

110

5

-: HAND WRITTEN NOTES:-
OF
CIVIL ENGINEERING

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4

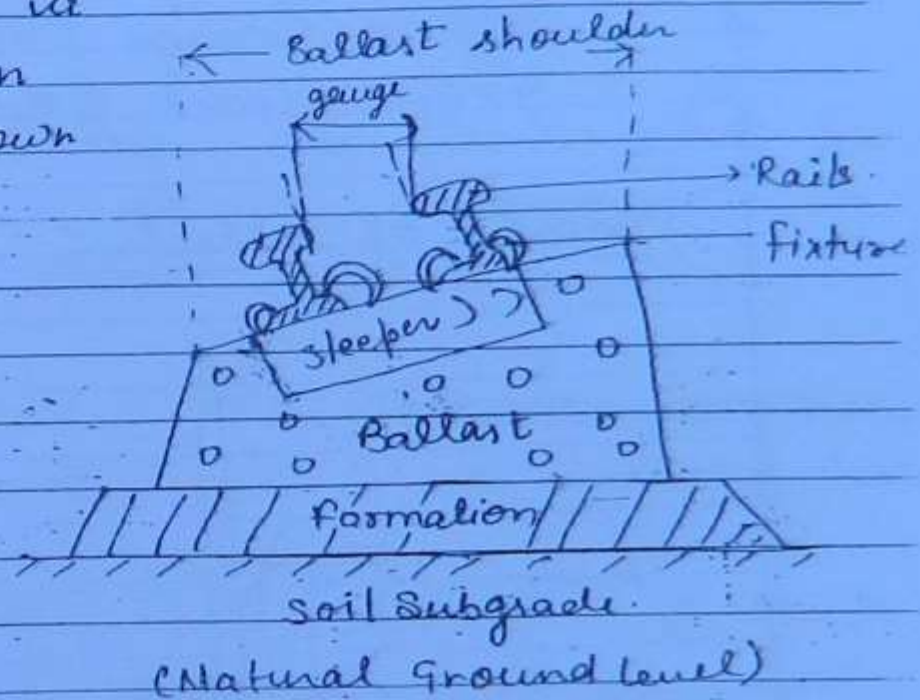
-: SUBJECT:-
RAILWAY
ENGINEERING

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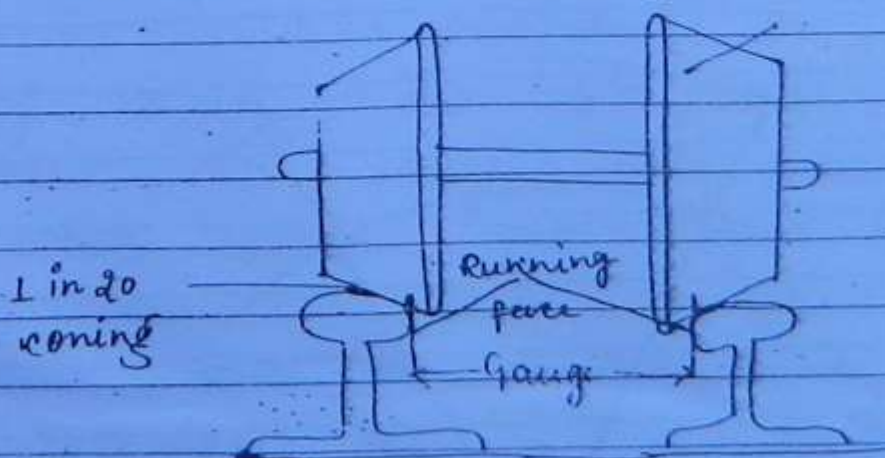
INTRODUCTIONImportant Terms :-

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)

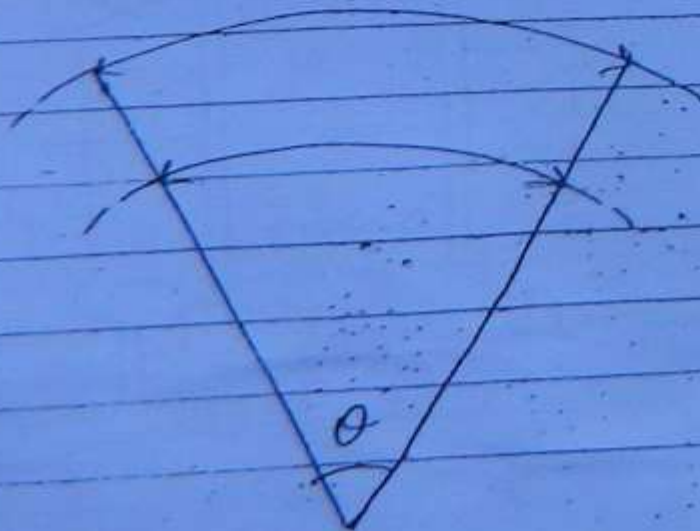
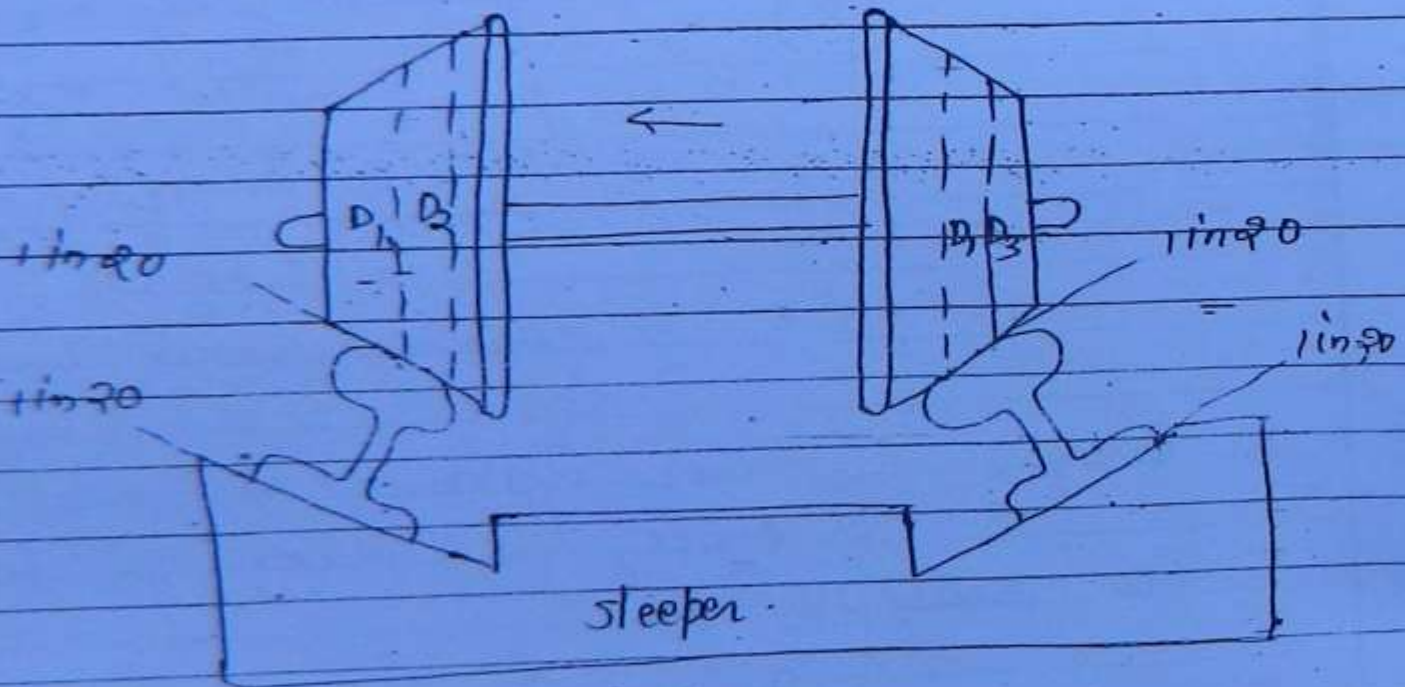


Different Gauge :-

1. Broad Gauge (BG) = 1.676 m.
2. Meter Gauge (MG) = 1.0 m.
3. Narrow Gauge (NG) = 0.762 m.
4. Feather 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.

Purpose:-

(5)

1. To keep the train just in central position during movement on straight tracks.
2. To adjust the distance travelled on two rails on a curved track.
3. To reduce wear & tear of rails & wheels (A gap b/w flange and rail should be maintained).

Theory:-

on straight track:-, A wheel 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 wheel is diverted back to its central position automatically.

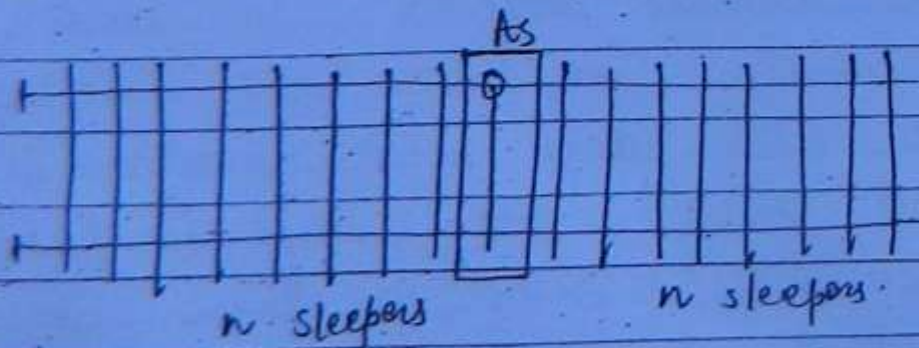
On curved track, the rail is moved outward due to centrifugal force, resulting increase of dia over outer rail. So distance to be travelled on outer and inner rails are adjusted.

(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 fixures, & sleepers.

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



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

increase $\Delta l = l \cdot \alpha T$

if all movement is not allowed
strain developed.

$$\textcircled{7} \quad e = \frac{\Delta l}{l} = \frac{l \alpha T}{l} = \alpha T$$

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

8) - $p_s = \text{stress} = e E_s = \alpha T \cdot E_s$

if $A_s =$ area of steel (one rail)

force developed

$$P = A_s \times p_s$$

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

if one sleeper can provide R resistance.
no. of sleeper required to resist P
force

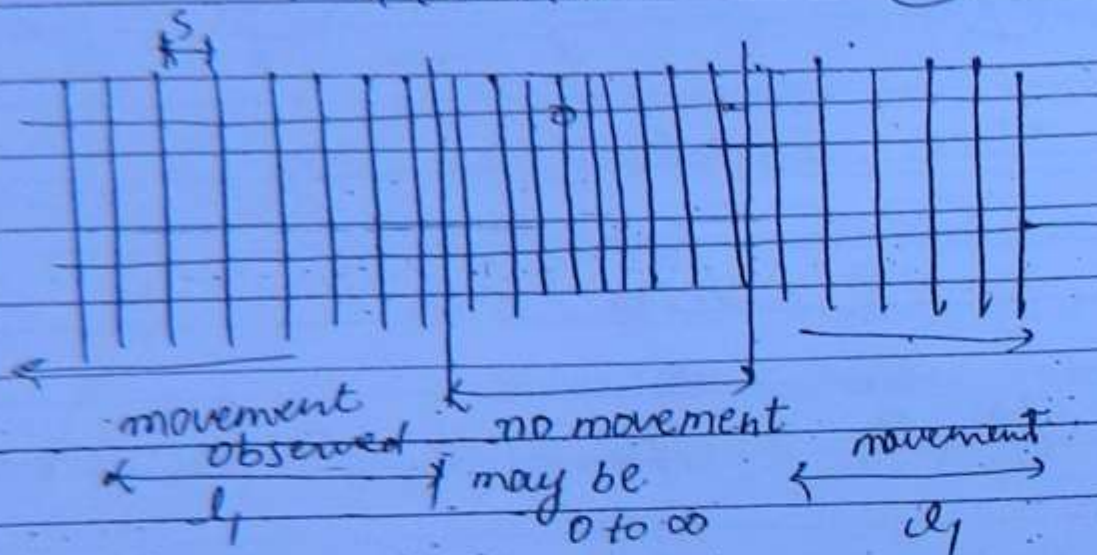
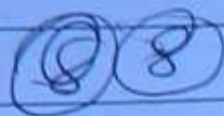
$$n = \frac{P}{R} = \frac{A_s \times \alpha T \cdot E_s}{R}$$

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.

$$= 2l_1$$

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



ES-2001

Ques:

Determine the min^m theoretical 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

$$\rightarrow \text{c/s area} = 66.15 \text{ cm}^2$$

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

$$\alpha = 11.5 \times 10^{-6} / ^\circ\text{C}$$

B) SLEEPERS -

$$\rightarrow s = 60 \text{ cm}$$

$\rightarrow$ Avg. resistance force/
sleeper rail = 300 kg.

min^m length

increase in length = ΔL

strain developed if above increase is not allowed

$$\frac{\Delta L}{L} = \alpha T$$

(9)

stress developed = $\alpha T E_s$

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

$$= 724.5 \text{ kg/cm}^2$$

Force developed = $A_s \times p_s$

$$= 66.15 \times 724.5$$

$$47925.675 \text{ kg}$$

no. of sleepers = $\frac{47925.675}{300}$

(on one side)

$$= 159.75$$

$$\approx 160$$

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

$$= 2(160-1) \times \frac{1}{10}$$

$$= 190.80 \text{ m}$$

Sleepers:-

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

(18)

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

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 meter

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.

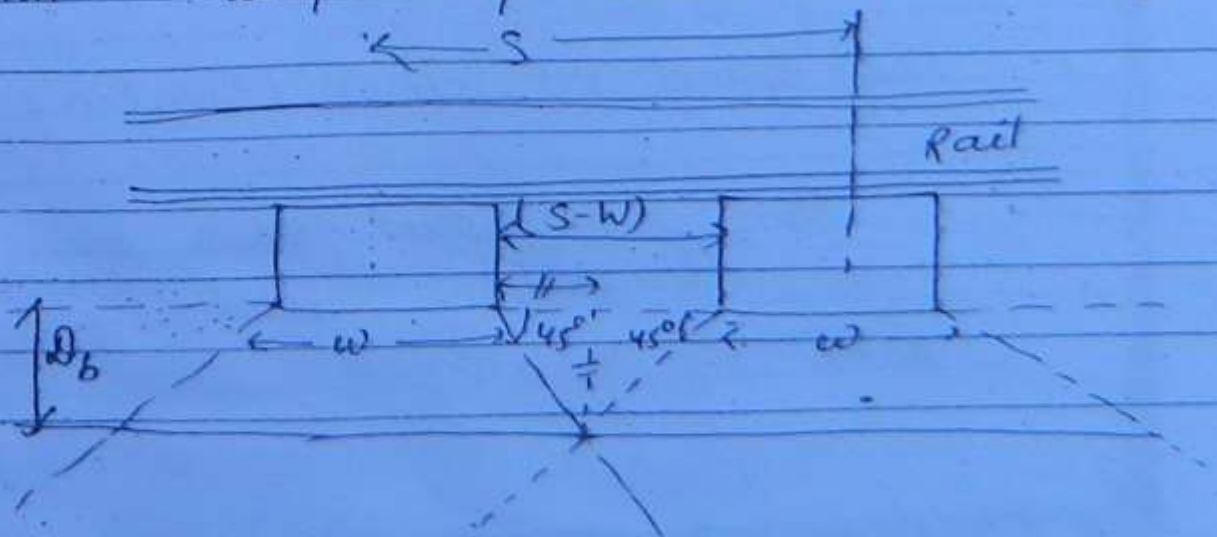
length of one rail = 12.8 m $\approx$ 13 m

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

$$\frac{12.8}{1000 \text{ m}} \times 18 \text{ number} \times 1000$$

$$= 1406 \text{ sleepers}$$

Min^m depth of ballast cushion:-



Min^m depth of ballast

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

Geometrical Design :-

(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 -
(where transition curve have been provided with simple curved)

(i) for BG & Mn track -

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

(13)

for NG

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

b) On Non-transitional curve :-

(When transition curve has not been provided) - 80% $V_{\max}$ for transition curve

i) for BG & Mn

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

ii) for NG

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

c) For High Speed trains -

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

in all above formula

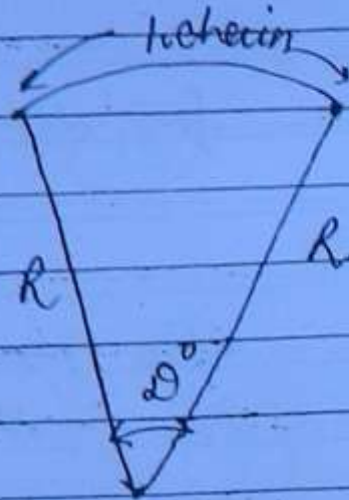
R = radius of curve in (m)

$V_{\max}$ = kmph

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

(14)

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



(i) for 30m chain length

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

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

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

$$D^\circ = \frac{1720}{R} \quad \text{--- (A)}$$

D	1°	2°	3°	4°	5°
R for 30m	1720m	860m	573m	430m	344m
R for 100m	1150	575	373m	298m	230m

(11) for 20 m chain length.

$$\frac{217R}{20} = \frac{360}{20}$$

(15)

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

$$\boxed{20 = \frac{1150}{R}}$$

12/11/11

Max^m degree of curve :-

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

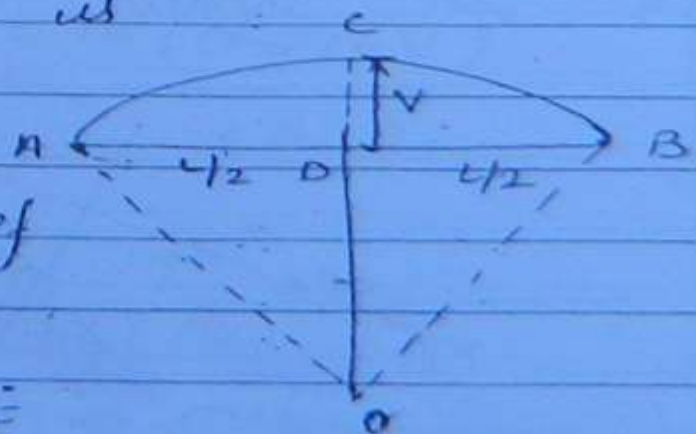
3.

Versine of curve :-

For a chord AB,

distance (CD = V) is called versine of curve.

By using property of circle.



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

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

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

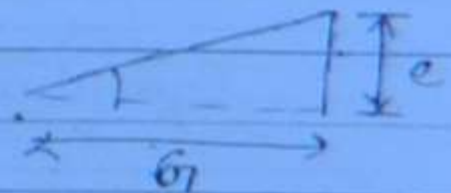
inward component of weight = $mg \sin \theta$
(There is no force of friction b/w
rail & wheel in lateral dirⁿ)

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

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

Superelevation or Cant

$$\begin{aligned} e &= G \tan \theta \\ &= G \cdot \frac{v^2}{gR} \\ &= \frac{Gv^2}{gR} \end{aligned}$$



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

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

where G = gauge in meter

V = speed in kmph.

