NEPAL ENGINEERING COUNCIL LICENSURE EXAMINATION

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TRANSPORTATION ENGINEERING SYLLABUS OF NEC LICENSE EXAM

9. Transportation **(ACiE09)**

9.1 Highway planning and survey: Modes of transport, history of road development in Nepal; classification of roads; road survey; highway alignment and controlling factors; evaluating alternate alignments; Road Standards of Nepal. (ACiE0901)

9.2 Geometric design of highway: basic design control and criteria; elements of highway cross-section; highway curves; super elevation; average and ruling gradients; stopping sight distance; design considerations for horizontal and vertical alignments, extra widening, and set back distance; design of road drainage structures; design considerations for hill roads. (ACiE0902)

9.3 Highway materials: types of aggregates and tests on their gradation, strength, durability; binding materials and their tests; design of asphalt mixes; evaluation of subgrade soil. (ACiE0903)

9.4 Traffic engineering and safety: impact of human and vehicular characteristics on traffic planning; traffic operations and regulations; traffic control devices; traffic studies (volume, speed, O&D, traffic capacity, traffic flow characteristics, parking, accident, flow); road intersections (types, configurations, design); traffic lights; factors influencing night visibility, road safety measures. (ACiE0904)

9.5 Road pavement: different types of pavement; design methods for flexible and rigid pavements (DOR Guidelines); loads and other factors controlling pavement design; stress due to load, temperature. (ACiE0905)

9.6 Road construction & maintenance: activities, techniques, tools, equipment and plants used in road construction; preparation of road subgrade; field compaction control and soil stabilization; construction of asphalt concrete layers; construction procedure for penetration macadam, bituminous bound macadam and plain cement concrete pavements; road maintenance, repair and rehabilitation. (ACiE0906)

- **HORIZONTAL CURVES**
  - Provided between two straight alignments of highways in order to change the direction.
  - enhances comfort to the passengers by avoiding the sudden change in direction
  - reduces mental strain by travelling monotonously along the straight route

HORIZONTAL CURVES

Necessity of curve arises due to the following reasons:

•Topography of the terrain

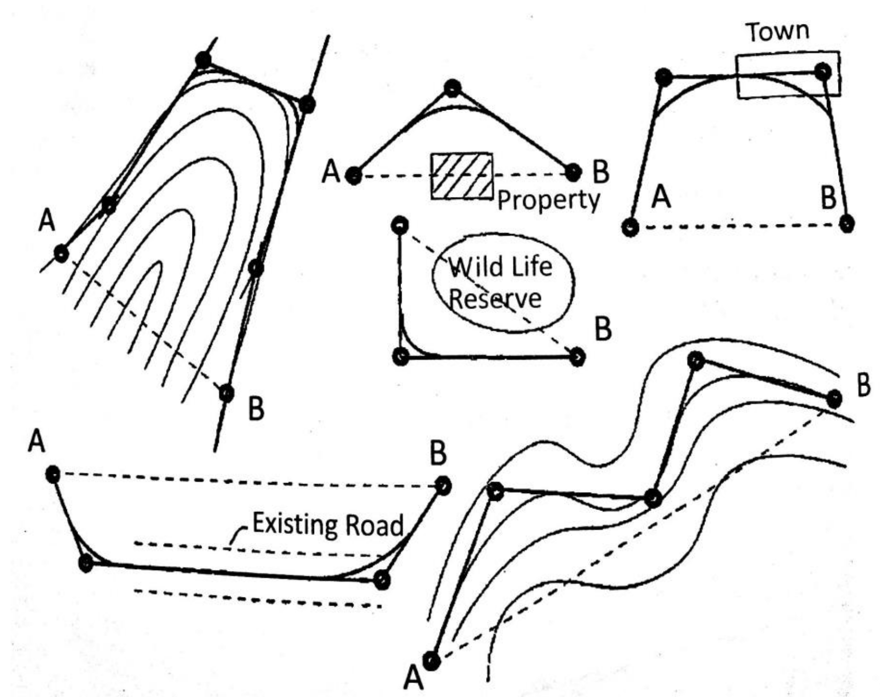
•Restrictions imposed by property

•Providing access to certain locality

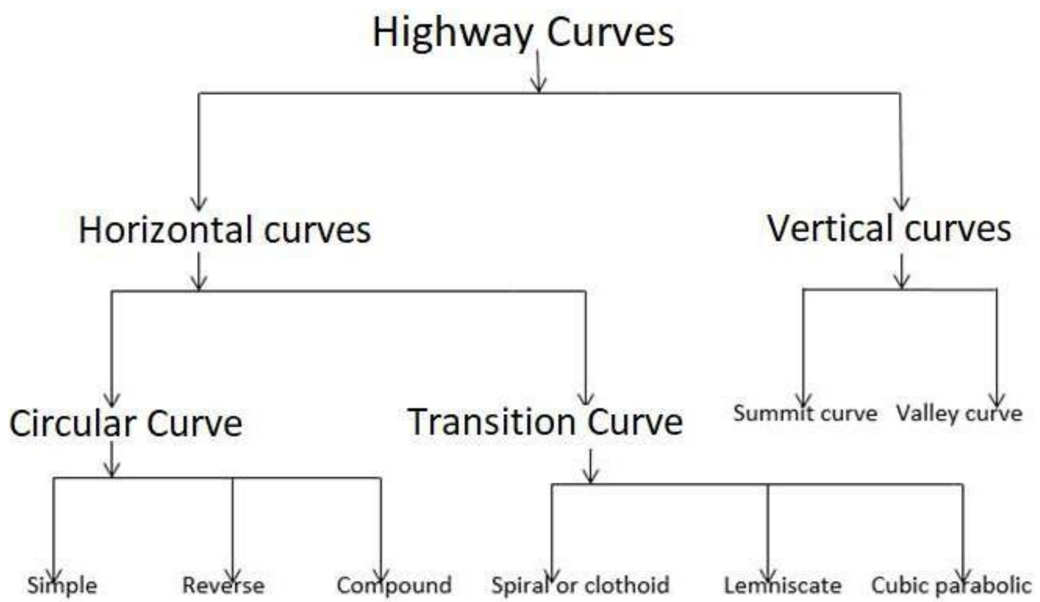
•Minimizing earthwork quantity

•Preservation of existing amenities

•Maintaining consistency with the topographical features of the terrain



TYPES OF CURVES



Simple circular curves: consists of a single arc connecting two straight lines.
Reverse circular curves: consists of two or more arcs of one or different circles turning in two opposite directions that join at the common tangent point.
Compound circular curves: consists of series of simple circular curves of one or different radius that turns in the same direction and meet at the common tangent point.

ELEMENTS OF CIRCULAR CURVE

- PI = Point of intersection, Apex point
- TC = Tangent to curve, Beginning of curve
- CT = Curve to tangent, End of curve
- MC = Middle point of curve
- α = Angle of deviation
- R = radius of curve
- T = Tangent length, Distance

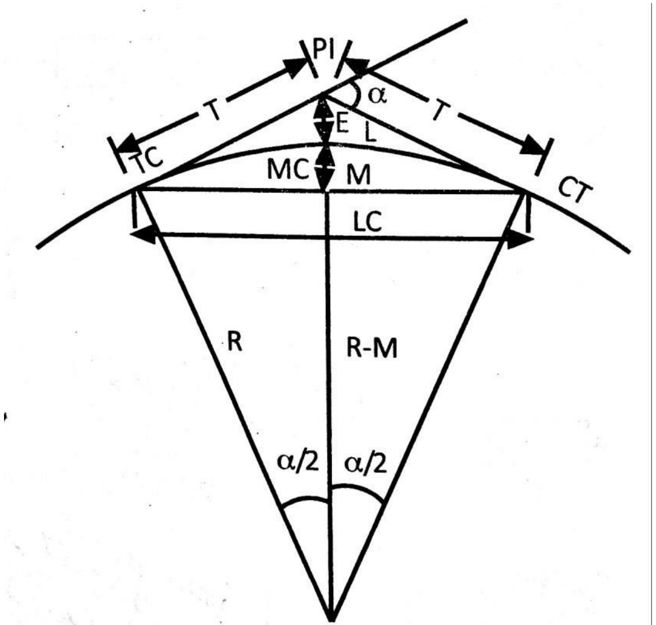
between PI to tangent point

•E = Apex distance, Distance from PI to MC

•L = Length of curve

•M = Chord to curve length

•Lc = Long chord length



From simple geometry of a circle, following derivations can be made

$T = R \tan \alpha/2$

$E = R (\sec \alpha/2 - 1) = R [1 / \cos (\alpha/2) - 1]$

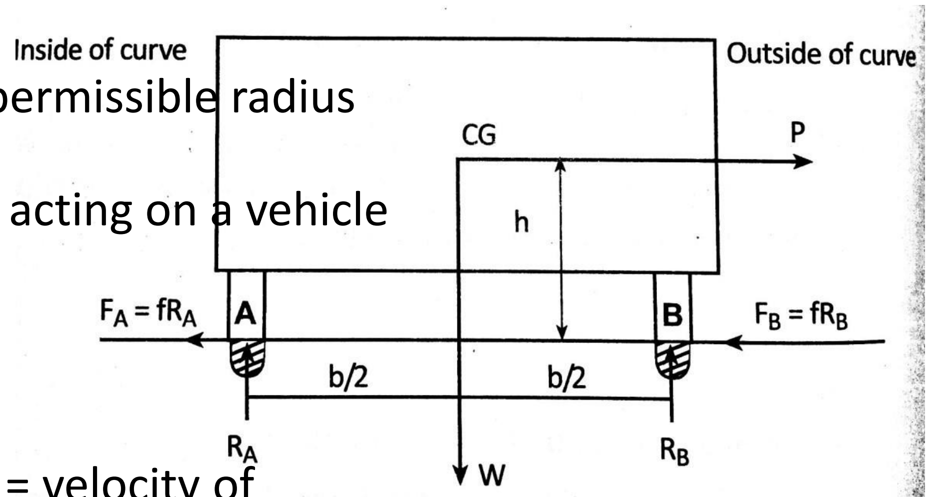
$M = R (1 - \cos \alpha/2)$

$L = \pi R \alpha/180$

$Lc = 2R \sin \alpha/2$

DESIGN OF HORIZONTAL CURVE

- involves calculation of minimum permissible radius to achieve desired level of safety
- Need understanding of the forces acting on a vehicle while travelling at curve path



Centrifugal force (P) = mv^2/R

= $(Wv^2) / (gR)$

Where, W = weight of vehicle in kg v = velocity of vehicle in m/s

g = acceleration due to gravity in m/s^2 R = radius of curve in m

The centrifugal ratio or the impact factor is given by:

$$(P/W) = v^2 / (gR)$$

THE CENTRIFUGAL FORCE HAS FOLLOWING EFFECTS.

