_1 = wt. of locomotive } in tonnes.
w_2 = wt of wagons

<u>Note</u>:– When train is moving, this resistance is not required to be considered.

b) <u>Due to acceleration</u> –



$$R_a = 0.028\, w \left(\frac{V_2 - V_1}{t}\right).$$

w = wt. of train in tonnes.
V_2/V_1 = speed in kmph.
t = time in seconds.

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4. Wind Resistance -

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

a = exposed area in m^2 of train
V_w = wind velocity in kmph.
R_w = wind resistance in tonnes.

for movement of train -

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

ES-2010

Qn. A locomotive on BG track with four pairs of driving wheels, carrying axle load of 20t each, is required to haul a train at a speed of 80 kmph.

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The train is made to run on a level track with curvature of 2°. Calculate max^m permissible load that can be pulled by the engine.

$\mu = 1/6$.

Locomotive

$n = 4$ pairs.

$w_d = 20t$

$\mu = 1/6$

Hauling capacity

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

$$= \frac{1}{6} \times 4 \times 20$$

$$= 13.33t$$

$V = 80$ kmph

$D^\circ = 2^\circ$

Hauling capacity = Total Resistance

$$13.33t = R_{T_1} + R_{T_2} + R_{T_3} + 0.0004\omega D$$
$$= 0.0016\omega + 0.00008\omega V + 0.0000006\omega V^2 + 0.0004\omega D$$

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$$13.33 = \omega(0.0016 + 0.00008 \times 80 + 0.0000006 \times 80^2 + 0.0004 \times$$

$$\omega = 1054.6 \text{ tonnes} \quad A_2$$

ES. 1990

Q. A locomotive with 8 pairs of driving wheels is to haul a train a 75 kmph speed.
load on each axle of driving wheel =
coeff of friction = 0.20.

1. What is the load the engine can pull on a straight Level track.
2. When the same track goes up a slope of 1 in 180, how would the speed be adjusted for same load.
3. If the track, when past the slope goes through a 2° curve on level ground, how would the speed be adjusted.

9. If slope + curve are both, then how much speed will be adjusted.

Soln Hauling capacity $= \mu \times n \times \omega_d$

$= 0.20 \times 3 \times 22$

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$= 13.2\ t$

(1) Speed = 75 kmph.

$H.C. = R_{T_1} + R_{T_2} + R_{T_3}$

$13.2 = 0.0016\,\omega + 0.00008\,\omega V + 0.0000006\,\omega V^2$.

$= \omega\,(0.0016 + 0.00008 \times 75 + 0.0000006 \times 75^2)$

$\omega = 1202.7$ tonnes.

(2) gradient — 1 in 180.

$R_g = \omega \tan\theta = \omega \times 1/180$

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

$13.2 = 0.0016 \times 1202.7 + 0.00008 \times 1202.7\,V + 0.0000006 \times 1202.7\,V^2 + 1202.7 \times \frac{1}{180}$

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$13.2 = 8.6059 + 0.096V + 0.00072V^2$

$0.00072V^2 + 0.096V - 4.594 = 0$

$V = 37.37$ kmph

Reduction of speed $= 75 - 37.3 = 37.7$ kmph

$=$

8.

$H.C. = R_{T_1} + R_{T_2} + R_{T_3} + 0.0004 \omega D$

$13.2 = 0.0016\omega + 0.00008\omega V + 0.000000\omega V^2 + 0.0004\omega D$

$= 0.0016 \times 1202.7 + 0.00008 \times 1202.7 \times 1 + 0.000000 \times 1202.7 V^2 + 0.0004 \times 1202.7 \times 2$

$13.2 = 2.886 + 0.096V + 0.00072V^2$

$0.00072V^2 + 0.096V - 10.314 = 0$

$V = 70.33$ kmph.

4. $HC = 0.0016\omega + 0.00008\omega V + 0.000000\omega V^2 + 0.0004\omega D + \omega \tan\theta$

$13.2 = 0.0016 \times 1202.7 + 0.00008 \times 1202.7V + 0.000000 \times 1202.7V^2 + 0.0004 \times 1202.7 \times 2 + 1202.7 \times \frac{1}{180}$

$$13.2 = 9.568 + 0.096V + 0.00072V^2$$

$$0.00072V^2 + 0.096V - 3.632 = 0$$

$$V = 30.7 \text{ kmph}$$

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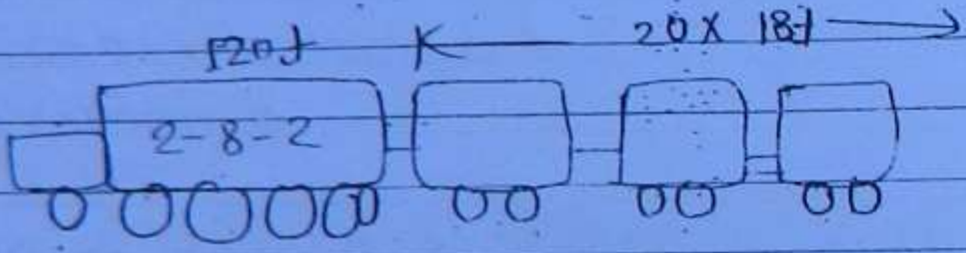
Q:11. A train having 20 wagons weighting 18 tonnes each, is to run at a speed of 50kmph. The tractive effort of a 2-8-2 locomotive with 22.5 t load on each axle, is 15 tonnes, The weight of locomotive is 120t Rolling resistance of wagons and locomotive are 2.5 kg/t and 3.5 kg/t respectively. The resistance which depend upon speed is 2.65 tonnes. Find out the steepest gradient for these conditions.



weight of locomotive $= 120t$

wt of wagon $= 360t$

total weight of train $= 480t = W$

$V =$ speed of train $= 50$ kmph

tractive effort $= 15t$

Hauling capacity $= n \cdot \mu \cdot W_d$

$$= 4 \times \frac{1}{6} \times 22.5 = 15t$$

max^m gradient $= ? = \tan\theta = ?$

$H.C. = RT_1 + RT_2 + RT_3 + W \cdot \tan\theta$ —— (1)

Here Rolling resistance

$RT_1 = 2.5\,kg \times 360 + 3.5\,kg \times 120$

$= 1320\,kg$

$RT_1 = 1.32\,t$

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RT_2 = Resistance dependent on speed

$RT_2 = 2.65$ tonnes

$RT_3 = 0.0000006\,W \cdot V^2$

$= 0.0000006 \times 480 \times 50^2$

$= 0.72$ tonnes

putting eq^n (1)

$\Rightarrow 15 = 1.32 + 2.65 + 0.72 + W \tan\theta$

$\Rightarrow \tan\theta = \frac{15 - 1.32 - 2.65 - 0.72}{480}$

$\Rightarrow \theta$ = slope = 1 in 46.56