

TRANSPORTATION ENGINEERING

UNIT-II

2.1 Importance of geometric Design

The geometric design of highways deals with the dimensions and layout of visible features of the highway. The emphasis of the geometric design is to address the requirement of the driver and the vehicle such as safety, comfort, efficiency, etc.

Geometric design of highways deals with following elements:

- i. Cross section elements
- ii. Sight distance consideration
- iii. Horizontal alignment details
- iv. Vertical alignment details
- v. Intersection elements

2.1.1 Factors affecting geometric design

Factors affecting the geometric designs are as follows:

- i. Design speed
- ii. Topography
- iii. Traffic factors
- iv. Design hourly volume and capacity
- v. Environmental and other factors

Design speed: Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves. Since the speed of vehicles vary with driver, terrain etc, a design speed is adopted for all the geometric design.

Topography: It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multi form with the gradient and the terrain.

Traffic: It will be uneconomical to design the road for peak traffic flow. Therefore a reasonable value of traffic volume is selected as the design hourly volume which is determined from the various traffic data collected.

Environmental: Factors like air pollution, noise pollution etc. should be given due consideration in the geometric design of roads.

Economy: The design adopted should be economical as far as possible. It should match with the funds allotted for capital cost and maintenance cost.

Others: Geometric design should be such that the aesthetics of the region is not affected

2.2 Cross sectional elements

The feature of the cross-section of the pavement influences the life of the pavement as well as the riding comfort and safety.

2.2.1 Pavement surface characteristics:

For a safe and comfortable driving four aspects of the pavement surface are important;

Friction: Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed. Further, it also affects the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skidding or slipping of vehicles. Various factors that affect friction are: Type of the pavement (like bituminous, concrete, or gravel), Condition of the pavement (dry or wet, hot or cold, etc.), Condition of the tire (new or old), and Speed and load of the vehicle. The choice of the value of f is a very complicated issue since it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed and coefficient of lateral friction as 0.15.

Unevenness: It affects the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tires. Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulation of the pavement surface recorded per unit horizontal length of the road.

Light reaction: White roads have good visibility at night, but caused glare during day time. Black roads has no glare during day, but has poor visibility at night

Drainage: The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers.

2.2.2 Cross Slope or Camber

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain off rain water from road surface. The objectives of providing camber are: Surface protection especially for gravel and bituminous roads Sub-grade protection by proper drainage. Quick drying of pavement which in turn increases safety.

Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface. The values suggested by IRC for various categories of pavement is given in Table 2.1. The common types of camber are parabolic, straight, or combination of them (Fig 2.1)

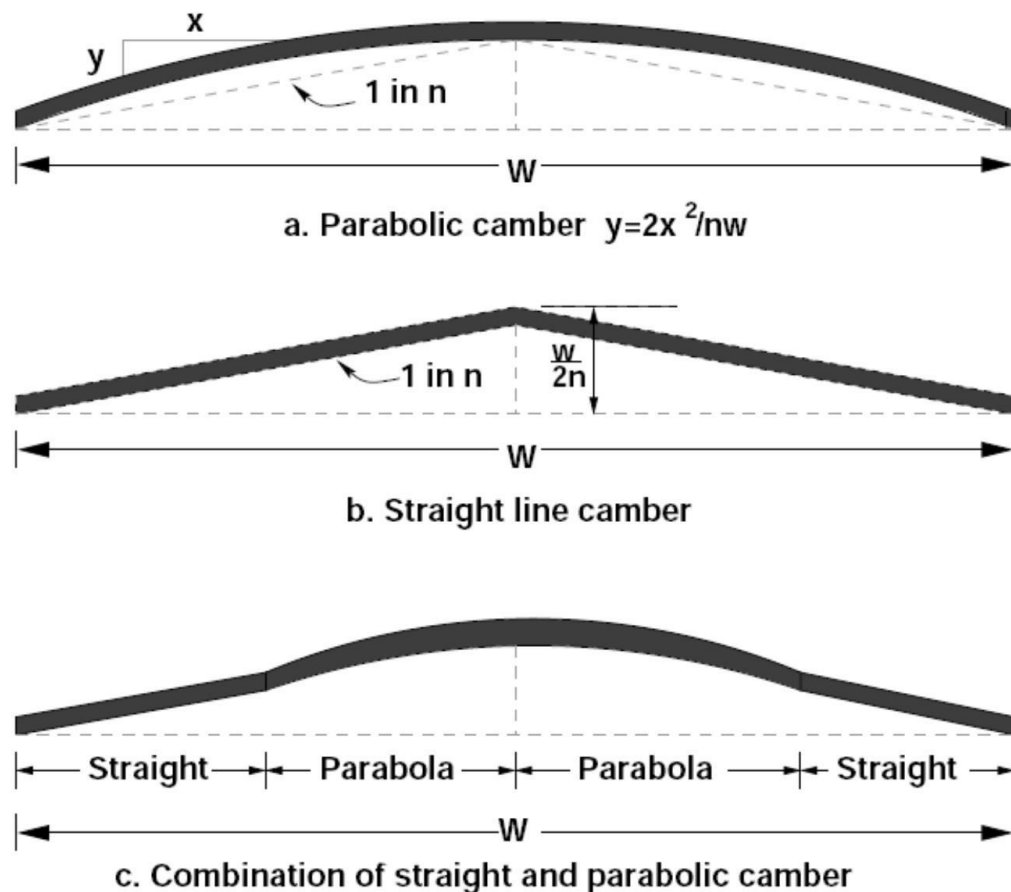


Fig. 2.1 Different types of camber

Table 2.1: IRC Values for camber

Type of surface	Heavy Rainfall	Low Rainfall
CC roads	1 in 50	1 in 60
Thin bituminous roads	1 in 40	1 in 50
Water Bound Macadam roads	1 in 33	1 in 40
Village Roads	1 in 25	1 in 33

2.2.3 Width of pavement or Carriageway

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.44 and the desirable side clearance for single lane traffic is 0.68 m. This require minimum of lane width of 3.75 m for a single lane road (Fig 2.2). However, the side clearance required is about 0.53 m, on both side and 1.06 m in the center. Therefore, a two lane road require minimum of 3.5 meter for each lane (Fig 2.2). The desirable carriage way width recommended by IRC is given in Table 2.2.

