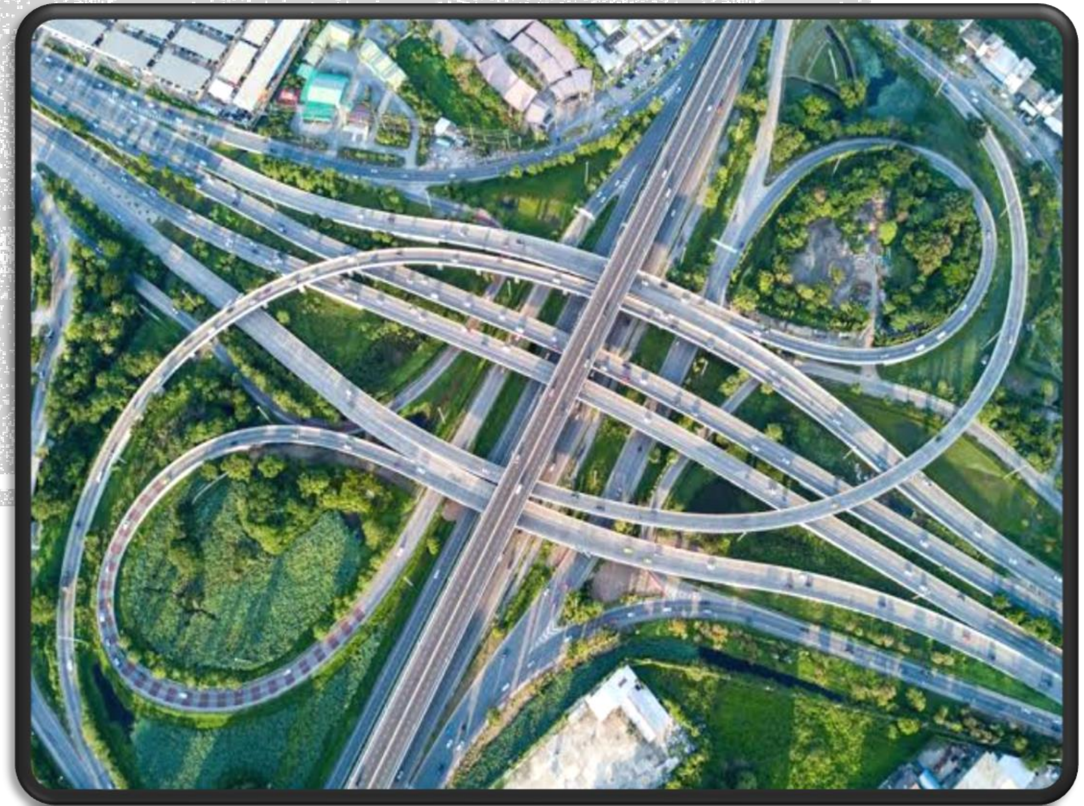
HIGHWAY ENGINEERING

Chapter 1

INTRODUCTION



BY:- ER. P. K. SAHO

1 Introduction

1.1 Importance of Highway transportation: importance organizations like Indian roads congress, Ministry of Surface Transport, Central Road Research Institute.

1.2 Functions of Indian Roads Congress

1.3 IRC classification of roads

1.4 Organisation of state highway department




- **Highway Engineering** is a branch of transportation engineering which deals with the design, construction and maintenance of different types of roads. It is also called as road engineering.

it involves the study of the following :

1) Planning, location and development of roads.

2) Materials required for their construction.

3) Highway traffic performance and its control.

4) Drainage of roads etc

- **Importance of Roads or Highway Engineering :**

Following are the importance of roads or highway transportation.

1. They provide conveyance to the people, goods, raw materials, etc., to reach different parts of the country.

2. They are the only source of communication in hilly regions.

3. Helps in agricultural development.

4. Helps in dairy development.

5. Helps in tourism development.
6. Helps in fisheries development.
7. Helps in maintaining law and orders in a country.
8. Forestry development.
9. They improve the medical facilities.
10. They improve the land value.
11. They generate the more employment opportunities.
12. They play important role in defence activities.
13. They become the symbol of country's progress and development.

1.1 IMPORTANCE OF HIGHWAY TRANSPORTATION

1.1 Indian Roads Congress (I.R.C.):

- The Indian Roads Congress was established by the Central Government in 1934 as per the recommendations of the Jayakar Committee.
- The I.R.C. was constituted to provide a forum for the regular pooling the technical ideas, experiences and know-how for the panning of the development of the roads throughout the country.
- I.R.C. provides the recommended specifications regarding the design and construction of the roads in the country.
- IRC has collaborated with the road wing of the ministry of the surface transportation of Govt. of India. It publishes journals, standard specifications and guidelines on various aspects of highway engineering.

1.2 ***Functions of Indian Roads Congress (IRC)***

IRC a body of professional highway engineers provides the following services:

- It provides a forum for the expression of the collective opinion of its members for all matters affecting the construction and maintenance of roads in India.
- It promotes the use of standard specifications and practices.
- It provided with the suggestions for the better methods of planning, designing, construction, administration and maintenance of roads.
- It conducts periodical meetings to discuss technical problems regarding roads.
- It makes the laws for the development, improvement and protection of the roads.
- It furnishes and maintains libraries and museums for encouraging the science of road-making.

Central Road Research Institute (CRRI)

- CRRI was started by the Central Government in 1950, for the research work in highway engineering. CRRI is a series of laboratories under the council of scientific and industrial research in India.

It offers the following services.

- Carries basic and applied research for the design, construction and maintenance of the highways.
- Carries research on traffic safety and transport economics.
- Carries research on economical utilization of locally available materials for construction and maintenance of roads.
- Research for the development of the new machinery, tools equipment and instruments for highway engineering.
- To provide technical advice and consultancy services to various organizations.

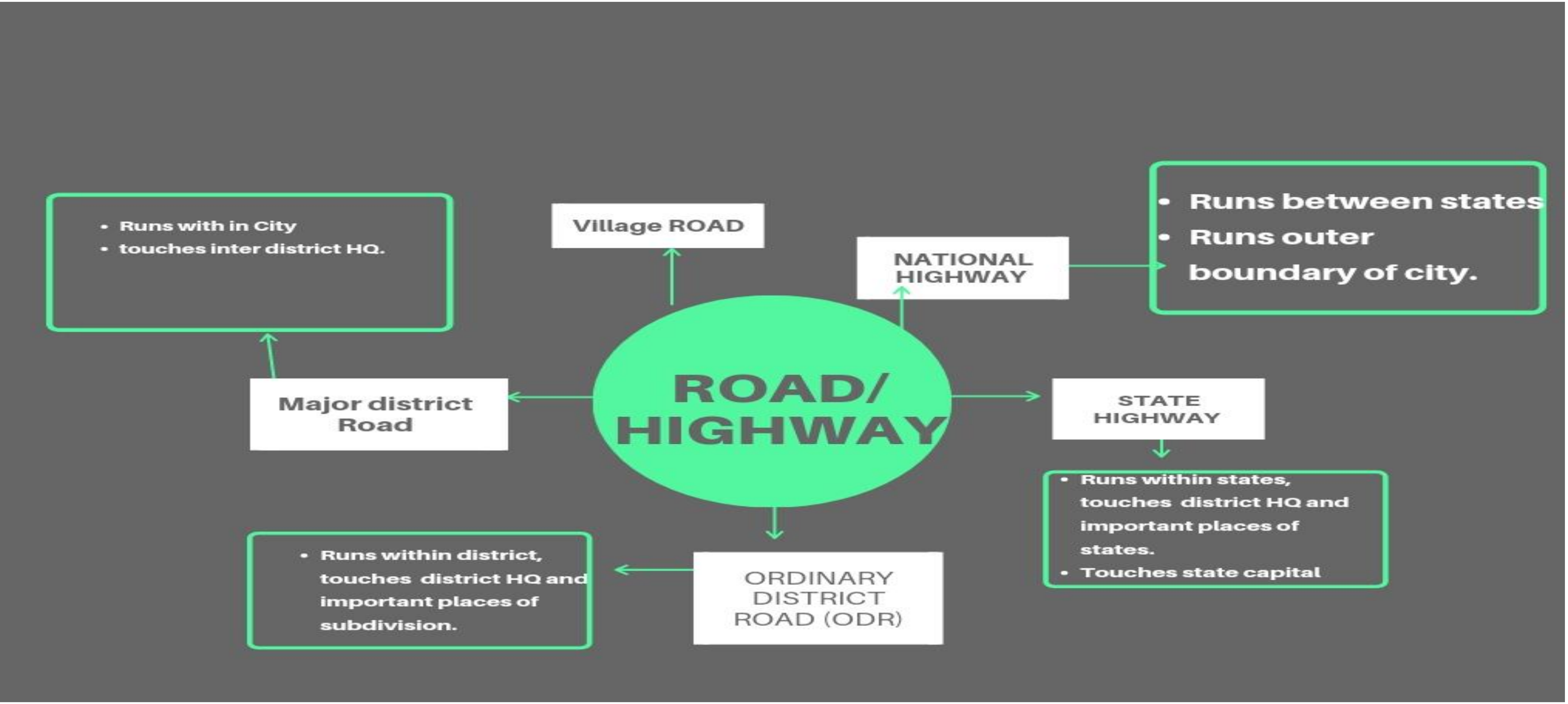
Roads wing of the ministry of surface transport

- The roads wing of the Ministry of Surface Transport handles the road matters of the Central Govt. It is headed by a Director-General.
  The Director-General is assisted by two Additional Director Generals(one for roads and one for bridges), a number of Chief Engineers, Superintending Engineers, Executive Engineers and Asst.
  Executive Engineers. The roads wing has a Chief Engineer for the North-East region posted at Guwahati and a Liaison-cum-Inspectorate organization consisting of S.E's and E.E's in the various states.

The functions of the roads wing of Surface Transport are as follows.

- **To control funds approved by the Central Government for the development of National Highways.**
- **To control the central road fund (CRF.)**
- **To prepare plans for the development and maintenance of National Highways in consultation with state PWDs.**
- **To oversee technically the quality of works executed by the agencies.**
- **Administer matters regarding road research.**
- **Examine technically the projects and bridges prepared by the PWDs.**
- **To administer the central road program other than National Highways in the Union Territories.**

1.3 IRC CLASSIFICATION OF ROADS



- According to IRC, roads are classified as

1) National Highways (NH)
2) State Highways (SH)
3) Major District Roads (MDR)
4) Other District Roads (ODR)
5) Village Roads (VR)

1. National highways

National highways are the main highways running through the length and breadth of India. It connects many roads like major ports, foreign highways, capitals of large states and large industrial tourist centres.

It carries about 30 to 50 percent of total traffic of our country. National highways are the main roads on which the entire road communication is based.

They are assigned the respective number for the sake of convenience such as **NH-1, NH-2, NH-3** and so on ; as is clear from below ;
NH-1 stands for Amritsar - Ambala - Delhi Road
NH-3 stands for Agra - Bombay Road

To meet with the present day fast moving traffic, the **express highways or expressways** have been constructed recently for connecting important places.

The responsibility of construction and maintenance of these roads lies with the Central Government.

2) State Highways (SH)

- State arterial roads of a state, connecting up with the National highways of adjoining states, district head quarters and important cities within the state. These are also known as **Provincial Highways**.
- The responsibility of construction and maintenance of these roads lies with State Governments. However, the Central Government gives grant for the development of these roads.

3) Major District Roads (MDR)

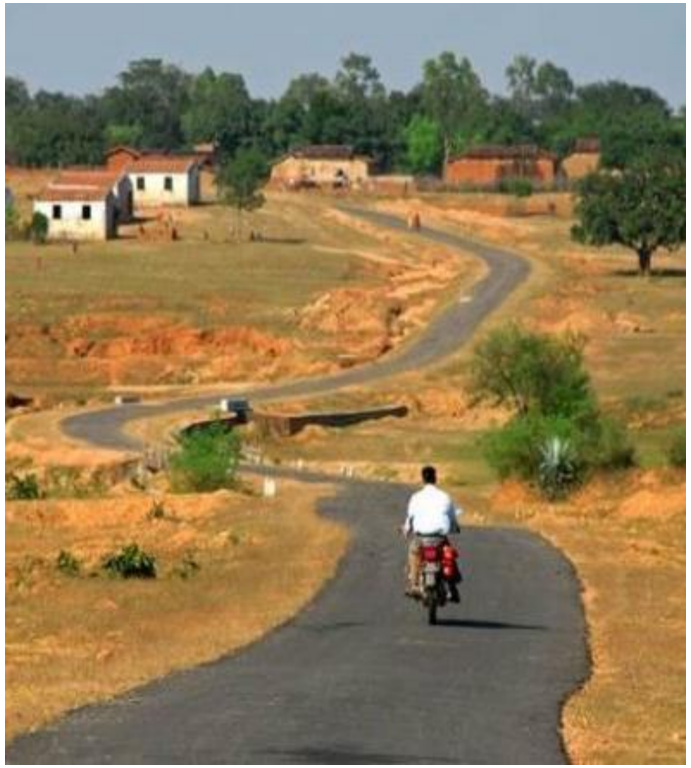
- Major district roads are important roads within a district serving areas of production and markets and connecting those with each other or with the main highways.
- MDR is used for only low speed. The responsibility of construction and maintenance of these roads lies with the District Authorities. However, the state Government gives grant for development of these roads.

4) Other District Roads (ODR)

- Other district roads are the roads serving rural areas of production and providing them with outlet to market centres, taluk head quarters, block development head quarters and other main roads. ODR is also used for low speed.

5) Village Roads (VR)

- Village roads connect villages to other villages and also connects villages to the nearest road of highways.