R = radius in meter.

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

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

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

2) if sanctioned speed < 50 kmph

$$V_{eq} = V_{max}$$

3. Weighted avg. speed -

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

 ----- (19)

weighted avg. speed

$$V_{av} = \frac{n_1 V_1 + n_2 V_2 + \dots}{n_1 + n_2 + \dots}$$

$V_{av} = \frac{\sum nV}{\sum n}$

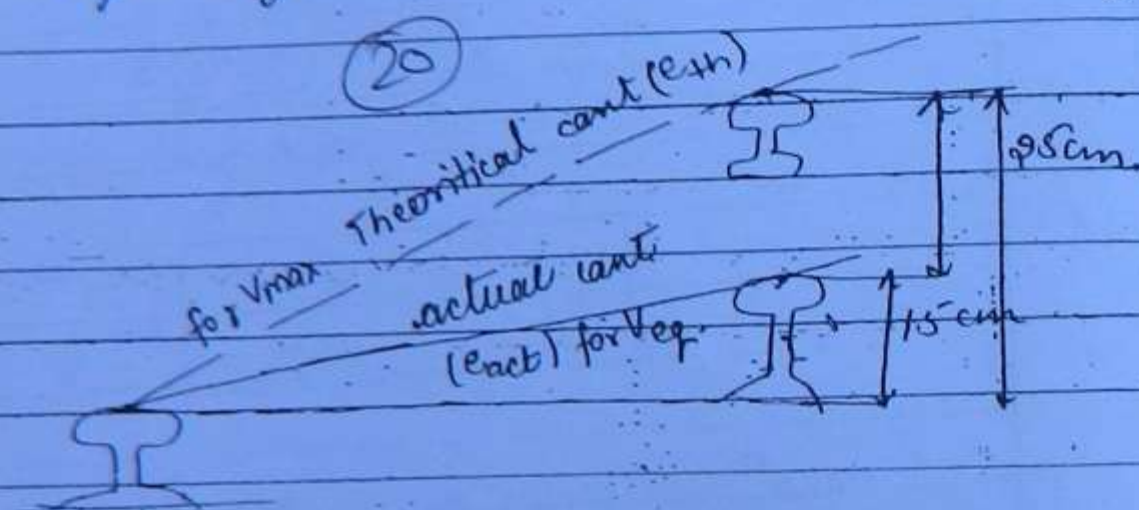
max^m limit of super-elevation -
 (actual cant provided) =

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

⑥ Cant Deficiency :- (Q)

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 | BB track | |
| | $V < 100 \text{ kmph}$ | 7.60 cm |
| | $V > 100 \text{ kmph}$ | 10.0 cm |
| ② | MG | 5.10 cm |
| ③ | NG | 3.80 cm |

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

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

② For 3° curve, $R = \frac{1730}{3} = 573 \text{ m}$
 $R = 573 \text{ m}$

① Martin's Formula

max^m safe sp. on the curve =

$$\begin{aligned} & 4.35 \sqrt{R - 67} \\ &= 4.35 \sqrt{573 - 67} \\ &= 97.85 \text{ kmph} \end{aligned}$$

② from cant formula -

actual cant provided for

$$V_{eq} = 75 \text{ kmph}$$

$$\begin{aligned} e_{act} &= \frac{GV^2}{127R} = \frac{1.676 \times 75^2}{127 \times 573} \\ &= 0.129 \text{ m} \end{aligned}$$

$$e_{act} = 12.9 \text{ cm}$$

Theoretical cant allowed

$$e_{th} = e_{act} + 2$$

$$e_{th} = 12.90 + 7.60$$

$$= 20.50 \text{ cm} = 0.205 \text{ m}$$

for max^m speed

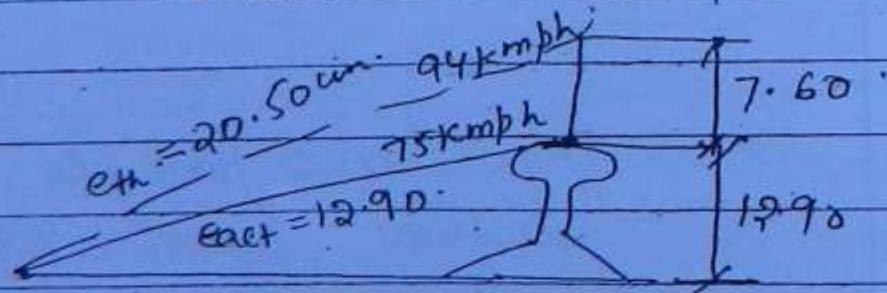
$$e_{th} = \frac{G \cdot V_{max}^3}{127 R} \quad (22)$$

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

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

$$= 94.34 \text{ kmph}$$

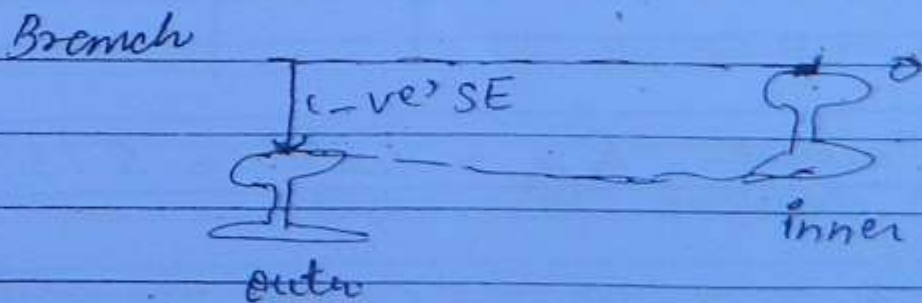
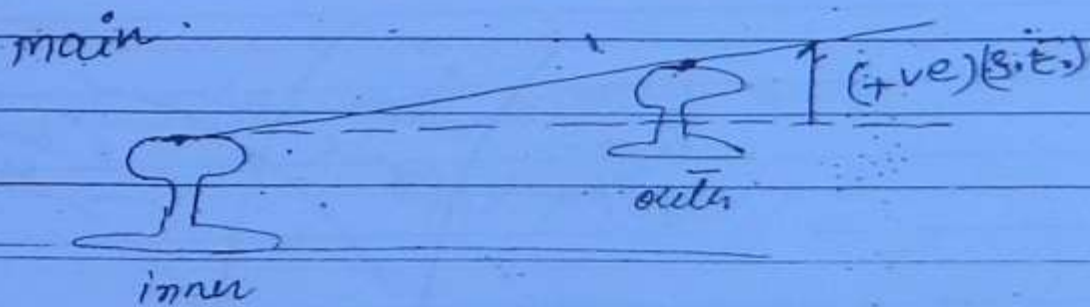
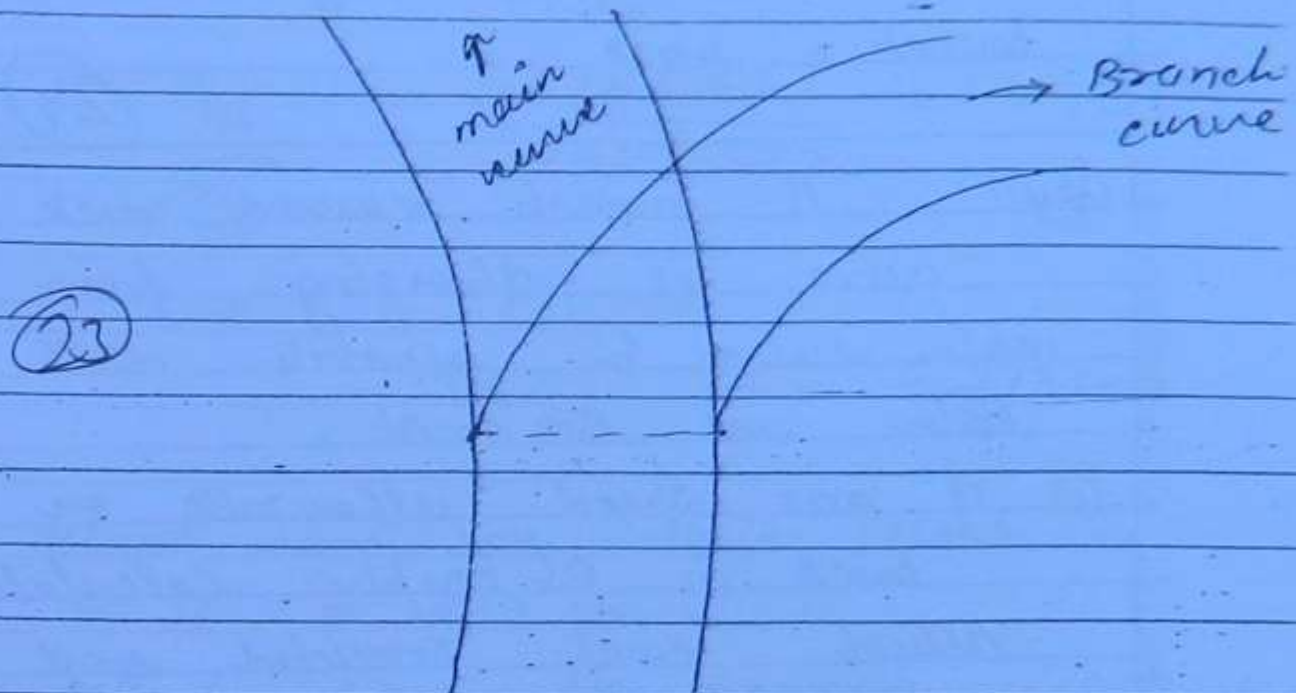
max. speed allowed = 94 kmph



Negative Super elevation :-

If outer rail is provided at lower elevation, w.r.to inner rail

it is called a negative superelevation



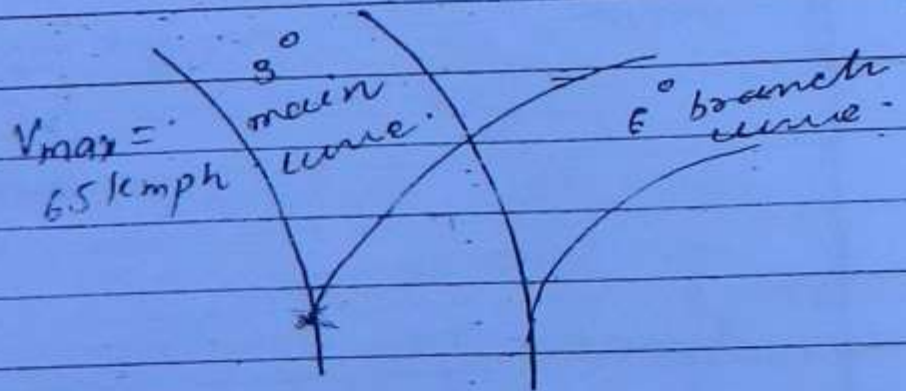
in case when a branch curve track is diverging from a main curved track in opposite dirⁿ, +ve

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

(24)

Ques- A branch curved track of 6°
curve is diverging from a 3°
main curve in opposite dirⁿ.
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 $R_A = \frac{1720}{3} = 573 \text{ m}$

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

max^m speed on main curve

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

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

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

(25)

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

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

actual cant on main track is

$$+ve = 2.13 \text{ cm}$$

actual cant on branch track is

$$-ve = -2.13 \text{ cm}$$

e_{th} for branch track -

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

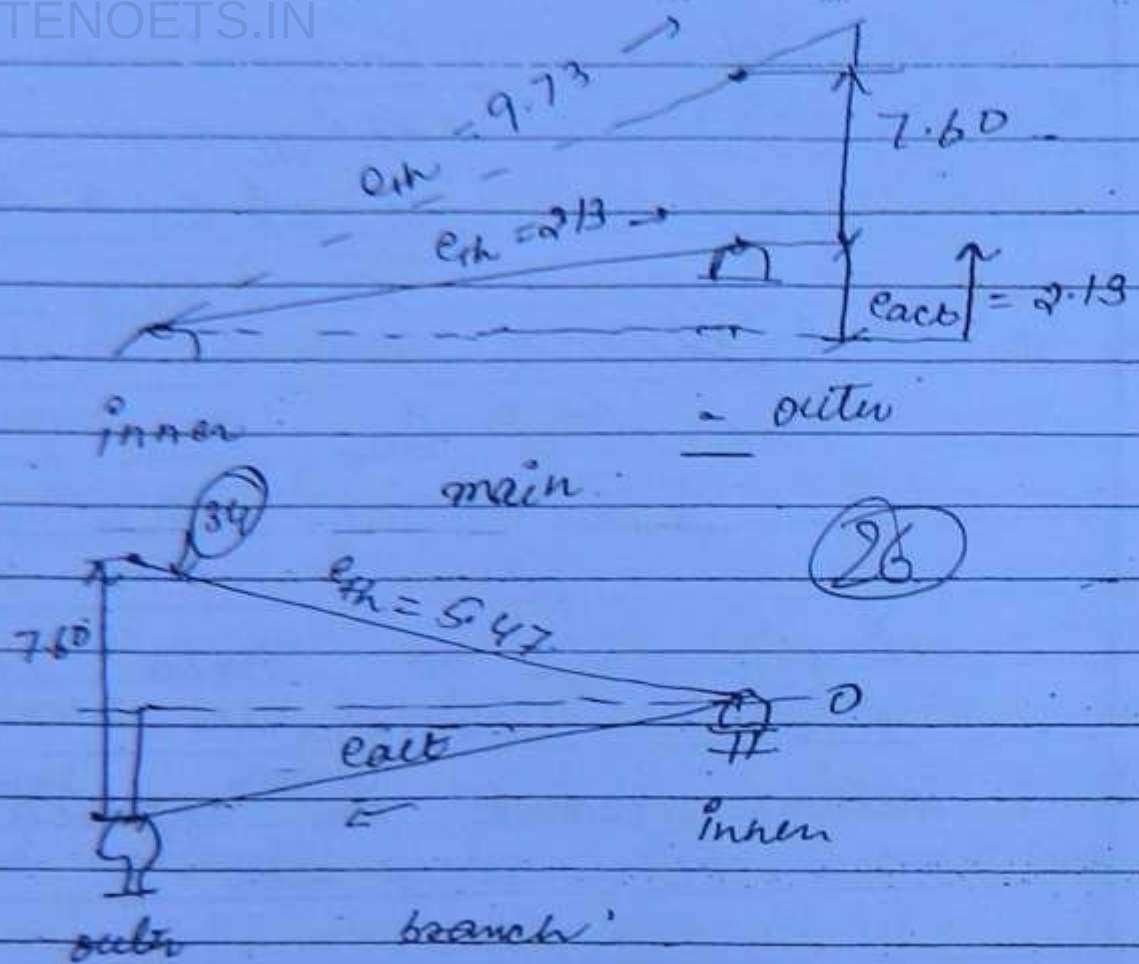
$$= -2.13 + 7.60$$

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

V_{max} for branch track.

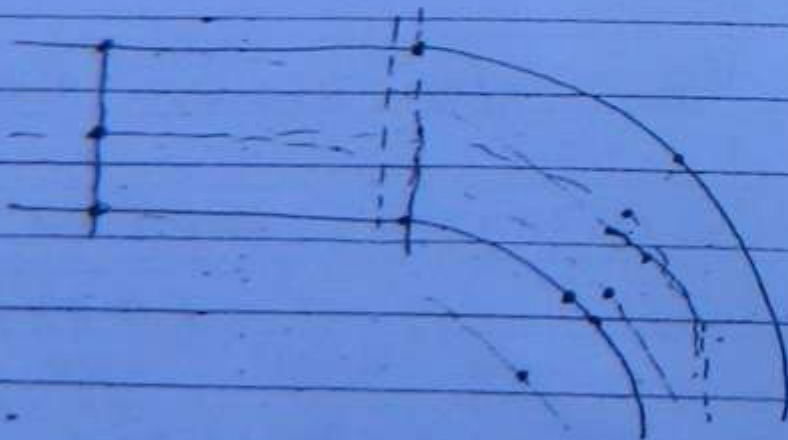
$$0.0547 = \frac{1.676 \times V_{max}^2}{127 \times 286}$$

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



B

Transition Curve :-



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

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.

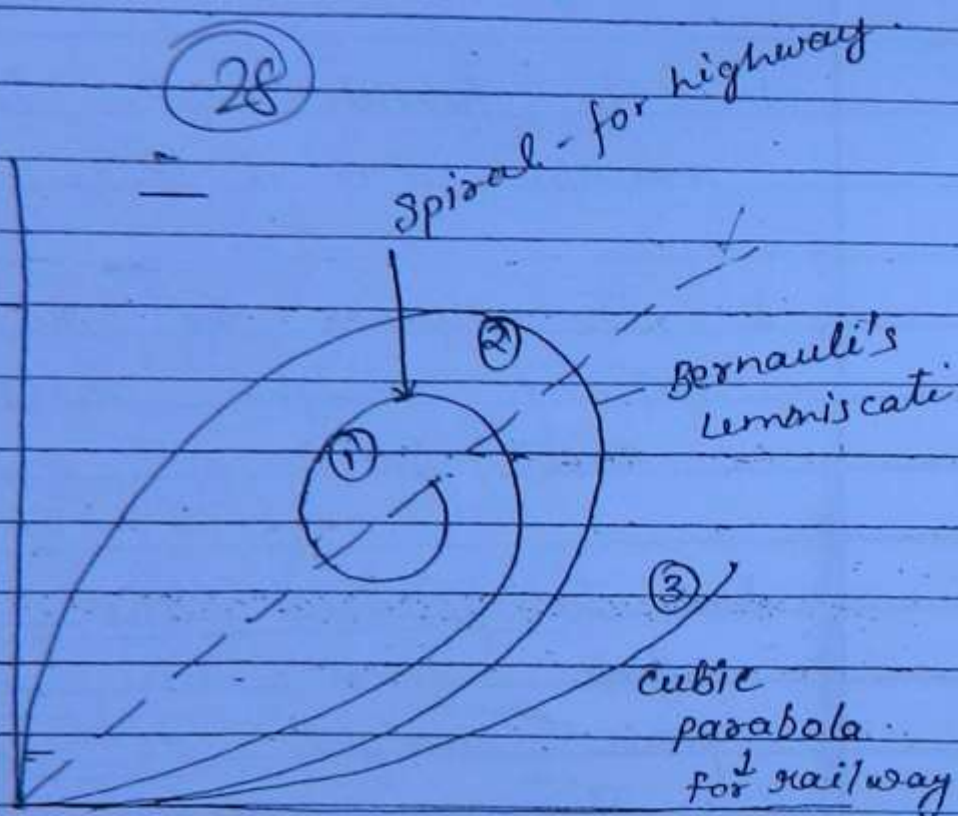
(At straight junction $\rightarrow$ Radius of transition curve $= \infty$)

At curved junction $\rightarrow$ Radius of T.C $= R$
Radius of simple curve

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

Types :-

(28)



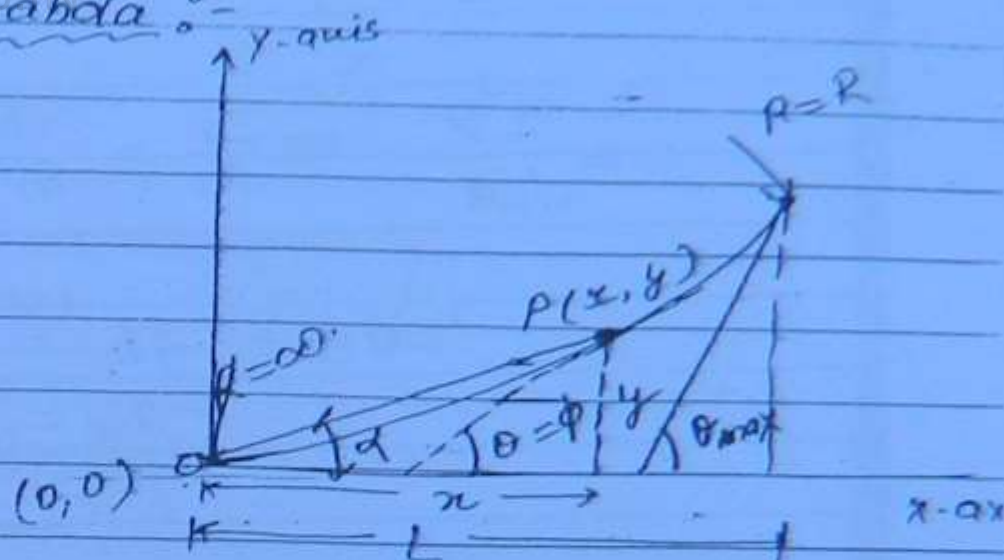
Cubic Parabola - Cubic Parabola is used for railway Transition curve.

