2.3 CURVES

HORIZONTAL CURVES

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.

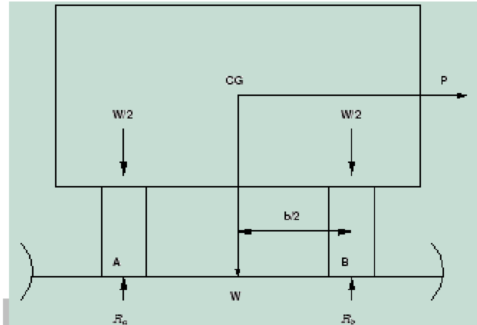


Figure 1: Effect of horizontal curve

The centrifugal force P in kg/m^2

$$P=Wv^2/gR$$

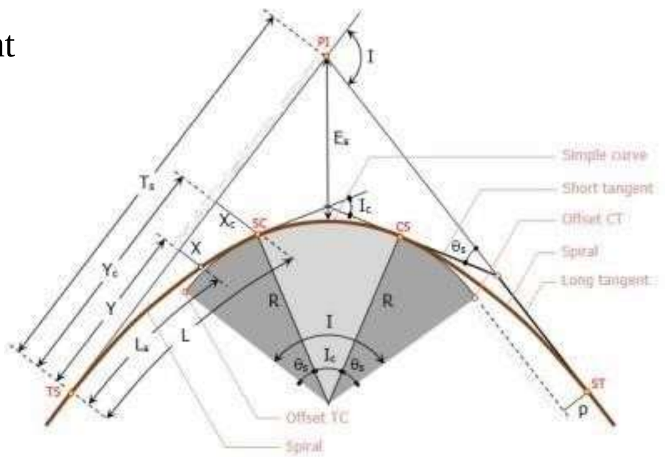
Where W is the weight of the vehicle in kg, v is the speed of the vehicle in m/sec, g is the acceleration due to gravity in m/sec^2 and R is the radius of the curve in m.

Two effects of horizontal curve,

1. Overturning effect
2. Skidding effect

TRANSITION CURVE

A transition curve has a radius which decreases from infinity at the tangent point to a designed radius of the circular curve. The rate of change of the radius of the transition curve will depend on the equation of the curve or its slope.



Thus the functions of transition curves in the horizontal alignment of highway may be summed up into the following points.

- ✓ To introduce gradually, the centrifugal force between the tangent point and the circular curve.

1. To enable the driver turn the steering gradually for his own comfort and security.
2. To improve the aesthetic appearance of the road.

Different types of transition curves:

1. Spiral
2. Lemniscate
3. Cublic parabola.

EXTRA WIDENING AT CURVES

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.

- ✓ Additional width required for a vehicle taking a horizontalcurve.
- ✓ Due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on acurve.

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 centrifugalforce.

Maximum and Minimum Super Elevation

Depends on

1. Slow movingvehicle
2. Heavy loaded trucks with highCG.

IRC specifies a **maximum super-elevation-** 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.

Design of super elevation:

There are four steps involved in the design of super elevation.

Step 1:

Calculate the super elevation necessary for 75% design speed and assume No lateral friction is developed

That is $f = 0$

$$V = 75\% (V) = 0.75V$$

We know that $e + f = \frac{V^2}{127R}$

$$e = \frac{(0.75V)^2}{127R}$$

Therefore, $e = \frac{V^2}{225R}$

If e value is less than emax = 0.07, provide calculated e value. Otherwise proceed to next step

Step 2:

When ecal> emax

Provide e = emax = 0.07 in this step and go to next step.

Step 3:

From the above step we have the value of e. so, check for lateral friction factor is applied in this step for the known value of e.

$$0.07 + f = \frac{V^2}{127R}$$

$$f_{cal} = \frac{V^2}{127R} - 0.07$$

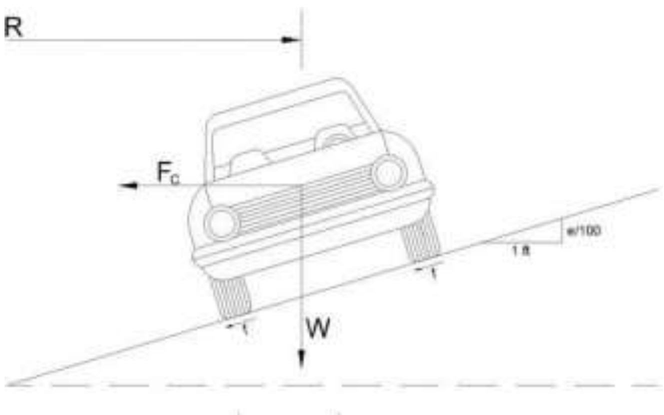
If fcal< fmax (0.15)

Then e = 0.07 is safe.

But if fcal> 0.15

Then restrict the values to f = 0.15, e = 0.07

And go to last step.



Step 4:

In this step we will find out the value of restricted speed.

Let V = Va

$$e + f = \frac{(Va)^2}{127R}$$

$$0.07 + 0.15 = \frac{(Va)^2}{127R}$$

$$V_a = \sqrt{127R(0.22)}$$

If Va> V, then e = 0.07, f= 0.15

If Va< V , then also e = 0.07, f = 0.15

VERTICAL CURVES

ISummit Curve / Crest curve

Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet as illustrated in figure 1 in any of the following four ways:

a. When a positive gradient meets another positive gradient.

b. When positive gradient meets a flat gradient.

c. When an ascending gradient meets a descending gradient.

d. When a descending gradient meets another descendin ggradient.

Type of Summit Curve

- ✓ Mostly use **parabolic curves** in summitcurves.
- ✓ This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient toanother.
- ✓ **Circular curve** offers equal sight distance at every point on the curve, for very small deviation angles a circular curve and parabolic curves are almost congruent.
- ✓ Furthermore, the use of parabolic curves was found to give excellent ridingcomfort.

