www.ramauniversity.ac.in

TRANSPORTATION ENGINEERING – I

DEPARTMENT OF CIVIL ENGINEERING

FACULTY OF ENGINEERING & TECHNOLOGY

TRANSPORTATION ENGINEERING – I (Highway Engineering) UNIT-2 LECTURE - 1

Topics to be covered:

- Horizontal Curves
- Super Elevation
- Design Super Elevation
- Extra Widening
- Radius of Horizontal Curve
- Problems related to the Topics Discussed

PREPARED BY:

SHASHIKANT SRIVASTAVA

ASSISTANT PROFESSOR DEPARTMENT

OF CIVIL ENGINEERING

FACULTY OF ENGINEERING & TECHNOLOGY

RAMA UNIVERSITY UTTAR PRADESH, KANPUR (INDIA)

HORIZONTAL CURVE :

A curve is nothing but an arc which connects two straight lines which are separated by some angle called deflection angle.

This situation occurs where the alignment of a road way or rail way changes its direction because of unavoidable objects or conditions. The object may be a hill or a lake or a temple etc.

The presence of horizontal curve imparts centrifugal force which is a reactive force acting outward on a vehicle negotiating it.

Centrifugal force depends on speed and radius of the horizontal curve and is counteracted to a certain extent by transverse friction between the tyre and pavement surface.

On a curved road, this force tends to cause the vehicle to overrun or to slide outward from the centre of road curvature.

For proper design of the curve, an understanding of the forces acting on a vehicle taking a horizontal curve is necessary.

For the ease of movement of vehicle at this point a curve is provided.

In general, there are two types of curves and they are :

1. Horizontal curves
2. Vertical curves

Horizontal Curves

The curve provided in the horizontal plane of earth is called as horizontal curve.

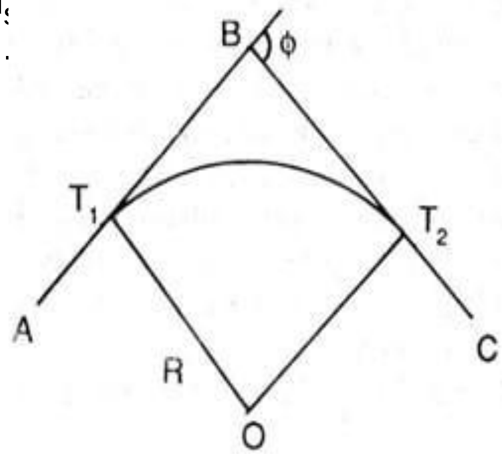
It connects two straight lines which are in same level but having different directions.

Horizontal curves are of different types as follows

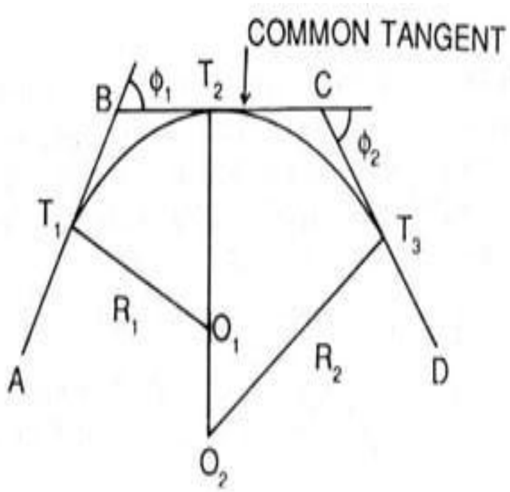
a) Simple circular curve
b) Compound curve
c) Reverse curve
d) Transition curve

HORIZONTAL CURVE :

SIMPLE CIRCULAR CURVE : Simple circular curve is a horizontal curve which connect two straight lines with constant radius.

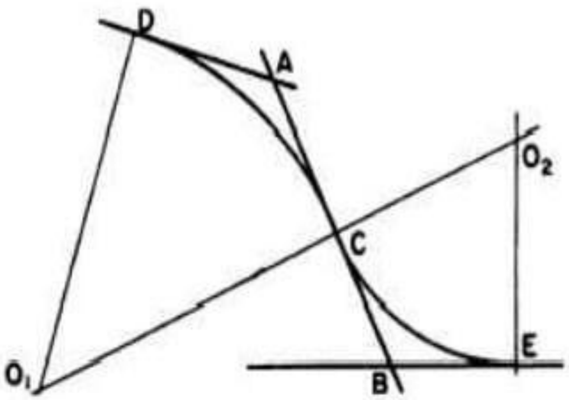


COMPOUND CURVE : Compound curve is a combination of two or more simple circular curves with different radii. In this case both or all the curves lie on the same side of the common tangent.

