Rolling resistance : Vehicular (gear change गर्दा आउने)
: Friction betn tyres and pavement

$$f_{rl} = 0.01\left(1 + \frac{V}{147}\right) \qquad V \text{ in ft/s}$$

Horsepower to overcome rolling resistance.

$$\boxed{hp_{RR} = \frac{f_{rl} W V}{550}}$$

Q.1. A 2500-lb car is driven at sea level ($\rho = 0.002378$ slugs/ft^3) on a level paved surface. The car has $C_D = 0.38$ and 20 ft^2 of frontal area. It is known that at maxm speed, 50 hp is being expended to overcome rolling and aerodynamic resistance. Determine the car's maxm speed.

Ans: Given,

$$\rho = 0.002378 \text{ slugs/ft}^3$$
$$W = 2500 \text{ lb}$$
$$C_D = 0.38$$
$$A_f = 20 \text{ ft}^2$$

Now,

$$50 = hp_{RA} + hp_{RR}$$
$$= \frac{\rho C_D A_f V^3}{1100} + 0.01\left(1 + \frac{V}{147}\right)\frac{WV}{550}$$
$$50 = \frac{0.002378 \times 0.38 \times 20 \times V^3}{1100} + 0.01\left(1 + \frac{V}{147}\right)\frac{2500\,V}{550}$$

$$\therefore V = 132.83 \text{ ft/sec}$$
$$\simeq 133 \text{ ft/sec}$$

Grade Resistance : is simply gravitational force.

$R_g = W\sin\theta$ $\quad$ θ is very small

$= WG$ $\quad$ [$\sin\theta \approx \tan\theta \approx G$]

Q.2 Given, $W = 2000$ lb

$C_D = 0.40$

$A_f = 20\,ft^2$

Tractive effort, $F = 255$ lb

$RL = 5000$ ft

$\rho = 0.002045$ slugs/ft³

$V = 70$ mi/h

$= 70 \times 1.4667 = 102.67$ ft/hr

Max^m grade = ?

We have,

$F = \cancel{ma}^{0} + R_a + R_{rl} + R_g$ —— ①

$ma = 0$, for constant speed given in Q.

$R_a = \frac{\rho}{2} C_D A_f V^2$

$= \frac{0.002045}{2} \times 0.4 \times 20 \times 102.67^2$

$= 86.22$ lb

$R_{rl} = f_{rl} \times W = 0.01\left(1 + \frac{V}{147}\right) \times 2000$

$= 0.01\left(1 + \frac{102.67}{147}\right) \times 2000$

$= 33.97$ lb

$R_g = W \times G$

$= 2000G$

From ①, $255 = 86.22 + 33.97 + 2000G$

$\therefore G = 0.6742 = 67.42\%$

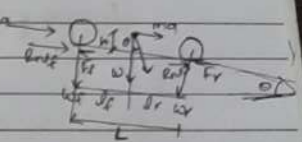
Discussion: For given condition .... G = 67.42%

Max^m Tractive Effort : (that roadway surface-tire contact can support)

For rear wheel drive, $F_{max} = \frac{\mu W (l_f - f_{rl}h)/L}{1 - \mu h/L}$

for front wheel drive, $F_{max} = \frac{\mu W (l_r + f_{rl}h)/L}{1 + \mu h/L}$

Q.3 Given,



$W = 2500$ lb $\quad \mu = 0.6$

$l = 120$ inch

$l_f = 40$ inch $\quad l_r = l - l_f$

$h = 22$ inch $\quad = 120 - 40 = 80$

For rear wheel drive,

$F_{max} = \frac{\mu W (l_f - f_{rl}h)/L}{1 - \mu h/L}$ $\quad$ [$f_{rl} = 0.01\left(1 + \frac{V}{147}\right)$ $= 0.01$ [V=0]]

$= \frac{0.6 \times 2500 (40 - 0.01 \times 22)/120}{1 - \frac{0.6 \times 22}{120}}$

$= 558.70$ lb

for front wheel drive,

$F_{max} = \frac{\mu W (l_r + f_{rl}h)/L}{1 + \mu h/L}$

$= \frac{0.6 \times 2500 [80 + 0.01 \times 22]/120}{1 + \frac{0.6 \times 22}{120}}$

$= 903.37$ lb

Engine generated tractive Effort :
Generated by vehicle's engine.

Depends on : Shape of combustion chamber
Quantity of air drawn into combustion chamber
Types of fuel used
fuel intake design

Engine generated Horse power, $h_{pe} = \frac{2\pi M_e n_e}{550}$

M_e = engine torque, ft-lb
n_e = engine speed in crankshaft
= revolution/sec
1 horse power = 550 ft-lb/s

4.Q. Given,

$M_e = a n_e - b n_e^2$

Max^m torque, $M_{e_{max}} = 92$ ft-lb

$n_e = 3200$ rev/min $= \frac{3200}{60} = 53.33$ rev/sec.

Engine max^m power = ?

We know that,

$M_e = a n_e - b n_e^2$

$92 = a3200 - b3200^2 \Rightarrow 92 = 53.33a - 53.33^2 b$ —(1)

At max^m torque,

$\frac{dM_e}{dn_e} = 0$

$a - 2bn_e = 0$

or, $a - 2b \times 53.33 = 0$

$\therefore a = 106.66b$ —(2)

Solving (1) & (2),

$92 = 53.33a - 53.33^2 \times (106.66b)$

$\therefore b = 0.032$

$a = 3.413$

$\therefore M_e = 3.413 n_e - 0.032 n_e^2$

Now, Engine generated power, $h_{pe} = \frac{2\pi M_e n_e}{550}$

$= \frac{2\pi}{550}[3.413 n_e - 0.032 n_e^2] n_e$

$= \frac{2\pi}{550}[3.413 n_e^2 - 0.032 n_e^3]$

For engine's max^m power, $\frac{dh_{pe}}{dn_e} = 0$

$0 = \frac{2\pi}{550}[3.413 \times 2n_e - 0.032 \times 3n_e^2]$

$\therefore n_e = 71.20$ rev/sec

$\therefore h_{pe} = \frac{2\pi}{550}[3.413 \times 71.20 - 0.032 \times 71.20^2] \times 71.20$

$= 66.61$ hp

Engine generated Tractive Effort reaching the drive wheel is given by:

$F_e = \frac{M_e \varepsilon_0 \eta_d}{r}$

F_e in lb
M_e = Engine torque in ft-lb
ε_0 = Overall gear reduction ratio
η_d = mechanical efficiency of the drivetrain
r = radius of drive wheel in ft.