1. Tendency to overturn the veh. About the outer wheels

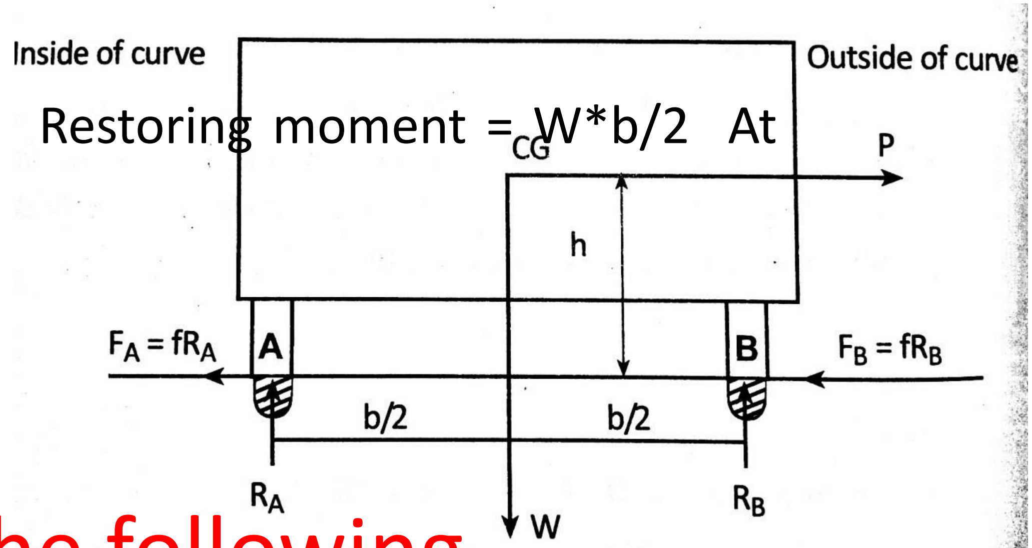
From figure,

Overturning moment = P*h Restoring moment = W*b/2 At equilibrium,

P*h = W*b/2

Or, P/W = b / (2h)

Or, v^2 / (gR) = b / (2h)



Thus for safety the following condition must be satisfied, Or, b / (2h) > v^2 / (gR)

2. TENDENCY OF VEHICLE TO SKID LATERALLY UPWARD

For equilibrium, P = F

Where, P = Centrifugal force F = Transverse skid resistance Or, P = FA + FB

Or, P = f (RA + RB)

Where, f = coefficient of lateral friction

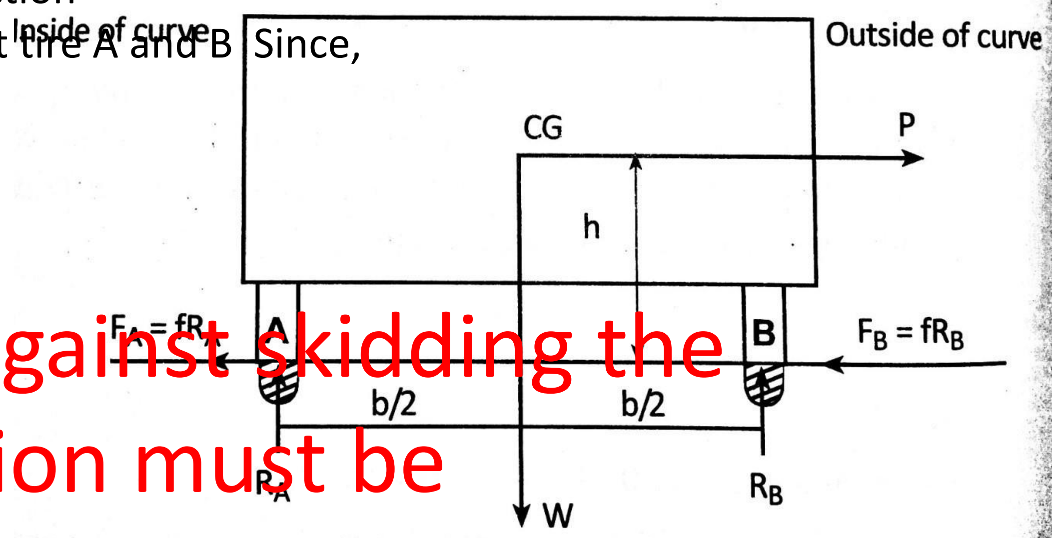
FA and FB are the frictional force at tire A and B Since,

W = RA + RB

Then,

Or, P = f*W Therefore,

P/W = f = v^2 / (gR)



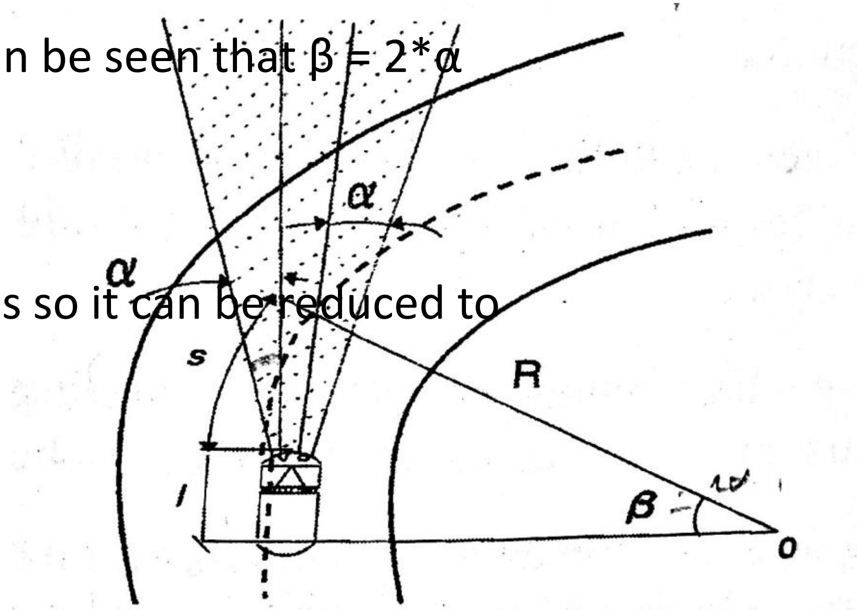
Thus for safety against skidding the following condition must be satisfied f > v^2/ (gR)

DESIGN OF HORIZONTAL CURVES INCLUDING NIGHT VISIBILITY CONSIDERATION

Let a vehicle of wheel base (l) travelling in a curved path of radius (R) requires seeing objects at a distance (s) from him.
Let α be the angle of headlight beam dispersion in the horizontal plane. Let β be the angle subtended at the center by an arc of length (s + l).

- From geometry of the figure it can be seen that $\beta = 2*\alpha$
- Then, $\beta = (s + l) / R$
- Or, $\beta = (s + l)*180 / (\pi * R)$
- Then, $R = 28.6\,(s + l) / \alpha$
- Since l is very small compared to s so it can be reduced to
- Therefore,

• $R = 30s/\alpha$

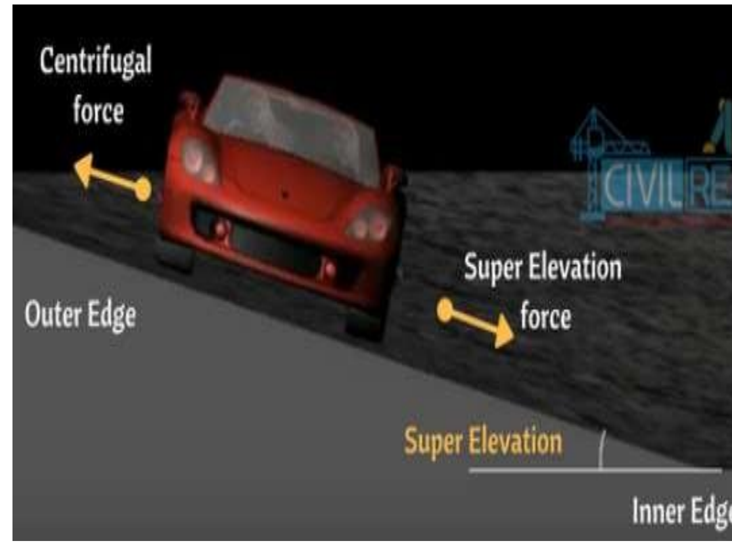


The **angle α** for vehicles on a horizontal plane may be approximately taken as **2 deg.**
As the value of s increases the value of R also increases abruptly which are very high for design considerations.

SUPER ELEVATION /CANT/BANKING

- Transverse slope provide at horizontal curve to counteract the centrifugal force
- the outer edge of the road is raised above the inner edge.
- The Indian road congress(IRC) has prescribed the max value of Super Elevation is 1 in 15. (NRS 2070 same as well)

- **Advantages**
- achieve the higher speed of vehicles.
- increases the stability of fast-moving vehicles when they pass through a horizontal curve, and it also decreases the stresses on the foundation.
- In the absence of super elevation on the road along curves, potholes are likely to occur at the outer edge of the road.



Superelevation Formulae

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

e = Rate of Superelevation in %

f = Lateral friction factor

V = Velocity of Vehicle in KM/hr

R = Radius of circular curve in m

If, $f = 0$; $e = v^2/gR$ result v. high superelevation

If, $e = 0$; $f = v^2/gR$ result v. high coefficient of friction

Now, if $e = 0.07$ i.e. 7%; & $f = 0.15$

For safe travelling, Restricted speed $v_a = (0.22gR)^{0.5}$

DESIGN PROCEDURE OF SUPERELEVATION

Step 1:

- Calculate the superelevation necessary for 75% design speed and assume No lateral friction is developed
- If e value is less than e_{max} = 0.07, provide calculated e value. Otherwise proceed to next step

Step 2:

- When $e_{cal} > e_{max}$
- Provide $e = e_{max} = 0.07$ in this step and go to next step.

Step 3:

- From the above step we have the value of e. so, check for lateral friction factor is applied in this step for the known value of e.
- If $f_{cal} < f_{max}$ (0.15)
- Then e = 0.07 is safe.

But if $f_{cal} > 0.15$

- Then restrict the values to f = 0.15, e = 0.07
- And go to last step.