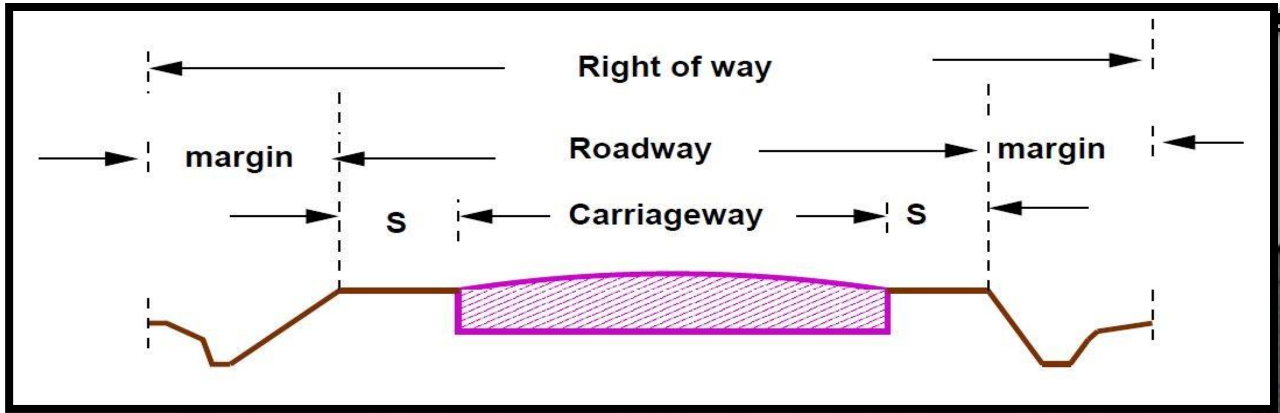


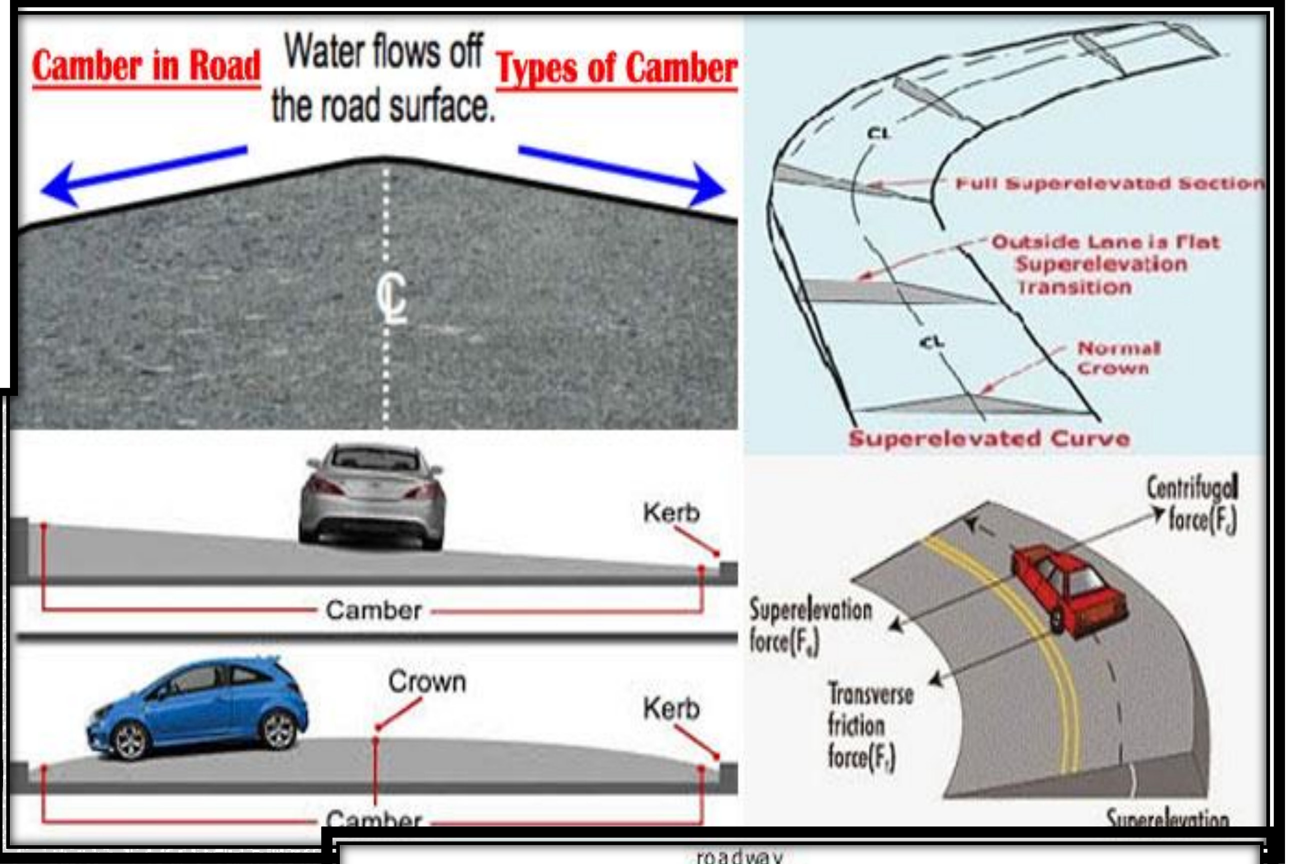
- **EXPRESS WAYS**
- Expressways are a separate class of highways with superior facilities and design standards.
- These expressways have controlled access and grade separation at all roads and rail crossings. It is the routes having very high volume of traffic.
- These highways should allow only fast moving vehicles. These roads are of higher class than National highway.

1.4 Organisation of state highway department

- Works department (PWD)

State Highways play major role in economic development of the people as it connects major & important places of the State as well as neighboring States. Also, development of these roads will improve tourism activities in the State as it connects major tourist places.





HIGHWAY ENGINEERING

CHAPTER 2

ROAD GEOMETRIC

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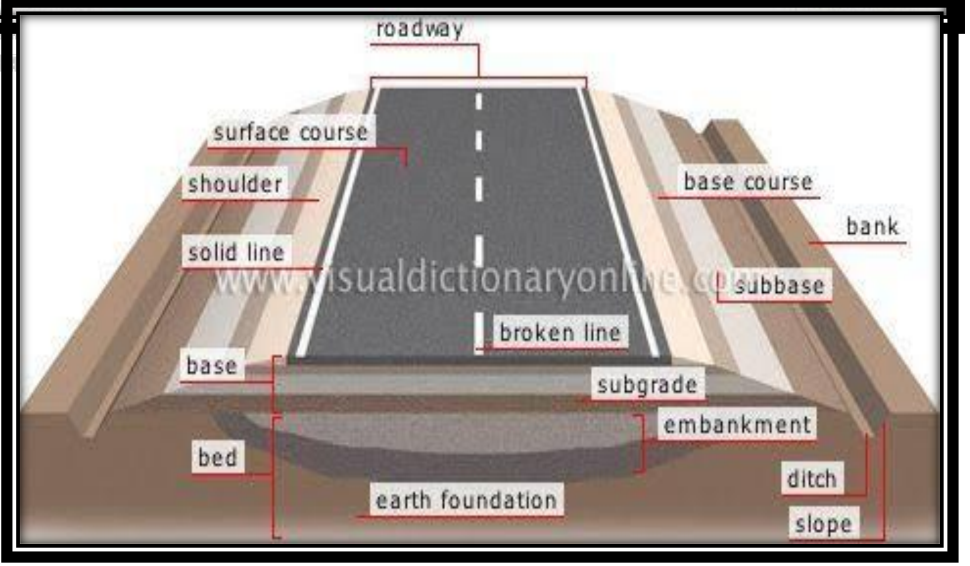


2 Road Geometric

- 2.1 Glossary of terms used in geometric and their importance, right of way, formation width, road margin, road shoulder, carriage way, side slopes, kerbs, formation level, camber and gradient
- 2.2 Design and average running speed, stopping and passing sight distance
- 2.3 Necessity of curves, horizontal and vertical curves including transition curves and super elevation, Methods o f providing super – elevation

2.1 The visible dimensions are technically known as road geometrics. Road geometrics can be divided as follows :-

1. Right of way or permanent land width

2. Road margins

3. Formation width

4. Carriage way width

5. Shoulders or footpath
6. Side slopes

7. Kerbs

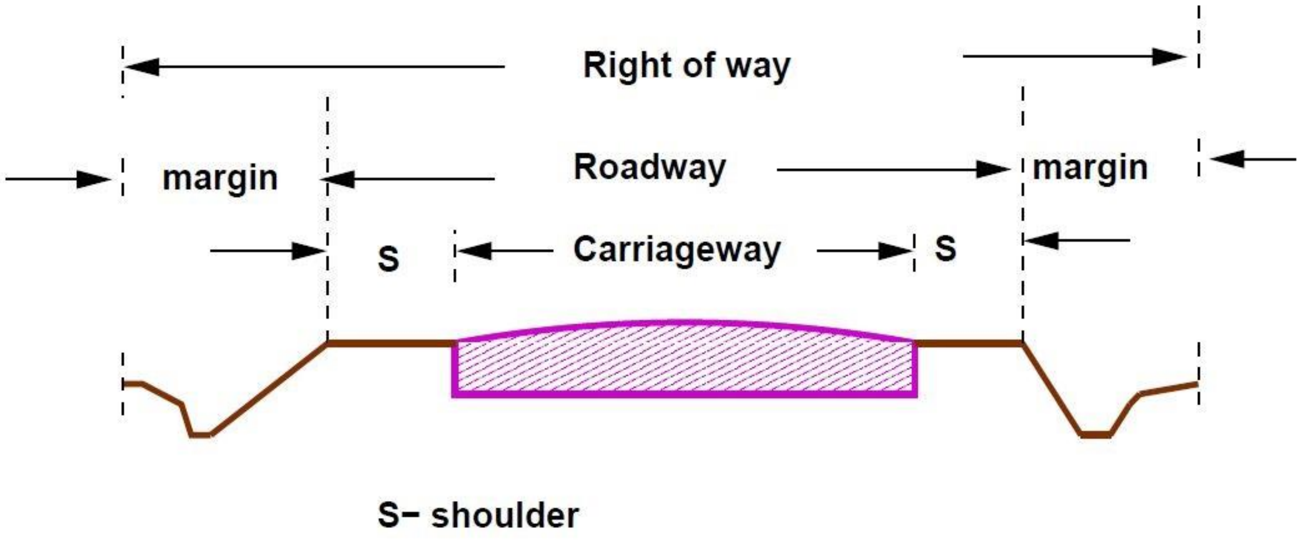
8. Formation level

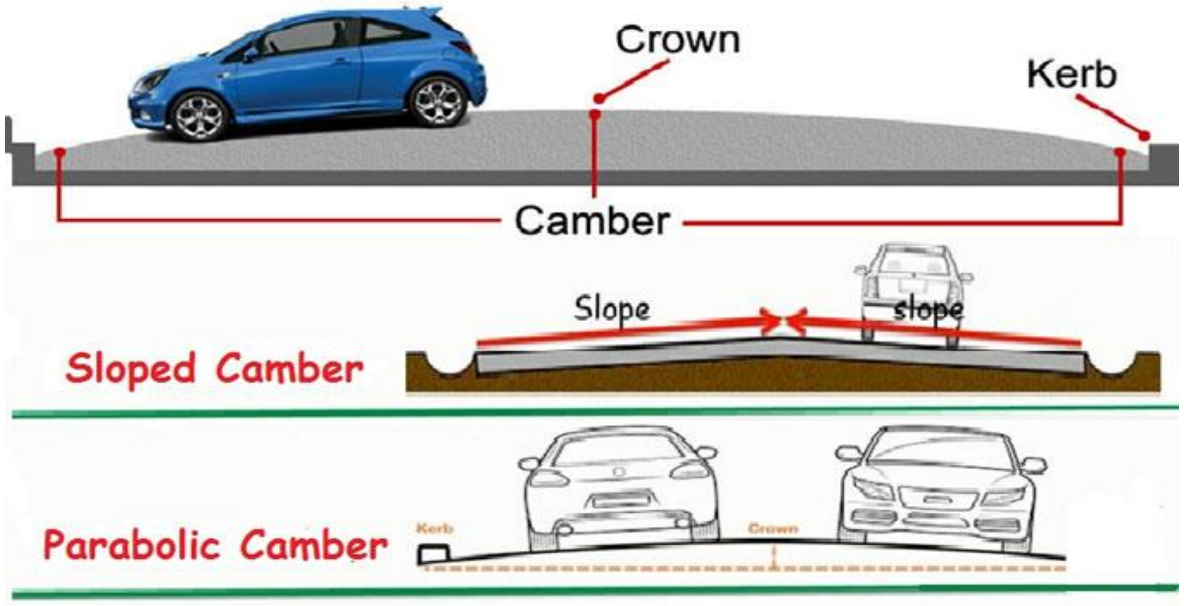
9. Camber or cross fall or cross slope

10. Gradient

11. Super elevation

12. Curves





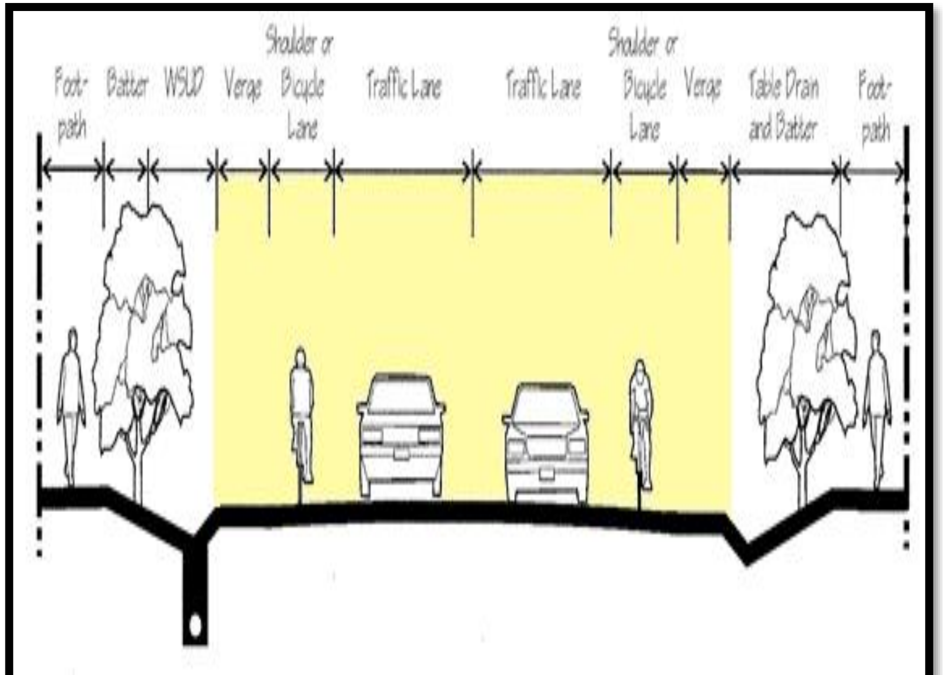
- **1. Right of way :** It is the area of land acquired and reserved for construction and development of the road along its alignment.
Permanent Land width as per Recommendations of I.R.C