IIValley (Sag)curve:

When two grades meet at the valley (sag) and the curve will have convexity downwards, the curve is simply referred as the valley (sag)curve.

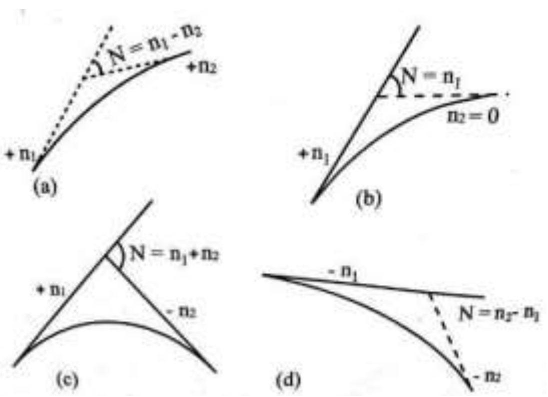


Figure 2.3.1 Valley Curve

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 142]

- The centrifugal force at these curves acts downwards along the weight of the vehicle. This add to the pressure on the springs and the suspension of the vehicle.
- Hence the rate of change of centrifugal acceleration should govern the design of valley curves.

Summit Curve

For determining the minimum length of the curves:

- The vehicle headlight sight distance
- Motorists comfort
- Drainage control
- General aesthetic considerations.

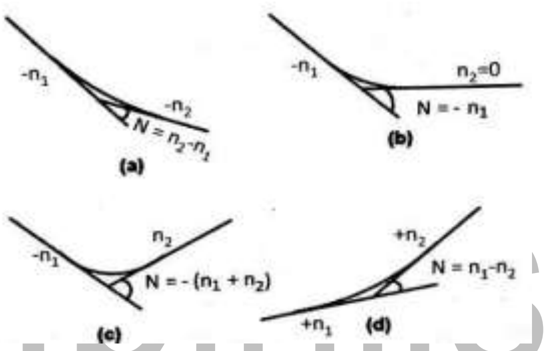


Figure 2.3.1 Summit Curve

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 144]

2.4 Gradient

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x (1 vertical unit to x horizontal units). The gradient is also expressed as percentages such as n%, the slope being n vertical units to 100 horizontal units

Types of gradient

a) Ruling Gradient

b) Limiting Gradient

c) Exceptional Gradient

d) Minimum Gradient

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 plain terrain, it may be possible to provide at gradients, but in hilly terrain it is not economical and sometimes not possible also.

The IRC has recommended ruling gradient values of

a) 1 in 30 on plain and rolling terrain

b) 1 in 20 on mountainous terrain

c) 1 in 16.7 on steep terrain.

Limiting gradient

Where topography of a place compels adopting steeper gradient than the ruling gradient, 'limiting gradient' is used in view of enormous increase in cost in constructing roads with gentler gradients. However, the length of continuous grade line steeper than ruling gradient should be limited. On rolling terrain and on hill roads, it may be frequently necessary to exceed ruling gradient and adopt limiting gradient, but care should be taken to separate such stretches of steep gradients by providing either a level road or a road with easier grade.

Exceptional gradient

In some extra ordinary situations, it may be unavoidable to provide still steeper gradients than limiting gradient at least for short stretches and in such cases the steeper gradient up to 'exceptional gradient' may be provided. However, the exceptional gradient should be strictly limited only for short stretches not exceeding about 100 m at a stretch.

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.

The road with zero gradient passing through level land and open side drains are provided with a gradient of 1 in 400.A minimum of 1 in 500 may be sufficient to drain water in concrete drains or gutter, on inferior surface of drains 1 in 200 or 0.5%, on kutcha open drains steeper slope up to 1 in 100 or 1 % may be provided

Gradient for roads in different terrains

Type of Terrain	**Ruling Gradient**	**Limiting Gradient**	**Exceptional Gradient**
Plain or Rolling	3.3 %, 1 in 30	5 %, 1 in 20	6.7 %, 1 in 15
Mountainous terrain and steep terrain having elevation more than 3000 m above the mean sea level	5 %, 1 in 20	6 %, 1 in 16.7	7 %, 1 in 14.3
Steep terrain up to 3000 m height above mean sea level	6 %, 1 in 16.7	7 %, 1 in 14.3	8 %, 1 in 12.5

2.1 HIGHWAY CROSS SECTION ELEMENTS

The cross section elements involved in highway geometric design,

- Kerbs
- Camber
- Shoulders
- Guard rails
- Side walks
- Right of way
- Service roadsT
- Drainage andFootpath

Cross Slope or Camber

Cross slope or camber is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface. Drainage and quick disposal of water from the pavement surface by providing cross slope is considered important because of the following reasons:

1) To prevent the entry of surface water into the pavement layers and the subgrade soil through pavement.
2) To prevent the entry of water into the bituminous pavement layers, as continued contact with water causes stripping of bitumen from the aggregates and results in deterioration of the pavement layer
3) To remove the rain water from the pavement surface as quickly as possible and to allow the pavement to get dry soon after the rain.

SHAPE OF CROSS SLOPE

In the field, camber of the pavement cross section is provided with a suitable shape.

