Geometrical design

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Guidelines on superelevation

- While designing the various elements of the road like superelevation, we design it for a particular vehicle called design vehicle which has some standard weight and dimensions. But in the actual case, the road has to cater for mixed traffic.
- Different vehicles with different dimensions and varying speeds ply on the road.
- For example,in the case of a heavily loaded truck with high centre of gravity and low speed, superelevation should be less, otherwise chances of toppling are more.
- Taking into practical considerations of all such situations, IRC has given some guidelines about the maximum and minimum superelevation etc. These are all discussed in detail in the following sections.

Design of super-elevation

- For fast moving vehicles, providing higher super-elevation without considering coefficient of friction is safe, i.e. centrifugal force is fully counteracted by the weight of the vehicle or super-elevation.
- For slow moving vehicles, providing lower super-elevation considering coefficient of friction is safe, i.e. Centrifugal force is counteracted by super-elevation and coefficient of friction . IRC suggests following design procedure:

Step 1 Find e for 75 percent of design speed, neglecting f, i.e $e_1 = \frac{(0.75v)^2}{gR}$.

Step 2 If $e_1 \leq 0.07$, then $e = e_1 = \frac{(0.75v)^2}{gR}$, else if $e_1 > 0.07$ go to step 3.

Step 3 Find f_1 for the design speed and max e, i.e $f_1 = \frac{v^2}{gR} - e = \frac{v^2}{gR} - 0.07$. If $f_1 < 0.15$, then the maximum $e = 0.07$ is safe for the design speed, else go to step 4.

Step 4 Find the *allowable speed* v_a for the maximum $e = 0.07$ and $f = 0.15$, $v_a = \sqrt{0.22gR}$ If $v_a \geq v$ then the design is adequate, otherwise use speed adopt control measures or look for speed control measures.

Maximum and minimum super-elevation

- Depends on (a) slow moving vehicle and (b) heavy loaded trucks with high CG. IRC specifies a maximum super-elevation of 7 percent for plain and rolling terrain, while that of hilly terrain is 10 percent and urban road is 4 percent.
- The minimum super elevation is 2-4 percent for drainage purpose, especially for largeradius of the horizontal curve.

Attainment of super-elevation

1. Elimination of the crown of the cambered section by:

(a) rotating the outer edge about the crown : The outer half of the cross slope is rotated about the crown at a desired rate such that this surface falls on the same plane as the inner half.

b) shifting the position of the crown: This method is also known as diagonal crown method. Here the position of the crown is progressively shifted outwards, thus increasing the width of the inner half of cross section progressively.

2. Rotation of the pavement cross section to attain full super elevation by: There are two methods of attaining super-elevation by rotating the pavement

- (a) rotation about the centre line : The pavement is rotated such that the inner edge is depressed and the outer edge is raised both by half the total amount of super-elevation, i.e., by E/2 with respect to the centre.
- (b) rotation about the inner edge: Here the pavement is rotated raising the outer edge as well as the centre such that the outer edge is raised by the full amount of super-elevation with respect to the inner edge.

Radius of Horizontal Curve

- The radius of the horizontal curve is an important design aspect of the geometric design. The maximum comfortable speed on a horizontal curve depends on the radius of the curve. Although it is possible to design the curve with maximum super-elevation and coefficient of friction, it is not desirable because re-alignment would be required if the design speed is increased in future. Therefore, a ruling minimum radius R_{ruling} can be derived by assuming maximum super-el ion.

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

Extra widening

- Extra widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment. This widening is done due to two reasons: the first and most important is the additional width required for a vehicle taking a horizontal curve and the second is due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve.
- The first is referred as the mechanical widening and the second is called the psychological widening. These are discussed in detail below.