Vehicle speed and engine speed is given by, $\boxed{V = \frac{2\pi r n_e(1-i)}{\varepsilon_0}}$
V in ft/s

n_e = engine speed in crankshaft rev/sec
i = slippage of drive axle generally 2-5%
i = ~~0.02~~ to 0.05 for passenger vehicles

Vehicle Acceleration : can by determine by available tractive effort (F)

$$F = ma + R_a + R_{rl} + R_g$$
$$F - \Sigma R = \gamma_m . ma$$

γ_m is mass factor, $\gamma_m = 1.04 + 0.0025 \varepsilon_0^2$

5.Q $V = 10 \text{ mi/h}$
$= 10 \times 1.4667 = 14.667 \text{ ft/hr}$
$\mu = 0.20$
$C_D = 0.30$
$A_f = 20 ft^2$
$W = 3000 lb$
$L = 120''$
$h = \cancel{30} 20''$
$l_f = 50''$ $\rho = 0.002045 \text{ slugs/ft}^3$
$l_r = 120 - 50 = 70''$
$M_e = 95 \text{ ft-lb}$
$\varepsilon_0 = 4.5 \text{ to } 1$
$r = 14''$
$\eta = 80\%$

We have, $F = \gamma_m ma + \Sigma R$
$F = \gamma_m ma + R_a + R_{rl} + R_g$

$$R_a = \frac{\rho}{2} C_D A_f V^2$$

$$= \frac{0.002045 \times 0.3 \times 20 \times 14.667^2}{2}$$

$= 1.32 lb$

$R_{rl} = f_{rl} \times W$ $R_G = WG$
$= 0.01 \left(1 + \frac{V}{147}\right) W$ $= 0$ [∵ G is negligible]

$= 0.01 \left(1 + \frac{14.667}{147}\right) \times 3000$ ∴ $\Sigma R = R_a + R_{rl} + R_g$
$= 1.32 + 32.996 + 0$
$= 32.996 lb$ $= 34.316$

F = Engine generated tractive effort + Max^m tractive effort
" front wheel F_{max} + Rear wheel F_{max}.

$$F_e = \frac{M_e \varepsilon_0 \eta_d}{r}$$

$$= \frac{95 \times 4.5 \times 0.8}{14/12}$$

$= 293.14 lb$

~~Front~~ Rear wheel $F_{max} = \frac{\mu W (l_f - f_{rl} h)/L}{1 - \mu h/L}$ $f_{rl} = 0.01 \left(1 + \frac{14.667}{147}\right)$ $= 0.011$

$$= \frac{0.20 \times 3000 \left(\frac{50 - 0.011 \times 20}{120}\right)}{1 - \frac{0.20 \times 20}{120}}$$

$= 257.48 lb$

~~Rear~~ Front wheel $F_{max} = \frac{\mu W (l_r + f_{rl} h)/L}{1 + \mu h/L}$

$$= \frac{0.2 \times 3000 \left(\frac{70 + 0.011 \times 20}{120}\right)}{1 + \frac{0.20 \times 20}{120}}$$

$= 339.77 lb$

Date
Page

a) If car is front wheel drive, Take $F = 293.14\ lb$

$$F = \Sigma R + \gamma_m \times ma$$

$$293.14 = 34.316 + \gamma_m \times \frac{3000}{32.2} \times a$$

$m = \frac{W}{g}$

$g = 9.81 m/s^2$

$g = 9.81 \times 3.28 = 32.176$

$$258.824 = 1.09 \times \frac{3000}{32.2} \times a$$

$\gamma_m = 1.04 + 0.0025 G_0^2$

$= 1.04 + 0.0025 \times 4.5^2$

$= 1.09$

$\therefore a = 2.55 ft/sec^2$

b) If car is rear wheel drive, Take $F = 257.37\ lb$.

$$257.37 = 34.316 + 1.09 \times \frac{3000}{32.2} \times a$$

$\therefore a = 2.19 ft/s^2$

Tr

Elemen

1. Vehicle
2. Motive
3. Way
   a.
   b.
   c.
4. Term
   of th
   take

Com

1. Obl
2. Mob

3. Efficiency : Relation between cost of transportation and productivity of the system

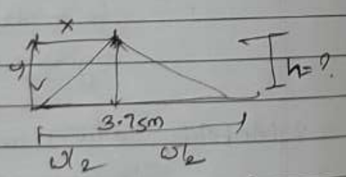
Design of Transportation facilities (55 marks)
→ Highway Engineering
→ Railway Engineering
→ Airport Engineering
→ Ropeways

Geometric design of Highway
To fit the highway to the topography

Arterial Road : City to City connection
less accessible
high mobility

Access Control : Entry & Exit control

Q. $W = 3.75m$
$h = ?$



WBM, par
Camber = ~~3.5%~~ 4%

$Y = nx$

$Y = \frac{2nx^2}{W}$

$= \frac{2 \times 0.04 \times (3.75/2)^2}{3.75}$

$= \cancel{0.1875}$ $0.075 m$

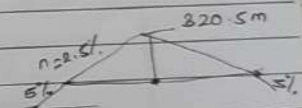
$Y = nx$
$= 0.04 \times \frac{3.75}{2}$
$= \cancel{0.09375}$
$= 0.075m$

For 7.5m width,
$Y = nx$
for bituminous ⇒ $n = 2.5\%$
$Y = 0.025 \times \frac{7.5}{2} = 0.094$

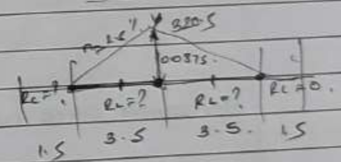
$Y = \frac{2nx^2}{W}$

$= \frac{2 \times 0.025 \times 3.75^2}{7.5}$

$= 0.094$



Q. $W = 3.5m$
Shoulder 1.5
Total $W = 10m$



$Y = nx$
$= 0.025 \times \frac{3.5}{2}$
$= \cancel{0.0875}$
$= 0.04375$

for straight line, RL of center of lane is $320.5 - \cancel{0.0875}$ 0.0435 $= 320.46 m$

RL of " " " is $320.5 - 0.0435 = 320.46 m$

RL of edge of pavement $= 320.5 - 5\%$ of 1.5
$= 320.425m$

For, Parabolic, RL of center of lane $= 320.5 - \frac{2 \times 0.025 \times (3.5/2)^2}{3.5}$