→ upto a certain value of deflⁿ angle, shape of all these three curves are similar.

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

Cubic Parabola :-

(29)



General eqⁿ of cubic parabola -

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

at $n = 0$, $y = 0 =$

$$0 = 0 + 0 + 0 + d$$

$$\boxed{d = 0}$$

now differentiate -

$$\frac{dy}{dn} = 3an^2 + 2bn + c$$

at $n = 0$, slope $\frac{dy}{dn} = 0$

then $\boxed{c = 0}$

again differentiate -

curvature = $\frac{d^2y}{dn^2} = 6an + 2b = \frac{1}{R}$

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

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

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

$$0 + 2b = 0$$

$$\boxed{b=0}$$

at $x=L$

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

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

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

$$\boxed{y = \frac{1}{6RL} x^3}$$

(deflⁿ eqⁿ)

$$\text{Ans } \frac{dy}{dx} = \frac{x^2}{2RL}$$

(slope eqⁿ)

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

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

max^m slope

$$\theta_{\max} = \frac{L^3}{2RL} = \frac{L}{2R}$$

(31)

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

Spiral Angle :- (ϕ)

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

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

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

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

Deflection Angle :- (α) :-

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

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

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

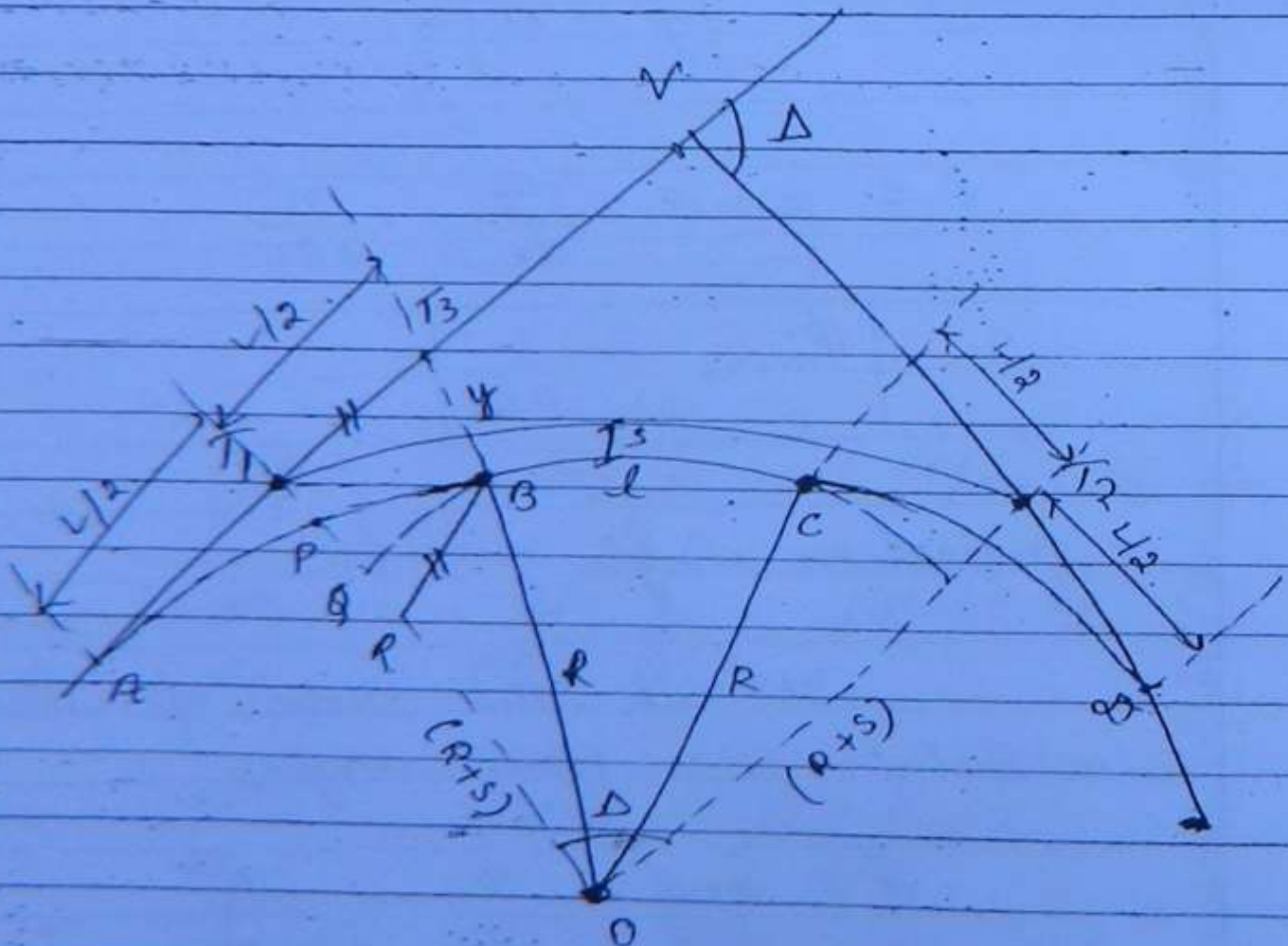
$$\alpha = \frac{1}{3} \phi$$

(32)

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

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

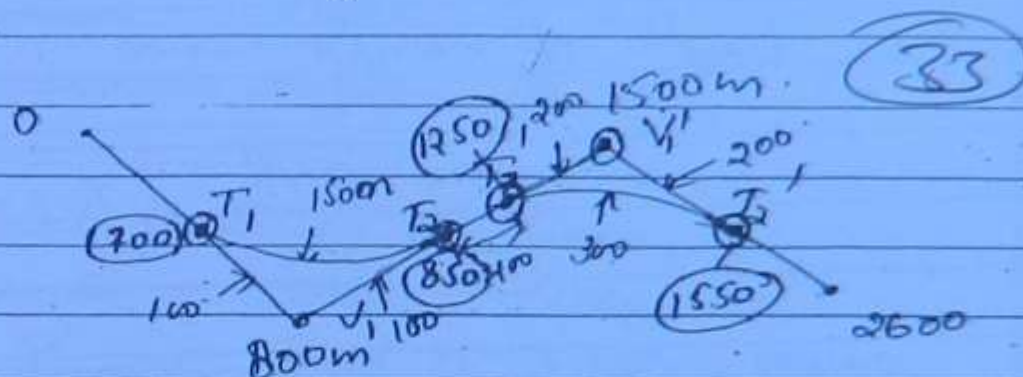
Providing cubic parabola as Transition curve on a railway track :-



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

→ Transition curve is provided such that $\frac{1}{2}$ length is available on both side of initial tangent points (T_1 or T_2).

eg:-



→ If chainage of $V = \text{given}$

→ 1st tangent length = AV

$$= AT_1 + T_1V$$

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

$$\text{chainage } A = \text{chainage } V - AV$$

$$\text{chainage of } (B) = \text{chainage } (A) + AB$$

$$= \text{chainage } (A) + L$$

$$\text{chainage of } (C) = \text{chainage } (B) + BC$$

$$= \text{chainage } B + d$$

$$\text{chainage of } (D) = \text{chainage } (C) + L$$

$$\text{Angle } LPOB = \frac{L/2}{R} = \frac{L}{2R} = \phi$$

= Spiral angle

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

length of simple curve

(34)

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

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

$$S = T_1Q = T_1M - QM$$

$$= T_1B - (OB - OM)$$

$$= y - [R - R \cos \phi]$$

$$= \frac{y^3}{6RL} - R(1 - \cos \phi)$$

$$= \frac{L^3}{6R} - R(2\sin^2 \frac{\phi}{2})$$

$$= \frac{L^3}{6R} - 2R \left(\frac{\phi}{2} \right)^2$$

$$= \frac{L^3}{6R} - 2R \times \left(\frac{L}{4R} \right)^2$$

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

Length of transition curve on Railways

There are two approaches -
1st approach -

1. $L = 7.2 e$ (3)

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. $L = 0.073 \Delta \cdot V_{max}$

Δ = cant deficiency

V_{max} = kmph.

L = meter.

2nd approach.

1. $L = 4.4 \sqrt{R}$ → Railway Board formula

R = radius of curve in m.

L = in m.

$$L = 3.6e$$

Based on super-elevation

 $e =$ cant in cm.

 $L =$ length in m. (36)

3. Length req for rate of change of radial acceleration -

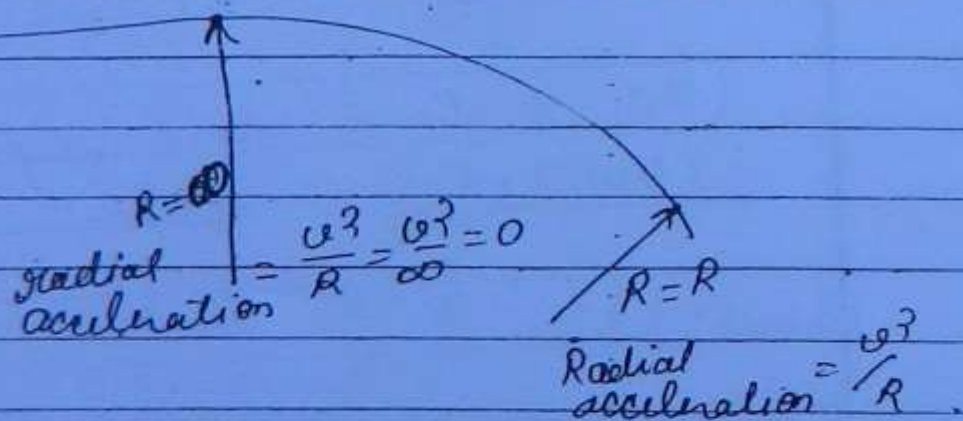
$$L = \frac{3.28 v^3}{R} = \frac{v^3}{eR}$$

here $C = 0.3048 \text{ m/sec}^2$

$v =$ 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 = $\frac{v^2}{R}$

in radial

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

if rate of change of radial acceleration is C .

(31)

of

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

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

$$L = v.T$$

$$T = \frac{L}{v} \quad \text{--- (2)}$$

equating (1) & (2)

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

$$v^3 = LCR$$

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

← length of T.C based on rate of change of R.A.

$$C = 0.3048$$

$$L = \frac{3280^3}{R}$$

0

Max^m speed based on length of transition curve -

① For normal speed -

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

(38)

or

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

here L = length of T.C. in (m)

e = cant in mm

D = cant deficiency in mm. --

② For High Speed Train -

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

Q. Equilibrium cant is provided on a B& 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 & deflⁿ angle = 85°.

calculate chainage of important points on the curve.

Set out the transition curve at every 10m distance.

Solⁿ 4° curve $\Rightarrow R = \frac{1720}{4} = 430$

$G = 1.676m$ - (39)

$V_{eq} = 80 \text{ kmph}$

$e_{act} = \dots$

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

$= 19.64 \text{ cm}$

$e_{max} = 16.50 \text{ cm}$

So actual cent provided = 16.50 cm

Max^m Speed allowed -

1) Safe speed on curve.

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

82.87 kmph.

as per cent formula -

$$\begin{aligned}e_{th} &= e_{acc} + d \\&= 16.50 + 7.60 = 24.10 \text{ cm} \\&= 0.241 \text{ m}\end{aligned}$$

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

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

$$V_{max} = 88.61 \text{ kmph}$$

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

$$L = 7.2e$$

$$L = 7.2 \times 16.50$$

$$= 118.8 \text{ m} \approx 119 \text{ m}$$

②

$$L = 0.073 \times e \times V_{max}$$

$$= 0.073 \times 16.50 \times 82.88 = 99.8 \text{ m}$$

(3)

$$L = 0.073 \times R \times V_{\max}$$

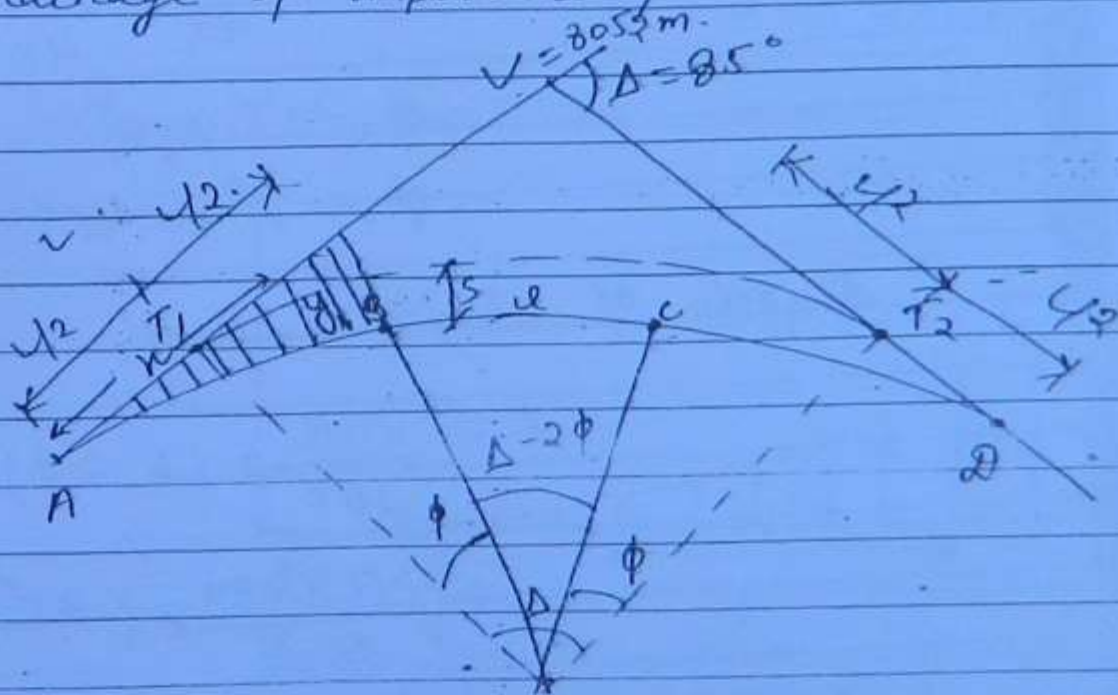
$$= 0.073 \times 7.60 \times 82.88$$

(41) $= 45.98 \text{ m}$

So length of transition curve = 119

using on a curve

chainage of important points -



chainage $V = 805.2 \text{ m}$

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

1st tangent length -

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

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

$$= 454.78 \text{ m}$$

(42)

length of simple curve.

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

$$\phi = 7.928^\circ$$

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

length of simple curve.

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

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

$$= 518.92 \text{ m}$$

$$\text{chainage V} = 8052 \text{ m}$$

$$- (VA) = - 454.78 \text{ m}$$

$$\text{chainage of A} = 7597.22$$

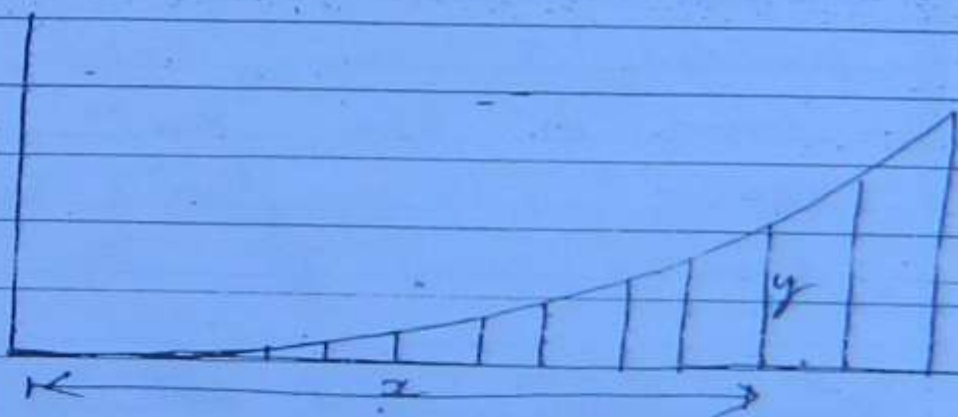
$$\text{chainage of B} = \text{chainage of A} + 119$$

$$\begin{aligned}\text{chainage of B} &= 7597.22 + 119 \\ &= 7716.22 \text{ m}\end{aligned}$$

$$\begin{aligned}\text{chainage of C} &= \text{chainage of B} + L \\ \textcircled{43} &= 7716.22 + 518 \\ &= 8235.14 \text{ m}\end{aligned}$$

$$\begin{aligned}\text{chainage of D} &= \text{chainage of C} + L \\ &= 8235.14 + 119 \\ &= 8354.14 \text{ m}\end{aligned}$$

Setting of transition curve:-



$$y = \frac{x^3}{6RL} = \frac{x^3}{6 \times 430 \times 119} = \frac{x^3}{307070}$$

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	1.17	1.66	2.37 ^m

100	110	119
3.25	4.83	5.48 ^m

WWW.GATENOETS.IN valley
Ex-03: Solⁿ is given after some.

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.