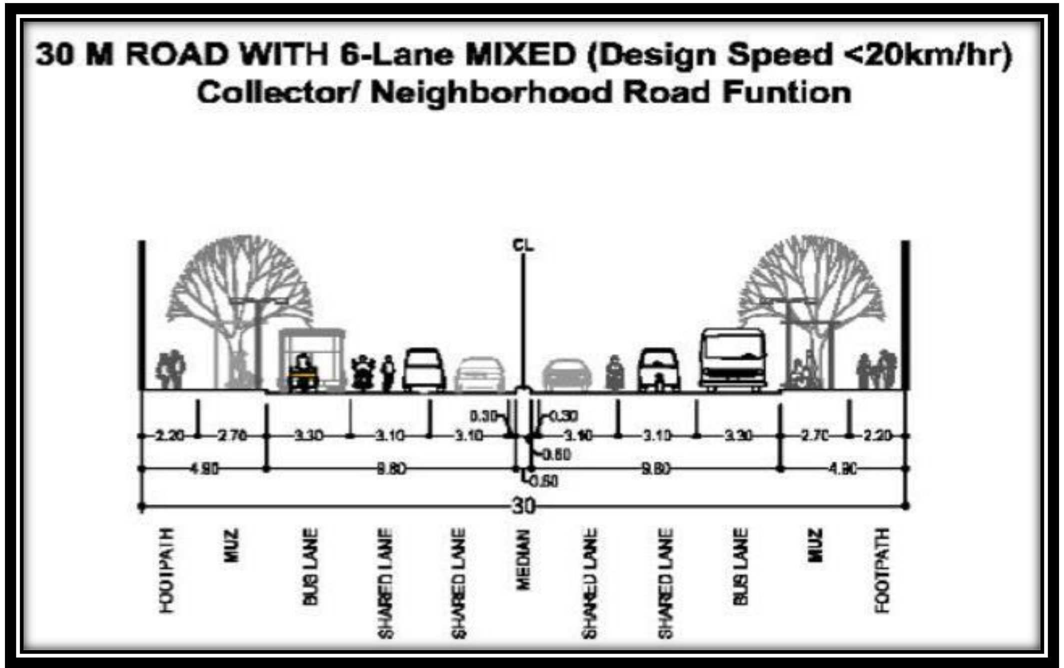
Class of Roads	Minimum formation width in Metres	
	Plain Area	Hilly Area or Rock cutting
National and state highways	12·0	7·90
Major district roads	10·0	6·70
Other district roads	8·0	6·70
Village roads	7·5	4·25

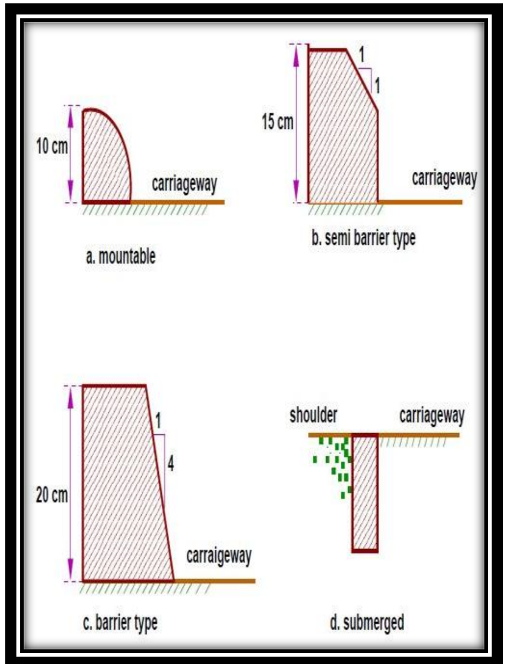
Class of Road	Right of way widths in metres			
	Open country		Built up Area	
	Mini-mum	Desirable	Mini-mum	Desirable
National and state highways	30·5	30·5 to 61·0	24·4	24·4 to 61·0
Major district roads	24·4	24·4 to 30·5	12·2	12·2 to 18·3
Other district roads	12·2	12·2 to 24·4	9·2	9·2 to 15·3
Village roads	12·2	12·2 to 18.3	9·2	9·2 to 15·3

- **2. Road margins :** It is the portion of land width on either side of formation width of a road. It includes footpaths, cycle track, guard raid, embankment slopes and parking lane etc.
3. Formation width : It is the top width of road embankment or bottom width of road cutting excluding the side drains. It is also known as crest.
Formation width as per Recommendation of I.R.C.

- **4. Carriage way :** It is the portion of the roadways used by vehicular traffic. It is in general the metalled portion of the road as per Indian Road Congress (I.R.C.) it is 3-8 metre for single lane traffic and 3-5 m. per lane in case of two or more than two lanes.
5. Shoulder for footpath : It is the portion of the roadway between the outer edge of the pavement and top edge of the side slope. Its width generally varies between 1-2 to 1-8 m.
6. Side slopes : The slopes given to the sides of earthwork of road in embankment or cutting for its stability are called side slopes.
7. Kerbs : The boundaries between the pavement and footpath is known as kerbs.





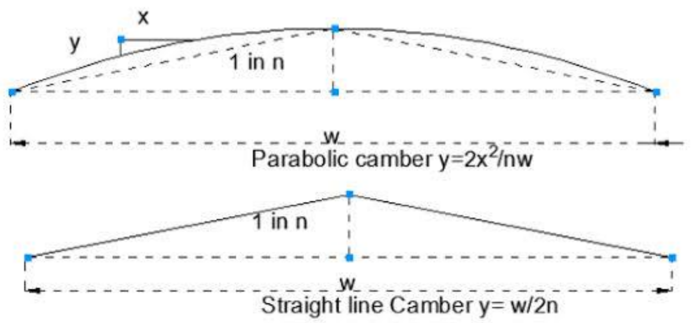


- **8. Formation level :** The reduced level of the finished surface of the earth work for a roadway o railway in embankment or cutting is known as formation level.
  9. Camber / Cross slope : The central highest point of a curved road surface is known as crown of the road.
- **Cross slope**, **cross fall** or **camber** is a geometric feature of pavement surfaces: the transverse slope with respect to the horizon. It is a very important safety factor. Cross slope is provided to provide a drainage gradient so that water will run off the surface to a drainage system such as a street gutter or ditch. **As per I.R.C. Recommendations**

Types of Roads Surface	Camber
Earth roads, foot paths	1 in 20 to 24
Gravel roads	1 in 24 to 30
Water bound macadam roads	1 in 30 to 48
Bituminous roads inside towns	1 in 30 to 48
Bituminous roads outside town paving	1 in 48 to 60
Cement concrete roads	1 in 60 to 72

10. Gradient : Gradient is the longitudinal slope of the road. The slope of the road which is adopted in road design and calculations of cuts and fills is called 'Ruling Gradient'. It is of three types :
1. Limiting gradient
2. Exceptional gradient
3. Minimum gradient

11. Super elevation : It is the inward tilt of the road surface provided at the horizontal curves to compensate the effect of centrifugal force.
12. Curves : The geometrical arcs provided at the intersection of straight alignments either in horizontal or in vertical plane to have gradual change in direction is known as a curve.



IRC Values for camber

Surface type	Heavy rain	Light rain
Concrete/Bituminous	2 %	1.7 %
Gravel/WBM	3 %	2.5 %
Earthen	4 %	3.0 %

4.2.8 Typical Cross Sections of Roads

Some of the typical cross sections of rural roads of different categories and urban roads are shown in Fig. 4.6 to 4.10.

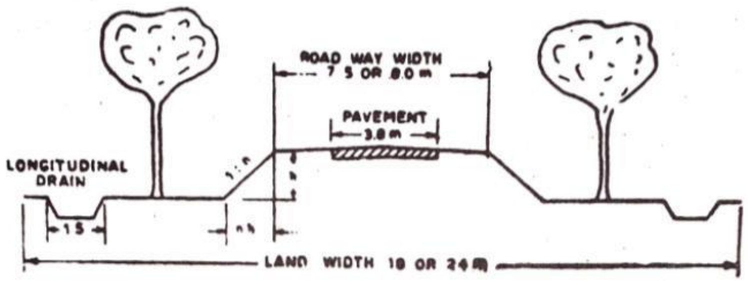


Fig. 4.6 Cross Section of VR or ODR in Embankment in Rural Area

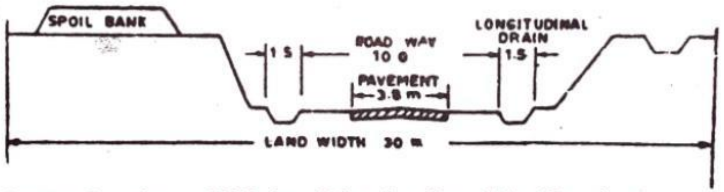


Fig. 4.7 Cross Section of Major District Road in Cutting in Rural Area

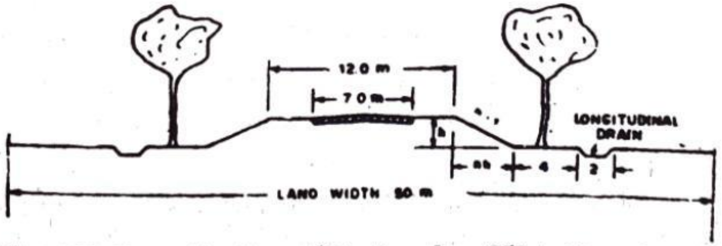


Fig. 4.8 Cross Section of National or SH in Rural Area

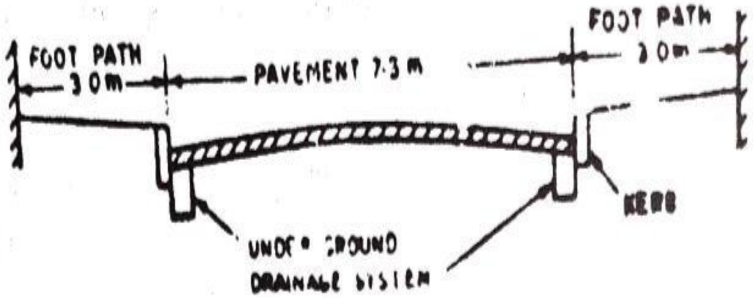


Fig. 4.9 Cross Section of Two-lane City Road in Built-up Area

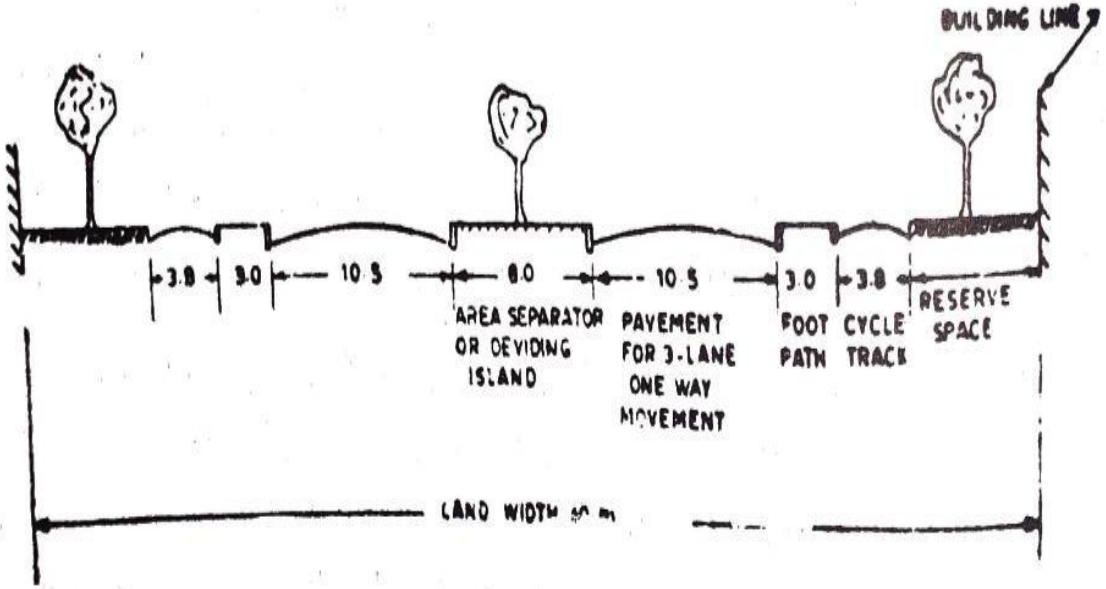


Fig. 4.10 Cross Section of Divided Highway in Urban Area

- **Ruling Gradient in Road**

It is the maximum gradient within which the designer attempts to design the vertical profile of a road. It is also known as design gradient. As per IRC, the recommended value of ruling gradient for plain or rolling terrain is **1 in 30** or 3.3 %.