Step 4:

- In this step we will find out the value of restricted speed.
- Let V = Va

$$e + f = \frac{(Va)^2}{127R}$$

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

$$V_a = \sqrt{127R(0.22)}$$

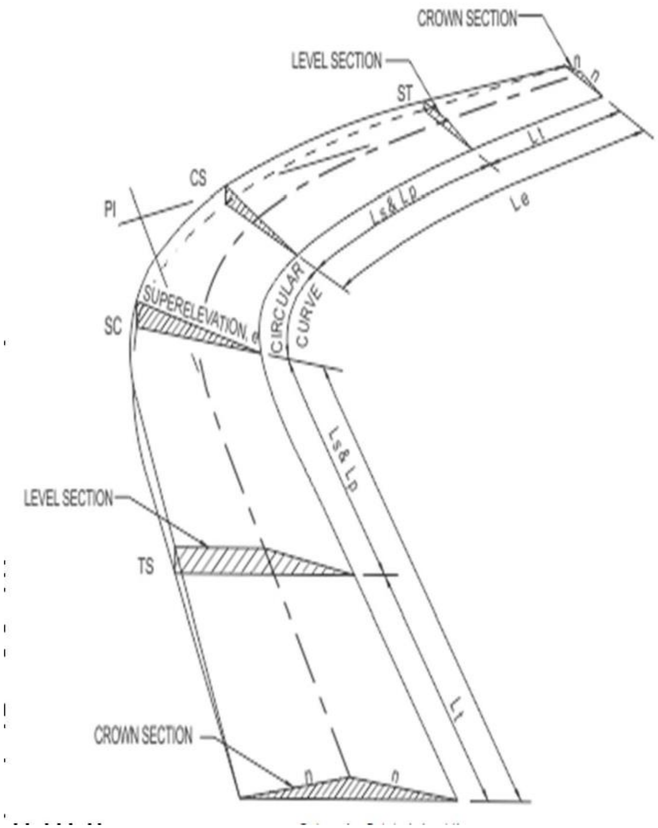
- If Va > V, then e = 0.07, f= 0.15
- If Va < V , then also e = 0.07, f = 0.15 but, speed restriction board is provided which consists the value of Va As shown in figure below.

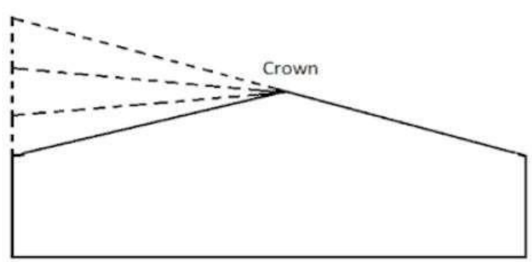
METHOD OF PROVIDING SUPER ELEVATION

- Introduction of super elevation on a horizontal curve of a road is an important feature in road construction. Super elevation is provided in the following two methods.
  - –Elimination of the crown of the c
  - –Rotation of pavement to attain f

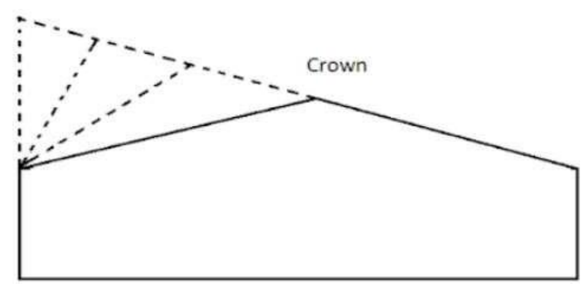
1. ELIMINATION OF THE CROWN OF THE CAMBERED SECTION

- In this method, the outer half of the camber is gradually decreased. This may be done by **two methods.**
  - **In the first method,** the outer half of the camber is rotated about the crown at the desired rate such that the surface falls on the same plane as the inner half.
  - **In the second method,** the crown is progressively shifted outwards. This method is not usually adopted.





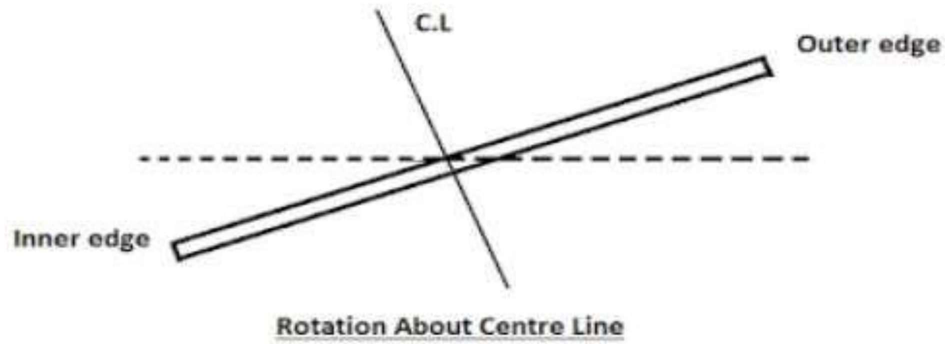
Outer edge Rotated about the crown



Crown Shifted Outwards(Diagonal Crown Method)

2. ROTATION OF PAVEMENT TO

- In this stage, supere
  the full width of the
  superelevation is av
  circular curve.

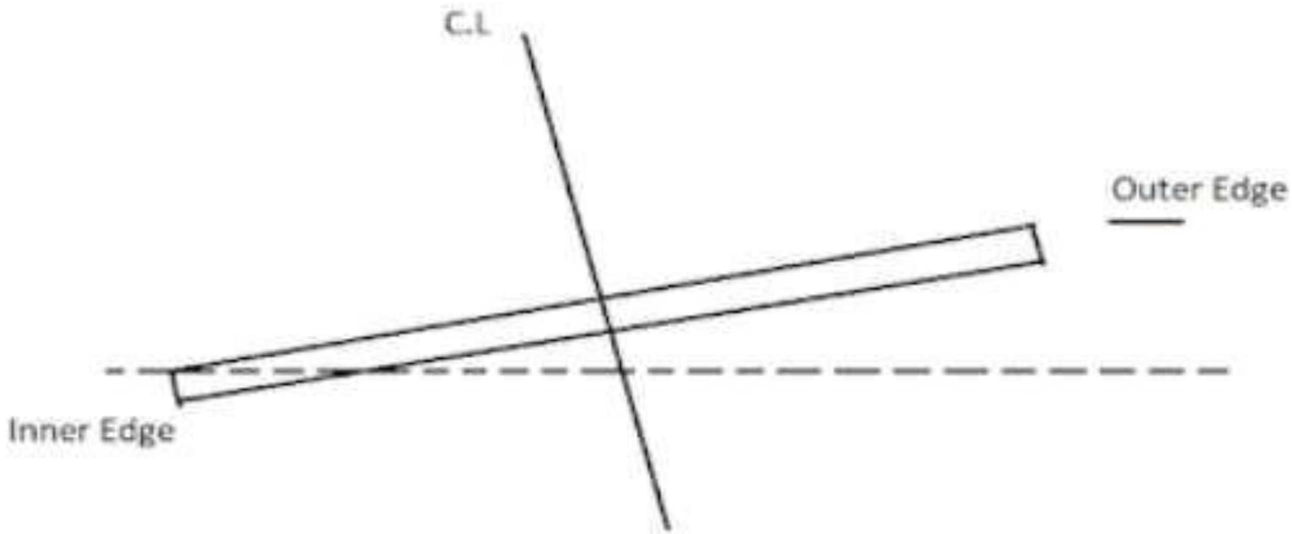


Rotation about the center line

- **The different method employed for attaining the superelevation is as follows:**

A. Revolving Pavement About The Center Line

In this method the surface of the road is rotated about the center line of the carriageway, gradually lowering the inner edge and rising the upper edge. The level of the center line is kept constant. **This method is widely used.**



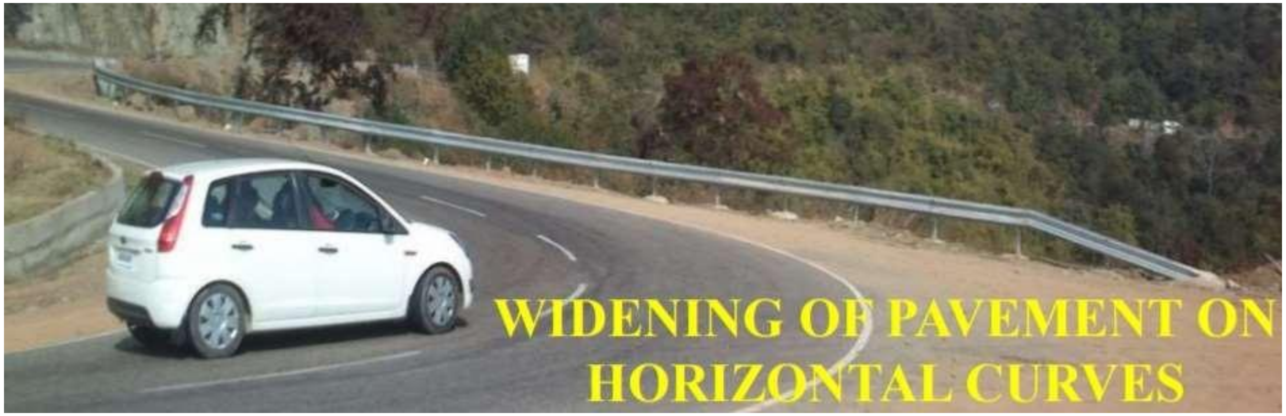
Rotation about the inner edge

C. Revolving Pavement About The Outer Edge

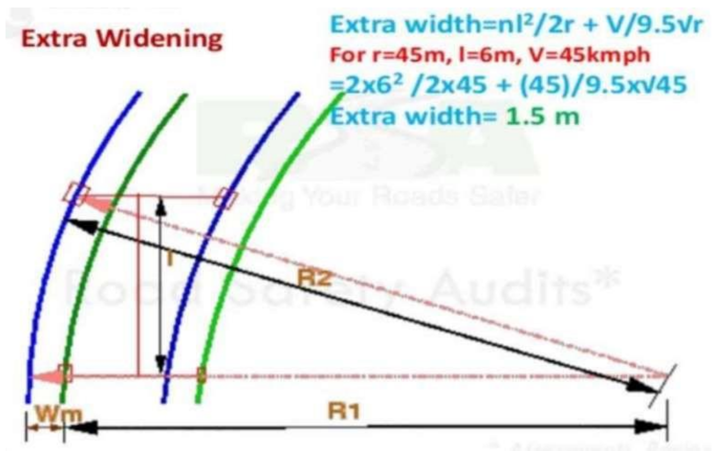
– In this method, the surface of the road is rotated about the outer edge depressing the center and inner edge.