(94)

Ques. Calculate the max^m permissible speed on a B.G 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 -

(i) 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 -

$$\begin{aligned}
 V_{max} &= 4.58 \sqrt{R} \\
 &= 4.58 \sqrt{860} \\
 &= 134 \text{ kmph}
 \end{aligned}$$

(45)

② as per cant formula -

$$\begin{aligned}
 \text{cant} &= 9 \text{ cm} \\
 \text{cant deficiency} &= 10 \text{ cm} \\
 e_{th} &= e_{act} + \Delta \\
 &= 9 + 10 \\
 &= 19 \text{ cm} = 0.19 \text{ m}
 \end{aligned}$$

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

$$V_{max} = 111.27 \text{ kmph}$$

③ as per length of transition curve

$$\begin{aligned}
 V_{max} &= \frac{198 L}{e} \quad \text{or} \quad \frac{198 L}{\Delta} \\
 &= \frac{198 \times 125}{90} \quad \text{or} \quad \frac{198 \times 125}{100} \\
 &= 275 \text{ kmph} \quad \text{or} \quad = 247.5
 \end{aligned}$$

(4) Max^m sanctioned speed by railway -
 = 145 kmph
 (46)

So max^m speed allowed = 111 kmph. ~~Ans~~

Q On a transition curve on B.G 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.

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

$$e_{th} = \frac{e_{act} + \Delta}{R} \quad \left\{ \begin{array}{l} e_{act} = \frac{GV^2}{127R} \\ e_{th} = \frac{84.46}{R} + 7.6 \times 10^{-2} \end{array} \right. = \frac{1.676 \times 80^2}{127R}$$

$$\frac{84.46}{R}$$

$$4.35 \sqrt{R-67} = 1.35 \sqrt{\frac{127R}{1.676}} \left\{ \frac{84.46}{R} + \frac{7.1}{10} \right\}$$

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

(47)

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

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

$$8.4286R = 12931.8075$$

$$R = 1534.5$$

$$R = 1535 \text{ m}$$

$$\begin{aligned} \textcircled{3} \quad e_{act} &= \frac{84.46}{R} = \frac{84.46}{1535} = 0.055 \\ &= 0.055 \times 100 \\ &= 5.5 \text{ cm} \end{aligned}$$

② By martin's formula

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

By cent formula

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

$$V = 123 \text{ kmph}$$

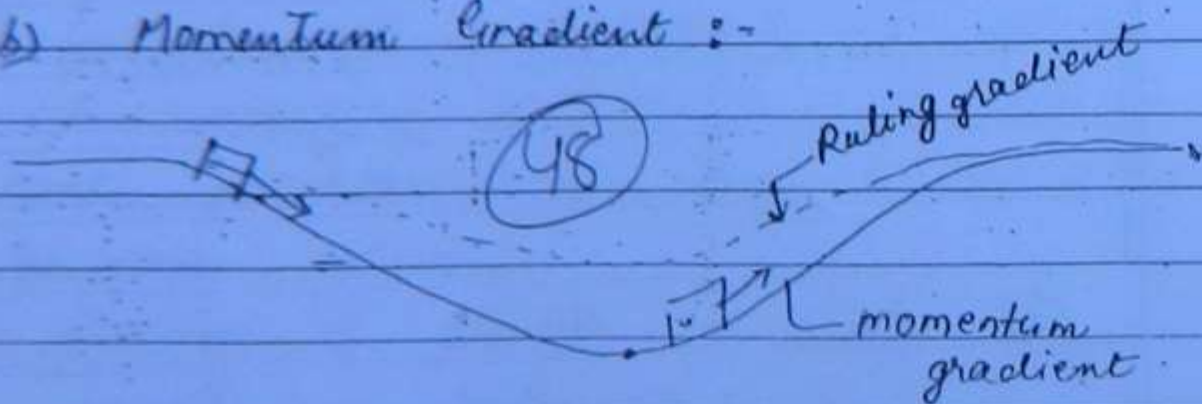
So max^m speed = 123 kmph.

Design of Vertical Alignment :-

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

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 ordinary situation, there is no other option, Pusher Gradient can be provided that need extra engine to push the train on steeper gradient.

↓ 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 drainage
 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 accommodate the effect of curve. The value of

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

(58)

$$B\&T = 0.04\% \text{ per degree of curve} = 0.0004^\circ$$

$$M\&T = 0.03\% \text{ per degree of curve} = 0.0003^\circ$$

$$N\&T = 0.02\% \text{ per degree of curve} = 0.0002^\circ$$

eg:-

Ruling gradient = 1 in 150

curve of 3° on a B\&T Track.

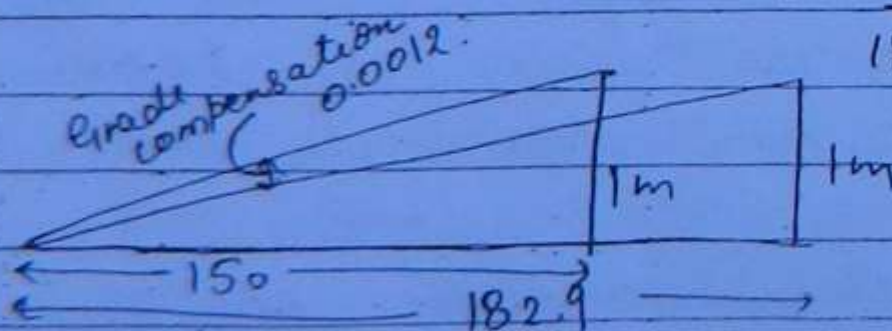
Grade compensation = 0.04% per degree

$$= \frac{0.04}{100} \times 3 = 0.0012$$

$$\text{compensated gradient} = \frac{1}{150} - 0.0012$$

$$= 5.467 \times 10^{-3}$$

$$= \frac{1}{182.9}$$



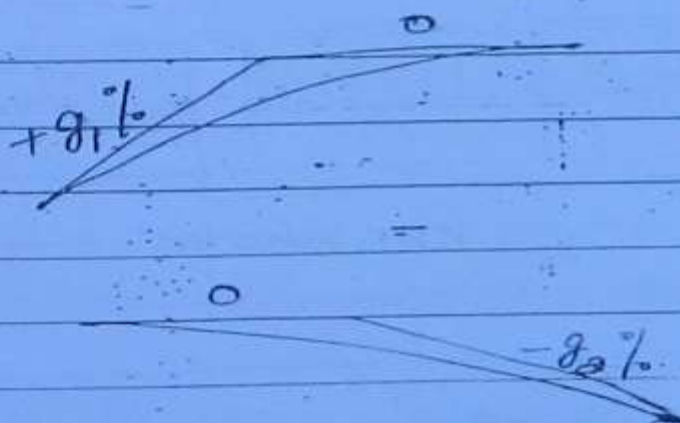
Vertical Curve -

① Summit Curve

② Valley Curve

(51)

① Summit Curve



② Valley Curve



Summit Curve :-

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

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

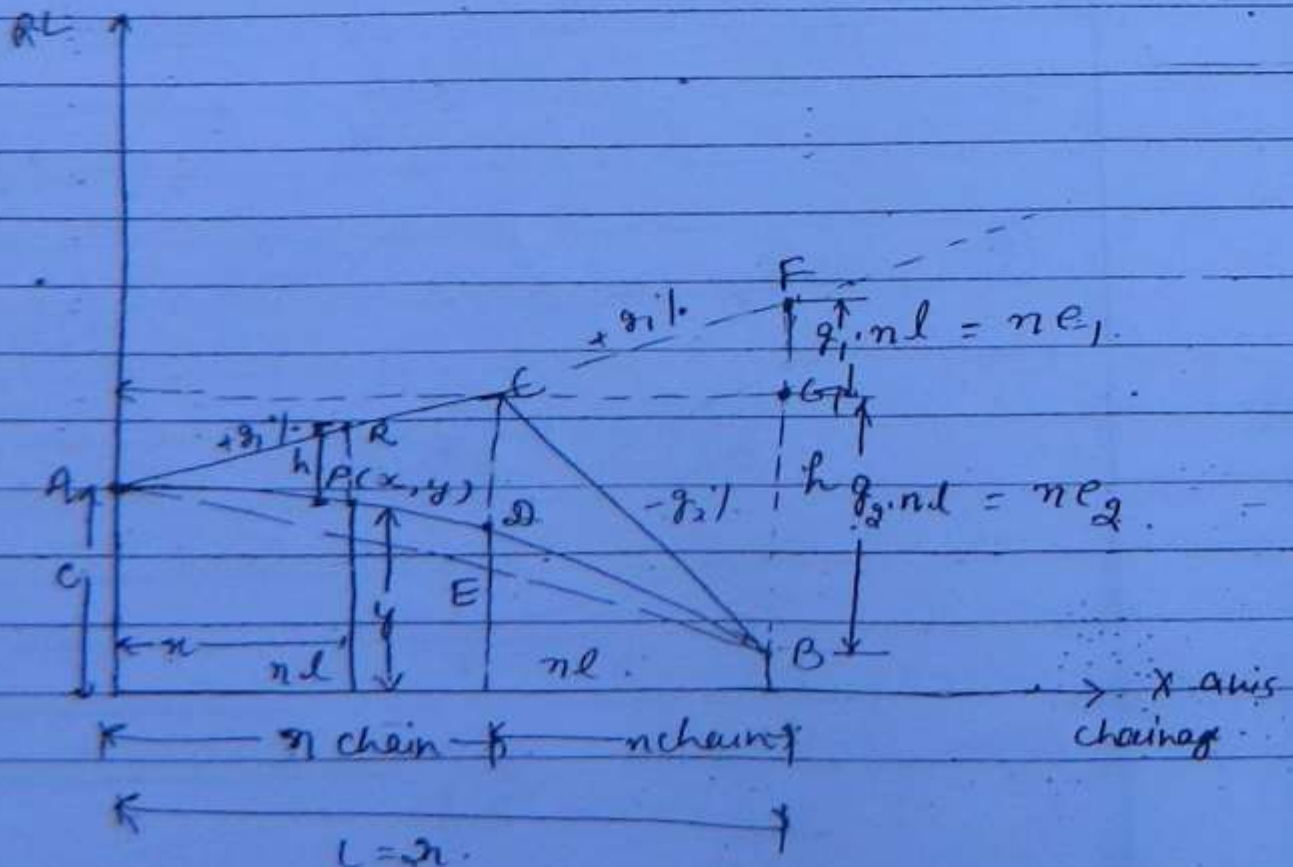
(S2)

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

length of summit curve

$$L = \left| \frac{(g_1 - g_2)}{\sigma} \right| \leftarrow \text{General formula.}$$

$$= 2n \text{ chains}$$



if RL of C = known

$$R.L \text{ of } A = R.L \text{ of } C - \frac{I_1}{100} \times nl$$

(53)

$$R.L \text{ of } B = R.L \text{ of } C - \frac{I_2}{100} \times nl$$

$$R.L \text{ of } E = \frac{R.L \text{ of } A + R.L \text{ of } B}{2}$$

$$R.L \text{ of } D = \frac{R.L \text{ of } C + R.L \text{ of } E}{2}$$

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

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

→ A simple curve parabola is used for summit curve.

General eqⁿ of curve -

$$\text{std eqⁿ - } y = an^2 + bn + c \quad \text{--- (1)}$$

$$\text{at } n = 0, y = 0 + 0 + c$$

$$y = c$$

slope eqⁿ $\frac{dy}{dx} = 2ax + b$

at $x = 0$

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

$$b = g_1$$

(54)

eqⁿ $\rightarrow$

$$y = ax^2 + g_1x + c \quad \text{--- (A)}$$

To find out RL of (P)

$$\begin{aligned} \text{RL of (R)} &= \text{RL of (A)} + g_1x \\ &= c + g_1x \end{aligned}$$

$$\text{RL of P} = \text{RL of R} - h$$

$$h = \text{RL of R} - \text{RL of P}$$

$$= c + g_1x - y$$

$$h = c + g_1x - (ax^2 + g_1x + c)$$

$$h = -ax^2$$

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

$$\therefore h = kn^2$$

$$e_1 = \text{rise per chain length (for } +g_1) \\ = \frac{g_1}{100} \times l$$

$$e_2 = \text{fall per chain length (for } -g_2) \\ = -\frac{g_2}{100} \times l$$

For last point on curve

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

For point B $n = 2n$

$$h = kn^2$$

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

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

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

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

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

Final value

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

for diffⁿ point on the curve

$$n = 0, 1, 2, 3, 4 \dots \text{no. of chains}$$

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 2500m 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).

$$g_1 = +0.65\%$$

$$g_2 = -0.85\%$$

$$r = 0.15\%$$

(56)

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

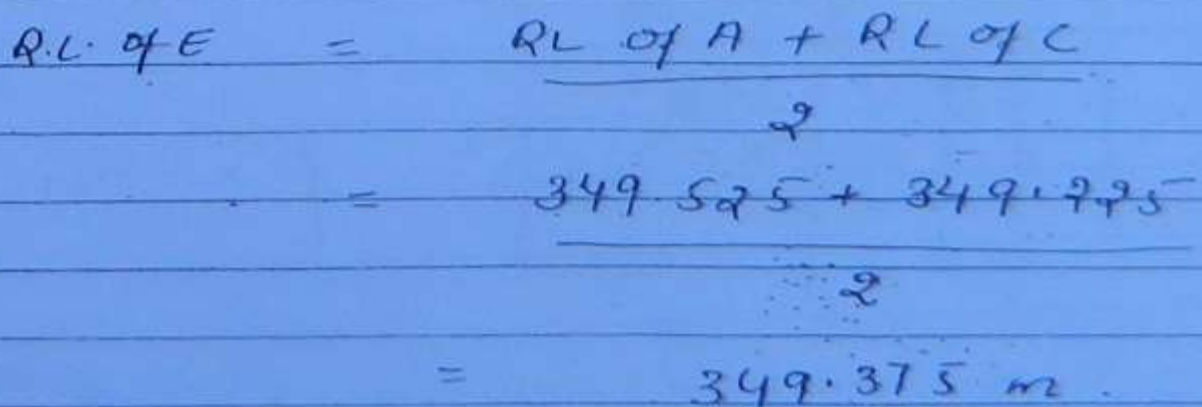
$$= 10 \text{ chain (20)}$$

$$n = 5 \text{ chains}$$

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

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

$$= 349.525\text{m}$$



$$\begin{aligned}
 RL \text{ of } D &= \frac{RL \text{ of } B + RL \text{ of } E}{2} \\
 &= \frac{350.50 + 349.375}{2} \\
 &= 349.9375 \text{ m}
 \end{aligned}$$

$$h = kn^2$$

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

(58)

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

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

$$\begin{aligned}
 k &= \frac{0.195 + 0.255}{4 \times 5} \\
 &= 0.0225
 \end{aligned}$$

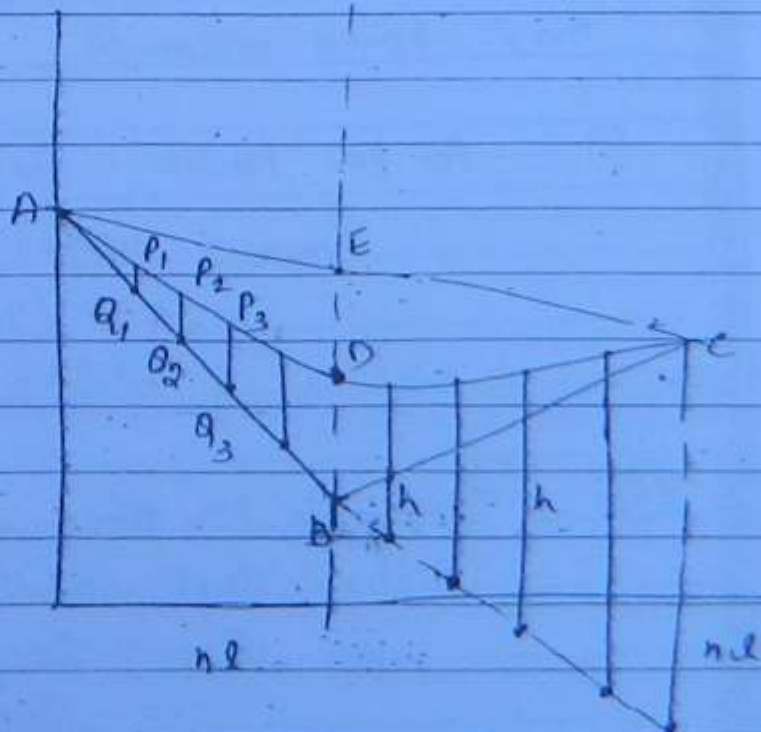
$$\begin{aligned}
 h &= kn^2 \\
 &= 0.0225 x^2 \quad \left\{ \begin{array}{l} n = 0, 1, 2, 3, \dots \end{array} \right.
 \end{aligned}$$

Points	Chainage	RL on points on 1 st tangent ($\frac{0.65}{100} \times 30 = 0.195$)	$h = kx^2$	RL on 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	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

(59)

$$RL \text{ of } P = RL \text{ of } A + L$$

Vally curve:-



Q. A valley curve has a down grade of 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 130.00 m & 100.50 m.

Calculate RL and chainage of diffⁿ points on valley curve (use 20m chain).

Solⁿ of Ques ESDB

4° curve

(66)

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

$$\text{cant} = 12 \text{ cm}$$

$$\text{max}^m \text{ design speed} = 100 \text{ kmph}$$

$$\text{cant deficiency} = 7.6 \text{ cm}$$

max^m speed allowed

① As per Martin's formula -

$$\begin{aligned} V_{\text{max}} &= 4.35 \sqrt{R - 67} \\ &= 4.35 \sqrt{430 - 67} \\ &= 82.88 \text{ kmph} \end{aligned}$$

② Speed as per cant formula -

theoretical cant

$$e_{th} = \text{Cant} + D$$

$$= 12 + 7.60$$

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

max^m speed allowed -

$$V_{max} = \sqrt{\frac{127 R \cdot e \cdot m}{a}}$$

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

(61)

$$= 79.9 \text{ kmph}$$

So max^m speed allowed on track = 100 kmph

So max^m speed = min^m of above three
= 79.9 or 80 kmph

using 2nd approach -

$$\textcircled{1} \quad L = 4.4 \sqrt{R}$$

$$= 4.4 \sqrt{430}$$

$$= 91.24 \text{ m}$$

$$\textcircled{2} \quad L = 3.6e$$

$$= 3.6 \times 12 = 43.2 \text{ m}$$

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

$$= 83.9 \text{ m}$$

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

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

eqⁿ of T.C.

