UNIT-II

Highway Geometric Design

Introduction:

Highway Geometric design deals with the dimensions and layout of the visible features of ~~a~~ a road such as Horizontal alignment, Vertical alignment, sight distance e.t.c.,

Proper geometric design will helps to reduce accidents.

Role of geometric design

To provide comfort and safety,

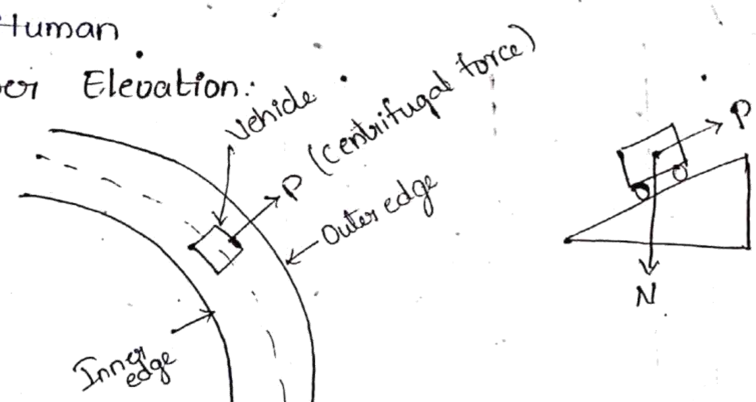
Economical facilities

To minimize environmental impacts

factors affecting on Geometric design

1. Design speed
2. Traffic
3. Topography
4. Vehicle properties (width of vehicle, weight of vehicle etc)
5. Enviromental factors
6. Human

Super Elevation:



The Transverse slope is provided at horizontal curve to counter act the centrifugal force by raising the outer edge of the pavement with respect to inner edge throughout the length of the Horizontal curve is called super elevation

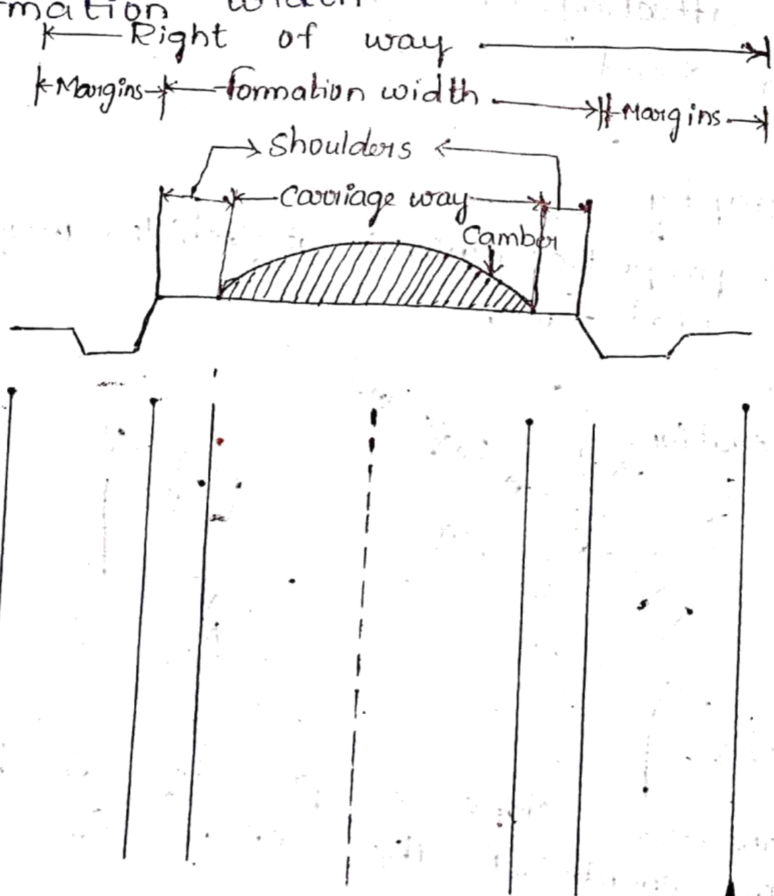
UNIT – II

Elements Of Geometric Design

1. Cross Sectional elements
2. Site distance (stopping side Distance & Overtaking Side Distance)
3. Horizontal alignment
4. Vertical alignment
5. Intersections

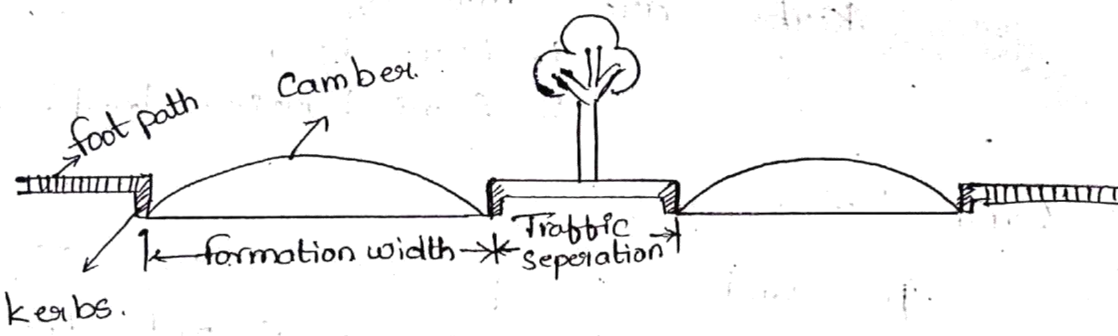
Cross Sectional elements:

1. Pavement Surface characteristics.
2. Carriage way / width of pavement
3. Cross slope / Camber
4. Traffic Separator / Median
5. Kerbs
6. Road margins
7. formation width



Pavement Surface characteristics:

1. Uneveness
2. Light reflection on road
3. Drainage



Carriage way:

The width of pavement on which vehicles travel is called carriage way.

For single lane 3.75m

for Two lanes 7.5m

(The width of vehicle is 2.5m)

Shoulders:

shoulders are provided beside the Carriage way.

In emergency cases the shoulders are used as emergency lane for ambulance, fire engines e.t.c.,

As per IRC the minimum width of shoulder is 2.5m.

Formation width:

The width of pavement including shoulders is called formation width i.e., formation width = Carriage way + shoulders

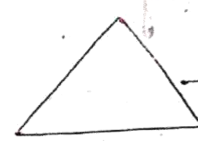
Kerb: The kerb is provided between footpath and pavement.

Kerbs are two types
1. Low kerbs
2. Semi-barrier kerbs

Camber / cross-slope:

A camber is provided on the top surface of the road to drain out the rain water on the road surface.


→ Parabolic.


→ straight


→ Combination of straight & parabolic

Traffic separator (or) Median:

The Traffic seperator is provided b/w two opposite lanes.

The Traffic is controlled by providing traffic seperators.

Road Margins:

shoulders
footpath
Cycle track
parking lane
embankment slope e.t.c.,

Right of way:

The total width between boundary lines beside the road is called "Right Of Way"

i.e., ROW = Carriage way } + shoulders + Margins

Sight Distance

The actual Distance along the road surface which a driver from a specified height above the carriage way has visibility of stationery objects or moving objects are called sight distance.

These are classified into two types

1. stopping sight distance (SSD) (or)
2. absolute minimum sight distance (or)
   Non-passing sight distance.
2. Over taking sight distance (OSD) (or)
   Non-passing sight distance

Apart from above two additional sight distances are considered by IRC

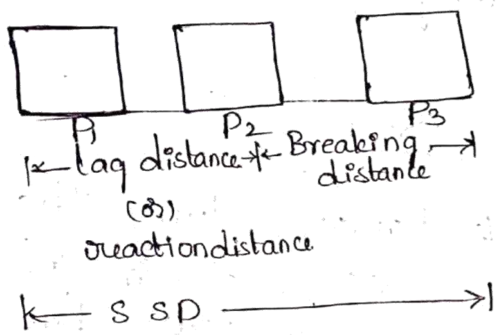
a) Intermediate sight distance (ISD)
   = Two times of stopping sight distance

When overtaking sight distance can't be provided to given limited Over taking oppurtunities for fast vehicles. The intermediate sight distance is provided.

b) Head light sight distance
   Distance visible to driver during the

night drives under the vehicle headlight.
this is critical at ascending gradients

1. Stopping sight distance



It is defined as the distance needed for drivers to see an object on the road way and bring their vehicles to safe stop before colliding with the object is called stopping sight distance.

As per IRC height of drivers eye
= 1.2m

height of object about road surface } = 0.15m

Total Reaction time: (t)

t = Perception time + Break reaction time

As per IRC,
The total reaction time is split into four types (PIEV theory)

P – Perception (time to see an object)
I – ~~Interpretation~~ Intelection (time to understand about the object)
E – Emotion (time to react)
V – Violation (time to initiate the action) i.e., for applying brakes

As per IRC
The total reaction time $t = 2.5$ sec

Lag distance or Reaction distance
The distance covered by a vehicle during total reaction time (t) is called lag distance

Breaking distance
The distance travelled (or) covered after application of breaks to a dead stop position. is known as Breaking distance

Lag distance $\cancel{d}$
$L =$ Velocity (speed) x time (reaction time)

i.e; $\boxed{L = v \times t}$

Speed $= \frac{\text{Dist}}{\text{time}}$
$D = v \times t$

where $v =$ velocity of vehicle in m/sec

$\cancel{t} =$

$L = 0.278\,Vt$ $\quad (v = 0.278\,V)$

where $V =$ Speed in KMPH

Breaking distance
On a level ground it is obtained by equating workdone to stopping a vehicle to kinetic energy loss.