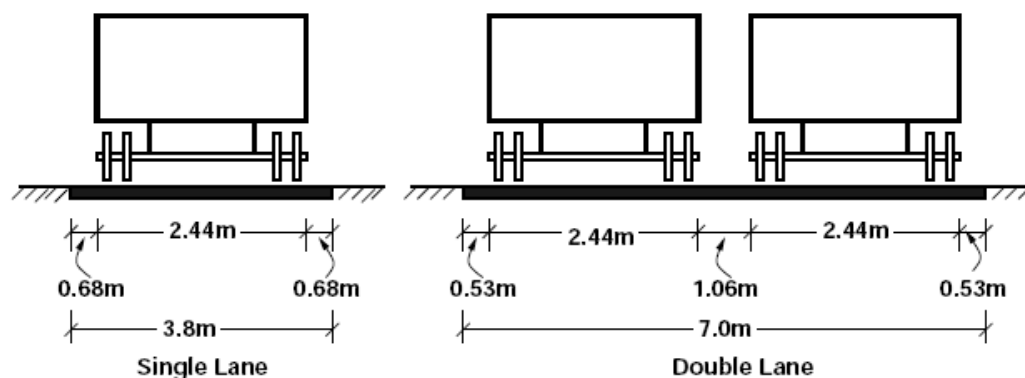


Fig. 2.2 Lane width for single and two lane roads

Table 22: IRC Speciation for carriage way width

Class of road	Width of carriageway
Single lane	3.75 m
Two lane, no kerbs	7.0 m
Two lane, raised kerbs	7.5 m
Intermediate carriage	5.5 m
Multi-lane	3.5 m per lane

2.2.4 Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are (Fig. 2.3).

Low or mountable kerbs: These types of kerbs are provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty.

Semi-barrier type kerbs: When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm above the pavement edge.

Barrier type kerbs: They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.

Submerged kerbs: They are used in rural roads. The kerbs are provided at pavement edges between the pavement edge and shoulders. They provide lateral confinement and stability to the pavement.

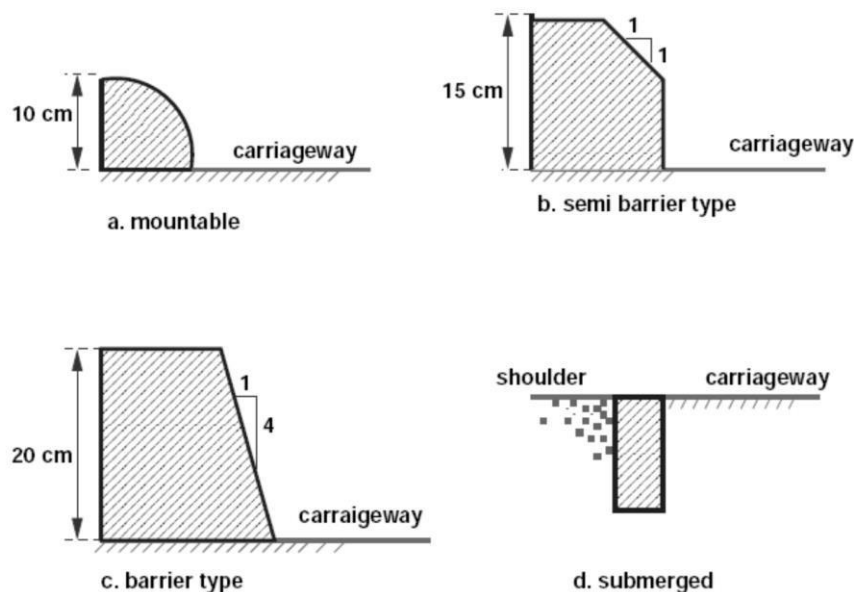


Fig. 2.3 Different types of Kerbs.

2.2.5 Road margins

The portion of the road beyond the carriageway and on the roadway can be generally called road margin. Various elements that form the road margins are given below.

Shoulders: A shoulder are provided along the road edge and is intended for accommodation of stopped vehicles, serve as an emergency lane for vehicles and provide lateral support for base and surface courses. The shoulder should be strong enough to bear the weight of a fully loaded truck even in wet conditions.

Parking lanes: Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for the vehicles moving in the road. The parking lane should have a minimum of 3.0 m width in the case of parallel parking.

Bus-bays: Bus bays are provided by recessing the kerbs for bus stops. They are provided so that they do not obstruct the movement of vehicles in the carriage way.

Service roads: Service roads or frontage roads give access to access controlled highways like freeways and expressways. They run parallel to the highway and will be usually isolated by a separator and access to the highway will be provided only at selected points.

Cycle track: Cycle tracks are provided in urban areas when the volume of cycle traffic is high. Minimum width of 2 meter is required, which may be increased by 1 meter for every additional track.

Footpath: Footpaths are exclusive right of way to pedestrians, especially in urban areas. They are provided for the safety of the pedestrians when both the pedestrian traffic and vehicular traffic is high. **Guard rails:** They are provided at the edge of the shoulder usually when the road is on an embankment. They serve to prevent the vehicles from running on the embankment, especially when the height of the fill exceeds 3 m.

