

## Chapter 14

# Horizontal alignment I

### 14.1 Overview

Horizontal alignment is one of the most important features influencing the efficiency and safety of a highway. A poor design will result in lower speeds and resultant reduction in highway performance in terms of safety and comfort. In addition, it may increase the cost of vehicle operations and lower the highway capacity. Horizontal alignment design involves the understanding on the design aspects such as design speed and the effect of horizontal curve on the vehicles. The horizontal curve design elements include design of super elevation, extra widening at horizontal curves, design of transition curve, and set back distance. These will be discussed in this chapter and the following two chapters.

### 14.2 Design Speed

The design speed as noted earlier, is the single most important factor in the design of horizontal alignment. The design speed also depends on the type of the road. For e.g, the design speed expected from a National highway will be much higher than a village road, and hence the curve geometry will vary significantly.

The design speed also depends on the type of terrain. A plain terrain can afford to have any geometry, but for the same standard in a hilly terrain requires substantial cutting and filling implying exorbitant costs as well as safety concern due to unstable slopes. Therefore, the design speed is normally reduced for terrains with steep slopes.

For instance, Indian Road Congress (IRC) has classified the terrains into four categories, namely plain, rolling, mountainous, and steep based on the cross slope as given in table 14:1. Based on the type of road and type of terrain the design speed varies. The IRC has suggested desirable or ruling speed as well as minimum suggested design speed and is tabulated in table 14:2.

Table 14:1: Terrain classification

| Terrain classification | Cross slope (%) |
|------------------------|-----------------|
| Plain                  | 0-10            |
| Rolling                | 10-25           |
| Mountainous            | 25-60           |
| Steep                  | > 60            |

The recommended design speed is given in Table 14:2.

Table 14:2: Design speed in  $km/hr$  as per IRC (ruling and minimum)

| Type  | Plain  | Rolling | Hilly | Steep |
|-------|--------|---------|-------|-------|
| NS&SH | 100-80 | 80-65   | 50-40 | 40-30 |
| MDR   | 80-65  | 65-50   | 40-30 | 30-20 |
| ODR   | 65-50  | 50-40   | 30-25 | 25-20 |
| VR    | 50-40  | 40-35   | 25-20 | 25-20 |

### 14.3 Horizontal curve

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. Various forces acting on the vehicle is illustrated in the figure 14:1. 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  $P$  in  $kg/m^2$  is given by

$$P = \frac{Wv^2}{gR} \quad (14.1)$$

where  $W$  is the weight of the vehicle in  $kg$ ,  $v$  is the speed of the vehicle in  $m/sec$ ,  $g$  is the acceleration due to gravity in  $m/sec^2$  and  $R$  is the radius of the curve in  $m$ . The centrifugal ratio or the impact factor  $\frac{P}{W}$  is given by:

$$\frac{P}{W} = \frac{v^2}{gR} \quad (14.2)$$

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 other when the vehicle is just about to override is give as:

$$Ph = W \frac{b}{2} \quad \text{or} \quad \frac{P}{W} = \frac{b}{2h}$$

At the equilibrium over turning is possible when

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

and for safety the following condition must satisfy:

$$\frac{b}{2h} > \frac{v^2}{gR} \quad (14.3)$$

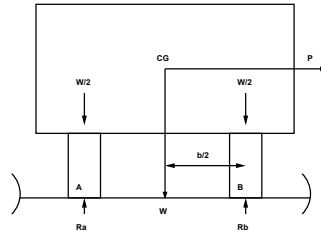


Figure 14:1: Effect of horizontal curve

The second tendency of the vehicle is for transverse skidding. i.e. When the the centrifugal force  $P$  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:

$$\begin{aligned} F &= F_A + F_B \\ &= f(R_A + R_B) \\ &= fW \end{aligned}$$

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:

$$P = fW \quad \text{or} \quad \frac{P}{W} = f$$

At equilibrium, when skidding takes place (from equation 14.2)

$$\frac{P}{W} = f = \frac{v^2}{gR}$$

and for safety the following condition must satisfy:

$$f > \frac{v^2}{gR} \quad (14.4)$$

Equation 14.3 and 14.4 give the stable condition for design. If equation 14.3 is violated, the vehicle will overturn at the horizontal curve and if equation 14.4 is violated, the vehicle will skid at the horizontal curve

