TRANSPORTATION ENGINEERING.
MODULE II

Sight distance, stopping sight distance, overtaking sight distance
Design of horizontal alignment and vertical alignment.

Sight distance.

Sight distance is the length of road visible ahead to driver at any instance. OR the actual distance along the road surface which a driver from a specified height above the carriageway has visibility of stationary or moving objects.

Three sight distances are considered in design.

i) stopping sight distance
ii) Safe overtaking or passing sight distance
iii) Safe sight distance for entering into uncontrolled intersection.

Apart from these 3, following two sight distances are also considered by IRC

a) Intermediate sight distance :

When overtaking sight distance can not be provided, intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles.

ISD = 2 x SSD

b) Head light sight Distance :

Distance visible to driver during night driving under the illumination of the vehicle headlight.

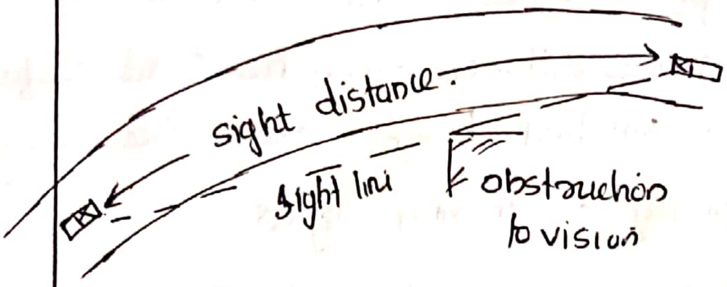
HSD = SSD

Restriction to sight distance may be

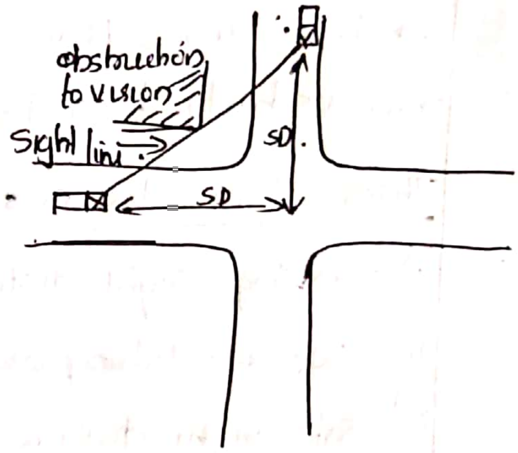
a) at horizontal curve

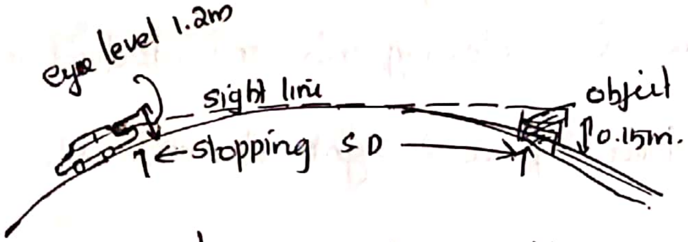
b) at vertical summit curve

c) at intersection



a) at H.C.





c) at i/s

b) at vertical summit curve

~~Stopping Sight Distance (SSD)~~

It is the sight distance available to a driver travelling at design speed to stop the vehicle safely without collision with any other obstruction.

Sight distance available on a road to a driver at any instance depends on

i) Features of road ahead

ii) Height of driver's eye above the road surface
IRC suggested this as 1.2m

Atmost

iii) Height of object above road surface

IRC suggested height of object as 0.15m

Stopping Sight Distance (SSD)

It is the sight distance available to a driver travelling at design speed to stop the vehicle safely without collision with any other obstruction.

Factors affecting SSD

a.) Speed of vehicle

b.) Reaction Time of driver

c) Brake efficiency

d) Frictional resistance b/w road and tyre

e) Gradient of road.

a) Speed of vehicle

a) Speed of vehicle

Higher the speed, more will be the distance required to stop the vehicle

b) Reaction Time of driver

It is the time taken from the instant the object is visible to the driver to the instant the brakes are effectively applied.

PIEV Theory:

According to this theory total reaction time of the driver is split into 4 parts.

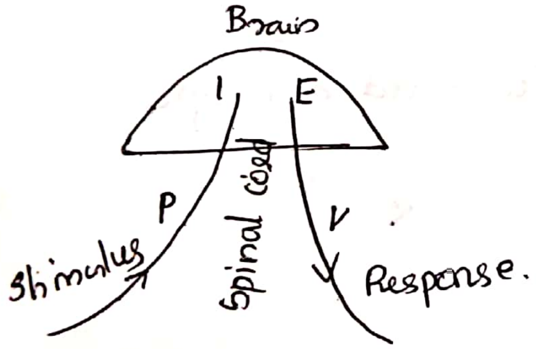
i) (P) Perception Time : Time required for the sensations received by eyes or ears to be transmitted to brain through nervous system.

ii) (I) Intellection time : Time required for understanding the situation.

iii) (E) Emotion Time : Time elapsed during emotional sensations and disturbance such as fear, anger or any other emotional feelings.

iv) (V) Volition time : Time taken for final action

$$R_T = P + I + E + V$$



P - Perception

I - Intellection

E - Emotion

V - Volition.

As per IRC, reaction time for calculation of SSD is taken as 2.5s

c) Braking efficiency

If brakes are 100% efficient, vehicle will stop the moment when brakes are applied.

Higher the breaking efficiency, shorter will be the distance required to stop the vehicle.

d) Frictional resistance b/w road and tyre.

Higher the friction factor, lesser will be the distance required to stop the vehicle.

e) Gradient of road.

→ while climbing up a gradient, SSD required will be less

→ while descending, gravity also comes into play which increases the distance required to stop the vehicle.

<u>Computation of SSD</u>

Stopping sight distance of a vehicle is the sum of

i) <u>Lag distance</u>: Distance travelled by the vehicle during total reaction time.

ii) <u>Braking distance</u>: Distance travelled by the vehicle after application of brakes, to a dead stop position

SSD = Lag distance + Braking distance.

i) <u>Lag distance</u>

If design speed is ~~V kmph~~ v m/s and reaction time is t s

Lag distance = $v \times t$ $t = 2.5s$ as per IRC

v in m/s.

If V is in kmph. Lag distance = $0.278Vt$.

ii) <u>Braking Distance</u>

Coefficient of friction f depends upon several factors such as type & condition of road, tyre, speed etc.

Speed (kmph)	20-30	40	50	60	65	80	100
Longitudinal coeff of friction f	0.40	0.38	0.37	0.36	0.36	0.35	0.35

Work done to stop the vehicle = Kinetic Energy.

If F is the maximum frictional force developed and l is the braking distance

Work done against friction to stop the vehicle

$$= \text{Force} \times \text{Distance}$$

$$= F \times l$$

$$= fW \times l \quad \text{— (1)}$$

W = Total weight of vehicle.

Kinetic energy $= \frac{1}{2} m v^2$

$$= \frac{1}{2} \frac{W v^2}{g} \quad \text{— (2)}$$

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

equating (1) & (2)

$$f \cancel{W} \times l = \frac{\cancel{W} v^2}{2g}$$

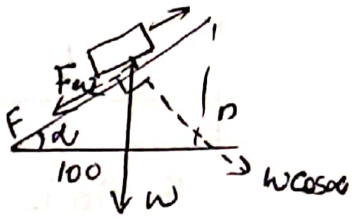
$$l = \frac{v^2}{2gf}$$

v in m/s
$g = 9.81\ m/s^2$.

$SSD = vt + \frac{v^2}{2gf}$	v - speed in m/s $g = 9.81\ m/s^2$, $t = 2.5s$
$SSD = 0.278\, Vt + \frac{V^2}{254 f}$	V - speed in kmph $t = 2.5s$.

SSD at ~~stop~~ slopes

When there is an ascending gradient, $+n\%$ the component of gravity adds to braking action and hence braking distance is decreased.



Component of gravity acting parallel to the surface which adds to frictional force is $\frac{Wn}{100}$.

$F_w = W\sin\alpha$

$\approx W\tan\alpha$

$= \frac{Wn}{100}$

$\therefore$ equating work done = KE

$$\left(F + \frac{Wn}{100}\right) l = \frac{1}{2}\frac{Wv^2}{g}$$

$$\left(fW + \frac{Wn}{100}\right) l = \frac{1}{2}\frac{Wv^2}{gR}$$

$$l = \frac{v^2}{2g(f + 0.01n)}$$

Similarly, in case of descending gradient

$$\left(fW - \frac{Wn}{100}\right) l = \frac{1}{2}\frac{Wv^2}{gR}$$

$$l = \frac{v^2}{2g(f - 0.01n)}$$

$$\text{SSD at slope} = vt + \frac{v^2}{2g(f \pm 0.01n)}$$

v speed in m/s, $t = 2.5$ s

$+$ for ascending $-$ for descending

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

V - Speed in kmph

$t = 2.5\,s$

If Brake efficiency is (η) given. just multiply this with 'f'.

ie.

$$SSD = 0.278\,Vt + \frac{V^2}{254 f \eta}$$

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

Que:) Calculate the safe stopping sight distance for design speed of 50 kmph for

a) Two way traffic on a two lane road

b) Two way traffic on a single lane road.