- **Exceptional Gradient**

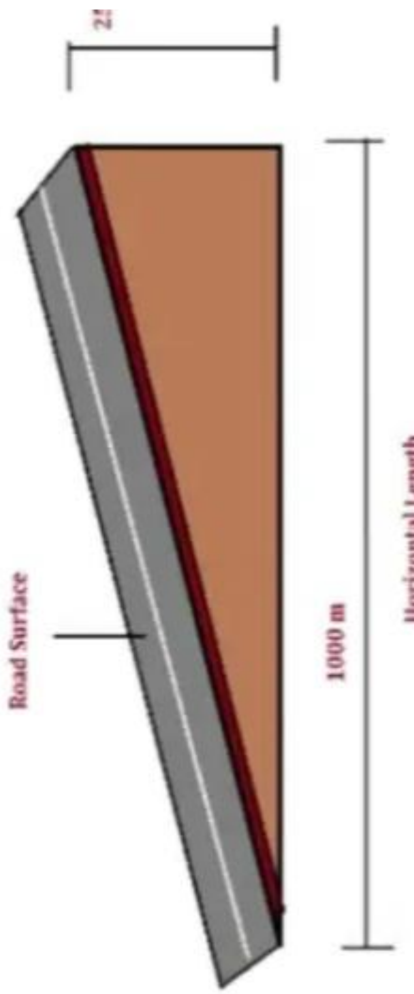
Exceptional gradients are very steeper **gradients** given at unavoidable situations. They should be limited for short stretches not exceeding about 100 metres at a stretch. In mountainous and steep terrain, successive **exceptional gradients** must be separated by a minimum 100 metre length gentler **gradient**.

- **Limiting Gradient**

The **gradient** steeper than the ruling **gradient**, which may be used for a limited Road length, is called **limiting gradient** or maximum **gradient**. It is used where the topography of place compels adopting a steeper **gradient** than the ruling **gradient** to minimize the cost of road construction.

- **Floating Gradient**

The **gradient** on which a motor vehicle moving with a constant speed continues to descend with the same speed without any application of power brakes is called a **floating gradient**.



2.2 Design and average running speed, stopping and passing sight distance

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. Thus the geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead . This distance is said to be the sight distance.
- Three sight distance situations are considered for design:

• Stopping sight distance (SSD) or the absolute minimum sight distance

• Intermediate sight distance (ISD) is defined as twice SSD

• Overtaking sight distance (OSD) for safe overtaking operation

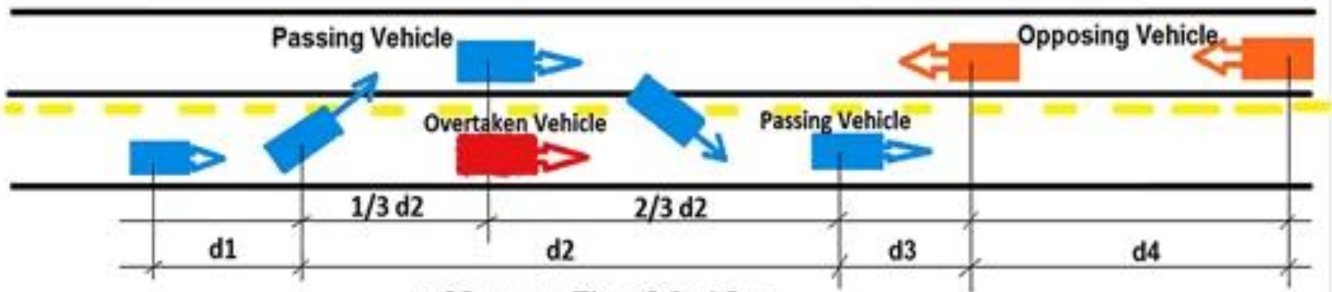
• Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights

• Safe sight distance to enter into an intersiection.

AASHTO (2004) PASSING SIGHT DISTANCE (PSD)

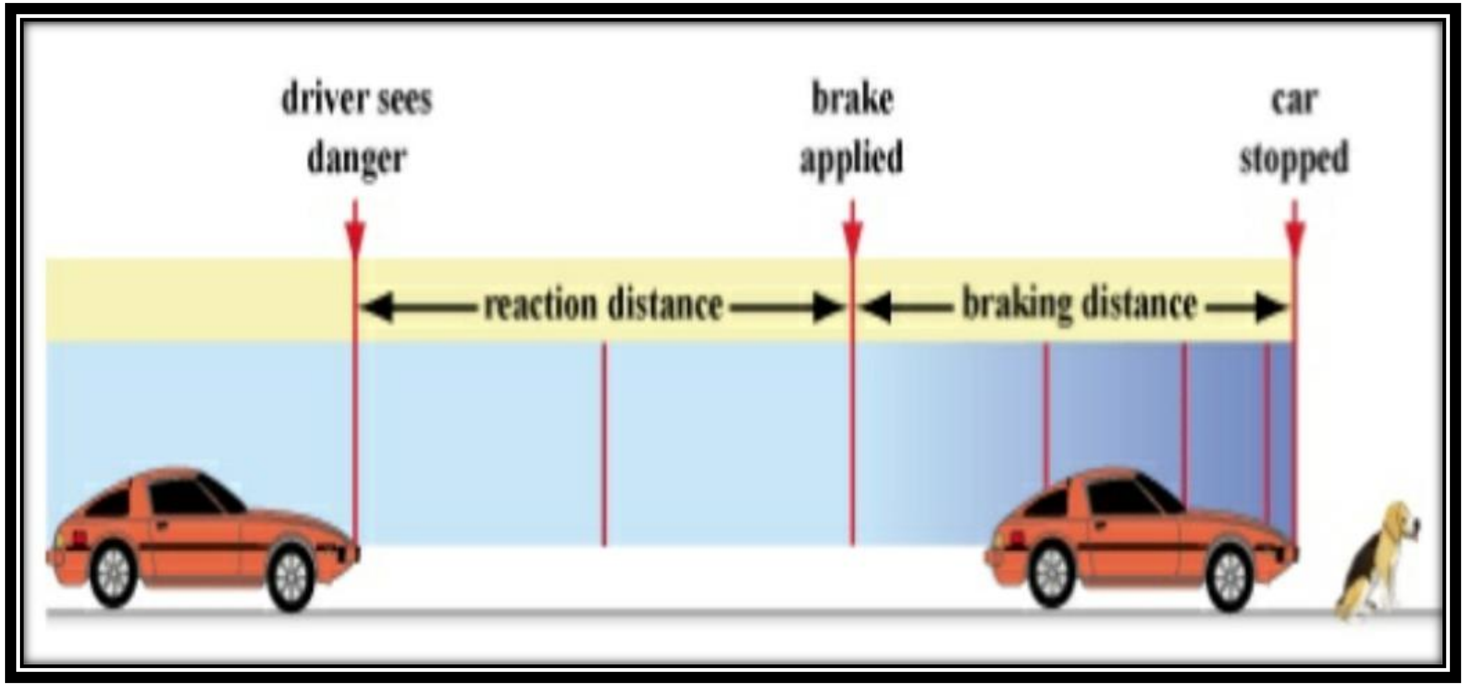
d1 : Initial Maneuver Distance
d2 : Left Lane Distance
d3 : Clearance Distance
d4 : Opposing Veh Distance

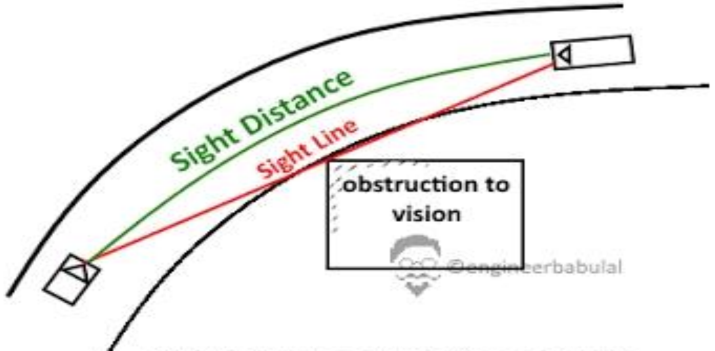
$$PSD = d1 + d2 + d3 + d4$$



$d1 = 0.278 t_i [v - m + (a t_i / 2)]$
$d2 = 0.278 v t_2$
$d3 = 30.0 - 90.0$ m
$d4 = 2/3\ d2$

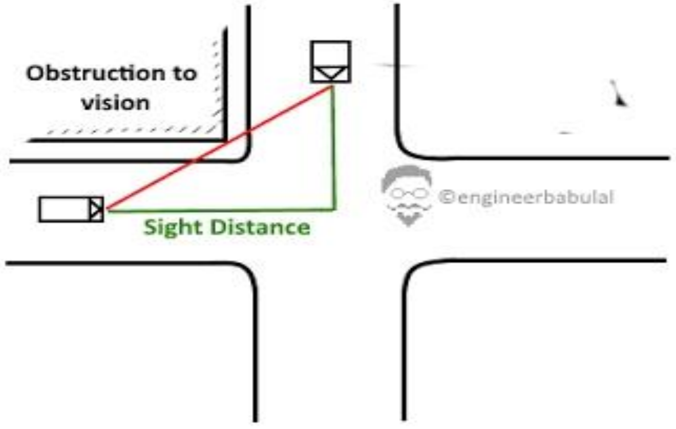
t_i : Maneuver Time, 3.6 - 4.5 sec
v : Speed of Passing Vehicle, km/h
a : Acceleration Rate, 2.25 - 2.41 km/h/sec
m : Differential Speed, km/h
t_2 : Left Lane Time, 9.3 - 11.3 sec





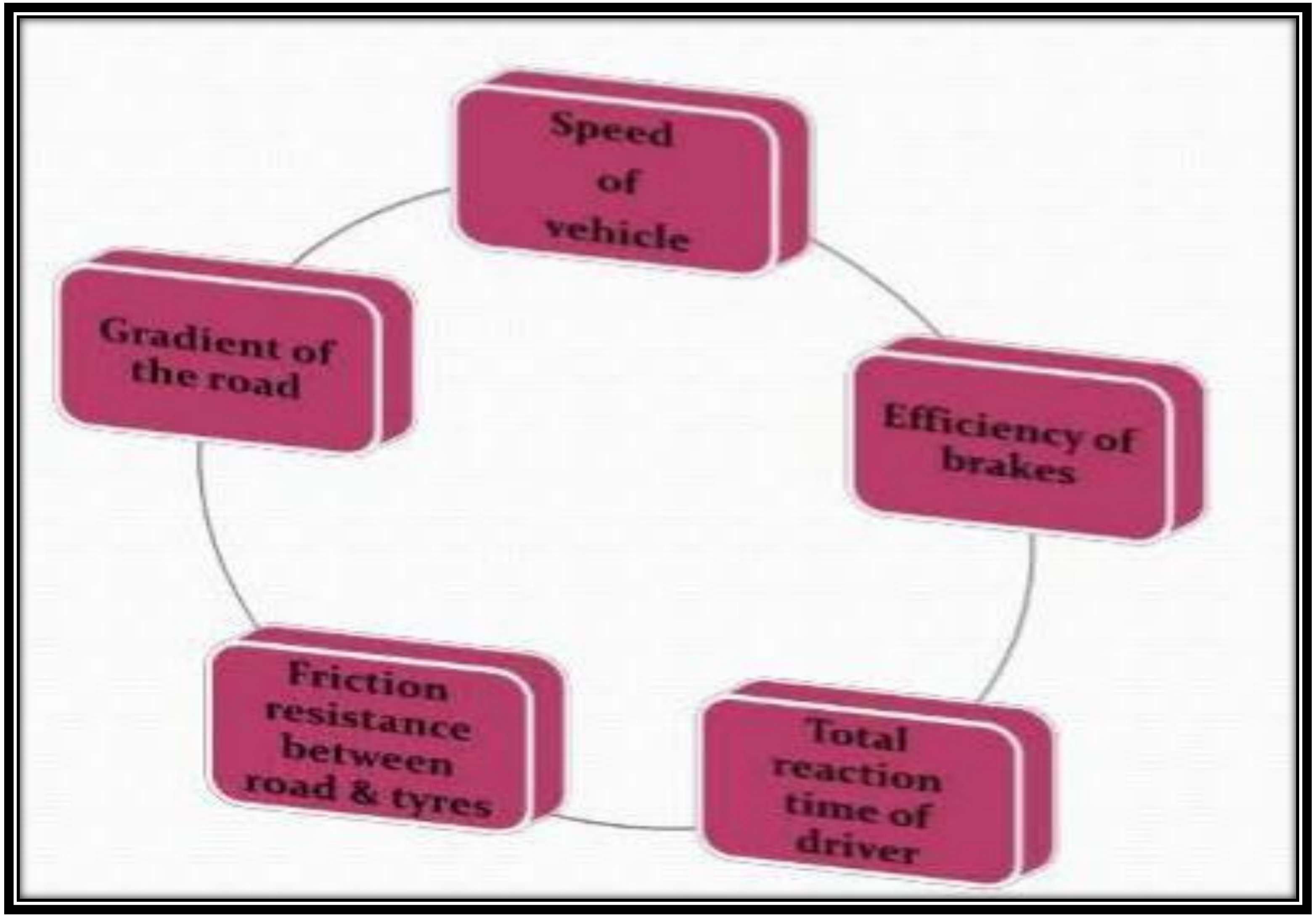
Sight Distance at Horizonal curve

Sight Distance at vertical summit curve



Sight Distance at Intersection

- Factors affecting sight distance:-



Factors affecting Sight distance:- (Road SE GF)

- **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. **IRC suggests a reaction time of 2.5 secs.**

- **Speed of the vehicle**

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. Therefore the sight distance required will be more when the efficiency of brakes are less. Also for safe geometric design, we assume that the vehicles have only 50% brake efficiency.