Different shapes that are commonly adopted are

1) Parabolic
2) Straight Line
3) Straights with parabolic curve

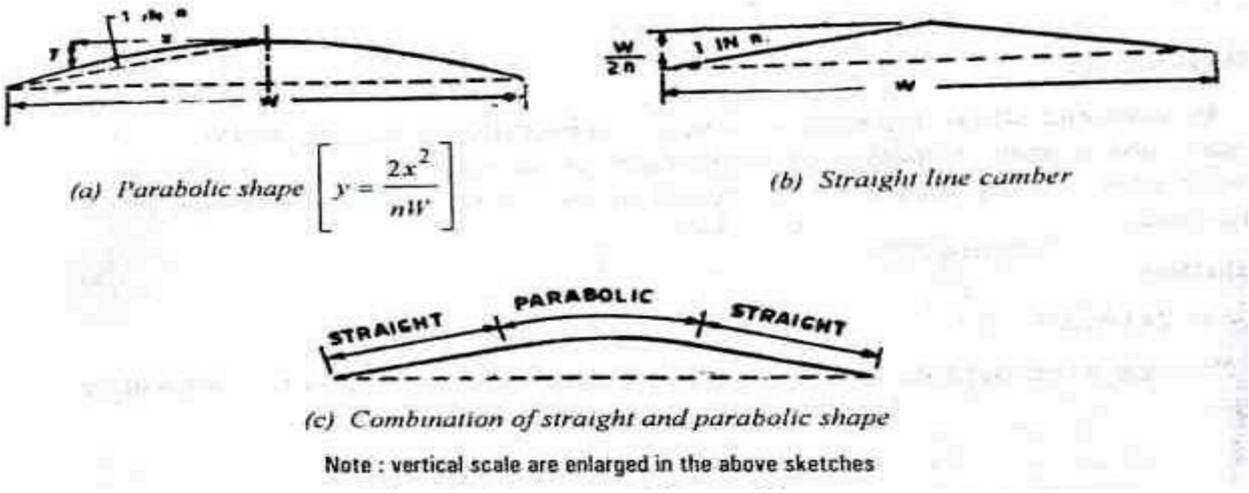


Figure 2.1.1 Shape of Cross Slope

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 70]

WIDTH OF PAVEMENT OR CARRIAGEWAY

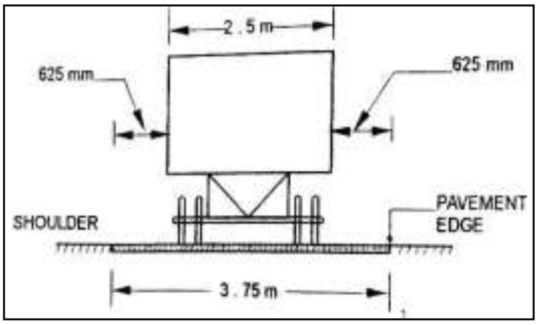
The width of pavement or carriageway depends on

1) Width of Traffic Lane 2) Number of Lanes.

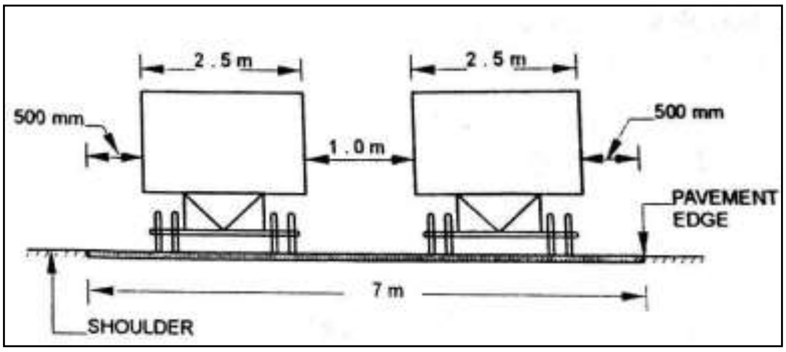
The portion of carriageway width that is intended for one line of traffic movement is called a traffic lane. As different classes of vehicles travel along the same roadway generally the lane width is decided based on a standard vehicle such as the passenger car. However, it is also necessary to consider the maximum width of the largest vehicle class such as the heavy commercial vehicle (HCV) which is legally permitted to use the roadway in the country.

Width of carriageway recommended by IRC

Class of Road	Width of Carriageway, m
Single Lane Road	3.75
Two Lane Road, without raised kerbs	7.0
Two Lane Road, with raised kerbs	7.5
Intermediate Carriageway	5.5
Multi Lane Pavements	3.5 per lane



Single Lane Pavement



Two Lane Pavement

Figure 2.1.2 Lateral Placement of Vehicle

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 79]

MEDIANS/TRAFFIC SEPARATORS

In highways with divided carriageway, a median is provided between two sets of traffic lanes intended to divide the traffic moving in opposite directions. The main function of the median is to prevent head-on collision between vehicles moving in opposite directions on adjacent lanes. The median is also called or traffic separator. The traffic separators used may be in the form of pavement markings, physical dividers or area separators. Pavement marking is the simplest of all these, but this will not rule out head on collision. The mechanical separator may be suitably designed keeping in view safety considerations.

Kerbs: The boundaries between pavement and shoulders or footpath are known as kerbs.

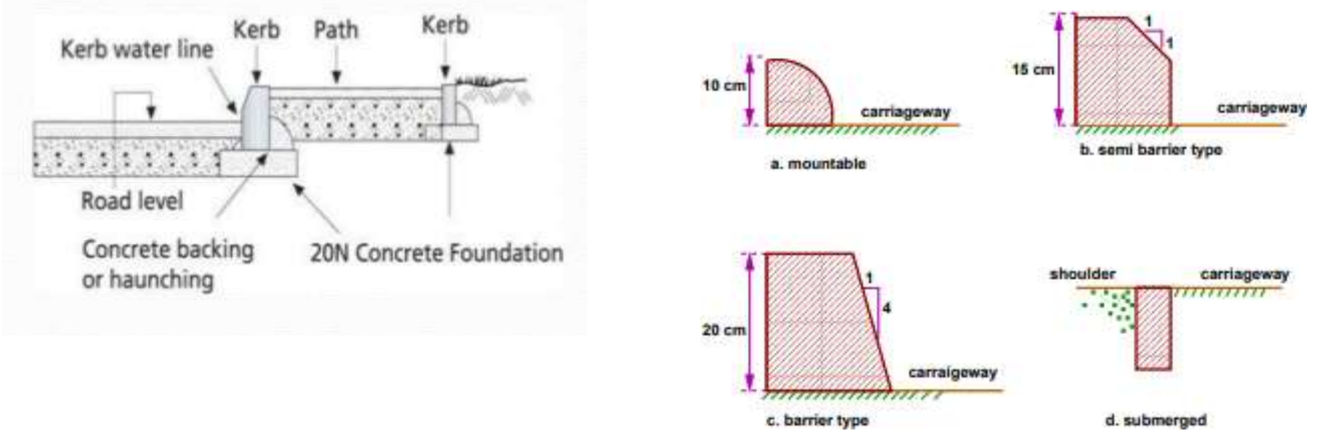


Figure 2.1.3 Kerbs

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 80]