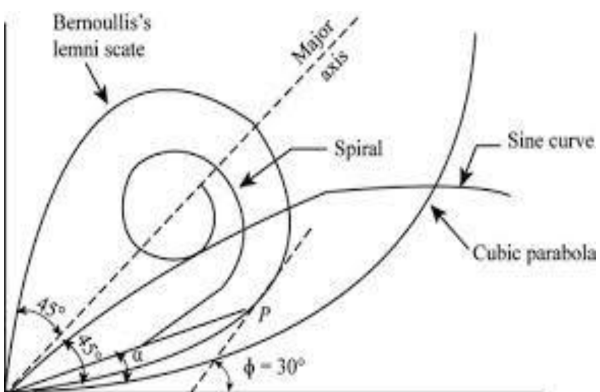


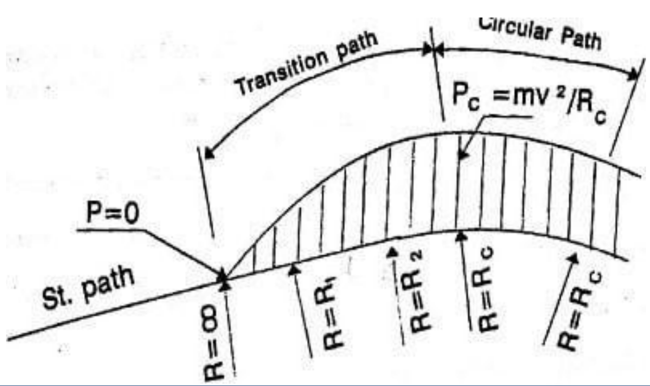
HORIZONTAL CURVE :

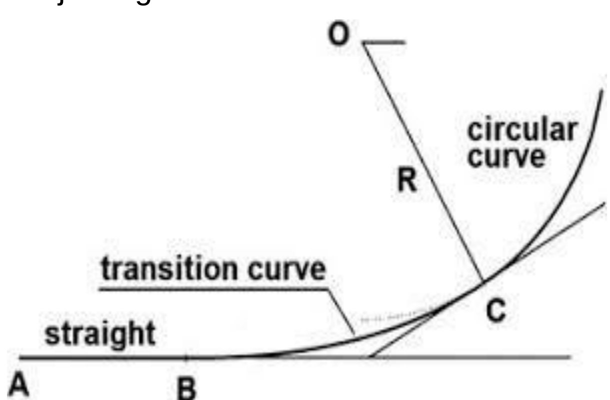
REVERSE CURVE : Reverse curve is formed when two simple circular curves bending in opposite directions are meet at a point. This points is called as point of reverse curvature. The center of both the curves lie on the opposite sides of the common tangent. The radii of both the curves may be same or different.



TRANSITION CURVE : A curve of variable radius is termed as transition curve. It is generally provided on the sides of circular curve or between the tangent and circular curve and between two curves of compound curve or reverse curve etc. Its radius varies from infinity to the radius of provided for the circular curve. Transition curve helps gradual introduction of centrifugal force by gradual super elevation which provides comfort for the passengers in the vehicle without suddenjerking.







HORIZONTAL CURVE :

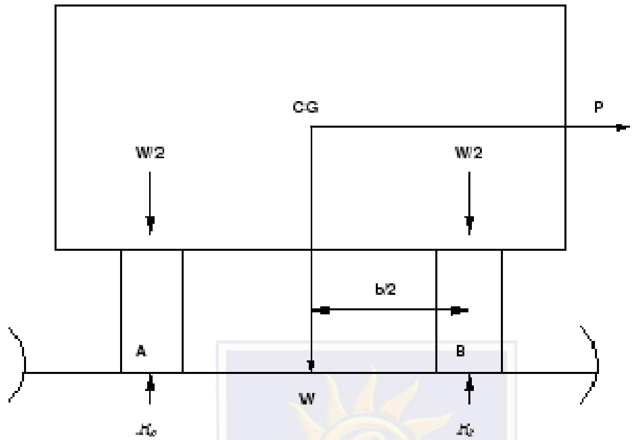


Figure 1: Effect of horizontal curve

They are the centrifugal force (P) acting outward, weight of the vehicle (W) acting downward, and the reaction of the ground on the wheels (R_A and R_B). The centrifugal force and the weight is assumed to be from the centre of gravity which is at h units above the ground. Let the wheel base be assumed as b units. The centrifugal force in kg/m^2 is given by : $P = \frac{Wv^2}{gR}$

where W is the weight of the vehicle in , v is the speed of the vehicle in m/s , g is the acceleration due to gravity in m/s^2 and R is the radius of the curve in m.