Mechanical widening

- The reasons for the mechanical widening are: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels as shown in figure . This phenomenon is called of-tracking, and has the effect of increasing the effective width of a road space required by the vehicle.
- Therefore, to provide the same clearance between vehicles traveling in opposite direction on curved roads as is provided on straight sections, there must be extra width of carriageway available. This is an important factor when high proportion of vehicles are using the road. Trailer trucks also need extra carriageway, depending on the type of joint.
- In addition speeds higher than the design speed causes transverse skidding which requires additional width for safety purpose. The expression for extra width can be derived from the simple geometry of a vehicle at a horizontal curve as shown in figure .

$$
\begin{aligned}
R_2^2 &= R_1^2 + l^2 \\
&= (R_2 - W_m)^2 + l^2 \\
&= R_2^2 - 2R_2W_m + W_m^2 + l^2 \\
2R_2W_m - W_m^2 &= l^2
\end{aligned}
$$

Therefore the widening needed for a single lane road is:

$$W_m = \frac{l^2}{2R_2 - W_m}$$

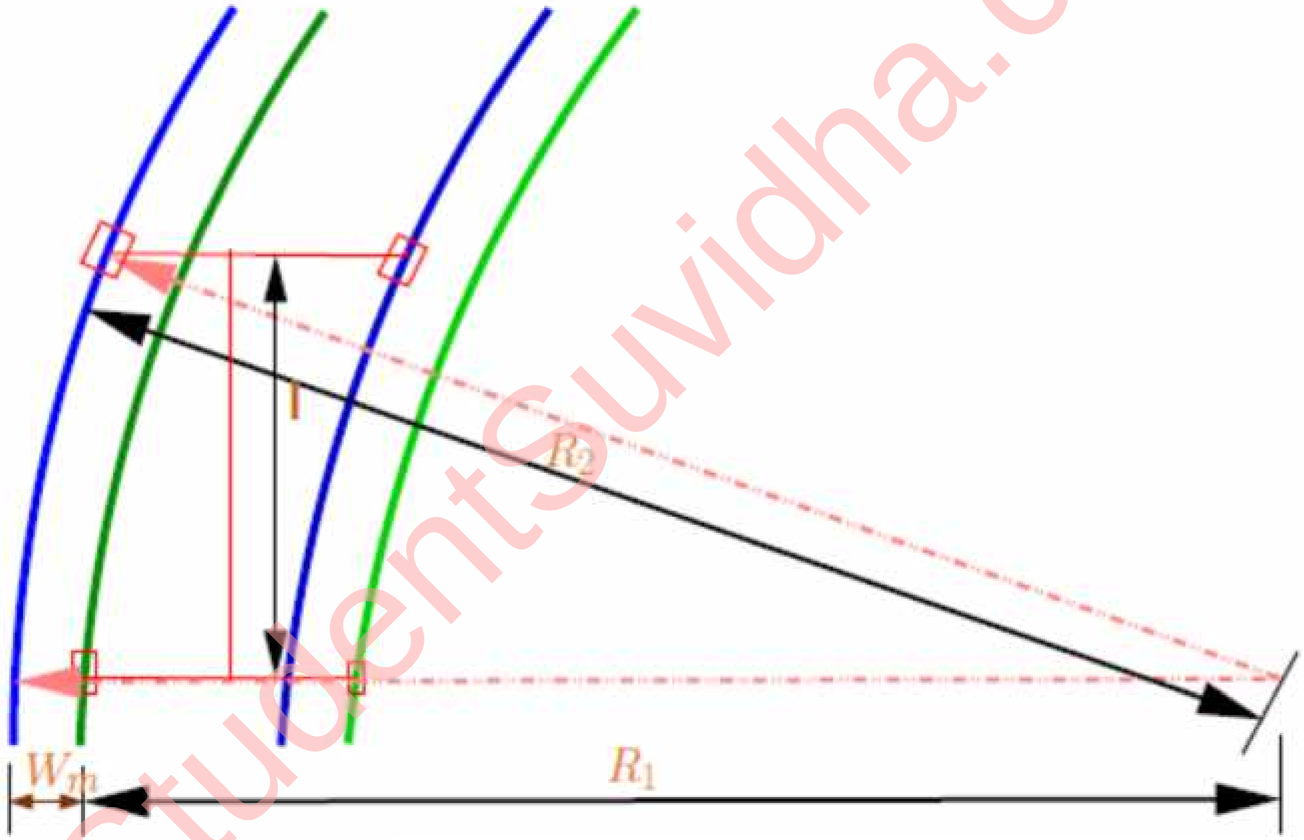
If the road has n lanes, the extra widening should be provided on each lane. Therefore, the extra widening of a road with n lanes is given by,

$$W_m = \frac{nl^2}{2R_2 - W_m}$$

Please note that for large radius, R2 = R, which is the mean radius of the curve,then Wm is give