Let $W =$ weight of the vehicle
$f =$ longitudinal co-efficient of friction (range 0.35 to 0.4)

work done $=$ frictional force x Breaking distance
$= F \times B$
$= f \times W \times B \rightarrow (1)$

$$K.E = \frac{1}{2} m v^2 \qquad \left[\begin{array}{l} w = mg \\ m = \frac{w}{g} \end{array} \right]$$

$$= \frac{1}{2} \times \frac{w}{g} v^2$$

$$K.E = \frac{w v^2}{2g} \longrightarrow (2)$$

from equation (1) & (2)

work done = kinetic energy

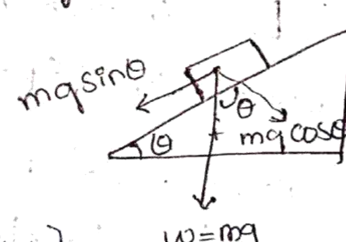
$$f \cancel{w} B = \frac{\cancel{w} v^2}{2g}$$

$$B = \frac{v^2}{2gf} \qquad v = 0.278\,V$$

$$B = \frac{(0.278V)^2}{2 \times 9.81\, f}$$

$$\boxed{B = \frac{V^2}{253.8\, f}}$$

Effect of gradient on breaking distance. (B)



$$K.E = W.D$$

$$\frac{1}{2} m v^2 = \underbrace{\left[f \times mg(\cos\theta) + mg\sin\theta \right]}_{\text{friction force}} \times B$$

$$\frac{1}{2} \cancel{m} v^2 = \cancel{m} g B (f\cos\theta + \sin\theta)$$

[If θ is small, $\cos\theta = 1$, $\sin\theta = \tan\theta$]

$$\frac{v^2}{2} = gB[f + \tan\theta]$$

$$\boxed{B = \frac{v^2}{2g(f + \tan\theta)}}$$

Note: In case stopping sight distance provided is not sufficient, a moving vehicle will collide with the object or another parked vehicle. The principle to be used in this analysis is as follows. for Breaking distance.

i.e., Kinetic energy lost = Work done in Skidding before collision.

$$\frac{1}{2} m v^2 = f \times B$$

$$\frac{1}{2} m \left[V_i^2 - V_f^2\right] = f \times W \times B$$

where V_i = initial velocity before application of breaks.

V_f = final velocity before collision

S.No	Surface	SSD (v in m/s) Lag distance + Breaking	SSD (V in KMPH) distance.
1.	Level surface	$vt + \frac{v^2}{2gf}$	$0.278\,Vt + \frac{V^2}{254f}$
2.	Inclined surface (n% of Gradient)	$vt + \frac{v^2}{2g(f \pm 0.01n)}$ n is gradient +ve = ascending gradient −ve = Descending gradient	$0.278\,Vt + \frac{V^2}{254(f \pm 0.01n)}$
3.	Level surface with breaking efficiency (η)	$vt + \frac{v^2}{2gf\eta}$	$0.278\,Vt + \frac{V^2}{254f\eta}$

Note: for single lane → 1-way traffic
$SSD' = SSD$

→ 2-way traffic $SSD_1 = 2SSD_2$
(SSD_2 = SSD calculated with single lane)

for Two lanes
→ 1-way traffic $SSD' = SSD$
→ 2-way traffic $SSD' = SSD'$

2) If the co-efficient of longitudinal frictional is 'f', The retardation (acceleration) developed in the process of breaking.

: $a = fg$

Eg: ~~Assuming~~ a longitudinal co-efficient of friction to be 0.4, The resulting retardation of a vehicle being brought to a stop is ?

Given
Co efficient of friction = 0.4

we know that retardation $a = f \times g$

$g = \cancel{9.81}$ [acceleration due to gravity]

$g = 9.81\ m/sec^2$

$a = 0.4 \times 9.81$

$= 3.924\ m/sec^2$

Determine the minimum stopping sight distance of a design speed of 50 kmph with longitudinal co-efficient of friction 0.36 when

a) Two lane two way traffic
b) Single lane two way traffic

$$S.S.D = vt + \frac{v^2}{2gf}$$

Given that

$$v = 50 \times \frac{1000}{3600}$$

$$= 50 \times \frac{10}{36}$$

$$= 13.88 \text{ m/sec.}$$

we know that
The total reaction time IRC

$$t = 2.5 \text{ sec.}$$

$$f = 0.36$$

$$g = 9.81 \text{ m/sec.}$$

$$S.S.D = 13.88 \times 2.5 + \frac{13.88^2}{2 \times 9.81 \times 0.36}$$

$$= 61.97 \text{ m}$$

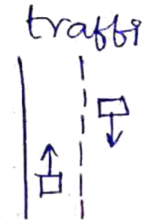
(or)

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

$$= 0.278 \times 50 \times 2.5 + \frac{50^2}{254 \times 0.36}$$

$$S.S.D. = 62 \text{ m}$$

a) Min SSD for two lane two way traffic



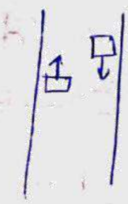
$$\text{Min SSD} = SSD$$
$$= 62 \text{ m.}$$

b) Min SSD for single lane two way traffic

Min SSD $= 2 \times S.S.D$

$= 2 \times 62$

$= 124\ m$



2. Calculate the min SSD on a high way at an ascending gradient 3 %. with a design speed of 40 KMPH

Given

ascending gradient $n = 3\%$

Co eff of friction $f = 0.35$ (range 0.35 – 0.4)

$$v = 40 \times \frac{1000}{60 \times 60} = 11.11\ m/sec.$$

$t = 2.5\ sec$

$g = 9.81\ m/sec^2$

we know that

$$S.SD = vt + \frac{v^2}{2g(f + 0.01n)}$$

$$= 11.11 \times 2.5 + \frac{11.11^2}{2 \times 9.81\,(0.35 + 0.01(3))}$$

$= 44.33\ m.$

$$SS.D = 0.278\,Vt + \frac{V^2}{254(f + n\%)}$$

$$= (0.278 \times 40 \times 2.5) + \left[\frac{40^2}{254\,(0.35 + 0.03)}\right]$$

$= 44.37\ m.$

Determine a minimum stopping sight distance of a moving vehicle with a design speed of 60KMPH with a Break efficiency 80% and a co-efficient of friction is 0.4

Given

$V = 60\ KMPH \qquad v = 60 \times \frac{1000}{60 \times 60} = 16.67$

Break efficiency $\eta = 80\%$.

From IRC: $t = 2.5$, $f = 0.35$, $g = 9.81$

$$S.S.D = vt + \frac{v^2}{2gf\eta}$$

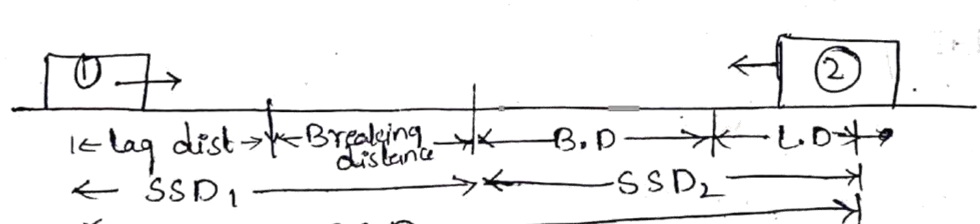
$$= 16.67(2.5) + \frac{16.67^2}{2 \times 9.81 \times 0.35 \times 80} = 42.18$$

(or)

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

$$= 85.936\ m.$$

Calculate the minimum sight distance required to avoid a collision of two cars approaching from the opposite directions at 90KMPH and 60KMPH. Assume a reaction time of 2.5 sec, co-efficient of friction of 0.7 and break efficiency of 50% in both the cases.



Given that

speed of first vehicle $v_1 = 90\ KMPH$

$= 90 \times \frac{1000}{3600} = 25\ m/s$

$v_2 = 60\ KMPH = 60 \times \frac{1000}{3600} = 16.67\ m/s$

SSD for 1^{st} vehicle

$$SSD_1 = v_1 t + \frac{v_1^2}{2gf\eta}$$

$$= (25 \times 2.5) + \left[\frac{25^2}{2 \times 9.81 \times 0.7 \times 0.5}\right]$$

$$= 153.51\,m.$$

$$SSD_2 = v_2 t + \frac{v_2^2}{2gf\eta}$$

$$= [16.67 \times 2.5] + \left[\frac{16.67^2}{2 \times 9.81 \times 0.7 \times 0.5}\right]$$

$$= 82.12\,m.$$

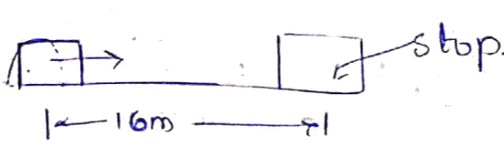
S.S.D req to avoid collision b/w two vehicles

$$S.S.D = S.S.D_1 + S.S.D_2$$

$$= 153.51 + 82.12$$

$$= 235.63\,m.$$

* Breaking is applied on a vehicle which skids a distance of 16 m before coming to stop. If the developed average co-efficient of friction b/w the tyres and pavement is 0.4 then calculate the speed of vehicle before skidding..



Dist = 16m = 0.016 km.

Breaking dist = $\frac{V^2}{254f}$

$$0.016 = \frac{V^2}{254 \times 0.35}$$

$$V = 1.27 \, m/sec$$

Breaking dist = $\frac{v^2}{2gf}$

$$16 = \frac{v^2}{2 \times 9.81 \times 0.35}$$

$$v = 11.27 \text{ KMPH}$$

Over taking sight distance:

The minimum distance open to the vision of a driver of a ~~overtaking~~ ~~weight~~ vehicle intending to ~~op~~ overtake slow vehicle with saftey against the traffic in the opposite direction

(or)

The min. dist required to over take a vehicle coming from the opposite against the vehicle direction is called "OSD" (or) "safe passing side distance."