EXTRA WIDENING

- Additional width of carriageway required on curve section of road
- Two types:
  - Mechanical Widening
  - Psychological Widening



MECHANICAL WIDENING



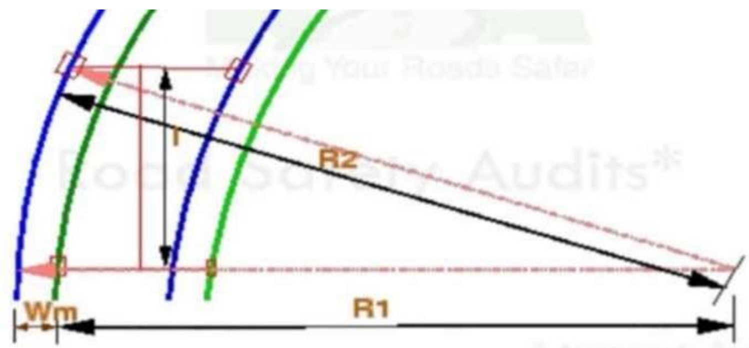
- While turning vehicle on horizontal curve, the rear wheels do not follow the same path as that of the front wheels. This phenomenon is called '**off tracking'.**
- The off tracking depends on

  (1)the length of the wheel base of the vehicle

  (2) the turning angle or the radius of the horizontal curves.
- The widening required to account for the off tracking due to the rigidity of wheel base is called Mechanical widening 'W_m'

DERIVATION OF W_M

$R_2=R_1+W_m$ $R_2^2 = R_1^2+l^2$
$=(R_2-W_m)^2+l^2$ $R_2^2=R_2^2-2R_2W_m+$



$2R_2W_m - W_m^2 \quad = l^2$
$W_m=l^2/(2R_2-W_m)$ -> for a single
$=nl^2/(2R_2-W_m)$ -> for multi lane road For
large radius $R_2=R_1=R$

And since W_m <<R, $2R_2-W_m=2R$

$$W_m=nl^2/2R$$

Where,
n =number of traffic lanes
l = length of wheel base of longest vehicle in m
R= radius of horizontal curves in m

PSYCHOLOGICAL WIDENING

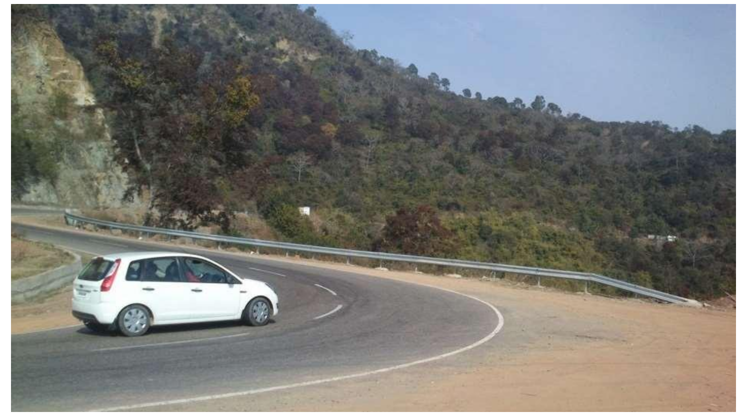
- extra width of pavement is provided for psychological reasons for greater maneuverability of steering at higher speeds
- An empirical formula has been recommended by IRC for deciding the additional psychological widening ‘Wps’ which is dependent on the design speed, V of the vehicle and the radius. R of the curve.

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

R= radius of horizontal curves in m

V= design speed Kmph

- Hence the total widening We required on a horizontal curve is given by:



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

$$W_e = \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}}$$

R= radius of horizontal curves in m
v= design speed m/s

`

- Find out the total width of pavement on a horizontal curve for a new highway with a ruling minimum radius if the speed of slow moving vehicles is 80 km/hr. Take highway width = 7m, length of wheel base = 6.1m

  Hints:

$$V_a = \sqrt{27.94\,R} \quad \text{kmph}$$

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

Ans: W_T = W+We = 7.72m

SIGHT DISTANCE

- length of carriageway that is visible to the driver at any instant from normal height of the driver's eye above road surface
- Restriction to SD may be due to :
  - Sharpness of horizontal curves
  - Objects obstructing Vision (e.g. building, tree, etc)
  - Vertical summit
  - At road intersections.

TYPES OF SIGHT DISTANCES:

1. Stopping Sight Distance (SSD)
2. Overtaking Sight Distance (OSD)

   Other sight distances are:

   (i) Intermediate Sight Distance

   (ii) Headlight Sight Distance

STOPPING SIGHT DISTANCE (SSD)

- minimum sight distance available along the road to stop a vehicle travelling at design speed, safely without collision with any other obstruction
- Factors affecting stopping distance
  - **Total reaction time of the driver**
  - **Frictional resistance between the road and the tyres**
  - **Speed of vehicle**
  - **Gradient of the road**
  - **Efficiency of brakes**

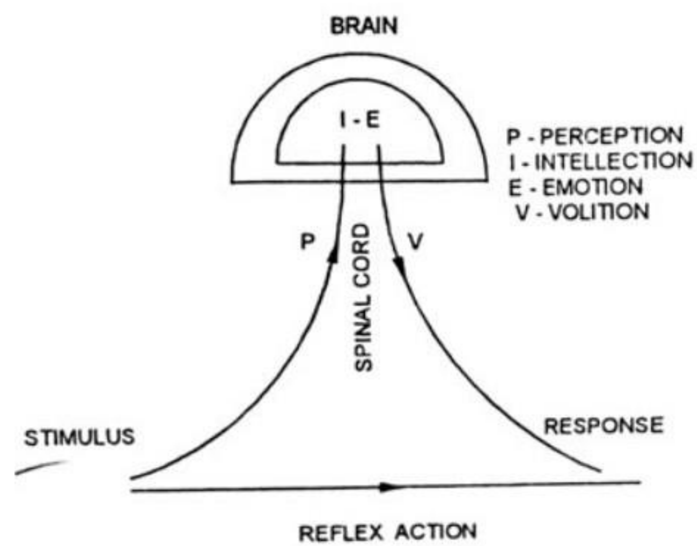
- Total Reaction Time
  - Reaction time of the driver is the time taken from the instant the object is visible to the driver to the instant the brakes are effectively applied.
  - The stopping distance increases with increase in reaction time of the driver.
  - It may be divided into two parts:

(a)Perception time -> time required for a driver to realise that brakes must be applied

(b)Brake reaction time -> time elapse between the moment the foot is removed from the accelerator paddle and placed on the brake paddle and time to actuate brake action.

PIEV THEORY

- According to this theory, the total reaction time of the driver is split into four parts:
  - (a)Perception Time -> time required to perceive an object or situation.
  - (b)Intellection Time ->time required to understand the situation.
  - (c)Emotion Time ->determination of an appropriate response to the stimulus
  - (d)Volition Time: physical response resulting from the decision.



ii) Speed of Vehicle

Higher the speed, higher will be the stopping distance.

iii)Efficiency of Brakes

The braking efficiency is said to be 100% if thee wheels are fully locked preventing them from rotating on application of the brakes, which will result in 100% skidding.

iv)Frictional resistance between road and tyre

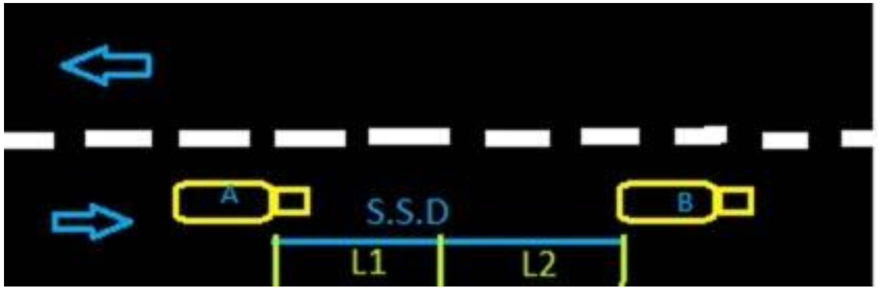
depends on the type and condition of the road surface and the tyres.

More frictional resistance less SSD

v) Gradient of the Road

ascending gradient required less SSD descending gradient required more SSD

ANALYSIS OF SSD



- S.S.D = L1+L2
- Where
- L1 = the distance travelled by vehicle during total reaction time of driver = Lag distance
- L2 = the distance travelled by the vehicle after the application of brakes = Braking distance

Where,

Lag distance L1 = v.t

t = perception time +break reaction time

According to IRC t = 2.5 seconds

(but for OSD t= 2 sec imp)

CALCULATION OF BRAKING DISTANCE

- **Work done = K.E**

  $f * w * L2 = 0.5 * (w/g) * v^2$

(f = Coefficient of longitudinal frictior `

$$L2 = \frac{V^2}{2gf}$$

"f" Values As Per IRC

Design Speed in KMPH	Longitudinal Friction (f)
20-30	0.4
40	0.38
50	0.37
60	0.36
65	0.36
80	0.35
100	0.35

$$\text{Finally S.S.D} = L1 + L2 = V.t + \frac{V^2}{2gf}$$

Considering gradient and brake efficiency **SSD = vt + $v^2/(2gf+i\eta)$** -> ascending gradient **SSD = vt + $v^2/(2gf-i\eta)$** -> descending gradient Where,

i -> gradient in decimal

η -> brake efficiency in decimal

But practically the sight distance provided on the road should satisfy the following rules:

1. SD = SSD for one way or two way movement in same no. of lanes
2. SD = ISD = 2*SSD = for two way traffic movement in a single lane

The stability of slopes is considered while designing?
a) National highway
b) State highway
c) Hill roads
d) District roads

The width of the pavement for a lane in two-lane road is

a. 3.75 m
b. 3.5 m
c. 5.5 m
d. 7.0 m

As per IRC, the maximum value of rate of change of centrifugal acceleration in transition curve is

a. 0.25
b. 0.5
c. 0.8
d. 1.2

As per NRS, the minimum super-elevation provided for bituminous road in snow bounded hilly terrain is

a. 2.5%
b. 4%
c. 7%
d. 10%

- In plain and rolling terrain 7%
- In snow bound areas 7%
- In hilly areas not bound by snows 10%

The safe travelling speed of the vehicle on horizontal curve of radius 300m is [Coefficient of friction = 0.15 and zero super-elevation]

a. 70 km/hr
b. 65 km/hr
c. 75 km/hr
d. 56 km/hr

The ratio between centrifugal force and weight of the vehicle is called

a. Impact ratio
b. Impact factor
c. Centrifugal impulse
d. Centrifugal Factor

The stopping sight distance does not depend on ___________

a. Break reaction time
b. Speed of vehicle
c. Length of vehicle
d. Friction

The stopping sight distance of a vehicle moving with 45kmph and having a coefficient of friction as 0.4 is

a. 48m
b. 50m
c. 51m
d. 49m

What is the Perception Reaction Time for braking on highways?

b) 1 second
c) 2.5 seconds
d) 3.5 seconds
e) 3 seconds

The extra widening required for 14m wide pavement on a horizontal curve of radius 300m is ……. If wheel base of 8 m and design speed of 100 km/hr is considered.