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

Let R1 is the radius of the outer track line of the rear wheel, R2 is the radius of the outer track line of the front wheel l is the distance between the front and rear wheel, n is the number of lanes, then the mechanical widening Wm (refer figure 15:1) is derived below



Psychological widening

- Widening of pavements has to be done for some psychological reasons also. There is a tendency for the drivers
- to drive close to the edges of the pavement on curves. Some extra space is to be provided for more clearance
- for the crossing and overtaking operations on curves. IRC proposed an empirical relation for the psychological widening at horizontal curves Wps:

$$W_{ps} = \frac{v}{2.64\sqrt{R}}$$

$$\begin{aligned} W_e &= W_m + W_{ps} \\ &= \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}} \end{aligned}$$

Problems

1.A national highway passing through a rolling terrain has two horizontal curves of radius 450 m and 150m. Design the required super-elevation3.Two lane road, V=80 kmph, R=480 m, Width of the pavement at the horizontal curve=7.5 m.

2.Design super elevation for mixed traffic. (ii) By how much the outer edge of the pavement is to be raised with respect to the centre line, if the pavement is rotated with respect to centre line. [Ans:(i) 0.059 (ii)0.2

3.Design rate of super elevation for a horizontal highway curve of radius 500 m and speed 100 kmph. [Ans: e=0.07, f=0.087 and with in limits]

4. Given V=80 kmph, R=200m Design for super elevation. (Hint: f=0.15) [Ans: Allowable speed is 74.75 kmph and e=0.07]

5.Calculate the ruling minimum and absolute minimum radius of horizontal curve of a NH in plain terrain. (Hint: Vruling=100kmph, Vmin=80kmph., e=0.07, f=0.15) [Ans: 360 and 230 m]

6.Find the extra widening for W=7m, R=250m, longest wheel base, l=7m, V=70kmph. (Hint: n=2) [Ans:0.662m]

7.Find the width of a pavement on a horizontal curve for a new NH on rolling terrain. Assume all data. (Hint: V=80kmph for rolling terrain, normal W=7.0m, n=2, l=6.0m, e=0.07, f=0.15). [Ans: Rruling=230m, We=0.71, W at HC=7.71m] for the curves as per IRC guidelines.

Horizontal Transition Curves

- Transition curve is provided to change the horizontal alignment from straight to circular curve gradually and has a radius which decreases from infinity at the straight end (tangent point) to the desired radius of the circular curve at the other end (curve point)
- There are five objectives for providing transition curve and are given below:

1. to introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle. This increases the comfort of passengers.
2. to enable the driver turn the steering gradually for his own comfort and security,
3. to provide gradual introduction of super elevation, and
4. to provide gradual introduction of extra widening.
5. to enhance the aesthetic appearance of the road.

Type of transition curve

- Different types of transition curves are spiral or clothoid, cubic parabola, and Lemniscate.
- IRC recommends spiral as the transition curve because:

It fulfils the requirement of an ideal transition curve, that is;

(a) rate of change or centrifugal acceleration is consistent (smooth) and

(b) radius of the transition curve is ∞ at the straight edge and changes to R at the curve point ($Ls \propto 1/R$) and calculation and field implementation is very easy.