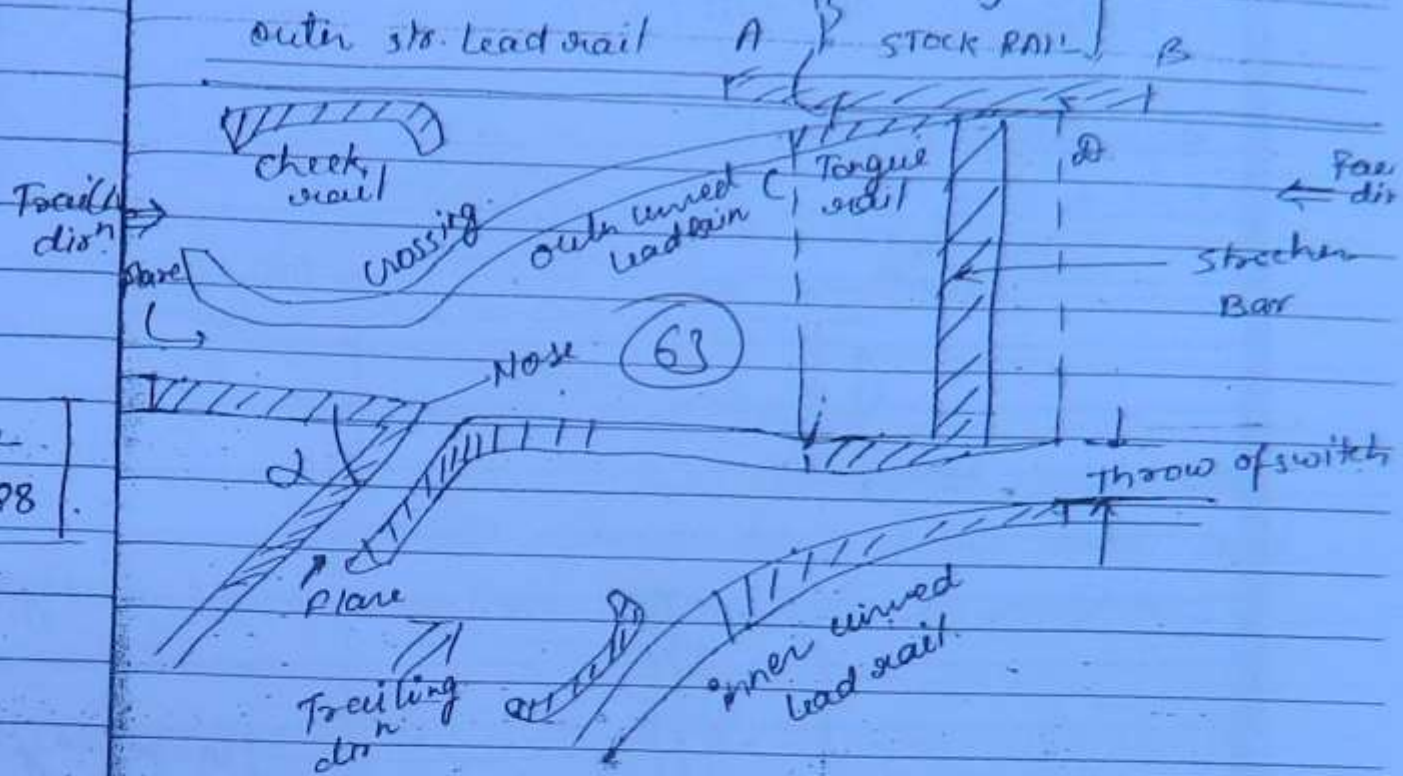
(62)

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

Total
dist

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



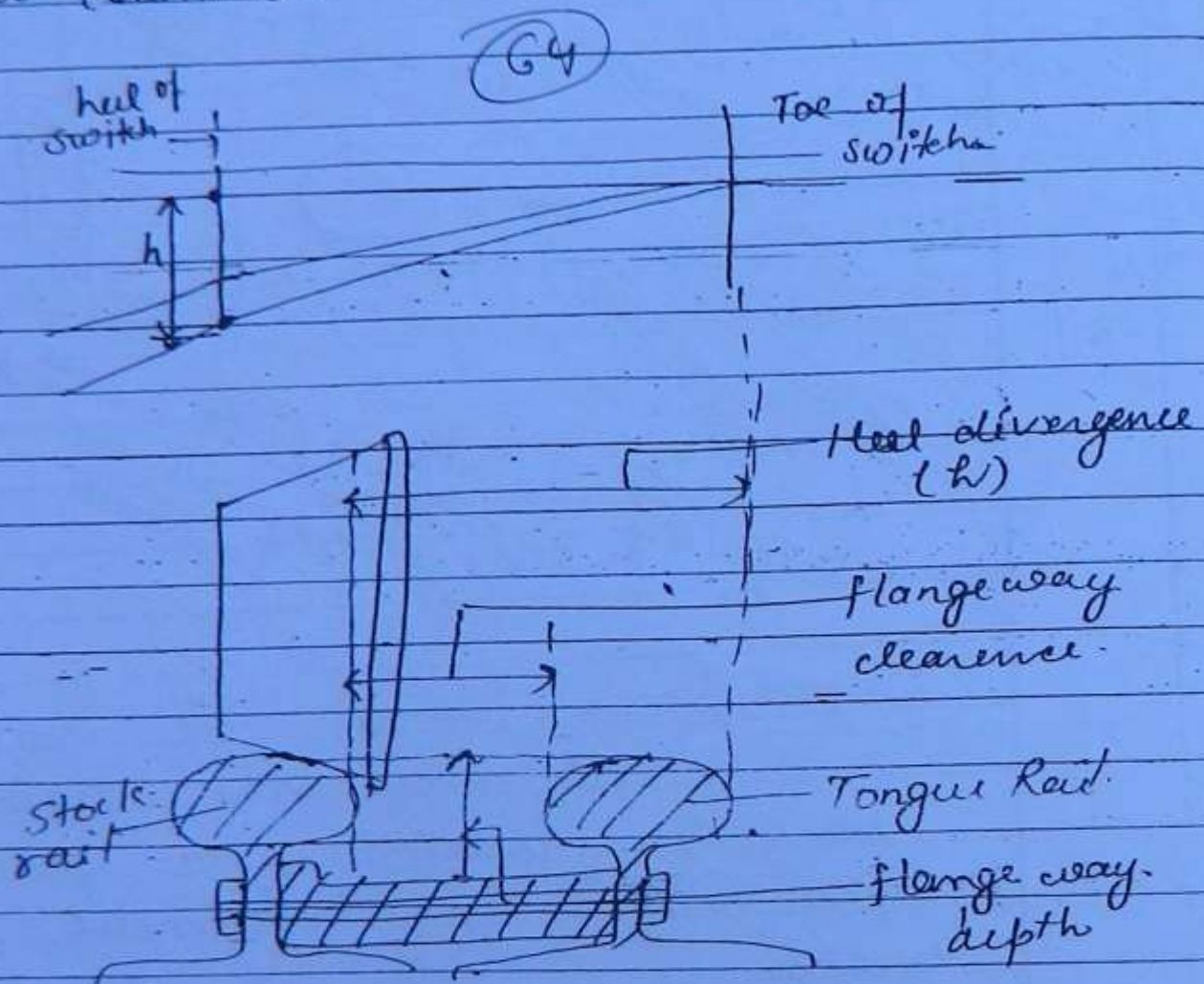
Turn out :- Turnout is an arrangement to divert the train from one track to another, to get better flexibility of movement b/w different tracks.

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

→ Diffⁿ component are shown in fig.

Component of turnout :-

a) Point (Switch) :-



Section at heel of switch.

② 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.

(65)

(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

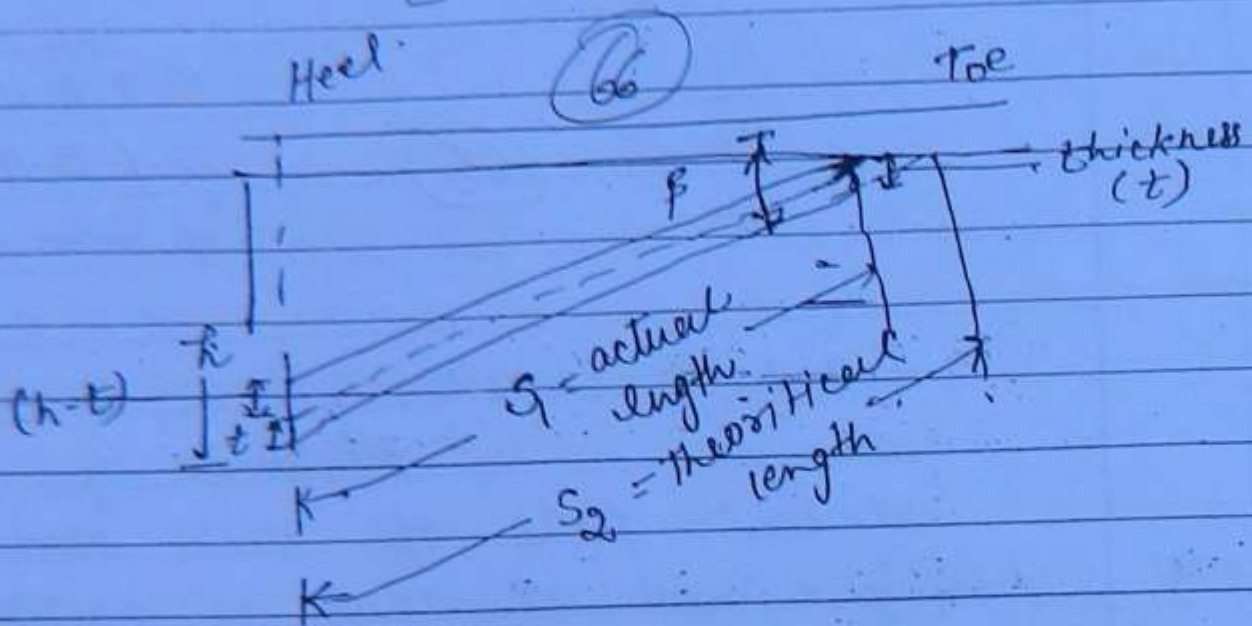
BG

9.5 cm.

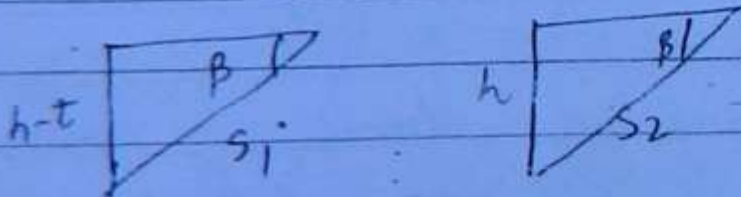
- MG/NG - -

8.9 cm.

⑤ Switch Angle :-



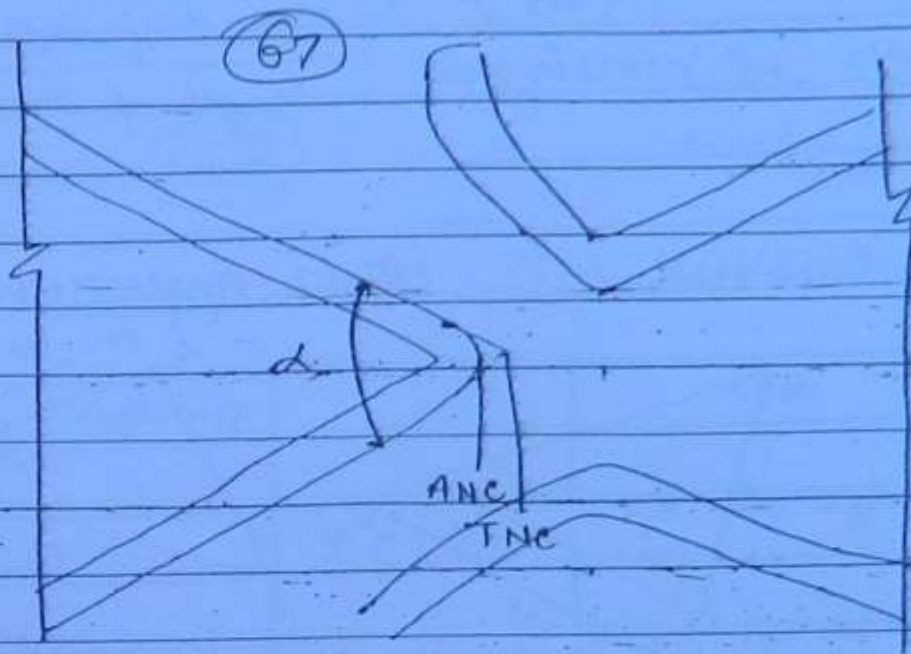
if S_1 = actual length of tongue rail
 S_2 = Theoretical length of tongue rail



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

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

Crossing :-



- Crossing should be rigid to sustain severe impact loads, vibration etc.
- Medium or high mag. manganese steel is used.

Important Points :-

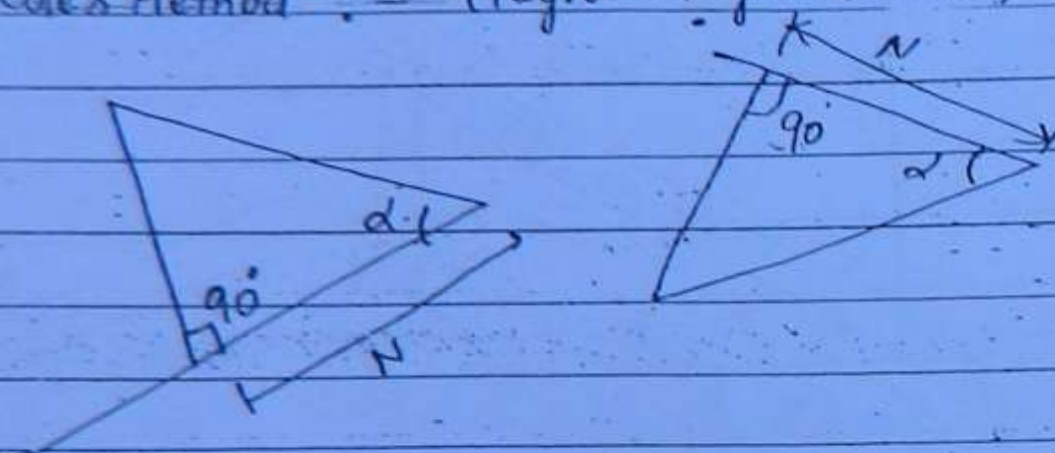
- ① ANC - Actual Nose of crossing due to blunt face.
- ② TNC - Theoretical nose of crossing intersection points of two sails.

⑤ Angle of crossing OR Number of crossing :-

(68)

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

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



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

$$N = \cot \alpha$$

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

α = angle of crossing.

$1/N$ = number of crossing.

This method is used on Indian railway.

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

$$\cot \alpha = 12$$

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

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

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

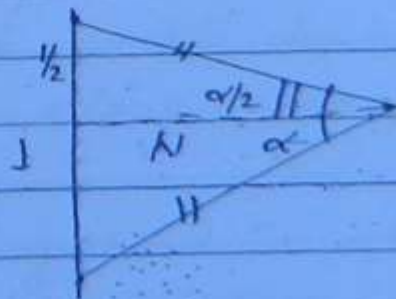
No. of crossing	α	use.
1 in 6	$9^{\circ} 27' 44''$	used in symmetrical split
1 in $8\frac{1}{2}$	$6^{\circ} 42' 35''$	used in station yard where space is restricted and speed is low
1 in 12	$4^{\circ} 45' 49''$	used on station yard of m. line.
1 in 16	$3^{\circ} 34' 35''$	used on high speed turn on main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

② Centre line Method :-

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

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

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



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

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

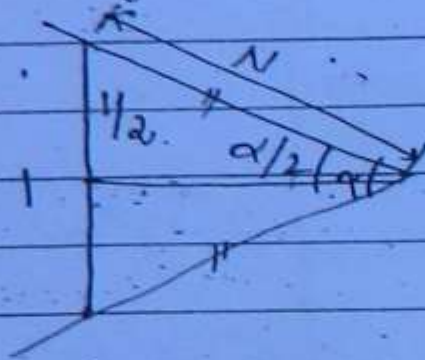
(70)

This method is used in US & UK.

5. Isosceles Triangle Method :-

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

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



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

$$\boxed{N = \frac{1}{2} \text{cosec } \frac{\alpha}{2}} \quad \text{no of crossing}$$

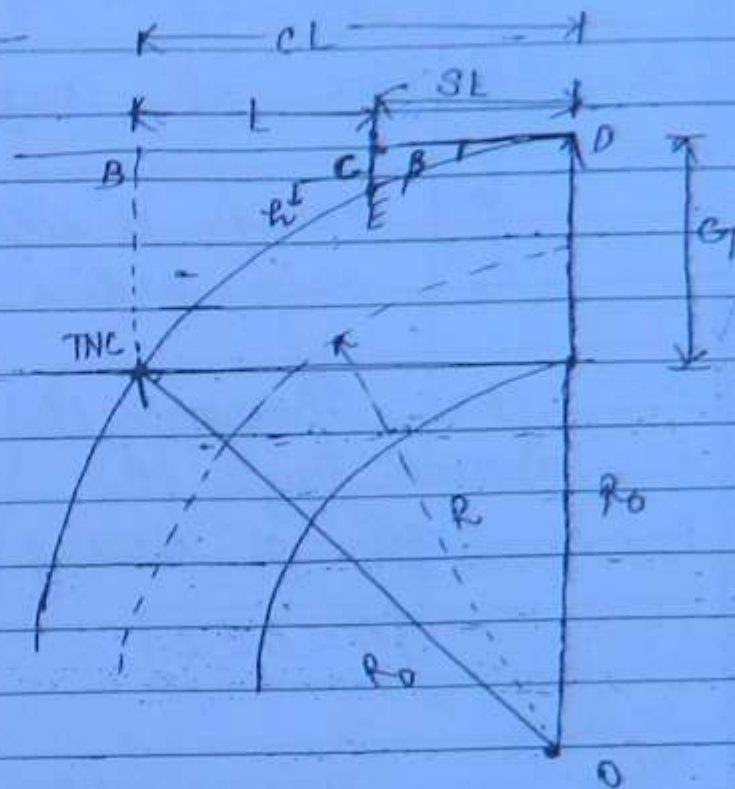
$$\boxed{\alpha = 2 \text{cosec}^{-1}(2N)} \quad \text{angle of crossing}$$

This method is used in tramways.

Design Calculation of Turnout

Components :-

(71)



- ① Curve lead (CL) :- The distance b/w toe of switch to TNC measured along straight lead rail
- ② Switch lead (SL) :- The distance b/w toe of switch to heel of switch measured along straight rail.
- ③ Lead (L) or Crossing lead :- Distance b/w heel of switch to TNC measured along straight rail.

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

4. Radius of curve :-

R = radius of curve

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

5. Heel Divergence (θ)

6. Switch Angle (β)

7. Angle of crossing (α)

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

There are three methods :-

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

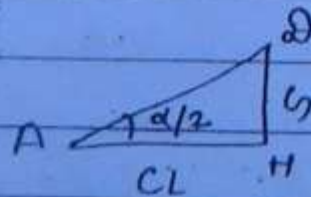
Given values - G , α or N .