As per IRC, the distance measure along the center line of a road which a driver with his eye level at 1.2m above the road surface can see the top of an object 1.2m above road surface

factors affecting on OSD

1. The speed of over taking vehicle, Over taken vehicle (slow vehicle) and vehicle coming from the opposite direction.
2. Skill of driver, Reaction time of driver
3. Rate of acceleration of Over taking vehicle

Note:

* Break efficiency does not effect on OSD
* Gradient does not effect on OSD

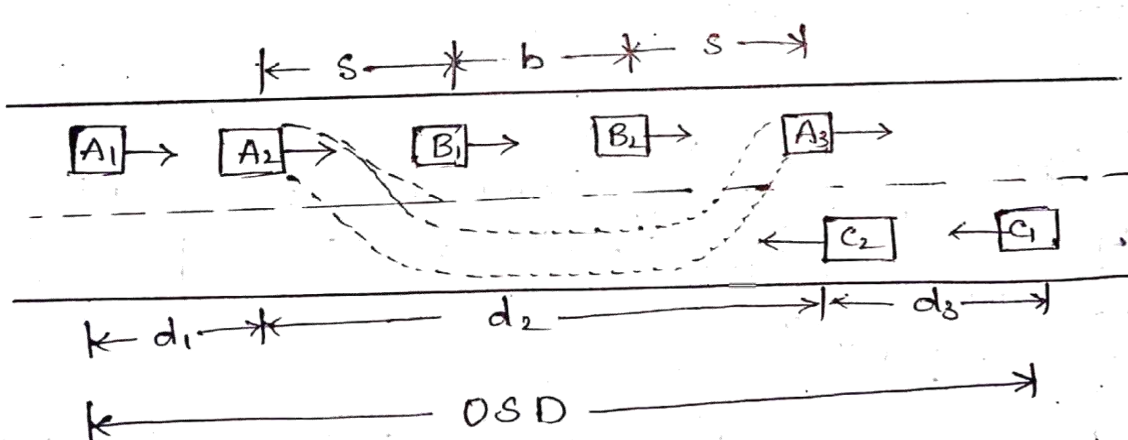
Calculation of "OSD"

Let, ~~A = Over~~

A = Over taking vehicle

B = Over taken vehicle (slow vehicle)

C = Opposite vehicle coming in the opposite direction.



d_1 = distance travelled by Over taking vehicle [A] during reaction time from position A_1 to A_2

d_2 = distance travelled by vehicle A from A_2 to A_3 during over taking operation of vehicle A

d_3 = distance travelled by oncoming vehicle or opposite vehicle (C) from C_1 to C_2 during the overtaking operation of vehicle 'A'

Let v = design speed in m/sec

V = design speed in KMPH

v_b = Speed of slow moving vehicle in m/sec

V_b = Speed of slow moving vehicle in KMPH

(a) Distance travelled by Overtaking vehicle A from position A_1 to A_2 during reaction time 't'

$\boxed{d_1 = v_b \times t}$, meters

where t = reaction time of a driver in Over taking sight distance = 2 sec [as per IRC]

(b) $d_2 = S + b + S$

$d_2 = b + 2S$

where $b = v_b T$

$d_2 = v_b T + 2S \longrightarrow (1)$

where T = Overtaking time in sec

but we know that

$d_2 = ut + \frac{1}{2}at^2$

$u = v_b \quad t = T$

$$d_2 = v_b T + \frac{1}{2} a T^2 \longrightarrow ②$$

equate ① & ② equations

$$\cancel{v_b T} + 2s = \cancel{v_b T} + \frac{1}{2} a T^2$$

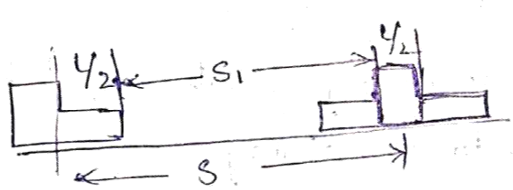
$$2s = \frac{1}{2} a T^2$$

$$aT^2 = 4s$$

$$\boxed{T = \sqrt{\frac{4s}{a}}} \text{ sec}$$

$$T = 2\sqrt{\frac{s}{a}}$$

where S = Spacing between vehicles (center to center)



where S_1 = lag distance while over taking

i.e., S_1 = Speed × time

$= v_b \times T$

$$S_1 = 0.7 v_b$$

[Reaction time T = 0.7 sec as per IRC]

$$\therefore S = \frac{L}{2} + S_1 + \frac{L}{2}$$

$$S = S_1 + L$$

$$\boxed{S = 0.7 v_b + 6}\text{, m}$$

where $L = 6$ m as per IRC [length of vehicle]

(c) d_3 = dist. travelled by on coming vehicle or opposite vehicle (C) from position C_1 to C_2 during over taking operation.

$$d_3 = v \times T$$

$$\therefore OSD = d_1 + d_2 + d_3$$

$$\boxed{OSD = [v_b t] + [v_b T + 2S] + vT}, \text{ meters}$$

(or)

$$\boxed{OSD = [0.278 V_b t] + [0.278 V_b T + 2S] + [0.278 V T]} \text{ KMPH}$$

where, T = Over taking time = $\sqrt{\frac{4S}{a}}$ sec

$$\boxed{T = \sqrt{\frac{14.4S}{A}}}$$

where a = acceleration in m/sec^2

A = acceleration in KMPH / sec

Note:

If speed of slow moving vehicle is not given

$\therefore$ take speed of slow moving vehicle $\boxed{v_b = v - 4.5}\ m/sec$

(or)

~~$V_b = 0.27V - 4.5$ KMPH~~

$\boxed{V_b = V - 16}$ KMPH

Note:

for two lanes one way traffic

Safe OSD = $d_1 + d_2$ [$d_3 = 0$ there is no opposite vehicle] for two lanes, two way traffic

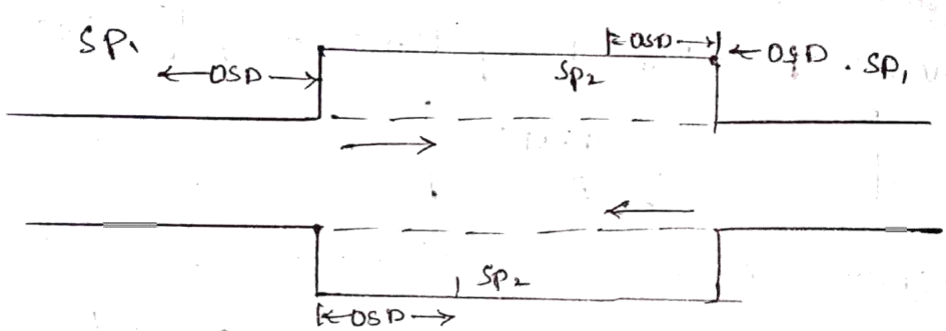
Safe OSD = $d_1 + d_2 + d_3$

for four lanes, two way traffic

Safe OSD = $d_1 + d_2$

"except in two lanes, two way traffic in all other cases d_3 should not be consider for calculating OSD"

Over taking zone:



where SP1 = Over taking zone ahead (information sign)

SP2 = End of Over taking zone (mandatory sign.)

The minimum length of over taking zone = 3 x OSD

The desirable length of over taking zone = 5 x OSD (as per IRC)

These zones are provided in single lane roads to facilitate over taking.

1. The speed of overtaking and over taken vehicles are 80KMPH and 50 KMPH respectively. The acceleration of over taking vehicle is $0.98\,m/sec^2$. for two lanes two way traffic i) Determine OSD
ii) Determine min length of over-taking zone
iii) Draw over taking zone diagram and mention sign posts

Given

Speed of over taking vehicle $(V) = 80$ KMPH
$v = 22.2\,m/sec$

Speed of over taken vehicle $V_b = 50$ KMPH
$v_b = 13.8\,m/sec.$

Acceleration of over taking vehicle $a = 0.98\,m/sec^2$

OSD reaction time $t = 2\,sec$ (as per IRC)

Spacing b/w vehicles $S = 0.7\,v_b + 6$

$= 0.7 \times 13.8 + 6$

$\boxed{S = 15.72\,m}$

(or)