## 14.4 Analysis of super-elevation

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. The forces acting on a vehicle while taking a horizontal curve with superelevation is shown in figure 14:2

Forces acting on a vehicle on horizontal curve of radius  $R$  m at a speed of  $v$  m/sec<sup>2</sup> are:

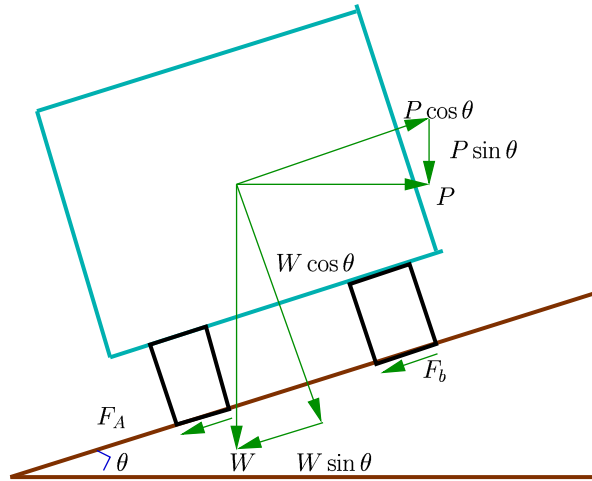


Figure 14:2: Analysis of super-elevation

- $P$  the centrifugal force acting horizontally out-wards through the center of gravity,
- $W$  the weight of the vehicle acting down-wards through the center of gravity, and
- $F$  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,  $\theta$  is the transverse slope due to superelevation. Dividing by  $W \cos \theta$ , we get:

$$\begin{aligned}
 \frac{P \cos \theta}{W \cos \theta} &= \frac{W \sin \theta}{W \cos \theta} + \frac{f W \cos \theta}{W \cos \theta} + \frac{f P \sin \theta}{W \cos \theta} \\
 \frac{P}{W} &= \tan \theta + f + f \frac{P}{W} \tan \theta \\
 \frac{P}{W} (1 - f \tan \theta) &= \tan \theta + f \\
 \frac{P}{W} &= \frac{\tan \theta + f}{1 - f \tan \theta}
 \end{aligned} \tag{14.5}$$

We have already derived an expression for  $P/W$  equation 14.2. By substituting this in equation 14.5, we get:

$$\frac{v^2}{gR} = \frac{\tan \theta + f}{1 - f \tan \theta} \tag{14.6}$$

This is an exact expression for superelevation. But normally,  $f = 0.15$  and  $\theta < 4^\circ$ ,  $1 - f \tan \theta \approx 1$  and for small  $\theta$ ,  $\tan \theta \approx \sin \theta = E/B = e$ , then equation 14.6 becomes:

$$e + f = \frac{v^2}{gR} \tag{14.7}$$

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  $m$  and  $g = 9.8m/sec^2$ .

Three specific cases that can arise from equation 14.7 are as follows:

- 1 If there is no friction due to some practical reasons, then  $f = 0$  and equation 14.7 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  $e$ .
- 2 If there is no super-elevation provided due to some practical reasons, then  $e = 0$  and equation 14.7 becomes  $f = \frac{v^2}{gR}$ . This results in a very high coefficient of friction.
- 3 If  $e = 0$  and  $f = 0.15$  then for safe traveling speed from equation 14.7 is given by  $v_b = \sqrt{fgR}$  where  $v_b$  is the restricted speed.

## 14.5 Summary

Design speed plays a major role in designing the elements of horizontal alignment. The most important element is superelevation which is influenced by speed, radius of curve and frictional resistance of pavement. Superelevation is necessary to balance centrifugal force. The design part is dealt in the next chapter.

## 14.6 Problems