2.2.6 Width of formation

Width of formation or roadway width is the sum of the widths of pavements or carriage way including separators and shoulders. This does not include the extra land in formation/cutting. The values suggested by IRC are given in Table 2.3.

Table 2.3 Width of formation for various classed of roads

Road classification	Roadway width in m	
	Plain and Rolling terrain	Mountainous and Steep terrain
NH / SH	12.00	6.25 – 8.80
MDR	9.00	4.75
ODR	7.50 – 9.00	4.75
VR	7.50	4.00

2.2.7 Right of way

Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development.

Width of formation: It depends on the category of the highway and width of roadway and road margins. Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment. Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc. Drainage system and their size which depends on rainfall, topography etc. The importance of reserved land is emphasized by the following Extra width of land is available for the construction of roadside facilities.

The importance of reserved land is emphasized by the following. Extra width of land is available for the construction of roadside facilities. Land acquisition is not possible later, because the land may be occupied for various other purposes (buildings, business etc.) The normal ROW requirements for built up and open areas as specified by IRC is given in Table 2.4. A typical cross section of a ROW is given in Fig.2.4.

Table 2.4 Normal right of way for open areas

Road classification	Roadway width in m	
	Plain and Rolling terrain	Mountainous and Steep terrain
Open areas		
NH / SH	45	24
MDR	25	18
ODR	15	15
VR	12	9
Built-up areas		
NH / SH	30	20
MDR	20	15
ODR	15	12
VR	10	9

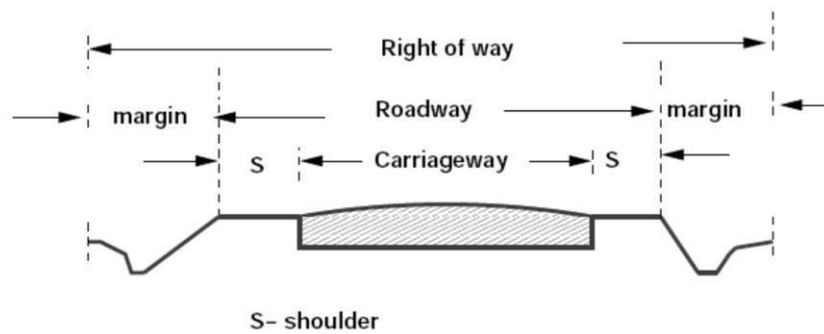


Fig. 2.4 A typical Right of way (ROW)

2.3 Sight distance

The safe and efficient operation of vehicles on the road depends very much on the visibility of the road ahead of the driver.

2.3.1 Types of sight distance

Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects.

Three sight distance situations are considered for design:

1. Stopping sight distance (SSD) or the absolute minimum sight distance
2. Intermediate sight distance (ISD) is defined as twice SSD and
3. Overtaking sight distance (OSD) for safe overtaking operation
4. Head light sight distance is the distance visible to a driver during night driving under the illumination of head light

Safe sight distance to enter into an intersection depends on:

2.3.2 Stopping sight distance (SSD)

The most important consideration in all these is that at all times the driver traveling at the design speed of the highway must have sufficient carriageway distance within his line of vision to allow him to stop his vehicle before colliding with a slowly moving or stationary object appearing suddenly in his own traffic lane.

The computation of sight distance depends on:

- **Reaction time of the driver:**

Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory (Perception time, Intellectual time, Emotion time, and Volition time). In practice, all these times are usually combined into a total perception- reaction time suitable for design purposes as well as for easy measurement.

- **Speed of the vehicle:**

The speed of the vehicle very much affects the sight distance. Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.

- **Efficiency of brakes:**

The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied. But practically, it is not possible to achieve 100% brake efficiency.

- **Frictional resistance between the tire and the road:**

The frictional resistance between the tire and road plays an important role to bring the vehicle to stop. When the frictional resistance is more, the vehicles stop immediately. Thus sight required will be less. No separate provision for brake efficiency is provided while computing the sight distance.

- **Gradient of the road:**

Gradient of the road also affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less.

2.3.2.1 Analysis of stopping distance

SSD is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

Lag distance: is the distance the vehicle travelled during the reaction time t and is given by vt , where v is the velocity in m/sec. (or) $0.278Vt$, where V in Kmph.

Braking distance: is the distance travelled by the vehicle during braking operation. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle. If F is the maximum frictional force developed and the braking distance is l , then work done against friction in stopping the vehicle is $Fl = fWl$ where W is the total weight of the vehicle. The kinetic energy at the design speed is

$$\frac{1}{2}mv^2 = \frac{1}{2} \frac{Wv^2}{g}$$

$$fWl = \frac{Wv^2}{2g}$$

$$l = \frac{v^2}{2g}$$

$$2gf$$

Therefore, the SSD = lag distance + braking distance and given by: $SSD = vt + \frac{v^2}{2gf}$

Where v is the design speed in m/sec,

t is the reaction time in sec,

g is the acceleration due to gravity and

f is the coefficient of friction. The coefficient of friction f is given below for

Speed, Kmph	<30	40	50	60	>80
F	0.40	0.38	0.37	0.36	0.35

When there is an ascending gradient of say +n%, the component of gravity adds to braking action and hence braking distance is decreased. The component of gravity acting parallel to the surface which adds to the braking force is equal to $W \sin \alpha = W \tan \alpha = Wn/100$. Equating kinetic energy and work done:

$$\left(fW + \frac{Wn}{100}\right)l = \frac{Wv^2}{2g}$$

$$l = \frac{v^2}{2g(f + 0.01n)}$$

Similarly the braking distance can be derived for a descending gradient. Therefore the general equation is given by Equation

$$SSD = vt + \frac{v^2}{2g(f \pm 0.01n)}$$

2.3.3 Overtaking sight distance (OSD)

The overtaking sight distance is the minimum distance open to the vision of the driver of a vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction. The overtaking sight distance or passing sight distance is measured along the center line of the road over which a driver with his eye level 1.2m above the road surface can see the top of an object 1.2 m above the road surface.