Assume coefficient of friction as 0.37 and reaction time of driver as 2.5s.

Ans:

SSD = lag distance + Braking distance

Given $V = 50$ kmph.

$f = 0.37$

$t = 2.5s$

Stopping distance $= 0.278Vt + \frac{V^2}{254f}$

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

$= 34.75 + 26.60$

$= 61.35$ m.

If you follow the eqn with m/s

$SSD = vt + \frac{v^2}{2gf}$

$v = 50$ kmph

$= \frac{50 \times 1000}{60 \times 60}$

$= 13.9$ m/s

$= (13.9 \times 2.5) + \frac{13.9^2}{(2 \times 9.8 \times 0.37)}$

$= 61.4$ m.

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a) SSD on 2 way traffic on 2 lane road

$= SSD = 61.4$ m

b) SSD for 2 way traffic on single lane road

$= 2 \times SSD$

$= 2 \times 61.4$

$= 122.8$ m.

Que:) Calculate the minimum sight distance required to avoid a head on collision of 2 cars approaching from the opposite directions at 90 and 60 kmph. Assume a reaction time of 2.5s, coefficient of friction of 0.7 and a brake efficiency of 50%.

Ans:

$V_1 = 90$ kmph $\quad V_2 = 60$ kmph

$t = 2.5s$

$f = 0.7$

$\eta = 50\% = 0.50$

$$SD_1 = 0.278 V_1 t + \frac{V_1^2}{(254 f \eta)}$$

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

$$= 62.55 + 91.113$$

$$= \underline{153.66 \text{ m}}$$

$$SD_2 = 0.278 V_2 t + \frac{V_2^2}{(254 f \eta)}$$

$$= (0.278 \times 60 \times 2.5) + \frac{60^2}{(254 \times 0.7 \times 0.5)}$$

$$= 41.7 + 40.49$$

$$= \underline{82.2 \text{m}}$$

S.D to avoid head on collision of a approaching car

$= SA + SD_2$

$= 153.6 + 82.2 = \underline{\underline{235.8 m}}$

Que: Calculate stopping sight distance on a highway at a descending gradient of 2% for a design speed of 80 kmph. Assume other data as per IRC recommendations.

Ans: $V = 80$ kmph. , Descending gradient $n = 2\%$.

Assume, $t = 2.5 s$

$f = 0.35$

SSD on descending gradient

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

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

$$= 55.6 + 76.35$$

$$= \underline{\underline{132 m}}.$$

Que:) Calculate the values of

i) Head light S.D ii) Intermediate S.D

for a highway with a design speed of 65 kmph. Assume suitably all the other data.

Ans:

V= 65 kmph given

Assume $t = 2.5s$, $f = 0.36$.

SSD = Lag distance + Braking distance

$$= 0.278Vt + \frac{V^2}{254f}$$

$$= (0.278 \times 65 \times 2.5) + \frac{65^2}{(254 \times 0.36)}$$

$$= 45.17 + 46.20$$

$$= 91.4\,m.$$

i) Head light S.D = SSD

$$= 91.4\,m$$

ii) Intermediate S.D = $2 \times SSD$

$$= 2 \times 91.4$$

$$= 182.8\,m.$$

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Overtaking Sight Distance (OSD)

Minimum S.D open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against traffic of opposite direction is known as minimum Overtaking sight distance (OSD) or safe passing distance.

OSD depends on various factors.

a) speed of overtaking vehicle, overtaken vehicle, vehicle coming from opposite direction

b) Spacing b/w vehicle

c) Skill and reaction time of driver.

d) Rate of acceleration of overtaking vehicle.

e) Gradient of road.

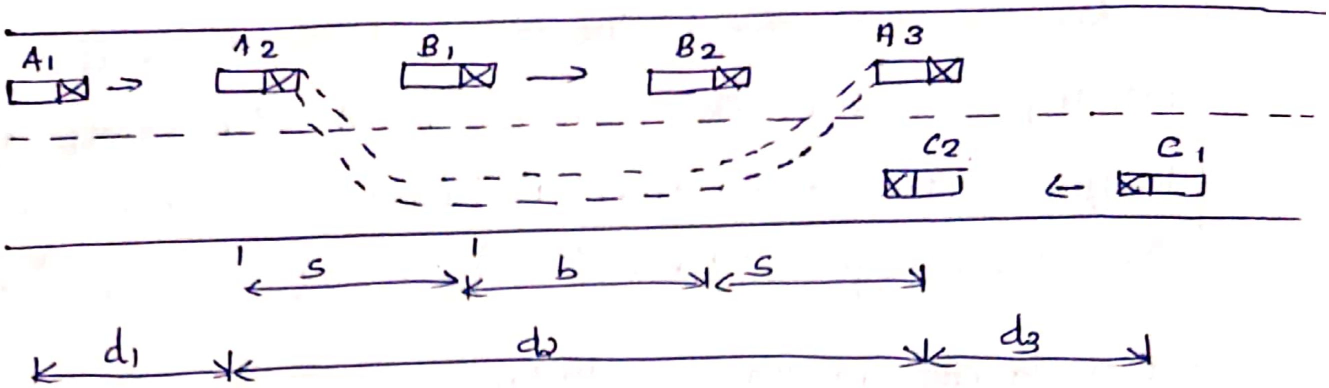
Analysis of Overtaking Sight Distance

Fig. shows overtaking manoeuvre of vehicle A traveling at ~~speed~~ design speed, and another slow vehicle B on a two lane road with two way traffic.

Third vehicle C comes from the opposite direction.

The entire over taking operation can be divided into 3.

Parts - d_1, d_2, d_3



A is the overtaking vehicle travelling at design speed v m/s or V kmph.

B is the slow moving vehicle moving with uniform speed v_b m/s or V_b kmph.

c is the vehicle coming from opposite direction at design speed v m/s or V kmph.

It may be assumed that vehicle A is forced to reduce its speed to the speed v_b of slow vehicle B and moves behind it keeping a space s, till there is an opportunity for safe overtaking operation.

* Distance travelled by vehicle A during this reaction time $= d_1 =$ Distance b/w A1 & A2

$$d_1 = v_b t$$
$$= 0.278 V t$$

$\Big\}$ $t =$ as for OSD.

From position A2, the vehicle A starts accelerating, shift to adjacent lane, overtake vehicle B and shift back to its original lane ahead of B in position A3 in time T sec. ~~called~~ d_3

The straight distance b/w A2 and A3 is

The minimum distance b/w position A_2 and B_1 may be taken as the minimum spacing 's' of 2 vehicle.

Minimum spacing b/w vehicle $s = 0.7v_b + 6$ v_b in m/s

$= 0.2V_b + 6$ V_b in kmph

$b \rightarrow$ is the distance travelled by B during T sec.

$b = v_b T$ v_b in m/s

$= 0.278 V_b T$ V_b in kmph

$\therefore d_2 = b + 2s$

$= v_b T + \frac{aT^2}{2} =$

$\boxed{s = ut + \frac{1}{2}at^2}$

$b = v_b T$

$\therefore 2s = \frac{aT^2}{2}$ a = acceleration in m/s^2

$T = \sqrt{\frac{4s}{a}}$; a is in m/s^2

$= \sqrt{\frac{14.4s}{a}}$; a is in kmph.

$d_2 = v_b T + 2s.$

d_3 is the distance travelled by on-coming vehicle C from C_1 to C_2 during the overtaking operation of A ie in T secs.

$d_3 = vT$ v in m/s

$= 0.278 VT$ V in kmph.

In case, speed of overtaken vehicle V_b is not given take it as $(V-16)$ V_b & V in kmph acceleration

V (kmph)	a (kmph/s)	a (m/s²)
25	→ 5	→ 1.41
50	→ 4	→ 1.11
80	→ 2.56	→ 0.72
100	→ 1.92	→ 0.53

* If not able to remember this, first take a = 2.5 kmph/s.

OSD = $d_1 + d_2 + d_3$

$= \cancel{v_b t}$

$d_1 = v_b t$

$d_2 = b + 2s$

$= v_b T + 2s$

$s = \cancel{0.2v}\ 0.7 v_b + 6.$

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

a in m/s^2.

$d_3 = \cancel{v_b}\ vT.$

v in m/s
v_b in m/s.

t = 2 s

a in m/s^2.

$d_1 = 0.278\,Vt$

$d_2 = b + 2s$

$= \cancel{0}\ 0.278\,V_b T + 2s$

$s = 0.2 V_b + 6$

$T = \sqrt{\frac{14.4s}{a}}$ a in kmph/sec

$d_3 = 0.278\,V\,T$

V_b in kmph.
V in ~~m/s~~ kmph

t = 2s.

a in kmph.

OSD on one way traffic $= d_1 + d_2$ (no vehicle in opposite d/n, hence $d_3 \neq 0$)

OSD on 2 way traffic $= d_1 + d_2 + d_3$

10M Previous

Overtaking zone.

Zones which are provided for overtaking are called overtaking zone.

Sign posts should be installed at sufficient distance in advance to indicate the start of the overtaking zones. This distance may be equal to $(d_1 + d_2)$ for one way roads & $d_1 + d_2 + d_3$ for two way roads.