a. 0.82 m
b. 1.02m
c. 0.92 m
d. 1.14 m

The length of wheel base usually considered is

a. 5.5m
b. 5.7m
c. 5.9m
d. 6.1m

The rate of change of acceleration in m/sec^3 for a design speed of 85 kmph is

a. 0.6
b. 0.5
c. 0.7
d. 0.8

If super elevation is zero, then the design speed of highway having a curve of 200m and coefficient of friction is 0.1 is

a. 40 kmph
b. 50 kmph
c. 55 kmph
d. 60 kmph

The SSD is based on ___________
a) Speed of vehicle
b) PIEV theory
c) Voluntary action of brain
d) Reflex action of brain

The length visible to driver at any instance of time is called ___________
a) Sight distance
b) Visibility limit
c) Head light distance
d) Overtaking sight distance

The stopping sight distance does not depend on ___________
a) Break reaction time
b) Speed of vehicle
c) Length of vehicle
d) Friction

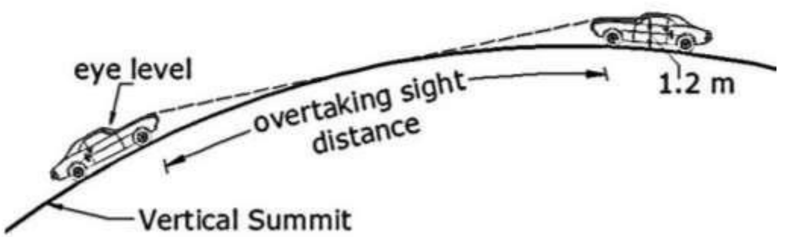
The reaction time considered in OSD is ___________
a) 1.5 sec
b) 2 sec
c) 2.5 sec
d) 3 sec

The desirable relationship between OSD and length of overtaking zone is ___________
a) Length of overtaking zone = OSD
b) Length of overtaking zone = 2 OSD
c) Length of overtaking zone = 3 OSD
d) Length of overtaking zone = 5 OSD

If the speed of overtaken vehicle is 80Kmph, then the design speed is ___________
a) 80kmph
b) 96kmph
c) 100kmph
d) 106kmph

OVERTAKING SIGHT DISTANCE (OSD)

- The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction
- Factors affecting OSD



(i) Speeds of :

(a) Overtaking vehicle
(b) Overtaken vehicle
(c) Vehicle coming from opposite direction

(ii) Distances between overtaking and overtaken vehicles.
(iii) Skill and reaction time of the driver.
(iv) Rate of acceleration of overtaking vehicle.
(v) Gradient of the road.

ANALYSIS OF OSD

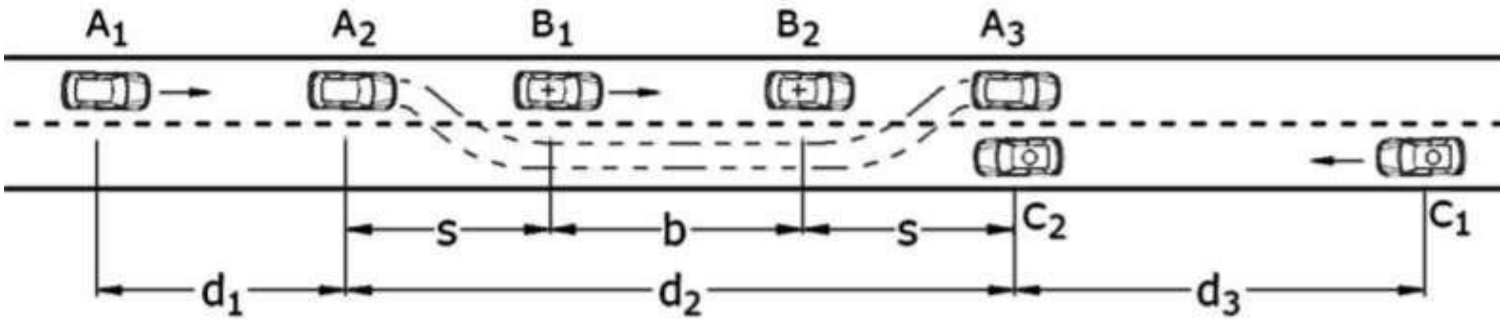


fig: Overtaking Manoeuvre

Here,

A = position of overtaking vehicle

B = position of overtaken vehicle or slow moving vehicle

C = position of vehicle coming from the opposite direction

d_1= distance travelled by overtaking vehicle A during the reaction time ‘t’ sec. from A_1 to A_2

d_2 = distance travelled by vehicle A from A_2 to A_3 during actual overtaking operation in ‘T’ sec.

d_3= dist. travelled by on-coming vehicle from C_1 to C_2 during overtaking operation of vehicle A.

- Hence, overtaking sight distance is given by; OSD = $d_1 + d_2 + d_3$

OSD = $v_b t + v_b T + 2s + vT$ Where,

v_b= speed of overtaken vehicle, m/s = (V-16)km/hr generally

t = reaction time of driver = 2.0 sec

v = speed of overtaking vehicle or design speed

s = spacing of vehicles = $0.7v_b + 6$; where, '6' is wheel base

T= duration of actual overtaking

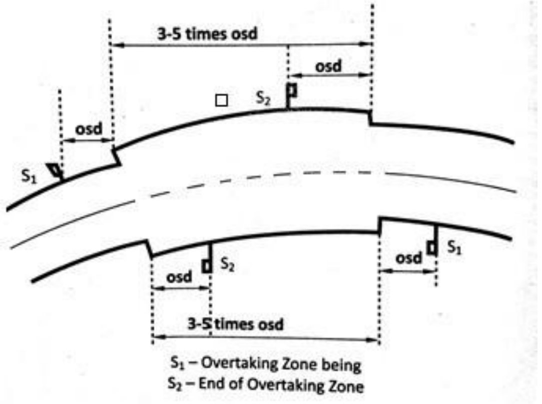
T = $\sqrt{(4s/a)}$ where, a = acceleration, m/s2 = 0.694

T = $\sqrt{(14.4s/A)}$ where A =acceleration, km/hr/s = 2.5

Note

On divided highway d_3 need not to be considered

OVERTAKING ZONE



- Provided when OSD cannot be provided through out the length of the highway.

Desirable length = 5*OSD

Minimum length = 3*OSD

- Width of the overtaking zone = min width of two lane road
- Single lane road, passing zone = min 2*OSD

SETBACK FROM OBSTRUCTIONS

- Distance required from the centerline of a horizontal curve to an obstruction at the inner side of the curve so as to provide adequate sight distance

depends upon the following factors:

i) Required sight distance, S

ii) Radius of horizontal curve, R

iii) Length of the curve, which may be greater or lesser than S.

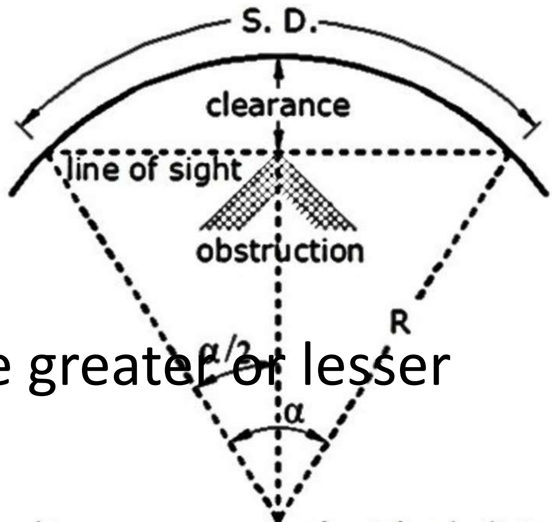


fig: clearance on curve / set-back distance for desired sight distance

CASE (A) $L_C > S$

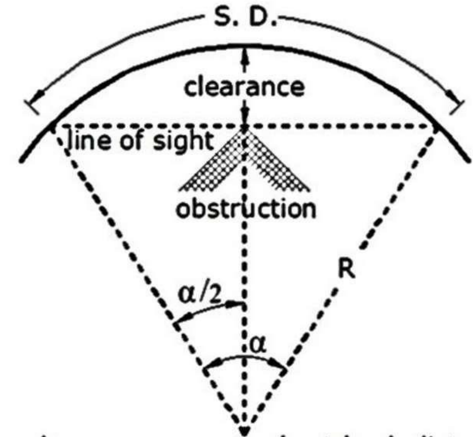


fig: clearance on curve / set-back distance for desired sight distance

From the figure;
For single lane road

$$\frac{\alpha}{2} = \left(\frac{S}{2R}\right)^{c} = \left(\frac{180\,S}{2\,\pi\,R}\right)^{o}$$

distance from the obstruction to the center of curve

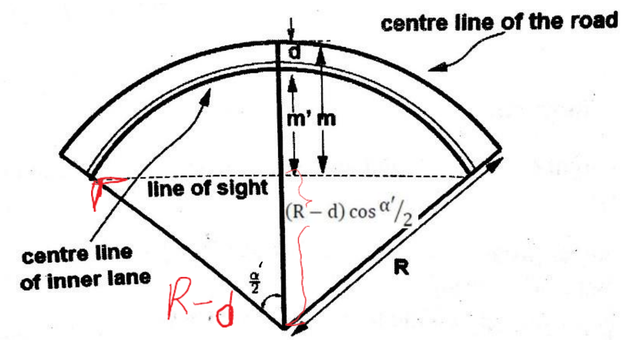
$$D = R \cos\alpha/2$$

Setback $m = R - R\cos{}^{\alpha}/_{2}$

For Multiple lane road

Setback Wh $m = R - (R - d)\cos{}^{\alpha'}/_{2}$

d -> distance between the centerline of the road and the centerline of the inside lane in meter



$$\frac{\alpha'}{2} = \left[\frac{180\,S}{2\pi\,(R - d)}\right]^{o}$$

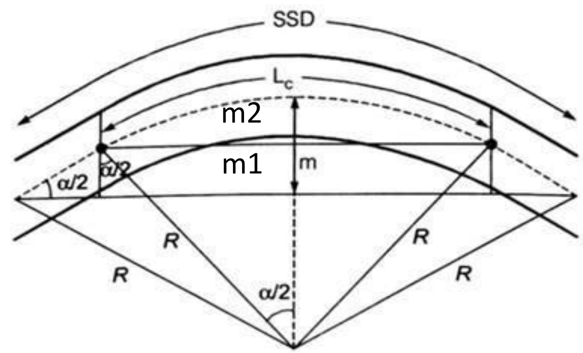
CASE (B) $L_c < S$

- angle subtended at the center is determined with reference to the length of circular curve L_c