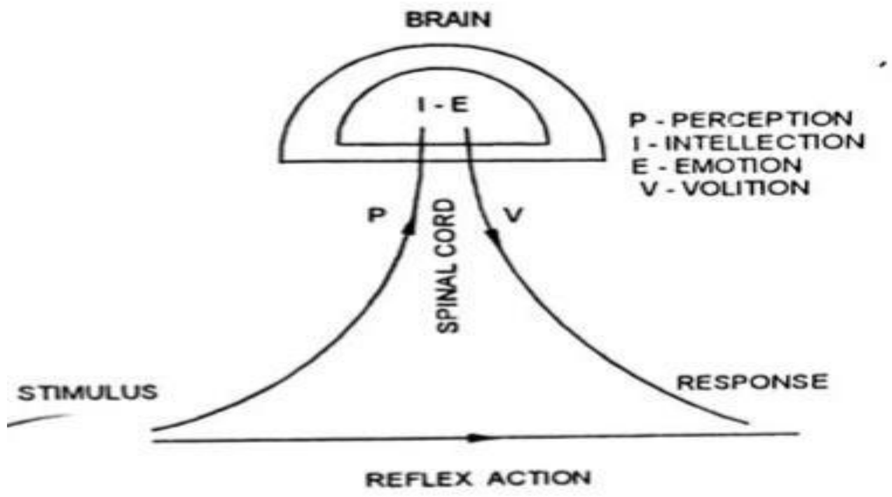
- **Frictional resistance between the tyre and the road**

The frictional resistance between the tyre 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. IRC has specified the ***value of longitudinal friction in between 0.35 to 0.4.***

- **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. While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in this case.

- **PIEV theory**
  1) Perception 2) Intellection 3) Emotion 4) Violation



- 1)***Perception time:*** is time required for the sensations received by the eyes or ears of the driver to be transmitted to the brain through the nervous system & spinal cord or it is the time required to perceive an object or situation.
- 2)***Intellection time :*** is the time require for the driver to understand the situation it is also the time required for comparing the different thoughts.
- 3) ***Emotion time:*** is the time elapsed during emotional sensational and other mental disturbance such as fear, anger or any other emotional feeling superstition etc
- 4) ***Volitiontime:*** is the time taken by the driver for the final action such as brake application.
- PIEV is the amount of time it takes a driver to react to a hazard. piev mean PIEV time - perception, intellection, emotion and volition. Before we can stop an automobile, four specific areas of activity need to happen
  The total reaction time may be split up into four components based on PIEV theory. In practice, all these times are usually combined into
  Full form of PIVE theory perception intellection emotion and volition

Stopping sight distance

Stopping sight 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.

Therefore, the SSD = lag distance + braking distance and given by:

$$SSD = vt + \frac{v^2}{2gf} \tag{13.1}$$

where v is the design speed in m/sec^2, 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 various design speed. When there is an

Table 13:1: Coefficient of longitudinal friction

Speed, kmph	<30	40	50	60	>80
f	0.40	0.38	0.37	0.36	0.35

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 the braking force is equal to $W \sin\alpha \approx W \tan\alpha = Wn/100$. Equating kinetic energy and work done:

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

$$l = \frac{v^2}{2g\left(f + \frac{n}{100}\right)}$$

Similarly the braking distance can be derived for a descending gradient. Therefore the general equation is given by Equation 13.2.

$$SSD = vt + \frac{v^2}{2g(f \pm 0.01n)} \tag{13.2}$$

ex- Calculate SSD for V = 50Kmph for
a) two lane, two-way road
b) - Two way traffic for single lane road.

SIGHT DISTANCE

Assume coefficient of friction as 0.37 and reaction time of driver as 2.5 seconds.

Solution

Stopping distance (Eq. 4.4) = lag distance + braking distance

$$= vt + \frac{v^2}{2gf}$$

$$V = 50 \text{ kmph} \text{ or } v = \frac{50}{3.6} = 13.9 \text{ m/sec}$$

$$t = 2.5,\ g = 9.8,\ f = 0.37$$

$$\text{Stopping distance} = 13.9 \times 2.5 + \frac{13.9^2}{2 \times 9.8 \times 0.37}$$

$$= 34.8 + 26.6 = 61.4 \text{ m}$$

Alternatively, the stopping distance may also be calculated from Eq. 4.2 as follows :

$$SD = 0.278\ V_t + V^2/254\ f$$

$$= 0.278 \times 50 \times 2.5 + \frac{50^2}{254 \times 0.37} = 61.4 \text{ m}$$

(a) Stopping sight distance when there are two lanes = stopping distance = 61.4 m

(b) Stopping sight distance for two-way traffic with single lane = 2 [stopping distance] = 2 × 61.4 122.8.

Calculate the minimum sight distance required to avoid a head-on collision of two cars approaching from the opposite directions at 90 and 60 kmph. Assume a reaction time of 2.5 seconds, coefficient of friction of 0.7 and a brake efficiency of 50 percent, in either case.

Solution

Stopping distance for one of the cars (Eq. 4.1).

$$\text{SD metres} = vt + \frac{v^2}{2gf}$$

$$V_1 = 90 \text{ kmph}, v = \frac{90}{3.6} = 25 \text{ m/sec}$$

$$V_2 = 60 \text{ kmph}, v = \frac{60}{3.6} = 16.67 \text{ m/sec}$$

As the brake efficiency is 50%, the wheels will skid through 50% of the braking distance and rotate through the remaining distance. Therefore, the value of coefficient of friction developed f may be taken as 50% of the coefficient of friction, i.e., $f = 0.5 \times 0.7 = 0.35$.

$$= 25 \times 2.5 + \frac{25^2}{2 \times 9.8 \times 0.35} = 153.6 \text{ m}$$

For second car, $$SD_2 = 16.67 \times 2.5 + \frac{16.67^2}{2 \times 9.8 \times 0.35} = 82.2 \text{ m}$$

Sight distance to avoid head-on collision of the two approaching cars

$$= SD_1 + SD_2 = 153.6 + 82.2 = 235.8 \text{ m.}$$

Example 4.4

Calculating the stopping sight distance on a highway at a descending gradient of 2% for a design speed of 80 kmph. Assume other data as per IRC recommendations.

Solution

Total reaction time t may be taken as 2.5 seconds and design coefficient of friction as f = 0.35.

$$V = 80 \text{ kmph};\ n = -2\% = -0.02,\ G = 9.8 \text{ m/sec}^2$$

$$v = \frac{80}{3.6} = 22.2 \text{ m/sec}$$

SSD on road with gradient is given in Eq. 4.3 and 4.4.

From Eq. 4.3, $$SSD = vt + \frac{v^2}{2g\,(f \pm n\%)} = 2.2 \times 2.5 + \frac{22.2^2}{2 \times 9.8(0.35 - 0.02)}$$

$$= 55.5 + 76.2 = 131.7 \text{ m say } 132 \text{ m}$$

Alternatively, using Eq. 4.4

$$SSD = 0.278\ V.t + \frac{V^2}{254\,(f \pm 0.01)\,n}$$

$$= 0.278 \times 80 \times 2.5 + \frac{80^2}{254(0.35 - 0.02)} = 55.6 + 76.4 = 132 \text{ m}$$

Example 4.5

Calculate the values of (i) Head light sight distance and (ii) Intermediate sight distance for a highway with a design speed of 65 kmph. Assume suitably all the data required.

Solution

$$V = 65 \text{ kmph};$$

Assume $$f = 0.36,\ t = 2.5 \text{ secs.}$$

(i) Head light sight distance = $SSD = 0.278\ Vt + \dfrac{V^2}{254\,f}$ = 91.4 m

ISD = 2 × SSD = 182.8 m.

- **Overtaking sight distance**
- 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 1.2 m above the road surface.
- The factors that affect the OSD are:

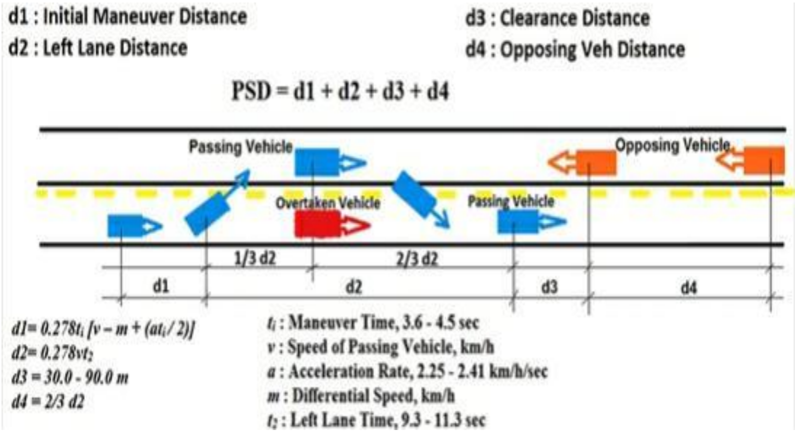
• Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.

• 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



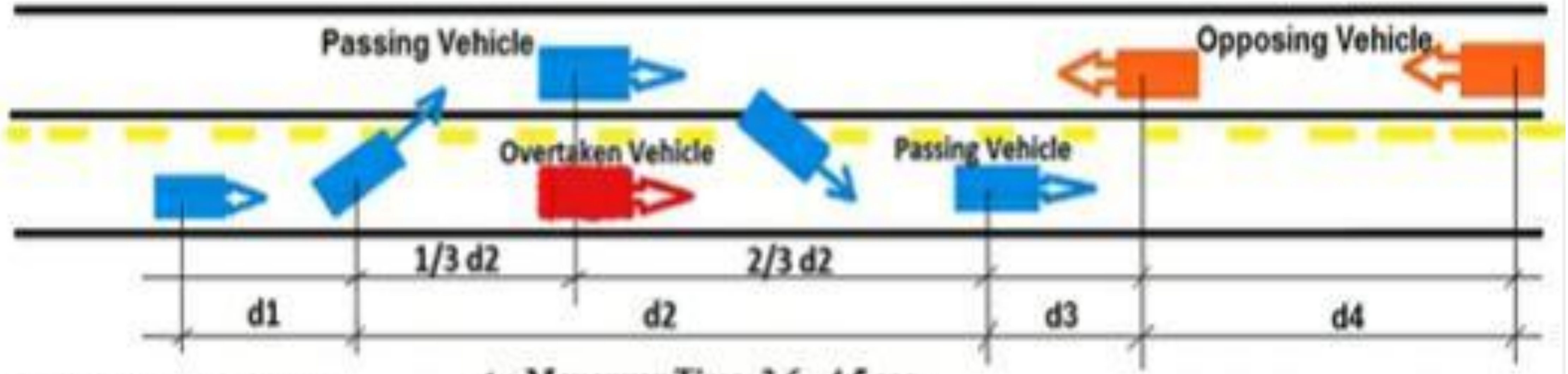
d1 : Initial Maneuver Distance

d2 : Left Lane Distance

d3 : Clearance Distance

d4 : Opposing Veh Distance

$$PSD = d1 + d2 + d3 + d4$$



$d1 = 0.278t_1 [v - m + (at_1 / 2)]$

$d2 = 0.278vt_2$

$d3 = 30.0 - 90.0\ m$

$d4 = 2/3\ d2$

t_1 : Maneuver Time, 3.6 - 4.5 sec

v : Speed of Passing Vehicle, km/h

a : Acceleration Rate, 2.25 - 2.41 km/h/sec

m : Differential Speed, km/h

t_2 : Left Lane Time, 9.3 - 11.3 sec

- d_1 the distance traveled by overtaking vehicle A during the reaction time $t = t_1 - t_0$
- d_2 the distance traveled by the vehicle during the actual overtaking operation $T = t3 - t1$
- d_3 is the distance traveled by on-coming vehicle C during the overtaking operation (T).

Therefore:

$$OSD = d_1 + d_2 + d_3 \tag{13.3}$$

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:

$$d_1 = v_b t \tag{13.4}$$

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:

$$s = 0.7v_b + 6 \tag{13.5}$$

Let T be the duration of actual overtaking. The distance traveled 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 traveled is given by:

$$\begin{aligned} d_2 &= v_b T + \frac{1}{2} a T^2 \\ 2s + v_b T &= v_b T + \frac{1}{2} a T^2 \\ 2s &= \frac{1}{2} a T^2 \\ T &= \sqrt{\frac{4s}{a}} \\ d_2 &= 2s + v_b \sqrt{\frac{4s}{a}} \end{aligned} \tag{13.6}$$

The distance traveled by the vehicle C moving at design speed v m/sec during overtaking operation is given by:

$$d_3 = vT \tag{13.7}$$

The the overtaking sight distance is (Figure 13:1)

$$OSD = v_b t + 2s + v_b \sqrt{\frac{4s}{a}} + vT \tag{13.8}$$

where v_b is the velocity of the slow moving vehicle in m/sec^2, t the reaction time of the driver in sec, s is the spacing between the two vehicle in m given by equation 13.5 and a is the overtaking vehicles acceleration in m/sec^2. In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph slower the the design speed.