The factors that affect the OSD are:

- Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.
- Spacing between vehicles, which in-turn depends on the speed
- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road

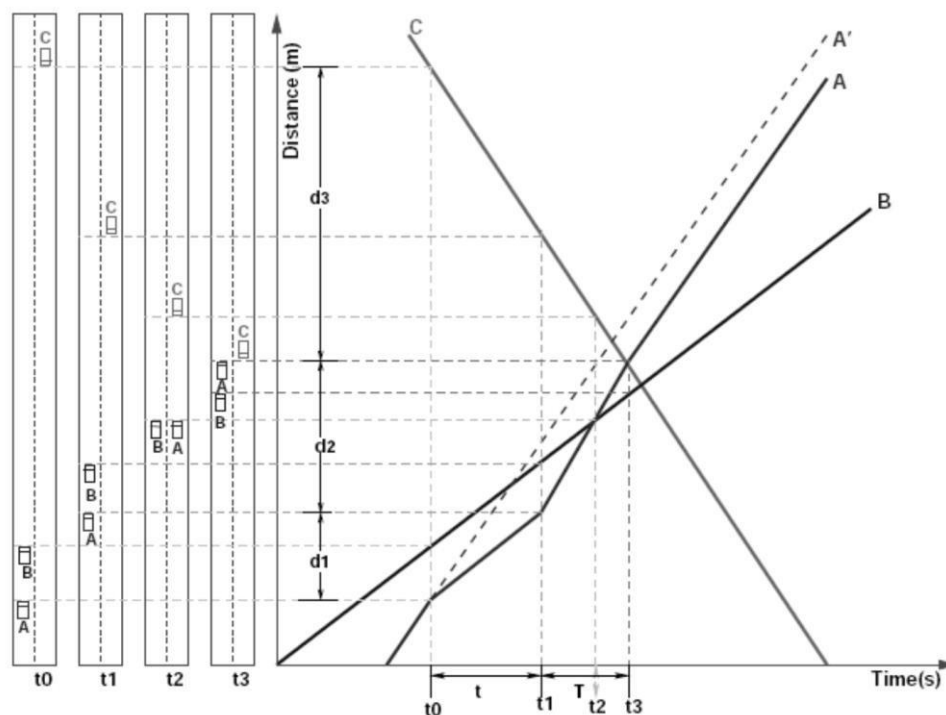


Fig. 2.5 Time-space diagram: Illustration of overtaking sight distance

The dynamics of the overtaking operation is given in the Fig which is a time-space diagram. The x-axis denotes the time and y-axis shows the distance travelled by the vehicles. The trajectory of the slow moving vehicle (B) is shown as a straight line which indicates that it is traveling at a constant speed. A fast moving vehicle (A) is traveling behind the vehicle B. The trajectory of the vehicle is shown initially with a steeper slope. The dotted line indicates the path of the vehicle A if B was absent. The vehicle A slows down to follow the vehicle B as shown in the Fig with same slope from t_0 to t_1 . Then it overtakes the vehicle B and occupies the left lane at time t_3 . The time duration $T = t_3 - t_1$ is the actual duration of the overtaking operation. The snapshots of the road at time t_0 , t_1 , and t_3 are shown on the left side of the Fig. From the Fig.2.5, the overtaking sight distance consists of three parts.

d_1 the distance travelled by overtaking vehicle A during the reaction time $t = t_1 - t_0$

d_2 the distance travelled by the vehicle during the actual overtaking operation $T = t_3 - t_1$

d_3 is the distance travelled by on-coming vehicle C during the overtaking operation (T).

Therefore:

$$OSD = d_1 + d_2 + d_3$$

It is assumed that the vehicle A is forced to reduce its speed to v_b , the speed of the slow moving vehicle B and travels behind it during the reaction time t of the driver. So d_1 is given by:

$$d_1 = v_b t$$

Then the vehicle A starts to accelerate, shifts the lane, overtake and shift back to the original lane. The vehicle A maintains the spacing s before and after overtaking. The spacing s in m is given by:

$$s = 0.7v_b + 6$$

Let T be the duration of actual overtaking. The distance travelled by B during the overtaking operation is $2s + v_b T$. Also, during this time, vehicle A accelerated from initial velocity v_b and overtaking is completed while reaching final velocity v . Hence the distance travelled is given by:

$$d_2 = v_b T + \frac{1}{2} a T^2$$

$$T = \sqrt{\frac{4s}{a}}$$

overtaking operation is given by:

$$d_3 = vT$$

The overtaking sight distance is (Fig.2.5)

$$OSD = d_1 + d_2 + d_3$$

Where v_b is the velocity of the slow moving vehicle in m/s^2 , t is the reaction time of the driver in sec, s is the spacing between the two vehicle in m given by equation and a is the overtaking vehicles acceleration in m/s^2 . In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph slower the design speed (V-16).

The acceleration values of the fast vehicle depends on its speed and given in Table 2.5

Table 2.5: Maximum overtaking acceleration at different speeds

Speed (kmph)	Maximum overtaking acceleration (m/sec^2)
25	1.41
30	1.30
40	1.24
50	1.11
65	0.92
80	0.72
100	0.53

- On divided highways (one way traffic), d_3 need not be considered.
- On divided highways with four or more lanes, IRC suggests that it is not necessary to provide the OSD, but only SSD is sufficient.