Types of kerbs:

1. Mountable
2. Semi-barrier
3. Barrier
4. submerged

a) 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.

b) Semi-Barrier Type Kerbs

When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm above the pavement edge.

c) 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.

d) Submerged Kerbs

They are used in rural roads. The kerbs are provided at pavement edges between pavement edge and shoulder

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

Shoulders are provided along the road edge and are 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. The shoulder width should be adequate for giving working space around a stopped vehicle. It is desirable to have a width of 4.6 m for the shoulders. A minimum width of 2.5 m is recommended for 2-lane highways in India.

The important functions of shoulders are:

(a) Shoulders provide structural stability and support to the edges of the flexible pavements.

(b) The capacity of the carriageway and the operating speeds of vehicles increase if the shoulders are laid and maintained in good condition.

(c) Shoulders serve as emergency lanes for vehicle compelled to be taken out of the main carriageway or roadway. Shoulders should have sufficient load bearing capacity to support loaded truck even in wet weather

(d) Shoulders also act as service lanes for vehicles that are disabled. The width of shoulder should be adequate to accommodate stationary vehicle fairly away from the edge of adjacent lane.

Guard rails

Guard rails are provided at the edge of the shoulder when the road is constructed on a fill so that vehicles are prevented from running off the embankment, especially when the height of the fill exceeds 3 m. Guard stones (painted with black and white strips) are installed at suitable intervals along the outer edge of the formation at horizontal curves of roads running on embankments along rural areas so as to provide better night visibility of the curves under head lights of vehicles

Footpath or side-walk

In order to provide safe facility to pedestrians to walk along the roadway, foot paths or side-walks are provided in urban areas where the pedestrian traffic is noteworthy and the vehicular traffic is also heavy. By providing good foot path facility, the pedestrians can keep off from the carriageway and they are segregated from the moving vehicular traffic. Thus, the operating speeds of the vehicular traffic increases and there will be marked reduction in accidents involving pedestrians.

Drive ways

Drive ways connect the highway with commercial establishment like fuel-stations, service-stations etc. Drive ways should be properly designed and located, fairly away from an intersection. The radius of the drive way curve should be kept as large as possible, but the width of the drive way should be minimised to reduce the crossing distance for the pedestrians.

Cycle tracks

Cycle tracks are provided in urban areas where the volume of cycle traffic on the road is very high. A minimum width of 2 m is provided for the cycle track and the width may be increased by 1.0 m for each additional cycle lane.

Parking lanes

Parking lanes are provided on urban roads to allow kerb parking. As far as possible only 'parallel parking' should be allowed as it is safer for moving vehicles. For parallel parking, the minimum lane width should be 3.0 m.

Bus bays

Bus bays may be provided by recessing the kerb to avoid conflict with moving traffic. Bus bays should be located at least 75 m away from the intersections.

Lay-byes

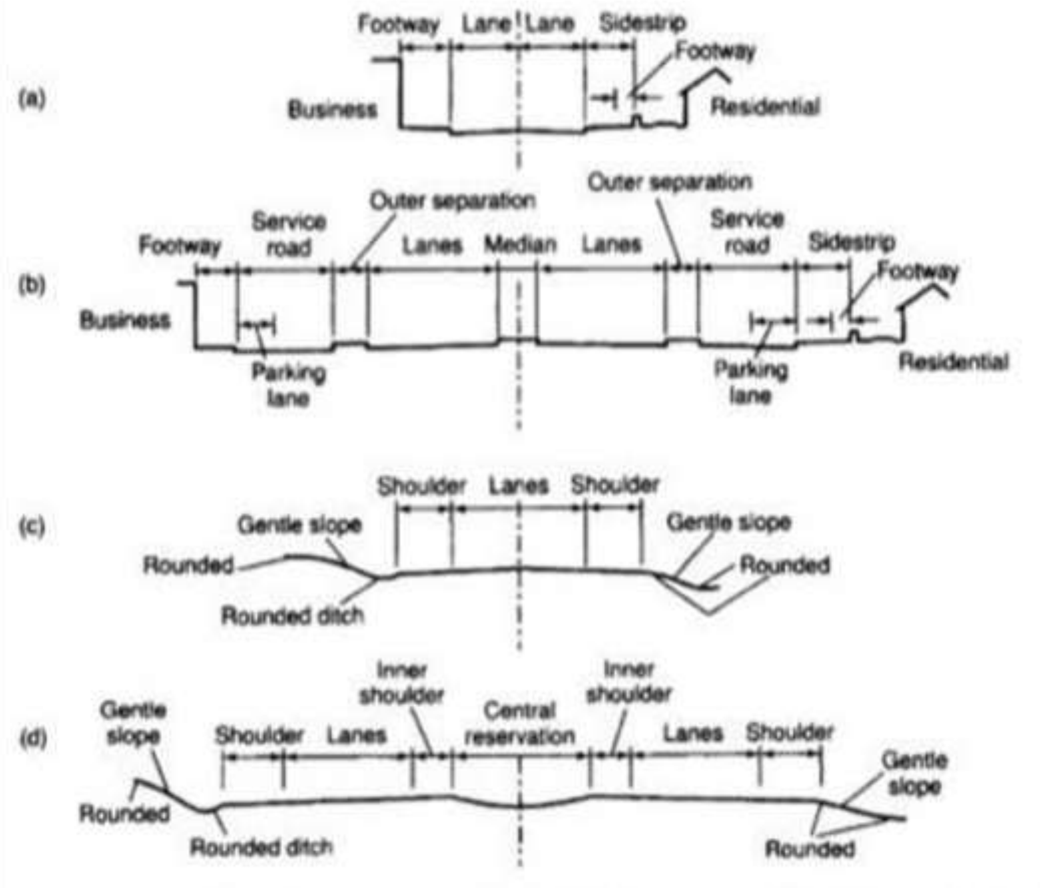
Lay-byes are provided near public conveniences with guide maps to enable drivers to stop clear off the carriageway. Lay-byes should normally be of 3.0 width and at least 30 m length with 15 m end tapers on both sides.