Length of transition curve

- The length of the transition curve should be determined as the maximum of the following three criteria:

1. Rate of change of centrifugal acceleration,
2. rate of change of super-elevation,
3. Empirical formula given by IRC.

1. Rate of change of centrifugal acceleration

- At the tangent point, radius is infinity and hence centrifugal acceleration is zero. At the end of the transition, the radius R has minimum value R. The rate of change of centrifugal acceleration should be adopted such that the design should not cause discomfort to the drivers. If c is the rate of change of centrifugal acceleration, it can be written as:

$$c = \frac{\frac{v^2}{R} - 0}{t}, \quad = \frac{\frac{v^2}{R}}{\frac{L_s}{v}}, \quad = \frac{v^3}{L_s R}.$$

Therefore, the length of the transition curve Ls1 in m is

$$L_{s_1} = \frac{v^3}{cR},$$

- where c is the rate of change of centrifugal acceleration given by an empirical formula suggested by by IRC as below

$$c = \frac{80}{75 + 3.6v},$$

subject to :

$$c_{\min} = 0.5,$$

$$c_{\max} = 0.8.$$

2. Rate of introduction of super-elevation

- Raise (E) of the outer edge with respect to inner edge is given by E = eB = e(W +We). The rate of change of this raise from 0 to E is achieved gradually with a gradient of 1 in N over the length of the transition curve (typical range of N is 60-150). Therefore, the length of the transition curve L_{s2} is

$$L_{s2} = Ne(W + W_e)$$

3. By empirical formula

- IRC suggest the length of the transition curve is minimum for a plain and rolling terrain:

$$L_{s_3} = \frac{35v^2}{R}$$

and for steep and hilly terrain is:

$$L_{s_3} = \frac{12.96v^2}{R}$$

and the shift s as:

$$s = \frac{L_s^2}{24R}$$

- The length of the transition curve Ls is the maximum of equations

$$L_s = \text{Max}: \ (L_{s_1}, L_{s_2}, L_{s_3})$$

Setback Distance

- Setback distance m or the clearance distance is the distance required from the centre line of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance at a horizontal curve. The setback distance depends on:
- 1. sight distance (OSD, ISD and OSD),
- 2. radius of the curve, and
- 3. length of the curve.

- Case (a) Ls < Lc

For single lane roads:

$$\alpha = \frac{s}{R} \text{ radians}$$
$$= \frac{180s}{\pi R} \text{ degrees}$$
$$\alpha/2 = \frac{180s}{2\pi R} \text{ degrees}$$

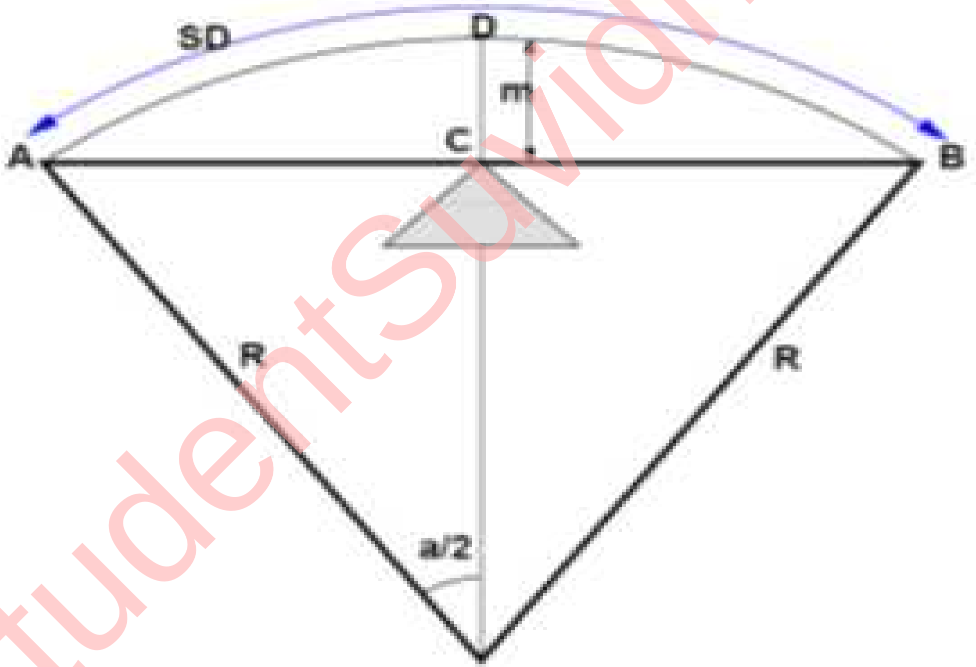
$$m = R - R\cos\left(\frac{\alpha}{2}\right)$$