$S = 0.2\,v_b + 6$

$= 16\,m$

Over taking time $T = \sqrt{\frac{4S}{a}}$

$= \sqrt{\frac{4 \times 15.72}{0.98}}$

$T = 8.01\,sec$

$\therefore$ Over taking sight distance

$OSD = d_1 + d_2 + d_3$

$$OSD = v_b t + v_b T + 2S + v T$$

$$= (13.8 \times 2) + (13.8 \times 8.01) + 2(15.72) + (22.22 \times 8.01)$$

$$OSD = 347.56\ m$$

(or)

$$OSD = (0.278 \times V_b t) + (0.278\ V_b T) + (2S) + V T\ 0.278$$

$$= (0.278 \times 50 \times 2) + (0.278 \times 50 \times 8.01) + (2 \times 15.72) + (0.278 \times 80 \times 8.01)$$

$$OSD = 348.72\ m$$

ii) Min length of Overtaking zone

$$= 3 \times OSD$$

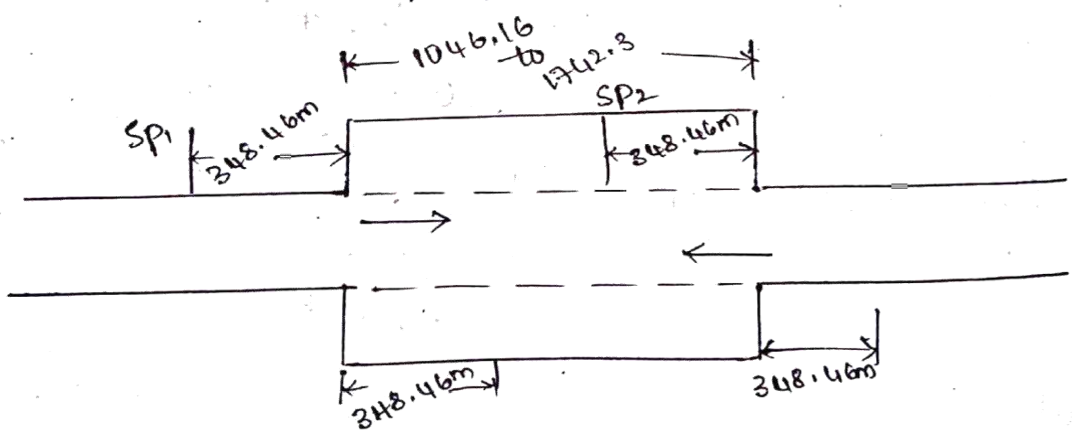
$$= 3 \times 348.72$$

$$= 1046.16\ m$$

The Desirable length of overtaking zone

$$= 5 \times OSD$$

$$= 1743.6$$



* If the speed of overtaking vehicle is 90 KMPH and acceleration is 2.5 KMPH/sec Determine min. length of OSD and Draw over taking zone

Speed of overtaking vehicle $V = 90$ KMPH

$v = 25 \text{ m/sec}$

acceleration $a = 2.5 \times \frac{1000}{60 \times 60}$

$= 0.69 \text{ m/sec}^2$

Speed of overtaken vehicle $v_b = v - 4.5$

$v_b = 25 - 4.5$

$v_b = 20.5 \text{ m/sec}$

$V_b = V - 16$

$= 90 - 16$

$V_b = 74$ KMPH

OSD reaction time $t = 2$ sec

Spacing $S = 0.2 V_b + 6$

$= 0.2 \times 74 + 6$

$= 20.8$ m.

or

$S = 0.7 v_b + 6$

$= 0.7 (20.5) + 6$

$= 20.35$ m.

Over taking time $T = \sqrt{\frac{4S}{a}}$

$T = \sqrt{\frac{14.4S}{A}}$

$= 10.8$

$T = \sqrt{\frac{4 \times 20.35}{0.69}}$

$= 10.86$

$$OSD = v_b t + v_b T + 2S + vT$$

$$= (20.5 \times 2) + (20.5 \times 10.86) + 2(20.35) + \cancel{8}(10.86)\ 25$$

$$OSD = 575.83\,m$$

(or)

$$OSD = (0.278 \times V_b t) + (0.278\, V_b T) + 2S + V\,0.278\,T$$

$$= (0.278 \times 74 \times 2) + (0.278 \times 74 \times 10.86) + (2 \times 20.35) + (0.278 \times 90 \times 10.86)$$

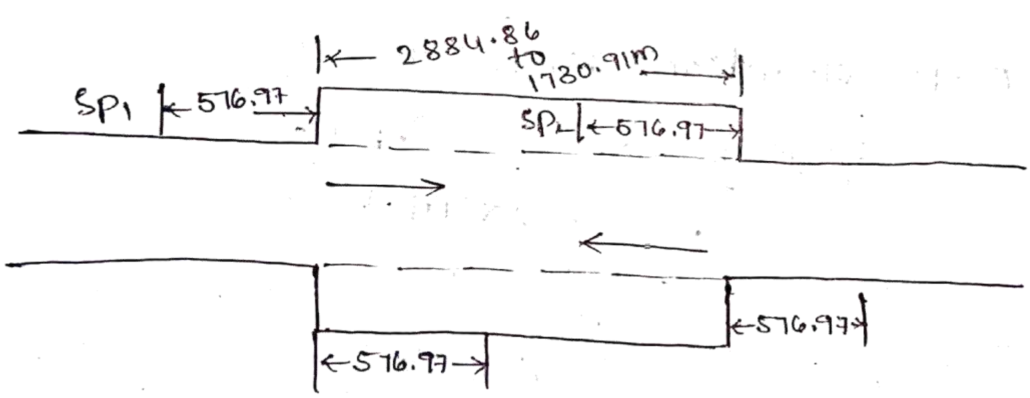
$$OSD = 576.97\,m.$$

min length of OSD $= 3 \times OSD$

$= 1730.91\,m.$

Desirable Max Length of OSD $= 5 \times OSD.$

$= 2884.8656$



Design of horizontal alignment

The alignment changes from horizontal to curve in horizontal direction is called horizontal alignment.

Design elements to be considered in Horizontal alignment.

1. Design speed
2. horizontal curve
3. Super elevation
4. Type & length of transition curves
5. widening of width of pavement on curves
6. Set back distance

1. Design Speed

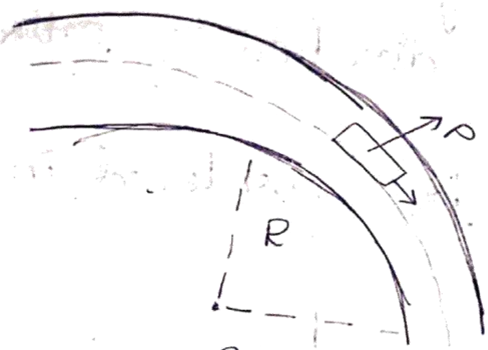
The design speed is the main factor on which geometric design elements depends.

The design speed of roads depends upon → class of the road
→ Terrain

Class of country

Terrain classification	Gross slope in %
plan	0-10
Rolling	10-25
Mountainous	25-60
Steep	>60

b. Horizontal curve



The centrifugal force is given by the following eqn

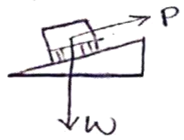
$$P = \frac{Wv^2}{2gR}$$

P = centrifugal force in kg

W = weight acting downward of vehicle in kgs

v = velocity speed in m/sec.

R = Radius of the circular curve (m)



A horizontal high way curve is a curve in plane to provide change in direction to the central line of road

when a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the center of gravity of the vehicle (C.G)

g = acceleration due to gravity = 9.81 m/sec²

* The ratio between centrifugal force (P) to weight of a vehicle is called the centrifugal ratio (or) impact factor

i.e., Centrifugal ratio $\frac{P}{W} = \frac{v^2}{gR}$

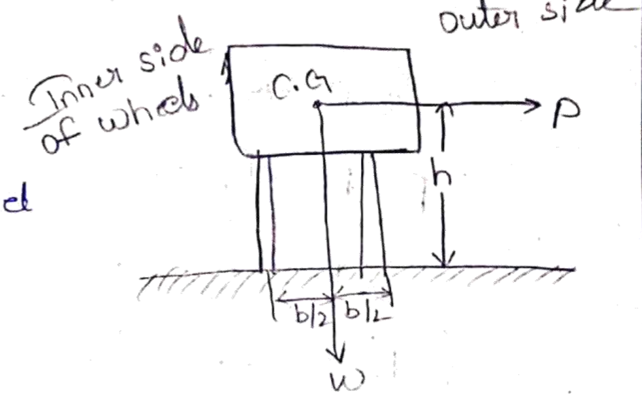
* The centrifugal force acting on a vehicle negotiating a horizontal curve has two effects

1. Tendency to overturn the vehicle outwards about the outer wheels

2. Tendency to skid the vehicle laterally outwards.

(a) Over turning

From equilibrium eq^{n}s (Moment about outer wheel



$$\Sigma M_{(o.w)} = 0$$

$$(P \times h) - \left(W \times \frac{b}{2}\right) = 0$$

$$Ph = W\frac{b}{2}$$

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

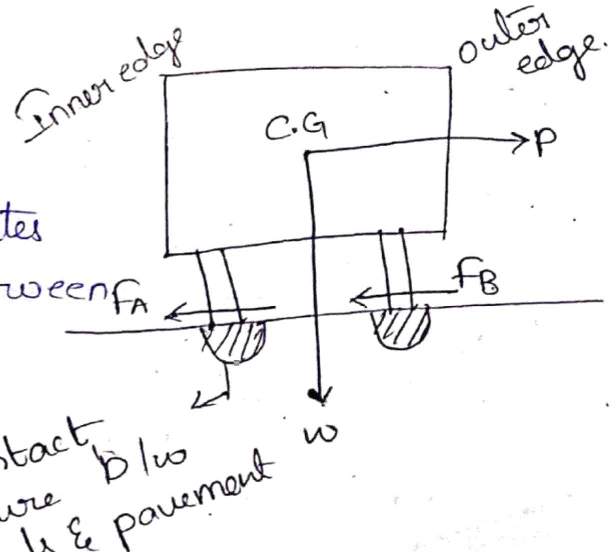
∴ The over turning will occur when the centrifugal ratio $\left(\frac{P}{W}\right)$ is equal to $\frac{b}{2h}$

(or)

$$\frac{v^2}{gR} = \frac{b}{2h}$$

(b) Skidding

From the figure the shaded area will indicates the contact pressure between wheels and pavement