2.3.3.1 Overtaking zones

Overtaking zones are provided when OSD cannot be provided throughout the length of the highway. These are zones dedicated for overtaking operation, marked with wide roads. The desirable length of overtaking zones is 5 time OSD and the minimum is three times OSD (Fig. 2.6).

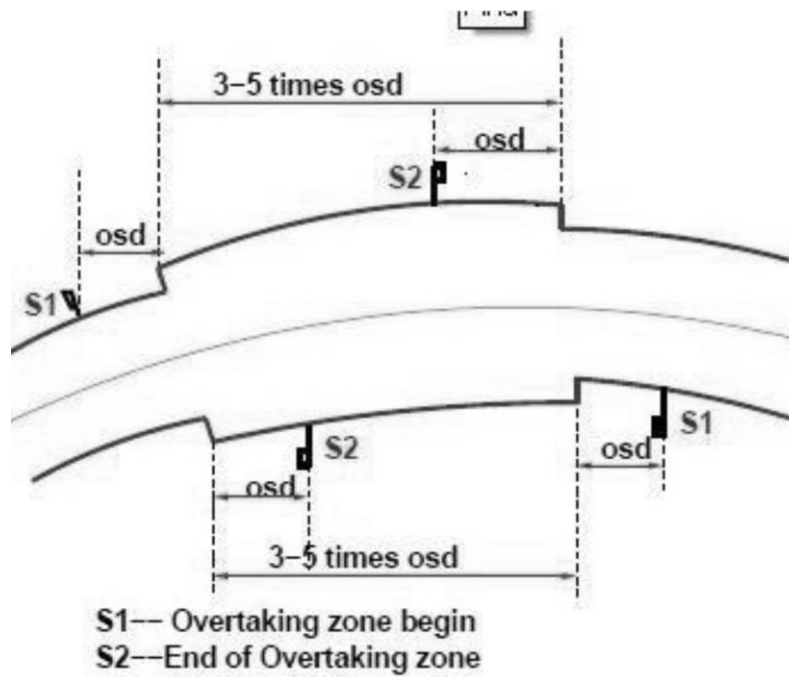


Fig. 2.6 Overtaking zones

2.3.3.2 Sight distance at intersections

At intersections where two or more roads meet, visibility should be provided for the drivers approaching the intersection from either sides. They should be able to perceive a hazard and stop the vehicle if required. Stopping sight distance for each road can be computed from the design speed. The sight distance should be provided such that the drivers on either side should be able to see each other. This is illustrated in the Fig. 2.7.

Design of sight distance at intersections may be used on three possible conditions:

- Enabling approaching vehicle to change the speed
- Enabling approaching vehicle to stop
- Enabling stopped vehicle to cross a main road

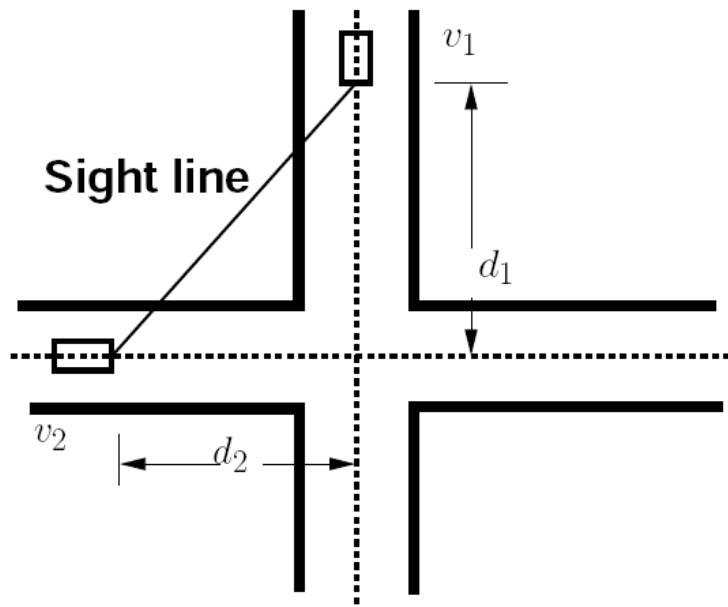


Fig. 2.7 Sight distance at intersections

2.4 Horizontal Alignment

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.

2.4.1 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 2.6. 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. The recommended design speed is given in Table 2.7.

Table 2.6 Terrain classification

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

Table 2.7 Design speed in kmph as per IRC (ruling and minimum)

Type	plain	Rolling	Mountainous	Steep
NH & SH	100 – 80	80 – 65	50 – 40	40 – 30
MDR	80 – 65	65 – 50	40 – 30	30 – 20
ORD	65 – 50	50 – 40	30 – 25	25 – 20
VR	50 - 40	40 - 35	25 - 20	25 – 20

2.4.2 Horizontal curve

The presence of horizontal curve imparts centrifugal force which is 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 are illustrated in the Fig.2.8.

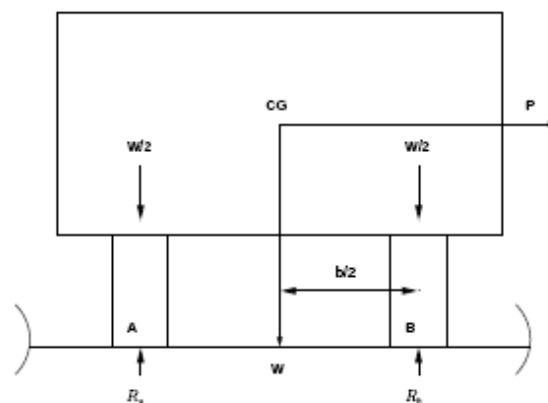


Fig. 2.8 Effect of horizontal curve

They are the centrifugal force (P) acting outward, weight of the vehicle (W) acting downward, and the reaction of the ground on the wheels (RA and RB). 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/m² is given by

$$P = \frac{Wv^2}{gR}$$

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/sec² and R is the radius of the curve in m.