Similarly, end of the overtaking zones should also be indicated by sign posts.

Minimum length of overtaking zone $= 3 \times OSD$.

Desirable length of overtaking zone $= 5 \times OSD$.

Length of overtaking zone = 3 to 5 times OSD

SP1 – Sign post – "overtaking zone ahead"

SP2 – Sign post – "End of overtaking zone".

Que:) Speed of overtaking and overtaken vehicles are 70 and 40 kmph respectively. If the acceleration of overtaking vehicle is 0.99 m/s².

a) Calculate safe overtaking S.D

b) mention the minimum length of overtaking zone

c) Draw a neat sketch of overtaking zone and show positions of sign post.

Ans: OSD for two way traffic = $d_1 + d_2 + d_3$

speed of overtaking vehicle, $V = 70$ kmph

" " overtaken " , $V_b = 40$ kmph.

$a = 0.99\ m/s^2$

a) $d_1 = 0.278 V_b t$

$= 0.278 \times 40 \times 2$

$= 22.2$ m

$d_2 = b + 2s$

$s = 0.2V_b + 6$

$= (0.2 \times 40) + 6$

$= 14$ m

$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 14}{0.99}} = 7.52$ s

$b = 0.278 V_b T = 0.278 \times 40 \times 7.52 = 83.6$ m

$d_2 = b + 2s = 83.6 + (2 \times 14) = 111.6$ m

$d_3 = 0.278\,VT$

$= 0.278 \times 70 \times 7.52$

$= \underline{146.33\ m}$

$OSD = d_1 + d_2 + d_3$

$= 22.2 + 111.6 + 146.33$

$= \underline{280m}$

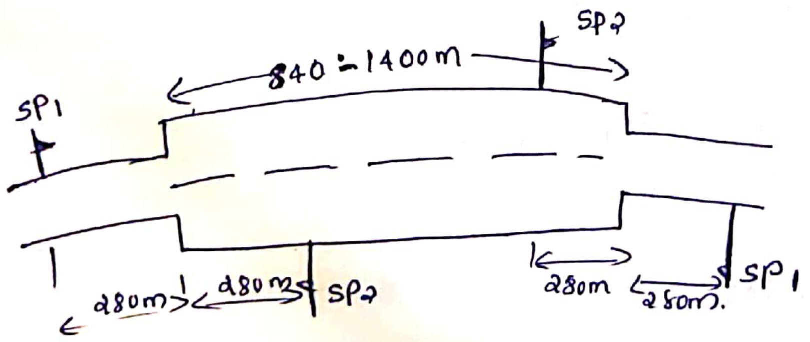
b) Minimum length of overtaking $= 3 \times OSD$

$= 3 \times 280$

$= \underline{840m}$

Desirable length of overtaking $= 5 \times OSD = \underline{1400m}$

c) Details of overtaking zone



SP1 = Sign post - Overtaking zone ahead.

SP2 = Sign post - End of overtaking zone.

Que:) Calculate safe overtaking sight distance for a design speed of 96 kmph. Assume all other data suitably.

$V = 96\,kmph$

$V_b = V - 16$ (Assume)

$= 96 - 16$

$= 80\,kmph$

Assume $a = 2.5\,kmph$, $t = 2\,sec$

$d_1 = 0.278 V_b t = 0.278 \times 80 \times 2 = \underline{\underline{44.48m}}$

$d_2 = b + 2s$

$s = 0.2 V_b + 6$

$= 0.2 \times 80 + 6 = \underline{\underline{22m}}$

$T = \sqrt{\frac{14.4 s}{a}} = \sqrt{\frac{14.4 \times 22}{2.5}} = \underline{\underline{11.25\,sec}}$

$b = 0.278 V_b T = 0.278 \times 80 \times 11.25 = \underline{\underline{250.2\,m}}$

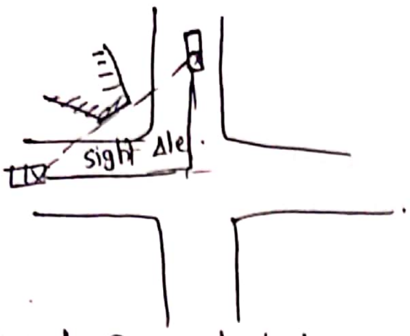
$d_2 = b + 2s = 250.2 + (2 \times 22) = \underline{\underline{294}}\,m$

$d_3 = 0.278 V T = 0.278 \times 96 \times 11.25 = \underline{\underline{300.24}}\,m$

OSD on one way traffic $= d_1 + d_2 = 44.48 + 294 = \underline{\underline{338.48m}}$

OSD on Two way traffic $= d_1 + d_2 + d_3 = \underline{\underline{638.72m}}$

Sight Distance at intersections



Design of S.D at intersection may be based on 3 possible conditions

i) Enabling the approaching vehicle to change speed
ii) Enabling approaching vehicle to stop
iii) Enabling stopped vehicle to cross a main road.

Design of Horizontal Alignment

Horizontal alignment is the layout of centre line of road in plan. It consists of straight stretches and horizontal curve.

- Horizontal curves are provided whenever there is change in direction of alignment.
- Design of horizontal curve include design speed, radius of horizontal curve, super elevation, length and type of transition curve.

Design Speed

- most important element in design of any geometric feature.

Design speed depends on class of road, terrain or topography through which it passes.

Design speed (kmph)

	Plain terrain Ruling	Plain terrain Mini	Rolling Terrain Ruling	Rolling Terrain Minimum
NH & SH	100	80	80	65
MDR	80	65	65	50
ODR	65	50	50	40
VR	50	40	40	35

Horizontal curve

When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through centre of gravity of the vehicle.

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

W = Weight of vehicle kg
P = Centrifugal Force
R = Radius of curve.

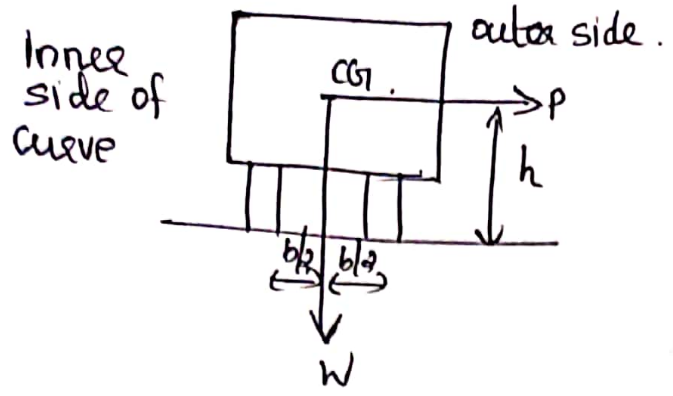
The ratio of centrifugal force to the weight of vehicle P/W is known as Impact Factor or Centrifugal Ratio.

Centrifugal force acting on a vehicle on horizontal curve has 2 effects.

i) Tendency to overturn the vehicle outwards about outer wheel
ii) Tendency to skid the vehicle laterally, outwards.

i) Overturning Effect

Centrifugal Force tends to overturn the vehicle about outer wheel B on



h = height of centre of gravity of vehicle above road surface
b = width of wheel base

Overturning moment due to centrifugal force $P = P \times h$

Resisting moment due to weight of vehicle $= W \times \frac{b}{2}$

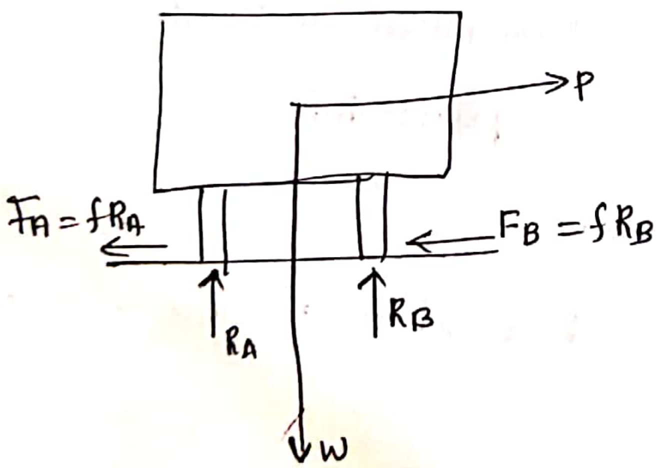
For equilibrium $Ph = \frac{Wb}{2}$

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

There is a danger of overturning when Impact factor $\frac{P}{W} = \frac{b}{2h}$

$\therefore$ Always $\frac{P}{W} < \frac{b}{2h}$

ii) Transverse skidding effect



If the centrifugal force P developed exceeds the maximum possible transverse skid resistance due to friction, vehicle will start skidding.

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Equlibrium condition

$$P = F_A + F_B$$

$$= f R_A + f R_B$$

$$= f(R_A + R_B) = fW$$

$$\frac{P}{W} = f$$

When Impact Factor attains a value equal to coeft. of lateral friction there is a danger of lateral skidding

Super elevation

Inorder to counteract the effect of centrifugal force and to reduce the tendency of vehicle to overturn or skid, the outer edge of the pavement is raised w.r.t inner edge, thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement is known as superelevation.