Let

R_A & R_B = Reactions at both wheels

f_A & f_B is frictional force at both wheels

from equilibrium equations

$$\Sigma H = 0$$

$$P - f_A - f_B = 0$$

$$P = f_A + f_B$$

$$\{ f_A = f.R_A, \quad f_B = f R_B \}$$

$$P = f R_A + f R_B$$

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

$$P = f (R_A + R_B) \longrightarrow (1)$$

$$\Sigma V = 0$$

$$R_A + R_B - W = 0$$

$$W = R_A + R_B \longrightarrow (2)$$

from (1)

$$P = f W$$

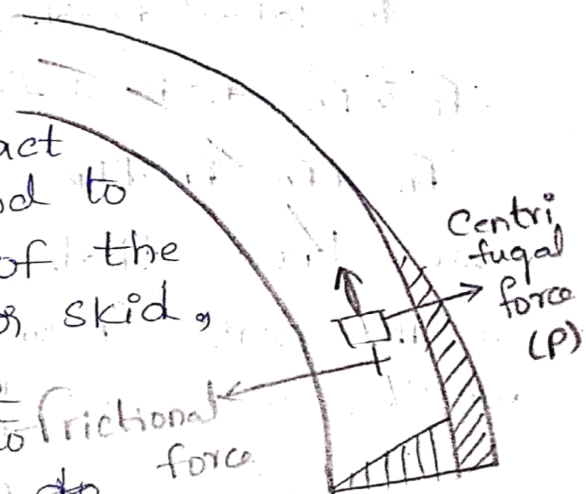
$$\boxed{\frac{P}{W} = f}$$

where f = frictional co-efficient in lateral direction

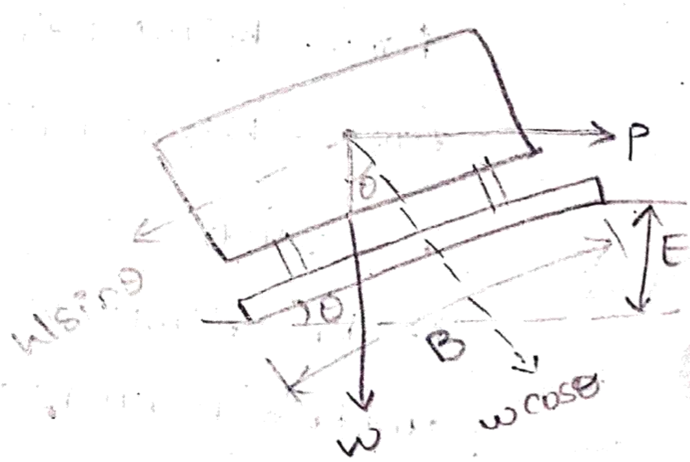
∴ If the centrifugal ratio is equal to the lateral coefficient of friction, the skidding will occur (or) $\frac{b}{2h} = f$, skidding will occur if $f < \frac{b}{2h}$ → Skidding will occur but not over turning

if $f > \frac{b}{2h}$ → ~~Sk~~ Vehicle will over turn on the outer side before skidding

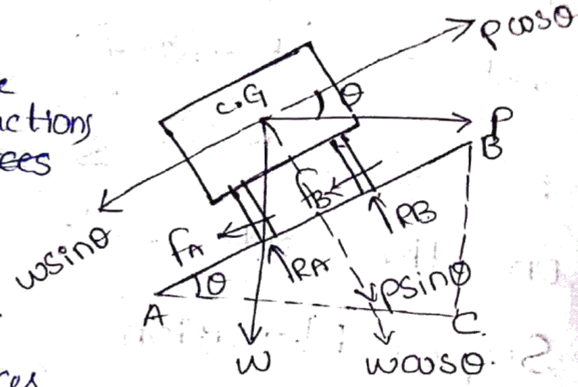
Super Elevation:



In order to counteract the centrifugal force and to reduce the tendency of the Vehicle to over turn or skid, The outer edge of the pavement with respect to inner edge is rised, ~~do~~ Thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as Super elevation (or) cant (or) banking



Analysis Of Super Elevation.



let W = weight of vehicle

R_A & R_B = Normal reactions ~~frictional forces~~

f = frictional coefficient in lateral direction.

F_A & F_B = frictional forces

$F_A = f R_A$ $F_B = f R_B$

we know that Super elevation (e) is defined as the ratio between outer edge to horizontal width i.e., $e = \frac{BC}{AC}$ but from figure

$$\tan\theta = \frac{BC}{AC}$$

$$\boxed{e = \tan\theta}$$

from equilibrium equations

$$\Sigma H = 0$$

$$P\cos\theta - W\sin\theta - F_A - F_B = 0$$

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

$$P\cos\theta = W\sin\theta + f(R_A + R_B) \rightarrow (1)$$

$$\Sigma V = 0$$

$$R_A + R_B - P\sin\theta - W\cos\theta = 0$$

$$R_A + R_B = P\sin\theta + W\cos\theta \rightarrow (2)$$

from eqn's (1) & (2)

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

$$P\cos\theta = w\sin\theta + fP\sin\theta + fw\cos\theta.$$

$$P\cos\theta - fP\sin\theta = w\sin\theta + fw\cos\theta.$$

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

$$\frac{P}{w}(\cos\theta - f\sin\theta) = (\sin\theta + f\cos\theta)$$

dividing with $\cos\theta$ on both sides

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

$$\frac{P}{w}(1 - f(e)) = (e + f)$$

$$\frac{P}{w} = \left(\frac{e+f}{1+ef}\right)$$

As per IRC for design purpose take the co-efficient of friction in lateral direction is equal to 0.15

$\tan\theta = e$ = Super-elevation (or) transverse slope exceeds 7 to 10 %.

∴ from the above equation

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

$$1 - f\tan\theta = 1 - (0.15 \times 0.07)$$

$$= 0.98 \cong 1$$

$$\frac{P}{w} \times 1 = \tan\theta + f$$

$$\frac{P}{w} = e + f$$

w.k.that $\frac{P}{w} = \frac{v^2}{gR}$.

$$\boxed{e + f = \frac{v^2}{gR}}$$ v in m/sec

$$e + f = \frac{(0.278V)^2}{9.81 \times R}$$

$$e + f = \frac{V^2}{\frac{9.81}{(0.278)^2} \times R}$$

$$e + f = \frac{V^2}{127 R} \quad V \text{ in KMPH}$$

where e = rate of super elevation
= $\tan\theta$ (exceeds 7 to 10%)

f = ~~co efficient~~ design of value of lateral frictional co-efficient 0.15

g = acceleration due to gravity = 9.81 m/sec

v = (velocity) speed of the vehicle in m/s

V = speed of the vehicle in KMPH

R = Radius of ~~curve~~ horizontal curve in m

if no super elevation is provided (e=0)

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

for the pressure on inner and outer wheels to be equal (or) for equilibrium super elevation counteracting centrifugal force fully i.e., f = 0

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

The Radius of a horizontal curve is 95m. The design speed is 50 KMPH and the design co-efficient of lateral friction 0.15.

1. Calculate the super elevation required if full lateral friction is assumed to develop
2. Calculate the coefficient of friction needed if no super elevation is provided
3. Calculate the equilibrium super elevation if the pressure on inner & outer wheels should be equal.

Given data

design speed $V = 50$ kmph

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

$$v = 13.889 \text{ m/sec.}$$

horizontal curve $R = 95$ m.

Co-efficient of lateral friction $f = 0.15$

Acceleration due to gravity $g = 9.81 \text{ m/sec}^2$

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

$$e + 0.15 = \frac{50^2}{127 \times 95}$$

$$e = 0.057$$

$$e = 5.7\%.$$

ii) No Super elevation is provided

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

$$= \frac{50^2}{127 \times 95}$$

$$f = 0.207$$

iii) The pressure at inner wheels and outer wheels are equal, then

$$f = 0 \quad , \quad e = \frac{V^2}{127R}$$

$$e = 0.207$$

* Design the super elevation required at a horizontal curve of Radius 300m for speed 60 KMPH. Assume suitable data.

Given data

Horizontal radius curve $R = 300mm$

Speed $V = 60$ kmpH

Co-efficient $f = 0.15$

acceleration due to gravity $g = 9.81$

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

$$e + 0.15 = \frac{60^2}{127 \times 300}$$

$$e = -0.055$$

Maximum super elevation.

* As per IRC the maximum limit of super elevation in plane, rolling terrains and snow bound areas as 7%.
* At hill roads not bound by snow, a maximum super elevation upto 10%. is recommended
* An urban road streches with frequent inter-section it may be necessary to limit the maximum super elevation to 4%.

* Minimum super elevation.

* from drainage considerations it is necessary to have a minimum cross slope to drain of the surface water
* If the calculated super elevation is equal (or) less than camber of road surface, then the minimum super elevation to be provided on horizontal curve may be limited to the camber of the surface

Steps for design of super elevation.

Step-1 The super elevation for 75% design speed is calculated, neglecting the friction

$$e = \frac{(0.7v)^2}{gR} \text{ in m/sec}$$

$$e = \frac{(0.75)^2 (0.278)^2 V^2}{9.81 \times R}$$

$$e = \frac{9.81 V^2}{(0.75)^2 (0.278)^2 \cdot R}$$

$$e = \frac{V^2}{225R} \quad V \text{ in KMPH}$$

Step-2 If calculated value of Super elevation (e) less than 70% (0.07) the value so obtained is provided.

If the value of super elevation (e) exceeds 7% then provide maximum super elevation equal to 7% and provide with step NO 3 & 4.

Step-3 check the co-efficient of friction developed for the maximum value of super elevation is 7% at the full value of design speed.