$= 320.456m$

for straight line in shoulder
RL of center of lane $= 320.456m$

for shoulder,
RL $= 320.425m$
RL of edge of pavement $= 320.5 - \frac{2 \times 0.05 \times (1.5/2)^2}{1.5} = 320.4625$

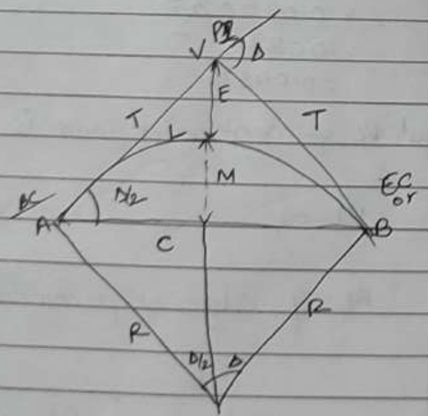
Horizontal curve fundamentals.

$T = R\tan\frac{\Delta}{2}$

$E = R\left[\frac{1}{\cos(\Delta/2)} - 1\right]$

$M = R\left(1-\cos\frac{\Delta}{2}\right)$

$L = \frac{\pi R \Delta}{180}$



$L = EC - BC$

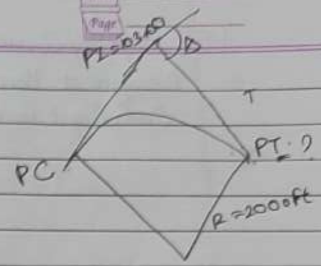
$T = PI - BC = EC - PI$

Q. $R = 2000$ ft

$T = 400$ ft

Chainage of PI = 103+00

Stationing of PT = ?



$T = R\tan\frac{\Delta}{2}$

$400 = 2000\tan\frac{\Delta}{2}$

$\therefore \Delta = 22.62°$

$\therefore$ Station of PC = station of PI − T

= 103 − ~~400~~ 4+00

= 99+00

$L = \frac{\pi R \Delta}{180}$

100 ft = 1+00

$= \frac{\pi \times 2000 \times 22.62}{180}$

= 789.58 ft ≈ 790 = 7+90

$\therefore$ Station of PT = Station of PC + L

= 99 + ~~789.58~~ 7+90

= ~~888.58 mm~~ ~~790 ft~~.

= 106+90

3.5 Highway Curves

Design of Horizontal curve: To change in direction

Centrifugal force, $P = \frac{Wv^2}{gR}$

W in kg

V in m/s, $g = 9.81 m/s^2$

P in kg.

a) Overturn effect:

$$Ph = \frac{Wb}{2}$$

$$\frac{P}{W} = \frac{b}{2h}$$

$\frac{P}{W} = \frac{v^2}{gR}$ attains value of $\frac{b}{2h}$

b) Tranverse skidding : less than $\frac{b}{2h}$

3.6 Super elevation

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

$f = 0.15$

V ~~m/s~~ kmph, R m, $g = 9.81 m/s^2$

$e_{max} = 7\%$

$$e = \frac{(0.75v)^2}{gR}$$

for different type of vehicle. (heterogenous traffic)

बाँकि f ले recover गर्छ

Q.1 $v = 80kmph = \frac{80}{3.6} = 22.22 m/s$

$R = 480 m$

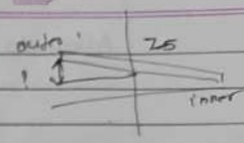
$e = ?$

Width of pavement = 7.5m

$$e = \frac{(0.75v)^2}{gR}$$

$$= \frac{(0.75 \times 22.22)^2}{9.81 \times 480}$$

$= 0.0589 < 0.07\%$ OK



pavement should be raised $\frac{7.5}{2} \times 0.059 = 0.226 m$

2.Q $R = 500m$

$V = \frac{100 kmph}{3.6} = 27.77 m/s.$

$$e = \frac{(0.75 \times 27.77)^2}{9.81 \times 500}$$

$= 0.088 > 0.07\%$

∴ Adopt $e = 7\%$

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

$$0.07 + f = \frac{100^2}{127 \times 500}$$

∴ $f = 0.087 < 0.15$ OK

3. $V = 80kmph = 22.22$

$R = 200m$

$e = \frac{(0.75v)^2}{gR} = 0.14 > 0.07\%$

Adopt $e = 0.07$,

$$0.07 + f = \frac{80^2}{127 \times 200}$$

∴ $f = 0.18 > 0.15$

∴ Adopt $f = 0.15$

Allowable speed,

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

$$0.07+0.15 = \frac{V^2}{127\times200}$$

$\therefore V = 74.75$ kmph. (Multiple of 5)

Take $V = 70$ kmph

6. $W = 7.5$ m

$V = 96$ kmph $= 26.67$ m/s

$f = 0.15$.

$R = 240$ m

a) $e = ?$

$$e = \frac{(0.75V)^2}{gR} = \frac{(0.75\times26.67)^2}{9.8\times240} = 0.169 > 0.07$$

(for design case only use $e = \frac{V^2}{225R}$)

$$e+f = \frac{V^2}{127R} \qquad e = \frac{96^2}{127\times240} - 0.15 = 0.15.$$

$\therefore$ Adopt $e = 0.07$

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

$f = 0$,

$$e = \frac{96^2}{127\times240} = 0.3$$

c) $R = 800$ m, $e = ?$

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

$$\therefore e = \frac{96^2}{127\times800} - 0.15 = \cancel{0.15}\ -0.06 \text{ (-ve)}$$

d) $e = 0$, $R = ?$

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

$$0+0.15 = \frac{96^2}{127\times R}$$

$\therefore R = 483.78$ m

e) $e = 1$ in $15 = \frac{1}{15}$, $R = 300$ m, $V = ?$

$e = 0.066$

$$0.066+0.15 = \frac{V^2}{127\times300}$$

$\therefore V = 90.71$ kmph.

f) $R = ?$ $e = \frac{1}{15} = 0.066$,

$$0.066+0.15 = \frac{96^2}{127\times R}$$

$\therefore R = 335.95$ m (Multiple of 5)

g) $R = ?$, $V = 16$ kmph $+ 96$

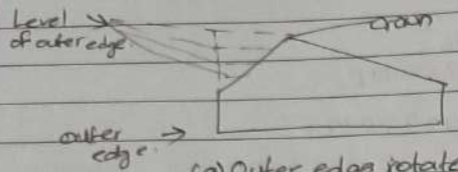
$$e+f = \frac{V^2}{127R}$$

$$0.07+0.15 = \frac{(96+16)^2}{127R}$$

$\therefore R = 450$ m

Methods of providing superelevation

1. Elimination of the crown of the cambered section.



(a) Outer edge rotated about the crown

2. $W_m = \frac{nl^2}{2R}$

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

n = no. of lanes.