The acceleration values of the fast vehicle depends on its speed and given in Table 13:2. Note that:

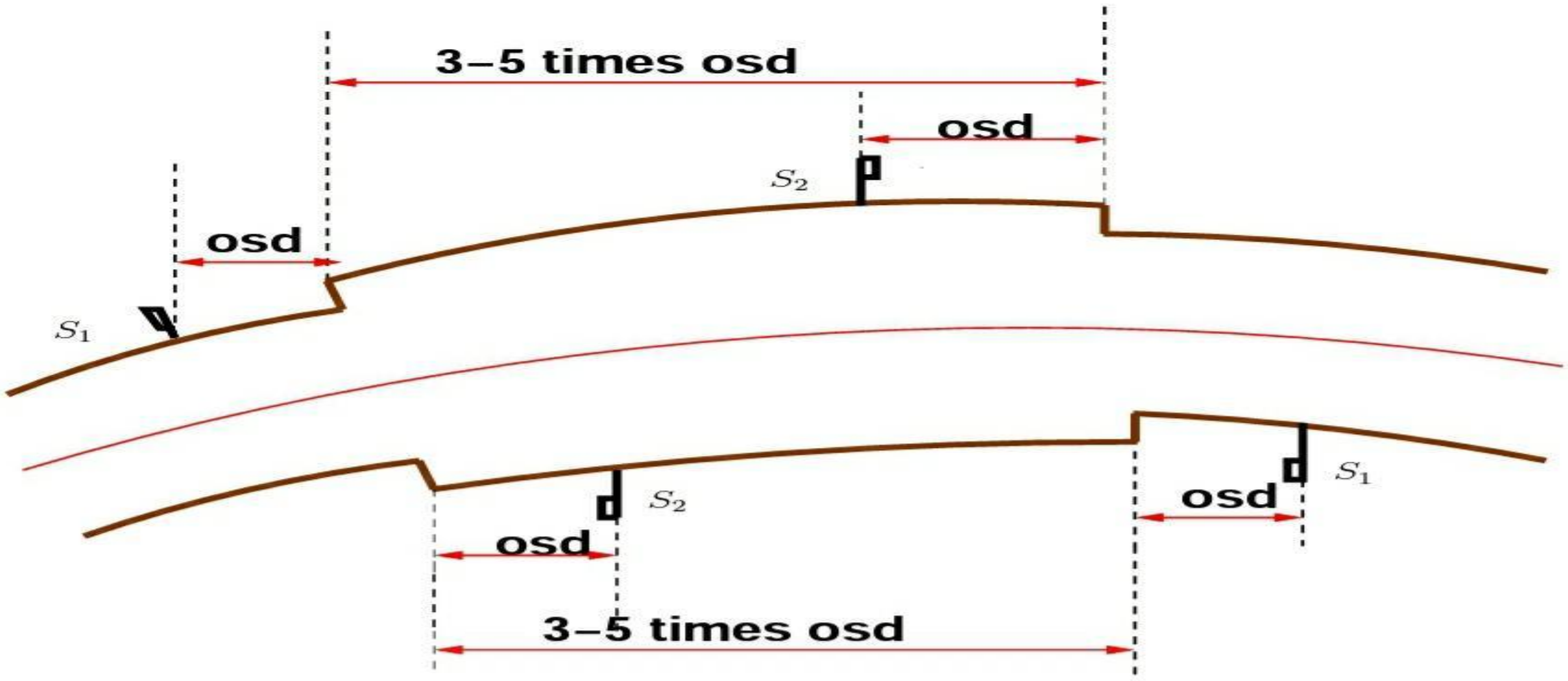
Table 13:2: Maximum overtaking acceleration at different speeds

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, 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.

- **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



S_1– Overtaking zone begin
S_2–End of Overtaking zone

The speed of overtaking and overtaken vehicles are 70 and 40 kmph, respectively on a two way traffic road. If the acceleration of overtaking vehicle is 0.99 m/sec^2.

(a) calculate safe overtaking sight distance

(b) mention the minimum length of overtaking zone and

(c) draw a neat-sketch of the overtaking zone and show the positions of the sign posts.

Solution

(a) Overtaking sight distance for two way traffic

$$= d_1 + d_2 = d_3 \quad (4.5)$$

Assume the design speed as the speed of overtaking vehicle A

$$V = 70 \text{ kmph}$$

$$v = \frac{70}{3.6} = 19.4 \text{ m/sec}$$

$$v_b = \frac{40}{3.6} = 11.1 \text{ m/sec}$$

Acceleration, $a = 0.99$ m/sec per sec.

$$D_1 = v_b . t \text{ (Adopt } t = 2 \text{ secs)} = 11.1 \times 2 = 22.2 \text{ m}$$

$$d_2 = v_b.T + 2.s$$

$$s = (0.7\, v_b + 6) = (0.7 \times 11.1 + 6) = 13.8 \text{ m}$$

$$T = \sqrt{\frac{4.s}{a}} = \sqrt{\frac{4 \times 13.8}{0.99}} = 7.47 \text{ secs}$$

$$d_2 = 11.1 \times 7.47 + 2 \times 13.8 = 110.5 \text{ m}$$

$$d_3 = v.\,T = 19.4 \times 7.47 = 144.9 \text{ m}$$

$$O.S.D = d_1 + d_2 + d_3$$

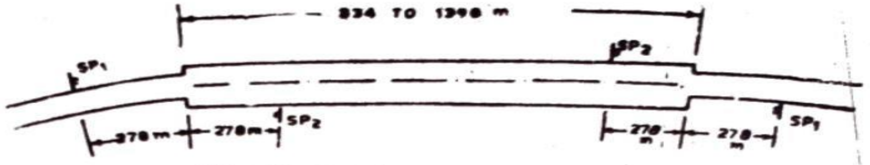
$$= 22.2 + 110.5 + 144.9 = 277.6 \text{ m, say } 278 \text{ m}$$

(b) Minimum length of overtaking zone = 3 (OSD)

$= 3\,(d_1 + d_2 + d_3)$ for two-way traffic $= 3 \times 278 = 834$ metres

Desirable length of overtaking zone $= 5 \times$ (OSD) $= 5 \times 278 = 1390$ m

(c) The details of the overtaking zone are shown in Fig. 4.16.



SP_1 = Sign Post "Overtaking Zone Ahead"

SP_2 = Sign Post "End of Overtaking Zone"

Fig. 4.16 Overtaking Zone (Example 4.6)

Example 4.7

Calculate the safe overtaking sight distance for a design speed of 96 kmph. Assume all other data suitably.

Solution

$$\text{O.S.D} = (d_1 + d_2) \text{ for one-way traffic}$$

$$= (d_1 + d_2 + d_3) \text{ for two-way traffic}$$

$$V = 96 \text{ kmph}$$

$$\text{Assume } V_b = V - 16 = 80 \text{ kmph and}$$

A 2.5 kmph/sec. (from Table 4.7); t = 2 secs.

$$d_1 = 0.28\ V_b\ t = 0.28 \times 80 \times 2 = 44.8 \text{ m}$$

$$d_2 = 0.28\ V_b\ T + 2.s$$

$$s = (0.2\ V_b + 6) = 0.2 \times 80 + 6 = 22 \text{ m}$$

$$T = \sqrt{\frac{14.4\,s}{A}} = \sqrt{\frac{14.4 \times 22}{2.5}} = 11.3 \text{ secs.}$$

$$d_2 = 0.28 \times 80 \times 11.3 + 2 \times 22 = 297 \text{ m}$$

$$d_3 = 0.28\ V\ T = 0.28 \times 96 \times 11.3 = 303.7 \text{ m}$$

O.S.D. on one-way traffic road = $d_1 + d_2 = 341.8$ m; say 342 m

O.S.D. on two-way traffic road = $d_1 + d_2 + d_3 = 645.5$ m; say 646 m

2.3 Necessity of curves, horizontal and vertical curves including transition curves and super elevation, Methods of providing super – elevation

CURVE:-

- A curve is nothing but an arc which connects two straight lines which are separated by some angle called deflection angle. This situation occurs where the alignment of a road way or rail way changes its direction because of unavoidable objects or conditions.
- The object may be a hill or a lake or a temple etc. so, for the ease of movement of vehicle at this point a curve is provided.

Necessity of curves:-

1. To bring about gradual change in direction of motion.
2. To bring about gradual change in grade and for good visibility.
3. To alert the driver so that he may not fall asleep.
4. To layout Canal alignment.
5. To control erosion of canal banks by the thrust of flowing water in a canal.

HORIZONTAL CURVES

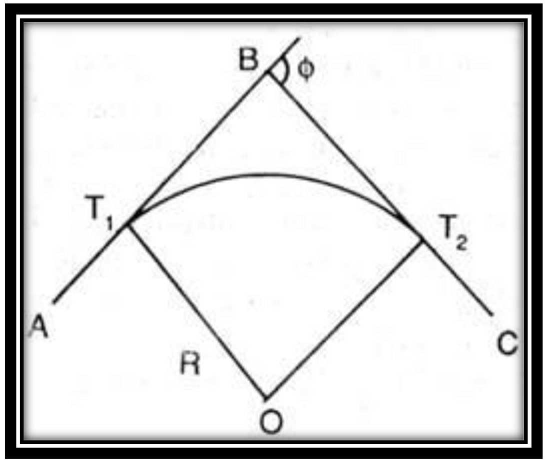
- Curves provided in the horizontal plane to have the gradual change in direction are known as horizontal curves.

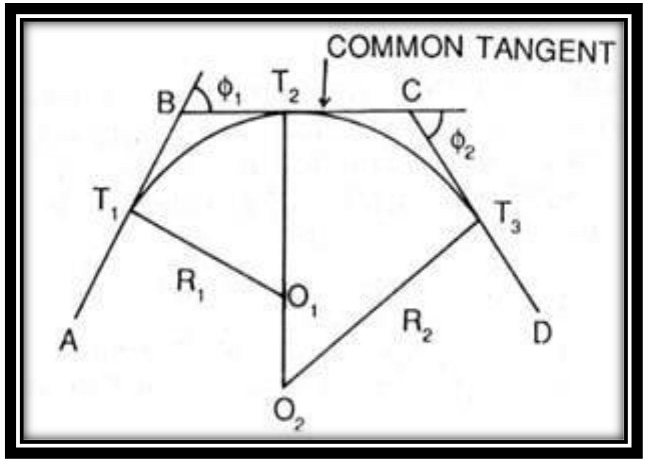
VERTICAL CURVES

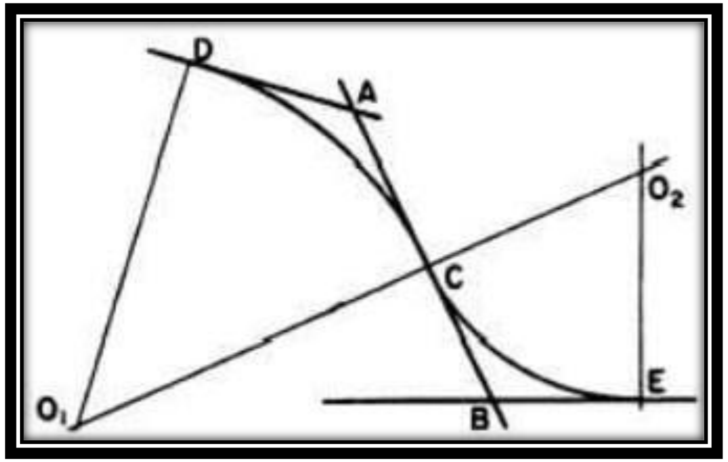
- Curves provided in the vertical plane to obtain the gradual change in grade are called as vertical curves.

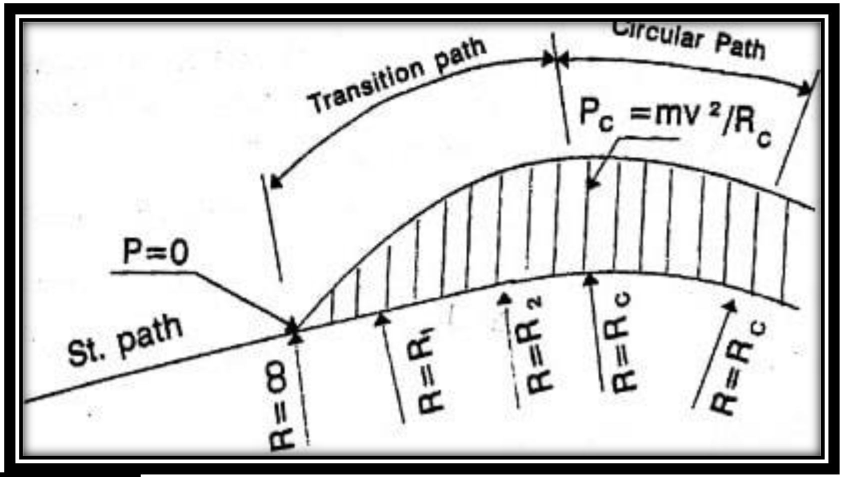
Horizontal curves are of different types as follows

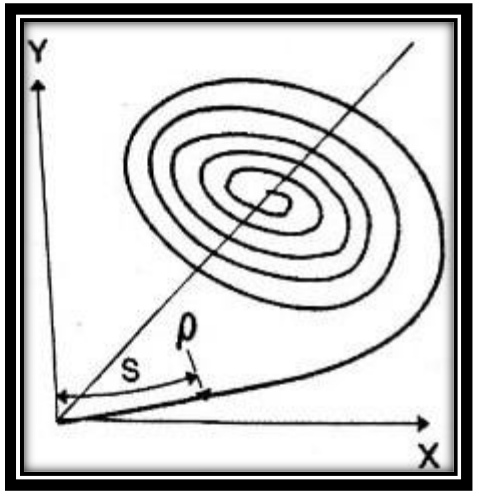
- Simple circular curve
- Compound curve
- Reverse curve
- Transition curve
- Spiral
- Lemniscate

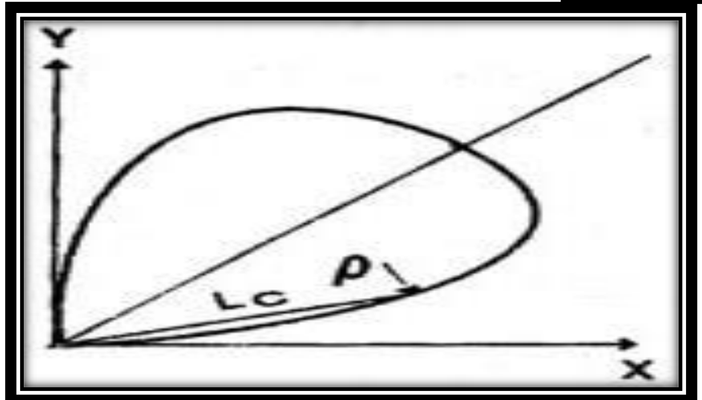












Simple Circular Curve

- Simple circular curve is normal horizontal curve which connect two straight lines with constant radius

Compound Curve

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

Reverse curve

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

Transition Curve

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

Spiral Curve

- Spiral is a type of transition curve which is recommended by IRC as ideal transition curve because of its smooth introduction of centrifugal acceleration. It is also known as clothoid.