For Single lane road

$$\frac{\alpha}{2} = \frac{180\,L_c}{2\pi\;R}\ \text{degrees}$$

m2 = R- R cosα/2



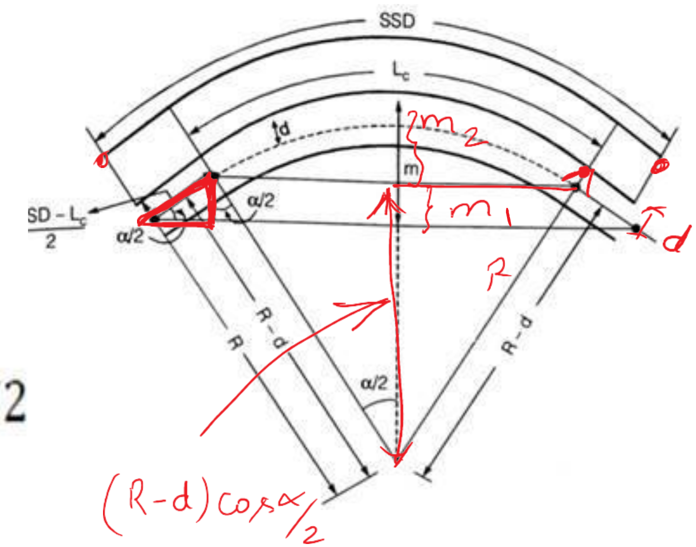
$$m1 = \frac{(S - L_c)}{2}\sin\alpha/2$$

$$m = m1 + m2 = \frac{(S - L_c)}{2}\sin\alpha/2 + R - R\cos\alpha/2$$

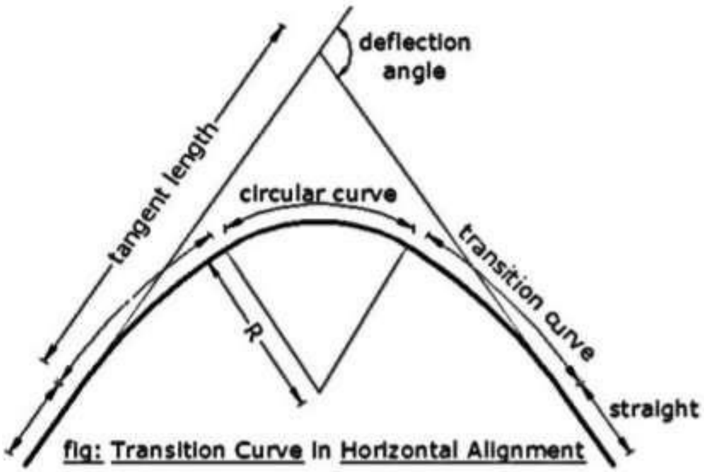
For multiple lane road

$$\frac{\alpha}{2} = \frac{180\,L_c}{2\pi\,(R-d)}\ \text{degrees}$$

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



TRANSITION CURVE



non-circular curve introduced between a straight and a circular curve

Objectives

- To introduce super-elevation in proportion to the rate of change of curvature.
- To introduce gradually the centrifugal force between the tangent point and beginning of the circular curve.
- To enable the driver turn the steering gradually for his own comfort and security.
- To introduce extra widening of pavement at desirable rate.
- To improve the aesthetic appearance of the road.

TYPES OF TRANSITION CURVE

(i) Spiral (or clothoid)

radius is inversely proportional to its length.

(ii) Lemniscate

radius varies inversely proportional as its length of chord.

(iii) Cubic parabola

radius varies inversely as its abscissa ‘x’.

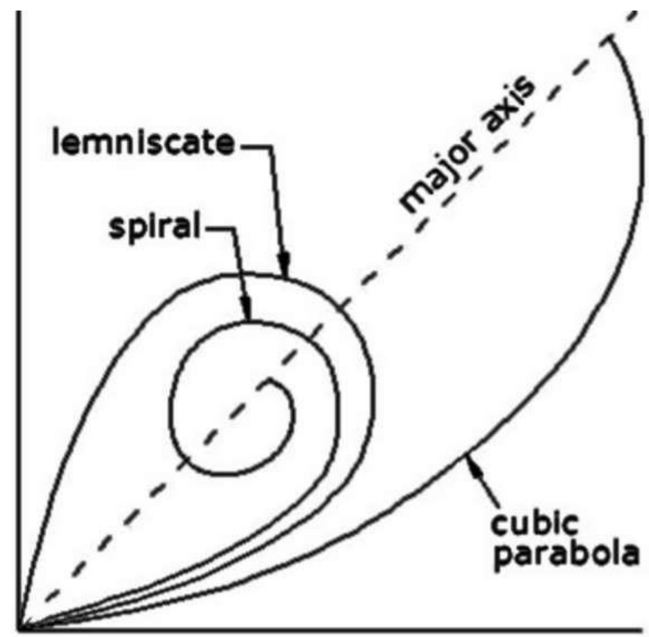


fig: different Tansition Curves

DESIGN OF TRANSITION CURVE

- The length of the transition curve is designed to fulfill the three condition as mention below and should be the highest of the three values.

1. The Rate of Change of Centrifugal Acceleration

From this consideration the length transition curve is given by the following equation:

L_t = 0.0215 V^3/ CR

Where,

L_t = Length of transition curve in m, V = Speed of vehicle in Km/h,

C = Rate of change of centrifugal acc... R = Radius of the circular curve in m.

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

The minimum and maximum values of C are limited to 0.5 & 0.8 respectively.

2. THE RATE OF INTRODUCTION OF SUPER ELEVATION

- Let, the rate of change of introducing super-elevation be 1 in N;

N = 150 (in plain and rolling) , N = 60 (for hilly area)

Also consider 'We' be the extra width provided at the circular curve; then

Pavement is rotated about inner edge.

$$L_t = e \, . \, N \, (W + W_e)$$

Pavement is rotated about centre line

$$L_t = \frac{E\,N}{2} = \frac{e\,B\,N}{2} = \frac{e\,N}{2}(W + W_e)$$

where, W_e = total extra widening = $\frac{n\,\ell^2}{2\,R} + \frac{V}{9.5\,\sqrt{R}}$

3. By Empirical Formula

- According to I.R.C standards, the length of the horizontal transition curve should act, then the value given by the following equations:

  a) For plain and rolling terrain

$$L_t = 2.7\ V^2/R$$

  b) For mountainous and steep terrain

$$L_t = V^2/R$$

Where V is Speed in km/hr. R is radius in m

- Calculation of lateral shift (S) $S = L_t^2/24R$

If S<0.25m -> no need of transition curve

- After providing the transition curve,

the elements of combine curve will be:

Tangent Length $(T)=(R+S)\tan\Delta/2 + L_t/2$

Apex distance $(E) = (R+S) (\sec\Delta/2 – 1)$

Spiral angle $(\Psi s) = L_t/2R$ radian $= L_t*180/(2\pi R)$

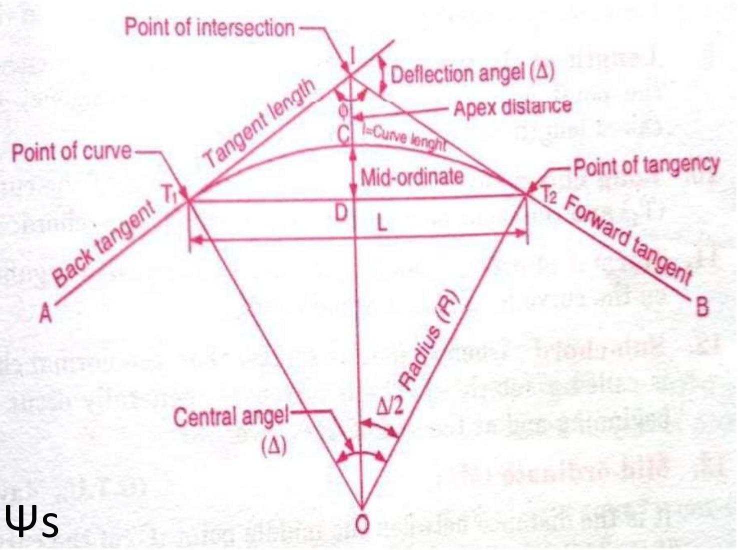
Degree Angle obtained by circular curve $(\Delta s) = \Delta-2\Psi s$

Length of Circular Curve $(Lc) = =\pi R\Delta s/180$

Total length of Composite curve $= Lc + 2L_t$

`

Notations for curve :



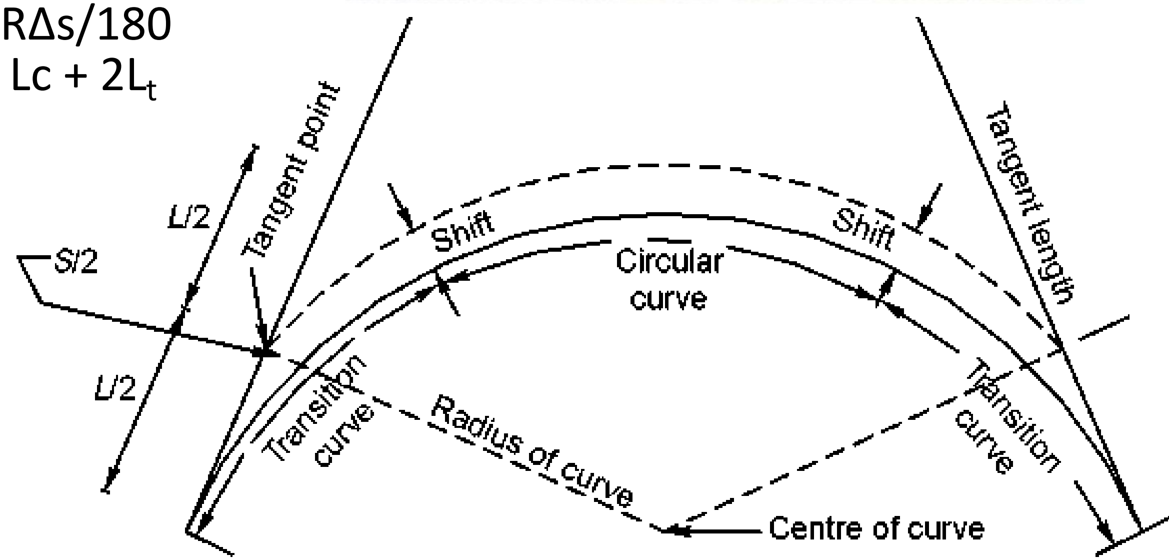
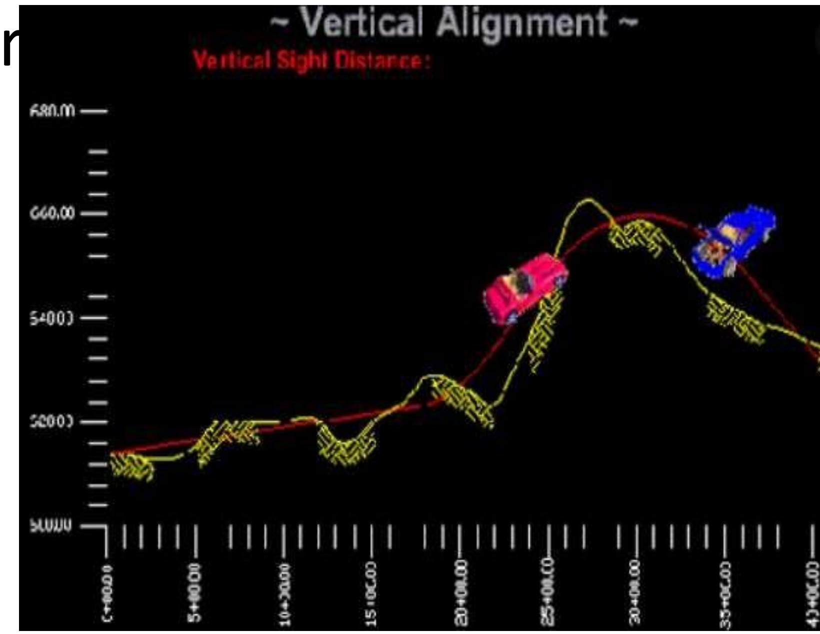