$\therefore W_m + W_{ps} = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

V in kmph.

R in m.

l = length of wheel of largest vehicle = ~~18m~~ 6.1 m

1 Q. $n = 2$

$R = 250m$

$l = 7m$, $V = 70 kmph$.

$W_m + W_{ps} = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

$= \frac{2\times 7^2}{2\times 250} + \frac{70}{9.5\sqrt{250}}$

$= 0.66m$

Q. $V = 80 kmph$

$R = ?$, $n = 2$

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

$W = \frac{2\times 6.1}{2\times R} + \frac{V}{9.5\sqrt{R}}$

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

$0.07 + 0.15 = \frac{80^2}{127R}$

$\therefore R = 229.06 m$.

$W = \frac{2\times 6.1^2}{2\times 22906} + \frac{80}{9.5\sqrt{229.06}}$ $\left[\because l = 6.1m \text{ assume}\right]$

$= 0.718 m$.

Transition Curve

Spiral → more used in highway.

cubic → higher speed

$L_s = 0.0215 \dfrac{V^3}{CR}$ V = kmph, L_s = m, R = m

$C = \dfrac{80}{75+V}$ ⇒ $0.5 < C < 0.8$ m/s^3

V in kmph.

b) If centre line rotated,

(i) $L_s = \dfrac{EN}{2} = e \times \dfrac{N}{2}(W + W_e)$

(ii) Inner edge rotated,

$L_s = e \times N (W + W_e)$

N is 1 in 150 if not given.

c) By empirical formula,

$\boxed{\text{Shift } (S) = \dfrac{L_s^2}{24R}}$

for plain & rolling, $L_s = \dfrac{2.7V^2}{R}$

Mountaneous & steep, $L_s = \dfrac{V^2}{R}$

Adopt highest value as length of transition curve.

Q. $L_s = ?$, $S = ?$

$V = 65$ kmph

$R = 220$ m

e = 1 in 150, if rotated about centre line.

$W = 7.5$ m. ∴ $N = 150$

$L_s = e \times \dfrac{N}{2}(W + W_e)$

$L_s = 0.0215 \times \dfrac{V^3}{CR}$

$= \dfrac{0.0215 \times 65^3}{\left(\dfrac{80}{75+65}\right) \times 220}$

$= 46.96$ m

(First मा e check गर्नै < 7%.

$e = \dfrac{V^2}{225R}$

$= \dfrac{65^2}{225 \times 220}$

$= 0.085 > 7\%$ not ok

Adopt $e = 0.07$, Check for f

$0.07 + f = \dfrac{65^2}{127 \times 220}$

∴ $f = 0.08 < 0.15$ OK

∴ $L_s = e \times \dfrac{N}{2}(W + W_e)$

$= 0.07 \times \dfrac{150}{2} \times 7.5$

$= 37.8$ m

By emperical, $L_s = \dfrac{2.7V^2}{R}$

$= \dfrac{2.7 \times 65^2}{220}$

$= 51.85$ m.

∴ Adopting higher value of $L_s = 51.85$ m,

$S = \dfrac{L_s^2}{24R} = \dfrac{51.85^2}{24 \times 220} = 0.51$ m

2. L_{ag} distance $= 0.278\,Vt$

$L = \frac{V^2}{254f}$

$SSD = 0.278\,Vt + \frac{V^2}{254f}$ $\quad t = 2.5 \quad f = 0.35 - 0.4.$

$= 0.278\,Vt + \frac{V^2}{254(f \pm 0.01n)}$

Q. $V = 50$ kmph

$f = 0.37$

$t = 2.5$ sec.

a) two way traffic on two lane road.

$SSD = 0.278\,Vt + \frac{V^2}{254(f \pm 0.01n)}$

$= 0.278 \times 50 \times 2.5 + \frac{50^2}{254(0.37 \pm 0.01 \times 0)}$

$= 34.75 + 26.60$

$= 61.35$ m.

b) two way traffic on single lane road. (both direction मा interaction हुन्छ ×2 गर्ने)

$SSD = 2 \times 61.35$

$= 122.70$ m.

2. $V_1 = 90$ kmph

$V_2 = 60$ kmph

$t_1 = 2.5$ sec, $t_2 = 3$ sec.

$f = 0.7$, $\eta = 50\%$

$SSD_1 = 0.278\,V_1t_1 + \frac{V_1^2}{254f}$

$= 0.278 \times 90 \times 2.5 + \frac{90^2}{254 \times (0.7 \times 0.5)} = 153.66$ m

$SSD_2 = 0.278\,V_2t_2 + \frac{V_2^2}{254f}$

$= 0.278 \times 60 \times 3 + \frac{60^2}{254 \times (0.7 \times 0.5)}$

$= 90.53$ m

$SSD = SSD_1 + SSD_2$

$= 153.66 + 90.53$

$= 244.19$ m

3. Downgradient मा speed धेरै so SD धेरै conclusion

$V = 80$ kmph

a) $n = +2\%$

b) $n = -2\%$

Sol^n a) $SSD = 0.278\,Vt + \frac{V^2}{254(f + 0.01n)}$

$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254(0.35 + 0.01 \times 2)}$

$= 123.69$ m

b) $SSD = 0.278 \times 80 \times 2.5 + \frac{80^2}{254(0.35 - 0.01 \times 2)}$

$= 131.95$ m

Hence, more stopping sight distance is required in downward gradient.

Overtaking Sight Distance

$$\boxed{OSD = 0.28V_bt + 0.28V_bT + 2s + 0.28VT}$$

in sec $T = \sqrt{\frac{4s}{a}}$ $\qquad s = 0.7V_b + 6\ (V_b\ m/s)$

$a = m/s^2$

or, $\boxed{T = \sqrt{\frac{14.4s}{A}}}$ $\qquad \boxed{s = 0.2V_b + 6}$ V_b in kmph

A = kmph/sec.

V_b is not given, $\boxed{V_b = V - 16\ \text{Kmph}}$

$V_b = V - 4.5$ m/s.