Analysis of superelevation

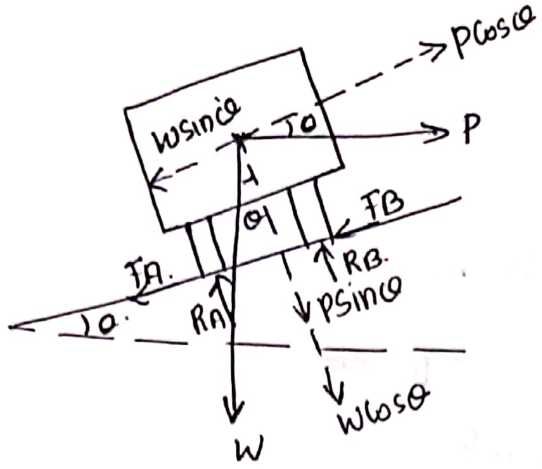
Forces acting on the vehicle while moving on a circular curve of radius R m

i) centrifugal Force . $P = \frac{Wv^2}{gR}$ acting horizontally outwards

ii) Weight w of the vehicle acting ~~hor~~ vertically downwards

iii) Frictional Force developed b/w wheels and pavement

outer wheel B on



For limiting equilibrium condition

$$P\cos\theta = W\sin\theta + F_A + F_B$$

$$= W\sin\theta + fR_A + fR_B$$

$$= W\sin\theta + f(R_A + R_B)$$

$$P\cos\theta = W\sin\theta + f(W\cos\theta + P\sin\theta)$$

$$= W\sin\theta + fW\cos\theta + fP\sin\theta$$

$$P\cos\theta - fP\sin\theta = W\sin\theta + fW\cos\theta$$

$$P(\cos\theta - f\sin\theta) = W(\sin\theta + fW\cos\theta)$$

Dividing by $W\cos\theta$

$$\frac{P}{W}(1 - f\tan\theta) = \tan\theta + f$$

$$\frac{P}{W} = \frac{f + \tan\theta}{1 - f\tan\theta}.$$

For $f = 0.15$ and maximum value of superelevation or $\tan\theta$ as 0.07, $f\tan\theta = 0.01$

Thus value of denominator $= 1 - f\tan\theta = 1 - 0.01 = 0.99 \approx 1$

$$\therefore \frac{P}{W} = f + \tan\theta = f + e$$

$$\frac{P}{W} = \frac{v^2}{gR}.$$

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$$\therefore \boxed{e+f = \frac{v^2}{gR}}$$

e = Rate of superelevation

f = lateral friction coefficient = 0.15

v = speed of vehicle m/s

R = Radius of curve in m

$g = 9.8\ m/s^2$.

If speed is in kmph

$$e+f = \frac{(0.278V)^2}{9.8R} = \frac{V^2}{127R}.$$

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

V → speed in kmph.
R → in m

If coeff. of friction is neglected, ie if f=0, the equilibrium superelevation required to counteract the centrifugal force fully is $e = \frac{v^2}{gR} = \frac{V^2}{127R}$.

If superelevation is provided according to this formula, the pressures on outer and inner wheel will be equal.

Que:) The radius of horizontal curve is 100m. The design speed is 50kmph and design coefficient of lateral friction is 0.15

a) Calculate the superelevation required if full lateral friction is assumed to develop

b) Calculate the coefficient of friction needed if no superelevation is provided

c) Calculate equilibrium superelevation if pressure on inner and outer wheels are equal

a)

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

$f = 0.15$, $V = 50\text{kmph}$, $R = 100\text{m}$

$$e = \frac{V^2}{127R} - f = \frac{50^2}{127 \times 100} - 0.15 = \underline{\underline{0.047}}$$

b)

$e = 0$

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

$$f = \frac{V^2}{127R} = \frac{50^2}{127 \times 100} = \underline{\underline{0.197}}$$

c)

For equal pressure on inner & outer wheel, ie equilibrium superelevation, $f = 0$

$$e = \frac{V^2}{127R} = \underline{\underline{0.197}}$$

Maximum Superelevation

Plain terrain 7% or 0.07

Hilly terrain not bound by snow 10% or 0.01

Hilly terrain with snow 7% or 0.07

Minimum superelevation

From drainage consideration it is necessary to have a minimum cross slope to drain off surface water.

Superelevation Design

Step 1:

Calculate superelevation for 75% of design speed & $f=0$

$$e = \frac{(0.75V)^2}{127R} \approx \frac{V^2}{225R} \quad \text{— (1)}$$

Step 2:

If calculated value of $e < 7\%$ or 0.07, the value so obtained is provided. If value of $e > 0.07$ in (1), provide maximum superelevation equal to 0.07 & proceed with step 3 & or 4

Step 3:

Check coefficient of friction developed for maximum value of $e = 0.07$

$$e + f = \frac{V^2}{127R} \qquad f = \frac{V^2}{127R} - 0.07$$

and B_1 may be

If value of $f < 0.15$; the superelevation of 0.07 is safe for design speed. If $f > 0.15$, calculate restricted speed as in step 4

Step4 :

$$e + f = 0.07 + 0.15 = \frac{V_a^2}{127R} = 0.22 \quad \text{——— (2)}$$

Calculate safe allowable speed V_a

If calculate above is higher than design speed, design is adequate.

If allowable speed is less than design speed, speed is limited to allowable speed V_a.

Attainment of Superelevation

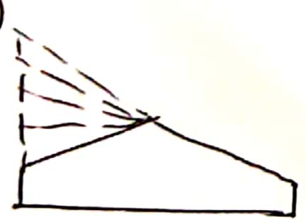
a) Elimination of crown of cambered section

b) Rotation of pavement to attain full superelevation.

a) Elimination of crown of cambered section

- 2 methods

i)



outer half of the cross slope is rotated about the crown such that surface falls on the same plane as inner half

Outer edge rotated about crown.

Drawback: Surface drainage will not be proper at outer half

ii)

Here crown is shifted outwards

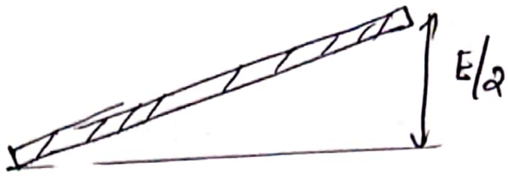
→ This method not used, bcoz during initial construction, there is negative SE on outer half

Crown shifted outwards (Diagonal crown method)

b) Rotation of Pavement to attain superelevation

i)

ii)



i) By rotating the pavement cross section about centre line, depressing the inner edge and raising outer edge each by half of total amount of superelevation

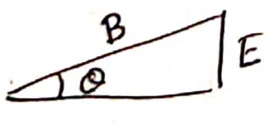
- vertical profile / centre line remains unchanged

- Drainage problem in inner side

ii) By rotating the ~~the~~ pavement cross section about the inner edge.

- here vertical profile / centre line changed

- No drainage problem



$$\tan\theta = \frac{E}{B} = e$$

$$E = Be$$

Amount the outer edge to be raised in case ii) = Be

Amount the edge to be raised in case i) = $\frac{Be}{2}$

Que) A two lane road with design speed 80km has horizontal curve of radius 480m. Design the rate of superelevation for mixed traffic. By how much should the outer edge of the pavement be raised w.r.t centre line, if the pavement is rotated w.r.t centre line and width of pavement at the horizontal curve is 7.5m.

Ans:- Given, $V = 80kmph$, $R = 480m$

$B = 7.5m.$

$$e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 80)^2}{127 \times 480} = 0.059$$

Since $e = 0.059 < 0.07$, provide $e = 0.059$

Raising of outer edge w.r.t centre $E = \frac{Be}{2}$

$$= \frac{7.5 \times 0.059}{2} = 0.22m$$

Que.) Design the rate of superelevation for a horizontal highway curve of radius 500m and speed 100kmph.

Ans:

Step1

$$e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 100)^2}{127 \times 500} = 0.089 > 0.07$$

Step2 Hence provide $e = 0.07$

Step3 $f = \frac{V^2}{127R} - e = \frac{100^2}{127 \times 500} - 0.07 = 0.087. < 0.15$

$\therefore$ Design is safe with superelevation of 0.07

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Que:) The design speed of a highway is 80kmph. There is a horizontal curve of radius 200m on a certain locality. Calculate the superelevation needed to maintain this speed. If the maximum superelevation of 0.07 is not to be exceeded, calculate the maximum allowable speed on this horizontal curve as it is not possible to increase the radius. Safe limit of transverse coefficient of friction is 0.15.

Ans:

Step 1 : $e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 80)^2}{127 \times 200} = 0.142 > 0.07$

Step 2: Since obtained $e > 0.07$

provide $e = 0.07$

Step 3 : $f = \frac{V^2}{127R} - e$

$$= \frac{80^2}{127 \times 200} - 0.07 = \underline{0.18} > 0.15$$

Step 4 :

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

$$0.07 + 0.15 = \frac{V^2}{127 \times 200}$$

$V = \underline{74.75}$ kmph which is less than the design speed of 80kmph

Hence restrict the speed to $74.75 \approx \underline{75}$ kmph.

Que) A major district road with thin bituminous pavement surface in low rainfall area has horizontal curve of radius 1400m. If the design speed is 65 kmph, what should be the superelevation ?