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

$$e = 0.07 \ (7\%)$$

$$f = \frac{v^2}{gR} = 0.07 \quad v \text{ in m/sec}$$

$$f = \frac{V^2}{127R} = 0.07 \quad V \text{ in KMPH}$$

If the value of (f) calculated is less than 0.15. The super elevation of 0.07 is safe for design speed. If not calculate the Required speed as given in step 4.

Step - 4

The allowable speed at the curve is Calculated by considering the design co-efficient of lateral friction and the maximum super elevation

$$e + f_1 = \frac{v_a^2}{gR}$$

$$e = 0.07, \quad f = 0.15$$

$$0.07 + 0.15 = \frac{v_a^2}{gR}$$

$$\frac{v_a^2}{gR} = 0.22 \quad v \text{ in } m/sec$$

$$\frac{V_a^2}{127R} = 0.22 \quad V \text{ in } kmPH$$

∴ allowable speed is calculated as

$$v_a = \sqrt{0.22\, gR} \quad \text{in } m/sec$$

$$V_a = \sqrt{0.22 \times 127 R} \quad \text{in } kmPH$$

$$V_a = \sqrt{27.9 R}.$$

If the allowable speed as calculated above is greater than design speed of the design speed is adequate and provide a super elevation of 0.07

If the allowable speed is less than the design speed, the speed limit is limited to the allowable Speed. Calculated above and appropriate varying sign and speed limit regulation sign are installed to restrict and regulate the speed.

* The design speed of horizontal curve is 80KMPH and the radius is 200m. Calculate the required Super elevation and also calculate the allowable speed at horizontal curve if there is no posibility to increase the radius of the curve

Given that

The design speed of a road $V = 80$ kmph

The radius of horizontal curve $R = 200$m

There is no possibility to increase there radius

∴ To avoid this problem determine the Super elevation for 75% design speed.

$$e = \frac{V^2}{225R} = \frac{80^2}{225 \times 200}$$

$$e = 0.14$$

The value of super elevation is greater than 0.07 (7%) as per IRC the super elevation should not exceed 7%.

Provide the super elevation $e = 0.07$

check the value of friction developed

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

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

$$f = 0.181$$

The value is greater than the maximum allowable safe friction co-efficient of 0.15 and also the radius can't be increased, the speed has to be restricted

∴ The maximum allowable speed is determined by

$$V_a = \sqrt{27.94 \times R}$$

$$= \sqrt{27.94 \times 200}$$

$$V_a = 74.75 \text{ KMPH}$$

The maximum allowable speed at that particular location is 74.75 KMPH

Extra widening:

On horizontal curves especially when there is < 300m Radius, it is common to wide the pavement slightly more than the normal width

The widening is needed for the following reasons

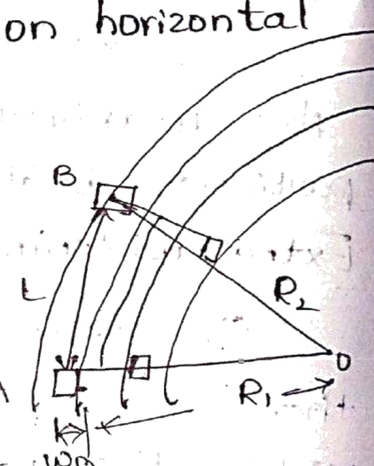
→ An auto-mobile has a rigid wheel base and only the front wheel can be turned, when the vehicle takes a turn to negotiate the horizontal curve, the real wheels do not follow the same path as that of the front wheels. This phenomenon is called as tracking

→ while two vehicles cross or over take at horizontal curve, there is psychological tend. ency to maintain a greater clearance b/w the vehicles for saftey

→ Greater visibility occur, this driver has tendency not to follow the central path of the lane but to use the outer side at the begining of the curve

→ At higher super elevation and lateral friction can't counteract centrifugal force and Skidding ~~may~~ may occur.

Analysis of extra widening on horizontal curve



It is divided into two parts

i) Mechanical widening (Wm)

ii) Psycological widening (Wps)

i) Mechanical widening (or) Off tracking

let R = Radius of horizontal curve

$R_1 = OA$ = Radius of the path traversed by the outer rear wheels in m.

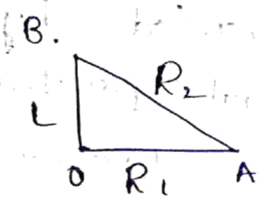
$R_2 = OB$ = Radius of the path traversed by the outer front wheels in m.

W_m = mechanical widening due to off tracking in m

l = length of wheel base in m
= 6m as per IRC for commercial vehicles

From figure

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



$R_2^2 = l^2 + R_1^2$

$R_2^2 = l^2 + (R_2 - W_m)^2$

$\cancel{R_2^2} = l^2 + \cancel{R_2^2} + W_m^2 - 2R_2 W_m$.

$l^2 + W_m^2 - 2R_2 W_m = 0$

$l^2 + W_m(W_m - 2R_2) = 0$

$W_m = \dfrac{l^2}{2R_2 - W_m}$ {W_m is neglected)

$W_m = \dfrac{l^2}{2R_2}$

Apparently $\boxed{W_m = \dfrac{l^2}{2R}}$

If road having n traffic lanes and n vehicles can travel simultaneously, mechanical widening is given by $W_m = \dfrac{nl^2}{2R}$

b) Psychological widening

Extra width of pavement is also provided for Psychological reasons such as to provide greater clearence for crossing and over taking vehicles on the curves.

An emperical formula has been recommended by IRC for deciding the additional psychological widening and is given by the following formula

i.e., $W_{ps} = \frac{V}{9.5\sqrt{R}}$

∴ ~~Without~~ The total extra widening

$$W_e = W_m + W_{ps}$$

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

where n = no. of traffic lanes

l = Length of the wheel base

= 6 m (recommended by IRC for commercial vehicles)

V = Design speed in KMPH

R = Radius of horizontal curve in m

Note:

1. for sharp curves of radius less than 50m. The extra widening shall be provided on inner side of the curve

2. for curves of R greater than 50m, widening shall be equally distributed on both side of the curves.

* Calculate the extra widening required for a pavement of 7m on a horizontal curve of radius 250m if the longest wheel base of vehicle expected on the road is 7m, The design speed is 70 KMPH

Given

width of pavement = 7m

i.e it is double lane

So $n = 2$

$R = 250\,m$

$V = 70\,KMPH$

$L = 7\,m.$

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

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

$W_e = 0.66$

* Radius of Horizontal curves

we know that

$$e \pm f = \frac{v^2}{gR}$$

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

Ruling : minimum radius based on ruling design speed.

$$R_{ruling} = \frac{v^2}{g(e+f)}$$

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

Absolute minimum radius based on minimum design speed.

$$R_{min} = \frac{(v')^2}{g(e+f)}$$

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

* find the total width of pavement on a horizontal curve for a new national highway to be aligned along a rolling terrain with a rolling minimum radius assumed for National highways on rolling terrain the ruling design speed = 80 KMPH

$n = 2$ $V = 80 KMPH$

$l = 7m$

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

The value of super elevation is 0.07

co-efficient of friction $f = 0.15$

$$R_{min} = \frac{(80)^2}{127(0.07+0.15)}$$

$$R_{min.} = 229.06\ m$$

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

$$= \frac{2 \times 7^2}{2 \times 229.06} + \frac{80}{9.5\sqrt{229.06}}$$

$$W_e = 0.77\ m.$$

The total width of pavement is $= 7 + 0.77$

$= 7.77$

*** Horizontal Transition Curve: (The curve having different radius)

A transition curve has a radius which decreases from infinity at the tangent point of the circular curve. to a designed radius of the

→ The rate of change of radius of the transition curve will depend on the shape of the curve adopted and the equation of the curve.

The transition curve is introducing between a striaght and circular curve

Types:

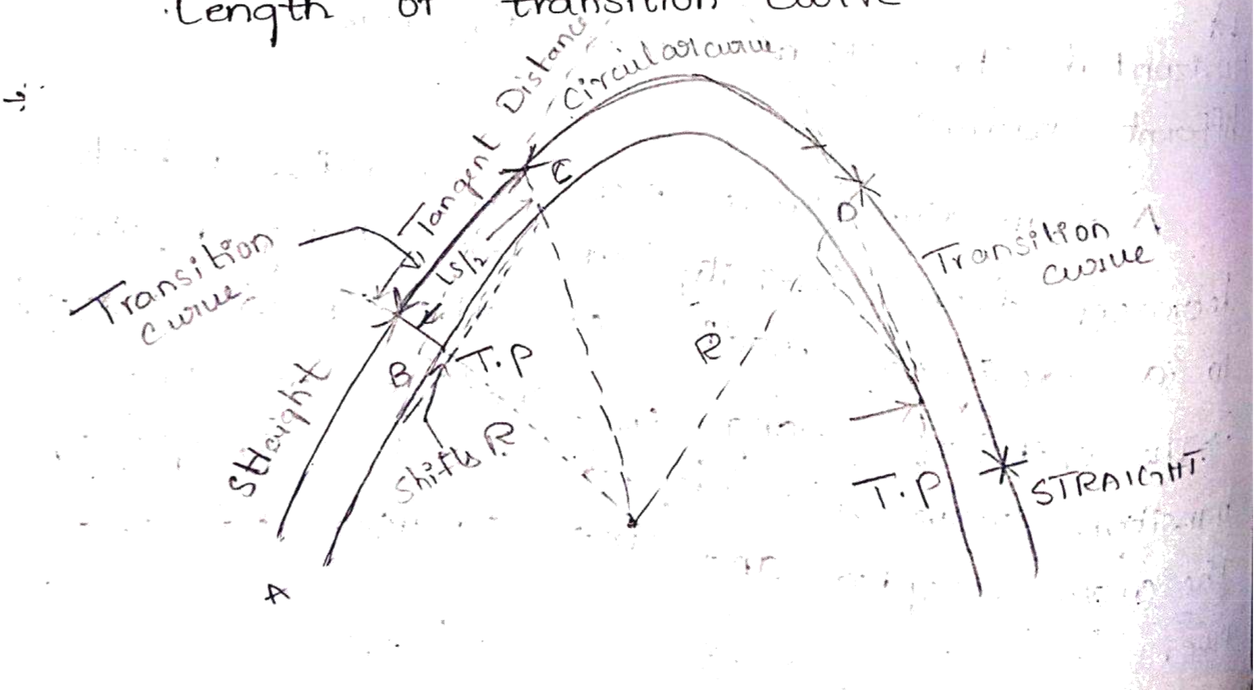
1. Spiral or clothoid or glovers spiral
2. Bernoulis lemni scale
3. Cubic parabola or froud's transition curve or easement curve

Objects of providing transition curve.