Width of Formation or Roadway

Width of formation or roadway is the sum of widths of pavement or carriageway including separators, if any and the shoulders. Formation or roadway width is the top width of the highway embankment or the bottom width of highway cutting excluding the side drains.

Right of Way and Land Width

Right of way is the area of land acquired for the road, along its alignment. The width of the acquired land for right of way is known as 'land width' and it depends on the importance of the road and possible future development. A minimum land width has been prescribed for each category of road. A desirable range of land width has also been suggested for each category of road. While acquiring land for a highway it is desirable to acquire more width of land as the cost of adjoining land invariably increases as soon as the new highway is constructed.



Simplified road cross-sections: (a) 2-lane street, (b) urban motorway, (c) 2- or 3-lane rural highway, and (d) rural motorway

Figure 2.1.2 Road Cross Section

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 82]

2.6 Hill Roads

A hill road may be defined as the one which passes through a terrain with a cross slope of 25% or more. There may be sections along hill roads with the cross slope less than 25%, especially when the road follows a river route. Even then these sections are also referred to as hill roads. Hence, to establish a hill road overall terrain must be taken into account.

The hilly regions generally have extremes of climatic conditions, difficult and hazardous terrains, topography and vast high altitude areas. The region is sparsely populated and basic infrastructural facilities available in plain terrain are absent. Hence, a strong stable and feasible road must be present in hilly areas for overall development of other sectors as well.

Design and Construction Problems

Design and Construction of roads in hills and mountain are more complex than in plain terrain. It is due to several factors associated in the region. They are:

- A hilly or mountainous area is characterized by highly broken relief with vastly differing elevations and steep slopes, deep gorges etc. which may unnecessarily increase road length.
- The geological condition varies from place to place.
- Hill slopes stable before construction may not be as stable due to increased human activities.
- There may be variation in hydro-geological conditions which may easily be overlooked during design and construction
- Due to highly broken relief construction of special structures should be done at different places. This increases the cost of the construction.

- Variation in the climatic condition such as the change in temperature due to altitude difference, pressure variation, precipitation increases at greater height etc.
- High-speed runoff occurs due to the presence of high cross slopes.
- Filling may overload the weak soil underneath which may trigger new slides.
- The need of design of hairpin bends to attain heights.

Special Consideration in Hill Road Design

Alignment of Hill Roads

Selecting an alignment in the hilly region is a complex task. The designer should attempt to choose a short, easy, economical and safe comforting route.

General considerations

When designing hill roads the route is located along valleys, hill sides and if required over mountain passes. Due to complex topography, the length of the route is automatically increased. Due to harsh geological conditions, special structures also have to be provided.

Apart from the highly broken relief which has a fixed role in determining the alignment and location of special structures, climatic and geological conditions are also important. In locating the alignment special consideration should be made in respect to the variations in:

1. Temperature
2. Rainfall
3. Atmospheric pressure and winds
4. Geological conditions

Temperature

- Air temperature is in the hills is lower than in the valley. The temperature drop being approximately 0.5° per 100 m of rising.
- On slopes facing south and southwest snow disappears rapidly and rain water evaporates quickly while on slopes facing north and northeast rain water or snow may remain for the longer time.

- Unequal warming of slopes, sharp temperature variations and erosion by water are the

causes of slope facing south and southwest.

Rainfall

- Rainfall increases with increase in sea level.
- The maximum rainfall is in the zone of intensive cloud formation at 1500-2500 m above sea level. Generally, the increase of rainfall for every 100 m of elevation averages 40 to 60 mm.
- In summer very heavy storms may occur in the hills and about 15 to 25% of the annual may occur in a single rainfall. The effects of these types of rainfall are serious and should be considered well.

Atmospheric pressure and winds

- It decreases with increase in elevation.
- At high altitudes, the wind velocities may reach up to 25-30 m/s and depth of frost penetration is also 1.5 to 2 m.
- Intensive weathering of rocks because of sharp temperature variations which cause high winds.

Geological conditions

- The inclination of folds may vary from horizontal to vertical stratification of rock. These folds often have faults. Limestone or sandstone folds may be interleaved with layers of clay which when wetted may cause fracturing along their surface. This may result in shear or slip fold.
- The degree of stability of hill slopes depends on types of rock, degree of strata inclination or dip, occurrence of clay seams, the hardness of the rocks and presence of ground water.

When locating the route an engineer must study the details of geological conditions of that area and follow stable hill slopes where no ground water, landslides, and unstable folds occur.

Hill roads may follow different path according to the feasibility of the road. However, a hill road alignment varies for the sections along the valley bottom and along the mountain pass. The first is called **river route** and the second is called **ridge route**.

River route

The location of a route along a river valley is the most frequent case of hill alignment as there is a great advantage of running a road at a gentle gradient. Also, there is a benefit of low construction cost and operation cost.

However, a river valley may run through numerous horizontal curves. Requirements for the construction of large bridges over tributaries also may occur. It may also be necessary to construct special retaining structures and protection walls on hill side for safe guarding the road against avalanches.

Some important considerations

- Road bed should be located sufficiently above and away from the maximum water level.
- When the road bed is near to the waste water course embankment slope should be well protected and stabilized.
- More care should be given to geological and hydrological structures.
- Best alternatives should be selected for crossing water sources.