1. Curve lead (CL) -

$$(ii) \quad CL = BD = AH$$

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

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



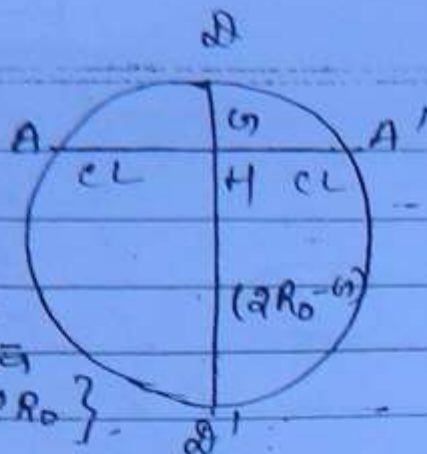
(c) using property of circle : —

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

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

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

$$\left\{ \begin{array}{l} 2R_0 - G = \\ 2R_0 \end{array} \right\}$$



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

24

(2) Radius (R & R_0) :-

$$h_0 = OD = OH + HD$$

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

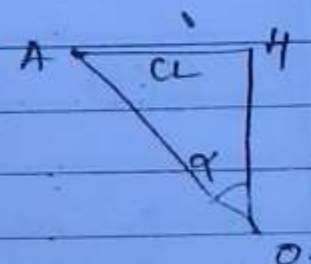
$$R_0 = CL \cot \alpha + G$$

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

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

As per Indian Railway.

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



$$R = R_0 - \frac{G}{2}$$

Lead

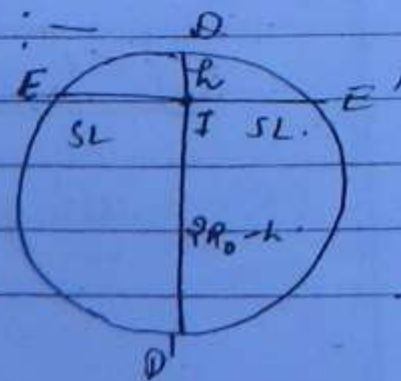
Switched Rail (SL) :-

Property of circle :-

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

$$(2R_0 - h \text{ or } 2R_0) -$$

$$h \times 2R_0 = SL^2$$



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

∴ Lead Crossing lead -

$$L = CL - SL$$

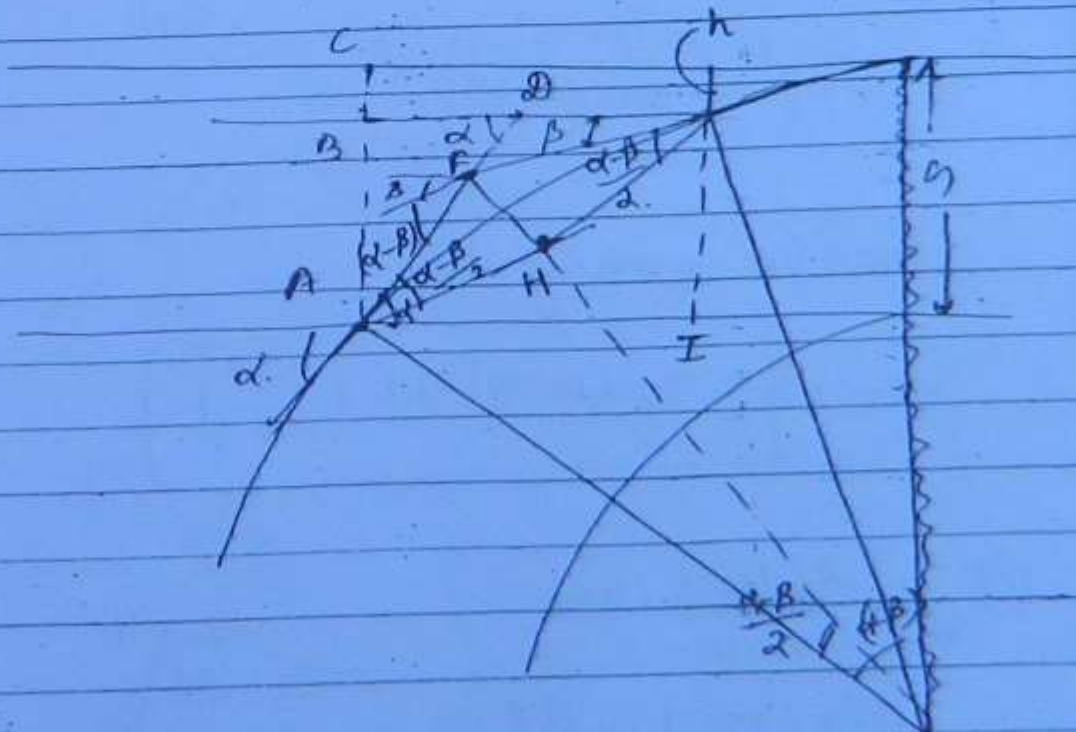
(79)

Method-2

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

Only two values are to be calculated

1. Lead or crossing lead (L)
2. Radius (R₀ or R)



Deflection angle $= \alpha - \beta$

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

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

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

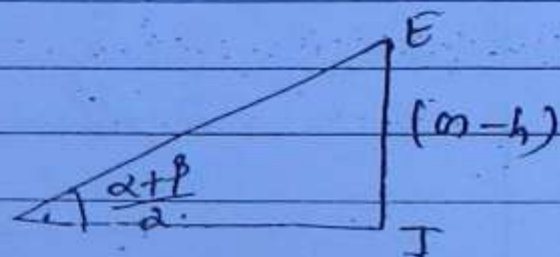
$$\angle AOH = \frac{\alpha - \beta}{2}$$

78

① Lead or crossing lead -

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

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



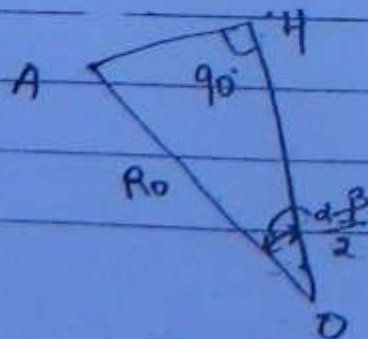
Lead or crossing lead.

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

② Radius :-

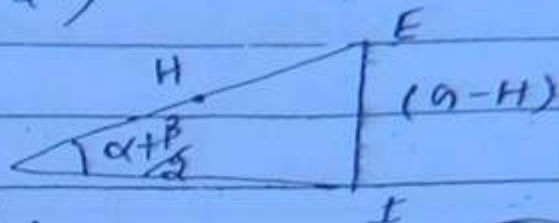
on ΔAHO

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



$$R_0 = \frac{AH}{\sin\left(\frac{\alpha+\beta}{2}\right)} \quad \text{--- (1)}$$

In $\triangle AEI$



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

(77)

$$AE = (G-H)$$

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

71

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

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

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

Put AH in eqⁿ (1)

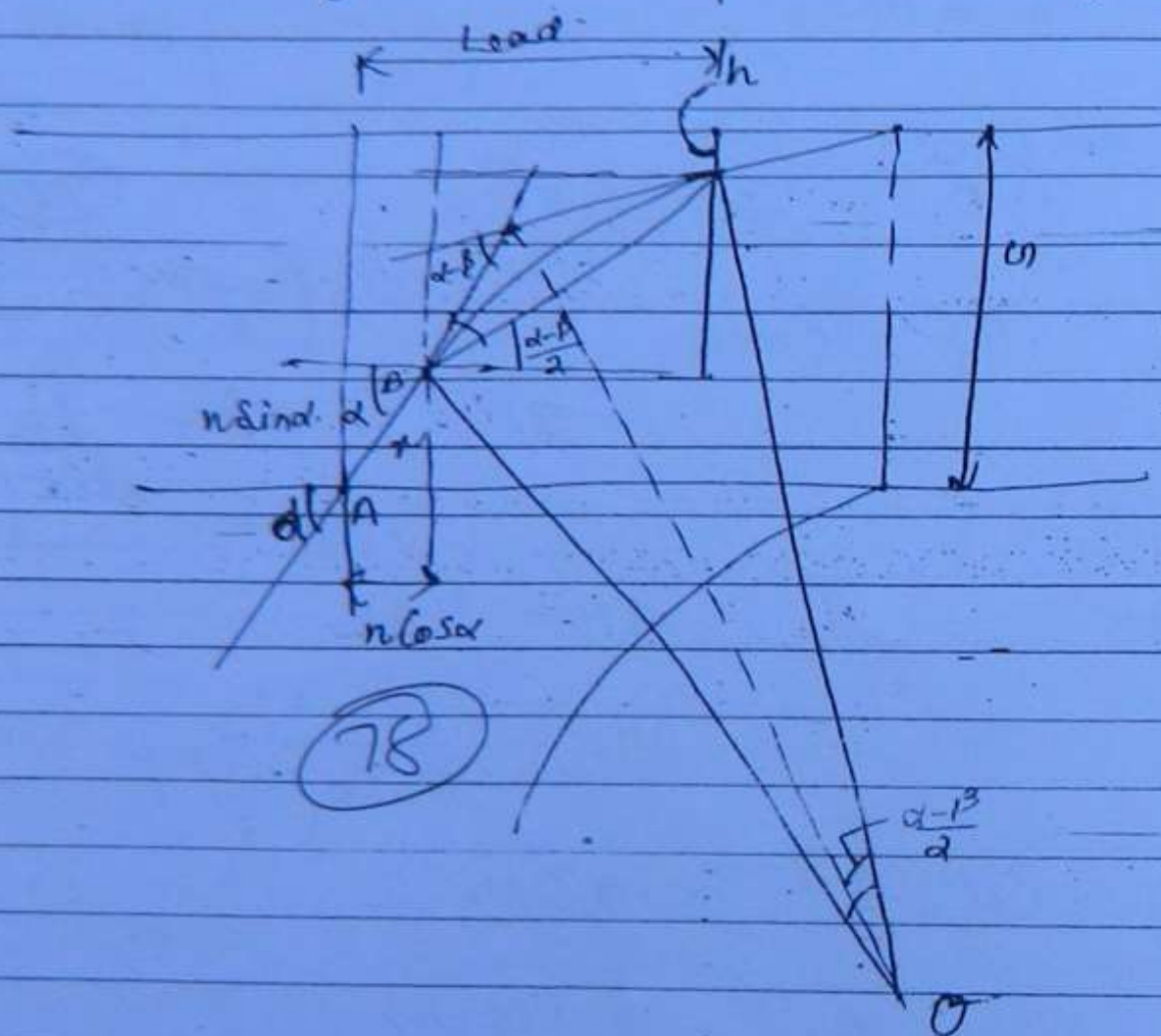
$$R_0 = \frac{(G-H)}{2 \sin\left(\frac{\alpha+\beta}{2}\right) \sin\left(\frac{\alpha+\beta}{2}\right)}$$

$$R_0 = \frac{G-H}{(\cos\beta - \cos\alpha)}$$

$$R = R_0 - \frac{G}{2}$$

Method-3

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



① Lead or crossing lead -

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

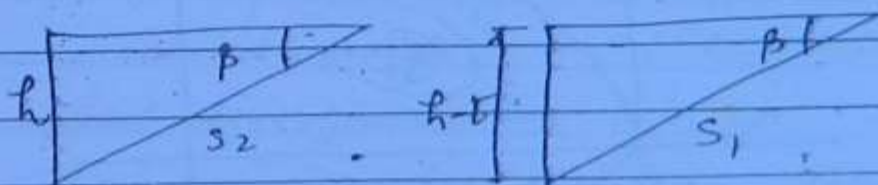
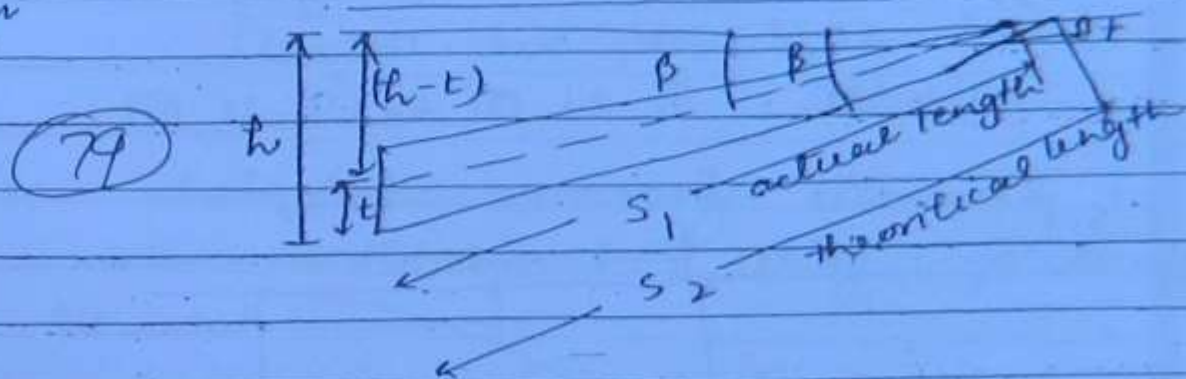
② Radius -

$$R = \frac{(G - h - n \sin \alpha)}{\cos^3 \beta - \cos \alpha}$$

Derivation is same as method ②.

Q: What will be angle of switch and
 rail divergence if
 theoretical length of switch = 5.10 m
 thickness of tongue rail at toe = 0.65 cm
 Actual length of tongue rail = 4.80 m.

Solⁿ



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

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

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

$$h = \frac{0.65 \times 510}{510 - 480} = 11.05 \text{ cm}$$

$$\text{Switch angle } \sin \beta = \frac{h}{S_2} = \frac{11.05}{510}$$

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

Q. Calculate necessary elements to set out a turnout taking from a straight B's track.

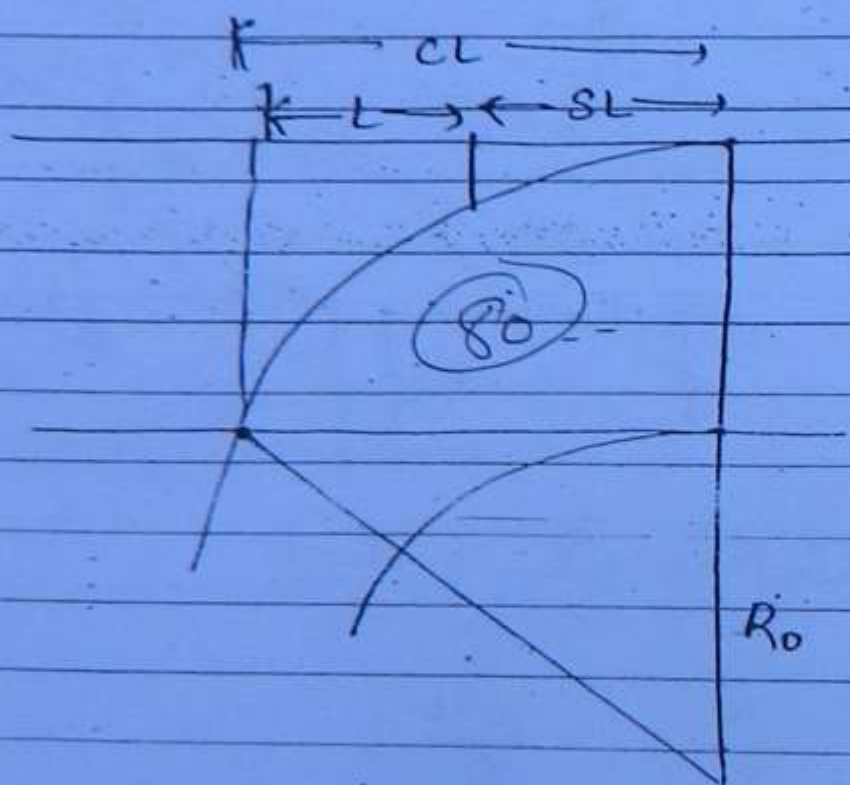
$$\text{No of crossing} = 1 \text{ in } 12.$$

$$\text{heel divergence} = 12 \text{ cm.}$$

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

calculate ① CL ② R_0 ③ SL ④ L.

Solⁿ



$$CL = 26N$$

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

$$CL = 40.224 \text{ m}$$

$$R_0 = 1.5N + 26N^2$$

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

$$R_0 = 48.5202 \text{ m}$$

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

$$= \sqrt{2 \times 485.202 \times 0.12}$$

$$[SL = 10.819 \text{ m}]$$

(81)

$$L = CL - SL$$

$$[L = 29.404 \text{ m}]$$

Q. Calculate necessary elements to set out a turnout using following data.
Back track.

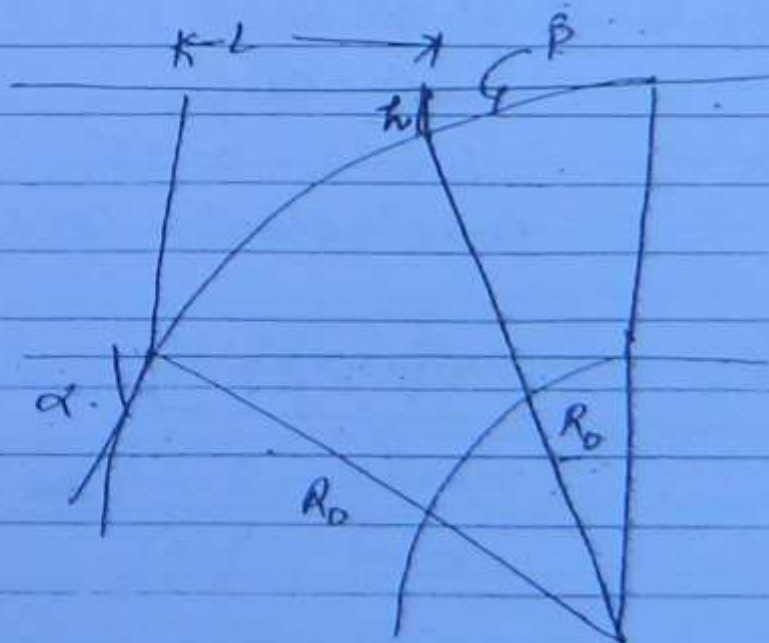
no. of crossing 1 in 16

Switch angle - $1^\circ 42' 30''$

heel divergence - 13.5 cm

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

Solⁿ



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

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

$$\textcircled{82} = \tan^{-1}\left\{\frac{1}{16}\right\}$$

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

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

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

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

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

$$L = 88.39 \text{ m}$$

$$R_D = \frac{G-h}{\cos\beta - \cos\alpha}$$

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

$$R_D = 1025.27 \text{ m}$$

ES-1994

Q. Calculate necessary elements to set out a $1 \text{ in } 8\frac{1}{2}$ 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 136 mm

Switch angle = $1^\circ 34' 27''$

Make a free hand sketch and show the calculated values:

(83)

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

$$\alpha = 6^\circ 42' 35.41''$$

$$\beta = 1^\circ 34' 27''$$

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

$$= 0.864 \cos 6^\circ 42' 35.41'' + (1.676 - 0.136 - 0.864 \sin 6^\circ 42' 35.41'')$$