Ans:

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

$$= \frac{(0.75 \times 65)^2}{127 \times 1400} = \underline{0.0134}$$

The superelevation value required is only 0.0134 which is less than the normal cross slope required to drain off the surface water.

The recommended camber for thin bituminous pavement in low rainfall area is 2% or 0.02.

Providing 2% cross slope, check for safety against centrifugal force at design speed along with the negative superelevation at the outer half of the pavement due to normal camber

Net transverse skid resistance $= -e + f = -0.02 + 0.15 = 0.13$

Centrifugal Ratio $= \frac{V^2}{127R} = \frac{65^2}{127 \times 1400} = 0.024 \; \underline{< 0.13}$

∴ This horizontal curve with normal cambered s/n is safe for design speed of 65 kmph.

Radius of Horizontal Curve

Ruling minimum Radius $R_{ruling} = \frac{V_{ruling}^2}{(e+f)\,127}$.

Absolute minimum radius $R_{min} = \frac{V_{min\ design\ speed}^2}{127(e+f)}$

$e = 0.07$, $f = 0.15$.

Que) Calculate the values of ruling minimum and absolute minimum radius of horizontal curve of a NH in plain terrain. Assume ruling design speed and minimum design speed values as 100 and 80kmph.

$$R_{uling} = \frac{V_{ruling}^2}{127(e+f)} = \frac{100^2}{127(0.07+0.15)} = \underline{\underline{357.9\,m}}$$

$$R_{min} = \frac{V_{min}^2}{127(e+f)} = \frac{80^2}{127(0.07+0.15)} = \underline{\underline{229\,m}}$$

Extra widening of Pavement on Horizontal curve

On Horizontal curve, pavement is widened slightly more than normal width due to following reason

a) An automobile has a rigid wheel base and only the front wheels can be turned. when this vehicle takes a turn to negotiate a horizontal curve, the rear wheels do not follow same path as that of front wheel

This phenomenon is called off-tracking

b) At speed higher than the design speed when superelevation and lateral friction developed are not fully able to counteract the thrust due to centrifugal force, some transverse skidding may occur and rear wheel take outside path those traced by front vehicle

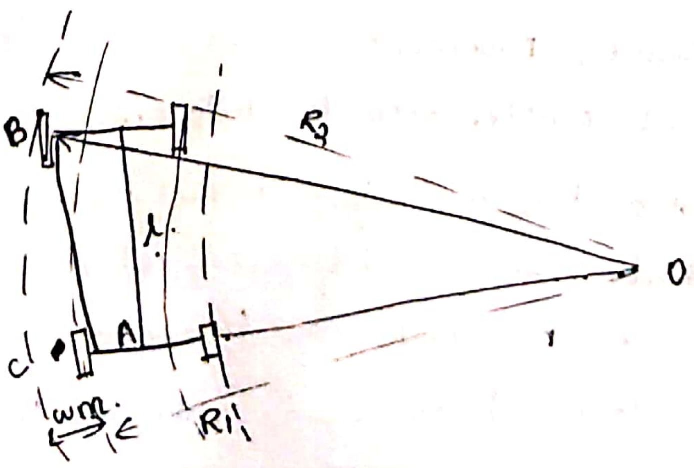
i) Inorder to take curved path with larger radius and to have greater visibility, drivers have tendency to not to follow the central path, but to use the outer side at beginning of curve

c) ~~wh~~ Driver has a psychological ~~wide~~ tendency to maintain greater clearance b/w vehicles when overtaking on curve.

Analysis of extra widening

i) mechanical widening

widening required to account for off tracking due to rigidity of wheel base is called Mechanical widening



R_1 = Radius of path taken by outer rear wheel
R_2 = " outer front wheel

W_m = off tracking / extra widening

l = length of wheel base

$$W_m = OC - OA$$
$$= OB - OA$$
$$= R_2 - R_1$$

ΔOAB, $OA^2 = OB^2 - BA^2$

$$R_1^2 = R_2^2 - l^2$$
$$R_1 = R_2 - W_m$$
$$(R_2 - W_m)^2 = R_2^2 - l^2$$
$$\cancel{R_2^2} - 2R_2W_m + W_m^2 = \cancel{R_2^2} - l^2$$
$$l^2 = W_m(2R_2 - W_m)$$
$$W_m = \frac{l^2}{2R_2 - W_m}$$
$$\approx \frac{l^2}{2R}$$

$W_m = \dfrac{nl^2}{2R}$ n = no. of lanes.

ii) Psychological widening

$W_p = \dfrac{V}{9.5\sqrt{R}}$ V in kmph

Extra widening = Mechanical widening + Psychological widening = $\dfrac{nl^2}{2R} + \dfrac{V}{9.5\sqrt{R}}$.

V in kmph.

Que:) Calculate extra widening required for a pavement of width 7m on a horizontal curve of radius 250m if the longest wheel base of vehicle expected on the road is 7m. Design speed is 70kmph. Compare the value obtained with IRC recommendations.

Ans: Extra widening = $W_m + W_{ps}$

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

$n = 2$ for pavement width of 7m.

l = length of wheel base = 7

$R = 250m$

$V = 70kmph$

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

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

$$= 0.196 + 0.466$$

$$= \underline{\underline{0.662m}}$$

Que:) Find the total width of a pavement on a horizontal curve for a new national highway to be aligned along a rolling terrain with a ruling minimum radius. Assume necessary data.

Ans: Assume

→ NH ∴ Ruling design speed, V = 80kmph

Normal Pavement width, W = 7

No. of lanes = 2

wheel base of truck, l = 6m

max. value of superelevation, e = 0.07

skid resistance f = 0.15

$$R_{ruling} = \frac{V^2}{127(e+f)} = \frac{80^2}{127(0.07+0.15)}$$

$$= \underline{229m}$$

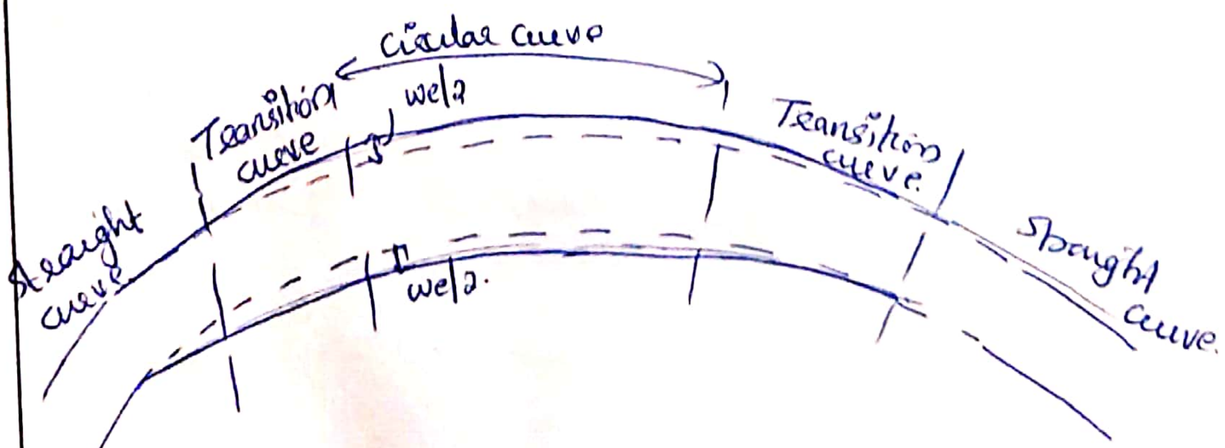
$$\text{Extra widening}, W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

$$= \frac{2\times6^2}{2\times230} + \frac{80}{9.5\sqrt{R}}$$

$$= 0.157 + 0.555$$

$$= \underline{0.712 m}$$

Total Pavement width on curve = W+We = 7+0.71 = $\underline{7.71 m}$



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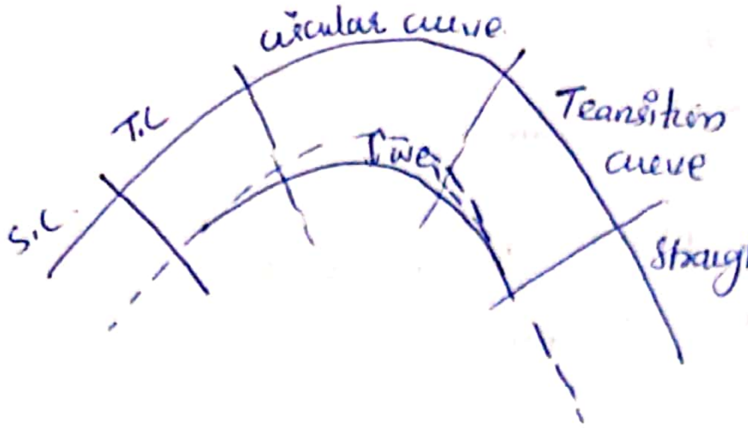


widening of Pavement on Shape curve

Transition Curve

It is a curve provided between a circular curve and straight path whose radius decreases from ∞ at the tangent point to the designated radius of the circular curve along the length of the curve.

Objectives of providing T.C or Functions

a) To introduce gradually the centrifugal force b/w the tangent point and the beginning of circular curve.

b) To enable the driver turn the steering gradually for his own comfort and security.