Ridge route

- It is characterized by the very steep gradient.
- A large number of sharp curves occurs on the road with hair pin bends.
- Extensive earthwork is required.
- The requirement for the construction of special structures.
- The necessity of long length away from the air route.

Gradient

In hill roads, a heavy amount of earthwork is required. So to reduce the earthwork for reducing construction cost the gradients selected are close to maximum. Although steep gradients help in reducing earthwork and length of road, it also causes increased fuel consumption and reduction in operating speed as the vehicles will be on low gears which will use more energy. So both these factors must be taken into account and a suitable solution should be chosen.

The cumulative rise or fall in elevation should not exceed 100 m in mountainous terrain and 120 m in steep terrains. Vertical curves are designed as the square parabola.

HAIR-PIN CURVES

The curve in a hill road which changes its direction through an angle of 180 degree or so, downthe hill on the same side is known as hair-pin curve.

This curve is so called because it conforms to the shape of a **hair-pin**. The bend so formed at the **hair-pin**curve in a hill road is known as **hair-pin bend**. This type of

curve should be located on a hill side having the minimum slope and maximum stability. It must also be safe from view point of land slides and ground water.

Hair-pin bends with long arms and farther spacing are always preferred. They reduce construction problems and expensive protective works. **Hair-pin** curves or bends of serpentine nature are difficult to negotiate and should, therefore, be avoided as far as possible.

2.8 LATERAL AND VERTICAL CLEARANCE ON UNDERPASS

Lateral clearance is the distance between the extreme edge of the carriageway to the face of the nearest support whether it is a solid abutment,pier or column.

Vertical clearance stands for the height above the highest point of the travelled way

- Minimum width clearance of 5m should be ensure over the full width of roadway.
- The vertical clearance should be measured with regard to the highest point of carriageway.
- Allowance for any future raising of pavement is also be made.

Underpass:

It implies a short passage beneath a grade separated structure to carry one or more streams of traffic.An underpass, or subway, is a tunnel containing a road or pedestrian passageway running underneath a road or railway. Underpasses can also be constructed to allow wildlife to pass safely under a transport corridor.

Construction Methods

There are three main methods for constructing underpasses:

- Precast concrete units.
- In situ concrete.
- Thrust-bored units.

Precast concrete units are often manufactured as standard units and can be provided to site as complete box-like open-ended sections, portal frame segments, or as separate wall and roof units.

Box units are typically jointed using a pre-formed sealant strip in a socket and spigot joint. Connection plates in the floor and roof are used to bolt together the units.

Portal frame units, which are pre-stressed, require the lower waterproofing membrane to be placed on a concrete slab, with continuous concrete bearing pads (usually 300 mm wide x 25 mm deep) are laid on top. The units are then placed in position, with lubrication applied to reduce stress-induced friction.

Wall and roof unit systems comprise precast units that are placed in position with the floor laid in situ using the units as shuttering. The roof units are then placed and the in situ loading slab poured, with loading requirements determining the thickness.

Thrust-bored units require a suspension of bentonite as lubrication. As a means of transmitting the thrust load, the units must have direct edge contact rather than the pre-formed sealing strip. This jointing method should allow edge contact for jacking, but be capable of receiving a sealing compound from the inner face. This is possible by forming a rebated joint filled with mortar prior to applying the sealant.

In situ concrete underpasses are constructed using the same methods as any underground tunneling construction.

2.2 SIGHT DISTANCE

Sight distance is the length of road visible ahead of the driver at any instance. Sight distance available at any location of the carriageway is the actual distance a driver with his eye level at a specified height above the pavement surface has visibility of any stationary or moving object of specified height which is on the carriageway ahead. The sight distance between the driver and the object is measured along the road surface.

TYPES OF SIGHT DISTANCE

Sight distance required by drivers applies to geometric designs of highways and for traffic control. Three types of sight distances are considered in the design

a) Stopping Sight Distance (SSD) or absolute minimum sight distance
b) Safe Overtaking Sight Distance (OSD) or Passing Sight Distance
c) Safe Sight Distance for entering into uncontrolled intersections.

Apart from the three situations mentioned above, the following sight distances are considered by the IRC in highway design

d) Intermediate Sight Distance)Head Light Sight Distance

STOPPING SIGHT DISTANCE (SSD)

The minimum distance visible to a driver ahead or the sight distance available on a highway at any spot should be of sufficient length to safely stop a vehicle travelling at design speed, without collision with any other obstruction. Therefore, this Stopping Sight Distance (SSD) is also called Absolute Minimum Sight Distance. This is also sometimes called Non Passing Sight Distance.

The sight distance available to a driver travelling on a road at any instance depends on the following factors:

a) Features of the road ahead
b) Height of the driver's eye above the road surface
c) Height of the object above the road surface

IRC has suggested the height of eye level of driver as 1.2 m and the height of the object as 0.15 m above the road surface.

Factors on which stopping distance depends

The distance within which a motor vehicle can be stopped depends upon the factors listed below

a) Total reaction time of the driver

b) Speed of vehicle

c) Efficiency of Brakes

d) Frictional Resistance between the road and the tyre

e) Gradient of the road, if any

TOTAL REACTION TIME OF DRIVER

Reaction time of the driver is the time taken from the instant the object is visible tothe driver to the instant the brakes are effectively applied. The actual time gap or the reaction time of the driver depends on several factors. During this period of time the vehicle travels a certain distance at the original speed, which may be assumed to be the design speed of the road. Thus, the stopping distance increases with increase reaction time of the driver.

The total reaction time (**t**) may be split up into two parts

Perception Time

It is the time required for a driver to realise that brakes must be applied. It is the time from the instant the object comes on the line of sight of the driver to the instant he realises that the vehicle needs to be stopped. The perception time varies from driver to driver and also depends on several other factors such as the distance of object and other environmental conditions.

Brake Reaction Time

It is also depending on several factors including the skill of the driver, the type of the problems and various other environmental factors.