Fig.13.12 Shift

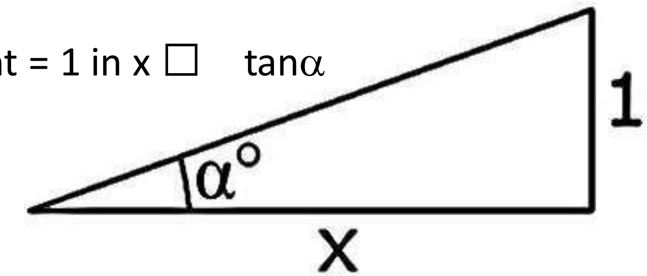
VERTICAL ALIGNMENT

- elevation or profile of the centr line of the road
- consists of *grade*s and *vertical curves*
- influences the vehicle speed, acceleration, deceleration, stopping distances, sight distances and comfort in vehicle movement at high speed



GRADIENT

Gradient = 1 in x □ tanα



- rate of rise or fall along the length of the road w. r. t. the horizontal.

Factors affecting gradient

(i)Characteristic of the traffic.

(ii)Design speed

(iii)Physical features of the site (drainage, safety, appearance, access to adjacent property).

(iv)Topography of the country.

TYPES OF GRADIENT

i) Ruling gradient (7% for Hilly, 5% for Terai)

- maximum gradient within which the designer attempts to design the vertical profile of a road.
- Also known as design gradient depends upon terrain, length of the grade, speed, pulling power of the vehicle and presence of horizontal curve.

ii) Limiting gradient (10% in Hilly, 6% for Terai)

- more than ruling gradient.
- Limited to 300m in a stretch
- Adopted if enormous increase in construction cost.
- Frequently use in rolling and hilly terrain.

III) EXCEPTIONAL GRADIENT (12% FOR HILLY, 7% FOR TERAI)

– Very steeper gradients provided at unavoidable situation for short stretches

– should not exceed about 100m at a stretch

Note:

- Maximum recovery gradient of 4% is applied after gradient in excess of 7%
- Limitation of maximum gradient length above 7% gradient = 300m

IV) MINIMUM GRADIENT

- Provided for drainage purpose
- depend upon rainfall run off, type of soil, topography and other site condition
- As per NRS 2070 min longitudinal gradients for drainage purpose is 0.5%

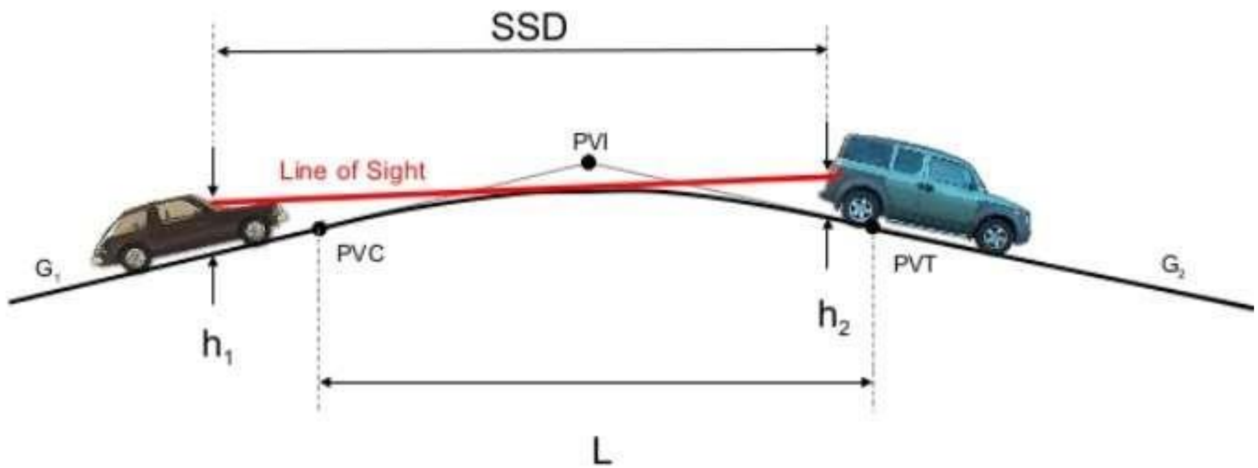
VERTICAL CURVE

- Curve that connect two different gradients in the vertical plane.
- Following are objective of vertical curve:
  - To obtain adequate visibility
  - To secure comfort to the passenger

Assumptions made during the computations of vertical curves:

- Curve is so flat that, length of curve = length of chord = length of horizontal projection
- Proportion of curve along tangents on either side of the point of intersection are equal for any values of n1 & n2
- Deviation angles are very small so tangent of this angle is equal to angle themselves (in radians)
- Proportion of parabola may be substituted by a circular curve of certain radius R

- It is often necessary to check for highest or lowest point on the profile along the curve to ensure minimum sight distance.



For SSD < L

$$L = \frac{A(SSD)^2}{100\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2}$$

For SSD > L

$$L = 2(SSD) - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$

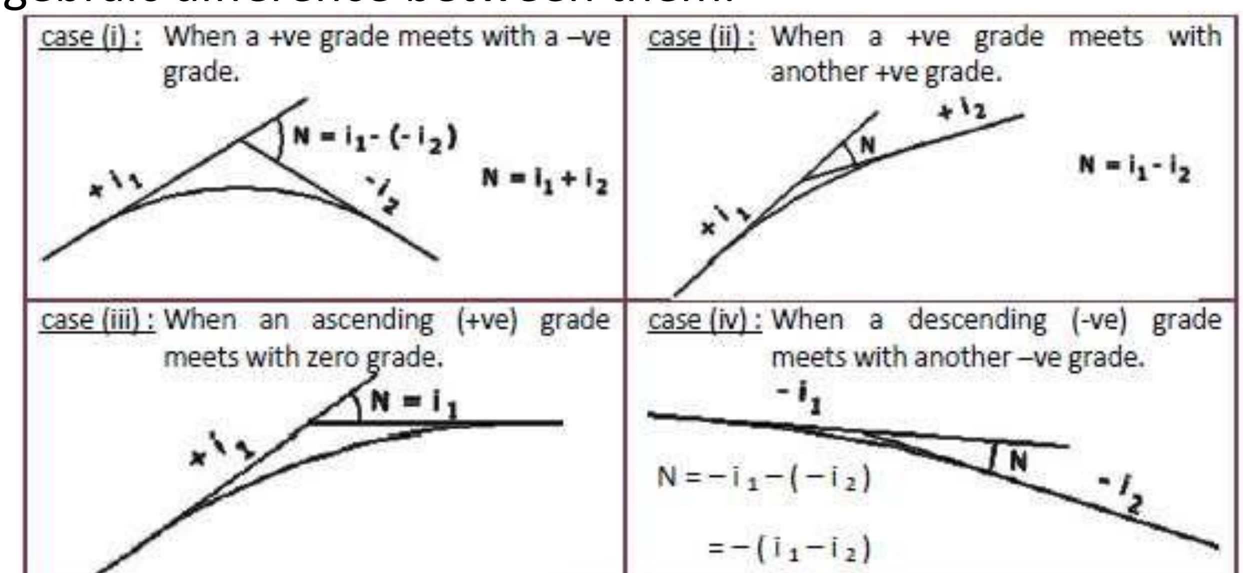
TYPES OF VERTICAL CURVES

1. Summit Curve 2. Valley Curve

Summit Curve

curve with the convexity upwards is called summit curve also called crest curves.

The deviation angle between the two interacting gradients is equal to the algebraic difference between them.



LENGTH OF SUMMIT CURVE FOR STOPPING SIGHT DISTANCE (SSD)

There are two cases: (I) When L > SSD (II) When L < SSD

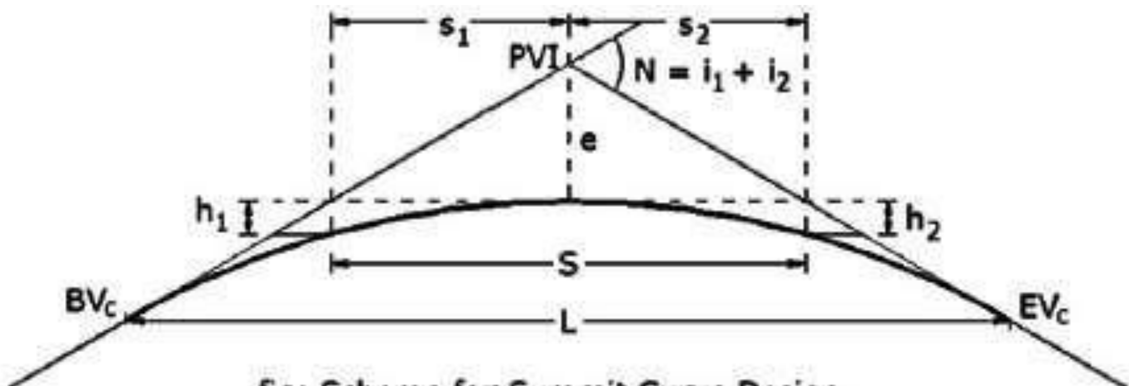


fig: Scheme for Summit Curve Design

Case: (I) When L > SSD

In the diagram,

h_1 = height of driver's eye from road surface

h_2 = height of the object lying on the road surface

Since, the curve is square parabola, offset from the line of sight are proportional to the square of the distance from the point, where the curve is tangential to the line of sight.