Overtaking zone = 3 × OSD [2 & more lane road]

= 2 × OSD [single lane road]

1.Q. Given,

$V = 70$ kmph

$V_b = 40$ kmph

$a = 0.99\ m/s^2$

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

$s = 0.7V_b + 6$ $\qquad \frac{40}{3.6} = 11.11$

$= 0.7 \times \cancel{40}^{11.11} + 6$

$= \cancel{34m}\ 13.77m$

$\therefore T = \sqrt{\frac{4 \times \cancel{34}\ 13.77}{0.99}}\ \cancel{11.72}$ sec. = 7.46 m

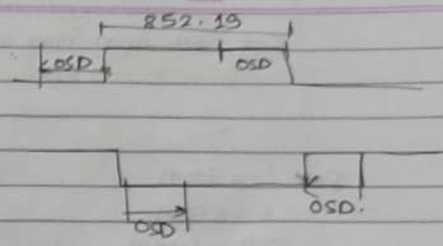
$OSD = 0.278V_bt + 0.28V_bT + 2s + 0.28VT$

$= 0.278 \times 40 \times 2.5 + 0.28 \times 40 \times \cancel{11.72}^{7.46} + 2 \times \cancel{34}^{13.77} +$

$0.278 \times 70 \times \cancel{11.72}\ 7.46$

$= 284.06m$

Overtaking zone = 3 × 284.06 = 852.19m



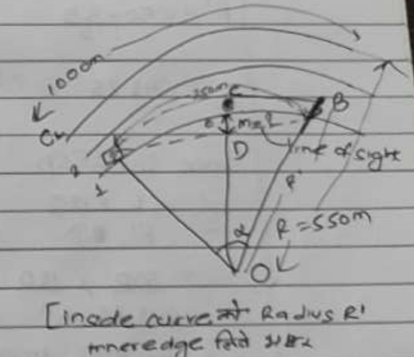
Set back distance on horizontal curves

Q. $L_c = 1000m$

$R = 550m$

$SSD = 250m$

$m = ?$



$\alpha = \frac{SSD}{R_1} \times \frac{180}{\pi}$ [$L_c > SSD$]

$= \frac{250}{\cancel{550}}$

[inside curve का Radius R' inneredge से लेना

$R' = R - 3.5 - \frac{3.5}{2}$

$550 - 3.5 - \frac{3.5}{2}$

$= 544.75$ m.

$\therefore \alpha = \frac{250}{544.75} \times \frac{180}{\pi}$

$= 26.29°$

$\frac{\alpha}{2} = 13.14°$

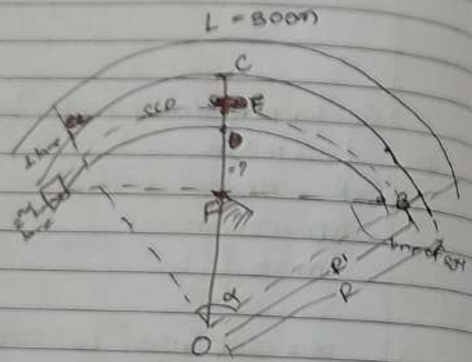
Now, $OD = OB\cos\frac{\alpha}{2}$

$= R'\cos\frac{\alpha}{2} = 544.75 \times \cos 13.14° = 530.49$ m

$CD = OC - OD = R' - 530.49 = 544.75 - 530.49 = 14.26$ m

Set back from inner edge $= 14.26 - \frac{3.5}{2}$
i.e. ED
$= 12.51$.

Q $L_c = 300m$
$R = 650m$
$SSD = 400m$



$R' = 650 - \frac{3.5}{2}$

$= 648.25$

Since $L_c < SSD$

$\frac{\alpha}{2} = \frac{L}{R'} \times \frac{180}{2\pi}$

$= \frac{300}{648.25} \times \frac{180}{2\pi}$

$= \cancel{26.52}\ 13.26^\circ$

$\therefore \frac{\alpha}{2} = \cancel{53.03}\ 13.25$

$\cos\frac{\alpha}{2} = \frac{R'}{OD}$

$\cos 13.26 = \frac{648.25}{OD}$

$\therefore OD = \cancel{668.19}\ 630.96$

$\cancel{ED = OC - OD}$ $DF = R' - OD$
$\cancel{= R - OD}$ $= 648.25 - \cancel{668}\ 630.96$
$= 17.29m$

$\therefore EF = \cancel{3.5 +} CD + DF$
$= \cancel{3.5} + 17.29 = 20.79m$

Q $W = 3.5m$

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

Assume speed = 70kmph

$0.07 + 0.15 = \frac{70^2}{127R}$ $1.33R = 70^2$

$\therefore R = 175.36m$

$SSD = 0.27Vt + \frac{V^2}{254f}$

$= 0.27 \times 70 \times 2.5 + \frac{70^2}{254 \times 0.35}$ $f = 0.35$ coeff of longitudinal friction.

$= 102.37m$

$\frac{\alpha}{2} = \frac{SSD}{R'} \times \frac{180}{2\pi}$

$= \frac{102.37}{\left(175.36 - \frac{3.5}{2}\right)} \times \frac{180}{\pi}$

$= \cancel{33.78}$
$= 16.89$

$R'\cos\frac{\alpha}{2} = \left(175.36 - \frac{3.5}{2}\right)\cos 16.89 = 166.12m$

Setback $= R - 166.12$
$= 175.36 - 166.12$
$= 7.4m$

Again, $V = 80kmph$ till setback is 10m

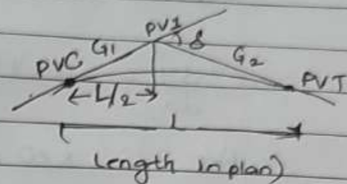
$0.07 + 0.15 = \frac{80^2}{127R} \Rightarrow R = 265.23m$

Vertical Alignment

Parabolic curve ⇒ constant rate of change of slope
⇒ equal tangent

$a = \frac{G_2 - G_1}{2L}$

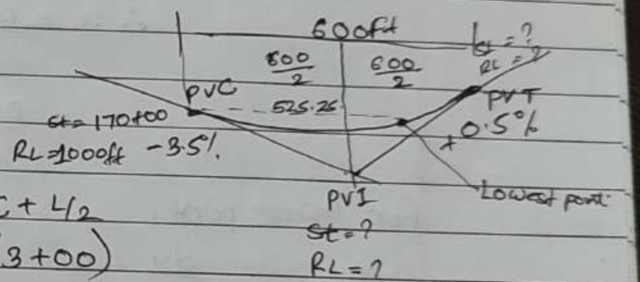
$b = G_1$



G_2, G_1 in decimal, L in ft.