The total reaction time may be explained with the help of PIEV theory.

PIEV THEORY

According to PIEV theory, the total reaction time of the driver is split into four parts, viz., time taken by the driver for

1) Perception

2) Intellection

3) Emotion

4) Volition

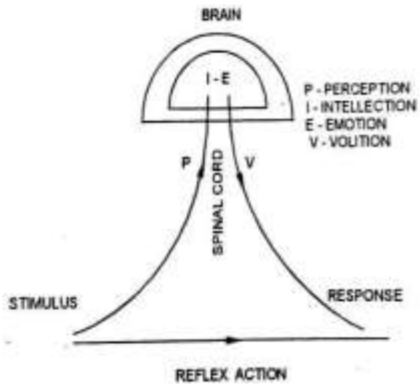


Figure 2.2.1 Reaction Time and PIEV Theory

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 89]

The PIEV time of a driver also depends on several factors such as physical and psychological characteristics of the driver, type of the problem involved, environmental conditions and temporary factors.

Speed of vehicle

The stopping distance depends very much on the speed of the vehicle. First, during the total reaction time of the driver the distance moved by the vehicle will depend on the speed. Second, the braking distance or the distance moved by the vehicle after applying the brakes, before coming to a stop depends also on the initial speed of the vehicle.

Efficiency of brakes

The braking efficiency is said to be 100 percent if the wheels are fully locked preventing them from rotating on application of the brakes. This will result in 100 percent skidding which is normally undesirable, except in utmost emergency. Also skidding is considered to be dangerous, as it is not possible for the driver to easily control a vehicle after it starts skidding.

Frictional resistance between road and tyres

The factional resistance developed between road and tyres depends upon the 'skid resistance' or the coefficient of friction, f between the road surface and the tyres of the vehicle.

Analysis of Stopping Distance

The stopping distance of a vehicle is the sum of

a) The distance travelled by the vehicle at uniform speed during the total reaction time, t which is known as **LAG DISTANCE**.

b) The distance travelled by the vehicle after the applications of the brakes, until the vehicles comes to a dead stop which is known as **BRAKING DISTANCE**.

LAG DISTANCE

During the total reaction time, t seconds the vehicle may be assumed to move forward with a uniform speed at which the vehicle has been moving and this speed may be taken as the design speed. If ‘v’ is the design speed in m/sec and ‘t’ is the total reaction time of the driver in seconds, then

Lag Distance = v t

If the design speed is V kmph, then the lag distance = V t x $\left\{\frac{1000}{60x60}\right\}$

= 0.278 V t ≈ **0.28 V t** in meters

IRC has recommended the value of reaction time t as 2.5 sec for calculation of Stopping Distance

BRAKING DISTANCE ON LEVEL SURFACE

The coefficient of friction f depends on several factors such as the type and condition of the pavement and the value of f decreases with the increase in speed. IRC has recommended a set of friction co efficient values for the determination of stopping sight distance.

Speed, kmph	20 – 30	40	50	60	65	80	100 and above
Longitudinal friction coefficient value, f for SSD	0.40	0.38	0.37	0.36	0.36	0.35	0.35

The braking distance, **l =** $\frac{v^2}{2gf}$

Where l - braking distance, m

v - speed of the vehicle, m/sec

f - design coefficient of friction, f (0.40 to 0.35)

g – acceleration due to gravity – 9.8 m/sec^2

Overtaking Sight Distance

It is desirable that adequate overtaking sight distance is available on most of the road stretches such that the vehicles travelling at the design speed can overtake slow vehicles at the earliest opportunity.

- On road stretches with two-way traffic movement, the minimum overtaking distance should be **($d_1 + d_2 + d_3$)** where overtaking is not prohibited.

- On divided highways and on roads with one way traffic regulation, the overtaking distance need be only **(d_1+d_2)** as no vehicle is expected from the opposite direction
- On divided highways with four or more lanes, it is not essential to provide the usual OSD; however, the sight distance on any highway should be more than the SSD, which is the absolute minimum sight distance.

Figure 2.2.2 Overtaking Sight Distance Calculation

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 95]

Overtaking Zones

It is desirable to construct highways in such a way that the length of road visible ahead at every point is sufficient for safe overtaking. This is seldom practicable and there may be stretches where the safe overtaking distance cannot be provided. In such zones where overtaking or passing is not safe or is not possible, sign posts should be installed indicating **No Passing** or **Overtaking Prohibited** before such restricted zones start. However overtaking opportunity for vehicles moving at design speed should be given at as frequent intervals as possible. These zones which are meant for overtaking are called **Overtaking Zones**.

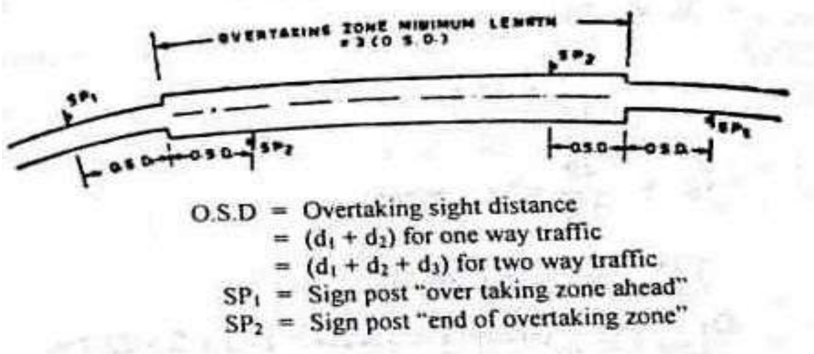


Figure 2.2.3 Overtaking Zones

[Source: "Highway Engineering" by S.K.Khanna,C.E.G.Justo, Page: 101]

The width of carriageway and the length of overtaking zone should sufficient for safe overtaking. Sign posts should be installed at sufficient distance m advance to indicate the start of the overtaking zones, this distance may be equal to

- **(d_1 + d_2) for one-way roads**

($d_1 + d_2 + d_3$) for two-way roads

The minimum length of overtaking zone = 3 (OSD) The desirable length of overtaking zones = 5 (OSD)

INTERMEDIATE SIGHT DISTANCE

At stretches of the road where requires OSD cannot be provided, as far as possible intermediate Sight Distance ISD equal to twice SSD may be provided. The measurement of the ISD may be made assuming both the height of the eye level of the driver and the object to be 1.2 metres above the road surface. Therefore ISD=2SSD.