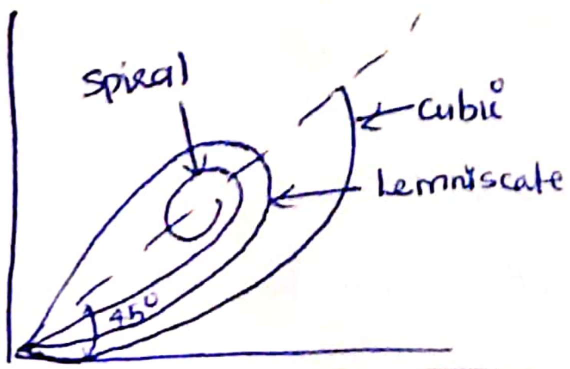
c) To enable gradual introduction of super elevation and extra widening of pavement at start of circular curve.

d) To improve aesthetic appearance of road.

In an ideal transition curve, the length should be inversely proportional to radius R

$$L_s \propto \frac{1}{R} \quad \text{ie} \quad L_s \times R = \text{Constant}.$$

Different Types of Transition Curve



1) Spiral or Clothoid
2) Lemniscate
3) Cubic Parabola.

IRC recommends the use of spiral as transition curve in horizontal alignment of highway due to following Reasons

i) Spiral curve satisfies the requirements of an ideal transition

ii) Geometric property of spiral is such that the calculations setting out of curve in the field is simple and easy.

Calculation of Length of Transition curve

Length of T.C is designed to fulfill 3 conditions.

a) Rate of change of centrifugal acceleration

$$\cancel{L_s = \frac{0.0215V^3}{CR}}$$

If t is the time taken in seconds to traverse the transition length at uniform design speed of v m/s

$$\text{time},\ t = \frac{L_s}{v}$$

$$\text{centrifugal acceleration} = \frac{v^2}{R}$$

$$\text{Rate of change of centrifugal acceleration} = \frac{v^2}{Rt} = \frac{v^2}{R \times \frac{L_s}{v}}$$

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

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

$$C = \frac{80}{75+V} \qquad 0.5 < C < 0.8$$

...age Problem. ... line same... ...perelevation

ii) a

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

Ls = Length of T.C in m
v = Speed in m/s
c = Rate of Change of centrifugal acceleration
$= \frac{80}{75+V}$ V kmph

R - Radius in m

$Ls = \frac{0.0215 V^3}{CR}$ V in kmph
Ls in m.

b) Rate of introduction of Superelevation.

If pavement rotated about centre line

$Ls = \frac{eN(W+We)}{2}$

e = Super elevation
N = Rate of introduction of SE
W = Normal width of Pavement
We = Extra widening

If pavement rotated about inner edge

$Ls = eN(W+We)$

c) By IRC Empirical Formula

- For plain and rolling terrain

$Ls = \frac{2.7 V^2}{R}$ V in kmph

- For mountainous and steep terrain

$Ls = \frac{V^2}{R}$ V in kmph.

* Length of T.C will be highest of above

~~Shift of~~ Shift of T.C $= \frac{Ls^2}{24R}$

Que:) Calculate the length of Transition curve and shift using following data.

Design speed = 65kmph

Radius of circular curve = 220m

Allowable rate of introduction of superelevation (pavement rotated about the centre line) = 1 in 150

Pavement width including extra widening = 7.5m

$V = 65$ kmph, $R = 220$m

Ans:

i) Length of T.C based on rate of change of centrifugal acceleration

$C = \frac{80}{75+V} = \frac{80}{75+65} = \underline{0.57}\ m/s^2$ It is b/w 0.5 & 0.8

Hence accepted

$Ls = \frac{0.0215V^3}{CR} = \frac{0.0215 \times 65^3}{0.57 \times 220} = \underline{47}\ m$

ii) Ls based on allowable rate of introduction of S.E

Superelevation $e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 65)^2}{127 \times 220} = 0.085 > 0.07$

$\therefore$ Take $e = 0.07$

$f = \frac{V^2}{127R} - e = \frac{65^2}{127 \times 220} - 0.07 = 0.08 < 0.15 \Rightarrow$ ok.

Pavement rotated about centre line.

$\therefore L_s = \frac{eN(W+We)}{2}$ $N = 150$ (Given)

$= \frac{0.07 \times 150 \times 7.5}{2}$ $W+We = 7.5$

$= \underline{\underline{39.37\,m}}$

II) $L_s = \frac{2.7V^2}{R} = \frac{2.7 \times 65^2}{220} = \underline{51.9\,m} \approx \underline{\underline{52m}}$

Length of T.C = Highest of above 3 values.

$= \underline{\underline{52m}}$

Shift $= \frac{L_s^2}{24R} = \frac{52^2}{24 \times 220} = \underline{\underline{0.51m}}$

Que:) A NH passing through rolling terrain in heavy rain fall area has a horizontal curve of radius 500m. Design the length of T.C assuming suitable data.

Ans. Given NH

∴ Assume, Design speed $V = 80kmph$

Normal Pavement width $W = 7m$

Allowable rate of introduction of SE = 1 in N = 1 in 150

Pavement rotated about inner edge.

a) L_s by rate of change of centrifugal acceleration.

$C = \frac{80}{75+V} = \frac{80}{75+80} = 0.52$ It is b/w 0.5 & 0.8 ⇒ ok.

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$$Ls = \frac{0.0215V^3}{CR} = \frac{0.0215 \times 80^3}{0.52 \times 500} = 42.3m$$

b) Ls by rate of introduction of superelevation

$$e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 80)^2}{127 \times 500} = 0.056 < 0.07$$

$\Rightarrow$ ok.

Extra widening at curve, $We = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

$$= \frac{2 \times 6^2}{2 \times 500} + \frac{80}{9.5\sqrt{500}}$$

$$= 0.45 m.$$

$$Ls = eN(W + We)$$

$$= \cancel{0.07}\ 0.057 \times 150 \times (7 + 0.45)$$

$$= \cancel{78}\ 63.69\ m.$$

c) $Ls = \frac{2.7V^2}{R} = \frac{2.7 \times 80^2}{500} = 34.6m$

Length of T.C = Highest of above 3 values

$$= 63.69\ m.$$

Curve Resistance

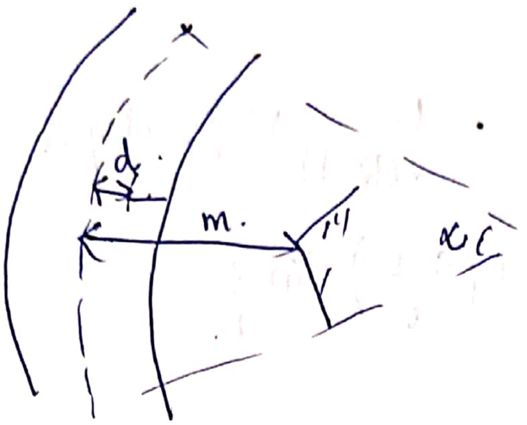
loss of tractive ~~effort~~ force due to turning of a vehicle on a horizontal curve

$= T(1 - \cos\alpha)$. T = Tractive force

α = Turning angle.

Set Back Distance

It is the clearance distance required from the centre line of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance.



Case a : $L_c > S$

length of curve > sight distance.

Half central angle $\frac{\alpha}{2} = \frac{S}{2R}$ Radian $= \frac{S}{2R} \times \frac{180}{\pi}$ degree

Set back distance from centre line

$$m = R - R\cos\frac{\alpha}{2} \quad \text{For single lane}$$

For 2 or more lane, d is the distance b/w centre line of road and centre line of inside lane.

$$\frac{\alpha}{2} = \frac{S}{2(R-d)} \text{ Rad} = \frac{S}{2(R-d)} \times \frac{180}{\pi} \text{ degree}$$

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

Case b: $L_c < S$ (Length of Curve < Sight distance)

$$\frac{\alpha}{2} = \frac{L_c}{2R} \cdot Rad = \frac{L_c}{2R} \times \frac{180}{\pi} \text{ degree}$$

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

For multilane

$$\frac{\alpha}{2} = \frac{L_c}{2(R-d)} \; Rad = \frac{L_c}{2(R-d)} \times \frac{180}{\pi} \text{ degree}$$

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

Que:) While aligning a highway in a built up area, it was necessary to provide a horizontal circular curve of radius 325m. Design

i) Superelevation

ii) Extra widening of pavement

iii) Length of Transition curve.

Design speed = 65 kmph, Length of wheel base of largest truck = 6m

Pavement width = 10.5m.

Ans:

i) Superelevation

~~Step1: $e = 0.75V$~~

Given.

$V = 65$ kmph.

$l = 6$ m.

$W = 10.5$ m

$R = 325$ m

Step1 : $e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 65)^2}{127 \times 325} = 0.058 < 0.07$

$\Rightarrow$ ok.

ii) Extra widening $W_e = W_m + W_{ps}$

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

$\boxed{n=3, \text{ as pavement width is } 3m}$

$$= \frac{3 \times 6^2}{2 \times 325} + \frac{65}{9.5\sqrt{325}}$$

$$= \cancel{0.110}\ 0.166 + 0.379$$

$$= \underline{\underline{0.545}}$$

iii) Length of Transition curve.

a) By rate of change of centrifugal acceleration

$C = \frac{80}{75+V} = \frac{80}{75+65} = 0.57\ m/s^3$ It is b/w 0.5 & 0.8 $\Rightarrow$ ok.