The centrifugal ratio or the impact factor $\frac{P}{W}$ is given by

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

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,

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

At the equilibrium over turning is possible when

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

and for safety the following condition must satisfy:

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

The second tendency of the vehicle is for transverse skidding. i.e. When the centrifugal force P is greater than the maximum possible transverse skid resistance due to friction between the pavement surface and tire. The transverse skid resistance (F) is given by

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

where F_A and F_B is the fractional force at tire A and B, R_A and R_B is the reaction at tire 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

At equilibrium, when skidding takes place

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

and for safety the following condition must satisfy:

$$f > \frac{v^2}{gR}$$

2.4.1 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 Fig.2.9.

Forces acting on a vehicle on horizontal curve of radius R m at a speed of v m/sec are:

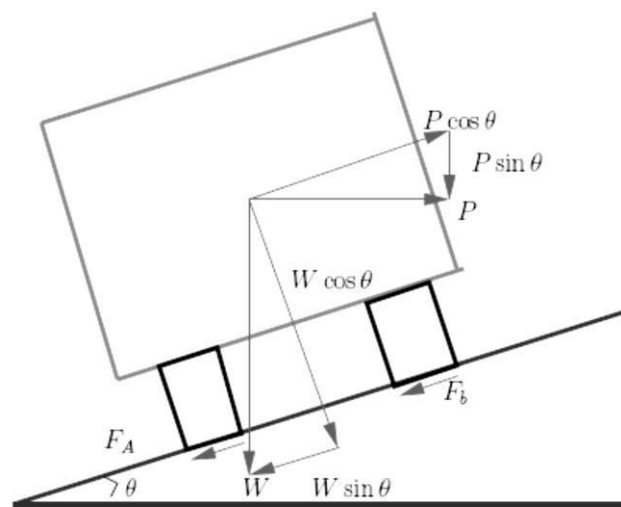


Fig. 2.9 Analysis of superelevation

- 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, f is the transverse slope due to super elevation. Dividing by W cos θ, we get:

$$\frac{P \cos \theta}{W \cos \theta} = \frac{W \sin \theta}{W \cos \theta} + \frac{f W \cos \theta}{W \cos \theta} + \frac{f P \sin \theta}{W \cos \theta}$$

$$\frac{P}{W} = \tan \theta + f + \frac{P}{W} \tan \theta$$

$$\frac{P}{W} = \frac{\tan\theta + f}{1 - f \tan\theta}$$

We have already derived an expression for P/W.

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

Relatively $f \tan\theta$ can be neglected.

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

2.4.1 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.

$$R_{\text{ruling}} = \frac{v^2}{ge}$$

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.

2.4.2 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 to as the mechanical widening and the second is called the psychological widening. These are discussed in detail below.

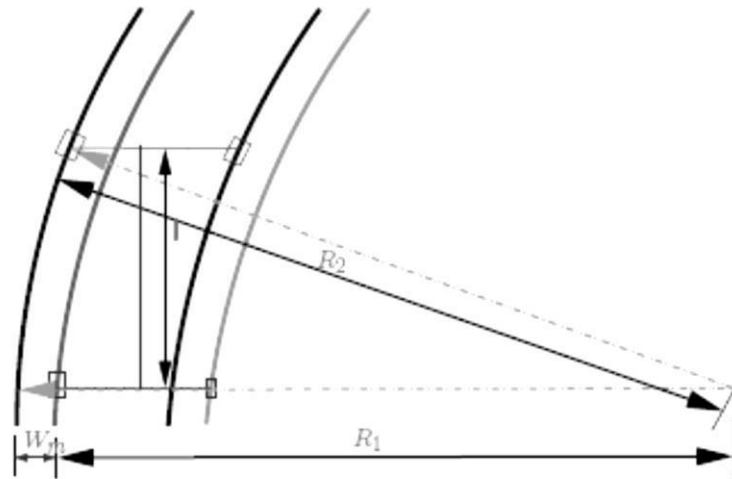


Fig. 2.10 Extra-widening at a horizontal curve

2.4.5.1 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 Fig. 2.10. 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. 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 Fig. 2.10. 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 given below

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

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

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 given as

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

Where, V in Km/h, R in metres.

Therefore, Extra widening, $W_e = W_m + W_{ps}$

2.4.6 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.

2.4.6.1 Type of transition curve

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

1. It fully fills the requirement of an ideal transition curve, that is;
 - (a) rate of change of 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 ($L_s \propto 1/R$) and calculation and field implementation is very easy.

2.4.6.2 Length of transition curve:

The length of the transition curve should be determined as the maximum of the following three criteria: rate of change of centrifugal acceleration, rate of change of super elevation, and an 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:

Therefore, the length of the transition curve L_{s1} in m is

$$L_{s1} = \frac{v^3}{CR}$$

Where, v in m/sec

‘ C ’ is the rate of change of centrifugal acceleration given by an empirical formula suggested by IRC as

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

Where, V in Kmph and C value lies between 0.5-0.8 ($0.5 < C < 0.8$).

2. Rate of introduction of super-elevation:

Raise (E) of the outer edge with respect to inner edge is given by $E = eB = e(W + W_e)$. 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:

$$L_{s2} = N e(W + W_e)$$

3. **By empirical formula:** IRC suggest the length of the transition curve is minimum for a plain and rolling terrain:

$$L_{s3} = \frac{2.7V^2}{R}$$

For mountainous terrain:

$$L_{s3} = \frac{V^2}{R}$$

Where, V in Kmph

2.5. Vertical Alignment

The vertical alignment of a road consists of gradients (straight lines in a vertical plane) and vertical curves. The vertical alignment is usually drawn as a profile, which is a graph with elevation as vertical axis and the horizontal distance along the centre line of the road as the horizontal axis.