Sight Distance at Uncontrolled Intersections

It is important that on all approaches of intersecting roads, there is a clear view across the corners from a sufficient distance so as to avoid collision of vehicles. This is all the more important at uncontrolled intersections. The sight line is obstructed by structures or other objects at the corners of the intersections. The area of unobstructed sight formed by the lines of vision is called the sight triangle.

The design of sight distance at intersections may be based on three possible conditions,

a) Enabling the approaching vehicle to change speed
b) Enabling approaching vehicle to stop
c) Enabling stopped vehicle to cross a main road
d) Enabling the approaching vehicle to change speed

PROBLEM BASED ON SIGHT DISTANCE

1. The speed of the overtaking and overtaken vehicles is 80 and 50 kmph respectively. On a two way traffic load, the acceleration of overtaking vehicles is 0.99m/sec^2. Calculate OSD, mention the minimum length of overtaking zone and draw the sketch of the overtaking zone with details. (A.U APRIL-MAY2017)

Data:

Speed of the overtaking,V = 80 kmph, v = 80/3.6 = 22.2

Speed of the overtaken vehicles, V_b = 50 kmph, v_b = 50/3.6= 13.8

Acceleration = $0.99 m/sec^2$

Solution:

OSD for two way traffic $= d1+d2+d3 = v_b t + v_b T+2s+vT$

Reaction time forovertaking,t =2s

$d1 = v_b t$

= 13.8x2 = 27.6m

d1 =27.6m

d2 = $v_b T$ (since $T = \sqrt{4s/s}$; s =0.7v_b+6=15.66)

= 13.8x 7.95

d2 =109.71m

d3 =vT

= 22.2x 7.95 = 176.49m

d3 =176.49m

Therefore,OSD =d1+d2+d3

= 27.6+109.71+ 176.49 = 313.8m = 314m

a) Minimum length of overtaking zone= 3 xOSD

= 942 m

b) Desirable length of overtaking zone= 5 xOSD

= 1570m

2. Calculate the safe stopping distance while travelling a speed of 100 kmph on a level road. Assume all other data.

Data:

DesignSpeed,V = 100kmph

Solution:

OSD for 1-waytraffic = d1+d2 = 0.278v_bt + 0.278v_bT+2s

Assume V_b is 16 km/h lesser than that of V

V_b = 100-16 = 84 km/h

Acceleration = 2.5 km/h/sec

Acceleration of overtaking vehicle = 2.5 x (1000~~00/3~~600) = 0.694m/sec^2

Reaction time for overtaking, t =2s

$d1 = 0.278 v_b t$
= 0.278 x 84 x 2 = 46.7m
d1 =46.7m

$d2 = 0.278 v_b T + 2s$ (since $T = \sqrt{4s/s} = \sqrt{4s} 22.8/0.694$
=11.49m; $s = 0.2 v_b + 6 = 22.80$m) Sub d and T value d2eq.

d2 = (13.8x 84 x 11.49) + (2 x22.8)

d2 =313.91m

Therefore, OSD =d1+d2

= 46.7 +313.91 = 360.61 m = 361m

OSD for 1-way traffic =361m

2.5 WIDENING OF PAVEMENT ONHORIZONTAL CURVES

Objectives

1) An automobile such as car, bus or truck has a rigid wheel base and only the front wheels can be turned. When the vehicle takes a turn to negotiate a horizontal curve, the rear wheels do not follow the same path as that of the front wheels. This phenomenon is called 'off tracking'. Normally at low speeds and up to the design speed when no lateral slipping of rear wheels take place, the rear wheels follow the inner path on the curve as compared with those of the corresponding front wheels. This means that if inner front wheel takes a path on the inner edge of a pavement at a horizontal curve, inner rear wheel will be off the pavement on the inner shoulder.

   The off-tracking depends on

   - The length of the wheel base of the vehicle
   - The turning angle or the radius of the horizontal curve negotiated.

2) At speeds, higher than the design speeds when the superelevation and lateral friction developed are not fully able to counteract the outwards thrust due to the centrifugal force, some transverse skidding may occur and the rear wheels may take paths on the outside of those traced by the front wheels on the horizontal curves. However, this occurs only at excessively high speeds
3) The path traced by the wheels of a trailer in the case of trailer units, is also likely to be on either side of the central path of the towing vehicle, depending on the speed, rigidity of the universal joints and pavement roughness
4) In order to take curved path with larger radius and to have greater visibility at curve, the drivers have tendency not to follow the central path of the lane, but to use the outer side at the beginning of a curve.
5) While two vehicles cross or overtake at horizontal curve there is a psychological tendency to maintain a greater clearance between the vehicles, than on straights for increase safety

   Thus, the required extra widening of the pavement at the horizontal curves, W_e depends on

   a) The Length of wheel based of the vehicle **l**,

   b) Radius of the curve negotiated ***R***

c) The psychological factor which is a function of the speed of the vehicle and the radius of the curve.

It has been a practice therefore to provide extra width of pavement on horizontal curves when the radius is less than about **300 m**.

Analysis of Extra Widening on Horizontal Curves

The extra widening of pavement on horizontal curves is divided into two parts.

Mechanical Widening

The widening required to account for the off-tracking due to rigidity of wheel base is called as 'Mechanical Widening' (Wm) and 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.

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

Hence Total Widening We is given by We = Wm + Wps

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

R – Radius of the curve n – No of lanes l – length of wheel base of longest vehicle, m