G_2, G_1 in % L in station.

1.Q. Ch → St^n
metric → m
fps → ft



Station of PVI = 170+00 + (3+00)   (station of PVC + L/2)
= 173+00

100ft = 1 station

Station of PVT = Station of PVI + $\frac{L}{2}$ or (PVC + L)
= 173+00 + (3+00)
= 176+00

RL of PVI = RL of PVC − 3.5% of $\frac{L}{2}$

$= 1000 - \frac{3.5}{100} \times 300$

= 989.5 ft.

RL of PVT = RL of PVI + 0.5% of $\frac{L}{2}$

$= 989.5 + \frac{0.5}{100} \times 300 = 991$ ft.

$y = ax^2 + bx + c$

for max or min $\frac{dy}{dx} = 0$

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

At PVC, $x = 0$, $b = \frac{dy}{dx} = g_1 = -3.5\% = -0.035$

$\frac{d^2y}{dx^2} = 2a = \frac{G_2 - G_1}{L}$

$\therefore a = \frac{0.0005 + 0.035}{2 \times 600}$

$= \cancel{0.000007083}$ 0.00003331

for lowest point,

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

$2ax + b = 0$

$x = -\frac{b}{2a}$

$= \frac{+0.035}{2 \times \cancel{0.000007083}\ 0.0000333}$

$= \cancel{247.05\ m}$ 525.52 ft

$Y = ax^2 + bx + c$

$= \cancel{525.52 + 1000}$ (c = elevation of PVC)

$= 0.000033 \times 525.52^2 + (-0.035 \times 525.52)$ x = distance from PVC.

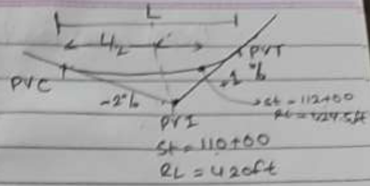
$+1000$

$= 990.72$ ft

$\therefore$ Elevation of lowest point

for check: [>PVI, <PVT]

Q.2



$b = G_1 = -2\% = 0.02$

$a = \frac{G_2 - G_1}{2L}$

$= \frac{0.01 + 0.02}{2L}$

Elevation of PVC $= 420 + (+2\% \text{ of } \frac{L}{2})$

$= 420 - \frac{2\% \times L}{100\%} = 420 + 0.01L$

At, $X = \frac{L}{2} + 200$, $Y = 424.5$ ft.

$Y = ax^2 + bx + c$

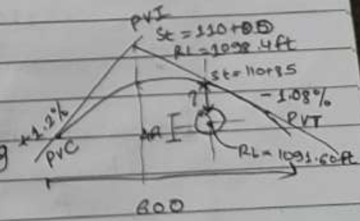
$424.5 = \frac{0.03}{2L} \times \left(\frac{L}{2} + 200\right)^2 - 0.02 \times \left(\frac{L}{2} + 200\right) + [420 + 0.01L]$

$L = 1347.96$ ft

or, $L = 118.69$ ft. cannot be accepted <200 m

$\therefore L = 1347.96$.

Q.



$b = 1.2\% = 0.012$

$a = \frac{-0.018 - 0.012}{2 \times 600} = \cancel{-0.000025}$ -0.000025

at $x = 300 + 85$ $\left(\frac{600}{2}\right)$

$= 385$ ft.

$Y = ax^2 + bx + c$

$= -0.000025 \times 385^2 + 0.012 \times 385 + 1094.8$

PVC - Point of vertical curve

PVI - " " " intersection

PVT - " " " Tangent

Elevation PVC $= 1098.4 - \frac{1.2}{100} \times 300 = 1094.8$ m.

$\therefore Y = 1095.60$ ft

Depth below road surface

$= 1096.80 - 1091.60 - \frac{4}{2}$

$= \cancel{2.11 ft} = 8 ft.$

For Highest point, $y = ax^2 + bx + C$

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

$0 = 2ax + b$

$x = \frac{-b}{2a}$

$= \frac{-0.012}{-2 \times 0.000019}$

$= \cancel{31.58} \; 315.79 ft \; \cancel{315.80}.$

$Y = ax^2 + bx + C$

At $x = 315.79 ft$,

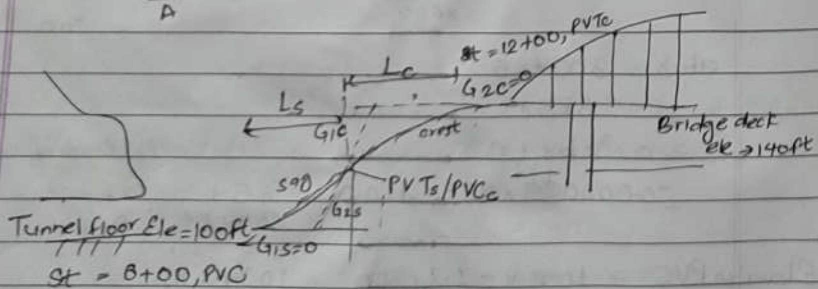
$y = 0.000019 \times 315.8^2 + 0.012 \times 315.80 + 1094.8$

$= 1100.48 ft$

Design of vertical curve is controlled by K

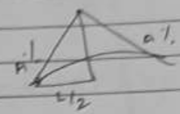
$K = \frac{L}{A}$

Q.



