Chapter 15

Horizontal alignment II

15.1   Overview

This section discusses the design of superelevation and how it is attained. A brief discussion on pavement widening at curves is also given.

15.2   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.

15.2.1   Design of super-elevation

For fast moving vehicles, providing higher superelevation without considering coefficient of friction is safe, i.e. centrifugal force is fully counteracted by the weight of the vehicle or superelevation. For slow moving vehicles, providing lower superelevation considering coefficient of friction is safe, i.e.centrifugal force is counteracted by superelevation 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.

15.2.2 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 large radius of the horizontal curve.

15.2.3 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 superelevation by rotating the pavement

   (a) 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 superelevation, 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 superelevation with respect to the inner edge.

15.3 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 superelevation 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 superelevation and coefficient of friction.

$$R_{\text{ruling}} = \frac{v^2}{g(e + f)} \tag{15.1}$$

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.

15.4 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.

15.4.1   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 15.5. This phenomenon is called off-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. Trailor 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 15.5. 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 (refer figure 15:1) is derived below:

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

Therefore the widening needed for a single lane road is:

$$
W_m = \frac{l^2}{2R_2 - W_m} \tag{15.2}
$$

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,

$$
W_m = \frac{nl^2}{2R_2 - W_m} \tag{15.3}
$$

Please note that for large radius, $R_2 \approx R$, which is the mean radius of the curve,then W_m is given by:

$$
W_m = \frac{nl^2}{2R} \tag{15.4}
$$

15.4.2   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_{ps}:

$$
W_{ps} = \frac{v}{2.64\sqrt{R}} \tag{15.5}
$$

Therefore, the total widening needed at a horizontal curve W_e is:

$$\begin{aligned} W_e &= W_m + W_{ps} \\ &= \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}} \end{aligned} \qquad (15.6)$$
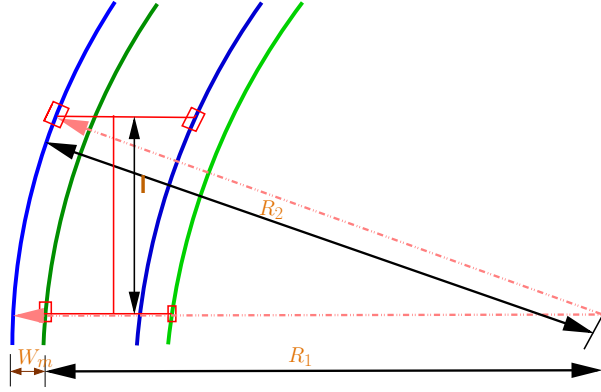

Figure 15:1: Extra-widening at a horizontal curve

15.5 Summary

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.

15.6 Problems

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.

    Solution

    Assumptions The ruling design speed for NH passing through a rolling terrain is 80 kmph. The coefficient of lateral friction f=0.15. The maximum permissible super elevation e=0.07.

    Case: Radius = 450m

    Step 1 Find e for 75 percent of design speed, neglecting f, i.e $e_1 = \frac{(0.75v)^2}{gR}$. $v = \frac{V}{3.6} = \frac{80}{3.6} = 22.22 m/sec$
    $e_1 = \frac{(0.75 \times 22.22)^2}{9.81 \times 450} = 0.0629$

    Step 2 $e_1 \leq 0.07$. Hence the design is sufficient.

    Answer: Design superelevation: 0.06.

Case: Radius = 150m

Step 1 Find e for 75 percent of design speed, neglecting f, i.e $e_1 = \frac{(0.75v)^2}{gR}$. $v = \frac{V}{3.6} = \frac{80}{3.6} = 22.22 m/sec$
$e_1 = \frac{(0.75 \times 22.22)^2}{9.81 \times 150} = 0.188$ Max.e to be provided $= 0.07$

Step 3 Find f_1 for the design speed and max e, i.e $f_1 = \frac{v^2}{gR} - e = \frac{22.22^2}{9.81 \times 150} - 0.07 = 0.265$.

Step 4 Find the *allowable speed* v_a for the maximum $e = 0.07$ and $f = 0.15$, $v_a = \sqrt{0.22gR} = \sqrt{0.22 \times 9.81 \times 150} = 17.99 m/sec = 17.99 \times 3.6 = 64 kmph$

2. 2.Given R=100m, V=50 kmph, f=0.15. Find:

    (a) e if full lateral friction is assumed to develop [Ans: 0.047]

    (b) find f needed if no super elevation is provide [Ans: 0.197]

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

3. 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. [Ans:(i) 0.059 (ii) 0.22m]

4. 4.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]

5. 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]

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

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

8. 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: R_{ruling}=230m, We=0.71, W at HC=7.71m]