$Ls = \frac{0.0215V^3}{CR} = \frac{0.0215 \times 65^3}{0.057 \times 325} = \underline{\underline{31.8\ m}}$

b) By rate of introduction of Superelevation

Assume $N = \cancel{150}\ 100$ (Rate of introduction of SE) and pavement rotated about centreline

$Ls = \frac{eN(W+W_e)}{2} = \frac{\cancel{0.57}\ 0.058 \times 100 \times (10.5 + 0.545)}{2} = 32m$

c) By IRC formula

$$L_s = \frac{2.7V^2}{R} = \frac{2.7 \times 65^2}{325} = \underline{\underline{35.1\,m}}$$

L_s = Highest of above 3 = $\underline{\underline{35m}}$

Que:) A state Highway passing through a rolling terrain has a horizontal curve of radius equal to ruling minimum ra

i) Design ~~the~~ la all the geometric features of this curve, assuming suitable data.

ii) Specify minimum set back distance from the centre line of the two lane highway on the inner side of the curve up to which the Buildings etc. should not be constructed so that intermediate sight distance is available throughout the circular curve. Assume the length of circular curve greater than sight distance.

Ans: Assume V = 80kmph (SH on rolling terrain)

a) Ruling Minimum Radius

$$R_{ruling} = \frac{V^2}{127(e+f)} = \frac{80^2}{127(0.07+0.15)} = \underline{\underline{229m}}$$

b) Super elevation

Step 1: $e = \frac{(0.75V)^2}{127R} = \frac{(0.75 \times 80)^2}{127 \times 229} = 0.127 > 0.07$

Step 2: provide $e = 0.07$

$f = \frac{V^2}{127R} - e = \frac{80^2}{127 \times 229} - 0.07 = \underline{\underline{0.15}} \leq 0.15 \Rightarrow$ Safe.

c) Assume 2 lane, $n = 2$. & $l = 6$.

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

$$= \frac{2 \times 6^2}{2 \times 230} + \frac{80}{9.5\sqrt{230}}$$

$$= 0.157 + 0.555$$

$$= \underline{\underline{0.712m}}$$

d) Length of Transition curve.

i) Ls by rate of introduction of centrifugal acceleration

$C = \frac{80}{75+V} = \frac{80}{75+80} = 0.52$. which is b/w 0.5 & 0.8 $\Rightarrow$ ok.

$Ls = \frac{0.0215V^3}{CR} = \frac{0.0215 \times 80^3}{0.52 \times 229} = \underline{\underline{92m}}$

ii) By rate of introduction of SE

Assume $N = 150$ for rolling terrain

$Ls = \frac{eN(W + W_e)}{2} = \frac{0.07 \times 150(7 + 0.712)}{2} = \underline{\underline{40.5m}}$

iii) By IRC.

$Ls = \frac{2.7V^2}{R} = \frac{2.7 \times 80^2}{230} = \underline{\underline{75.1m}}$

$\therefore$ Length of T.C = Highest of above $= \underline{\underline{92m}}$

e) ~~Into~~

Stopping sight distance $SSD = 0.278Vt + \frac{V^2}{254f}$

$= \underline{127.6\,m}$

Intermediate sight distance $= 2 \times SSD$

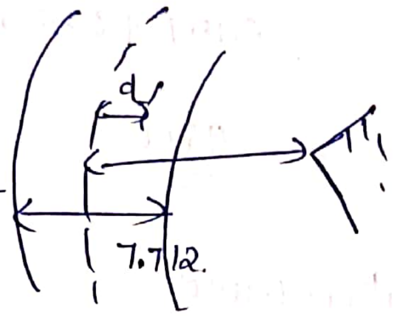
$= 2 \times 127.6$

$= \underline{255m}$

f) Set Back Distance

Here $n = 2$

$d = \frac{7.712}{4} = \underline{1.93m}$



Given $L_c > S$ (ie case a)

$\frac{\alpha}{2} = \frac{S}{2(R-d)}$ Rad $= \frac{S}{2(R-d)} \times \frac{180}{\pi}$ degree

$= \frac{\cancel{18}\ 255 \times 180}{\pi \times 2(\cancel{8}\ \cancel{220}\ 229 - 1.93)} = \underline{32.18^\circ}$

Set Back distance $m = R - (R-d)\cos\frac{\alpha}{2}$

$= 229 - (229 - 1.93)\cos 32.18^\circ$

$= \underline{36.6m}$

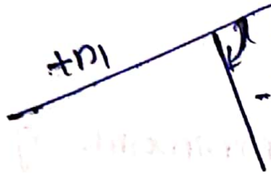
∴ Min. Set back distance or clearance required to provide clear vision for an ISD of 255m is 36.6m.

Vertical Alignment

Vertical alignment is the elevation or profile of the centre line of the road.

<u>Gradient</u> : It is the rise or fall along the length of road w.r.t horizontal. It is expressed as 1 in x.

Deflection angle (N) : Algebraic difference b/w 2 grades



$N = +n_1 - -n_2 = n_1 + n_2$

classification of gradient.

a) <u>Ruling Gradient</u>

- Maximum gradient within which the designer attempts to design the vertical profile of a road.
- Known as design gradient.
- Selection of ruling gradient depends on type of terrain, length of grade, speed, pulling power, presence of horizontal curve.

Ruling Gradient	Terrain
1 in 30	Plain and Rolling terrain
1 in 20	Mountainous
1 in 16.7	Steep terrain

b) limiting gradient: raising

when topography of a place compels adopting steeper gradients than ruling gradient, limiting gradients are used. [illegible] har

c) Exceptional gradient:

- In some extra ordinary situations it may be unavoidable to provide still steeper gradients atleast for short stretches
- should be limited to stretch upto 100m

d) Minimum gradient

It is desirable to have a certain minimum gradient on roads from drainage point of view.

Grade Compensation on Horizontal curve.

when there is a horizontal curve in addition to the gradient, there will be increased resistance to traction due to both gradient and curve. In such cases to avoid resistance going beyond permissible value, gradient should be decreased to compensate for loss of tractive effort due to curve.

This reduction in gradient at horizontal curve is called grade compensation.

[illegible]celeration Given.

Step1: ~~e = 0.75V)~~

V = 65 kmph.

l = 6m.

W = 10.5m

R = 325m

By rotating the ... sides

Grade Compensation = Minimum of $\left\{ \begin{array}{l} \dfrac{30+R}{R} \\ \\ \dfrac{75}{R} \end{array} \right.$ R = Radius.

According to IRC Grade compensation is not necessary for gradient < 4 %.

Que:) While aligning a hill road with a ruling gradient of 6 %, a horizontal curve of radius 60m is encountered. Find the compensated gradient at the curve.

Ans: Ruling gradient = 6 %.

$$\frac{75}{R} = \frac{75}{60} = 1.25\%$$

$$\frac{30+R}{R} = \frac{30+60}{60} = 1.5\%$$

Grade compensation = 1.25 %.

Compensated gradient = 6 − 1.25 = $\underline{4.75\%}$

Que:) Same problem Above, suppose ruling gradient = 5%.

Grade Compensation = 1.25 %.

Compensated gradient = 5 − 1.25 = 3.75 < 4 %.

∴ Compensated gradient = $\underline{4\%}$

Vertical curve

Due to changes in grade in vertical alignment of highway, it is necessary to introduce vertical curve at intersection of different grades.

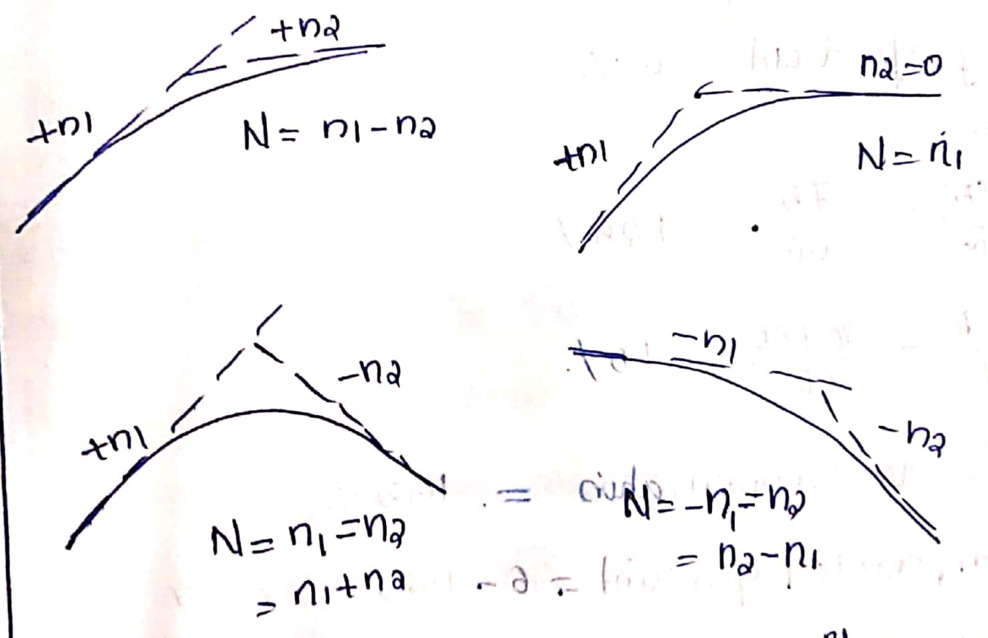
2 types

a) Summit curve / Crest curve

b) Valley or sag curve

Summit Curve

- Convexity upward



when vehicle moves along a summit curve, centrifugal force will act upwards, against gravity and hence a part of pressure on tyre is relieved. so there is no problem of discomfort to passengers on summit curve.