Lemniscate

- Lemniscate is a type of transition curve which is used when the deflection angle is very large. In lemniscate the radius of curve is more if the length of chord is less

TRANSITION CURVE

- It is a curve in plan which is provided to change the horizontal alignment from straight to circular curve gradually means the radius of transition curve varies between infinity to R or R to infinity.

Objectives for providing transition curves

- For the gradual introduction Centrifugal force
- To introduce super elevation gradually
- To introduce extra widening gradually
- To provide comfort for the driver that is to enable smooth vehicle operation on road.
- To enhance aesthetics of highways.

IRC recommends Spiral or clothoid as the ideal transition curve due to following reasons:

- It satisfies that rate of change of centrifugal acceleration is constant i.e., L_s.R = constant. Where L_s = length of transition curve R = radius of curve.
- The calculation and field implementation of spiral curve is simple and easy.
- It enhances aesthetics also

Determining length of transition curve

The length of transition curve can be calculated by 3 conditions.

1. Based on rate of change of acceleration
2. Based on rate of change of super elevation and extra widening
3. Based in IRC empirical formula

1. Based on rate of change of acceleration

- Radius of curve is infinity at the tangent point and hence centrifugal acceleration is zero. Similarly at the straight end radius of curve has minimum value means centrifugal acceleration is maximum. So, the rate of change of centrifugal acceleration should be adopted such that the design should not cause any discomfort to the drivers.
- Let Ls be the length of transition curve and a vehicle is moving with a speed of V m/s.

Force $P = (mV^2/R)$ Since it is similar to F= ma

$P = m\,(V^2/R)$ Therefore, centrifugal acceleration $a = V^2/R$

Let "C" be the coefficient of rate of change of centrifugal acceleration.

$C = (V^2/R).\,(1/t)$ Where t= time taken to travel the transition curve of length Ls, with a speed of V

$t = Ls/V$

$C = (V^2/R).\,(V/Ls)$

$Ls = (V^3/CR)$ According to IRC, $C = 80/(75+V)$ and C should be $(0.5<C<0.8)$.

Based on rate of change of superelevation and extra widening

- Let 1 in N is the allowable rate of introduction of super elevation and E is the raise of the outer edge with respect to inner edge. W is the normal width of pavement in meters. We is the extra width of pavement in meters. And e is the rate of superelevation. **E = (W+We).e**
- Therefore length of transition curve, **Ls = (W+We).e.N**
- If the pavement outer edge is raised and inner edge is depressed with respect to center of pavement then,

Ls = [(W+We).e.N]/2

- Typical range of introduction of super elevation is as follows according to IRC

super elevation is as follows according to IRC

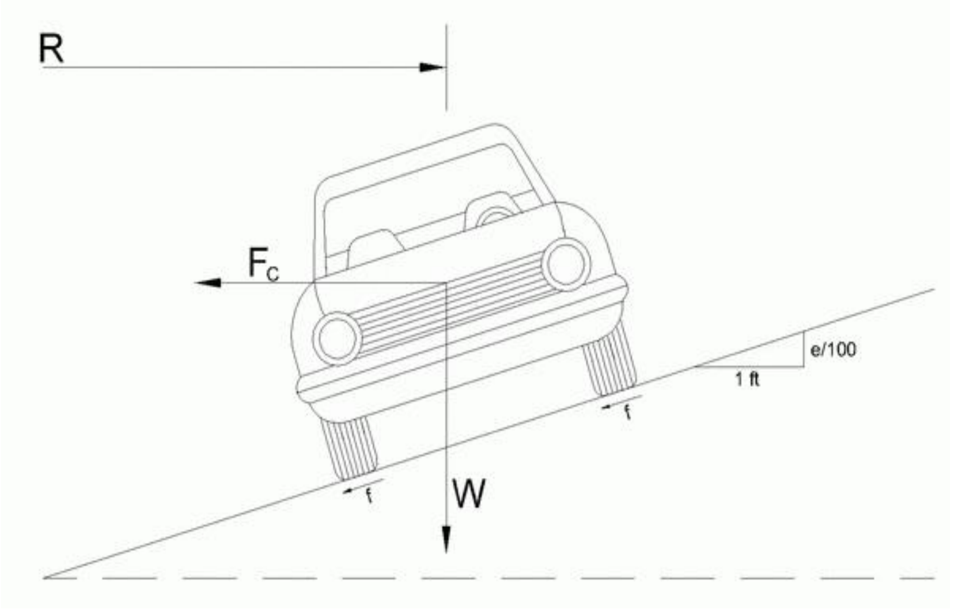
Type of terrain	Rate of super elevation 1 in N
For plain and rolling terrains	1 in 150
For built up areas	1 in 100
For hilly and steep terrains	1 in 60

Based on IRC empirical formula

- IRC given some direct formulae for finding the length of transition curve.
- For plain and ruling terrain:
- **$L_s = 2.7 (V^2/R)$**
- For mountainous and steep terrains
- **$L_s = V^2/R$**
- Hence these are the three criteria to determine the length of transition curve.
- The maximum of above three conditions will be considered as the length of transition curve.

Superelevation:-

- Superelevation is the transverse slope provided to counteract the effect of centrifugal force and reduce the tendency of vehicle to overturn and to skid laterally outwards by raising the pavement outer edge with respect to inner edge. superelevation is represented by “ e ”.



Limits for maximum superelevation:

According to IRC the Maximum Superelevation in Areas

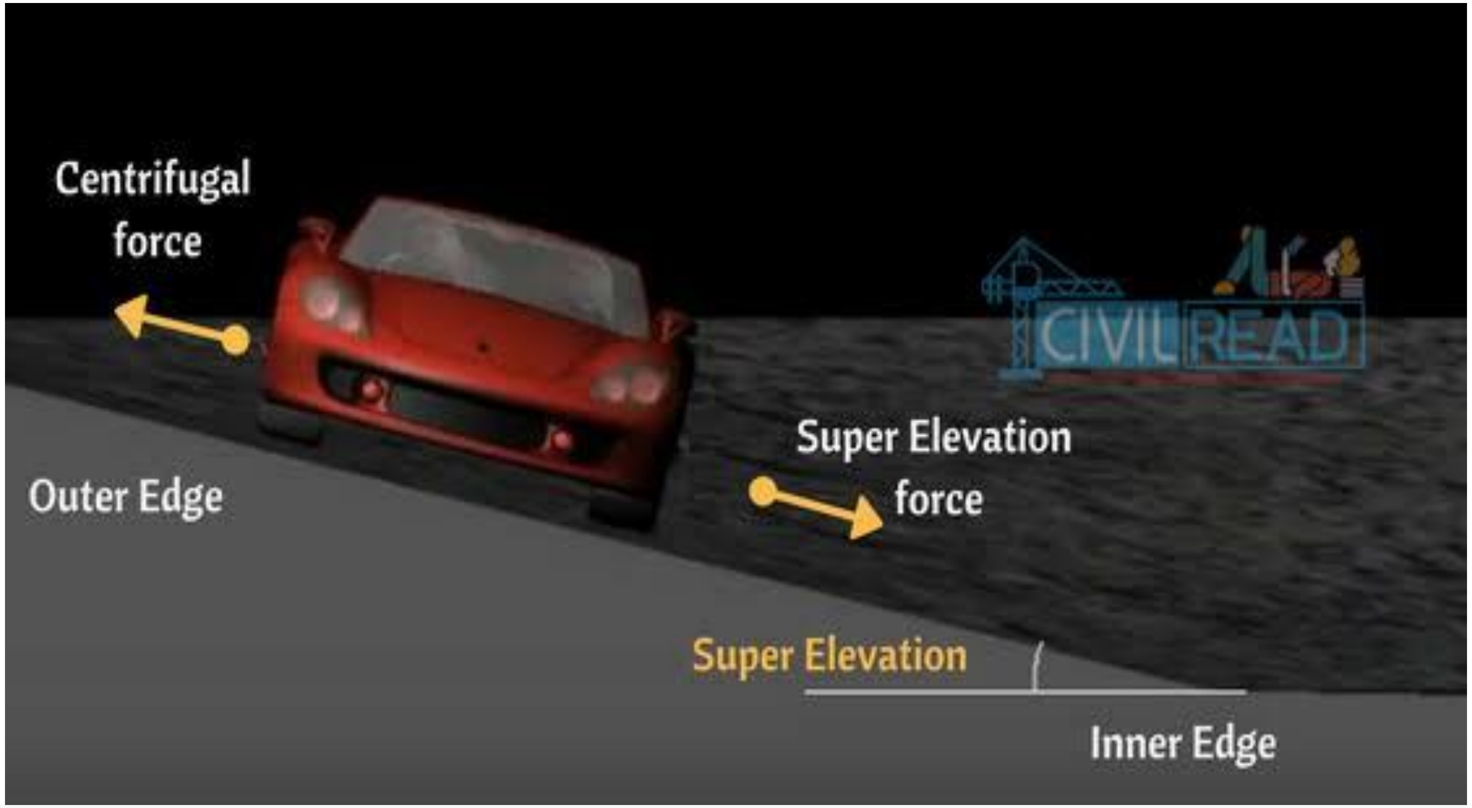
Which Are Bound by Snow fall – 7%

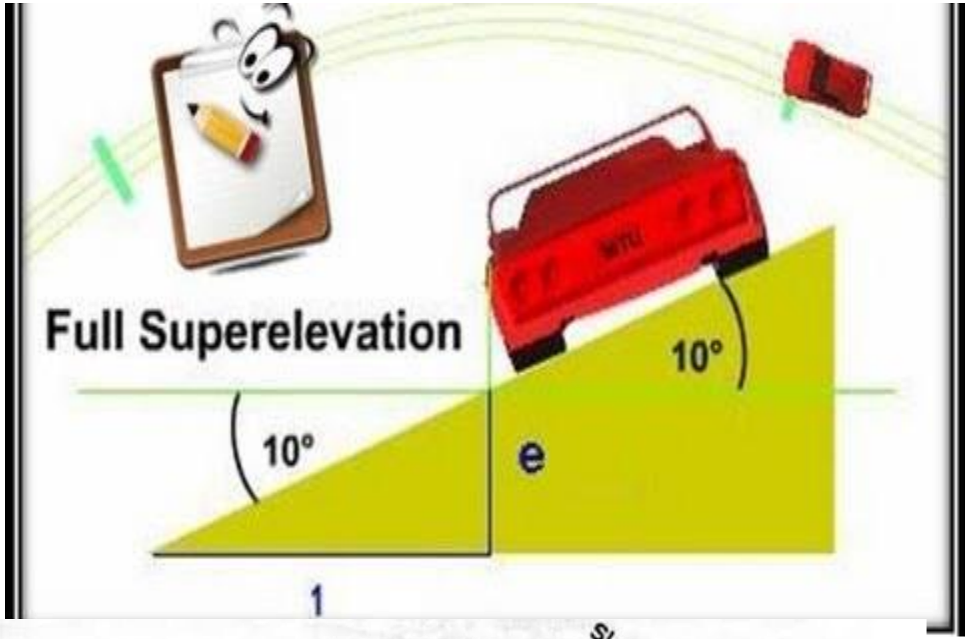
Which are not bounded by Snowfall – 10%

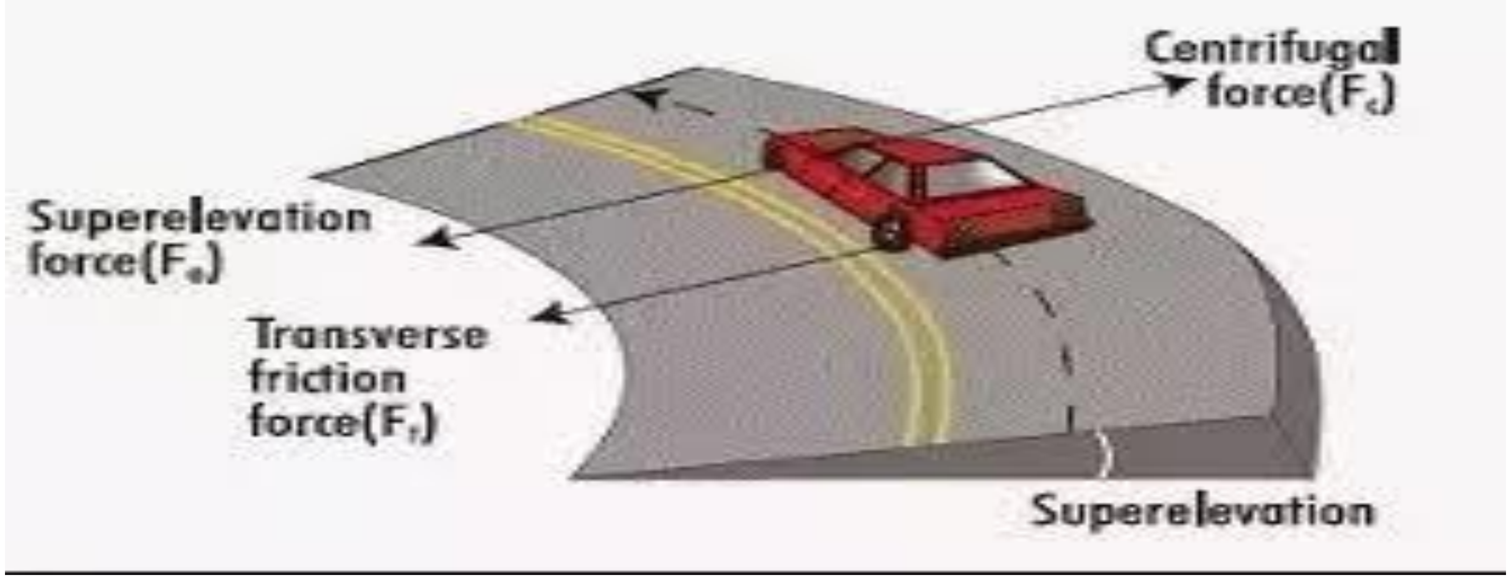
Limits for minimum superelevation

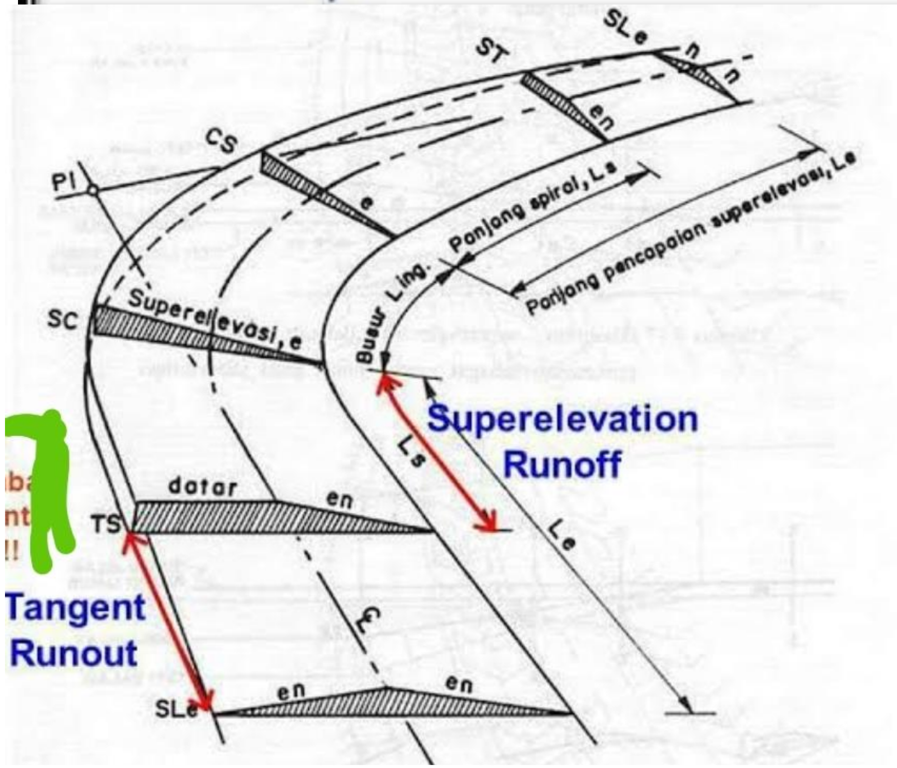
Minimum superelevation = camber or cross slope

Camber: Slope provide in the transverse direction to drain off rain water quickly is known as Camber or Cross slope. This will also prevents slipping and skidding of vehicles.


Centrifugal
force
CIVILREAD
Outer Edge
Super Elevation
force
Super Elevation
Inner Edge


Full Superelevation
10°
10°
e
1


Centrifugal
force(F_c)
Superelevation
force(F_e)
Transverse
friction
force(F_f)
Superelevation


SLe
ST
n
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en
CS
PI
e
Panjang spiral, Ls
Panjang pencapaian superelevasi, Le
Busur Ling.
SC
Superelevasi, e
Superelevation
Runoff
Ls
datar
en
TS
Le
Tangent
Runout
SLe
en
en

- **Analysis of superelevation**
- Let us say Design speed = V m/s
- Radius = R m

Various forces acting on the vehicle:

Where e = rate of superelevation in %

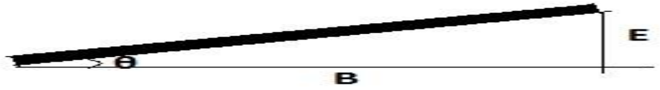
f = lateral friction factor = 0.15

V = velocity of vehicle in m/s

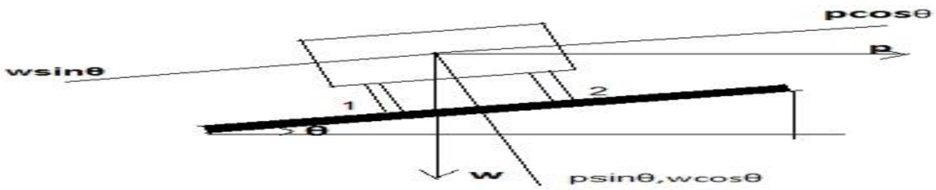
g = acceleration due to gravity = 9.81 m/s^2

R = radius of circular curve in meters.

If velocity is in KMPH then $\mathbf{e + f} = \frac{V^2}{127R}$



From above fig: tanθ = e = E/B .... (1)



Weight of vehicle, W (↓)

Centripetal force, P (→)

Frictional force, F1, F2 (←)

Divide with "Wcosθ"

Derivation

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

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

$$\frac{P}{W}(1 - f.\tan\theta) = \mathrm{Tan}\theta + f$$

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

$$\frac{P}{W} = e + f$$

But $\frac{P}{W} = \frac{V^2}{gR}$

Therefore $\mathbf{e + f} = \frac{V^2}{gR}$

Design of superelevation

There are four steps involved in the design of superelevation. And they are,

Step 1:

Calculate the superelevation 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 $e_{max} = 0.07$, provide calculated e value. Otherwise proceed to next step

Step 2:

When $e_{cal} > e_{max}$

Provide $e = e_{max} = 0.07$ 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 $f_{cal} < f_{max}$ (0.15)

Then e = 0.07 is safe.

But if $f_{cal} > 0.15$

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

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

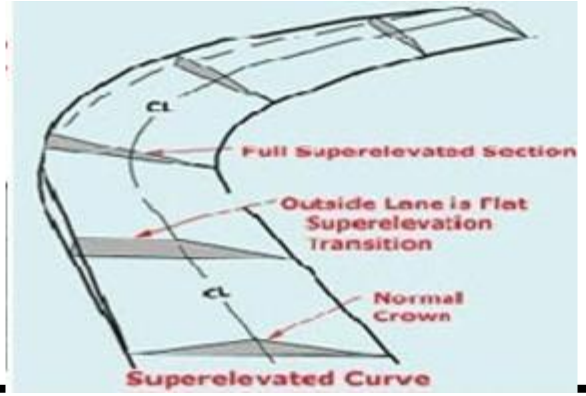
$$0.07 + 0.15 = \frac{(Va)^2}{127R}$$

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

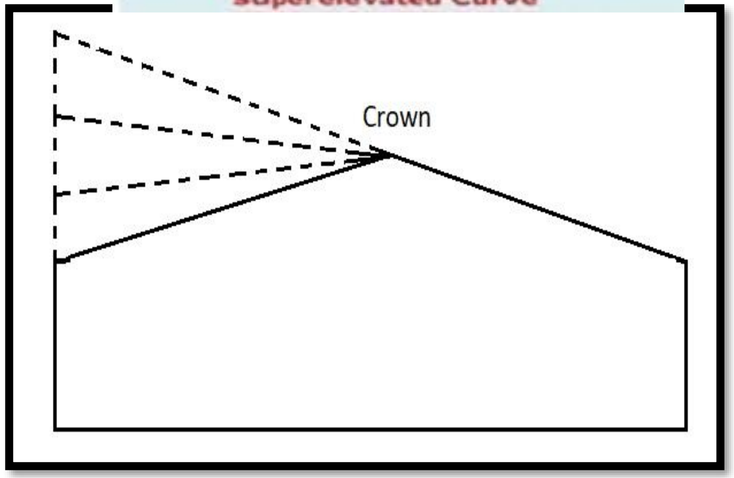
If Va > V, then e = 0.07, f= 0.15

If Va < V , then also e = 0.07, f = 0.15 but, speed restriction board is provided which consists the value of Va As shown in figure below.

Method Of Providing Superelevation

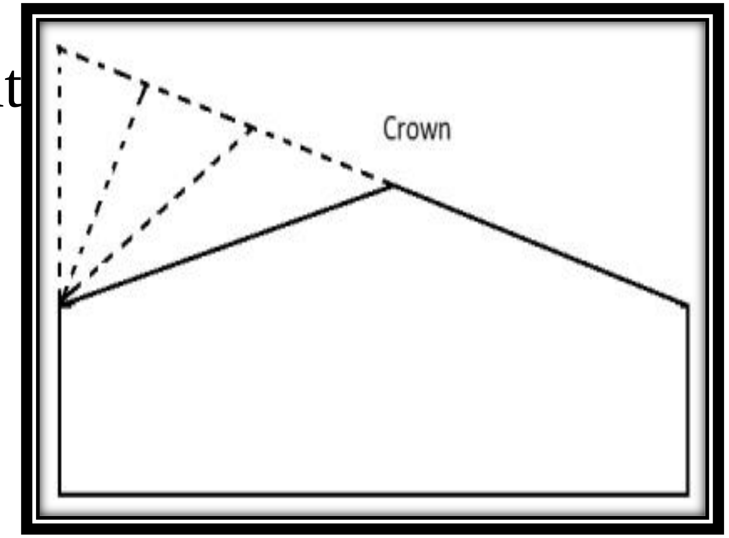


- Introduction of superelevation on a horizontal curve of a road is an important feature in road construction. Superelevation is provided in the following two methods.
  1. Elimination of the crown of the cambered section.
  2. Rotation of pavement to attain full superelevation.

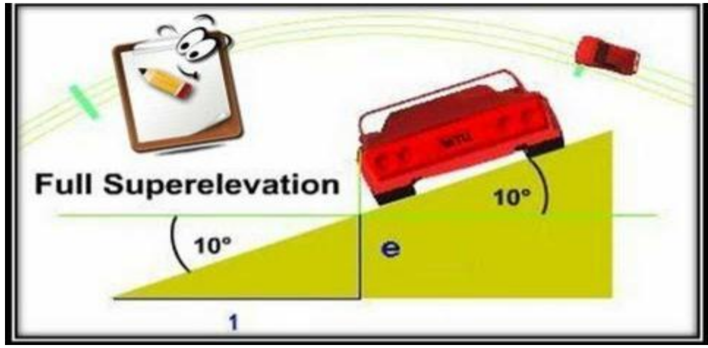


1. Elimination of The Crown of The Cambered Section

- In this method, the outer half of the camber is gradually decreased. This may be done by two methods.
- **In the first method,** the outer half of the camber is rotated about the crown at the desired rate such that the surface falls on the same plane as the inner half.
- **In the second method,** the crown is progressively shifted outwards. This method is not usually adopted.



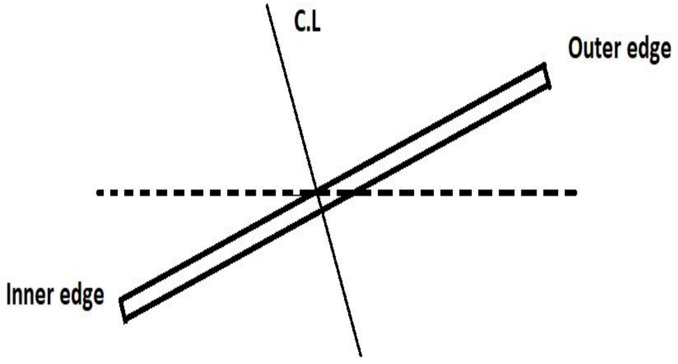
2. Rotation of Pavement To Attain Full Superelevation



- In this stage, superelevation is gradually provided over the full width of the carriageway so that the required superelevation is available at the beginning of the circular curve.

The different method employed for attaining the superelevation is as follows:

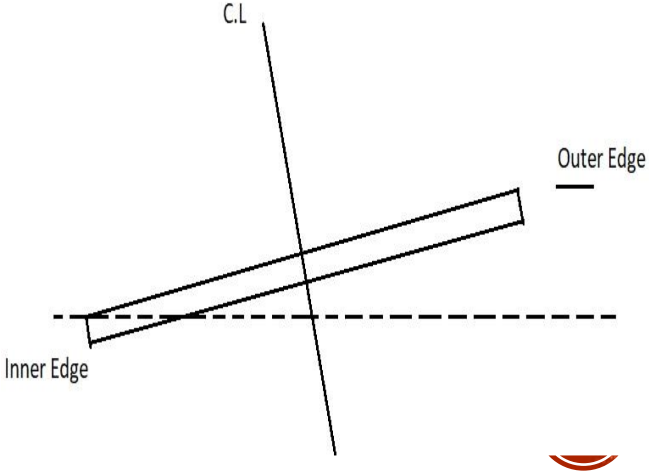
A. Revolving Pavement About The Center Line



Rotation About Centre Line

- In this method the surface of the road is rotated about the center line of the carriageway, gradually lowering the inner edge and rising the upper edge. The level of the center line is kept constant. **This method is widely used.**

B. Revolving Pavement About The Inner Edge



- In this method, the surface of the road is rotated about the inner edge, raising the center and outer edge.

C. Revolving Pavement About The Outer Edge

- In this method, the surface of the road is rotated about the outer edge depressing the center and inner edge.