2.5.1 Gradient

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided designing the vertical curve. Before finalizing the gradients, the construction cost, vehicular operation cost and the practical problems in the site also has to be considered.

2.5.1.1 Types of gradient

Many studies have shown that gradient up to seven percent can have considerable effect on the speeds of the passenger cars. On the contrary, the speeds of the heavy vehicles are considerably reduced when long gradients as low as two percent is adopted. Although, lower gradients are desirable, it is evident that the cost of construction will also be very high.

Ruling gradient: The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road. This depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve. In flatter terrain, it may be possible to provide low gradients, but in hilly terrain it is not economical and sometimes not possible also.

Minimum gradient: This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains requires some slope for smooth flow of water.

Limiting gradient: This gradient is adopted when the ruling gradient results in enormous increase in cost of construction. On rolling terrain and hilly terrain it may be frequently necessary to adopt limiting gradient.

Exceptional gradient: Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 meters at a stretch.

2.5.2 Summit curve

Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet as illustrated in figure below in any of the following four ways:

1. When a positive gradient meets another positive gradient
2. When positive gradient meets a negative gradient
3. When an ascending gradient meets a descending gradient.
4. When a descending gradient meets another descending gradient

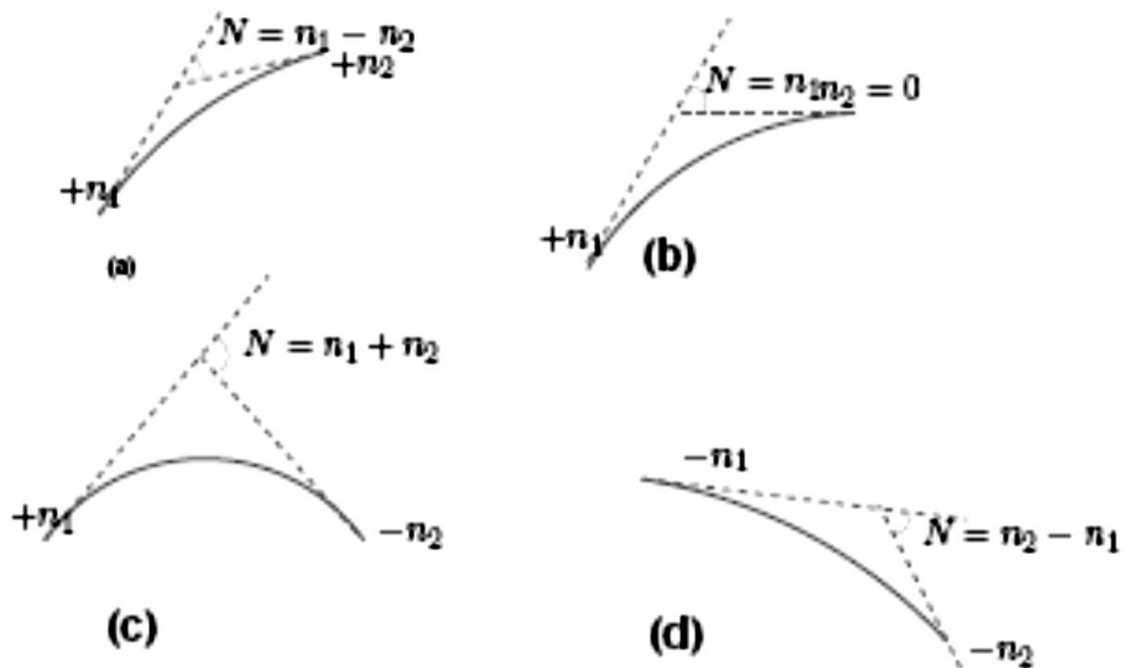


Fig. 2.11 Types of summit curves

2.5.2.1 Type of Summit Curve

Many curve forms can be used with satisfactory results; the common practice has been to use parabolic curves in summit curves. This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient to another.

Length of the summit curve The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration. Distance .Let L is the length

Case a: Length of summit curve greater than sight distance. The situation when the sight distance is less than the length of the curve ($L > SSD$)

$$L = \frac{NS^2}{2(\sqrt{h_1} + \sqrt{h_2})^2}$$

Case b: Length of summit curve less than sight distance ($L < SSD$)

When stopping sight distance is considered the height of driver's eye above the road surface (h_1) is taken as 1.2 meters, and height of object above the pavement surface (h_2) is taken as 0.15 meters. If overtaking sight distance is considered, then the value of driver's eye height (h_1) and the height of the obstruction (h_2) are taken equal as 1.2 meters.

$$L = 2S - \frac{(\sqrt{2h_1} + \sqrt{2h_2})^2}{N}$$

2.5.3 Valley curve

Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet as illustrated in figure below in any of the following four ways:

1. When a descending gradient meets another descending gradient
2. When a descending gradient meets at gradient
3. When a descending gradient meets an ascending gradient