The centrifugal ratio or the impact factor P / W is given by: $\frac{P}{W} = \frac{v^2}{gR}$

The centrifugal force has two effects: A tendency to overturn the vehicle about the outer wheels and a tendency for transverse skidding. Taking moments of the forces with respect to the outer wheel when the vehicle is just about to override, $Fh = W\frac{b}{2}$ or $\frac{P}{W} = \frac{b}{2h}$

At the equilibrium over turning is possible when : $\frac{v^2}{gR} = \frac{b}{2h}$

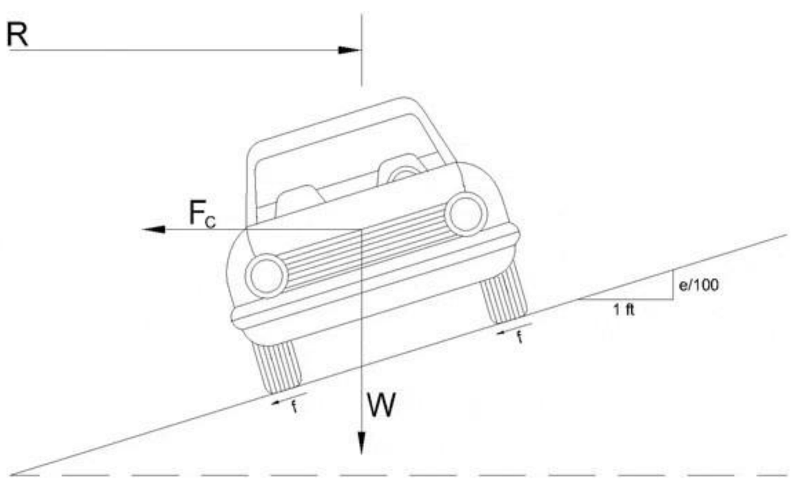
For safety the following condition must satisfy: $\frac{b}{2h} > \frac{v^2}{gR}$ The second tendency of the vehicle is for transverse skidding. i.e. When the centrifugal force is greater than the maximum possible transverse skid resistance due to friction between the pavement surface and tyre. The transverse skid resistance (F) is given by: $F = F_A + F_B = f(R_A + R_B) = fW$

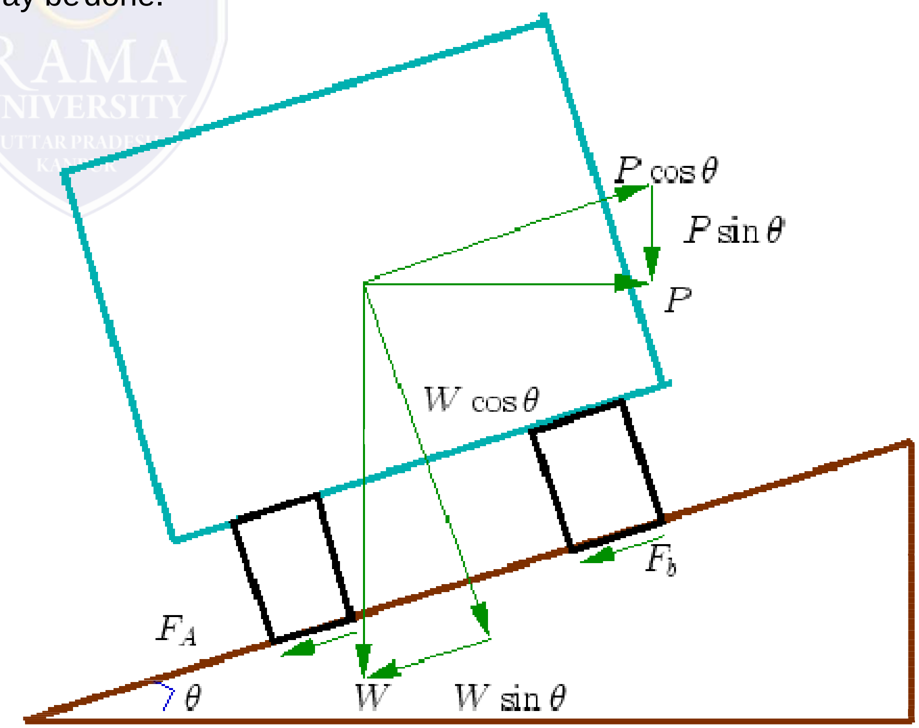
SUPER ELEVATION :