For multi lane roads, if d is the distance between centre line of the road and the centre line of the inner lane, then

$$m = R - (R-d)\cos\left(\frac{180s}{2\pi(R-d)}\right)$$

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

Set-back for single lane roads (Ls < Lc)



Case (b) $L_s > L_c$

For single lane:

$$m_1 = R - R\cos(\alpha/2)$$
$$m_2 = \frac{(S - L_c)}{2}\sin(\alpha/2)$$

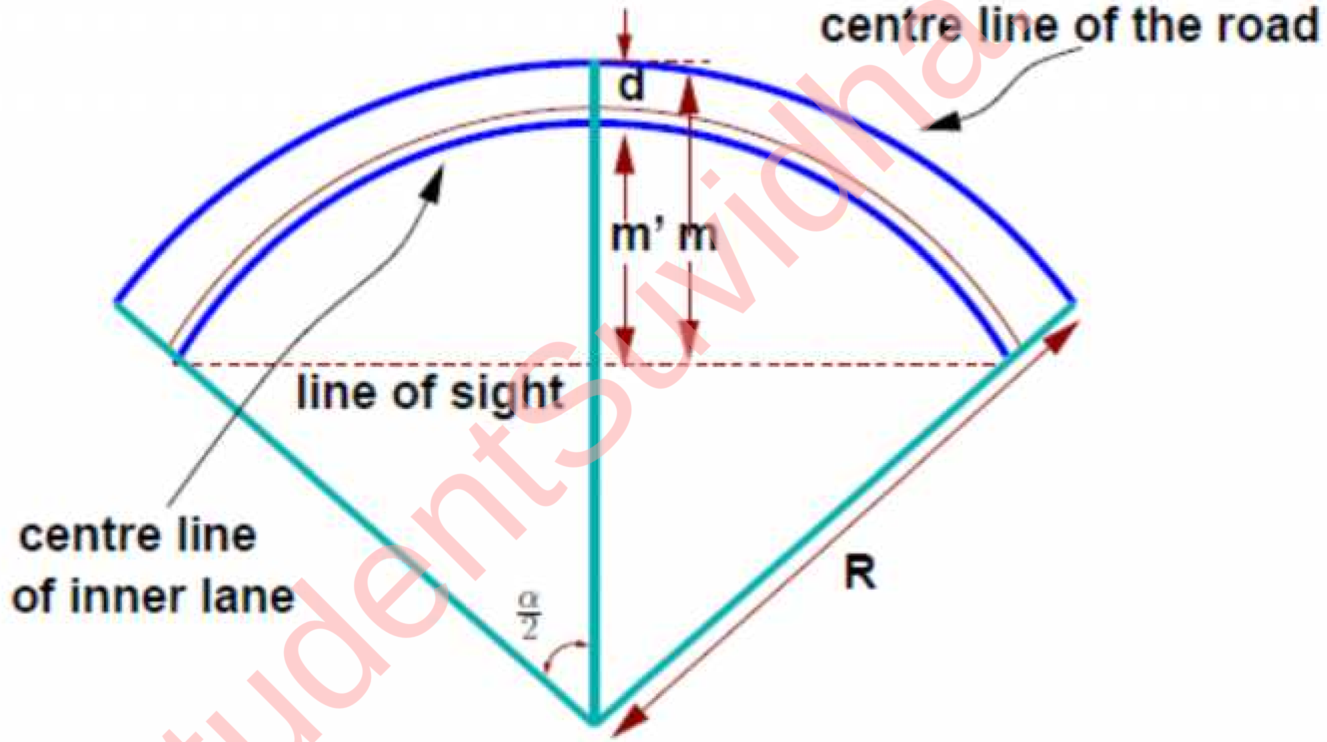
The set back is the sum of m_1 and m_2 given by:

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

where $\frac{\alpha}{2} = \frac{180 L_c}{2\pi R}$. For multi-lane road $\frac{\alpha}{2} = \frac{180 L_c}{2\pi(R-d)}$, and m is given by

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

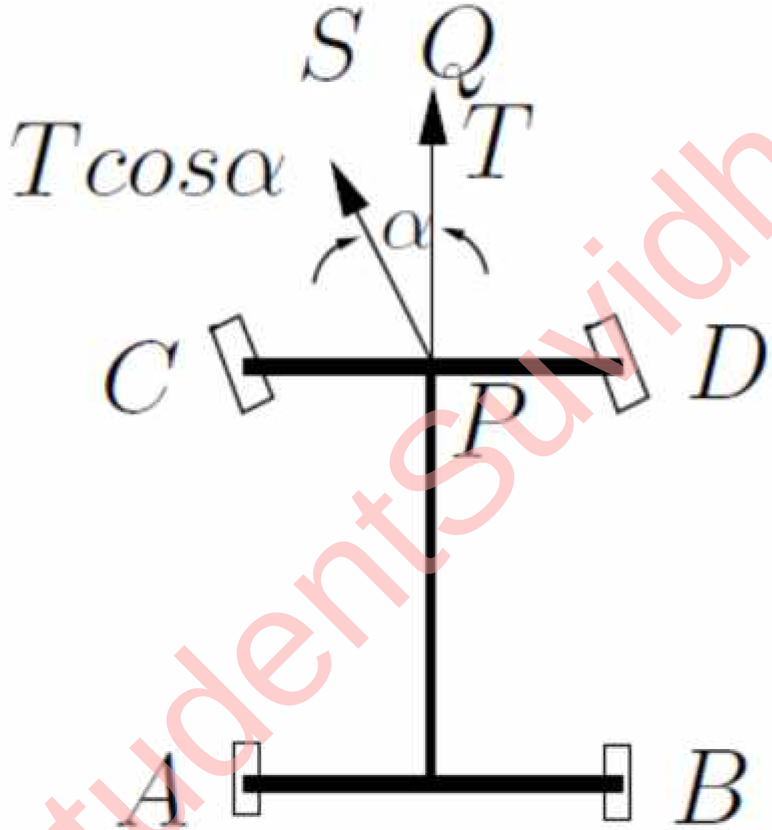
Set-back for multi-lane roads (Ls < Lc)



Curve Resistance

- When the vehicle negotiates a horizontal curve, the direction of rotation of the front and the r ear wheels are different. The front wheels are turned to move the vehicle along the curve, whereas the rear wheels seldom turn.
- This is illustrated in figure. The rear wheels exert a tractive force T in the PQ direction . The tractive force available on the front wheels is Tcosα in the PS direction as shown in the figure .
- This is less than the actual tractive force, T applied. Hence, the loss of tractive force for a vehicle to negotiate a horizontal curve is

$$CR = T - T\cos\alpha$$


S
Q
T
Tcosα
α
C
D
P
A
B

Problems

1.Calculate the length of transition curve and shift for V=65kmph, R=220m, rate of introduction of super-elevation is 1 in 150, W+We=7.5 m. (Hint: c=0.57) [Ans: Ls1=47.1m, Ls2=39m (e=0.07, pav. Rotated w.r.t centerline), Ls3=51.9m, s=0.51m, Ls=52m]

2. NH passing through rolling terrain of heavy rainfall area, R=500m. Design length of Transition curve.(Hint: Heavy rainfall. Pavement surface rotated w.r.t to inner edge. V=80kmph, W=7.0m, N=1 in 150) [Ans: c=0.52, Ls1=42.3, Ls2=63.7m (e=0.057, W+We=7.45), Ls3=34.6m, Ls=64m]

3. Horizontal curve of R=400m, L=200 m. Compute setback distance required to provide (a) SSD of 90m,(b) OSD of 300 m. Distance between center line of road and inner land (d) is 1.9m. [Ans: (a) $\alpha/2$ 6:5o, m=4.4 m (b)OSD>L, for multi lane, with d=1.9, m=26.8 m]

Thank you