$G_2S = G_1C = A$

$K = \frac{L}{A}$



$L_s + L_c = 1200 ft$ — ①

$\Rightarrow \frac{A}{100} \times \frac{L_s}{2} + \frac{A}{100} \times \frac{L_c}{2} = 140 - 100$

$\frac{A}{200}(L_s + L_c) = 40$

$\frac{A}{200} = \frac{40}{1200}$

$A = 6.67\%$

from ①, $K_s \times A + K_c \times A = 1200$

$K_s + K_c = \frac{1200}{6.67}$

$K_s + K_c = 179.92$ m per %

From Table, $K_s = 96$, $K_c = 84$ [close to 180 → [illegible] min^n speed [illegible]

Highest possible common design speed = 50 kmph

$L_s = K_s \times A = 96 \times 6.67 = 640 ft$

$L_c = K_c \times A = 84 \times 6.67 = 560 ft$

Station of PVI_s = St^n of $PVS_c + \frac{L_s}{2}$

$= 0 + \frac{640}{2}$

$= 320$

$= (3+20)$

Station of PVT_s = St^n of PVI + $\frac{L_s}{2}$

or, PVC_c = $\cancel{320}$

$= 6+40$

St^n of $PVI_c = (6+40) + \frac{560}{2}$

$= 900 \text{ ft}$

$= 9+20$

St^n of $PVT_c =$ ~~6+4~~ 12+00 (given)

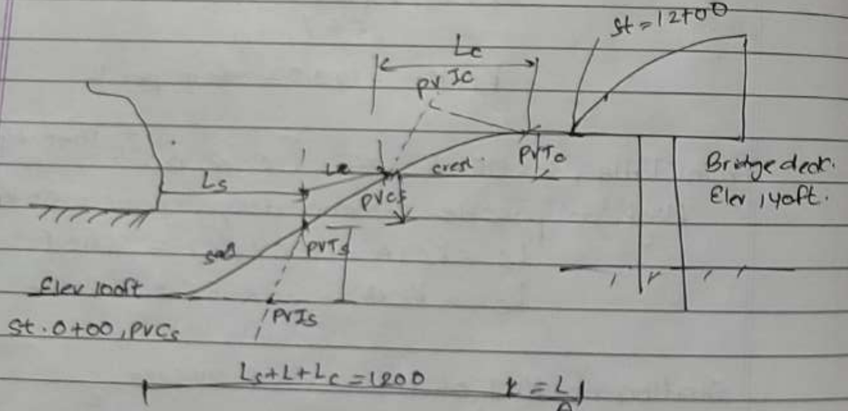
~~RL = 100~~ RL of PVC = 100

RL of PVI $= 100 + \frac{6.67}{100} \times \frac{640}{2}$

$= 121.34$

RL of PVT $= 121.34 + \frac{6.67 \times 640}{100 \cdot 2} = 142.684$

Q2.



$G_2S = \cancel{G} = G_1C = A$

$\frac{ALs}{200} + \frac{ALc}{200} + \frac{A \times L}{100} = 40$ (Elevation diff).

or, $\frac{Ks \times A^2}{200} + \frac{KcA^2}{200} + \frac{A}{100}(1200 - Lc - Ls) = 40$

or, $\frac{Ks.A^2}{200} + \frac{Kc A^2}{200} + \frac{A}{100}(1200 - KcA - KsA) = 40$

for 35ph, $Ks = 49$ [from graph]

$Kc = 29$

$\frac{49 \times A^2}{200} + \frac{29 \times A^2}{200} + \frac{A}{100}(1200 - 29 \times A - 49 \times A) = 40$

$A = 3.8\%$ or 26.9%.

Adopt less than 12. i.e. $A = 3.8\%$

$Ls = Ks \times A$

$= 49 \times 3.8\%$ [% मे लगाने in calculator]

$= 186.2 \text{ ft}$

$Lc = 29 \times 3.8\%$

$= 110.2 \text{ ft}$

$L_{constant} = 1200 - 186.2 - 110.2$

$= 903.6 \text{ ft}$

St^n of PVI_s, PVT_s, PVI_c, PVT_c

St. of $PVI_s =$ ~~0+~~ St. of $PVC_s + \frac{Ls}{2} = 0+00 + \frac{186.2}{2} = 93.1$

$= 0+93.1$

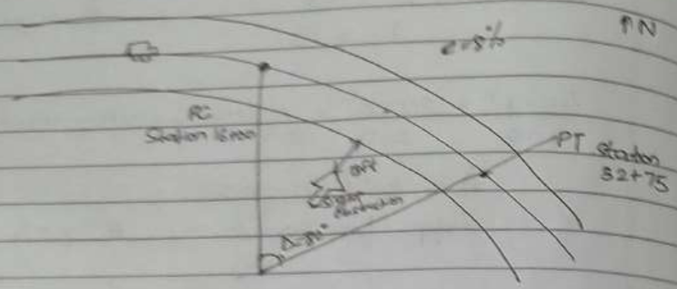
St. of PVT_s = St. of $PVI_s + \frac{Ls}{2} = 0+93.1 + \frac{186.2}{2} = 1+86.2$

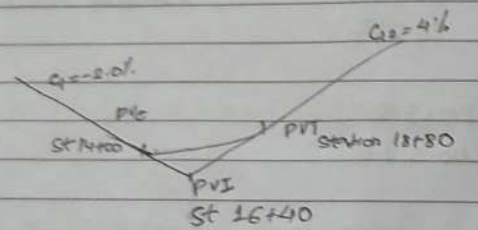
St. of PVI_c = St. of $PVT_s + 903.6 + \frac{Lc}{2}$

$= 1+86.2 + 9+03.6 + \frac{110.2}{2}$ 55.1

$=$ ~~1+591~~ 11+

8.





Here,

Length of horizontal curve = 3275 − 1600

= 1675 ft

$$\text{Radius of curve} = \frac{L}{\Delta} \times \frac{180}{\pi}$$

$$= \frac{1675}{80} \times \frac{180}{\pi}$$

= 1199.63 ft

Radius of inner lane = 1199.63 − 6 (12-ft 2 lane)

= 1193.63 ft

e = 8%

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

~~0.08+0.15~~ =

$$0.08 + f = \frac{(50 \times 1.467)^2}{32.2 \times 1193.63}$$

1.467 ft per sec = 1 mi/h

9.81 m/s = 32.2 ft/s.

f = 0.059 ≈ 0.06

From Table for 50mph, f = 0.14 > 0.06 OK

∴ radius and super elevation are sufficient for the 50mph design speed.

Calculate SSD considering set back distance of 18 + 6 ft from the center of inner lane.

SSD = 479.5 ft. which is > SSD of 425 ft from table.

i.e. crash is not due to provided set back distance.

Standard Gauge Width 1435m (East-West Railway)
60kg rail section means per m kg of rail.