A transition curve which is introduced between straight and a circular curve will help in:

a) Gradually introducing centrifugal force.
b) Gradually introducing design super elevation.
c) Gradually introducing extra widening
d) To enable the driver turn steering gradually for his own comfort and saftey.

Length of transition curve



The length of transition curve is designed to fulfill three conditions.

a. Rate of change of centrifugal acceleration to be developed gradually.

b. Rate of introduction of design super elevation

c. Minimum length by IRC empirical formula

a. Rate of change of centrifugal acceleration.

→ The length of transition curve is calculated as

$$L_s = \frac{v^3}{CR} \quad (\text{if } v \text{ is in m/sec})$$

$$L_s = \frac{0.0215 V^3}{CR} \quad (V \text{ is in KMPH})$$

where

$$C = \frac{80}{75+V} \ m/sec^3 \quad (0.5 < C < 0.8)$$

L_s = length of transition curve in m.

C = allowable rate of change of centrifugal acceleration (δ) jerk

v = design speed in m/sec

V = design speed in KMPH

R = Radius of curve in m.

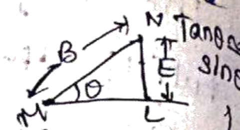
b. Rate of introduction of Super elevation

→ If the pavement is rotated about the center line

$$L_s = EN/2 = eN/2\,(W + W_e)$$

→ If the pavement is rotated about the inner edge

$$L_s = EN = eN(W + W_e)$$



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

$E = B\tan\theta$

$E = e.B$

where

W = width of pavement

W_e = extra widening

E = total raised pavement $= e.B$

B = total width of pavement $= (W + W_e)$

Rate of change of Super elevation of 1 in N

$N = 150, 100, 60$

c) Minimum length by IRC empirical formula.

A/c to IRC standards

a. for plane and rolling terrain

$$L_s = \frac{2.7V^2}{R}$$

b. for mountanious and steep terrain

$$L_s = \frac{V^2}{R}$$

Note: The length of transition curve shall be the highest of the above (centrifugal acceleration, Super elevation & empirical formula)

Shift of transition curve:

If the length of transition curve is 'L_s' & the radius of the circular curve is 'R'. The shift 's' of transition curve is given by

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

Calculate the Length of transition curve and shift using the following data

* Design speed = 65 KMPH
* Radius of circular curve R = 220 m
* allowable rate of introduction of super elevation [Pavement is rotated above the central line] = 1 in N = 1 in 150
* Pavement width including extra widening = 7.5 m

Given that

design speed V = 65 KMPH

Radius of circular curve R = 220 m

Rate of introduction of Super elevation = 1 in 150

N = 150

a) Length of transition curve as per allowable rate of centrifugal acceleration.

$$Ls = \frac{0.0215 V^3}{CR}$$

C = allowable centrifugal acceleration (or) Jerk

$$= \frac{80}{75+V}$$

$$= \frac{80}{75+65}$$

$C = 0.57\ m^3/sec^3$ $\{0.5 < C < 0.8\}$

$$Ls = \frac{0.0215 \times 65^3}{0.57 \times 220} = 47.08\,m.$$

b) length of transition by introducing S.E:
~~b)~~ Rate of introducing Superelevation

$N = 150.$

$$L_s = EN/2$$

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

$$e = \frac{V^2}{127R} = \frac{V^2}{225R} = \frac{65^2}{225 \times 220} = 0.085$$

$\left\{ \frac{v^2}{127R} \text{ for design speed of } 75\% = \frac{V^2}{225R} \right\}$

$$e = 0.085 > 0.07$$

The value is greater than 0.07

as per IRC the maximum superelevation is equal to 0.07 i.e., 7%. ∴

∴ provide the superelevation with 0.07

* Check for frictional co-efficient with design speed

i.e., $f = \frac{V^2}{127R} - e$

$$f = 0.08 < 0.15$$

∴ The value obtained is less than 0.15

(The max. value of lateral frictional co-efficie is 0.15 as per IRC)

∴ Provide the super elevation 0.07 with frictional coefficient 0.15

For the design speed of 65 KMPH

The length of transition curve for pavement rotated with respect to the center line

i.e., $L_s = \frac{EN}{2} = \frac{eN}{2}(W + W_e)$

$N = 150$

$E = eB = e(W + W_e)$

$E = 0.525$

$$L_s = \frac{0.07(7.5) \times 150}{2} = 39.375\,m$$

c) Length of transition curve by empirical formulae

For plane & rolling terrain

$$L_s = \frac{2.7V^2}{R} = \frac{2.7 \times 65^2}{220}$$

$$= 51.85\,m$$

∴ Adopt the heighest value from above 3 (a = 47.08, b = 39.375; c = 51.85)

Length of transition curve is

$\boxed{\therefore L_s = 51.85\,m} \cong 52$

Shift $S = \frac{L_s^2}{24R} = \frac{52^2}{24 \times 220} = 0.512\,m$

* Design the length of horizontal transition curve for a two lane N.H. having a radius of 300m and for a design speed of 100KMPH for rolling terrain. The average length of rigid

wheel base of vehicle is considered as 6m. Take the co-efficient of friction is 0.38

Given that

Design speed $V = 100$ KMPH

Radius of circular curve $R = 300$ m

Co-efficient of friction $f = 0.38$

The length of rigid wheel base $L = 6$m

for 2 lanes National Highway

The width of pavement = 7m

we know that

The total extra widening $W_e = W_m + W_{ps}$

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

$$= \frac{2 \times 6^2}{2 \times 300} + \frac{100}{9.5\sqrt{300}}$$

$W_e = 0.73$ m

∴ The total width of pavement including extra widening $= W + W_e$

$= 7 + 0.73$

$B = 7.73$ m

Given that the co-efficient of lateral friction is 0.38

"f" is greater than 0.15 so we have to change the design speed

The maximum allowable speed is

$$V_a = \sqrt{27.94 \times R}$$

$$= \sqrt{27.94 \times 300}$$

$$= 91.5 \text{ KMPH}$$

$$v_a = 25.437 \text{ m/sec}$$

* length of transition curve by rate of change of centrifugal acceleration.

$$L_s = \frac{v^3}{CR} = \frac{(25.437)^3}{0.79 \times 300}$$

$$= 69.44 \text{m}$$

$$L_s = \frac{0.0215\, V^3}{CR} = \frac{0.0215\,(91.5)^3}{0.79 \times 300} = 69.49 \text{m}$$

$$C = \frac{80}{75 + v} = \frac{80}{75 + 25.43} = 0.79$$

* Minimum length for a rolling terrain

$$L_s = \frac{2.7 V^2}{R}$$

$$= 75.35 \text{m}$$

* Length of transition curve by the rate of introduction of superelevation.

$$L_s = EN/2$$

$$= \frac{eN}{2}(w + w_e)$$

$$e = \frac{V^2}{225R} = \frac{(91.5)^2}{225 \times 300} = 0.124$$

The value of e is greater than 0.07 So consider 0.07 as the max. super elevation as per IRC

$$L_s = \frac{0.07 \times 150}{2} (7 + 0.73)$$

$$= 40.5\,m.$$

Adopt the highest of above three values.

∴ Consider length of transition curve $L_s = \underline{75.35\,m}$

f " It is greater than 0.15 So we have to change the design speed

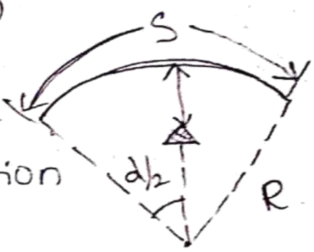
∴ The maximum allowable speed is

$$V_a = \sqrt{27.94 \times R}$$

$$= \sqrt{27.94 \times 300}$$

$$= 91.5 \text{ KMPH}$$

Set back distance (or) ~~Elevation~~ Clearence (m)



the distance between center of an horizontal curve to an obstruction @ inner side of the curve.

It is required to provide an adequate sight distance on the horizontal curve

(Obstructions are buildings, trees, cut slopes etc.)