Where F_A and F_B is the fractional force at tyre A and B , R_A and R_B is the reaction at tyre A and B, f is the lateral coefficient of friction and W is the weight of the vehicle. This is counteracted by the centrifugal force (P), and equating: $P = fW$ or $\frac{P}{W} = f$

At equilibrium, when skidding takes place : $\frac{P}{W} = f = \frac{v^2}{gR}$ and for safety the following condition must satisfy: $f > \frac{v^2}{gR}$

Super Elevation is the transverse slope provided to counteract the effect of centrifugal force and reduce the tendency of vehicle to overturn and to skid laterally outwards by raising the pavement outer edge with respect to inner edge. Super Elevation is represented by “ e ”. Super-elevation or cant or banking is the transverse slope provided at horizontal curve to counteract the centrifugal force, by raising the outer edge of the pavement with respect to the inner edge, throughout the length of the horizontal curve. When the outer edge is raised, a component of the curve weight will be complimented in counteracting the effect of centrifugal force. In order to find out how much this raising should be, the following analysis may be done.





SUPER ELEVATION :

Forces acting on a vehicle on horizontal curve of radius **R** meters at a speed of v (m/s) are:

a) P the centrifugal force acting horizontally out-wards through the center of gravity,

b) W the weight of the vehicle acting down-wards through the center of gravity, and

c)F the friction force between the wheels and the pavement, along the surface inward.

At equilibrium, by resolving the forces parallel to the surface of the pavement we get,

$$\begin{aligned} P\cos\theta &= W\sin\theta + F_A + F_B \\ &= W\sin\theta + f(R_A + R_B) \\ &= W\sin\theta + f(W\cos\theta + P\sin\theta) \end{aligned}$$

where **W** is the weight of the vehicle, P is the centrifugal force, **f** is the coefficient of friction, ɵ is the transverse slope due to super-elevation. Dividing b **W cos ɵ**, we get:

$$\begin{aligned} \frac{P\cos\theta}{W\cos\theta} &= \frac{W\sin\theta}{W\cos\theta} + \frac{fW\cos\theta}{W\cos\theta} + \frac{fPsin\theta}{W\cos\theta} \\ \frac{P}{W} &= \tan\theta + f + f\frac{P}{W}\tan\theta \\ \frac{P}{W}(1 - f\tan\theta) &= \tan\theta + f \\ \frac{P}{W} &= \frac{\tan\theta + f}{1 - f\tan\theta} \end{aligned}$$

We have already derived an expression for P/W.By substituting , we get: $\frac{v^2}{gR} = \frac{\tan\theta + f}{1 - f\tan\theta}$

This is an exact expression for super-elevation. But normally, $f = 0.15$ and $\theta < 4^\circ$'$1 - f\tan\theta \approx 1$ and for small ɵ, $\tan\theta \approx \sin\theta = E/B = e$

then equation becomes: $e + f = \frac{v^2}{gR}$

where, **e** is the rate of super elevation, **f** the coefficient of lateral friction 0.15 , **v** the speed of the vehicle in **m / sec**, **R** the radius of the curve in **meter** and g = 9.8 m/sec^2

Three specific cases that can arise from equation are as follows:

CASE 1 : If there is no friction due to some practical reasons, then **f = 0** and equation becomes $e = \frac{v^2}{gR}$. . This results in the situation where the pressure on the outer and inner wheels are same; requiring very high super-elevation **e** .

CASE 2 : If there is no super-elevation provided due to some practical reasons, then **e = 0** and equation becomes $f = \frac{v^2}{gR}$. This results in a very high coefficient of friction **f**.

CASE 3 : If **e = 0** and **f = 0.15,** then for safe traveling speed from equation is given by $v_b = \sqrt{fgR}$ where v_b is the restricted speed.

Design speed plays a major role in designing the elements of horizontal alignment.

The most important element is super-elevation which is influenced by speed, radius of curve and frictional resistance of pavement.

Super elevation is necessary to balance centrifugal force.

While designing the various elements of the road like super-elevation, 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, super-elevation 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 super-elevation etc.

GUIDELINES ON DESIGN OF SUPER-ELEVATION :

While designing the various elements of the road like super-elevation, 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, super-elevation 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 super-elevation etc.

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 **e1 <= 0.07** , then $e = e_1 = \frac{(0.75v)^2}{gR}$, else if **e1 >= 0.07** go to step 3**.**

STEP 3 : Find **f1** 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 :

The amount of maximum and minimum Super-Elevation dependson :

(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 large radius of the horizontal curve.