Ballast:

$D = \frac{\text{spacing} - \text{sleeper width}}{2}$

Staggered joint is preferred

Imp Q. 60 kg rail and 13m length of rail [1m = 60kg]

a) No. of rails per km length $= \frac{1000 \times 2}{13} = 153.846 \approx 154$ no.

b) Weight of rail $= 60\,kg \times 154 \times 13 = 120120\,kg$

c) No. of sleepers per km length $= \frac{\text{No. of rails per km} \times \text{sleeper density}}{2}$

$= \frac{154 \times \cancel{16120}\ 20}{2}$

$= 1540$

Sleeper density $= N + 7$

$= 13 + 7$

$= \cancel{16}\ 20$

N = Length of rail

d) No. of fish plates per one km of track length

= no. of rails per km × 2

= 154 × 2

= 308

e) No. of fish bolt = 2 × no. of fish plate per km

= 2 × 308

= 616

f) No. of bearing plates = 2 × No. of sleepers per km length

= 2 × 1540 = 3080

g) No. of Dog Spikes = no. of sleepers × 4
$= 1540 \times 4$
$= 6160$

Geometric design
→ Gradient : 1 in 400
Ruling gradient : max^m gradient → 1 in 150 – 1 in 250 plain
1 in 100 – 1 in 150 hilly

$P = W \times$ gradient

Momentum gradient : steeper than ruling gradient
Pusher gradient : helper gradient

Gradient in station yard:
Grade compensation on curve:

~~Ex~~ 1.Q. A 2° curve for a BG line with a ruling gradient of 1 in 200. Find the steepest gradient for

→ $\frac{70}{R}$ or 0.04% per degree whichever is min^n.

Compensation $= \frac{0.04}{100} \times 2$

$= 0.08\%$

$\frac{1}{200} \times 100 = 0.5\%$

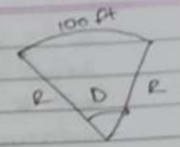
∴ Compensated gradient = 0.5 – 0.08 = 0.42% = 1 in 238
∴ The steepest gradient on the curved track is 1 in 238

Degree of the curve
$D = \frac{1750}{R}$, (R in m)

$D = \frac{5730}{R}$, (R in feet)

2. $R = 700$ m

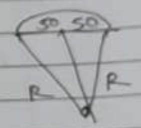
$\frac{D}{360} = \frac{100}{2\pi R}$



– Arc definition : $D = \frac{1750}{700} = 2.5°$

Chord Definition

$R = \frac{50}{\sin(D/2)}$



ft × 0.3048 = m

~~0.3048~~ ~~1.2~~ $\times 700 = \frac{50 \times 12 \times 2.54/100}{\sin(D/2)}$

$D = ~~8.19~~ \; 2.49°$

Superelevation / Cant
Cant Deficiency = Theoritical cant – actual cant
[from max^m speed   equilibrium condition]

Cant excess = actual cant – Theoretical cant

$e = \frac{GV^2}{127R}$
G → dyanamic gauge in mm
R → Radius in m
V = speed in km/H
e = super elevation in mm.

for BG Track, G = 1676mm + 74 = 1750mm
" MG " G = G = 1058
" NG " G . G = 772

Max^m superelevation $= \frac{1}{10}$th to $\frac{1}{12}$th of gauge.

Safe speed on curves:
$V_m = 0.27\sqrt{R(C_a + C_d)}$ C_a = actual cant in mm

Q. $D = 2^\circ$

deficiency $V = 110$ km/H

equil. ~~V~~ $= 80$ km/h

~~excess~~ book speed $= 50$ km/h

$R = \frac{1750}{D} = \frac{1750}{2} = 875$ m

Actual cant $= \frac{GV^2}{127R}$ $G = 1750$ for BG

$= \frac{1750 \times 80^2}{127 \times 875}$

$= 100.78$ mm

Cant for max^m sanctioned speed $= \frac{GV^2}{127R}$

$= \frac{1750 \times 110^2}{127 \times 875}$

$= 190.55$ mm

Cant deficiency (Cd) = Theoritical Cant − Actual Cant

$= 190.55 - 100.78$

$= 89.78$ mm > 75 . not ok

or, < 100 [considering chief engineer

considering chief engineer, Cant for booked speed $= \frac{Gv^2}{127R}$

$= \frac{1750 \times 50^2}{127 \times 875}$

$= 39.37$ mm.

Cant excess = Actual Cant − Theoritical cant

$= 100.78 - 39.37$

$= 61.41$ mm < 75 mm ok

∴ Max^m permissible speed $= 0.27\sqrt{R(C_a + C_d)}$

$= 0.27\sqrt{875(100.78 + 89.78)}$

$= 110.22$ kmph

If > 75 not ok.

Take $C_d = 75$ mm

Actual cant = Theo. Cant − Cant deff.

$= 190.55 - 75$

$= 115.55$ mm

Cant excess = Actual cant − Theoriti cant

$= 115.55 - 39.37$

$= 76.18$ mm > 75 not ok

Adopt Cant excess $= 75$ mm

Actual Cant = Cant excess + Theo cant

$= 75 + 39.37$

$= 114.37$ mm

Max^m Permissible speed $= 0.27\sqrt{R(C_a + C_d)}$

$= 0.27\sqrt{875(114.37 + 75)}$

$= 109.31$ kmph

Q. $D = 3^\circ$

Max^m sanctioned speed $= 110$ kmph

Equilibrium speed $= 80$ kmph

Booked speed $= 50$ kmph

$R = \frac{1750}{D} = \frac{1750}{3} = 583.33$ m

Actual cant $= \frac{GV^2}{127R}$

$= \frac{1750 \times 80^2}{127 \times 583.3}$

$= 151.18$ mm. < 165 mm ok

Cant for max^m sanctioned speed $= \frac{GV^2}{127R} = \frac{1750 \times 110^2}{127 \times 583.3}$

$= 285.83$ mm

Cant deficiency (C_d) = Theoritical Cant − Actual Cant
= 285.53 − 151.18
= 134.35 mm > 100 Not Allowed

Take cant deficiency = 100 mm

Actual Cant = Theoritical Cant − Cant deficiency
= 285.53 − 100
= 185.53 mm > 165 mm (Not allowed)

Take Actual Cant = 165 mm

Cant for booked speed $= \dfrac{GV^2}{127R}$

$= \dfrac{1750 \times 50^2}{127 \times 583.33}$

= 59.05 mm

∴ Cant excess = Actual Cant − Theoritical Cant
= 165 − 59.05
= 105.95 mm > 75 mm (Not allowed)

∴ Take C_e = 75 mm.

∴ Actual Cant = Cant excess + Cant theoritical
= 75 + 59.05
= 134.05 mm

∴ $V_{max} = 0.27\sqrt{R(C_a + C_d)}$
$= 0.27\sqrt{583.33(134.05 + 100)}$
= 99.76 kmph