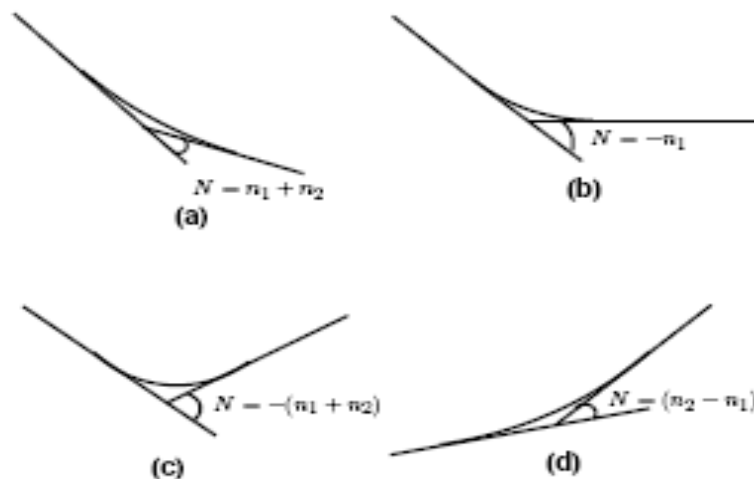


Fig. 2.12 Types of valley curve

2.5.3.1 Length of the valley curve

The valley curve is made fully transitional by providing two similar transition curves of equal length. The transitional curve is set out by a cubic parabola $y = bx^3$ where $b = 2N/3L^2$. The length of the valley transition curve is designed based on two criteria:

1. Comfort criteria; that is allowable rate of change of centrifugal acceleration is limited to a comfortable level of about 0.06m/s^3 .
2. Safety criteria; that is the driver should have adequate headlight sight distance at any part of the country.

Safety criteria Length of the valley curve for headlight distance may be determined for two conditions: length of the valley curve greater than stopping sight distance and Length of the valley curve less than the stopping sight distance.

Case 1: Length of valley curve greater than stopping sight distance ($L > S$):

The total length of valley curve L is greater than the stopping sight distance SSD . The sight distance available will be minimum when the vehicle is in the lowest point in the valley. This is because the beginning of the curve will have infinite radius and the bottom of the curve will have minimum radius which is a property of the transition curve.

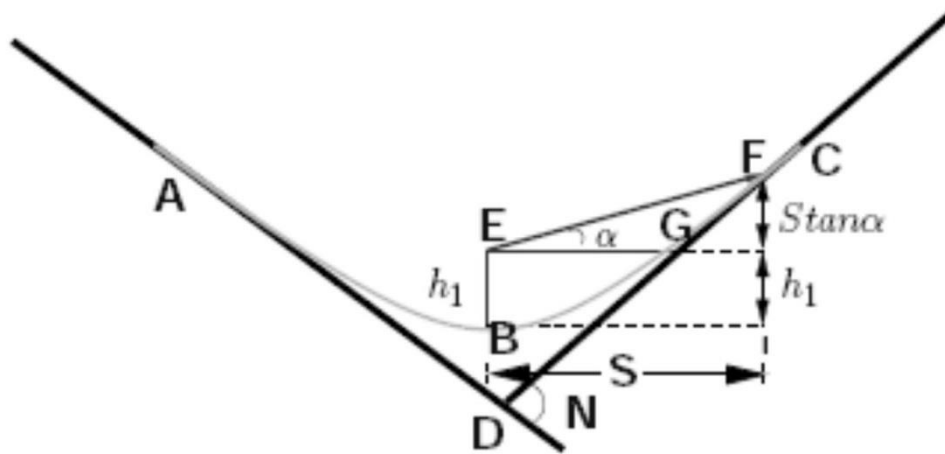


Fig. 2.13 Valley curve, case1, $L > S$

Where L is the total length of valley curve, N is the deviation angle in radians or tangent of the deviation angle or the algebraic difference in grades, and c is the allowable rate of change of centrifugal acceleration which may be taken as 0.06 m/s^3 .

Where N is the deviation angle in radians, h_1 is the height of headlight beam, α is the head beam inclination in degrees and S is the sight distance. The inclination α is = 1 degree.

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

Case 2 Length of valley curve less than stopping sight distance ($L < S$):

The length of the curve L is less than SSD. In this case the minimum sight distance is from the beginning of the curve. The important points are the beginning of the curve and the bottom most part of the curve. If the vehicle is at the bottom of the curve, then its headlight beam will reach far beyond the endpoint of the curve whereas, if the vehicle is at the beginning of the curve, then the headlight beam will hit just outside the curve. Therefore, the length of the curve is derived by assuming the vehicle at the beginning of the curve. The case is shown in figure below.

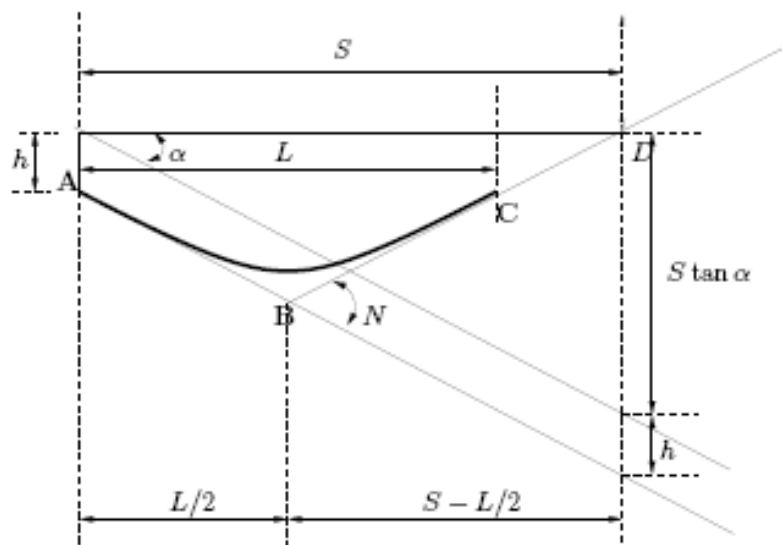


Fig. 2.14 Valley curve, case 2, $S > L$

$$L = 2S - \frac{2h + 2S \tan \alpha}{N}$$