The only problem in designing summit curve is to provide adequate sight distance.

Length of summit curve for SSD

Case 1 $L > SSD$.

When length of curve > SSD

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

L = length of summit curve

H = Height of eye level of driver = 1.5m

h = Height of object = 0.15m

N = Deviation angle

$$\boxed{L = \frac{NS^2}{4.4}}$$

Case 2 $L < SSD$

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

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

Length of summit curve for OSD

Case 1 $L > OSD$

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

Here $H = h = 1.2m$

$$\therefore L = \frac{NS^2}{8H} = \frac{NS^2}{9.6}$$

Case 2: $L < OSD$

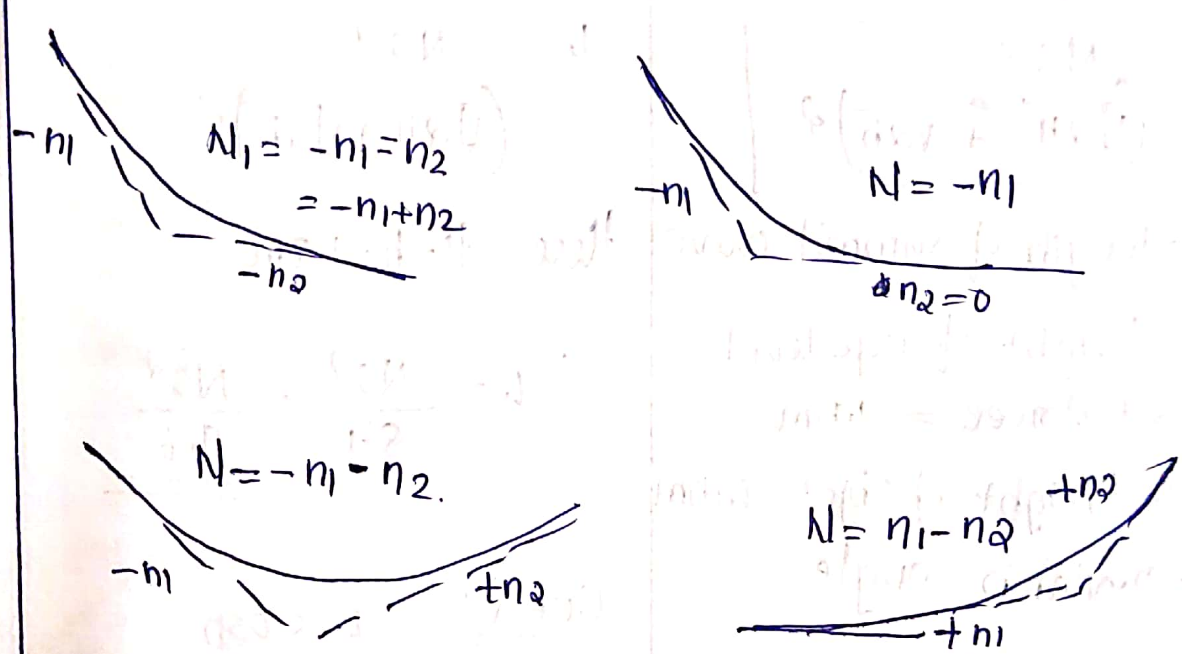
$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

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

Circular summit curve is ideal as the sight distance available throughout the length of circular curve is constant.

Valley Curve

- Sag curve



At valley curve, the centrifugal force acts downwards. ~~adding to the pressure on the wt~~. weight of vehicle also act downwards. Hence the allowable rate of change of centrifugal acceleration should govern the design of valley curve.

Length of valley Curve

1) Length of transition curve Ls for comfort conditions

$$L = 2\left[\frac{N v^3}{C}\right]^{1/2}$$ v is m/s

$$L = 0.38\left(NV^3\right)^{1/2}$$

L = Total length of valley curve

N = Deviation angle

V = Design speed (kmph.

2) Length of valley curve for headlight sight distance

Case 1 L > SSD length of curve > SSD.

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha}$$

h_1 = height of head light = 0.75

$\alpha = 1° =$ Beam angle

Case 2 L < SSD

$$L = 2S - \frac{2h_1 + 2S\tan\alpha}{N}.$$

Que:) A vertical summit curve is formed at the intersection of 2 gradients +3 and −5 percent. Design the length of summit curve to provide a stopping sight distance for a design speed of 80kmph. Assume other data.

Ans

$SSD = 0.278Vt + \frac{V^2}{254f}$ Assume $t = 2.5s$

$f = 0.35$

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

$= 128m$

N = Deviation angle $= +3=5=8\% = 0.08$

Assume Length of curve > SSD (L > SSD)

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

$= \frac{NS^2}{4.4}$

$= \frac{0.08 \times 128^2}{4.4}$

$= 297.9\ m > 128m$ ∴ Assumption is correct

∴ Length of summit curve $= 297.9\ m$

Que:) An ascending gradient of 1 in 100 meets a descending gradient of 1 in 120. A summit curve is to be designed for a speed of 80 kmph so as to have an overtaking sight distance of 470m.

$n_1 = \frac{1}{100}$, $n_2 = -\frac{1}{120}$

$N = \frac{1}{100} - -\frac{1}{120} = 0.0183$, OSD = 470m (given)

Assume. Length of curve > OSD

L > OSD

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

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

$$= \frac{0.0183 \times 470^2}{9.6} = \underline{421\,m.} \not> OSD = 470m$$

Assumption is wrong

Take L < OSD

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

$$= 2 \times 470 - \frac{9.6}{0.0183}$$

$$= \underline{415\,m} < OSD = 470m$$

$\Rightarrow$ ok.

∴ length of summit curve = $\underline{415m}$

Scanned with CamScanner

Que.) A vertical summit curve is to be designed when two grades, 1/50 and -1/80 meet on a highway. The stopping sight distance and overtaking sight distance required are 180m and 640m respectively. But due to site conditions the length of vertical curve has to be restricted to a maximum value of 500m if possible. Calculate the length of summit curve needed to fulfill the requirements of a) SSD b) OSD or atleast Intermediate sight distance

Ans:

$$N = \frac{1}{50} - -\frac{1}{80} = \underline{0.0325}$$

a) Requirements of SSD

Given SSD = 180m

Assume L > SSD

$$L = \frac{NS^2}{4.4} = \frac{0.0325 \times 180^2}{4.4} = \underline{239.3}\,m > (SSD = 180m)$$

Assumption is correct.

b) Requirements of OSD

Given OSD = $\cancel{400}$ 640m

Assume L > OSD

$$L = \frac{NS^2}{9.6} = \frac{0.0325 \times \cancel{400}\,640^2}{9.6} = \underline{1387m} > (OSD = 640)$$

Assumption ...

But it is given that length of curve limited to 500m if possible.
∴ It is not possible to provide required OSD of 640m.
∴ Provide limited overtaking opportunities (Intermediate Sight Distance)

$$ISD = 2 \times SSD = \underline{360m}$$

If $L > SD$

$$L = \frac{N S^2}{9.6} = \frac{0.0325 \times 360^2}{9.6} = \underline{439} \text{ m.} > \overset{(ISD)}{SD} = 360m)$$

Assumption correct.

Que) A valley curve is formed by a descending gradient of 1 in 25 meeting an ascending grade of 1 in 30. Design the length of valley curve to fulfill both comfort condition and headlight sight distance requirements for a design speed of 80kmph. Assume allowable rate of change of centrifugal acceleration $C = 0.6 \text{ m/s}^2$.

Ans: $N = \frac{-1}{25} - \frac{1}{30} = -0.073$

$V = 80\text{kmph}$, $v = \frac{80 \times 1000}{3600} = \underline{22.22} \text{ m/s}$

i) Comfort condition

$$L = 2\left[\frac{N v^3}{C}\right]^{1/2} = 2\left[\frac{0.073 \times 22.2^3}{0.6}\right]^{1/2} = \underline{73.1} \text{ m}$$

...ge Problem

ii) Headlight Sight Distance Condition

~~Assume L >~~

$$HSD = SSD = 0.278\,Vt + \frac{V^2}{254f}$$

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

$$= 55.60 + 71.99$$

$$= \underline{\underline{127.3\ m}}$$

Assume $L > SSD$

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha} = \frac{0.073 \times 127.3^2}{2 \times 0.75 + 2 \times 127.3 \times \tan 1^\circ} = \underline{199.5}\ m$$

$> (SSD = 127.3)$

$\Rightarrow$ Assumption is correct

cross sec

ed

essary

325m

of large