$h_1 = as_1^2$ ------- (i) and $h_2 = as_2^2$ ------- (ii) $(\because y = ax^2)$

where, a = constant of parabola

- $S = S_1 + S_2 = \sqrt{(H_1/A)} + \sqrt{(H_2/A)}$
  $S^2 = (1/\sqrt{A})^2(\sqrt{H_1}+\sqrt{H_2})^2$
- $S^2 = (2L/N)(\sqrt{h_1}+\sqrt{h_2})^2$

$$L = \frac{N S^2}{2\left[\sqrt{h_1}+\sqrt{h_2}\right]^2}$$

This is the general equation for length of parabolic curve, Where,
L = length of summit curve, m
S = stopping sight distance (SSD), m
N = deviation angle

Equation of summit curve

$$y = \frac{Nx^2}{2L}$$

(Also $y = ax^2$)

[∵ $a = N/2L$]

As per IRC,
h1 = 1.2 m & h2 = 0.15 m

$$\mathbf{L = \frac{N S^2}{4.4}}$$

In terms of overtaking sight distance (OSD) and intermediate sight distance (ISD),

Height h1 = 1.2m and h2 = 1.2m Substituting we get,

$L = Ns^2 / 9.6$

CASE: (II) WHEN L < SSD

From basic geometry, one can write,

Or, $s = L/2 + h_1/n_1 + h_2/n_2$

Or, $s = L/2 + h_1/n_1 + h_2 / (N – n_1)$

For minimum value of s we differentiate the equation with respect to n_1 and set it to zero,

Or, $ds/dh_1 = -h_1/n_1^2 + h_2 / (N – n_1)^2 = 0$

Or, $h_2 n_1^2 = h_1 * (N^2 + n_1^2 – 2*N*n_1)$

Solving the equation we get,

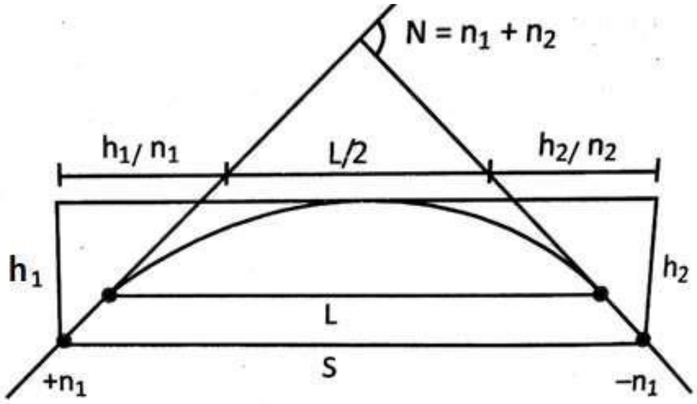
Therefore, $n_1 = (N * \sqrt{(h_1 h_2)} – N h_1) / (h_2 – h_1)$

Substituting value of n_1 in s we get,

Or, $s = L/2 + h_1 / (N * \sqrt{(h_1 h_2)} – N h_1) / (h_2 – h_1) + h_2 / [N – (N * \sqrt{(h_1 h_2)} – N h_1) / (h_2 – h_1)]$

Solving for L we get,

$L = 2s – [\sqrt{(2h_1)} + \sqrt{(2h_2)}]^2 / N$

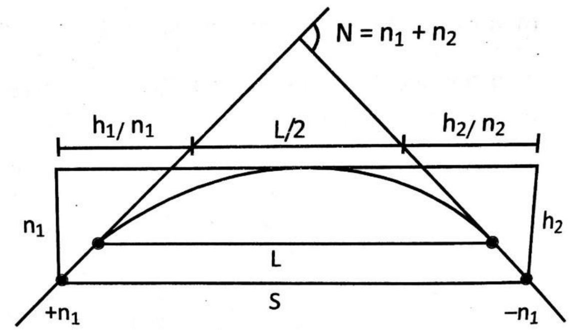


- In terms of stopping sight distance (SSD),

Height h_1 = 1.2m and h_2 = 0.15m

Substituting we get,

$L = 2s - 4.4/N$



- In terms of overtaking sight distance (OSD) and intermediate sight distance (ISD),

Height h_1 = 1.2m and h_2 = 1.2m

Substituting we get,

$L = 2s - 9.6/N$

It should be known that these values are the minimum lengths and greater sight distances should be used where there is economically and technically feasible.

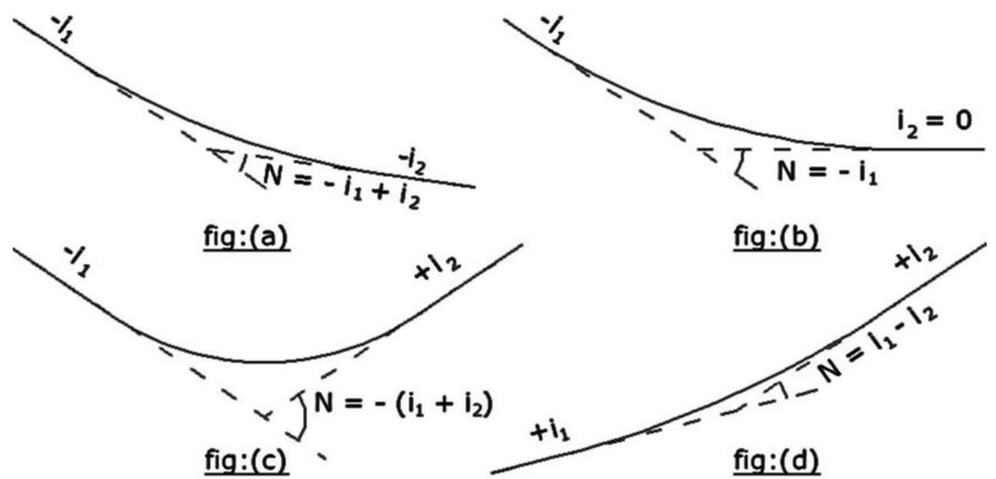
DESIGN OF VALLEY CURVE

- curve with the convexity downwards is called valley curve also called Sag curves.
- The most important factors considered in valley curve design are:

  (i)Impact free movement of vehicles at design speed or the comfort to the passengers.

  (ii)Availability of stopping sight distance under head lights of vehicles for night driving.

Cases of forming Valley Curves



- **Length of Valley Curve**

The length of valley curve is designed based on the two criteria:

a) The length of the transition curve (LS) for comfort condition

b) The length of valley curve for head light sight distance

(a) The length of Transition Curve (L_s) for Comfort condition

It is given by,

$$L_s = \frac{V^3}{C\,R} \qquad \dots\dots\dots\dots \quad (i)$$

$$\text{value of R (at length } L_s) = \frac{L_s}{N} = \frac{L}{2\,N}$$

Now equation (i) becomes;

$$L_s = \frac{V^3}{C\,L_s} \times N$$

$$\text{or,} \quad {L_s}^2 = \frac{N\,V^3}{C}$$

$$\text{or,} \quad L_s = \left[\frac{N\,V^3}{C}\right]^{1/2}$$

$$\text{now,} \quad L = 2L_s = 2\left[\frac{N\,V^3}{C}\right]^{1/2}$$

Where,

N = deviation angle V = speed (m/s)

C = allowable rate of change of centrifugal acceleration (taken as 0.6 m/s3)

(B) THE LENGTH OF VALLEY CURVE FOR HEAD LIGHT SIGHT DISTANCE

IT MAY BE DETERMINED FOR THE TWO CONDITIONS: (I) L > SSD (II) L < SSD

(i) When L > SSD

Consider the height head light is h1 and the focused portion of the beam of light is inclined at an angle α upwards.

If the valley curve is assumed to be of parabolic shape, with equation $y = ax^2$, where a = N /2L

So,

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

or,
$$L = \frac{N\,S^2}{2\,h_1 + 2\,S\tan\alpha}$$

If h_1 = 0.75 m and $\alpha = 1^0$, then

$$L = \frac{N\,S^2}{1.5 + 0.035\,S}$$

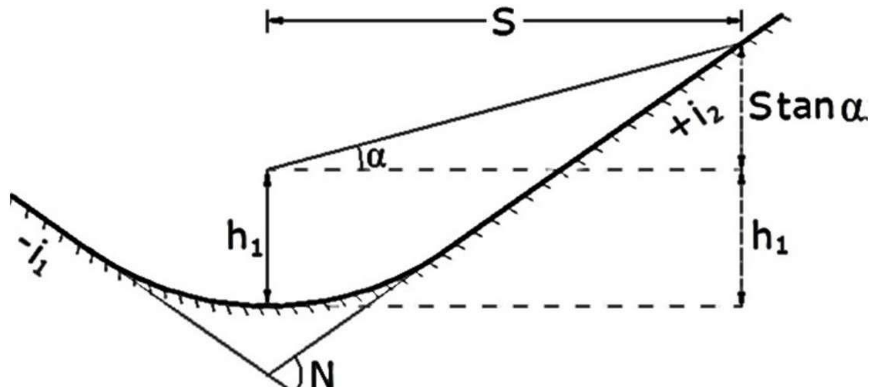


fig: Head Light Sight Distance when L > SSD

Where,
L = total length of valley curve S = SSD (m) N = deviation angle = $i_1 + i_2$

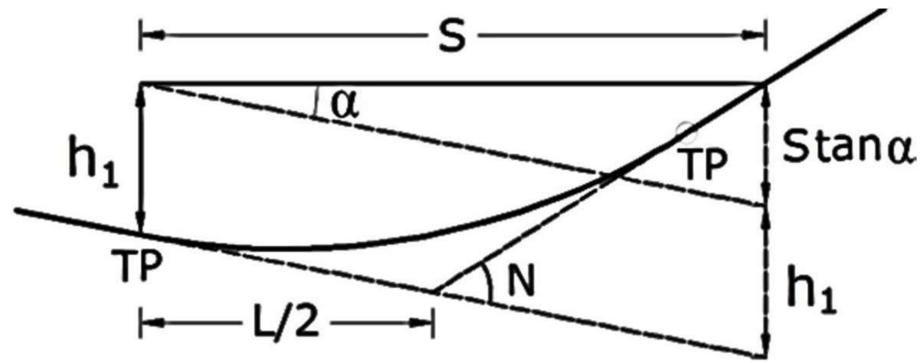


fig: Head Light Sight Distance when L < S

(ii) When L < SSD

Here,

$$h_1 + S\tan\alpha = \left(s - {}^{L}/_{2}\right)N$$

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

When, $h_1 = 0.75$ m & $\alpha = 1^0$, when L < SSD;

$$\boxed{L = 2\,S - \frac{1.5 + 0.035\,S}{N}}$$

59. The design speed used for design of superelevation is

   a. 100 % of design speed
   b. 98 % of design speed
   c. 50 % of design speed
   d. 75 % of design speed

60. The height of object above the ground for the design of summit curve is usually taken as:

a. 0.75 m
b. 1.2 m
c. 0.25 m
d. 0.15 m

61. The height of drivers eye above the ground for the design of summit curve is usually taken as:

a. 0.75
b. 1.2 m
c. 0.25 m
d. 0.15 m

62. The height of headlight for a passenger car above the ground for the design of valley curve is usually taken as:

a. 0.75
b. 1.2 m
c. 0.25 m
d. 0.15 m