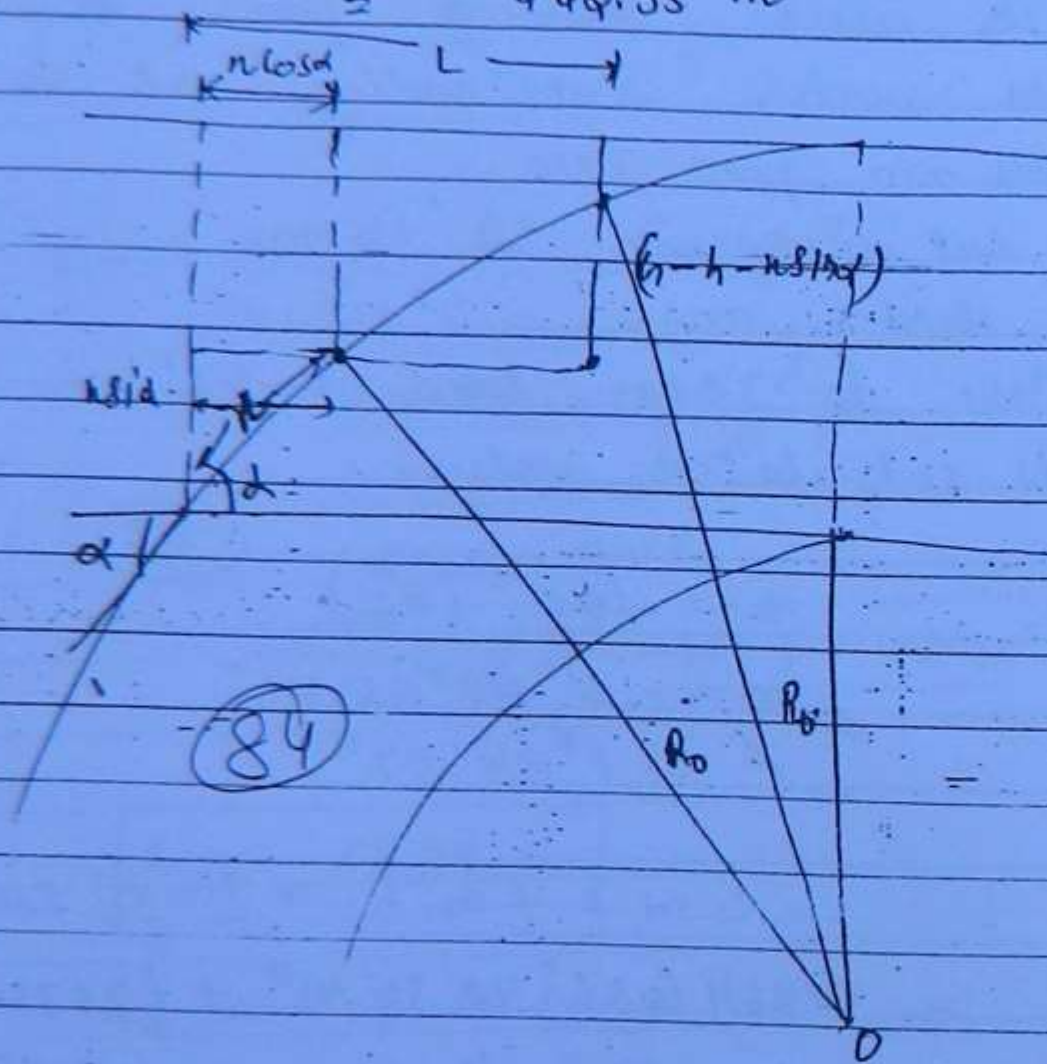
$$\cot \left(\frac{6^\circ 42' 35.41'' + 1^\circ 34' 27''}{2} \right)$$

$$21.1389 \text{ m}$$

$$R_D = \frac{G - h - x \sin \alpha}{\cos \beta - \cos \alpha}$$

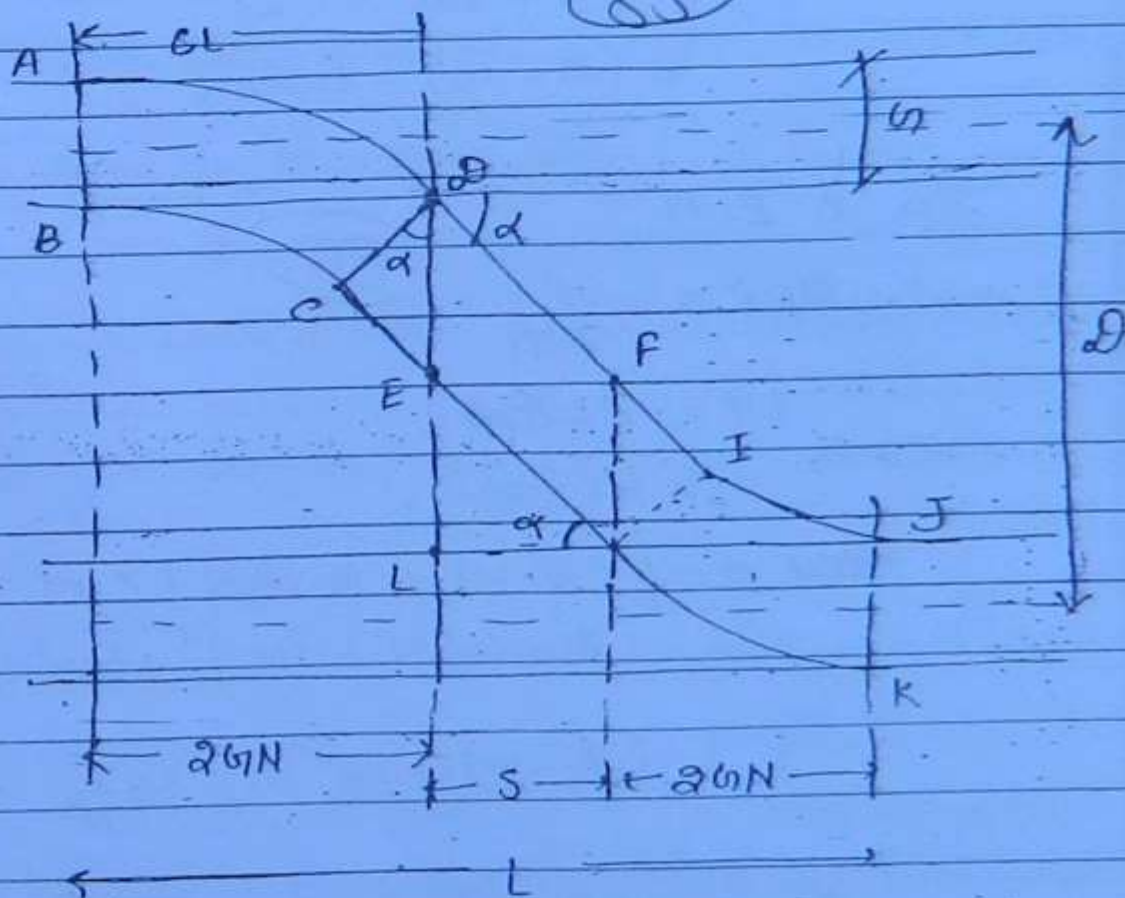
$$= \frac{1.676 - 0.136 - 0.864 \times \sin 6^\circ 42' 35.41''}{\cos 1^\circ 34' 27'' - \cos 6^\circ 42' 35.41''}$$

$$= 929.35 \text{ m}$$



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

(85)



$$CD = G = \text{gauge}$$

In this case total length of cross over

$$= BD + LH + HI$$

$$= 2GN + S + 2GN$$

$$= 4GN + S$$

S = strength portion of crossover b/w two turnout

In ΔCED

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

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

$$\begin{aligned} EL &= LD - ED \\ &= (D - G) - G \sec \alpha \end{aligned}$$

In ΔELH

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

$$LH = EL \cot \alpha$$

$$S = EL \cot \alpha$$

$$\begin{aligned} S &= [(D - G) - G \sec \alpha] \times \cot \alpha \\ &= (D - G)N - (G \sqrt{1 + \tan^2 \alpha}) \times N \end{aligned}$$

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

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

Overall length of crossover.

$$L = 4GN + S$$

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

ES 1995

Q. A crossover occurs b/w two parallel Bn 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.

Solⁿ

Refer to previous solg.

(87)

$$D = 5m, C = 1.676m, N = 8.5$$

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

To get length of straight portion S

$$CD = C = 1.676m$$

$$ED = C \sec \alpha = 1.676 \sec 6^{\circ}42'35.4'' = 1.688m$$

$$EL = (D - C) - ED$$

$$= (5 - 1.676) - 1.688$$

$$= 1.636m$$

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

$$= 13.91m$$

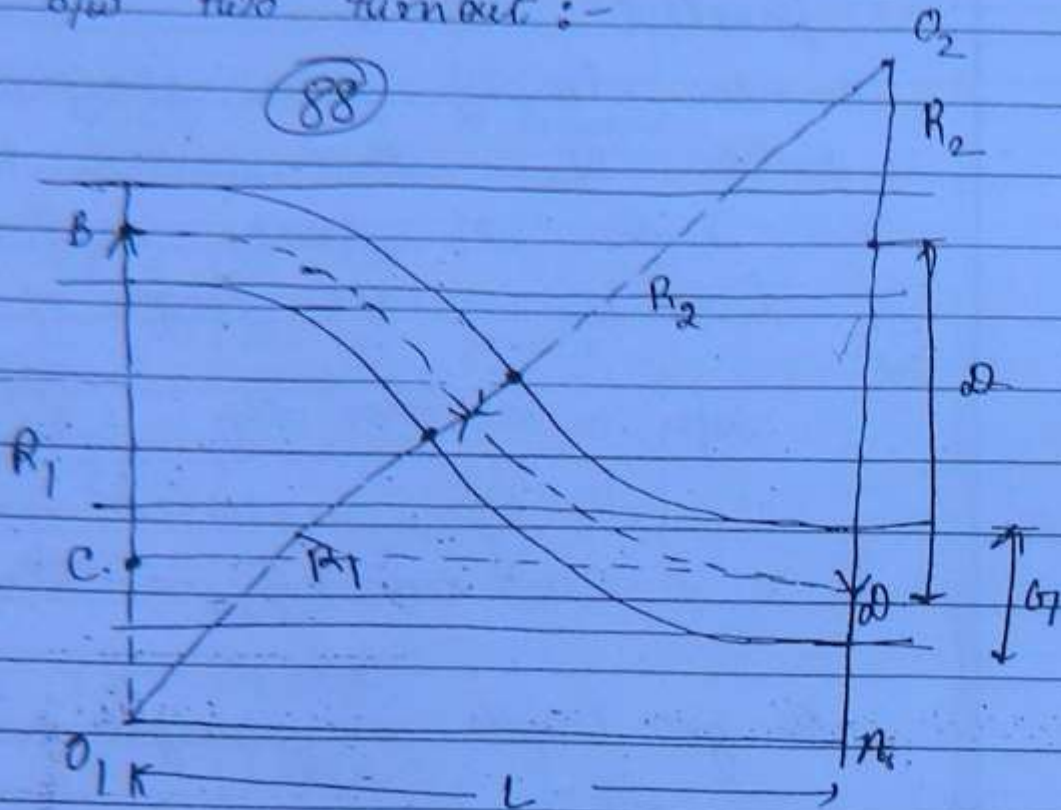
$$\text{overall length } L = 4CN + S$$

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

$$= 70.89m$$

Type 2 - Crossover with curved portion

b/w two turnout :-



if 1st turnout is 1 in N_1
2nd turnout is 1 in N_2

1. Radius - R_1 -

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

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

Radius R_2 -

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

$$R_2 = R_{20} - \frac{G}{2}$$

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

D = centre to centre distance b/w
tracks.

In triangle O_1O_2A

(89)

$$O_1O_2 = R_1 + R_2$$

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

Overall length of crossover

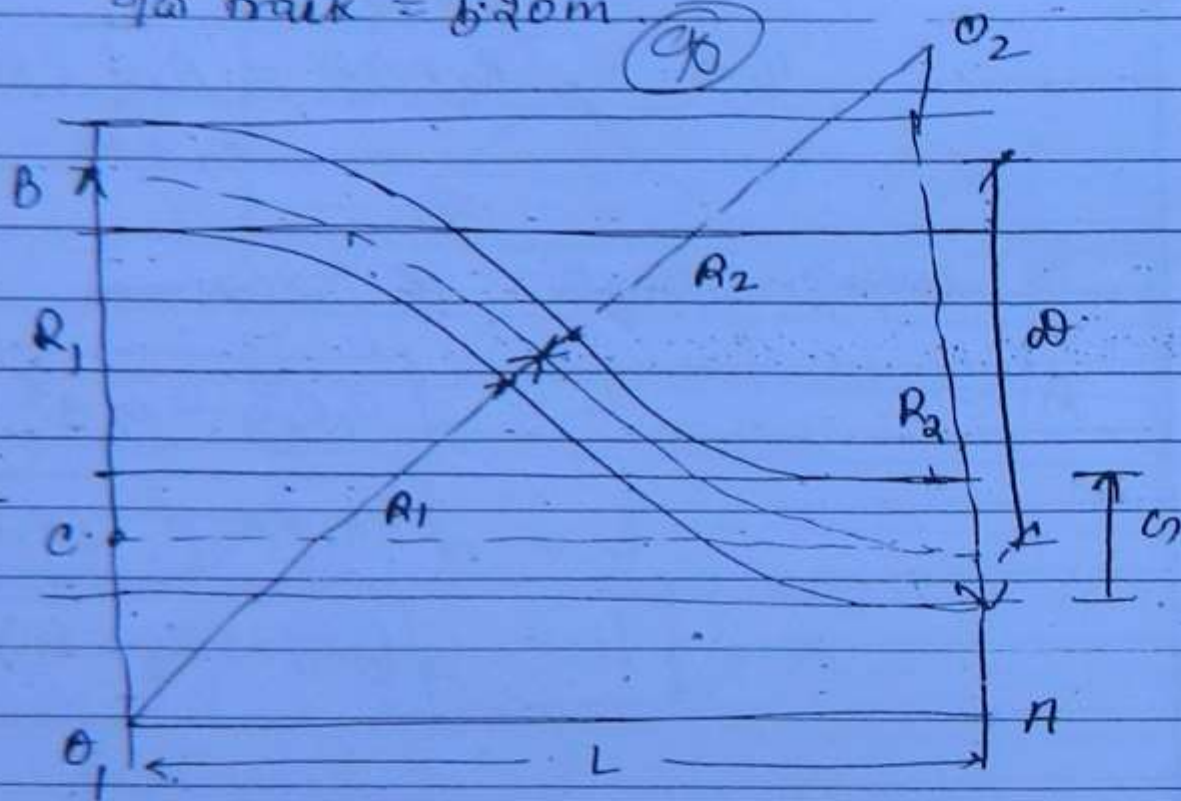
$$L = \sqrt{O_1O_2^2 - O_2A^2}$$

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

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

Ques 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. Findout overall length of crossover b/w these two BG track. centre to centre. b/w track = 6.20m.

Solⁿ



Turnout (1) = 1 in 12.

$$N_1 = 12$$

$$\begin{aligned} \text{Radius } R_{10} &= 1.5G + 2G N_1^2 \\ &= 1.5 \times 1.676 + 2 \times 1.676 \times 12^2 \\ &= 485.202 \end{aligned}$$

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

$$R_1 = 484.364 \text{ m}$$

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

$$\begin{aligned} R_{20} &= 1.56 + 20N_2^2 \\ &= 1.5 \times 1.676 + 2 \times 1.676 \times 16^2 \\ &= 860.626 \text{ m} \end{aligned}$$

$$\begin{aligned} R_2 &= \frac{R_{20} - G}{2} \\ &= \frac{860.626 - 1.676}{2} \end{aligned}$$

(9)

$$= 859.788 \text{ m}$$

$$\begin{aligned} O_1O_2 &= R_1 + R_2 \\ &= 484.364 + 859.788 \\ &= 1344.152 \text{ m} \end{aligned}$$

$$\begin{aligned} O_2A &= R_1 + R_2 - D \\ &= 1344.152 - 5.20 \\ &= 1338.952 \text{ m} \end{aligned}$$

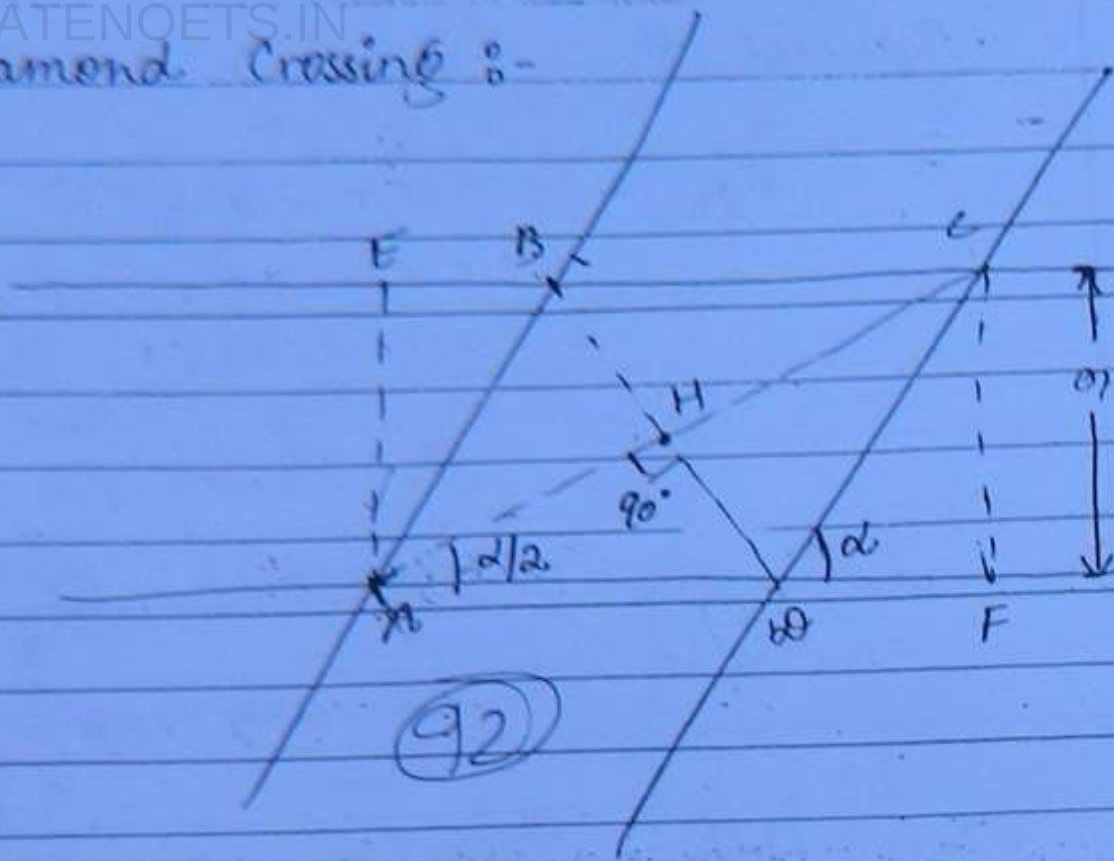
Overall length of cross over

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

$$L = \sqrt{(1344.152)^2 - (1338.952)^2}$$

$$L = 118.12 \text{ m}$$

Diamond Crossing :-



length $AB = BC = CD = DA$

In $\triangle CDF$ --

$$CD = G \sec \alpha$$

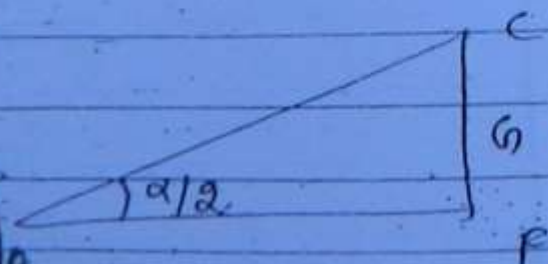
$$EB = DF$$

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

$$DF = G \cot \alpha$$

Diagonal AC

$$AC = G \sec \frac{\alpha}{2}$$



$$BD = 2HD$$

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

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

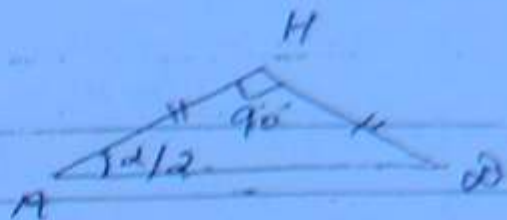
$$HD = \frac{AC}{2} \tan \frac{\alpha}{2}$$

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

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

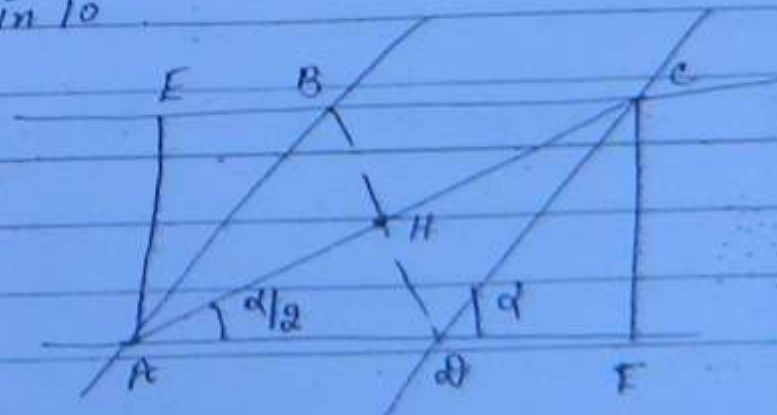
$$BD = 2HD$$

$$BD = \frac{AC \sec \alpha}{2}$$



ES-1997.