Note:

1. On Narrow road the sight distance is measured along the center line of the road.
2. On wider roads the sight distance is measured along the center line of inner side lane.
3. Set back distance is depends on sight distance (S), Radius of Curve (R), length of curve (L_c)

Analysis of set back distance:

Case-1 ⇒ If the length of curve is greater than sight distance ($L_c > S$)

Case-2 ⇒ If the length of curve is less than Sight distance ($L_c < S$)

Case - i If the length of curve is > Sight distance

(The length of curve) Set back dist = $R - R\cos\frac{\alpha}{2}$

where α = Subtended angle = $\frac{S}{R}$ radians

$$\alpha = \frac{S}{R} \times \frac{180}{\pi} \text{ degrees}$$

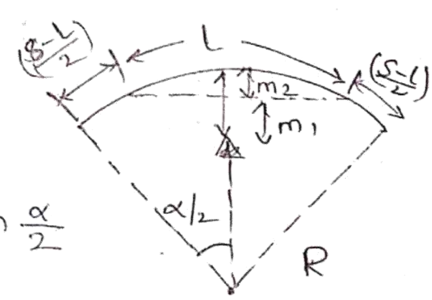
For multilane roads if, d is the distance between center line of a road and center line of an inner lane.

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

$$\alpha = \frac{S}{(R-d)} \text{ rad}$$

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

Case - ii If the length of curve is < than the sight distance.



For narrow road.

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

$$\alpha = \frac{L_c}{R} \text{ rad.}$$

$$= \frac{L_c}{R} \times \frac{180}{\pi} \text{ degrees.}$$

For wider road

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

$$\alpha = \frac{L_c}{(R-d)} \text{ rad}$$

$$\alpha = \frac{L_c}{R-d} \times \frac{180^\circ}{\pi} \text{ degrees.}$$

* There is a horizontal curve of radius 360m & length 180m. The clearence required from the center line of the inner side of the curve so as to provide
a) SSD of 80m
b) OSD of 250m

Given $L_c = 180\,m$

$R = 360\,m$

a) $S = 80\,m$ $(L_c > S)$ stopping sight distance

The length of curve $L_c = 180\,m$

$\therefore$ The set back dist (m) $= R - R\cos\frac{\alpha}{2}$

$= 360 - 360\cos\left(\frac{12^\circ 43' 56.62''}{2}\right)$

$m = 2.219\,m$

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

$$= \frac{80}{360} \times \frac{180}{\pi}$$

$$= 12^\circ 43' 56.62''$$

b) OSD $S = 250\,m$ $(L_c < S)$

$L_c = 180\,m.$

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

$$= 360 - 360\cos\left(\frac{28^\circ 32' 52.4''}{2}\right) + \frac{(250-180)}{2}\sin\left(\frac{28^\circ 32' 52.4''}{2}\right)$$

$\alpha = 28^\circ 32' 52.4''$

$m = 19.74\,m$

Vertical Alignment:

The elevation are the profile of Center line of a road is called Vertical Alignment.

It consists of grades (slopes) and Vertical curves

Gradients:

The rate of rise or fall along the length of the road with respect to the horizontal.

It is expressed as the ratio of 1 in N or percentage (%).

Types of Gradients:

1. Ruling gradient (or) Design Gradient
2. Limiting gradient
3. exceptional gradient
4. Minimum gradient

1. Design Gradient (or) Ruling Gradient

The maximum gradient with in that the Vertical profile is designed.

2. Limiting Gradient (topography)

In hilly roads it may be frequently necessary to exceed ruling gradient and adopt limiting gradient

3. Exceptional Gradient:

It is provided in extreme situations and it is steeper than Limit gradient

4. Minimum Gradient:

This is important only at locations where surface drainage is important.

It depends on Rainfall, Type of soil, and other site conditions.

Grade Compensation:

When sharp horizontal curve is to be introduced on a road which has already maximum permissible gradient, then the gradient should be decreased to compensate for loss of tractive efforts due to curve. This reduction in gradient at horizontal curve is called Grade compensation.

The Grade compensation = $\frac{30+R}{R}$ %

IRC gave the following specifications for grade compensation.

1. Grade compensation is not required for grades flater than 4% because the loss of tractive force is negligible

2. The maximum grade compensation is limited to $\frac{75}{R}$ % (whichever is less)

∴ Compensated Gradient = $\left.\begin{matrix}\text{Ruling}\\ \text{Gradient}\end{matrix}\right\} - \left.\begin{matrix}\text{Grade}\\ \text{compensation}\end{matrix}\right\}$

Eg: The longitudinal gradient on a road is 1 in 20 if the radius is 150m. Then what is the grade compensation.

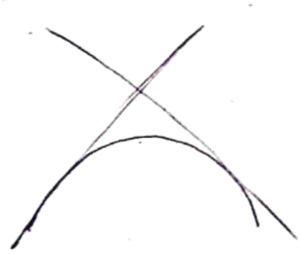
The grade compensation is $\frac{30+R}{R}$

$$= \frac{30+150}{150} = 1.2\%$$

$$\Rightarrow \frac{75}{R} = \frac{75}{150} = 0.5\%$$

Vertical curves

* Vertical curves are provided in elevation at change of gradients.
* These curves are convex when two curves (two grades) meet at summit and when they meet at sag they ~~meet~~ is called as concave.



Summit curves

Valley curves

Summit curves

* These are provided when
  i. Positive grades meets negative grades
  ii. Postive grades meets another milder positive grades

iii. Positive grades meet level stretch
iv. Negative grade meets steeper negative grades

Assumptions:
1. The length of curve is equal to the length of chord. (The curve is so flat)
2. The portions of curve along the two tangents on either side of the point of intersection are equal.
3. The angle subtended by the tangents are so small that the tangents of these angles are equal to the angles in radius themselves.

Length of Summit curve:

While designing the length of parabolic summit curves it is necessary to consider SSD and OSD separately

The length of summit curve for S.S.D

Case i: $L > SSD$

Case ii: $L < SSD$

L is greater than SSD $[L > SSD]$

General equation for length of curve is given by $L = \dfrac{NS^2}{\left(\sqrt{2H} + \sqrt{2h}\right)^2}$

where S = Stopping sight Distance
N = Deviation angle (or) Alzebraic difference in grades
H = Height of eye level of driver as per IRC $= 1.2m$

h = object height = 0.15m (as per IRC)

$$L = \frac{NS^2}{\left(\sqrt{2\times1.2} + \sqrt{2\times0.15}\right)^2} = \frac{NS^2}{4.4}$$

$$L = 0.227\,NS^2$$

Case-II L is less than SSD [L < S.S.D]

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

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

Length of summit curves for O.S.D.

Case-1 L is greater than OSD [L > OSD]

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

$$L = \frac{NS^2}{8(1.2)} = \frac{NS^2}{9.6} = 0.104\,NS^2$$

Case-2 L is less than OSD [L < OSD]

$$L = 2S - \frac{8H}{N}$$

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

Length of valley curves:

Factors considered in the design of valley curves.

1. Impact free movement of vehicles at design speed. (or) Comfort to passengers
2. Providing adequate sight distance under headlights of vehicles. ~~for~~ night driving
3. Locating lowest point of valley curve for providing suitable cross drainage facilities.
4. The valley curve and its length are designed as transition curves to fulfill to criterias
   i. Allowable rate of change of centrifugal acceleration
   ii. Headlight sight distance for night driving.

Length of valley curve for comfort conditions

$$L = 2\sqrt{\frac{NV^3}{C}} \quad V \text{ in m/sec.}$$

$$L = 0.38\sqrt{NV^3} \quad V \text{ in KMPH}$$

$$L = 2L_s \quad [L_s = \text{Length of Transition curve}]$$

where C = centrifugal acceleration (or) jerk $= \{0.5 < C < 0.8\}$ m/sec³
$= 0.6 \text{ m/sec}^3$

Length of valley curve ~~from~~ head light sight distance.

(i) (L > SSD) L is greater than S.S.D

$$L = \frac{NS^2}{(1.5 + 0.35S)}$$

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

∴ h_1 = height of headlight = 0.75 m (as per IRC)

α = beam angle = 1°

(ii) (L < SSD) L is smaller than S.S.D

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

$$L = 2S - \frac{1.5 + 0.35S}{N}$$

Note: 1. Overtaking sight distance is not a problem for valley curve as during night, other vehicles with head lights can be seen from a considerable distance.

∴ Headlight sight distance available shall be atleast equal to S.S.D

2. Impact factor – The ratio b/w centrifugal force (P) and the weight of the vehicle (W) is called impact factor (or) centrifugal ratio

i.e $I = \frac{P}{W} = \frac{1.6NV^2}{L}$

It is expressed in percentage (%) and should not greater than 17%.

3. Minimum radius of valley curve for cubic parabola $R = \frac{L_s}{N}$

$$L_s = \frac{L}{2}$$

$$R = \frac{L}{2N}$$

Example

A Vertical curve is formed by intersecting two gradients ~~plus~~ +3% and −5%. Determine the length of ~~valley~~ Summit curve to a stopping sight distance for a design Speed of 90KMPH.

Given that

ascending gradient = +3%.

Descending gradient = −5%.

design speed V = 90KMPH

∴ N = alzebraic difference b/w two gradients

i.e., $N = (+3) - (-5)$

$= 8\% = 0.08$

The stopping sight distance SSD =

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

$$= 0.298(90)2.5 + \frac{90^2}{254(0.35)}$$

where t = total reaction time = 2.5 sec.

f = longitudinal friction = 0.35

$\therefore$ SSD = 153.66 m.

Assume, The length of Summit curve is > S.S.D

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

$$= \frac{0.08 \times (153.66)^2}{4.4}$$

$$L = 429.29\,m.$$

* An ascending gradient of 1 in 100m, a descending gradient of 1 in 120. A Summit Curve is to be designed for a speed of 90KMPH so as to have an over-taking sight distance of 460m. Determine length of Summit curve.

Given that

An ascending gradient $= \frac{1}{100} = 0.01$

descending gradient $= \frac{1}{120} =$

The alzebraic difference b/w two gradients

$$= \frac{1}{100} - \left(-\frac{1}{120}\right) = \frac{11}{600}$$