ATTAINMENT OF SUPER-ELEVATION :

- 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 innerhalf.
- 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 sectionprogressively.
- Rotation of the pavement cross section to attain full super elevation by: There are two methods of attaining super-elevation by rotating the pavement
- Rotation about the center 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.
- 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 inneredge.

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 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.

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.

This phenomenon is called off-tracking, and has the effect of increasing the effective width of a road space required by the vehicle.

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.

Let **R_1** is the radius of the outer track line of the rear wheel, **R_2** 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 **W_m** is derived as:

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

Therefore the widening needed for a single lane road is: $W_m = \dfrac{l^2}{2R_2 - W_m}$

EXTRA WIDENING continues…….

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 $R_2 \approx R$ which is the mean radius of the curvature, then **Wm** is given by : $W_m = \frac{nl^2}{2R}$

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

Therefore, the tota widenin neede at a horizonta curve **W_e** is: $W_e = W_m + W_{ps}$

or, **We =** $\frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}}$

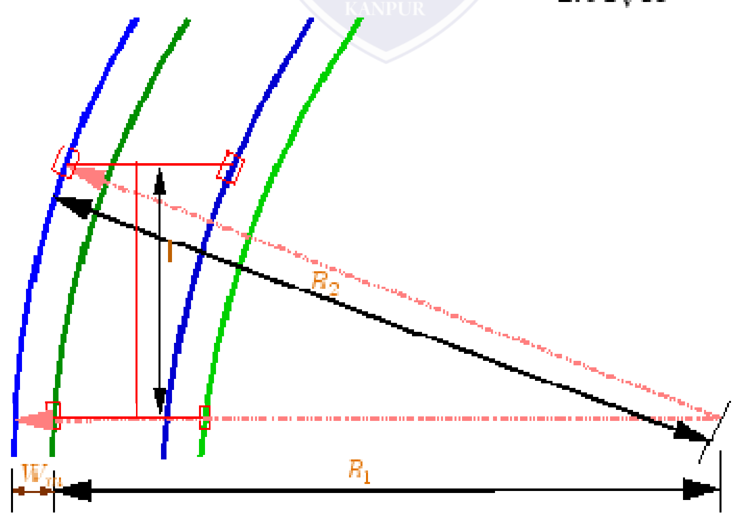


Figure : Extra-widening at a horizontal curve

RADIUS OF HORIZONTAL CURVE :

In our country, the design of super-elevation follows IRC guidelines wherein the initial design is done by considering 75% of design speed and the safety of design is assessed. Pavement is to be given extra width at curves to account for mechanical and psychological aspects.

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-elevation and coefficient of friction.

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

Ideally, the radius of the curve should be higher than **R_{Ruling}.**

However, very large curves are also not desirable.

Setting out large curves in the field becomes difficult.

In addition, it also enhances driving strain.

PROBLEMS RELATED TO THE TOPICS DISCUSSED :

1. A national highway passing through a rolling terrain has two horizontal curves of radius 450 m and 150 m. Design the required super-elevation for the curves as per IRC guidelines.
2. Given R=100m, V=50 kmph, f=0.15. Find:

a) If full lateral friction is assumed to develop [Answer: 0.047]

b) Find needed if no super elevation is provide [Answer: 0.197]

c) Find equilibrium super-elevation if pressure on inner and outer wheel should be equal (Hint: f=0) [Answer:0.197]

3. Two lane road, V=80 kmph, R=480 m, Width of the pavement at the horizontal curve=7.5 m.

   (i) Design super elevation for mixed traffic.

   (ii)By how much the outer edge of the pavement is to be raised with respect to the centerline, if the pavement is rotated with respect to centerline. [Answer:) 0.059 (ii) 0.22m]
4. Design rate of super elevation for a horizontal highway curve of radius 500 m and speed 100 kmph. [Answer: e=0.07, f=0.087 and within limits] Given V=80 kmph, R=200m.
5. Design for super elevation. (Hint: f=0.15) [Answer: Allowable speed is 74.75 kmph and e=0.07]
6. Calculate the ruling minimum and absolute minimum radius of horizontal curve of a NH in plain terrain. (Hint: V_{Ruling} = 100 kmph V_{min} =80kmph., e=0.07, f=0.15) [Answer: 360 and 230 m]
7. Find the extra widening for W=7m, R=250m, longest wheel base, l=7m, V=70kmph. (Hint: n=2) [Answer:0.662m]
8. 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). [Answer: R_{Ruling} =230m, We=0.71, W at HC =7.71m]

“Thank you”

Have Any Query ?

Ask us @ shashikant.fet@ramauniversity.ac.in or shashikantchitransh3@gmail.com