Ques. Design a diamond crossing b/w two BR tracks crossing each at an angle of $1^\circ 10'$.



$$\ln N = \ln 10$$

$$N = 10$$

$$\cot \alpha = 10$$

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

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

(44)

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

$$\text{Length } AB = BC = CD = DA$$

$$= r \operatorname{cosec} \alpha$$

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

$$= 16.84 \text{ m}$$

$$\text{Length } EB = DF$$

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

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

$$= 33.645 \text{ m}$$

$$\text{Diagonal } BD = r \sec \frac{\alpha}{2} = \frac{1.676}{\cos\left(\frac{5^{\circ}42'38.14''}{2}\right)}$$

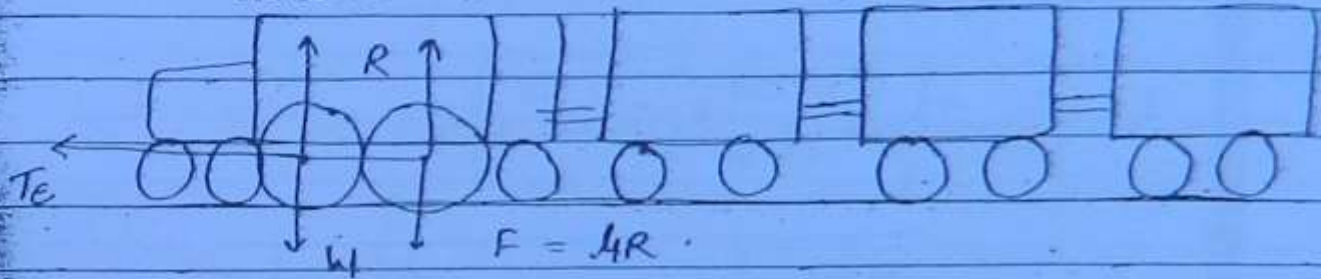
$$= 1.678 \text{ m}$$

TRACTION & TRACTIVE EFFORT :-

To understand this topic three important points are -

(93)

engine (locomotive) + wagons = train



① Tractive effort :- This is the ~~sch~~ 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

$$F_f = 4R = H.C.$$

$$H.C = F_f = 4R = 4 \cdot W$$

$$\boxed{HC = 4 \mu W_d}$$

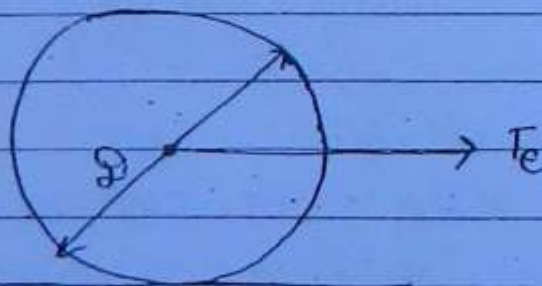
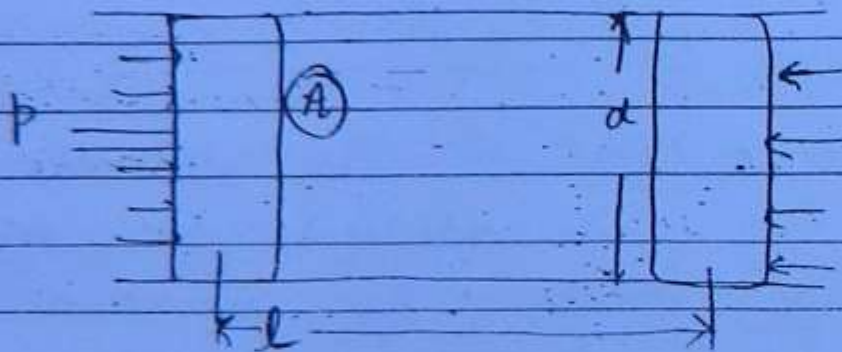
3. Total Resistances - Total resistance offered by train due to various reason during movement.

For movement of train

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

(96)

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 (97)

Power generated = work done

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

$$\boxed{T_e = \frac{n p l d^2}{4 d}} \quad \text{--- (A)}$$

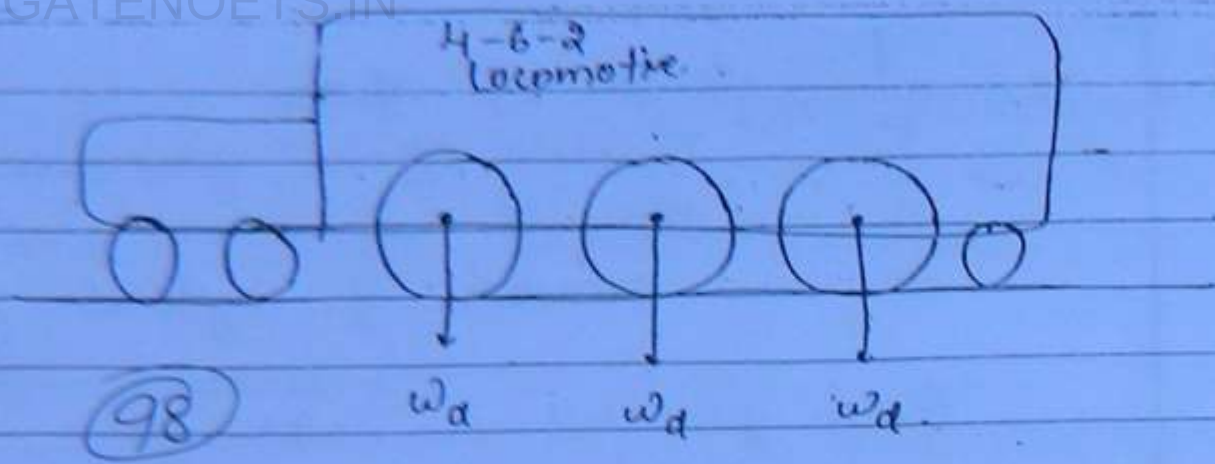
Tractive effort $T_e \propto \frac{1}{d}$

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.



n = no. of pairs of driving wheels.

w_d = wt on each pair of driving wheels.

μ = Coeff. of friction.

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

value of μ

At low speed $\mu = 0.30$

at high speed $\mu = 0.10$

During movement

value of μ considered $\mu = 0.20$

$$\text{or } \mu = \frac{1}{6} = 0.166$$

Designation of a locomotive -

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

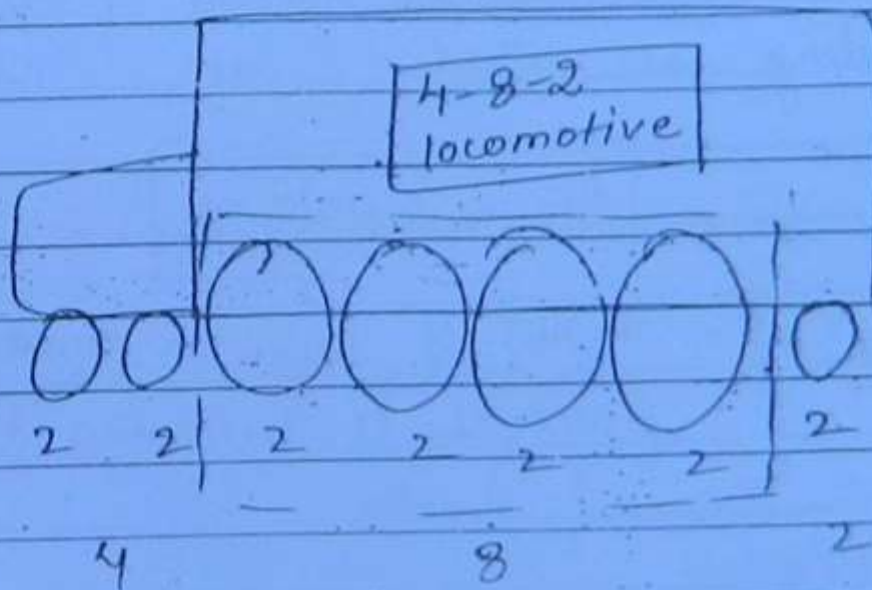
n_1 = Total no. of front wheel.

n_2 = Total no. of driving wheel

n_3 = Total no. of rear wheels.

for hauling capacity

(99) $n = \text{nos of pairs} = \frac{n_2}{2}$

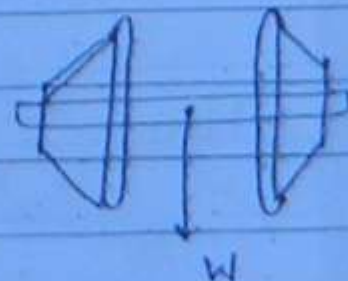


Max^m axle load :-

BG = 28.56 t

MG = 17.34 t

NG = 13.26 t



one axle = one pair of wheels

2. Total Resistances -

(100)

1. Train Resistance (R_T)

a) Resistance independent of speed (R_{T1})
(Rolling Resistance) :-

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

$$R_{T1} = 0.0016 w$$

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

b) Resistance dependent on speed (R_{T2}) -

$$R_{T2} = 0.00008 w V$$

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

c) Atmospheric Resistance :- (R_{T3})
(even when wind speed = 0)

$$R_{T3} = 0.0000006 \omega V^2$$

Total train Resistance - (10)

$$R_T = R_{T1} + R_{T2} + R_{T3}$$

$$R_T = 0.0016\omega + 0.00008\omega V + 0.0000006\omega V^2$$

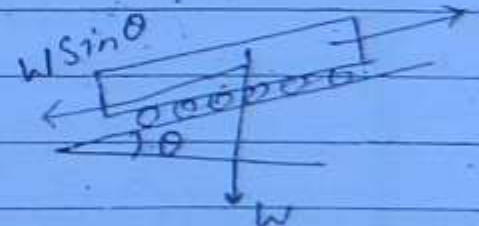
↑
always considered.

2. Resistance due to track profile -

a) Due to Gradient :-

$$R_g = \omega \tan \theta$$

for small value of θ
 $\theta = \sin \theta = \tan \theta$



b) Resistance due to curve -

for BG -

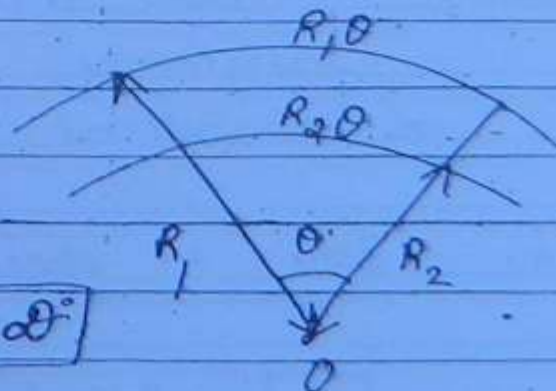
$$R_c = 0.0004 \cdot \omega \cdot \theta^\circ$$

for MG

$$R_c = 0.0003 \omega \theta^\circ$$

for NG

$$R_c = 0.0002 \omega \theta^\circ$$



Here w = wt. of train in tonnes.

θ° = degree of curve.

3. Resistance due to starting and acceleration -

(102)

a) Due to starting -

$$R_{\text{locomotive}} = 0.15 w_1$$

$$R_{\text{wagon}} = 0.005 w_2$$

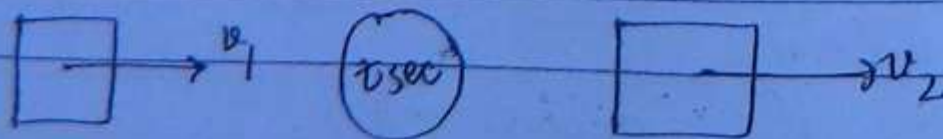
Total resistance.

$$R_{st} = 0.15 w_1 + 0.005 w_2$$

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

Note:- When train is moving, this resistance is not required to be considered.

b) Due to acceleration -



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

w = wt. of train in tonnes.

V_2/V_1 = speed in kmph.

t = time in seconds.

(103)

4. Wind Resistance

$$R_w = 0.00017 a V_w^2$$

a = exposed area in m^2 of train

V_w = wind velocity in kmph.

R_w = wind resistance in tonnes.

for movement of train -

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

Q. A locomotive on B/G 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.

(104)

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

$$n = 4 \text{ pairs}$$

$$w_d = 20t$$

$$\mu = 1/6$$

Hauling capacity

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

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

$$= 13.33t$$

$$V = 80 \text{ kmph}$$

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

Hauling capacity = Total Resistance

$$13.33L = R_{T_1} + R_{T_2} + R_{T_3} + 0.0004wD$$

$$= 0.0016w + 0.00008wV + 0.0000006wV^2 + 0.0004wD$$

(105)

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

$$13.33 = w \times 0.008$$

$$w = 1054.6 \text{ tonnes } A_1$$

ES:1990

Q. A locomotive with 8 pairs of driving wheels is to haul a train at 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 part the slope goes through a 2° curve on level ground, how would the speed be adjusted.

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

Solⁿ

$$\begin{aligned} \text{Hauling capacity} &= M \times n \times w_d \\ &= 0.20 \times 3 \times 22 \\ &= 13.2 \text{ t} \end{aligned}$$

(106)

① Speed = 75 kmph.

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

$$13.2 = 0.0016w + 0.00008wV + 0.0000006wV^2$$

$$= w (0.0016 \pm 0.00008 \times 75 + 0.0000006 \times 75^2)$$

$$w = 1202.7 \text{ tonnes.}$$

② gradient - 1 in 180.

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

$$H.C. = 0.0016w + 0.00008wV + 0.0000006wV^2 + w \tan \theta$$

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

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

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

$$V = 37.37 \text{ kmph}$$

$$\text{Reduction of speed} = 75 - 37.3 = 37.7 \text{ kmph}$$

$$= 37.7$$

$$\text{H.C.} = R_{T1} + R_{T2} + R_{T3} + 0.0004 \omega \Delta$$

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

$$= 0.0016 \times 1202.7 + 0.00008 \times 1202.7 \times 1$$

$$+ 0.000000 \times 1202.7 V^2 +$$

$$0.0004 \times 1202.7 \times 2$$

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

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

$$V = 70.33 \text{ kmph}$$

$$\text{H.C.} = 0.0016\omega + 0.00008\omega V + 0.000000\omega V^2 + 0.0004\omega \Delta + \omega \tan \theta$$

$$13.2 = 0.0016 \times 1202.7 + 0.00008 \times 1202.7 V + 0.000000 \times 1202.7 V^2 + 0.0004 \times 1202.7 \times 2$$

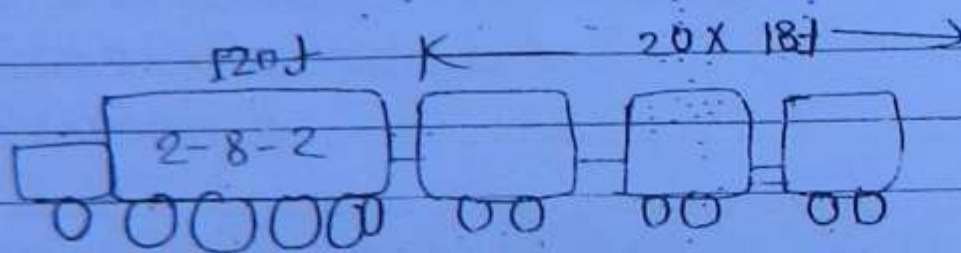
$$+ 1202.7 \times \frac{1}{180}$$

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

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

$$V = 30.7 \text{ kmph} \quad (108)$$

20/11 A train having 20 wagons weighting 18 tonnes 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 axle, is 15 tonnes. The weight of locomotive is 120 t. 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 = 120 t

wt of wagon = 360 t

total weight of train = 480 t = W

V = speed of train = 50 kmph

tractive effort = 15 t

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

$$= 4 \times 1 \times 22.5 = 15 \text{ t}$$

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

$$H.C. = RT_1 + RT_2 + RT_3 + w \tan \theta \quad \text{--- (1)}$$

Here Rolling resistance

$$RT_1 = 2.5 \text{ kg} \times 360 + 3.5 \text{ kg} \times 120$$

$$= 1320 \text{ kg}$$

$$RT_1 = 1.32 \text{ t}$$

(109)

$RT_2 =$ Resistance dependent on speed

$$RT_2 = 2.65 \text{ tonnes}$$

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

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

$$= 0.72 \text{ tonnes}$$

putting eqⁿ (1)

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

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

$$\Rightarrow \theta = \text{slope} = 1 \text{ in } 46.56$$